Kariba Reservoir

Experience and Lessons Learned Brief

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1. Introduction

In post-World War II, Britain had large areas of influence in Africa, including southern Africa. Other than Portuguese East Africa (now Mozambique) and South West Africa (Namibia), the rest of southern Africa comprised a cluster of countries under British authority. Rather than implementing separate development agendas for each of its territories, Britain proposed a federal structure for the territories north of the Limpopo River. Under this arrangement, some facilities (e.g., secondary and tertiary education; key medical facilities) could be strategically developed under the federal umbrella, thereby avoiding duplicating facilities which the less developed protectorates of Nyasaland (Malawi) and Barotseland would likely be unable to sustain.

A key requirement for the development agenda in the Federation of Rhodesia and Nyasaland was the availability of bulk energy. Each territory operated small thermal power stations, fuelled by coal from the Wankie Colliery in Southern Rhodesia. The obvious choice of bulk electrical energy at that time, however, was hydroelectric power. Three large rivers were prime candidates for this purpose, including the Shire River in Malawi, the Kafue River in Zambia and the Zambezi River, now a boundary river between Zambia and Zimbabwe. At that time, the power demand would have been greatest in

Figure 1. The Kariba Reservoir Basin.

the copper mining area of Zambia, the industrialized urban areas of Southern Rhodesia along the railroad line, and the growing commercial farming industry of Southern Rhodesia. The benefit to Malawi would be the repatriation of earnings from exported labor, mainly to Southern Rhodesia.

The failure of the British colonial office to appreciate the depth of the political anxiety of the northern territories was a grave political error, leading to dissolution of the federation within a decade of its formation. As a result, Kariba Reservoir (Figure 1; also referred to as Lake Kariba), which was planned under a unifying political environment, subsequently became a transboundary facility. Amenities for construction workers had been largely developed on the Southern Rhodesia side, and the headquarters of the Central African Company was placed in Salisbury (Harare). Thus, the only visible development that took place in Zambia was construction of the power transmission lines to the Copperbelt mining area of northern Rhodesia (Zambia), with the load control system in Southern Rhodesia. In the perspective of the emerging nation of Zambia, their development agenda would be predicated by the political wishes of Southern Rhodesia.

2. The Dam

The Lake Kariba dam is a concrete double curvature arch dam, 128 m crest height and 627 m crest length, of mass concrete construction reinforced only around the spillway gate area (Table 1). The dam wall is located at the former Kariwa (Kariba) gorge.

The south bank power station has staggered turbine intake levels, ranging from 459-466 m asl to 451-444 m asl, with an average of 447.5 m asl (Balon and Coche 1974). Although the dam was designed with four spillway gates, the 1958 flood (which exceeded the 1:10000 probability) necessitated the addition of two more spillway gates in the design.

Table 1. Physical Characteristics of Kariba Reservoir and its Basin.

Parameter	Value
Basin area (km²)	687,049
Length (km)	280
Mean breath (km)	19.4
Area at full capacity (km²)	5,580
Shoreline development	953.8
Islands	293
Volume (km³)	185
Mean depth (m)	29.18
Max depth (m)	97
Volume development	2.1
Water retention period (yr)	3.3
Installed power capacity (MW)	1,350

The issue of the safety of Kariba dam wall is of constant concern, with the safety issues and maintenance activities to ensure its integrity discussed by Tapfuma et al. (2000). Major concerns include the geological heterogeneity of the south bank abutment (gneisses, biotites and micacious quartzites), and the behavior of concrete maturing under wetted conditions, which result in the Kariba dam wall not being a static structure. Another potential threat to the complex is the unstable weathered material sitting on clay seams downstream of the wall; if hydraulically loaded, it could result in subsidence that would dam the river downstream of the tailraces and flood the power plants.

In addition, the Zambezi Valley is part of the southern end of the East Africa Rift Valley and is therefore prone to seismic activity. The construction of the reservoir, with a total mass of approximately 180 billion metric tons, has increased the valley's seismic activity, with earth tremors increasing substantially after the filling of the lake. Figure 2 illustrates the incidence of seismic activity in the Zambezi valley and surrounding areas. It is noted that the highest concentration of seismicity is around the dam wall; in contrast, no similar enhanced activity is evident at Cahora Bassa, a reservoir further downstream on the Zambezi River (partially depicted in Figure 1). There were 20 earthquakes between 1963-1983 that exceeded 5.0 on the Richter scale, 6 (including the largest) occurring in 1963, the year the lake filled. The period of 1990-1995 contrasts with the period of 1964-1969 in illustrating relatively few incidences for seismic activity, as well as lower magnitudes. The period represents a dry episode in the region, when the lake water levels were low.

3. Basin Description

The Lake Kariba's drainage basin area is approximately 663,848 km² (Figure 1), lying in the territories of Angola, Zambia, Namibia, Botswana and Zimbabwe. However, the main basin, depicted in darker color/shade in Figure 1, contribute more than 95% of the lake's hydrological income. The Okavango River basin (the sub-basin depicted in lighter color/shade) becomes directly connected with the Zambezi River only when the region experiences extensive flooding, at which point the sub-basin either discharges into the Zambezi, or else receives backflow from the Zambezi, depending on the relative flood strength of the two basins. The Zambezi basin is traditionally divided into the Upper Zambezi (upstream of Victoria Falls), Middle Zambezi (from the Falls to Cahora Bassa Dam) and Lower Zambezi (downstream of Cahora Bassa to the Indian Ocean). The Upper Zambezi portion of the Lake Kariba catchment has extensive flood plains and wetlands, notably the Barotse Flood Plain, and the Chobe swamps and Caprivi wetlands in Botswana and Namibia, respectively, which are important biodiversity conservation areas.

The main soil type in the area of the main basin (as in Figure 1) north of the reservoir and in the Okavango basin is low ion-exchange, deep Kalahari sand formation, which can be as deep as 300 m (Bingham 2000), and water easily percolates into it.

Rainfall is highly seasonal, with the mean recorded rainfall ranging from over 1,000 mm in the northern part of main basin, to about 600 mm in the Middle Zambezi Valley. The water conductivity ranges between 20-75 μS/cm, depending on the flood regime.

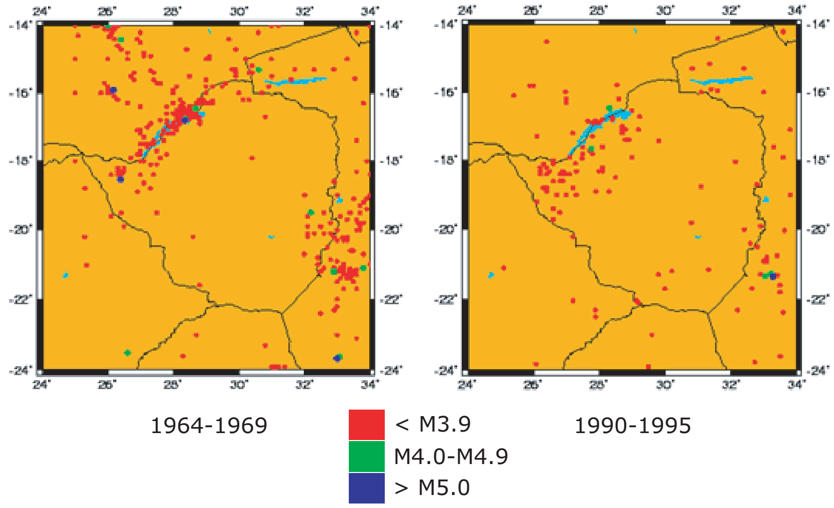

Figure 2. Earthquake Magnitude and Incidence around Kariba Reservoir, 1964-1969 and 1990-1995.

The main human activity in this same area is subsistence agriculture and livestock tending. While Lake Kariba was being built, these flood plains were sparsely populated, with the population of Zambia numbering scarcely more than three million. The Lozi people of western Zambia traditionally are cattle herders. The human population density in the Western Province of Zambia has increased from 3.3 persons/km² in 1969 to 5.5 /persons km² in 1990 (Bingham 2000). The population densities in the flood plains are considerably higher than these provincial averages. Similarly, the annual growth rate has risen from 1.6 to 2.8 over the same period. The Zambian urban population in the main basin is about 80,000, out of a provincial total of just over 600,000. Overall, the flood plain is preferred to the dry lands away from the flood plain. In the early-1970s, irrigated agriculture was attempted on the Zambian side of the Gwembe valley. However, the venture proved unprofitable, due to the extreme heat and poor, easily-erodable soils.

The only major urban areas in this same part of the catchment are Livingstone and Victoria Falls, with a combined population of about 132,000. These urban centers are the only significant source of organic pollution. Masundire (1998) reported that the bulk of untreated wastewater from Livingstone (population 100,000; annual growth rate of 2.6% in 1990) and Victoria Falls (32,000; annual growth rate of 14% in 1990) is largely discharged into the Zambezi with little or no treatment. Feresu and Van Sickle (1990) traced a plume of faecal coliform bacteria for a distance of over 20 km along the Zambezi River downstream of Victoria Falls.

