Natural Resources FORUM

Volume 18 Number 3 August 1994

This journal is indexed/abstracted in the following publications: *Current Contents/Social & Behavioral Sciences; Social Sciences Citation Index; Research Alert; Environment Abstracts* and *Enviro/Energyline Abstracts Plus*.

Natural Resources Forum 1994 18 (3) 181-192

Approaches to integrated water resource development and management

The Kafue Basin, Zambia

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In southern Africa institutional capacity in the water sector is severely limited by diminishing regular budget and external assistance allocations. The result has been an overall decline in operational water resource management. This is ironic given the international community's current concern with 'integrated' or 'comprehensive' water resources management. Often, so-called integrated attempts at river basin planning and development have been conceived within the framework of a river basin authority or regional master plans. Such large-scale attempts have not necessarily been compatible either with the national capacity in water resources management or the existing institutional and legislative frameworks. In many cases the actual integration of a basin's physical resources and social, economic and environmental demands is poorly executed. To examine a way forward in resolving what is clearly an unsustainable state of affairs, a diagnostic study of the Kafue Basin, Zambia, was carried out in order to identify a set of water resource management options for a basin currently under stress. A physical framework for the Kafue Basin was established and principal subcatchments and hydrogeological subsystems identified. Current water resource issues in the basin are discussed and a multiobjective approach is proposed to allow intersectoral competition for the basin's limited water resources to be reconciled.

The Kafue catchment has an area of 155 000 km^2 and occupies 20% of Zambia's total land area. It forms one of the principal subcatchments of the Zambezi Basin and has a mean annual flow of some 300 m^3/s near its confluence with the Zambezi. The mean annual flow represents only 6.2% of the mean annual rainfall of 1057 mm falling over the catchment. This low yielding hydrological regime is greatly influenced by the geological and geomorphological setting of the basin. The topography is very subdued, with the landforms being largely developed by chemical weathering and erosion as opposed to the mechanical processes which dominate landform development in most other large catchments. This suggests a very active and widespread role for groundwater circulation in the hydrology of the Kafue Basin. Minor down warping and tilting earth movements occurred in the late Pleistocene, forming swamps and drainage reversals. The net effect has been high open water losses from areas of impeded drainage and high evapotranspiration losses from groundwater seepage zones associated with saprolite and karstic aquifers.

An outline of the physical setting of the catchment is given in Figure 1 together with the principal Department of Water Affairs (DWA) hydrometric stations that are referred to throughout the text.

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This paper is a modified version of a paper to be presented to the International Conference on Integrated River Basin Planning at Wallingford, UK, 4–6 September 1994.

The Kafue Basin plays a central role in Zambia's economy with most of the mining, industrial and agricultural activities and approximately 50% of the Zambia's total population concentrated within the catchment area. However, continued economic development of the basin is not sustainable if intersectoral competition over limited surface water resources by non-consumptive and consumptive users continues. Such competition has recently involved interagency disputes over flow allocations during times of low flow.

Despite the detailed work that has gone into the catchment, particularly in the immediate post-independence years, the late 1960s and early 1970s, plans for the basin's development are currently based on a very limited understanding of the basin's resources. Given this legacy and the need to indicate a direction for the catchment and its development, management and conservation, a rapid diagnostic study was carried out in April 1993 by the United Nations in cooperation with the Department of Water Affairs (DWA), Lusaka [29], with funding from the Swedish International Development Agency (SIDA). This paper summarizes the findings of the study and outlines approaches for the integrated development of the catchment.

From this diagnostic it became apparent that past approaches to water resources development of the basin have generally failed to view the basin as an integrated system with distributed inputs, outputs and storage elements. Water supply schemes in the post-independence years have generally concentrated on stored surface water or run of river solutions and ignored the potential of some prolific and ideally located aquifers. More recent attempts to look at the system in environmental terms have been limited in their technical scope.

Clearly, the challenge for the basin is to find some way of resolving the economic, social and environmental demands placed upon it. The first requirement is to establish a physical framework leading to an understanding of the catchment hydrology. Second, the main water resource issues facing the catchment need to be examined. Third, the approaches for integrated resource management need to be considered.

Establishing a framework

An examination of the physical characteristics of the Kafue catchment has revealed a geological/geomorphological framework in which to discuss water resource development and management [29]. Figure 1 illustrates a set of principal subcatchments with well defined geological, geomorphological and hydraulic characteristics which, contributing to the catchment hydrological response, provide a template within which to discuss water resource planning. Without such a framework, it is difficult to explain adequately the hydrological response of the catchment and account for the distribution of the available surface and groundwater resources. The 1:1 500 000 hydrogeological map published recently as part of the World Bank/UNDP Sub-Saharan Hydrological Assessment for Zambia [33] provides a clear and up to date basis for such a framework. Figure 1 is an attempt to summarize this mapping and bring out the salient hydrological and hydrogeological features of the Kafue Basin.

