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# Water Scarcity in the Zambezi Basin in the Long-Term Future: A Risk Assessment

ARJEN Y. HOEKSTRA

UNESCO-IHE Institute for Water Education, Delft, The Netherlands

ABSTRACT

The aim of this paper is to explore possible futures for the Zambezi basin and to estimate the risks of different water management strategies. Existing uncertainties are translated into alternative assumptions. The risk of a certain management strategy, which has been developed under a given set of assumptions, is analysed by applying alternative assumptions. For the exploration of possible futures, a dynamic simulation model is used. Three 'utopias' and a number of 'dystopias' are considered. A utopia is based on a coherent set of assumptions with respect to world-view (how does the world function), management style (how do people respond) and context (exogenous developments). A dystopia evolves if some assumptions are taken differently. Using the risk assessment method described, the paper reflects on the water policy priorities earlier proposed in an expert meeting held in Harare. It is shown that in only one out of the nine cases putting the 'Harare priorities' into practice will work out effectively and without large trade-offs. It is concluded that minimising risks would require a radical shift from supply towards demand policy.

**Keywords:** water scarcity, simulation, risk assessment, cultural theory, Zambezi.

## 1. INTRODUCTION

The Zambezi basin in Southern Africa is one of the great international river basins in the world. Eight nations have part of their territory in the basin: Zambia, Angola, Zimbabwe, Mozambique, Malawi, Tanzania, Namibia and Botswana (Fig. 1). The catchment area of the Zambezi lies in the tropics, between 9 and 20 degrees south of the equator, and encompasses humid, semi-arid and arid regions. The rainy season is from November to April, in the southern summer. Annual rainfall varies between 600 mm/yr in the southern part of the basin and 1200 mm/yr in the northern part.

The total population in the Zambezi basin is estimated at about 25.5 million (in 1994). The gross basin product – defined as the sum of the gross national products insofar as generated within the basin – is estimated at about 10 billion US$ (in 1995). As a result, the gross basin product per capita is about 400 US$ per capita per year. Recent growth rates show that the population in the Zambezi basin has increased about 1.5 times faster than gross basin product, which implies that the average income per capita has decreased considerably (Table 1). The total cropland area has grown at a rate of about 10 per cent of population growth, while irrigated cropland increased by nearly as much as the population. In the past fifteen years the population in the Zambezi basin grew by 60 to 70 per cent and the total irrigated cropland area by 50 to 60 per cent.

In the past, water resources development in the Zambezi basin has been dominated by national single-purpose projects. These projects have rarely taken into consideration the interests of other users or countries or the consequential environmental impacts. Despite this lack of comprehensive planning, there have been no major conflicts in the utilisation of the Zambezi river system, probably due to the fact that many parts of the basin still offer sufficient scope for further development. However, if all current plans for such development are realised, different interests will inevitably begin to clash. At present, the installed hydropower generation capacity in the main stream of the Zambezi amounts to nearly 3500 MW, but there are plans in more or less advanced stages of development for at least another 6000 MW (Batoka Gorge 1600 MW, Devil's Gorge 1240 MW, Mupata Gorge 1000 MW, extension Cahora Bassa 550 MW, Mapanda Uncua 1600 MW). At the same time there are ambitious plans throughout the basin to extend irrigation. According to Pallett [1] more than 500,000 hectares of land could be brought under irrigation in the next 30 years. Furthermore, given continuing population growth, an increasing level of urbanisation and an expected rise in

Address correspondence to: Arjen Y. Hoekstra, UNESCO-IHE Institute for Water Education, P.O. Box 3015, 2601 DA Delft, The Netherlands. Tel.: +31 15 2151 828; E-mail: arjen@ihe.nl

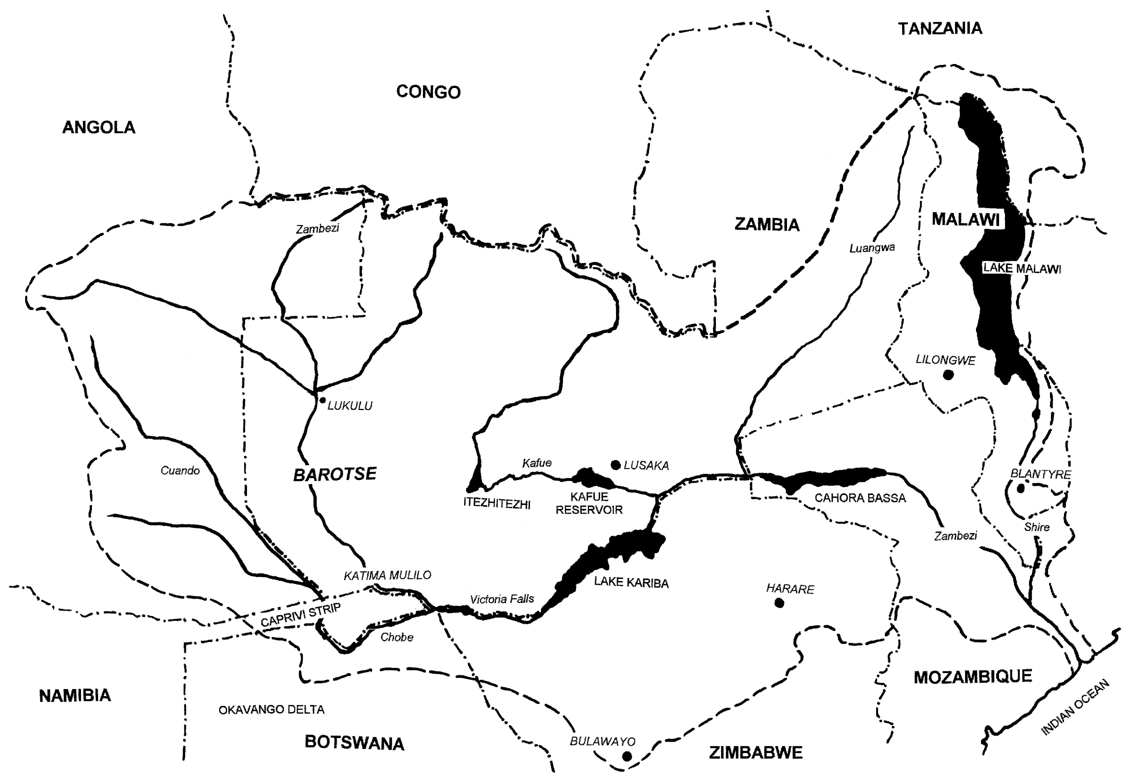


Fig. 1. Map of the Zambezi basin.

Table 1. Average annual growth rates (%/yr).

| | Period | Angola | Namibia | Botswana | Zambia | Zimbabwe | Tanzania | Malawi | Mozamb. | Zambezi basin[c] |
|---|---|---|---|---|---|---|---|---|---|---|
| Population[a] | 1980–1994 | 3.1 | 2.7 | 3.4 | 3.4 | 3.2 | 3.2 | 4.1 | 1.8 | 3.4 |
| Gross national product[b] | 1980–1991 | n.a. | 1.6 | 9.3 | 0.7 | 3.6 | 2.0 | 3.5 | −1.1 | 2.3 |
| Total cropland area[a] | 1980–1994 | 0.21 | 0.05 | 0.35 | 0.23 | 0.83 | 1.5 | 1.8 | 0.23 | 0.36 |
| Irrigated cropland area[a] | 1980–1994 | 0.0 | 2.9 | 0.0 | 6.5 | 2.8 | 1.6 | 3.2 | 3.6 | 3.0 |

*Note*. [a]Calculated on the basis of data from [22].
[b][21].
[c]Data for the Zambezi basin have been calculated on the basis of the national data, weighted according to the relative contribution of a nation to the total population (respectively gross national product, total cropland area, irrigated cropland area) in the Zambezi basin.

average living standards, domestic water demand will increase significantly throughout the basin. In addition, proposals have been made to withdraw water from the Zambezi river near Katima Mulilo in Namibia, for export to South Africa to supply the water needs of Johannesburg, Pretoria, and surrounding agricultural areas [2].

It is open to question whether all individual plans can go ahead collectively. Most of the problems that might be expected will not emerge immediately as the result of one particular project, but rather they will develop as the long-term net result of a combination of activities [3–6]. In the long run, water resources development in the upstream parts of the Zambezi basin is likely to reduce the possibilities for downstream development. In addition, the increasing demand for water throughout the basin will certainly affect its current ecological functioning.

The aim of this paper is to explore the full range of possible long-term futures for the Zambezi basin and to estimate the risks of different water management strategies. The year 2050 will be taken as a time horizon. The approach followed fits in the tradition of model-based scenario development, which started in the sixties. The paper particularly aims to contribute to the development of methodology to deal with structural uncertainties inherent to complex systems.

The paper is composed as follows. The next section describes the method for risk assessment in long-term planning that has been applied. The third section briefly describes the simulation model that has been used. In the fourth section, three 'water utopias' are presented, according to three different 'perspectives': the hierarchist, egalitarian and individualist. A utopia is characterised by a coherent set of assumptions with regard to world-view, management style and exogenous developments. The fifth section discusses a number of different dystopian futures, which will evolve if alternative assumptions are made. These dystopias give some insight into the risks associated with each of the utopias. The sixth section reflects on the water policy priorities proposed by the participants of a workshop in Harare in 1996, discussing the kinds of risk that will emerge if these priorities are put into practice. The last section of the paper provides some suggestions for policy priorities that may reduce the various types of risk.

## 2. A METHOD FOR RISK ASSESSMENT IN LONG-TERM PLANNING

Long-term planners have to cope with large uncertainties. How fast will populations grow, and what type of economic development might be expected? How will consumption patterns change, and how will people respond to changes in prices? Efforts to increase knowledge might reduce uncertainties to some extent, but research often makes people aware of new uncertainties at the same time. In general, it has appeared that it is relatively easy to reduce uncertainties if one considers a particular phenomenon in isolation, but this becomes much more difficult if the interaction between a large variety of phenomena comes into play. Planning on the long-term typically involves the latter type of situation.

In order to assess risks involved in long-term planning, a six-step approach has been followed [7–9]:

1. identification of the major uncertainties in the field considered,
2. analysis of the consistency or inconsistency between different alternative assumptions,
3. qualitative description of a limited number of 'perspectives' (coherent sets of assumptions),
4. mathematical formalisation of the set of assumptions for each perspective,
5. development of scenarios by varying (sub-sets of) assumptions,
6. risk assessment of a certain management strategy by varying the other assumptions.