The part of the main basin south of the reservoir is located wholly in Zimbabwe. It consists of a mixture of communal lands, former commercial agricultural lands, major industrial urban centers, and mining centers. It also contains a major coal-fired thermal power station at Hwange. The major tributaries draining into Lake Kariba from this sub-catchment are the Gwai/Shangaan, Sengwa, Sanyati and Nyaodza Rivers, along with many smaller rivers arising either in the valley or from the escarpment.

The Zimbabwe Lake Kariba catchment has the highest slope factor of all its sub-catchments. While the mean slope of the Zambezi from its headwaters to Victoria Falls is 0.94 m/km, that of the Sanyati River is 2.3 m/km between its headwaters and Lake Kariba. The silt load from the Zimbabwe catchment, therefore, is much larger than those from the other sub-basins.

Although the northern watersheds of Zimbabwe were sparsely populated when Lake Kariba was constructed, they now have a mean population density of 20.2 persons/km². This translates to 30 livestock units/km² or 0.3 livestock units/ha for an area with a recommended carrying capacity of 3 -5 ha per livestock unit.

Since establishment of Lake Kariba, the Gokwe area, drained by the Sanyati River, has become a major cotton-producing area, with wide use of agrochemicals for weed and pest control. The impacts of agrochemicals will be discussed further in later sections.

4. Economic and Social Significance of Lake Kariba

4.1 Power Supply

Lake Kariba is one of the large hydroelectric dams in southern Africa. Prior to installation of the Kafue Dam Hydroelectric facility and the Cahora Bassa plant in Mozambique, Kariba was the only bulk supplier of hydropower to Zambia and Zimbabwe. The plant's generating capacity constitutes nearly 60% of the hydropower outputs for Zambia and Zimbabwe.

Being the first major post-World War II energy development project, Lake Kariba can be said to have powered the post-World War II development of Zambia and Zimbabwe. Further, through the then Federation of Rhodesia and Nyasaland, the economic benefits of Lake Kariba extended to Malawi by creating employment opportunities in the then-sister territories.

4.2 Fisheries

The creation of Lake Kariba offered opportunities for an inland fishery industry that previously did not exist in southern Africa south of the Kafue River Flats river fishery. During construction of Kariba Dam during the Federation of Rhodesia and Nyasaland period, only Malawi (Nyasaland) and Zambia (Northern Rhodesia) had a fishery tradition, being managed by well-developed Departments of Fisheries in the respective countries. Fish taxonomy and biology studies, for example, were well developed in Zambia, with a comprehensive taxonomic museum at Chilanga, Zambia. The sole participants in the fishery industry in these countries were low-investment artisan fishermen, served by middlemen fish traders who transported the fish products to low-income sectors of urban populations. In contrast, there was a small sport fishery industry in Southern Rhodesia, based on exotic trout and bass. This socioeconomic divergence in the fishery industry development in the former Federation had significant bearing on the manner the Lake Kariba fishery would subsequently develop.

Because the original fish species of the former Gwembe valley were lacustrine, only 38% of the lake habitat in the littoral area was used by native species. Both *Brycinus imberi* and *B. lateralis*, which occupied river pool habitats, were incapable of utilizing a truly eulimnetic habitat. To maximize the lake's productivity, therefore, it was necessary to introduce species capable of utilizing the pelagic habitat. In 1968/69, therefore, *Limnothrissa miodon*, (locally known as kapenta), a pelagic clupeid from Lake Tanganyika, was introduced into Lake Kariba at Sinazongwe, about 150 km upstream and southwest of the dam. Within five years after their introduction, the fish completely colonized the lake, existing in commercially-fishable stocks in the eastern Sanyati Basin. By the late-1980s, the annual catch of the kapenta fishery totaled about 30,000 metric tons, although the post-1990 period has exhibited an overall trend of declining fish landings (Figure 3).

In addition to the introduction of *Limnothrissa*, it was recognized that the Middle Zambezi River had a limited number of riverine species. The cichlid species that were the backbone of the artisan fishery in Zambia were particularly

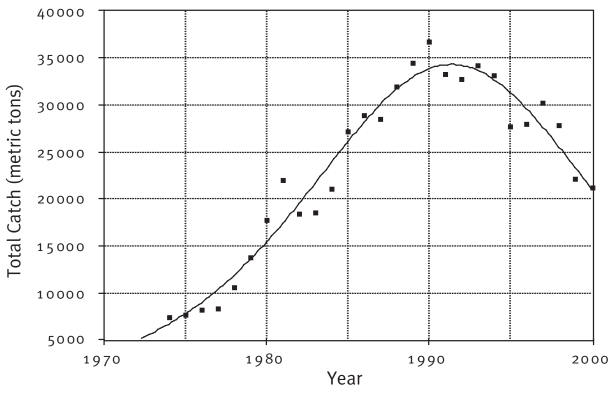

Figure 3. Growth of the *Limnothrissa* Fishery on Lake Kariba.

lacking. Thus, in addition to bioengineering the pelagic habitat to fill an empty niche, other cichlid species from the nearby Kafue fishery also were introduced. They now constitute the main catch of the artisan fishery, which totals about 9,000-10,000 metric tons annually (Moyo 1990).

While capture of *Limnothrissa* on Lake Tanganyika could be accomplished by relatively simple and cheap equipment, a behavioral change for Lake Kariba demanded a different technology. Large lift nets and submerged lighting are needed to capture the fish at depths below the water surface, which is capital-intensive, and was pioneered by white entrepreneurs.

Further, the political hostilities that emerged between Southern Rhodesia and the newly-independent state of Zambia deteriorated into military confrontation between the two neighboring states. While there were no restrictions of population movement between the Federation of Rhodesia and Nyasaland, the breakup of the Federation in 1963 led to the imposition of strict border controls between Zambia and Southern Rhodesia, in which the Rhodesian Navy and Air Force on Lake Kariba effectively prevented Zambians from developing a pelagic fishery on their side of the lake.

The net result of this historical development was that:

- The artisan fishermen of Zambia could not participate in the Lake Kariba fishery, in spite of having provided a fisheries management post at Sinazongwe, as well as fish storage cold rooms;
- The Tonga people, accustomed to a river fishery in the Zambezi Gwembe valley, were faced with a fish resource that did not benefit them because of lack of technology and the means of taking advantage of the resource;
- The kapenta (*Limnothrissa*) fishery, made possible by its introduction into Lake Kariba by the Zambia Department of Fisheries, was monopolized by the white Rhodesian business sector;
- At the normalization of relations between Zambia and the newly-independent Zimbabwe, the issue of equity and access to Lake Kariba's fisheries resources needed urgent political redress, in face of the realization that the lake fishery was almost fished to full capacity by 1980 by a small clique of Zimbabwean entrepreneurs. This situation was addressed by the formation of Joint Management Committee between Zambia and Zimbabwe, with one of its mandates being to ensure equitable distribution of the lake's fish resources; and,
- Within the new Zimbabwe, there were internal political pressures for black entrepreneurs to participate in the industry. However, because the industry is capital intensive, the Zimbabwe Government approach was that black participants would enter the industry as cooperatives, which could be capitalized by state loans.

It also involved some established white enterprises having to relinquish some of their fish quotas to enable the participation of state-sponsored black stakeholders without causing over-fishing of the lake.

Recent developments in attempts to empower artisan fishing communities have included transferring some management responsibilities to local government institutions (e.g., district councils in Zimbabwe; traditional leaders in Zambia), with the lakeshore being demarcated on the basis of local administrative areas. Local government authorities undertake the policing of resource use, after state fishery management authorities have determined fishing quotas. The intention is to spread the administrative costs more widely, thereby increasing management efficiency.

4.3 Tourism

Although there were large reservoirs of over 1 million m^3 capacity occupying more than 10 km^2 in area in 1960, from a tourism perspective, Lake Kariba offered the same recreation potential as that which holiday makers had traditionally sought at the Mozambican and South African sea coasts. The tiger fish (*Hydrocynus vitatus*) sport fishery, for example, became so popular that anglers traveled from as far as the United States, Europe and Australia to take part in the annual tiger fish tournament.

The provision of ferry transport for motor vehicles linked Kariba-based tourist facilities with other popular resorts of Victoria Falls and the Wankie Wildlife National Park, effectively creating a natural resource-based tourism belt stretching from the Mana Pools on the lower Middle Zambezi Valley to the facilities in the Chobe Swamps in Namibia/Botswana to the Okavango Delta or beyond.

Although not easy to quantify, this industry's economic benefits are estimated as being several billion US dollars, including hotel industries, wildlife safari industries, banking, boat building, and international and regional air travel. The combination of wildlife-based tourism and water leisure sports made Kariba an important hub in the region's tourist industry. Kariba Town is probably the only urban settlement where humans can brush shoulders with wildlife (e.g., elephant, buffalo, lion). The baboon population has acculturated itself to the human society of Kariba Town to the extent they freely roam through residents' properties with impunity. Nevertheless, the recent downturn related to developments in Zimbabwe underscores the sensitivity of this industry to good governance.

5. Climate Change and Climate Variation

Scudder (1993) pointed out that, in the two decades preceding 1993, the Zambezi River delivered about half its long-term average flow for the preceding period to Victoria Falls. Mazvidza et al. (2000) grouped precipitation records from a number of Zambian stations into decadal means between 1960-1990. Records from 10 of the 15 examined stations showed the 1980-1990 decade experienced the lowest means flows over the last 40 years, while 15 stations registered the lowest mean flow for the last 30 years in the same decade. Figure 4 illustrates a 20-year moving average rainfall in the Gwembe valley between 1940-1999. Seventy-seven percent of the variation in the twenty-year decadal means in the area can be explained by a declining mean precipitation over the last sixty years.