Previous water resource studies

Initial surveys in the catchment emphasized the role of surface water in satisfying the irrigation needs of the lower catchment [12] and the water supply needs of the Copper Belt [6]. At this stage a comprehensive review of the groundwater potential of the catchment's dolomitic and limestone aquifers was not considered necessary, despite the exploitation of the Lusaka dolomite which commenced in the early 1930s to serve the newly established capital.

Development plans in the mid-1960s still concentrated on the role of surface water [9] and stressed the role of deforestation in altering the hydrological regime of the catchment. Experimental catchments were set up in 1964 in the upper catchment at the Luano Forest Reserve, near Chingola, to research this issue [22] and the concern is perpetuated in the more recent literature [13]. However, the experimental catchment work was not completed, and despite the collection of much data, the results remain poorly documented and inconclusive.

The potential use of groundwater within Zambia as a whole was outlined in the mid-1960s by Lambert [18] and further elaborated at the end of the 1970s by Chenov [4]. In addition, the significance of geological controls on subcatchment water balances and flow durations had been appreciated by the early 1970s [21,31]. The Department of Water Affairs initiated groundwater studies for town supplies in Lusaka and the Copper Belt [27,15,16,17,11]. However, despite confirmation of the prolific groundwater resources of the dolomitic aquifers in both regions, surface water schemes predominated in the Copper Belt [10,2], and Lusaka was provided with a surface water intake to serve the rapidly growing metropolitan area as part of the Kafue Gorge Scheme [26]. It was not until a set of expensive surface water schemes at Lusaka, Kabwe and Ndola had been constructed that cheaper groundwater alternatives were proposed and developed [8,3]. It is therefore difficult to understand why analytical work on the catchment has concentrated on purely hydrological interpretations and analysis [1,5,24,25].

While elements of each individual study referred to above are useful, none provides a comprehensive and sufficiently detailed account of the subcatchments