The first step is to identify the major uncertainties that have to be handled. A practical way to do so is to look at controversies that exist between experts in the field. Controversies often betray the presence of uncertainties about the basic assumptions or hypotheses to be adopted. Major uncertainties can refer to unknown parameter values, but to the very nature of cause-effect relations as well. The outcome of this step depends largely on the type of policy questions to be answered. In long-term planning, 'structural' uncertainties deserve particular attention, because the existence of alternatives for a cause-effect mechanism will generally affect the outcome of the analysis to a larger extent than the existence of an uncertainty range for some parameter value. A structural uncertainty in the field of water resources planning is for instance: does increasing prosperity result in improved water supply and sanitation conditions or should one presume a reverse mechanism, in which improved water supply and sanitation are a precondition for improved health and economic development? The first mechanism means that investments in the economy will indirectly, but automatically, benefit water supply and sanitation conditions. If one evaluates the effectiveness of different investment strategies on the basis of this presupposition, one has built in a bias in favour of investments in the economy. On the other hand, presupposing the second mechanism will work out in favour of direct investments in water supply and sanitation infrastructure. Another example regards the causal relation between economic growth and environmental pollution. Some people hypothesise that economic growth is needed to pay measures against environmental pollution, while others hold that economic growth is the primary cause of pollution and should therefore be tempered. Thus one can see that there is a strong relation between the assumptions and the outcome of the analysis, which shows that clarifying the assumptions and analysing the implications of alternative assumptions is very important.

The second step is to analyse the consistency between different assumptions. Some assumptions can logically be combined, others cannot. For instance, regarding water demand as a given need (that depends on population numbers, food demand, etc.) fits with the conception of water demand as rather unmanageable (e.g., insensitive to price changes) and the idea that advanced technology and supply infrastructure are required to meet increasing demands and prevent water shortages. Another logical combination is to regard water as an economic good, water demand as primarily price-driven and market pricing as the proper way to reduce water scarcity. A combination of assumptions that is *not* consistent, for instance, is to regard water demand as a given need and to assume that market pricing reduces water shortages. One can distinguish two levels to evaluate whether assumptions logically combine or not. At the first level, one can look whether assumptions depend on each other *in reality* and at the second level one can look whether they depend on each other *in people's minds*. It probably needs no explanation that assumptions should at least be logically consistent at the first level. For instance, it does not make sense to estimate a certain natural constant 'high' in one part of the study area and 'low' in another part, at least not if one claims the natural constant to be a natural constant! Let us consider, however, the second level. It can happen that assumptions do not depend on each other at the first, physical level, but that they do at the second level, in people's minds. For instance, people who are very much concerned with environmental issues tend to assume conservative estimates for the purification capacity of rivers and a high vulnerability of rare species to pollution. At the same time they have low expectations of new technology, so they assume low rates for or even neglect technological development. It is questionable whether parameters such as 'purification rate', 'vulnerability of a species to environmental change' and 'technological development rate' really depend on each other, in physical sense, but people surely *behave* as if they were dependent. In order to simulate human behaviour, it makes sense to build scenarios on the basis of sets of assumptions that fit with one another not only at the first but also at the second level.

The third step is to describe different perspectives. A perspective is here defined as a coherent perception (set of assumptions and hypotheses) with regard to the functioning of the world and the way people act. Social scientists have shown that people handle uncertainties in different ways, according to their own 'perspective' (e.g., [10]). In this study, it has been chosen to use the four perspectives described in the cultural theory of Thompson et al. [11]: the hierarchist, egalitarian, individualist and fatalist. Current uncertainties and controversies in the water research field have been interpreted in terms of these four perspectives. According to the hierarchist for instance, water demand is a given need, so the way to solve water scarcity is to increase supply. The hierarchist is often described as the engineer, the bureaucrat or the technocrat. From the egalitarian point of view, the driving force behind water scarcity is the growing demand, so solutions should be found in demand management (the view of environmentalists). According to the individualist, the only right indicator of water scarcity is or should be the price of water. The solution to water scarcity would then be to introduce proper pricing mechanisms. According to the fatalist, uncertainties are so large that it is difficult to say whether one type of policy would be more beneficial than another one, so the basic attitude is to await the things to come.

The fourth step is to formalise the different assumptions and hypotheses for each perspective. The aim of this step is to arrive at a number of different analytical models, each one representing one particular perspective. However, the different analytical models are placed within one framework, so that one can easily switch one particular assumption or the whole set of assumptions to another perspective. An assumption can refer to either a particular quantity (e.g., the value of a parameter) or a certain relationship (e.g., the form of an equation). The whole set of assumptions is grouped into three categories:

- assumptions with regard to the autonomous behaviour of the system considered (*world-view*),
- assumptions about how the system is or should be managed (*management style*), and
- assumptions referring to the exogenous developments that are input to the model, such as demographic developments and economic growth (*context*).

Table 2. Basic characteristics of the four perspectives on water [8, 9].

| | Hierarchist | Egalitarian | Individualist | Fatalist |
|---|---|---|---|---|
| Water demand | A given need | A manageable desire | Price-driven | An unmanageable desire |
| Water-conserving technology | Large-scale technology push | Small-scale technology push | Price-driven | No policy |
| Water price policy | Incremental price increase | Water taxing | Market pricing | No policy |
| Water availability | Stable runoff | Stable runoff in inhabited areas | Total runoff or no limits | Irrelevant to individuals |
| Water scarcity | Supply problem | Demand problem | Market problem | Problem of individuals |
| Water allocation | Based on priorities | Water allocation should be equitable and environmentally sustainable | Markets care for efficient allocation | First come first served |
| Groundwater use | Inevitable | Below sustainable level | Desirable if cost-effective | Profitable to a few |
| Artificial groundwater recharge | Solution to water scarcity | Should not be necessary | Desirable if cost-effective | No policy |
| Artificial surface reservoirs | Solution to water scarcity | Undesirable | Desirable if cost-effective | No policy |
| Water trade | Controlled trade | No water trade | Free trade | Trade is for the rich |
| Food security policy | Food self-reliance | Food self-sufficiency | Free trade | No policy |
| Hydrological system | Robust within limits | Vulnerable to perturbations | Robust | Unpredictable |
| Public water supply | Incremental improvements | Basic supply to everyone | Driven by economic growth | Given to the rich |
| Water quality evaluation | Functional quality standards | Pristine quality as reference | Economic value | No reference |
| Wastewater policy | Treatment to meet standards | Decrease production and treat residuals | 'Polluters pay' principle | No policy |
| Flooding policy | Protection through dikes, divergent risk levels | Give room to and live with natural processes | Economic evaluation of options | Risk acceptance |

Part of step four is to calibrate the model separately for each of the world-views, on the basis of historical data for management and context. If one can obtain acceptable calibration results for each of the world-views, historical developments can apparently be explained according to alternative points of view. This is of course a precondition for applying the world-views for exploring the future.

In the fifth step, perspective-based scenarios are developed. Before running the model one can choose a certain context, world-view and management style. The management style can be chosen according to one of the four perspectives. The context and world-view can be chosen according to the hierarchist, egalitarian or the individualist perspective only (the fatalist regards the world as unpredictable: the future might randomly behave like one of the other perspectives). Scenarios are constructed by choosing a certain combination of context, world-view and management style. In this way, one arrives at $3\times3\times4=36$ possible futures. Three of these futures are called utopias, ‘ideal’ futures in which context, world-view and management style correspond to the same perspective. Dystopias are scenarios in which this is not the case.

In the sixth and last step, the risks of different policy strategies are estimated by analysing the dystopian futures: what happens if a certain management style, which corresponds to one particular perspective, is applied in a world which appears to behave according to another perspective. In this way, the risk concept is not defined from one particular perspective, but is understood at a level that exceeds the individual perspectives. Such a risk assessment can support the formulation of policy priorities that go beyond the preferences of separate perspectives. It can for instance provide the information that is necessary if one would like to put the ‘precautionary principle’ into practice. This principle says that high risks should be avoided as much as possible, even if that would mean that a preferred management strategy should be abandoned. The basic idea behind the precautionary principle is that the ‘best strategy’ under some specific assumptions might be one of the worst under other assumptions. A more robust strategy would therefore be one that works out ‘good’ under some assumptions and ‘sufficiently’ (or not too bad) under other assumptions.

For the results of the first three steps, the reader is referred to [8, 9]. As a summary, Table 2 gives the basic characteristics of the four perspectives on water. The current paper focuses on the final three steps. Section 3 addresses the fourth step (modelling); Sections 4 and 5 address the fifth step (construction of scenarios); and Sections 6 and 7 address the sixth step (risk assessment).

## 3. THE AQUA ZAMBEZI MODEL

AQUA is a tool for integrated water assessment, particularly designed for the analysis of the interaction between long-term socio-economic development and changes in the water system [8, 12]. It is an explorative tool, meant for the examination of the implications of varying assumptions and hypotheses. The AQUA Zambezi Model is a particular application of the AQUA tool. This section gives a concise description of the AQUA Zambezi Model.

### 3.1. Schematisation of the System

In order to structure the various elements within the overall system, four sub-systems are distinguished: pressure, state, impact and response. The pressure system refers to a variety of processes that affect the state of the water system. The state system refers to water stocks, flows and water quality. The impact system refers to the performance of human activities that depend on water and the functioning of ecosystems. The response system refers to human action that is undertaken in reaction to certain impacts. If put in relation to each other, the four sub-systems form a closed causal loop, because response feeds back to pressure, state and impact. Corresponding to this schematisation, the AQUA model consists of four interacting sub-models.

The year 1990 has been chosen as the initial year of simulation. The year 2050 has been chosen as the time horizon. For the description of pressure, impact and response processes, the basin has been schematised into eight socio-economic regions, corresponding to the national territories that constitute the basin. For the description of hydrological processes and water quality (the state system), the Zambezi basin has been schematised into eight sub-basins: Upper Zambezi, Barotse, Cuando-Chobe, Middle Zambezi, Kafue, Luangwa, Lake Malawi – Shire, and Lower Zambezi (Fig. 2). The Zambezi rises in the Upper Zambezi basin and flows via the Barotse, Middle Zambezi and Lower Zambezi basins towards the Indian Ocean (Fig. 3). The Cuando-Chobe basin connects to the Middle Zambezi basin at the Chobe confluence, just upstream of Victoria Falls. The Kafue, Luangwa and Lake Malawi – Shire basins drain into the Lower Zambezi basin. Table 3 shows the extent to which the national territories lie within the different sub-basins.

The pressures on the Zambezi water system per country are translated into pressures per sub-basin in order to calculate changes in the state of the water system for each sub-basin. The changes per sub-basin are then translated back into changes per country, so that impacts and societal response can be calculated for each country. The calculations in the pressure, impact and response models are made only for those parts of the national territories that lie within the Zambezi basin.