5.1 Climate Variation and Fish Catch

With an annual catch of 30,000 metric tons, the Kariba kapenta fishery has been valued at US$25 million (ZIMCONSULT, cited in Kaluba and Mukupe 2000). Thus climate-induced declines in the fishery output translate to considerable economic loss to the riparian states. Figure 3 shows that, although the kapenta fishery grew continuously between 1974-1990, there were periods of depressed catches coinciding with drought periods in the early-1980s and early-1990s. Figure 5 illustrates a detrended two-year moving average of fish catch and precipitation in the Lake Kariba basin, indicating the catch data tended to vary with precipitation variations in the valley. Periods of reduced precipitation also are periods of higher-than-average temperatures, during which blue-green algae tended to dominate the phytoplankton species (Cronberg 1997). In a separate study on Lake Chivero, Magadza (1994) adduced experimental evidence of zooplankton population reduction associated with *Microcycstis*- and *Anabaenopsis*-dominated eutrophic conditions, in which zooplankton was unable to utilize the phytoplankton. Chifamba (2000) found negative relationships between the Catch-per-Unit Effort (CPU) in the pelagic *Limnothrissa miodon* fishery of Lake Kariba, while precipitation and river runoff were positively correlated with CPU. Although nutrient deficiency during low riverflow was cited as the probable cause of collapse in fishery catches

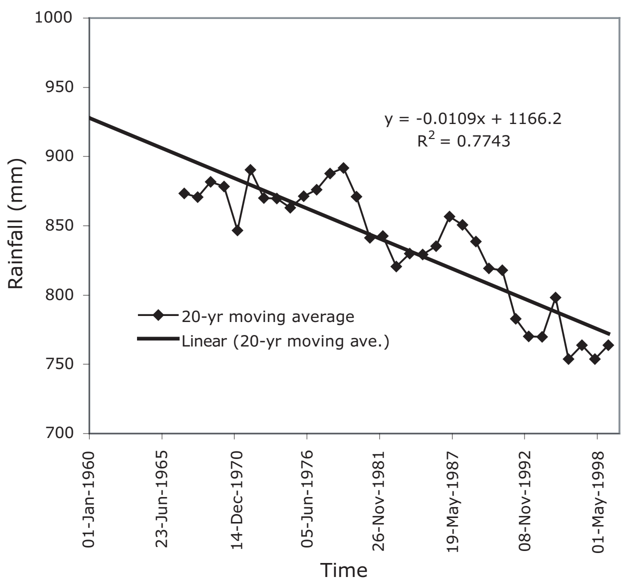

Figure 4. Twenty-year Moving Average of Precipitation in Gwembe Valley.

(e.g., Marshall et al. 1982), no evidence of nutrient deficiency in the reservoir was established.

5.2 Climate Variation and Power Generation

Using first-generation GFD climate change models, Urbiztondo (1992) suggested that, under double CO_2, Lake Kariba normally would fail to meet its generation capacity because of low water levels, even in tandem with the proposed Batoka Gorge Dam. Magadza (1994) compared the 1991/92 drought cycle with the Urbiztondo scenario, and found similarities between the Urbiztondo model and Lake Kariba's response to that drought. For that same period, Magadza (1996) reported an increase in Penman evaporation of up to 90% of the long-term mean value for a temperature increase of some 2°C. Of particular interest are the estimates of Arnell (1999) of a 10-20% decline in precipitation, a 20-25% increase in evaporation, and a 20-40% decrease in runoff.

Corroborative evidence of the likely impacts of power generation comes from the generating output record. According to Soils Inc. in the World Commission on Dams Report (2000), the expected power output was 6,720 GWh per annum. However, the average output in the 20 years between 1977 - 1997 has been 6,400 GWh per annum (95% of the expected output), being attributed to prolonged periods of low hydraulic head, due to droughts in the basin.

The economic impacts arising from curtailment of the hydropower generation from Lake Kariba because of the 1991/92 drought was estimated to be about US$102 million loss in GDP, US$36 million loss in export earnings, and a loss of 3,000 jobs (Benson and Clay 1998). The direct agriculture impacts and associated impacts also were quite severe. These limited estimates provide an estimate of the possible economic impacts of climate change-mediated water resources changes in the medium term (i.e., into the middle of this century), a time span within the economic development strategy planning window (Desanker and Magadza 2001).

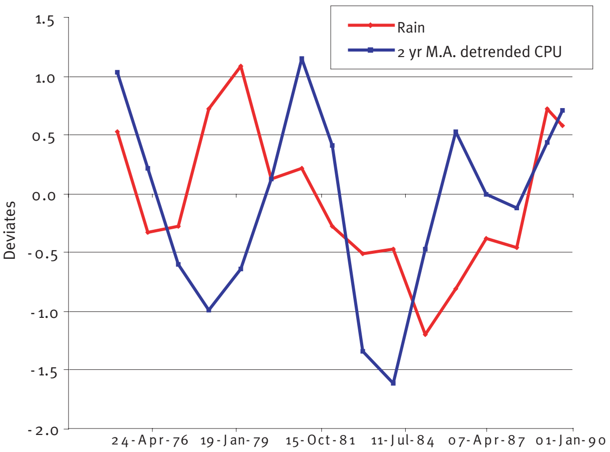

Figure 5. Detrended, Two-year Moving Average of Catch Per Unit (CPU) Effort and Precipitation.

6. Flood Management

Boxes 1 and 2 illustrate the flood management issues associated with Lake Kariba and the Zambezi River reservoirs as a whole. Unlike Vaal Dam on the Val River in South Africa, which has an flood-attenuation capacity of 26% of its volume, no large Zambezi River system impoundments is designed with a flood management capacity. Thus, threats to the dam structures from large floods are automatically passed to downstream communities. While there is no statistical proof of changes in the flood frequencies in the last two decades, the lower Zambezi River did suffer from previously-unexperienced flood-related damages to infrastructure and loss of life. An emerging reality is that, in the event of sustained cyclonic precipitation in the Shire and upper Zambezi River systems, the need to protect Lake Kariba and Lake Cahora Bassa will certainly lead to severe flooding in the Lower Zambezi areas, especially the Zambezia Province of Mozambique. On the other hand, the need to optimize live water storage as a precaution against droughts minimizes the use of the Zambezi River basin reservoirs as flood management facilities. When Lake Kariba was designed, the lower Zambezi River was sparely populated, with limited infrastructure facilities, and the issue of downstream community protection against flooding could be simplified to early warning for evacuation. As the Zambezia area becomes more developed, however, flood management will become an increasingly important economic and humanitarian issue.

Overall, the Zambezi River reservoirs have reduced streamflow variation and have reduced the peak flooding that would have occurred without the reservoirs. In years of normal precipitation, this apparent flood amelioration effect has encouraged villagers to move closer to the river banks, thereby rendering them more vulnerable to flooding. The major issue here, however, is that of managing the risks of extreme flood events, with the Intergovernmental Panel on Climate Change

Box 1. Chronology of Events during Construction of Kariba Dam, Illustrating its Flood Management Limitations.

Kariba Dam was designed for the safe passage of a 1 in 10,000-year flood event. The original design was for a 3-month flood, with a volume of 68 km^3, based on the 1924-1955 data series. During its construction in 1957, the highest flood on record occurred, with a peak of 8,200 m^3/s, leading to revision of the design flood value from 68 to 74 km^3. In the following year, a flood with a peak of 16,000 m^3/s, and a 3-month volume of 61 km^3, occurred; the spillway capacity was again increased, this time to 92 km^3. If the project had been built a number of years earlier with its original design capacity of 68 km^3, its spillway would have been completely under-designed.

Source: Soils, Inc. (2000).

(IPCC 2001) warning that flood risk frequency is likely to increase in the future. Thus, for a system of reservoirs in the same basin that have no organic operational coordinating protocol, the outcome of an unpredicted extreme flooding event will depend primarily on the nature and circumstances of the event. Against this background, it is prudent to heed Vas's advice: "The operating rules of all the existing large dams should be reviewed to check whether they work for flood attenuation as much as allowed by the other present uses of the dams" (Vas 2000).

7. Environmental Management

In planning for Lake Kariba, it never occurred to its developers that such a hostile, disease-ridden environment as the Zambezi valley would be a major tourist attraction. Parts of the original Kariba Town itself were designed as a temporary village for construction workers, and were destined for demolition at the project's completion. Thus, infrastructure facilities for waste and wastewater management were designed as temporary facilities for a small community. However, the Kariba Town population increased from under 5,000 in the early-1960s to about 30,000 by the end of the 20th century. In the absence of an urban development plan, the town developed in a helter-skelter manner, with many shore-based facilities discharging wastewaters directly to the lake. Figure 8 illustrates faecal coliform bacteria counts from shoreline areas of Kariba Town, compared to an offshore sampling station. Although the municipality has since constructed large oxidation ponds, many shoreline properties in the municipality have no access to a public sewer. Similarly, other smaller urban areas and fishing camps in the lakeshore area do not have adequate waste treatment facilities.