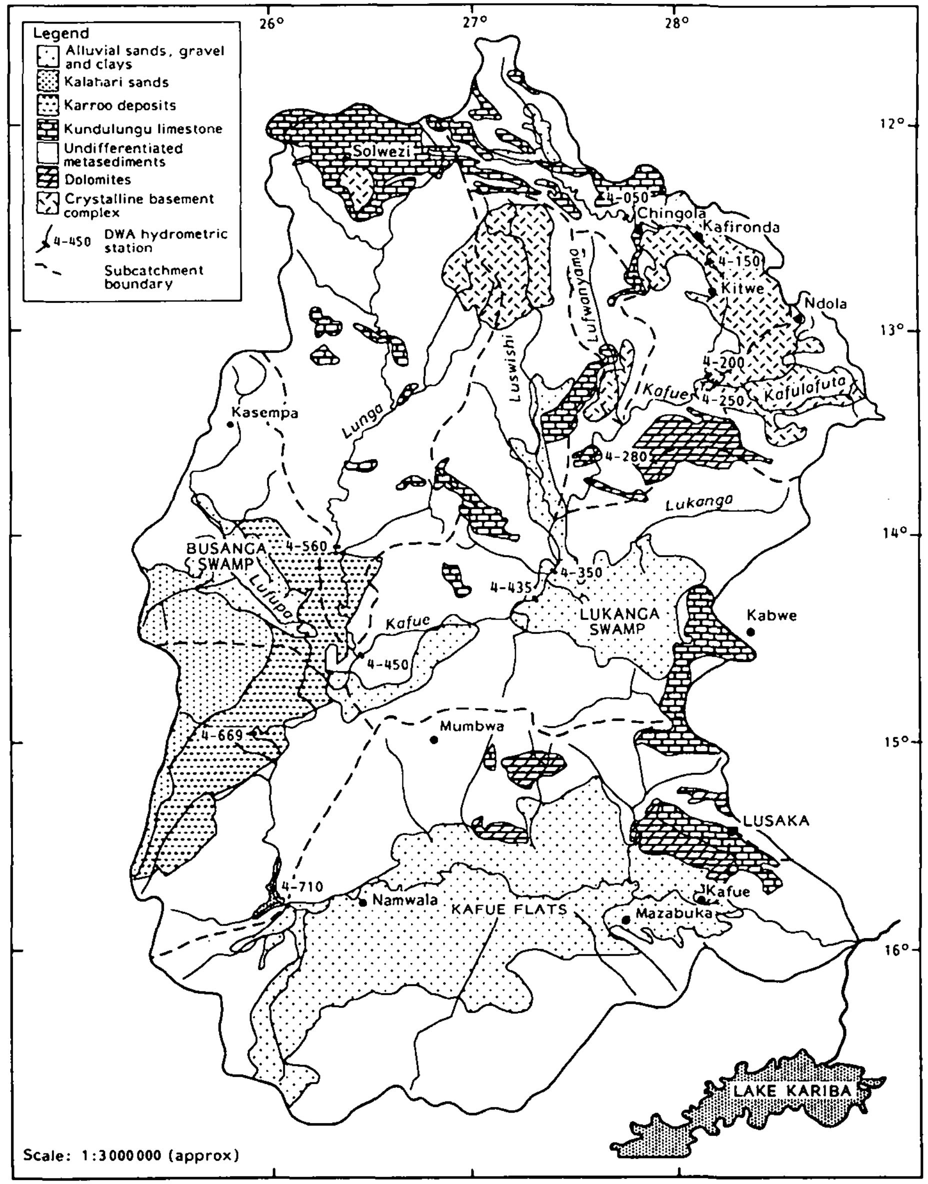

Figure 1. Kafue Basin geology, hydrology and selected discharge monitring stations.

throughout the whole basin on which to base, first, an understanding of the hydrological and hydrogeological subsystems operating within the basin and, second, a sound framework for water resource planning. To this end a more comprehensive breakdown of the basin's subcatchments is suggested in Table 1 and a geomorphological subdivision in Table 2.

However, from this review of research and development on the Kafue Basin, it is apparent that there has been a general failure to integrate the hydrological system with the known hydrogeological subsystems operating within the basin. It could be argued that, as a result, there has been suboptimal resource development and significant overinvestment in surface water supply schemes.

Catchment yield

The yield of the basin is limited. Mean annual rainfall over the catchment amounts to 1060 mm but is subject to distinctive temporal and spatial variations [28]. However, at the entrance to the Kafue Gorge at Kasaka (catchment area 151 000 km^2) mean annual flows amount to approximately 66 mm or 10 000 Mm^3, which represents only 6.2% of the catchment rainfall. This contrasts with the adjacent Luangwa catchment which over an area of 144 000 km^2 yields 13% of its mean annual rainfall.

Three principal physical explanations may be invoked to explain the Kafue's low yield in relation to regional hydrology:

(i) The low topographic relief within the catchment coupled with a thick mantle of permeable soils which contribute to the attenuation and diffusion of hydrograph response.
(ii) The spatial and temporal variability of rainfall over the catchment, which causes related variations in the river flows and recharge and consequent changes in groundwater storage and discharge.
(iii) The geological and geomorphological evolution of the catchment has led to high open water and evapotranspiration losses from areas of impeded drainage and seepage zones associated with saprolite and karstic aquifers. The consequence is a low contribution from the aquifers to river base flow.

With these physical controls, the annual regime of the Kafue at Kafue Hook follows a remarkably consistent pattern of a single principal peak at end-February or early March, followed by a long uniform recession until the onset of the early rains in late November. Figure 2 shows a plot of the monthly flows at Kafue Hook and Pontoon stations covering 1905 to 1993, to illustrate the flow regime over the longest period available.

However, the Kafue Hook hydrograph masks significant variation in upstream routeing and lateral inflow. To illustrate this feature, a composite plot of daily discharge data for 1962-63 has been plotted in Figure 3 for a set of representative mainstream and tributary stations. The 1962-63 data were chosen for their depiction of a water year with near mean annual discharges and the reliability and availability of the data.

The implications for water resource development and management in such a low yielding complex catchment are manifold, but the choice of approaches to water resource development and management must be based on a sound understanding of these hydrological and hydrogeological limitations if the approach is to be considered at all 'integrated'.

Developing a framework

Most of tropical Africa has been exposed as continental land above sea level for over 200 million years. In the Kafue Basin the resulting modern landforms are extensive old land surfaces interrupted by isolated high lands, scarps and broad linear valleys of tectonic origin. This landscape is the result of two main erosion cycles, the African and Post-African.

The upper basin largely lies on the African erosion surface. The African surface in the Kafue Basin is characterized by an extremely smooth plateau surface with subdued slopes, shallow and wide drainage patterns and scattered inselbergs. The middle and lower basin lies mainly on the Post-African erosion surface. The Post-African surface is polycyclic and more hilly and incised than the African surface. The relationship of well defined catchment zones to the erosion surfaces is indicated in Table 2.