### 3.2. The Pressure Sub-Model

The pressure sub-model calculates water demand from determinants such as population size, gross national product, value added in the industrial sector and demand for irrigated

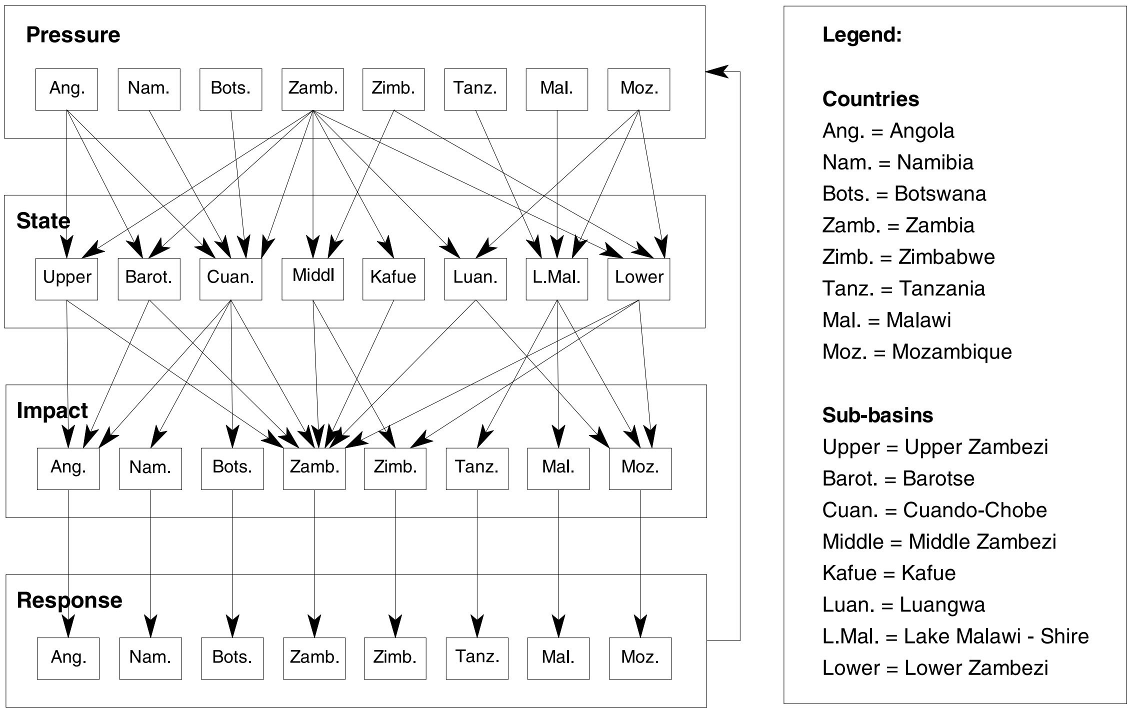


Fig. 2. Model structure of the AQUA Zambezi Model.

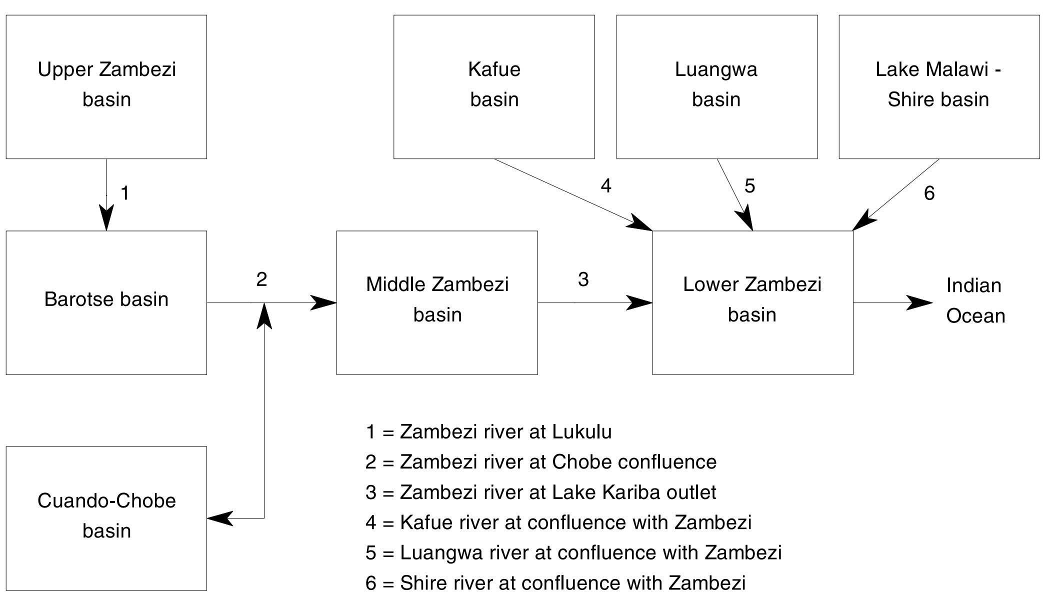


Fig. 3. River flow schematisation in the AQUA Zambezi Model.

cropland. The model distinguishes four water-demanding sectors: the domestic, irrigation, livestock, and industrial sector. In addition, water export to South Africa is considered. Domestic water demand is split up into urban and rural demand, and in both cases into public and private demand. Within the livestock sector, a distinction is made between cattle and an aggregate category of sheep, goats and pigs. As water sources, the model distinguishes between surface and groundwater. In addition to water withdrawals, the pressure model calculates consumptive water use (the part of the withdrawal that gets lost through evaporation), wastewater production and wastewater treatment.

For the livestock sector, specific demand is supposed to remain constant. For each of the other sectors, specific

Table 3. Spatial schematisation of the Zambezi basin (areas in $10^9\,m^2$).

| Sub-basin | Angola | Namibia | Botswana | Zambia | Zimbabwe | Tanzania | Malawi | Mozambique | Total |
|---|---|---|---|---|---|---|---|---|---|
| Upper Zambezi | 109 | – | – | 96 | – | – | – | – | 205 |
| Barotse | 37 | – | – | 115 | – | – | – | – | 152 |
| Cuando-Chobe | 92 | 16 | 12 | 15 | – | – | – | – | 135 |
| Middle Zambezi | – | – | – | 31 | 135 | – | – | – | 166 |
| Kafue | – | – | – | 158 | – | – | – | – | 158 |
| Luangwa | – | – | – | 147 | – | – | – | 4 | 151 |
| Lake Malawi – Shire | – | – | – | – | – | 27 | 107 | 21 | 155 |
| Lower Zambezi | – | – | – | 20 | 80 | – | – | 138 | 238 |
| Total | 238 | 16 | 12 | 582 | 215 | 27 | 107 | 163 | 1360 |

Source: sub-basin boundaries have been taken from [36] and country boundaries from [37].

water demand $WD_{spec}$ in kg/yr is calculated as:

$$\frac{dWD_{spec}(t)}{dt} = \left[El_G(t) \times \frac{dGNP_{pc}(t)/dt}{GNP_{pc}(t)} + El_P \times \frac{dWP(t)/dt}{WP(t)} - \frac{dEff_{act}(t)/dt}{Eff_{act}(t)}\right] \times WD_{spec}(t) \quad (1)$$

in which $GNP_{pc}$ represents gross national product per capita, $WP$ the water price and $Eff_{act}$ the actual water-use efficiency. The (sector-specific) growth elasticity $El_G$ has a positive value and is defined as a function of $GNP_{pc}$ (it is assumed that the response of demand to economic growth will decrease if a certain stage of development has been reached). The price elasticity $El_P$ has a negative value. Efficiency improvements are driven by technological innovation and increased public awareness of the environmental impacts of excessive water use. A simple logistic curve with a diffusion rate $d$ has been assumed, to simulate the diffusion of water-conserving technology:

$$\frac{dEff_{act}(t)}{dt} = d \times Eff_{act}(t) \times (Eff_{\max}(t) - Eff_{act}(t)) \quad (2)$$

The maximum possible efficiency value $Eff_{max}$ determines the ceiling of the logistic curve. In the case of irrigation, efficiency is defined as the fraction of the total water withdrawal that actually benefits the crop (i.e., the part taken up and transpired by the plant). The remainder consists of water losses through evaporation and groundwater recharge. The maximum possible efficiency in the case of irrigation has a natural upper limit of 100 per cent. In the case of domestic and industrial water use, efficiency is a relative concept, which means that an efficiency value has meaning only if compared to a previous efficiency value. The development of $Eff_{max}$ is here considered to be an input scenario:

$$\frac{dEff_{max}(t)}{dt} = TD \quad (3)$$

in which $TD$ is a measure of technical development in $yr^{-1}$ with a value greater than or equal to zero.

### 3.3. The State Sub-Model

The state model describes hydrological processes and freshwater quality. The hydrological cycle is modelled by distinguishing three dynamic water stores (soil moisture, groundwater and surface water) and by simulating the flows between these stores. This yields estimates of evapotranspiration, net precipitation, direct runoff and percolation, delayed runoff, and total river runoff. For calculating evaporation and runoff, five land-cover types are distinguished: forest, grassland, rain-fed and irrigated cropland, and open water. Water quality is described in terms of four water quality variables (nitrate, ammonium, dissolved organic nitrogen and phosphate) and four quality classes (good, adequate, inadequate, and poor). Good means suitable for the maintenance of natural aquatic ecosystems. Water of adequate quality does not meet natural conditions but is suitable for most human purposes. Inadequate means unsuitable for both natural aquatic ecosystems and drinking, and poor means unsuitable also for agricultural and industrial purposes.

Potential evaporation is calculated on a monthly basis, using the empirical relations of Thornthwaite [13]. Actual evaporation and soil moisture dynamics are calculated according to [14]. Net precipitation is divided into two fractions: direct runoff and percolation. Both the groundwater and the surface water store are modelled as linear reservoirs, which means that outflow linearly relates to storage. Each water store is represented by a mass balance:

$$\frac{dS(t)}{dt} = \sum F_{in}(t) - \sum F_{out}(t) \quad (4)$$

in which $S$ is the storage in kg, $\sum F_{in}$ the sum of the inflows and $\sum F_{out}$ the sum of the outflows.

### 3.4. The Impact Sub-Model

The impact model calculates actual water supply to households, irrigated lands, livestock and industry as a function of demand and actual allocation. On the basis of water use and water availability, the model calculates water scarcity (on a scale between zero and hundred per cent). Water costs per litre are calculated per sector on the basis of water scarcity and water quality. Hydroelectric power generation is calculated as a function of the generation capacity and the utilisation fraction, the latter depending on the river runoff.

The water availability in a region is divided into two components: internal and external sources. The first refers to the available amount of water due to precipitation within the region. The second consists of the water flow entering the region from upstream. Where the Zambezi river forms the border between two countries (first between Zambia and Namibia and, further downstream, between Zambia and Zimbabwe), it has been assumed that both riparian countries have access to the entire river flow. (This does not mean that they have the *right* to use it all.) No external sources have been assumed for the Zambezi basin territories of Angola, Botswana, Zambia, Tanzania and Malawi. The external water source of the Namibian territory has been defined as the runoff from the Barotse basin (which is generated in Angola and Zambia). The external water sources of Zimbabwe are formed by the runoff from the Barotse and Kafue basins. The latter fully originates in Zambia, but is available to Zimbabwe after the Kafue has joined the Zambezi. Theoretically, Zimbabwe can also draw on the runoff from the Cuando-Chobe basin, but this flow is generally negligible. The external sources of Mozambique consist of the runoff from the Middle Zambezi basin (which is generated mainly in Angola, Zambia and Zimbabwe), the runoff from the Kafue and Luangwa basins (generated in Zambia), and the runoff from the Lake Malawi – Shire basin (descending mainly from Malawi and Tanzania).