Water pollution also arises from water transport systems. Mulendema (2000) estimates that fishing vessels discharge 3.6 metric tons of human waste directly to the lake each night. Further, large public transport ferries ply the lake daily, with a passenger capacity of about 200 persons who spend an average of 22 hours on the lake. She also reports a figure of 1,900 "house boats" which spend variable times on the lake. Thus, an estimated human waste discharge in the order of 1,500 metric tons is discharged annually into the lake. Sampling site L/Bay in Figure 6 is a deepwater sampling site in the Sanyati basin of the lake; although the faecal coliform counts from this station are much less that those from inshore sites, the data nevertheless indicates measurable levels of coliform bacteria in the pelagic zone of the lake.

The Zimbabwe Inland Shipping Act makes it mandatory for vessels of specified sizes to incorporate a sewage containment facility on board. However, there are no harbor facilities to service such sanitation facilities; therefore, the only legal requirement is that sewage tanks not be discharged less than 5 km from the shore. There is no similar regulatory statute for the Zambian side of Lake Kariba.

7.1 Eutrophication?

Large amounts of biomass were inundated during Lake Kariba's filling phase. In-lake phosphorus concentrations reported for the early period of the lake ranged between 6-66 µg/L (Balon and Coche 1974). At that time, about 25% of the lake surface was covered with *Salvinia molesta*. In sheltered bays (e.g., Mwenda Bay), the tertiary phenology

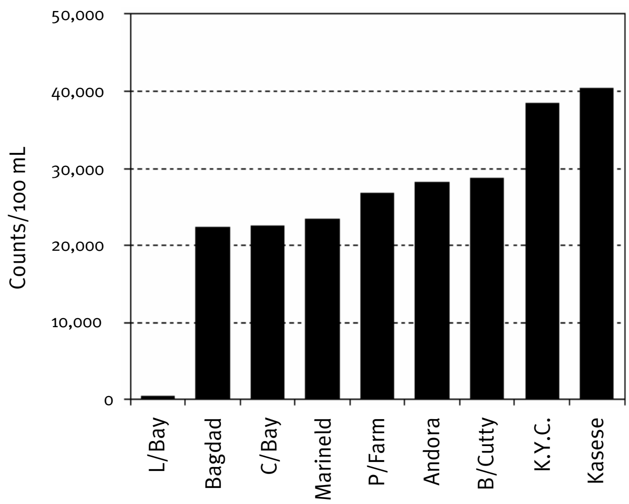

Figure 6. Coliform Counts in Lake Kariba Inshore Waters (Source: Magadza and Dhlomo (1996)).

Box 2. Lake Kariba Flood Impacts on Cahora Bassa Reservoir.

The largest flood in the Zambezi River basin since the area's independence occurred in March 1978. Both Kariba and Cahora Bassa reservoirs were already almost at full capacity when intense, prolonged precipitation occurred in large areas of the basin and ultimately caused the largest-ever flood to enter Lake Kariba.

Due to the state of war at that time between Mozambique and former Rhodesia, there were no direct communications between Lakes Kariba and Cahora Bassa. Rather, relevant information was sent from Lake Kariba to the headquarters of "Hidroeléctrica de Cahora Bassa" in Portugal, which would then send it to Maputo to be conveyed to Tete, and finally to the operators of Lake Cahora Bassa, with a total information relay delay of 1-2 weeks.

Thus, when the Lake Kariba spillway gates were successively opened, relevant Cahora Bassa agencies did not have complete knowledge about it. Thus, when the Lake Kariba flood discharges arrived at Cahora Bassa, the reaction was to almost immediately open all 4 spillway gates at Cahora Bassa that were still closed, thereby creating an enormous flood wave that, when added to the floodwaters of the tributaries located downstream of the dam, completely flooded the Lower Zambezi.

Source: Vas (2000).

of the mat facilitated growth of other wetland plants (e.g., sages, *Typha*, *Ludvigiat*) from compacted floating rafts. As the nutrient input from inundated biomass decreased, the in-lake phosphorus concentrations also decreased, with Salvinia virtually disappearing from the lake by the early-1990s. It was then assumed the lake had become oligotrophic, thereby being unable to further stimulate growth of the exotic weed. However, after the lake filled, following the 1991/92 drought period, it was suddenly invaded by *Eichhornia crassipes*, which developed into large floating mats.

The phosphorus concentrations along the lake between 1987-1992 suggest levels are above the threshold concentration between a eutrophic and oligotrophic state in most of the lake. The total phosphorus concentration is highest (almost 40 µg/L) in the area where the Zambezi enters the lake, decreases towards the middle (15 µg/L or lower) and again rises with proximity to the outlet near Kariba Town (between 20-30 µg/L). The mean phosphorus and nitrogen inflows from the Zimbabwean rivers, witch constitute 15% of Lake Kariba's inflows, also indicate that these rivers now carry high nutrient levels. Thus, the appearance of *Eichhornia* can be interpreted as an indication of a developing eutrophic state in some of the lakes sub-basins.

In addition to river nutrient inflows into the lake, the internal nutrient sources from boat usage were previously noted. Another potential nutrient source is the cage culture industry. Although still a relatively small enterprise, data gathered from cage culture sites already indicate nutrient enrichment from excess fish feed and fish faeces.

8. Land Use and Involuntary Resettlement

The Tonga are the native inhabitants of what was the Gwembe valley of the Middle Zambezi River. They were a relatively isolated community because of a lack of infrastructure development in the valley. Although little is known of their lifestyle before construction of Lake Kariba, some workers (e.g., Scudder 1962, 1973; Colson 1971; Scudder and Colson 1971) have attempted a reconstruction of the Tonga life style and ecological culture before the Lake Kariba project. These various studies have been summarized by Magadza (1994).

8.1 The Tonga Relocation

8.1.1 Perceptions Regarding the Tonga

It is noted that, while the project set aside £4 million for resettlement of the Tonga, a much larger sum raised from international sources concerned about the plight of wild animals was used in the Operation Noah animal rescue project. Some 5,274 animals were captured in this project, with a net 4,129 being saved, nearly 50% of which were the ubiquitous impala, *Aepyceros elampus*. Land was set aside as national parks for the translocated animals.

In contrast, about 80,000 Tonga were relocated, in what some characterized as a litany of failures. Compared to the funds allocated for "African resettlement", the relative expenditures were about £968 per animal and £50 per person. Resentment of this disparity continues to the present time, with ordinary Zambezi Valley rural inhabitants still exhibiting a resentful attitude toward wildlife today.

The Tonga had evolved an agricultural strategy that gave them a number of options for coping with their food needs in the valley. Using both seasonal rains and the flood patterns of the Zambezi River, they were able to raise crops throughout the year, mainly cultivating the alluvial soils of the floodplain. With the inundation of the valley, however, they were translocated to semi-arid lands, with a high risk of crop failure. As a result, the Tonga subsequently became a food-deficit people. Further, the presence of the tsetse fly made it impossible for them to rear livestock. Accordingly, there were indications of widespread famine in the early days of the Tonga resettlement efforts (Magadza 1994).

There also was a policy divergence between the British Colonial Office, which was more directly involved in the Northern Rhodesian part of the Tonga, and the Southern Rhodesia Government, which had some autonomy in the way it managed the natives. While Northern Rhodesia administrators attempted to itemize compensation benefits (hut replacement; harvest loss; cost of land preparation; etc.), the Rhodesian authorities had the view that the Tonga should not view the relocation exercise as an opportunity for financial gains. Thus, they offered no compensation packages, with the relocated victims simply offered alternative land and, in some cases, transportation to it.

8.1.2 Lack of Awareness Campaign

In the preparatory stages of the relocation, there were no attempts to educate the Tonga on the Lake Kariba project. Rather, less than a year before the valley was to be flooded, the Tonga were simply told they would have to move from their homes. Accustomed to the annual floods of the Zambezi River, the villagers failed to comprehend the concept of permanent, extensive inundation, with some therefore resisting the order to move, and resulting in the use of firearms by police authorities.

8.1.3 Limited or Lack of Infrastructure

Although some planning was undertaken on the Northern Rhodesian side to provide basic infrastructure (roads; administrative facilities; etc.), the mid-project decision to raise the height of the dam wall by 5 m effectively nullified these plans. Because the reservoir had already started to fill, the translocation of the Tonga thereby became a hurried exercise in moving the population to areas with little or no infrastructure or civic amenities.

8.1.4 Social disruption

By Colson's (1971) account, the Tonga lived in closely-knit families. Girls married early, thereby needing peer support from their elder female relations on how to manage their household, as well as in the schooling of skills to map out their resource base so as to cope with seasonal changes and impacts of climate variation impacts on it. Further, the Zambezi River was a common resource, not a state boundary, with families regularly commuting across the river.

The flooding of the Gwembe valley sundered a once unitary ethnic group into Zambian (Northern Rhodesian) and Zimbabwean (Southern Rhodesian) subjects, with normal international laws of transboundary travel applying. Further, except for the Kariba border post, there were (and still are) no border post facilities along the 300-km length of the lake. Separated families, if they wish or need to visit, now have to travel hundreds of kilometers to find legal crossing points, and at a great cost to them, rather than simply canoeing across the river.