The brief examination of the physical characteristics of the Kafue Basin and the previous attempts to model its hydrological regime confirm the need to consider a geological/geomorphological framework in which to discuss water resource development and management. At this stage it is only possible to outline the framework as illustrated in Figure 4. This figure depicts the major subcatchments and storage components of the system and the relationship to the hydrogeological subsystems and centres of irrigation demand. It is a first attempt at dividing and distributing the catchment into discrete basin subsystems and will doubtless require modifying and updating as more data become available and more focused research is carried out, but it does offer a template upon which water resource optimization and planning can be realistically tested.

Table 1: Principle subcatchments and incremental catchments in the Kafue Basin.

Subcatchment or basin increment	Area (km^2)	Hydrometric station no	Mean flow (m^3/s)	Rainfall (mm)	Runoff (mm)	% runoff	Mean flow (Mm^3 pa)	Geology and geomorphology
Upper Kafue–Raglan Farm	5 000	4-050	37	1300	231	18	1 154	Upper catchment on Kundulungu limestones, shales etc
Upper Kafue–Smiths Bridge	8 599	4-130	80	1300	291	22	2507	On to basement complex (BC). Granitic gneiss, north of Kitwe
Upper Kafue–Wusakile Bridge	9 195	4-150						Still on BC (gneiss and metasediments south of Kitwe)
Upper Kafue–Mpatamato	11 655	4-200	95	1306	257	20	2996	Just coming off BC onto the lower Palaeozoic Kundulungu shales surrounded by quartzites and dolomites of the Katanga supergroup
Kafulafuta	4 817	4-250	27	1275	178	14	857	Basement complex gneiss and metasediments
Lufwanyama	3 000	4-272						
Middle Kafue–Machiya	22 922	4-280						Set in Upper Roan dolomites and Lower Road quartzites of the Katanga supergroup The hydrology here strongly influenced by the Mpongwe block storage and losses
Luswishi	9 000	4-340						
Lukanga	16 000							
Middle Kafue–Chilenga	34 178	4-350	189	1257	175	14	5967	On Kundulungu shales and alluvium associated with the Lukanga depression
Middle Kafue–Meswebi	50 479	4-435	203	1189	127	11	6402	On Kundulungu shales and alluvium associated with the Lukanga depression
Middle Kafue–Lubungu	54 442	4-450	199	1170	115	10	6282	Just upstream of Lunga confluence on the controlling edge of the BC culmination (Hook granites)
Lunga confluence	24 268	4-595	117	1250	152	12	3700	Principally on Kundulungu shales with isolated limestone outcrops in central and lower catchment and more complete Kundulungu limestone cover in upper catchment
Lufupa								Principally Karroo and Kalahari deposits
Middle Kafue–Kafue Hook	95 053	4-669	336	1160	112	10	10602	Entry of Kafue onto Hook culmination. Some inflow from Karroo (Mesozoic) and Kalahari/Karroo (Cenozoic) catchments to the west
Middle Kafue at Itezhi-Tezhi	105 620	4-710	317	1151	95	8	9997	Entry on to the Kafue flats with upstream lateral inflow from granite subcatchments probably accounting for some flashiness
Lower Kafue at Kasaka	150 971	4-977	314	1057	66	6	9902	Kafue flats on Karroo and alluvium surrounded by dolomite to the north and folded BC to the south. Lateral inflow probably insignificant
Lower Kafue at Zambezi confluence	154 829							Kafue Gorge set in BC and mine series. Falls on to Karroo deposits associated with the Zambezi rift

Table 2. Geomorphological zoning of the Kafue basin.

Catchment zone	DWA station	Area (km^2)	Elevation range (m) (mean above sea level)	Erosion surface	Geology
Upper Kafue Upper Mutanda Upper Lunga	4–200 4–500 4–560	11 655 1 706 620	1370–1132	Cretaceous (post-Gondwana) and African (Early Tertiary)	Folded Kundulungu limestones and shales and basement complex culminations
Middle – Kafue Hook	4–670 (4–699)	94 920	1132–1073	African (mid-Tertiary)	Kundulungu shales, siltstones and sandstones with Karroo and alluvium
Middl – Itezhi-Tezhi	4–710	105 620	1073–980	Post-African	Hook granites and Karroo
Lower – Kafue Flats	4–980	151 000	980–966	Post-African (late Tertiary)	Karroo deposits and alluvium
Lower – Gorge	Confluence	155 000	966–370	Congo (Pleistocene)	Karroo deposits and alluvium

Water resources issues

Chronology of economic development

The economic development of the basin commenced in the 19th century. A brief outline of the basin's development is summarized in Table 3, which shows events that have, directly or indirectly, impinged upon the water resources. The main development of the Kafue has involved the construction of the Kafue Gorge dam and power plant completed in 1971 and the subsequent construction of the regulation dam at Itezhi-Tezhi which was completed in 1978.