### 3.5. The Response Sub-Model

The annual expenditure required to meet a certain water demand is calculated as the product of the demand and the costs per litre. Expenditure needs are calculated separately for the domestic, irrigation, livestock and industrial sectors. In a similar way, the model calculates required expenditure for sanitation, hydropower, and domestic and industrial wastewater treatment. Actual expenditures are a function of required expenditures and actual allocation of means. The response model includes a number of policy variables – in the form of 'manageable' parameters – that can be changed by the user of the model. The maximum expenditure for a certain sector, expressed as a fraction of the gross national product, is such a policy variable. Other policy variables in the model are: the technological development rate (representing the effect of research and development programmes), the diffusion rate (representing the effect of public awareness raising), the ratio between water prices and actual costs (water pricing policy), and export of water to another river basin.

### 3.6. Input Data

Data on water stocks in lakes, reservoirs and wetlands have been derived mainly from [15]. Water stocks in rivers have been estimated per sub-basin on the basis of river runoff, stream velocity and river length, using data from [16]. Population data for the initial year 1990 have been derived from the population density map of Deichman [17]. The populations of the basin states have been assumed to grow according to either the low, medium or high scenarios of the United Nations [18]. Country data on the ratio between rural and urban populations have been taken from [19]. It has been assumed that the urbanisation level over the whole basin will increase according to the same trend as has been noticed in developed countries (see [20]). The following initial values of specific domestic water demand are used: 150 kg/day per capita for public water supply in urban areas, and 25 kg/day for public water supply in rural areas and for private water supply in both rural and urban areas. Although the author is aware that there are considerable spatial differences, these figures have been adopted for all countries. As argued in [8] the regional specific data available have very low reliability. Initial data for public water supply coverage and sanitation coverage have been taken from [21].

National livestock figures for the initial year 1990 have been taken from [22]. Growth rates for livestock have been assumed to be equal to the population growth rates. Specific water demand for cattle has been assumed to be constant at 33 kg/day per head. The specific water demand for sheep, goats and pigs has been assumed to be eight times less.

Initial land cover data have been derived from the digital land cover map of Olson et al. [23] supplemented by data from [22]. The areas of irrigated cropland have primarily been derived from [22]. It has been assumed that the total area of cropland in each country extends at a rate between 0.3 and 0.6 per cent per year – at the expense of forests and grasslands. The areas of irrigated land have been assumed to increase between 2 and 4.5 per cent per year. Initial irrigation water demand has been assumed at $10 \times 10^6$ kg/yr per hectare for all countries.

Data for the gross national products in 1990 have been taken from [24]. National data on the value added of the industrial sector have been taken from [25]. Economic growth rates have been assumed to vary between 2 and 4 per cent a year. For all countries, specific industrial water demand has been assumed 70 kg/yr per US$ value added in the industrial sector, a value corresponding to the global average at the beginning of the 20th century. Data on hydropower generation capacity in the Zambezi basin have been taken from [26].

Data on the relative use of surface water and groundwater have been taken from [19, 27, 28]. Due to a lack of data, wastewater treatment coverage in 1990 has been assumed to be 5 per cent throughout the river basin, for both domestic and industrial wastewater. Water supply – cost curves have been assumed based on a case study for Zimbabwe's section of the Zambezi basin, using data from [29]. Further it has been assumed that 25 per cent of the actual costs are charged to the consumer, a rough estimate taken from [30].

River runoff has been calibrated separately for each of the eight sub-basins distinguished (see [8]). The calibration was carried out for an 'average' year with respect to climatic conditions and under water-use conditions in the year 1990. Monthly precipitation and temperature data per sub-basin and land cover type have been derived from [31]. Monthly river runoff data for different hydrometric stations were derived from [32].

### 3.7. Representation of the Four Perspectives

The model has been built in such a way that the user can apply different perspectives on how the system behaves (world-views), on how the system is or should be managed (management styles) and on how external factors will develop (contexts). For that purpose, different perspective-based model formulations and different input values are available (Table 4).

The assumptions with respect to exogenous developments can be varied according to three coherent 'contexts' – the hierarchist, egalitarian and individualist context. The

Table 4. Basic assumptions per perspective.

| | Hierarchist | Egalitarian | Individualist | Fatalist |
|---|---|---|---|---|
| *Socio-economic context* | | | | |
| Gross national product[a] | Growth rate 3.0% $yr^{-1}$ | Growth rate 2.0% $yr^{-1}$ | Growth rate 4.0% $yr^{-1}$ | – |
| Population[b] | UN medium scenario | UN low scenario | UN high scenario | – |
| Total cropland area[a] | Growth rate 0.4% $yr^{-1}$ | Growth rate 0.3% $yr^{-1}$ | Growth rate 0.6% $yr^{-1}$ | – |
| Irrigated cropland area[a] | Growth rate 3.0% $yr^{-1}$ | Growth rate 2.0% $yr^{-1}$ | Growth rate 4.5% $yr^{-1}$ | – |
| New hydropower plants | Extension Cahora Bassa, construction of Batoka | No new large dams | Extension Cahora Bassa, construction of Batoka | – |
| *World-view* | | | | |
| Driving forces water demand | GNP, technology | GNP, water price, technology | GNP, water price | – |
| Measure of water availability | Stable runoff | Stable runoff | Total runoff | – |
| Measure of water scarcity | Consumptive water use/stable runoff | Total water supply/stable runoff | Consumptive water use/total runoff | – |
| Growth elasticities, water demand[c] | Medium | Low | High | – |
| Price elasticities water demand[c] | Zero | Low | High | – |
| Fractions consumptive water use[c] | Medium | High | Low | – |
| Water supply costs[d] | Increase moderately | Increase rapidly | Increase slowly | – |
| *Management style* | | | | |
| Water export to South Africa | After 2015: $1.5\times10^{12}$ kg/yr | No export | After 2015: $3\times10^{12}$ kg/yr | No export |
| Technological diffusion rate[c,e] | High | Low | Zero | Zero |
| Technological development rate[c,e] | High | Low | Zero | Zero |
| Percentage water price/actual cost | Growing towards 75% in 2025 | Growing towards 110% in 2025 | Growing towards 100% in 2025 | Ratio remains constant |
| Public water supply coverage | Growing towards 100% in 2050 | Growing towards 100% in 2025 | Depending on economic growth | Coverage remains constant |
| Sanitation coverage | Growing towards 100% in 2050 | Growing towards 100% in 2025 | Depending on economic growth | Coverage remains constant |
| Fraction of wastewater treated | Growing towards 100% in 2050 | Growing towards 100% in 2050 | Depending on economic growth | Coverage remains constant |

*Note.* [a]Growth rates have been assumed equal for all countries within the basin and for the entire simulation period. In reality, it is likely that growth rates will fluctuate over the years and differ in the countries. However, it is assumed here that the average growth rates in the long term will be distributed quite uniformly over the basin states.
[b]The UN scenarios provide country specific data up to 2025 [18]; for the period 2025–2050, the 2025 growth rates have been assumed.
[c]The exact figures are given in [8].
[d]Cost curves differ per water-use sector, quality of the intake water and region.
[e]These parameters refer to (non-price driven) improvements in water-use efficiency.

hierarchist context is largely an extrapolation of the recent trends shown in Table 1. The egalitarian context is characterised by more modest growth rates. The individualist context represents a future of rapid economic growth.

The assumptions with respect to the functioning of the system considered can be varied according to three 'world-views' – the hierarchist, egalitarian and individualist world-view. Each world-view consists of a specific set of equations and initial and parameter values, representing a coherent perception of how the world works.

The assumptions with respect to the response behaviour of people can be varied according to four pre-defined management styles – the hierarchist, egalitarian, individualist and fatalist management style. Each management style consists of a particular set of parameter values representing a certain policy strategy. Once a pre-defined management style has been chosen, the user of the model can adjust particular elements if preferred. The user of the model can get an insight into the risks of a particular management style by varying the world-view and context while keeping the management style constant.

## 4. THREE UTOPIAS

### 4.1. The Hierarchist Water Utopia

The hierarchist utopia will evolve within the hierarchist context, assuming that the world functions according to the hierarchist world-view and that a hierarchist management style is adopted. An important assumption behind the hierarchist water utopia is that the economies of the Zambezi countries will show moderate growth during the 21st century, slightly higher than during the past fifteen years. The population will continue to increase, but growth rates will decline according to the medium population scenario of the United Nations. Average gross basin product per capita will grow slowly to 450 US$/yr in 2050. The annual growth rates of total and irrigated cropland have been assumed to equal the average growth rates of the past fifteen years. In accordance with current plans, a new dam and hydropower plant will be build at Batoka Gorge (with an installed capacity of 1600 MW) and the present hydropower generation capacity at Cahora Bassa will be extended from 2075 to 2625 MW. Occasional problems of flooding in the basin will be reduced due to enlarged regulating capacity. Starting in the year 2015, water from the Zambezi will be exported to South Africa. The diverting point will be at Katima Mulilo in Namibia and the volume of export will be $1.5\times10^{12}$ kg/yr, half of what can be withdrawn without having to provide storage in the Zambezi river [2, 5].

Under these conditions, total water supply in the Zambezi basin will grow by a factor of about 7.5 in the period 1990–2050 (Fig. 4). In 2050, water export will constitute 11 per cent of the total water withdrawal in the basin and 21 per cent of the consumptive water use. The irrigation sector will remain the largest water user, both in terms of total

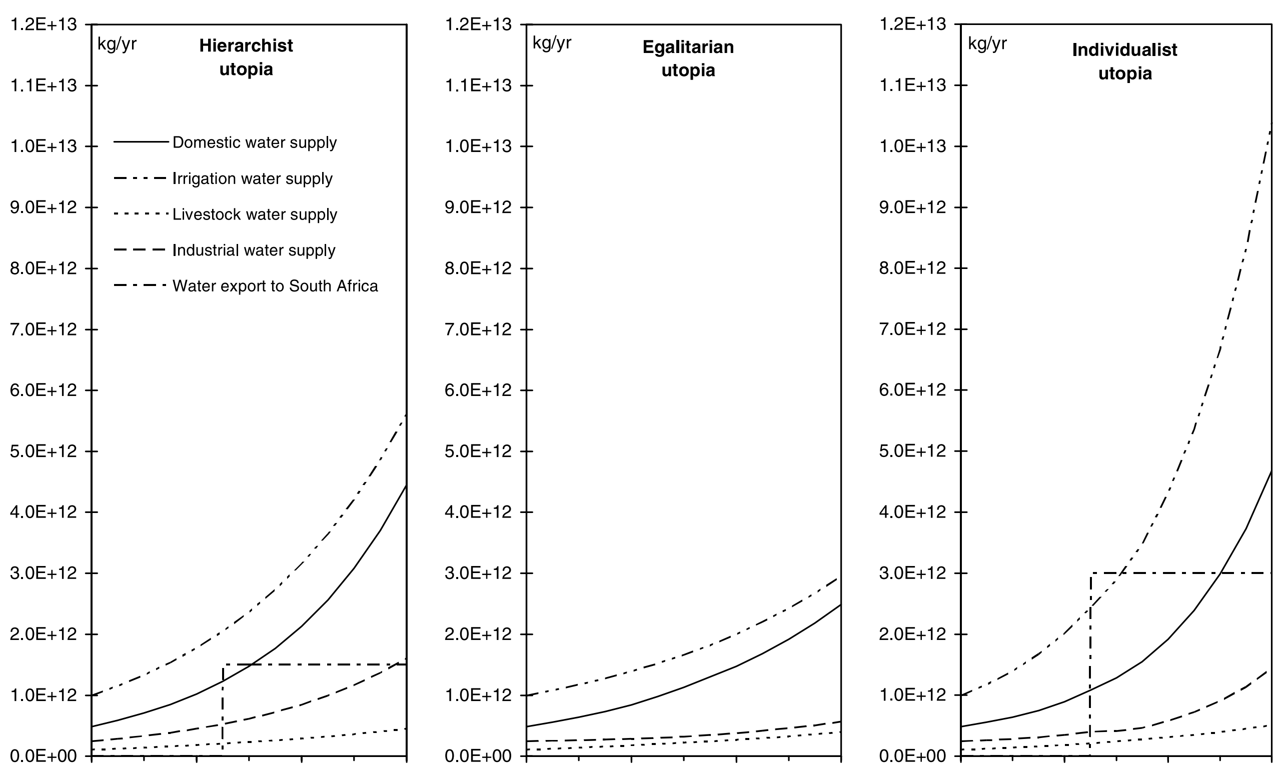


Fig. 4. Sector water supplies in the Zambezi basin in each of the three utopias. Water export from the Zambezi basin to South Africa is regarded as a separate sector.