The second type of social disruption regarding the Tonga was that family groups were not necessarily relocated in the same areas. This broke down the peer support system, as mentioned above, that was needed by young families. Colson (1971) even cites cases of suicide among young wives attributed to sheer desperation.

8.1.5 Ecological Disruption

The Tonga were adapted to a combination of floodplain and rain-fed agriculture, while also being quite adept at a hunter-gatherer mode of subsistence, the latter being an important skill in times of drought.

The resettlement areas were radically different from the accustomed habitat of the Tonga. The hunter-gatherer options no longer existed, since the terrain consisted largely of *Colophospermum mopane* and *Combretaceae*. Further, hunting wild animals was strictly controlled by the Wildlife Management authorities in each territory. Little of the herbaceous vegetation components of vegetation, such as senkenene (*Paspalum paspaloides*), was present in the vegetation of the resettlement areas. Furthermore, it was no longer possible to use the fertile floodplain during the dry season for a second crop over the year. Instead, the Tonga had been reduced to one option; namely, hand-tilling semi-arid mopane woodlands in an area of highly erratic rainfall for only one harvest a year.

Magadza (1993) examined the food production and consumption patterns in Omay communal resettlement areas, determining that food consumption was below the recommended nutritional level, with . He further noted that attempts by agricultural experts to improve food security by introducing high-yield maize varieties made the communities more vulnerable to droughts, as they shifted from mixed cropping of drought-resistant crops to the new maize cultivars (Magadza 1993).

8.1.6 Economic Alienation

As noted above, creation of Lake Kariba gave rise to new entrepreneurial opportunities in the fishery, tourism, and wildlife safari sectors, as well as public sector employment opportunities. These new opportunities required skills and formal education portfolios lacking by the Tonga. Thus, as one elder remarked during a World Commission on Dams hearing, they watched while other ethnic groups exploited the resources of the valley that used to be their home. Further, while Lake Kariba could boast of a multi-million fishing industry, the Tonga remained a food aid-dependant group, even well after majority rule had been attained in both countries. The author also recalls married Tonga men attending primary education classes in the mid-1980s in order to improve their marketability on the employment market.

8.1.7 What Has Been Learned?

Although the Tonga case study is well documented, developers appear to have learned little from this experience. As in the Lake Kariba case, disputes between displaced communities and developers led to loss of life in the Lesotho Highlands project. In the case of the Zimbabwean Osborne Dam, villagers were simply moved to new areas, with no regard for the investments the villagers had previously made, in terms of fruit trees, etc. Further, in the Pungwe pipeline project in Zimbabwe, villagers were falsely promised piped water at their homesteads. Only 7 years after the Lake Kariba experience, Cahora Bassa caused another forced migration syndrome. The manner in which forced resettlement resulting from water resource development is managed is a matter of ethics, which are only subscribed to in varying degrees by governments and development lobbyists.

8.2 Remedial Measures

Following the consultative process initiated in the Lake Kariba Case Study stakeholder discussions of the World Commission on Dams, there are moves to bring some of the Lake Kariba economic benefits back to the valley, in the form of improved infrastructure development and social services (e.g., education, health services). However, these efforts are being funded from donor sources, rather than from direct revenues from the Lake Kariba operations, thereby making their sustainability tenuous. In fact, no formula has yet been developed by the contracting states to address the Tonga resettlement issue.

8.3 The Kariba Household Energy Anomaly

As indicated above, the Lake Kariba developers did not envisage a permanent post-project settlement at Kariba. Hawkes and Magadza (1988) conducted a survey of energy usage in the post-project Kariba Town, more than 20 years after completion of the dam. They found that every household in Kariba Heights, where white workers lived during the construction phase, was served by a 13.2-KW power supply, while the original black workers compound only had sufficient power for three 60-W light bulbs. In recognition of the post-project continuation of urban settlement, the Town Council established a township residence in 1978 called Nymhunga, with the first housing units not being electrified. Table 2 summarizes the electrification status of the various suburbs in Kariba Town. Apart from the middle class suburb of Kariba Heights, all other sampled households either had no electricity or could not run heating appliances or refrigeration (including the Police Compound). Consequently, wood fuel was the main source of household energy, even though virtually all interviewees preferred electricity. At the time of the survey, the cost of legally-procured fuel wood was similar to that of electricity.

On the other hand, Kariba Town is tightly surrounded by a wildlife management area, to an extent that the Park boundary in Nyamhunga is only a few meters from the peripheral houses. Collecting any material from the Parks estates is a statutory offence, resulting in constant conflict between urban residents and wildlife management personnel, as well as frequent attacks of fuel wood poachers by wild animals, some being fatal.

8.4 Secondary Social impacts

There also are secondary impacts from facilitating human migration onto the lake environs or vicinities. Infrastructure provision has enabled the penetration and settlement of once-remote areas at an unprecedented rate, and without due regard to the ecological consequences of such human transmigrations. Magadza (1993) noted that the population growth rate in the Omay Communal lands was 114%, due largely to migrants to the valley. Inappropriate land use by these migrants (namely maize production and livestock holding) has led to accelerated land degradation in the surrounds of the Zambezi Valley without the benefits of improved nutritional status, while also creating resource use conflicts in the valley (Magadza 1986, 1993). These have led to increased erosion, with streams that used to store dry season water in pools no longer able to do so because of siltation of the rivers (e.g., all the former pools in the Nyaodza River are now filled with sand).

8.5 Tertiary Social Impacts

An example of a tertiary social impact is the dramatic rise in sexually-transmitted diseases (STD) in the Lake Kariba environs. During the lake construction phase, the contractors supplied single quarter accommodation for laborers. At the end of the construction project, these one-room units became family homes. In a survey on energy usage, for example, the author observed a 15-member family living in one these small rooms.

The creation of a comparatively well-paid male workforce invariably attracted the attention of impoverished females in the area and further afield. Similarly, the creation of an artisan fishery resulted in the establishment of isolated "fishing camps" where the majority of fisher folk were male migrants from the hinterland villages. Of the fishermen in these camps, Wilson et al. (1995) wrote: "Because they receive income each week they are often visited by prostitutes from Kariba and even larger cities like Harare and Bulawayo, between pay days, when clients elsewhere have no money." Of Kariba Town itself, he noted: "It is an SDT treatment center for the town, lake shore and rural hinterland."

Figure 7 illustrates the trends in SDT and, by proxy, HIV, prevalent among antenatal clinic patients at Kariba Hospital. It also shows how much can be achieved by community education in HIV prevention. The data are from a collaborative project between the Canadian CIDA and the University of Zimbabwe Lake Kariba Research Station to address some of the impacts of hydropower development in the basin. In hindsight, it is now evident that if the project had factored in the issues of sexuality and provided family housing units for the construction workers, and the Department of Parks and Wildlife Management, through project funds, had planned structured fishing villages with necessary amenities, the Lake Kariba lakeshore settlements might not have become the highest STD risk area of Zimbabwe.

Table 2. Electrification Status of Surveyed Households in Kariba Town, 1988 (Units: Number of Households).

Electric service		Area				
		Kariba Heights	Mahombe-kombe	Nyamhunga	Police camp	Total
No electricity	Not wired	0	33	15	0	48
	Not connected	0	1	8	1	10
Paid by employer	Metered	1	4	0	0	5
	Load-limited	0	22	0	29	51
Paid by resident	Metered	9	1	3	0	13
	Unspecified load-limit	0	9	0	0	9
	7.5 amp	0	7	34	0	41
	1 - 2.5 amp	0	3	19	0	22
Total		10	80	79	30	199

Source: Hawkes and Magadza (1988).

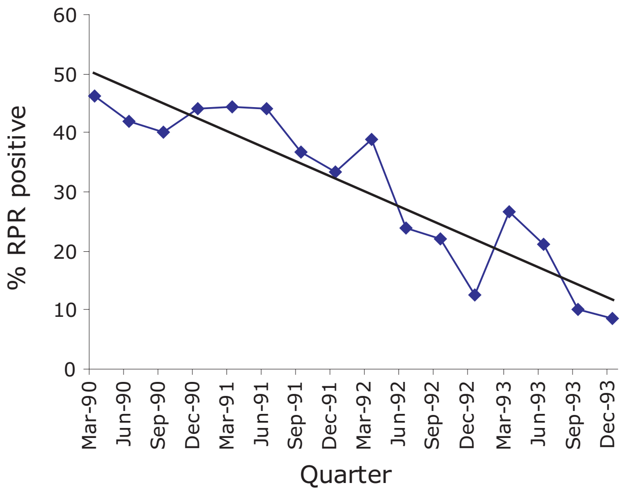

Figure 7. Trend in Reduction of Sexually-transmitted Disease, Kariba.

9. Pest Control

A major land use issue associated with Lake Kariba is pest control for vector-borne diseases. The issue arose out of the need to clear the Tonga resettlements of insect disease vectors. Although the resettlement areas were climatically unsuited for rainfed subsistence agriculture, it was assumed by administrators that the cause of the chronic food shortages was the inability of the resettled peasants to cultivate sufficient land to feed themselves because of lack of drought power. This was believed due to their inability to rear cattle because of Trypanosomaisis transmitted by *Glossina morsitans*. For over 30 years, therefore, some part of the Lake Kariba environment were sprayed with DDT and other insecticides to control the pest, with the intensity and frequency of spraying dependant on the tenacity of the fly to re-invade sprayed areas.