This sequence of development may be considered typical of the 20th-century evolution of Zambesi sub-basins and others in southern Africa. The principal development has been driven by hydroelectric considerations and the power generation authorities hold the principal water rights. There are burgeoning irrigation demands within the subcatchments and many towns regularly deal with water shortages and load shedding. The impact of mining activities in the Copper Belt has not been strictly regulated and deterioration of water quality is locally significant. This characteristic cycle points to a poor overall water resource management with very little attempt to optimize existing resources let alone plan for future developments.

Catchment resources and demand

From a mean annual flow of only 366 m^3/s at Kafue Hook and 314 m^3/s at Kafue Gorge and assuming a population in the catchment of 3 000 000 with a 65% urban and 35% rural split, the current and projected uses are tabulated in Table 4.

Even using these simplified assumptions, it is evident that the main competition for water is between power generation and irrigation. Compared with these demands the requirements for rural and urban water supplies are small. However, discussion with water supply engineers in the basin has indicated that there are difficulties in securing reliable sources for raw water. This relates primarily to the design of intake structures on inadequately researched subcatchments and the lack of up to date research into local groundwater occurrences. More recent demands from environmentalists have resulted in occasional freshet releases from Itezhi-Tezhi to simulate the annual flooding regime in the Kafue Flats.

Options for water resource development

Options for further large-scale impoundment in the upper and middle catchment are severely limited if mean annual flows in the lower catchment are to be sustained and the environmental integrity of the basin preserved. Despite the limitations, there are plans to abstract a further 4.0 m^3/s from the Kafue at Kafue

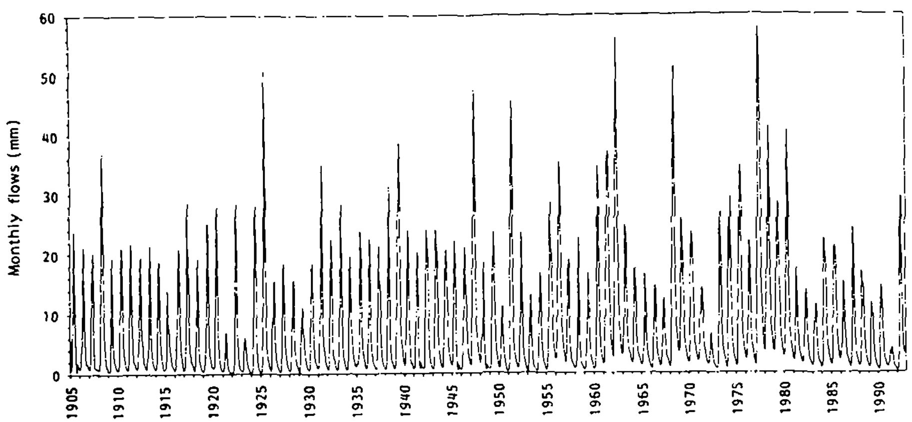

Figure 2. Kafue Hook monthly flows October 1905-September 1993.

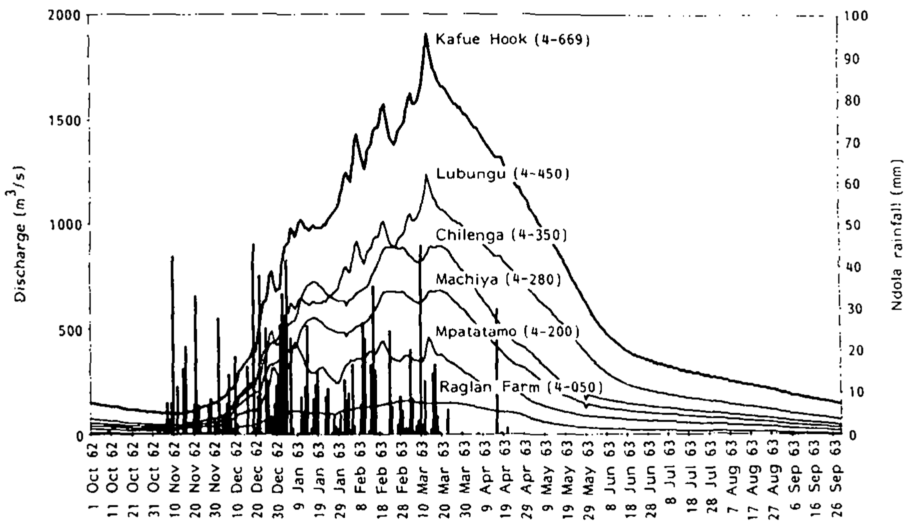

Figure 3. Selected hyrdorgraphs for the water year 1962-63.