withdrawal and in terms of consumptive water use. Water supply for irrigation will increase slightly less than the area of irrigated land, because the average water application factor per hectare will decrease by about 6 per cent, due to the introduction of more efficient irrigation techniques. The domestic sector will remain the second largest water user. The relative growth of water use in this sector will be greater than in the irrigation, livestock and industrial sectors, because not only will the population grow, but so will average water demand per capita, as a result of increasing prosperity, urbanisation and public water supply coverage. The most dominant factor after population growth will be urbanisation, resulting in an increase in domestic water use of about 40 per cent.

Within the hierarchist world-view, water scarcity is defined as the ratio of consumptive water use to water availability. The latter is assumed to be equal to stable runoff. Applying these definitions, water scarcity in the Zambezi basin will grow from 2 per cent in 1990 to 15 per cent in 2050. Water scarcity will be highest in Malawi, largely because of the high population density, which will reach 440 people per $(km)^2$ of land in 2050, greater than the present densities in countries such as India or Japan and nearly as high as the current density in the Netherlands. Water scarcity in Malawi will grow from 4.4 per cent in 1990 to 27 per cent in 2050 (Fig. 5). This means that serious water supply problems could occur in several parts of the country, probably mainly in urban areas such as Lilongwe, Blantyre, Mzuzu and Zomba. From a hierarchist point of view, the ultimate solution to Malawi's water scarcity problems of the future is to rely on water supply from Lake Malawi. After Malawi, greatest water scarcity will occur in the parts of the Zambezi basin in Zambia, Zimbabwe and Mozambique. As an example, Figure 5 shows total water supply, consumptive water use and water availability in Zimbabwe's section of the basin. There are two important reasons why water scarcity in Zimbabwe's part of the basin will remain much lower than in Malawi. The first is that the population density will continue to be lower, with about 110 people per $(km)^2$ in 2050, the second is the availability of external water sources. The external water sources of Zimbabwe are formed by the runoff from the Barotse and Kafue basins. However, it has to be realised that, as can be seen in the figure, the water availability from external sources will decrease as a consequence of increased water use upstream, the most severe effect coming from the withdrawal of water at Katima Mulilo for export to South Africa.

In the hierarchist utopia water supply costs in the Zambezi basin will grow by a factor of nearly 2, due to increased water scarcity (Fig. 6). The average price of water will increase much more than the costs, because the fraction of the total costs charged to the consumer will go up from about 25 to 75 per cent. Expenditure in the water sector, expressed as a fraction of gross basin product, will grow

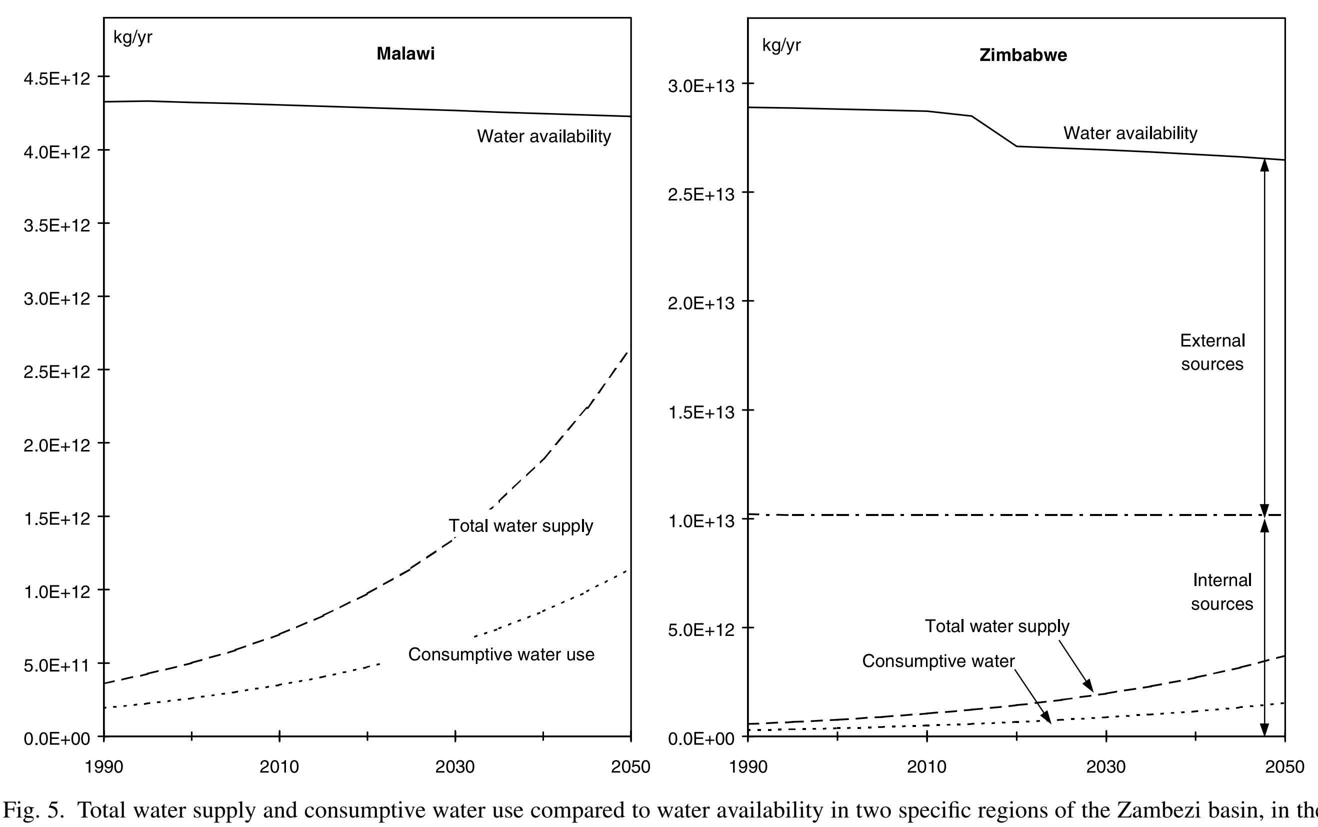


Fig. 5. Total water supply and consumptive water use compared to water availability in two specific regions of the Zambezi basin, in the hierarchist utopia. In the case of Zimbabwe, water availability consists of an internal and an external component. In the case of Malawi, water availability depends entirely on internal sources.

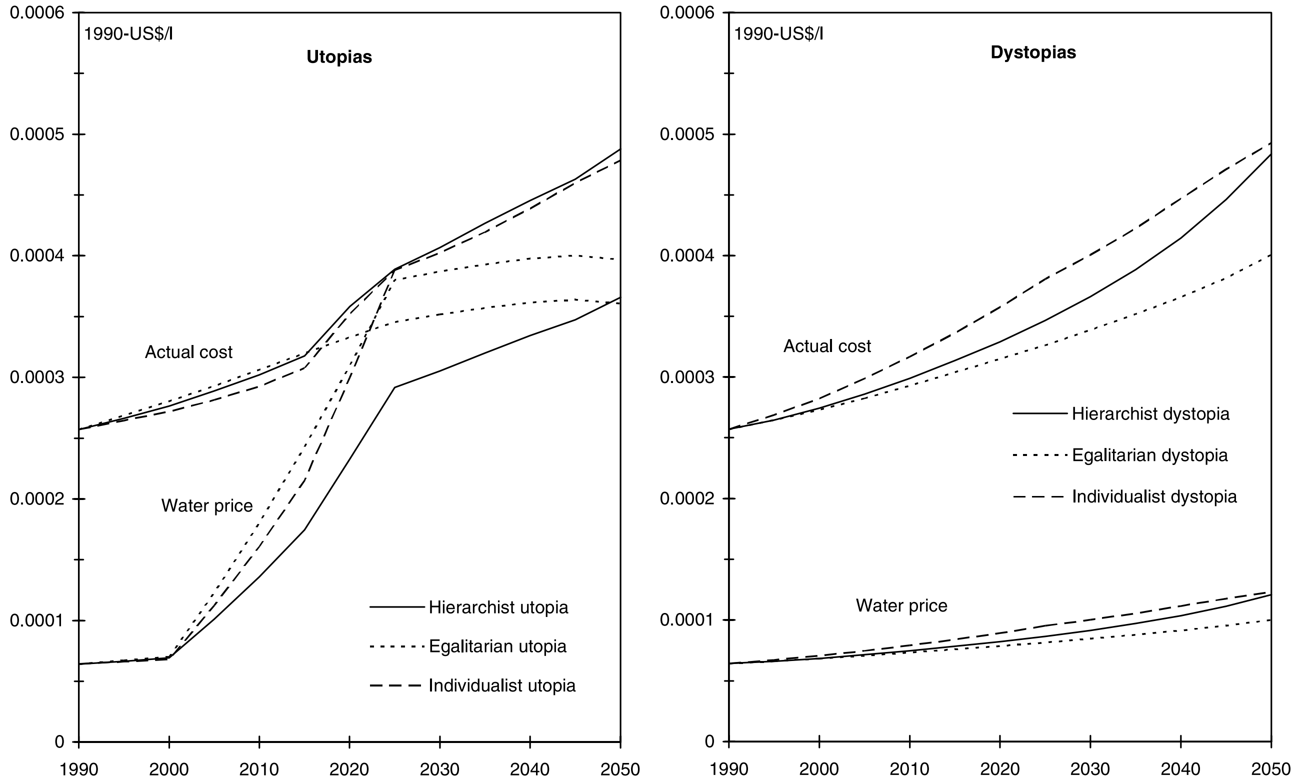


Fig. 6. Average water costs and prices in the Zambezi basin. In all possible futures, water costs will increase as a result of increasing water scarcity. In the hierarchist and individualist utopias the effect of water export can be seen in the sharp increase in costs in the year 2015. In the three utopias, water prices will increase most strongly during the first quarter of the 21st century, due to active pricing policies. In the three dystopias, costs not only rise as a result of increased scarcity but also as a result of decreased water quality. In the dystopias active pricing policies are lacking, which keeps prices low but results in less efficient water use and higher water demand.

from about 8% in 1990 to about 17% in 2050. The largest part of the total expenditure goes to public water supply, sanitation and irrigation. Smaller fractions go to livestock water supply, industrial water supply and wastewater treatment. Despite the still large investment in wastewater treatment, resulting in extended treatment coverage, water quality will decrease slightly during the first quarter of the 21st century, due to the increase in total wastewater production. However, during the second quarter of the century the effect of growing treatment coverage will become greater than the effect of increased wastewater production, resulting in an improvement in water quality. This is shown for the Lake Malawi – Shire basin in Figure 7. The improved water quality tempers the increase of costs to some extent.