As access to the area improved over time, new areas opened for resettling other plateau farmers from congested Tribal Trust Land areas in the then-Southern Rhodesia, especially in the Gokwe area. In addition to cultivating food crops, these more entrepreneurial farmers started producing cotton, which also requires large quantities of pesticides to control pests. The need to control vector diseases in the resettlement areas led to prolonged use of residual and topical pesticides (e.g., DDT, dieldrin, endrin, endosulfan). While advances in research led to development of more environmentally-friendly methods for controlling the tsetse fly (e.g., odor-baited fly-trap; Torr et al. 1997), DDT remains the cornerstone of malaria vector control.

9.1 Environmental Impacts of Pest Control

Magadza (1995) summarizes the impacts of tsetse fly control on terrestrial ecosystems, including levels of impacts in sprayed and unsprayed areas. The impacts are classified into presence of DDT, observed mortalities during application, changes in species abundances, and species' loss. These impact levels are examined for numerous ecological categories, including soil, invertebrates, lizards, birds, mammals and fish communities. It is clear that the program had significant impacts on terrestrial ecosystems surrounding the lake during the assessment period. Magadza (1995) estimated that as much as 20 species insectivorous of bats were missing in the operation area. An assessment of the DDT impacts by the Natural Resources Institute (Douthwaite et al. 1994) revealed that bat puppies were intoxicated by the DDT in their mother's milk, leading to reproductive failure.

9.2 Impacts on Aquatic Ecosystems

The pest control program has facilitated accumulation of persistent pesticide pollutants in aquatic ecosystems. Studies (e.g., Berg et al. 1992; Berg and Kautsky 1994), show that, by the mid-1990s, there were measurable levels of persistent organochloride pollutants in Lake Kariba ecosystem organisms, including birds of prey and diving birds. Further, Douthwaite (1992) found sufficient DDT in Lake Kariba cormorants to cause egg thinning and reproductive failure.

The impacts of DDT on fish populations have not been fully assessed. Although DDT levels in various fish species have been made, no assessment of the biological impacts of these levels have been made. However, studies by Sanyanga (1996) on *Synodontis zambeziensis* showed a much smaller proportion of reproductively active males than previously existed, even though the juvenile sex ratio was almost equal.

9.3 Impacts on Human Health

There are no direct studies of the impacts of the pest control program on human health. The data in Table 3, however, suggests that, based on known impacts of DDT elsewhere, it is likely there are pest control impacts on human health that simply not have been monitored. The paradox of DDT usage in the Lake Kariba environments is that, although the pesticide is banned for agricultural use, Zimbabwean health authorities maintain that DDT is still the most effective answer to malaria control.

Table 3. Comparison of DDT, DDT Derivatives and PCB in Mother's Milk (Concentration in ng/g milk fat).

Area	Land use characteristics	Mean age of mothers	Sum PCB	pp-DDE	pp-DDT	Sum DDT	Ratio DDT/DDE
Kariba	DDT for vector control	23	2.78	13,606	9,080	25,259	0.6
Kadoma	Cotton	22	59.55	5,049	1,254	7,047	0.2
Esigodini	Subsistence farming	25	13.27	1,176	250	1,607	0.22

Source: Adapted from Chikuni et al. (1997), as cited in Magadza (2002).

10. Governance and Institutional Arrangements

The Zambezi River Authority has its historical origins in the Central African Power Corporation (CAPCO), which was set up as a jointly-owned company by Southern and Northern Rhodesia. The corporation was dissolved in 1987, due to the politically-inequitable distribution of assets, and the political culture in which it operated before the Zimbabwean elections.

The CAPCO mandate was primarily engineering in nature, including the following:

- Monitoring the hydrology of the basin with respect to lake level management and flood control;
- Monitoring and recommending remedial measures in regard to dam wall safety; and,
- Generating bulk electricity and selling it to territorial energy authorities.

Figure 8 illustrates the institutional governance structure of Lake Kariba and its catchment. Central to this structure is the role of the Zambezi River Authority (ZRA). The ZRA operates under the mandate of an Operational Charter given it by the Intergovernmental Ministerial Council composed of representative ministries from Zambia and Zimbabwe. The functions of the Council are governed by the Interministerial Council Bilateral Treaty between the contracting parties, with the ministers from the respective countries reporting to their Parliaments.

The Interministerial Council Bilateral Treaty provides for establishing a Board whose composition must reflect representational equity between the contracting states, as well as relevant expertise in engineering and financial skills, with the duties and obligations of the Zambezi River Authority set out in Article 9 of the agreement. The agreement states "The functions of the Authority shall be to:

a) operate, monitor and maintain the Kariba Complex;

b) in consultation with the National Electricity Undertakings, investigate the desirability of constructing new dams on the Zambezi River and make recommendations thereon to the Council;

c) subject to the approval of the Council, construct, operate, monitor and maintain any other dams on the Zambezi River;

d) collect, accumulate and process hydrological and environmental data of the Zambezi River for the better performance of its functions and for any other purpose beneficial to the Contracting States;

e) in consultation with the National Electricity Undertakings, regulate the water level in the Kariba reservoir and in any other reservoirs owned by the Authority;

f) make such recommendations to the Council as will ensure the effective use of the waters and other resources of the Zambezi River;

g) liaise with the National Electricity Undertakings in the performance of its functions that may affect the generation and transmission of electricity to the Contracting States;

h) subject to the provisions of Article 13, recruit, employ and provide for the training of such staff as may be necessary for the performance of its functions under this Agreement;

i) from time to time and subject to the approval of the Council, make such revisions of salaries, wages and other remuneration to its employees as it considers appropriate;

j) submit development plans and programmes to the Council for approval;

k) give effect to such directions as may, from time to time, be given to it by the Council;

l) carry out such other functions as are provided for in this Agreement or are incidental or conducive to the better performance for its functions."

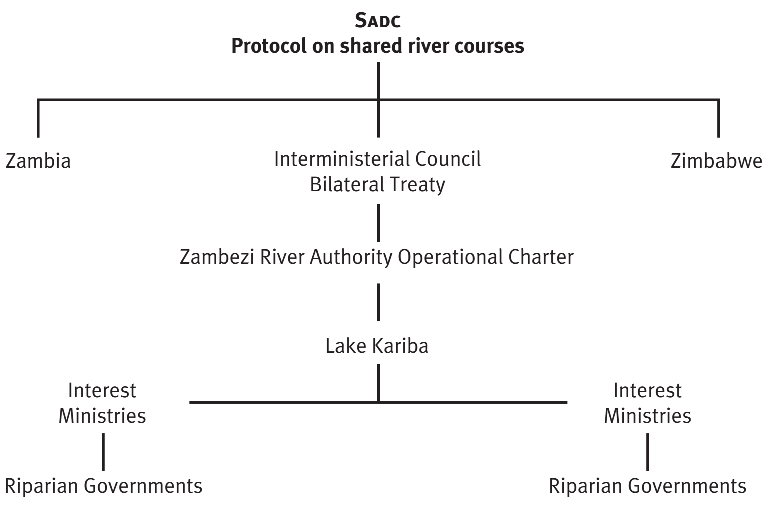

Figure 8. Institutional Structures of the Lake Kariba Management Process.

Although these arrangements have been derived via bilateral negotiations between Zambia and Zimbabwe, in their sovereign rights as members of the Southern African Development Council (SADC), management of the entire Zambezi River basin also is under the purview of the SADC Protocol on Shared Water Courses, with the SADC general principles enunciated in Article 2 (see (http://www.thewaterpage.com/SADC). This protocol, whose jurisdictional powers and legal status, although framed in compelling language as "Member States shall...", are not explicit, sets the framework for water resource development and water quality management.

Reflecting its bilateral nature, the Interministerial Council Bilateral Treaty defines the Zambezi River as "that part of the Zambezi River common to the borders of the two States" (Article 1). This designation covers only some 700 km of the river between Kazungula and Villa do Gumbo. Thus, for integrated, basin-wide management of Lake Kariba, ZRA relies on other international instruments and initiatives, including the SADC Protocol on Shared Water Courses, SADC Zambezi River Action Plan (ZACPLAN), and territorial legislation in relevant states. ZACPLAN identifies management issues at the drainage basin level, and makes recommendations to the riparian states on methods for addressing the identified issues.

To rationalize the hitherto-uncontrolled development activity in the Lake Kariba environs, the Zimbabwe Government, through its Department of Physical Planning, produced the Kariba Combination Master Plan 1998 (Kariba Lakeshore Combination Master Plan Preparation Authority 1998), which covers the Administrative districts surrounding the lake. The plan sets out guidelines for the development and utilization of such natural resource-related components as agriculture, fishing, wildlife, forestry and tourism.

The plan also attempts to establish guidelines for developing infrastructure and clarifying administrative jurisdictional interests and boundaries. This concept has since been extended to the Zambian foreshore. Finally, the plan attempts to outline implementation strategies and identify appropriate agencies and institutions for its various aspects. This combination master plan is the nearest semblance to public participation of lake and lakeshore users in the Lake Kariba management process. Lakeside users, through their local authorities, can provide inputs into resource management issues and, where appropriate, levy resource users to fund the management costs.