Table 3: Economic chronology of the Kafue basin.

Date	Event
1890–1930	Establishment of mining activities and line of rail in the Copper Belt
1930	Establishment of Lusaka as capital: groundwater development for Lusaka water supply
1936	*Water Affairs and Irrigation Department* established. Monitoring networks initiated and large-scale commercial irrigation commences
1940	Mine dewatering becomes significant
1964–45	Independence and Unilateral Declaration of Independence (UDI)
1958	Impoundment at Kariba and resettlement in Gwembe
1960	Establishment of the Nchanga Tailings Leach Plant near Chingola
1966	Expansion of irrigation schemes, Nkambala, Chilaga, Chisamba, Chirundu and significant population growth
1968	FAO multipurpose study published
1970–1	Kafue intake and Kafue-Lusaka pipeline constructed (4.5 m^3/s). Impoundment at Kafue Gorge
1975	Kafue industrial developments, Kasempa rice scheme
1978	Impoundment at Itezhi-Tezhi
1992	Completion of Konkola mine feasibility study. Mine dewatering at Konkola set to continue at 7.0 m^3/s
1993	Lusaka water supply requirement for a further 4.0 m^3/s from the Kafue

Table 4. Summary of water use in the Kafue basin.

Category of use/loss	*Use* (m^3/s^1)	*Assumptions*
Non-consumptive use		
Hydropower	168.0	ZESCO water right
Kafue wetlands simulated flood release in dry years	(117)	Optional freshet release to sustain 300 m^3/s^1 discharge over four-week period in March in dry years
Fish farming	–	Negligible
Subtotal	168.0	
Consumptive use		
Rural water supply	0.8	1 050 000 rural population at 60 litres per day per head
Urban water supply	4.0 (8.0 projected)	1,950,000 urban population at 100 litres per day per head
Stock watering	0.3	500 000 at 50 litres per day per head cattle
Irrigation	35.0	35 000 ha at 1l/s/ha
Industrial use	3.0	Assumed
Sub total	43.1	

Town to supply Lusaka. These plans are likely to conflict with hydroelectric and irrigation demands upon the base flow of the Kafue in the lower catchment. The demands for freshet releases to simulate an annual flood in the Kafue Flats exacerbates the conflict.

Bearing these issues in mind, two observations can be made with regard to surface water development options. First, the Lunga subcatchment contribution is crucial and the subcatchment needs to be protected to conserve its contribution to the overall Kafue yield. Second, options for minimizing existing losses from permanently inundated areas, principally the Lukanga swamp, may become increasingly attractive if further consumptive and non-consumptive use is required downstream. On purely hydrological criteria, the environmental demands of the Kafue Flats are difficult to justify unless the Flats are less efficient at evaporating water than the Itezhi-Tezhi reservoir and the actual bankful discharge of the Flats channel system is known. The need to sustain a largely unproductive wetland has always been questioned on account of the mosquito and tsetse fly populations which still prevent human and livestock colonization.

In addition to surface water options, the groundwater resource development potential of the basin is also significant. The productive limestone and dolomite aquifers possess considerable natural storage. Opportunities for large-scale groundwater abstraction exist on these outcrops to develop the natural storage before much of the annual recharge is lost to unproductive open-water evaporation and evapotranspiration at the discharge points, which are the springs and the seepage zones. The widespread distribution of the limestone and dolomite aquifers have an advantage over the linear distribution associated with surface water development. Furthermore, the undeveloped state of many of the aquifer blocks merits attention for future infrastructural and agricultural development plans [32].

Fortunately, the present stage of groundwater abstraction from these aquifers is such that there is still time to bring existing groundwater development under control, even if that development is accelerated. Ultimately, however, when such developments approach the sustainable yield of the aquifer block, control of development and authority to prohibit further drilling will have to be enforced. In addition, the often discrete configuration of the karstic groundwater catchments needs to be determined before interference effects are assumed. Under these circumstances regional groundwater monitoring networks need to be established across each outcrop and registration and auditing of all abstractions should be enforced. Because the karstic nature of the aquifers presents high pollution risks, aquifer protection zones are required to reduce these risks.

Data analysis

Currently there is no analysis of hydrometric records. The Department of Water Affairs does not have the resources to do anything other than data collection and compilation. Previous support to the hydrometric network has acted as purely a data rescue operation [14]. On going support from the Southern African Development Community (SADC) Hydroelectric Hydrological Assistance Project, Phase 2, is concentrating on maintaining monitoring of inflows to the Itezhi-Tezhi reservoir. However, with current budget constraints, the DWA network is too extensive to maintain. The network could be rationalized to concentrate on fewer high quality stations in the major subcatchments. Such rationalization could be based on present and future needs and should involve monitoring the main tributaries. Many water level stations could be discontinued and resources saved until specific monitoring sites are required for development projects. In addition, it is time that groundwater monitoring networks for the principal limestone and dolomite aquifers be established ideally under the auspices of local water supply utilities.