The hierarchist utopia can best be characterised as a world balanced between the desirable (high growth) and the possible (limited availability of resources). The demand for water will increase rapidly, as in the individualist utopia, but water availability is clearly limited, as it is in the egalitarian utopia. As a result, water will become scarcer in the hierarchist utopia than in the other two utopias. High-tech infrastructure is needed to supply the water requirements of each sector of society. In the year 2050, urban water supply in Bulawayo, Zimbabwe, will for instance depend largely on water from Lake Kariba, about 350 kilometres to the north of the city. Lake Kariba might in fact be regarded as the ultimate source of water for a large part of Zimbabwe (see also [5]). The same will apply to Lake Malawi for Malawi.

### 4.2. The Egalitarian Water Utopia

The egalitarian utopia is a future with a relatively slow increase in population, accompanied by relatively low economic growth. The most basic difference with the hierarchist utopia is that egalitarians prefer not to balance on the edge of the maximum possible, but rather to stay on a comfortable level below this maximum and strive for stabilisation. This means that priority is given to water demand policy over water supply policy. Instead of building new large dams, governments will stimulate more efficient water-use. With regard to water supply, the main concern in the egalitarian utopia is to increase the number of people with proper water supply and sanitation, because an estimated 10 million people in the Zambezi basin presently lack access to such facilities, i.e., about 40 per cent of the entire population of the basin. Improving water supply and sanitation conditions is expected to raise living standards

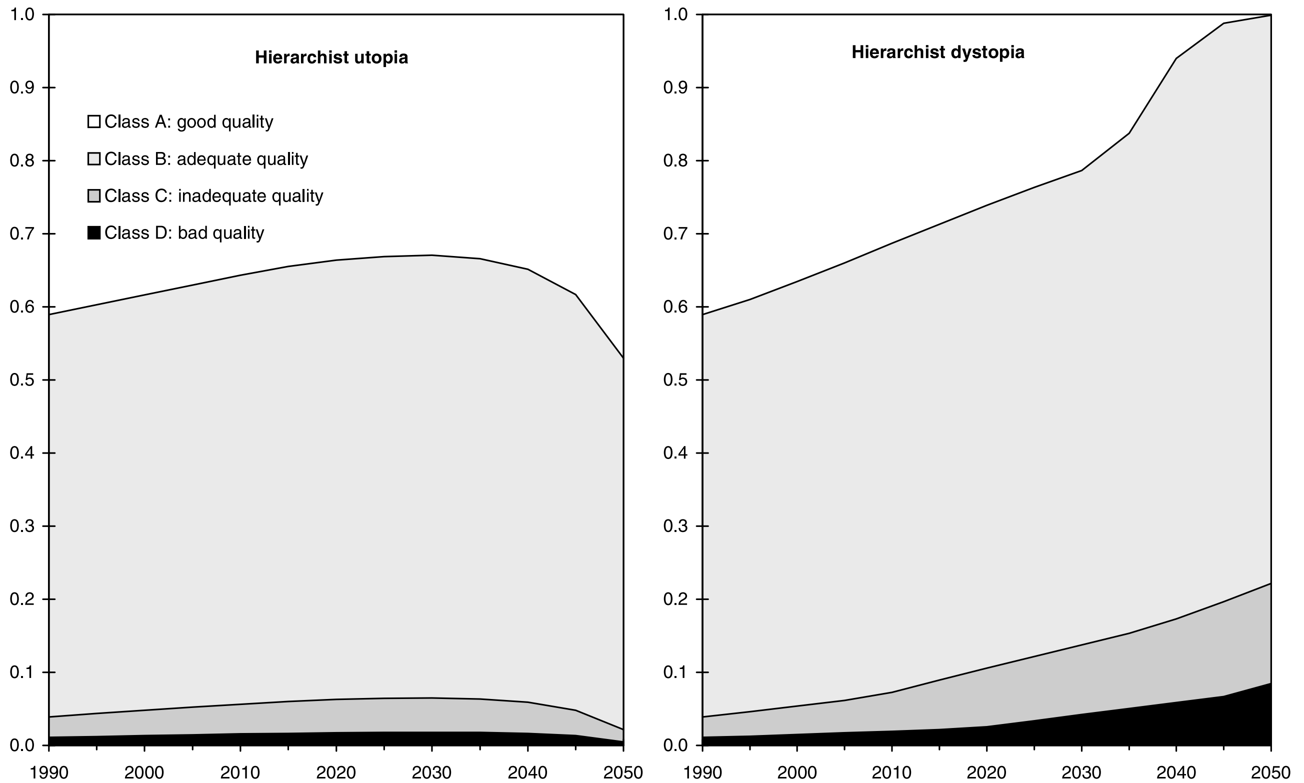


Fig. 7. Surface water quality in the Lake Malawi – Shire basin in the hierarchist utopia and dystopia. In the dystopia, an increasing volume of untreated wastewater will cause severe pollution problems. Such problems are prevented in the utopia by investing heavily in wastewater treatment, eventually leading to better water quality than today.

and reduce the number of people affected by waterborne diseases. In the egalitarian utopia, high investment in public water supply and sanitation aims to attain full coverage by the year 2025.

Total water supply in the Zambezi basin will grow much less than in the hierarchist utopia (Fig. 4), partly because of the absence of water export to South Africa. Contrary to the hierarchist utopia, people generally obtain their water from nearby sources, which is possible because water demand is much smaller and a relatively high level of water self-sufficiency can be maintained. Occasional floods will continue to occur.

Within the egalitarian world-view, water scarcity is defined as the ratio of total water supply to water availability, the latter being equal to stable runoff. Using this definition, water scarcity in the Zambezi basin will grow from 4 per cent in 1990 to 13 per cent in 2050. As a result of the increasing scarcity, water supply costs will increase, but less so than in the hierarchist utopia (Fig. 6). However, water prices will increase much more than in the hierarchist utopia, due to the strong pricing policy introduced, including a water tax of 10 per cent of actual costs. This policy is partly responsible also for the only modest increase in total water demand. Expenditure in the water sector will be much less than in the hierarchist utopia, even if expressed as a fraction of gross basin product. Total expenditure in the water sector will grow from about 8% of the gross basin product in 1990 to about 15% in 2050.

### 4.3. The Individualist Water Utopia

The individualist utopia is a future of rapid growth (Table 4). In the period 1990–2050, gross basin product per capita more than doubles, resulting in improved water supply and sanitation conditions. Due to the favourable economic conditions, there is room for high investment in advanced water supply infrastructure, water re-use techniques and wastewater treatment, all more than in the hierarchist and egalitarian utopias. However, the need for high investment in the individualist utopia is also greater than in the other utopias, as a result of relatively high water demand and wastewater production. Especially water supply for irrigation will be much more extensive than in the other two utopias (Fig. 4). Furthermore, it is assumed that the SADC countries will achieve agreement on exporting water from the Zambezi to South Africa. As in the hierarchist utopia, the water will be diverted at Katima Mulilo, starting in 2015, but the volume of export is assumed to be $3 \times 10^{12}$ kg/yr, twice as large as in the hierarchist utopia. This is the quantity that can be diverted without having to provide storage in the Zambezi.

Within the individualist world-view water scarcity is defined as the ratio of consumptive water use to water availability, the latter assumed to equal total runoff. Using these definitions, water scarcity in the Zambezi basin will grow from 1 per cent in 1990 to 10 per cent in 2050. The costs of water supply will grow at the same rate as in the hierarchist utopia (Fig. 6). Water quality improvements will suppress the growth in water supply costs in the period 2030–2050 to some extent, due to decreasing costs of water purification. In the period 2000–2025 a market-pricing policy will be introduced, which means that water tariffs will increase towards 100 per cent of actual costs, including both depreciation costs and operational and maintenance costs. In absolute terms, expenditure in the water sector in the individualist utopia will be much larger than in the hierarchist or egalitarian utopias, but they will be lower if expressed as a fraction of gross basin product (about 12% in 2050).

The effects of increasing water use throughout the basin will be most noticeable in the downstream parts of the basin, where all effects accumulate. Figure 8 shows how upstream water consumption affects river runoff from the Middle and Lower Zambezi basins. Because the outflow from Lake Kariba is regulated by man, minimum river runoff from the Middle Zambezi basin will not change, but the effects will become visible in the size of peak flows. In the case of the Lower Zambezi basin, however, there will also be significant effects on the minimum river runoff (a reduction of 12 per cent in the period 1990–2050). The individual effect of water export is shown by presenting the resulting hydrographs if there were no water export. Increased water consumption in the Zambezi basin will influence hydropower generation at both the existing hydropower plants and the plants yet to be constructed. The annual outflow from Lake Kariba in the year 2050 will be 17 per cent lower than the current outflow. If there is no spillage, as occurred in the 1980s, any reduction in outflow will lead to a comparable reduction in electrical output. In relatively wet years, when spillage is not nil, intelligent operation of the reservoir can diminish the effect of upstream water consumption on hydropower generation to some extent (by reducing the spill flow), but in dry years any reduction in reservoir outflow can be linearly translated into a reduction in electricity generation. The generation potential of the existing hydropower plants at Lake Cahora Bassa will barely if at all be affected because there is an installed capacity of only 2075 MW, which is far below the potential of the lake. According to SADCC [26], the discharge at maximum electrical output of the existing plants is about $5.9 \times 10^{12}$ kg/month. As can be seen in Figure 8, this flow is available throughout the year, not only now but also in the year 2050. This means that, in an average year, increased water consumption will not affect hydropower