Historically, ZRA and its predecessor is probably one of the fully-functional binominal management institutions. The essence of its success is in the committed funding of its operations with revenues from the energy-generating authorities in the riparian states, with only specific projects being funded through donor funds.

There are, however, a number of existing ground-level operational contradictions. That portion of Lake Kariba in Zimbabwe territorial waters is administered as a national park, to control user activities on the lake and regulate the fishery industry. Further, there are areas adjacent to the lake on the Zimbabwean side dedicated to wildlife conservation and tourism. No such facilities, however, exist on the Zambian side. On the Zimbabwe side, various departmental agencies regulate urban development and planning, while similar facilities in Zambia are only weakly developed. Further, departmental authorities within the riparian states often proceed with activities directed by their respective authorities, sometimes in contradiction to the overall ZACPLAN. One reason for this hiatus is that most state institutions and their relevant legislations predate the bilateral agreement between Zambia and Zimbabwe, with no subsequent facilitation for harmonization between institutional operations.

A further weakness of Lake Kariba governance is the virtual non-existence of interagency cooperation, both at territorial and transboundary levels. This reflects the governance style of the respective governments, which provides little opportunity for non-governmental institutions to be directly involved in the management process. As an example, before ZRA established its water quality monitoring facility, the University of Zimbabwe had established a research facility dating back to the early days of the lake. Similarly, the United Nations Food and Agriculture Organisation (FAO) established a fisheries research laboratory to study the lake's limnology and fisheries development. This facility is now called the "Lake Kariba Fisheries Research Institute" and is administered by the Zimbabwean Department of National Parks and Wildlife Management. No existing mechanism either recognizes or provides for the close cooperation between these institutions and the ZRA, the latter left to the discretion of relevant officers. As a result, the overall performance of the institutions is somewhat below optimum achievement.

One of the outcomes of lack of cohesive interagency cooperation is the virtual absence of any vestiges of integrated water resource management in the basin. As a result, resource use and management activities within the basin are poorly coordinated, including for the following reasons:

- Low level of awareness of integrated water resources management among the basin communities. Even where basin catchment management authorities have been established according to SADC requirements, the main concern is water supply;

- Poor connectivity and communality of management concerns among basin communities. Cotton growers in the Gokwe areas, for example, have little in common with the floodplain communities of the Upper Zambezi Barotse flood plain; and,

- Inadequate infrastructure and institutional development for basin-wide integrated water resource management. At the level of economic and human development, the infrastructure and institutional resources required to implement a basin-wide integrated management program, such as the kind seen at the North American Great Lakes, simply are not yet readily available in the Lake Kariba basin.

11. Research

The established facilities that do research on Lake Kariba include:

- University Lake Kariba Research Station (formerly Nuffield Kariba Research Station);
- Aquatic Division, Department of National Parks and Wildlife Management, Government of Zimbabwe; and,
- Zambezi River Authority.

There also are various other institutions, both local and overseas, that have done research on the lake, including:

- Zimbabwe Government Ministry of Health Blair Laboratory;
- The Danish Bilharzia Laboratory, Charlottenlund;
- University of Lund, Sweden;
- University of Colorado, USA;
- Various British technical colleges;
- University of the Witwatersrand (until 1980);
- University of Zimbabwe, Faculty of Agriculture;
- University of Zimbabwe, Centre for Applied Social Studies; and,
- University of Zambia.

More than 200 publications have been produced on Lake Kariba and its environment, including nearly 20 post-graduate dissertations and theses.

While the local institutions have met the basic expenditures of salaries and services, the research costs have essentially been funded by donor agencies. Although this has provided essential funding, at times it has also lead to donor hegemony, in which the propensity of guest participants to advance their research interests has marred project performance. Furthermore, donor-driven programs tend to be exclusive, resulting in diminished cooperation between local organizations working in the same area, as well as uncoordinated, sometimes competing efforts. Finally, donor initiatives often are predicated by undertakings by beneficiary institutions and governments to subsume responsibilities for continued funded of activities at the end of the donor-funding period, which unfortunately are rarely honored.

In spite of such difficulties, however, research efforts on Lake Kariba have resulted in significant insights over the years into the implications of water resource development of the magnitude of the lake. Useful knowledge on ecosystem evolution and management of large reservoirs has been acquired, as well as insights into the social consequences of development projects that result in large-scale involuntary resettlement. Other useful information exists on the impacts of pesticide use in vector control, as well as a working model of the likely impacts of climate change, and the level of economic impacts of such climate-induced perturbations on the Lake Kariba system. There also are engineering lessons garnished from the construction of the Lake Kariba Dam and its subsequent maintenance.

12. Analysis

12.1 The Legal and Institutional Framework

The legal and institutional framework for the management of Lake Kariba and its resources is discussed by Syampangu (1998), and summarized by Nyambe (2001). Nyambe lists 18 separate legislative items in Zambia applicable to Lake Kariba and hinterland administration, while he lists 9 for Zimbabwe. This legislation has overlapping jurisdictions whose applications are not always coordinated, since there are vertical ministerial command structures. None of this territorial legislation provides for lateral links with the Zambezi River Authority, one reason for this legislative and administrative multiplicity being that much of it predates the Zambezi River Authority Act.

Recognizing the limitations imposed on the Zambezi River Authority, moves are underway to form a basin-wide commission, the Zambezi River Commission (ZAMCOM). The provisions of the proposed commission are not yet known. However, unless issues of territorial sovereignty are adequately addressed, and territorial legislations revisited to ensure a workable dovetailing of the commission's jurisdiction and those of participating states, there is a danger the commission would be constrained in addressing basin-wide watershed management issues, in much the same way as the SADC protocol has limited, if any, jurisdictional authority. What is needed are legal documents that are more than framework agreements; rather, they must be instruments in which the issue of sovereignty, paramount in the SADC Protocol on Shared Waters, takes cognizance of shared interests in the water resources of the basin as a whole.

The lack of a framework in which stakeholders and non-governmental organizations can participate in resource management issues is a severe curtailment to the evolution of community responsibility in environmental management and resource stewardship. On the Zambian side of the lake basin, the fisheries resource local management was under the jurisdiction of local chiefs (Siyampaku 1998), while resource management of the lake on the Zimbabwe side was firmly in the hands of the central government. Siyampaku (1998) notes that, in the early period of the Lake Kariba fishery in Zambia, the chiefs enforced closed seasons during the breeding period, ensuring that nurseries were not fished. As local communities authority diminished, however, the fishery suffered from over-fishing and disregard for conservation measures. The recently-adopted Kariba Combination Plan, which purports to reinvest local responsibility in local lakeshore communities through local authorities, may help address this issue.

12.2 The Climate Issue

Although observational data on climate trends for the area are exploratory, global trends and experimental modeling data strongly suggest the need for a precautionary approach. The past two decades have seen shifts in the frequencies of extreme events, and therefore, the management of Lake Kariba, as well as planning for future reservoirs on the Zambezi River, must take the climate trends into consideration. As previously noted, the power generation from Lake Kariba has fallen below the design capacity, with analysts suggesting long periods of low lake water levels are part of the explanation (e.g., see Hulme 1996). Conversely, the watershed can experience flush floods during wet years, as those discussed by Vas (2000), and which illustrate the important role large reservoirs can play in flood management. In 1978, neither Lakes Kariba or Cahora Bassa had sufficient water storage capacity to control the flooding; in contrast, Cahora Bassa, more by good fortune than design, had sufficient storage capacity in 1997 to attenuate downstream flooding. In the 1978 flood, Vas (2000) cited poor communication as a major contributing factor in the failure to warn downstream communities in time. Fortunately, telecommunications and satellite flood warning facilities are now well developed. What is now needed is a joint flood management protocol among the basin states to coordinate flood management, as well as established community responses to flood threats.

12.3 Environmental Issues

The most problematic area in managing Lake Kariba and its watershed probably is that of environmental management (i.e. managing land use in the basin; water quality of inflow rivers; invasive species; etc.). As previously noted, other than for the main Zambezi River, these issues are managed by various territorial institutions and riparian states. The capacity of each riparian state to implement the provisions of the relevant statutes, however, is relatively weak. Further, the Zambezi River Authority Act restricts ZRA jurisdiction to that segment of the Zambezi River where it forms the Zambia-Zimbabwe common boundary, thereby restricting ZRA to deal only with water-related environmental issues of the lake itself. With appropriate statutory authority, however, it is hoped the proposed ZAMCOM can address these issues at the drainage basin level. Nevertheless, whatever institutional structures are eventually adopted, the riparian states must be prepared to provide substantial funds to guarantee the success of the commission's programs. The current riparian programs depend largely on donor-funded initiatives, through the Zambezi River Action Plan (ZACPLAN).

12.4 Displacement

Because there was no Environmental Impact Assessment conducted prior to implementation of the Kariba Dam construction project, not only was there limited knowledge of the area's animal and plant ecology, but also little knowledge of the Tonga population of the Gwembe valley. Further, the downstream impacts of the Kariba project, in both ecological and human terms, was never considered. The Tonga led a riverine livelihood and culture, and their resettlement resulted in physical, economic and cultural displacement. Although the severity of the impacts of this displacement was little understood at the time, even when the predicament of the Tonga came to be known, they lacked the necessary advocacy skills to be able to respond appropriately. In fact, for more than a half-century now, they have remained the least-developed communities in both Zambia and Zimbabwe.