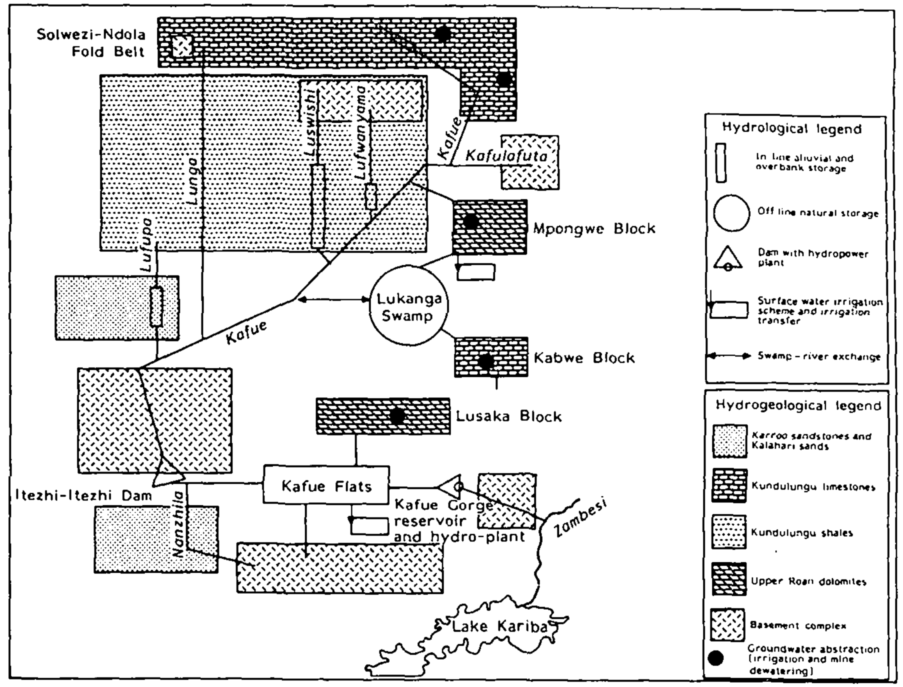

Figure 4. Kafue Basin hydrological elements and hydrogeological subsystems.

Existing water policy and legislation

At present an outmoded Water Act of 1964 sits side by side with the recent Environmental Protection and Pollution Control Act of 1990. While the latter defines the aquatic environment as comprising both surface and groundwater, the Water Act only makes provision for surface water regulation. The implicit water policy within the Water Act was inherited from a previous administrative system whose aims were clearly to promote the rapid development of surface water resources to increase the economic growth of the country. Lacking concise knowledge of the country's groundwater resources, the water policy recognized private ownership of groundwater and allowed unregulated development. After independence, economic and social development placed increased demands on surface and groundwater resources. The creation of the industrial township at Kafue and urban growth elsewhere required comprehensive surface and groundwater studies. The ready availability of surface water data and the lack of understanding of the groundwater development potential led to a strategy of surface water development for many urban water supplies.

Clearly changes in Zambia's water policy and enabling legislation are long overdue. Elsewhere it has been observed that increased understanding of both surface and groundwater interactions can drive changes in water policy that improve society's use of limited resources [7]. In the Zambian context it is also prudent to consider how legislation can be used as a tool for development and not merely as a regulatory device. However, there may be reasons for delaying or inhibiting change where prior water rights stand to be questioned or transferred.

Approaches to integrated development and management

Against a background of a naturally limited system, deficiencies in data and hydrological understanding of the catchment and an uncoordinated water policy and legislative framework, the reconciliation of apparently conflicting economic, social and environmental demands may seem insurmountable. However, if the single sector approach to basin planning is perpetuated, intersectoral competition for water will continue together with its consequences: environmental degradation, urban water shortages, load shedding, and declines in overall welfare and productivity. Under these circumstances, some of the options for initiating change to ensure sustainable development are discussed below.

Institutional innovation

According to institutional theory [19], the discrepancy ('stress') between social goals and the complex of technology, environment and institutions that constitute the Kafue's actual circumstances should lead to institutional innovation, such as harmonized water policy and enabling legislation. Such innovation should allow society to adapt and remove the stress. It could be argued, however, that institutional innovation has barely made an appearance in Zambia since man started applying technology to the Kafue. Moreover, the technology that has been applied (principally surface water storage) has simply exacerbated the stress by enhancing evaporative losses from the basin. Fortunately, the most recent drought in the basin during 1992-1993 seems to be driving some institutional reform with comprehensive reviews of the functions of the Department of Water Affairs.