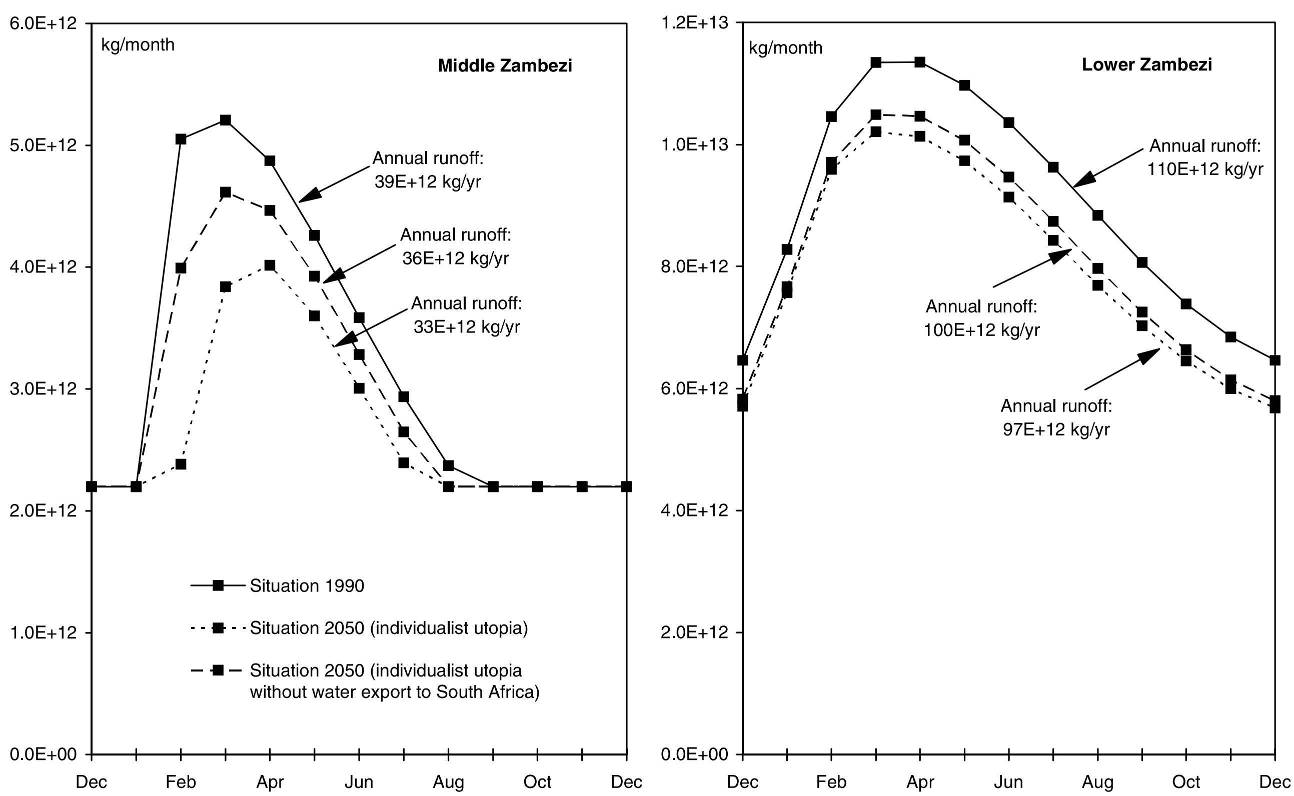


Fig. 8. Changes in the hydrographs for the Middle and Lower Zambezi basins in the individualist utopia. The effect of water export to South Africa is shown by presenting hydrographs for both the case with export and the case without export.

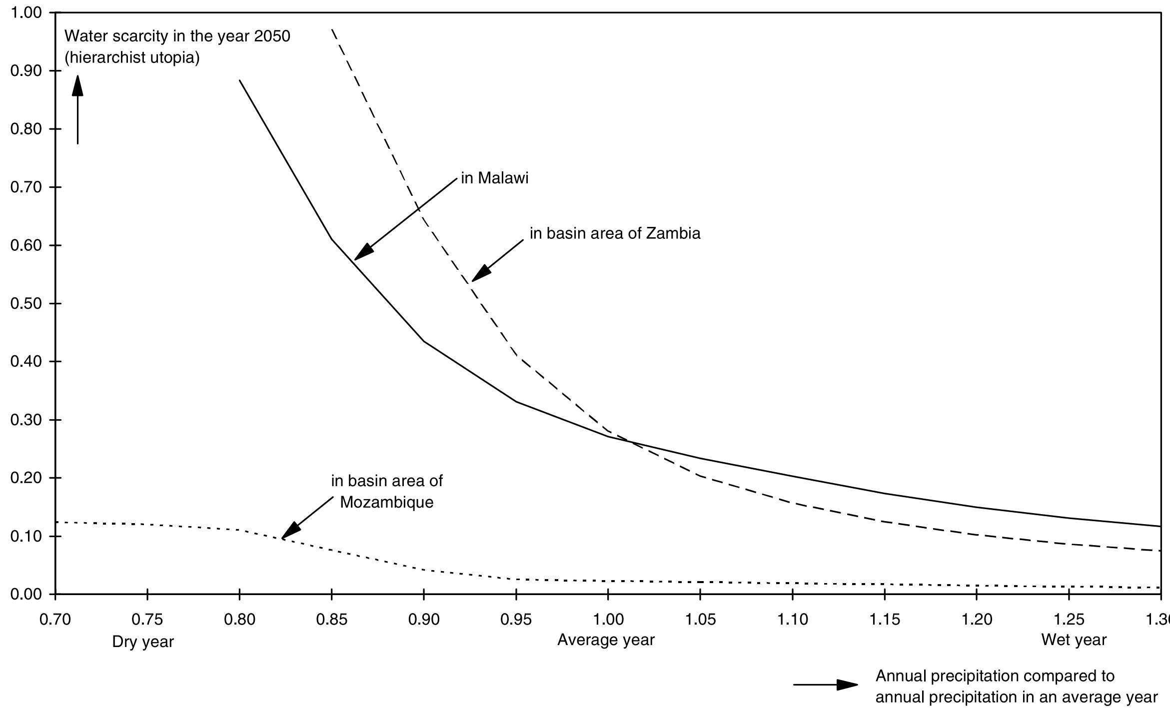


Fig. 9. Sensitivity of water scarcity to climatic variation in the year 2050.

generation at the existing plants of Cahora Bassa. Only in dry years and in the case of ineffective operation of the reservoir, might upstream water consumption reduce hydropower generation at the existing plants. However, in the individualist utopia the total installed hydropower generation capacity at Cahora Bassa will be extended by another 550 MW, requiring an extra flow of about $1.6 \times 10^{12}$ kg/month, which is not available in every month. As a result of increased water consumption in the period 1990–2050, the utilisation fraction will be 3.5 per cent less in an average year; the effect will be smaller in wet years and greater in dry years. Another plan to be carried out in the individualist utopia is the construction of a dam and hydropower plant at Batoka Gorge, just downstream of Victoria Falls. The capacity of this plant will be 1600 MW, to be shared between Zambia and Zimbabwe [33]. The Batoka installation will be a run-of-river plant without monthly storage, thus not influencing regional evaporation or river runoff patterns. Complete use of the installed hydropower generation capacity requires a flow of about $1120\,m^3/s$, which is far from available during dry months. The reason for installing a capacity of 1600 MW is the benefit that can be obtained from conjunctive use of the Batoka and Kariba plants. The Batoka plant can make full use of the high natural flows during the wet months while Kariba can run at reduced capacity and store the incoming water [26]. Due to the instream character of the Batoka plant, a reduction in river runoff as a result of upstream water consumption will also reduce hydropower generation. For this reason hydropower generation at Batoka Gorge in the individualist utopia will in 2050 be about 7 per cent lower than it could be today (utilisation fraction of 77 per cent instead of 83 per cent). Due to the enlarged regulatory power in the basin, the frequency of flooding events is expected to decrease.

### 4.4. Increasing Vulnerability to Drought

Given the growing demand for water under all utopias, it is clear that the effects of droughts will become increasingly severe. The regions most in danger are the upstream areas that lack external water sources. This is the case already today, but the effects of droughts will become much more serious. This is illustrated in Figure 9, which shows the sensitivity of water scarcity to climatic variation in three different regions in 2050. The data refer to the hierarchist utopia, which is more affected in this respect than the other utopias. Figure 9 has been based on experiments with drought periods of five years. The effect of droughts on water scarcity will be more severe if the drought periods were longer. In the context of global climate change, such a scenario should not be ignored.

## 5. DYSTOPIAS AND RISKS

Each of the three water utopias discussed in the previous section can be regarded as a ‘best possible future’ according to a particular perspective. As illustrated in the previous section, these ‘best possible futures’ are not ideal worlds, in which no trade-offs would take place between different sectors or between upstream and downstream development. Such trade-offs are unavoidable in any possible future. Each utopia is preferable from a particular point of view, but none of the utopias can be called more desirable from an objective standpoint. This section will discuss several types of future which are not preferable from any particular perspective, but which will emerge if disparate elements from the three utopias are combined or if the fatalist management style is applied. These dystopian futures show what risks are attached to the three utopias.

First, it will be examined what happens in each of the three utopias if the fatalist management style is applied instead of the utopian management style. Secondly, it will be shown what happens in the utopias if there are external constraints on the amount of investment in the water sector. This may be the case if no development aid is provided to support the investment needed or if there is lack of political support within the region. Finally a type of dystopian future will be discussed which appears to be the most catastrophic of all possible futures: the hierarchist or egalitarian utopia confronted by rapid growth.

The first risk is that policy does not develop according to the utopian management style. In general, the fatalist management style appears to work least well in all utopias. The principal characteristic of this management style is that no new water policy measures are implemented and that current practice remains more or less unchanged. Applying the fatalist management style in the hierarchist or the egalitarian utopia is most catastrophic in the following fields: public water supply, sanitation, and water quality. In addition, there will be no improvement in water-use efficiency, which means that more water is withdrawn for the same purposes. However, in the hierarchist dystopia total water withdrawal by the year 2050 will be less than in the hierarchist utopia, due to the absence of water export to South Africa. The water scarcity situation in the hierarchist and egalitarian dystopias will not differ greatly from that in the respective utopias. The increase in water costs will be of the same order of magnitude, but prices will be kept low (Fig. 6). Expenditure for irrigation, livestock water supply and industrial water supply will be higher than in the utopias, due to inefficient water use. Expenditure in public water supply, sanitation and wastewater treatment will be lower, resulting in a sharp decline in public water supply, sanitation and wastewater treatment coverage. Applying the fatalist management style in the individualist utopia has rather different consequences to applying it in the hierarchist or egalitarian utopias. Within the individualist world-view improvements in water supply and sanitation conditions depend on economic growth, and not the other way round as in the hierarchist and egalitarian world-views. As a result, the fatalist management style will not lessen the increase in public water supply and sanitation coverage. Also, water quality will improve as a result of increasing wastewater treatment coverage. The greatest problem in the individualist dystopia is inefficient water use, resulting in a total water withdrawal that is nearly 25 per cent larger than in the individualist utopia and total expenditure for water supply which is nearly 50 per cent higher.