As noted by the World Commission on Dams, communities that do not own land or other visible assets are often marginalized by projects such as the construction of Lake Kariba. Ownership in this case is defined within the Western culture context, which has limited understanding of traditional law ownership in an overall communal ownership setting (e.g. the formalized communal lands tenure of southern African states). However, there are clearly defined individual and communal property rights in these communities which are lost when the communities are displaced. In the case of Lake Kariba, although the displaced Tonga were allocated alternative land, it could not replace their ecological and cultural ties with the Gwembe valley flood plain ecosystem. It is this loss, which is not measurable in material terms, that has caused long lasting trauma in the Tonga community.

In the project planning phase of large reservoirs like Lake Kariba, therefore, it is necessary that the ecology of the communities to be displaced is understood, and that any deficits arising from relocation be fully appraised. It also must be appreciated that, although the land that they occupy might be state land, the tenure and ownership perceptions of the concerned community might be at variance with those of the state and, as in the case of Lake Kariba, may predate the state itself.

The Tonga appreciate how the sacrifice of their land has benefited the sub-region, as exemplified by the bright lights of Kariba and Siyavonga Towns; luxury cruises on the lake; and expensive holiday cottages by the lakeshore. At the same time, however, the Tonga resettlement areas have sparse education, health and other benefits related to development of Lake Kariba. Such basic services also would have been made available to them if the Tonga had been given a share in the Kariba benefits via levying the power producers a development levy for the resettlement area, even if only for a limited number of years.

12.5 Integrated Watershed Management and Public Participation

Integrated watershed management is now the key approach in the developed world to managing water resources within river or lake basins. The land user is ultimately the key player in implementation of integrated watershed management in this approach, thereby also being the key participant.

In integrated watershed management case studies (e.g., Lake Biwa; Lake Champlain), specific attributes of basin citizens include the following:

- High literacy rate;
- High Human Development Index (HDI);
- Good access to lake basin information;
- High level of community concern about lake basin issues;
- Shared values in the environmental health of the lake and its basin;
- Citizen-driven environmental policies and programs;
- High per capita income;
- Low dependence on use of primary natural resources (e.g., fuel wood); and,
- Adequate financial resources in the basin to support citizen-driven management programs (e.g., the tourist industry in the Lake Champlain basin generated US$3.8 billion in the 1999 financial year).

Developing country lake basins (e.g., Lake Kariba), have few, if any, of these attributes available to them. Thus, public participation in lake basin management programs is generally lacking, with management activities being left to state institutions, whose main approach is to enforce state regulations, even though basin citizens often have limited knowledge of the lake management issues.

Schramm and Rubin (1999) outlined a protocol for establishing an integrated watershed management process, which assumes some of the above-outlined basin community attributes. They cite the following management principles as common to all Environmental Management Systems:

- A policy articulating a commitment to a specific level of environmental performance;
- Measurable quantity and quality objectives and performance targets;
- A planning process and strategy to meet the commitments;
- An organized institutional structure to execute the strategy;
- Implementation programs and support tools to meet objectives;
- Communications and training programs; and,
- A measurement and review process to monitor progress.

It is clear, however, that the Lake Kariba drainage basin does not measure up to their assumptions. On the other hand, Sheng (2001) outlined some issues in integrated watershed management in developing countries. Based on his analysis, the Lake Kariba watershed management process, as encapsulated in the ZRA mandate, is that of protecting “downstream investments”, including:

- Ensuring adequate water supply for hydroelectric operations;
- Safeguarding the safety of the dam wall; and,
- Monitoring water quality in regard to eutrophication threats (e.g., noxious weeds).

The management issues do not consider the needs of watershed users. Thus, upstream basin users have no incentives to cooperate in ZRA management interests. Thus, no communality of interest exists in regard to integrated watershed management, a syndrome that Sheng (2001) depicts as a typical problem regarding integrated watershed management efforts in developing countries. This represents a crucial finding in planning integrated watershed management efforts in the Lake Kariba drainage basin.

13. Lessons Learned

The lessons learned in the case of Lake Kariba include the following:

- A detailed investigation of the dam site geology is essential, since non-conforming geological features can lead to expensive, recurrent maintenance costs in the post-project phase;

- Large reservoirs located on, or near, geologic fault lines can cause significant, recurrent seismic activity, leading in some cases to loss of human life and significant property damage;

- The creation of large, relatively deep reservoirs can generate new ecological niches, which may require ecological manipulations to optimize ecosystem functioning;

- Reservoirs can create new opportunities that indigenous people may not share in without assistance;

- Forced relocation of poor communities in the course of water resource development, can lead to long-lasting, trans-generational social traumas; accordingly, reservoir planning must be explicit in addressing community needs, with equity issues in the sharing water resource development benefits being explicitly considered;

- Although decisions concerning the welfare of the Tonga people, and indeed any politically-weak community, may appear to have been influenced by perceptions of race, these perceptions were basically class prejudices; thus, there is a need for honest dialogue between developers and those likely to be affected by the development including, if necessary, appropriate facilitation by neutral parties;

- New opportunities offered by reservoir environments can raise issues of equity in resource access; accordingly, reservoir developers should anticipate this situation by identifying community sectors requiring education, finances and skills to compete with better-advantaged communities in regard to new reservoir resources and opportunities;

- Reservoir watersheds undergo constant change, some of which may be triggered by establishment of the reservoir itself; thus, post-project integrated watershed management efforts must be part of reservoir planning;

- Successful management of trans-boundary reservoirs with international watersheds is predicated on peaceful coexistence and international cooperation;

- There is need for greater coordination of research activities by relevant institutions, in order to maximize research results;

- There is a significant need for information dissemination on issues pertaining to Lake Kariba and its environments; and,

- There is need for the development of strategies applicable to integrated watershed management concepts in developing countries that recognize special circumstances in the socioeconomic and human development status of watershed user communities in developing countries.

14. Conclusions

Lake Kariba has a complex socio-political history. Envisaged as an engine of economic development, the location of the Lake Kariba dam was a result of both technical and political considerations; technical in that it was thought more hydrologically stable than the competing Kafue Gorge site in Zambia; political in that it assuaged the apprehensions of a minority white government in Southern Rhodesia of investing a strategic development facility in a country that could conceivably be governed by a majority black government. Further, the reservoir was designed during a period when human rights, social justice and equity in relation to colonial subjects were secondary concerns, as well as a period when environmental management was an emerging discipline in an era when engineers were an awesome community capable of harnessing nature's energy potential for the development of central southern Africa. Consequently there was little assessment of the potential environmental and social impacts of the proposed reservoir.

Only sparsely populated during the planning and construction period, the portion of the Lake Kariba catchment has been increasingly industrialized in the Zimbabwean sector, with more settlers also moving onto the headwaters floodplain of the Barotse flood plain. Further, the realization early in the lake's establishment that riverine fishes could not utilize the lake's pelagic zone led to the introduction of *Limnothrissa* and other cichlid fishes from the Kafue and Bangweulu flood plains. Although affirmatively-introduced species, other invasive species also established themselves in the lake.

The development of the lake's hinterland, including changes in population density and land use intensification, as well as upstream discharges of inadequately-treated wastes, especially in Zimbabwe, has generated increasing loads of eutrophicating chemicals, with the lake showing incipient signs of eutrophication with the invasion of the lake by water hyacinth. The control of veterinary and human pests has resulted in pesticide accumulation in the lake, as well as indications of heavy metal accumulation. The growth of Kariba Town and Siyavonga, and the establishment of many fishing camps with minimum town planning directives, as well as a growing tourism industry, has resulted in localised offshore microbial pollution, as well as waterborne disease vectors, including bilhartzia transmitting snails. Further, the geological response of the basin to the lake's establishment has been the reactivation of seismic activity in the valley, although the frequency and intensity of the tremors has declined with time.

In summary, the Lake Kariba project was conceived in an unstable political environment, involving racially- and politically-polarised communities. The contracting parties (Governments of Zambia and Southern Rhodesia) were on hostile terms for one-and-one decades, with the border between the two countries closed. Although management of the facility was in the hands of a company jointly owned by the two governments, CAPCO in Zambia was seen by many largely as a Rhodesian entity. Zimbabwe perceived itself in a "minority shareholder" position at its independence, necessitating renegotiation of a new equitable distribution of the Lake Kariba facility assets, together with establishment of a new management institution.

Another noteworthy observation is that the relocation of the Tonga community occurred at a time when issues of human rights, equity and racial equality were poorly developed. Even though the Tonga case study is now well documented, the so-called impacts assessments were conducted at that time more as a means of satisfying funding conditions, than in consideration of the welfare of the affected communities. As a result, translocation of the Tonga, with no acclimatization program in their new habitat, had both environmental and sociological impacts. The need to combat pathogen vectors, for example, resulted in environmental contamination processes with measurable adverse ecological impacts.

Therefore, although a clear governance structure is now in place in regard to Lake Kariba, there still is an overriding need for better coordination of lake management activities.

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