Institutional theory would also assert that with the expansion of the catchment database over time, and technical innovations in data processing and complex system modelling, the range of institutional options should open up to allow a wider range of choices about development goals and resource allocation. Considering all the hydrological and hydraulic work carried out in the Kafue Basin, and the advances in hydrological modelling, multiobjective analysis and computing power in recent years, it is unfortunate that the Kafue still has to rely on a lumped monthly rainfall/runoff model as its principal management tool [25].

Linking hydrology and water resource policy

To date the hydrology of the basin remains poorly explained. While there are many problems with data quality of both rainfall and runoff, very little analysis of the existing time series data has been carried out since the 1970s and the analysis that has been done has failed to interpret the distribution of daily rainfall and the form of annual hydrographs in physical terms. This is ironic since the geology and hydrogeology of the catchment are generally well established. It is evident that integrated development and management of the Kafue subbasin must appreciate the role of both hydrological and hydrogeological processes operating in the catchment. Moreover, optimal use of the subbasin's resources will require, at the very least, a distributed model of interlinked hydrological systems and hydrogeological subsystems.

However, the real issue lies not with hydrology or modelling accuracy, but with finding a way of resolving conflicting demands upon the resource. This will depend on a thorough understanding of basin processes; the ability to simulate development alternatives such as new irrigation and hydropower schemes; and the ability to evaluate their impact on key social, economic and environmental indicators. These simulations and evaluations can be presented to government as a range of options or scenarios each with its particular set of benefits and trade offs.

Toward an integrated approach

It is possible to develop a generalized physical framework for the Kafue Basin system based on geological and geomorphological considerations that respects the spatial distribution of the hydrological process and hydrogeological systems in a set of subcatchments. Such models have been attempted for more complex systems such as the Rio Colorado in Argentina [20] and North China [30].

Furthermore, such a framework could be used as a basis for a set of linked environmental and economic models to develop multiobjective/goal programming methods [23]. These may be used to examine the range of environmental and economic options for the Kafue basin in a truly cross-sectoral vision of the system. Multiobjective models are well suited to integrated basin management since the single resource (the river basin) has to supply multiple demands. Under these circumstances optimization methods seek to allocate the resource in a satisficing way, rather than in the maximizing manner associated with the more conventional use of price allocation in a supposedly free market.

The whole approach is not necessarily complex and can be carried out using simplified models until the processes and .ormulation techniques associated with multi-objective analysis are learnt, but the approach does require continuous collection and analysis of data and that the decision maker interacts with the computational processes in the identification of goals, values and priorities. To this extent the multiobjective approach is no more than an integrated and transparent tool for supporting decision making. Under present circumstances the Kafue Basin would be a good candidate for the application of multiobjective methods and while it would take time to establish and develop the methodology, it may offer the only sensible way to reconcile future water resource allocation in the basin

On the basis of work carried out by the United Nations in northern China [30], an outline of such a scheme could involve the following set of linked databases and models:

(i) a water resources management information system using key hydrometric station data;
(ii) subcatchment rainfall/runoff modelling with soil moisture and groundwater components using daily data wherever possible;
(iii) channel routeing module with conveyance losses attributable to overbank spillage and alluvial storage;
(iv) reservoir operation model;
(v) agricultural and industrial water demand models;
(vi) engineering economic analysis model;
(vii) macroeconomic model;
(viii) water resources simulation model;
(ix) multiobjective analysis/goal programming model (special case of linear programming model).

This outline is suggested as an alternative to the present planning/resource allocation system operating in the Kafue which neither takes account of the physical limitations of the catchment, nor makes an attempt to integrate the physical, social and economic objectives. It is not proposed as a remedy to the water resource problems the basin is facing, but rather as a method for examining development options and trade offs.

Conclusions

Very little attention has been paid to the establishment of a comprehensive and coherent framework for the hydrology of the Kafue Basin. Despite advances made in information management and modelling capability in the past decade, the 1990s still sees the use of lumped models with monthly data to manage the basin's water resources. Moreover, such planning that has been carried out comprises isolated sectoral studies for hydropower, irrigation, water supply and environment. This has resulted in suboptimal use of the system's resources and disputes among government agencies during dry season hydrograph recession. Groundwater resources in particular have been poorly understood yet their potential is significant in terms of urban and irrigated agriculture supply. However, while there are attendant institutional problems to be resolved, it is possible to see a way of resolving current resource allocation problems using simple multiobjective/goal programming techniques set in a sound geological/geomorphological framework.

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