A second risk is a lack of investment capacity. In each of the three utopias, total expenditure in the water sector increases considerably, even if expressed as a fraction of gross basin product. It is questionable whether expenditure exceeding 10 per cent of gross basin product is still realistic. In the formulation of the utopias, it was assumed that possible bottlenecks in the financing of future development projects would be solved by external support from donor countries. This is not necessarily unrealistic: development assistance to the Zambezi basin states in 1991 varied between 5 and 70 per cent of the gross national products of these states [34]. However, what would happen if a constraint is put on investment through either a lack of development aid or a lack of political support within the region? I will only look at constraints on the expenditure for public water supply, sanitation and irrigation, because the other items of expenditure never exceed 1.5 per cent of gross basin product and in most cases are much less. Of the three utopias, the hierarchist is most vulnerable if constraints are applied to the expenditure for public water supply. This can be understood by the fact that public water supply is relatively expensive in the hierarchist utopia: population growth is moderate, but investment capacity is moderate also and improvements in water-use efficiency are relatively small (compared to the egalitarian or individualist utopias). If in the hierarchist utopia expenditure for public water supply in each basin country is limited to 5 per cent of gross national product, the public water supply coverage in the basin would be only 61 per cent in 2050, instead of 100 per cent. The egalitarian utopia is most vulnerable if constraints are put on sanitation expenditure. This is caused by the fact that the egalitarian utopia has an ambitious target in respect of sanitation improvements, combined with a low investment capacity. Application of a '5 per cent of GNP' constraint on sanitation expenditure in all basin countries results in sanitation coverage in the basin of 69 instead of 100 per cent. The individualist utopia is most vulnerable to constraints on irrigation expenditure. This can be explained by the fact that the individualist utopia has by far the most ambitious programme of irrigation development, requiring relatively high investment. If irrigation expenditure in each country is limited to 5 per cent of gross national product, the irrigated cropland area in the Zambezi basin in 2050 will be 22 per cent smaller than without this constraint. The main reduction will be in Mozambique, where *current* irrigation expenditure already exceeds 5 per cent of gross national product.

The final risk to be considered here is the confrontation of the egalitarian or hierarchist utopia with high population growth and rapid economic development (the individualist context). In both utopias, rapid growth will be disastrous. In the egalitarian utopia total water withdrawal in the Zambezi basin would increase towards a level of $21 \times 10^{12}$ kg/yr by the year 2050, entirely for use within the basin (there is no water export). This is more than three times the level in the egalitarian utopia. Water scarcity in the basin as a whole will then grow to 44 per cent in 2050 (compared to 13 per cent in the utopia) and the costs of water supply will increase to an average of nearly 1 US$/$m^3$. Expenditure in the water sector will reach nearly a quarter of gross basin product. The situation will be worst in the parts of the basin in Malawi (scarcity at 92 per cent) and Zambia (scarcity at 56 per cent). In the hierarchist utopia rapid growth will have an effect which is even worse than in the egalitarian utopia, due to the lack of a water-pricing system which would discourage inefficient water use.

## 6. THE HARARE PRIORITIES: A RISK ASSESSMENT

In November 1996, a workshop on the Zambezi basin was held in Harare. The participants were mainly regional water experts. The aim of the workshop was to explore possible water futures and to develop promising water policy strategies for the region [35]. The participants were confronted with the same kind of analytical results as have been presented in the previous sections. At the end of the workshop, the participants were asked to translate their insights into policy priorities on empty ‘priority sheets.’ For this purpose they were grouped according to their home country. Table 5 presents the policy priorities proposed by the participants. The priorities have no formal status; they just are the outcome of a one-time policy exercise. Here I will interpret the results of this exercise and discuss what risks will typically emerge if the policy priorities proposed by the participants of the workshop were to be put into practice.

The most striking result is that all participants were very explicit in giving first priority to water supply policy and second priority to water demand policy. Apart from the fact that the participants disapproved of the idea of water export to South Africa, their approach typically fits within the hierarchist perspective, which is an indication that the hierarchist view on water is dominant in the basin at present. Although the results of the workshop are far from sufficient to draw a final conclusion on this subject, suppose that the future management of the Zambezi basin will resemble the hierarchist management style, although excluding water export to South Africa. The way in which this type of management will work in the next few decades depends strongly on external factors such as population growth and economic development and on the rules according to which matters within the Zambezi basin will proceed (i.e., according to which world-view). By varying the conditions, I arrive at the nine different scenarios shown in Table 6. Looking at the criteria of water scarcity, water costs and vulnerability to drought, the Harare priorities will work most favourably if operated under *low growth* conditions in a world which functions according to the *hierarchist world-view*. Under medium growth conditions the Harare priorities can also support socio-economic development effectively, although the trade-off now is a rather high vulnerability to drought

Table 5. Policy priorities proposed by the participants of the workshop in Harare [36].

| Policy | Namibia[a] | Zambia[a,b] | Zimbabwe[a,b] | Tanzania[a] | Malawi[a] | Mozambique[a] |
|---|---|---|---|---|---|---|
| *General* | | | | | | |
| Water demand policy | 25 | 20 → 40 | 20 → 30 | 2 | + | + |
| Water supply policy | 75 | 80 → 60 | 80 → 70 | 1 | ++ | ++ |
| *Water demand policy* | | | | | | |
| Water pricing (removing subsidies) | 33 | 60 → 25 | 10 → 10 | 2 | ++++ | ++++ |
| Water-use efficiency | 33 | 25 → 40 | 5 → 10 | 1 | +++ | +++ |
| Water education | 33 | 15 → 35 | 5 → 10 | 3 | ++ | ++ |
| Water export | 0 | 0 → 0 | 0 → 0 | 4 | 0 | −−−− |
| *Water supply policy* | | | | | | |
| Infrastructure policy | 60 | 60 → 50 | 70 → 50 | 1 | ++++ | ++++ |
| Public water supply | | 40 → 20 | 30 → 20 | 1 | +++ | +++ |
| Sanitation | | 10 → 20 | 10 → 10 | 1 | + | + |
| Irrigation | | 10 → 10 | 30 → 20 | 1 | +++ | +++ |
| Water quality policy | 20 | 20 → 30 | 5 → 10 | 3 | ++ | ++ |
| Land and soil policy | 20 | 15 → 15 | 5 → 10 | 2 | +++ | ++ |
| Climate policy | 0 | 5 → 5 | 0 → 0 | 4 | 0 | 0 |

*Note.* [a]Each country used its own method of presenting the priorities. Namibia, Zambia and Zimbabwe used a priority scale from 0 (low) to 100 (high); Tanzania ranked the priorities from 1 (high!) to 4 (low!); Malawi and Mozambique used a scale from 0 (low) to ++++ (high). Figures for Angola and Botswana are not available because there were no participants from these countries.
[b]Whereas the other country participants did not respond to the request to distinguish between past or present and future priorities, the participants from Zambia and Zimbabwe did, resulting in the trends as indicated by arrows.

Table 6. What will happen – under different conditions – if the 'Harare priorities' are put into practice?

| | Hierarchist context (medium growth) | Egalitarian context (low growth) | Individualist context (high growth) |
|---|---|---|---|
| Hierarchist world-view | Water demand increases by a factor of 6 to 7 in the period 1990–2050. Total water demand per capita grows by about 50%. Water scarcity grows from 2% to 12%. Average water costs per litre increase by about 60%. Water policy adequately supports continued economic growth, but the trade-off is a rather high vulnerability to drought. | The increase in water demand is relatively modest and can be satisfied without major problems. Water scarcity and water costs increase less than in the case of medium growth. Vulnerability to drought is relatively low. Water problems do not impede socio-economic development. Water policy appears to be effective. | Water demand increases relatively fast. The emphasis on supply policy appears to be inadequate. Water supply will fall short. Investment to further extend supply infrastructure cannot be afforded. Vulnerability to drought becomes very high. Strong demand policy is needed. |
| Egalitarian world-view | Water demand, water scarcity and water costs increase by about the same percentages as in the scenario above. Water policy adequately supports continued economic growth, but the trade-off is a rather high vulnerability to drought. Furthermore, a lack of an appropriate pricing policy results in waste of water. | Lack of an appropriate pricing policy, resulting in waste of water. However, water scarcity and water costs remain relatively low, due to a relatively small increase in water demand. Water demand can be supplied without major problems. Vulnerability to drought is relatively low. | Water demand increases relatively fast. The emphasis on supply policy appears to be inadequate. Water supply will fall short. Investment to further extend supply infrastructure cannot be afforded. Vulnerability to drought becomes very high. Strong demand policy is needed. |
| Individualist world-view | Lack of an appropriate pricing policy, resulting in inefficient water use. Despite the fact that water demand increases by a factor of 5, water scarcity and water costs remain relatively low, due to high water availability. | Lack of an appropriate pricing policy, resulting in inefficient water use. However, water scarcity and water costs remain relatively low, due to a relatively low increase in water demand and high water availability. | Lack of an appropriate pricing policy, resulting in inefficient water use. Despite the rapid increase in water demand, water scarcity and water costs do not increase greatly, due to high water availability. |

*Note.* The 'Harare priorities' have been translated into the model by assuming the hierarchist management style, but excluding water export to South Africa.

(comparable to the vulnerability to drought in the hierarchist utopia; see Section 4.4). Apart from the vulnerability to drought, application of the Harare priorities will carry two further risks. One of these is that water use will be inefficient, resulting in higher water demand and greater pressure on the water system than is necessary. This occurs if the world does not function according to the hierarchist, but according to the egalitarian or the individualist world-view. The other risk is that water supply will fall short while investment capacity is not large enough to further extend supply infrastructure. This happens if the world functions according to the hierarchist or the egalitarian world-view under high growth conditions. In these two scenarios, water expenditure would have to grow to about 25 per cent of gross basin product in order to supply the water demanded. As can be seen from Table 6, these two scenarios are the worst developments that could occur within the Zambezi basin if the Harare priorities were to be put into practice.

Let us presuppose that future growth in the Zambezi basin might be low, medium, or high, and that the three world-views are equally sound. In this case, one can say that proper application of the Harare priorities roughly carries the following odds. There is a chance of 1 in 9 that socio-economic development will be supported effectively without the necessity for trade-offs; a chance of 6 in 9 that socio-economic development will be supported effectively with relatively inefficient water use or a rather high vulnerability to drought, or both, as trade-off; and a chance of 2 in 9 that application of the Harare priorities will be ineffective. In the last case, water supply will fall short and expenditure in the water sector will become extraordinarily high. This would occur under high growth conditions, and would be a reason to be alert if application of the Harare or similar priorities were combined with rapid population growth and economic development.

## 7. CONCLUSION

Different mechanisms have been identified which could become important in the basin's future: the mechanism of rapid growth, the mechanism of balancing the desirable and the possible, and the mechanism of stabilisation. Each mechanism is preferable from a particular point of view. It has been shown that these mechanisms can interfere with each other, resulting in less desirable futures. These less desirable futures can be regarded as risks attached to the more desirable futures. This has been analysed by regarding 'dystopias' as derivations of the three 'utopias.' A major risk in both the hierarchist and the egalitarian utopia is that public water supply, sanitation and wastewater treatment fail to improve, as a result of either mismanagement or a lack of investment capacity. Furthermore, both utopias are vulnerable to high growth conditions, which can lead to absolute water scarcity conditions in several parts of the basin. The main risk to the individualist utopia is inefficient water-use and extraordinarily high expenditure for water supply, which can result from a price policy that does not conform to the market.

As concluded in Section 4 all utopias are vulnerable to drought. Although future droughts can to a large extent be regarded as unavoidable, their effects will depend on the type of development path that is followed. Independent of the world-view applied, the effects will be greater under high growth than under low growth conditions. Minimising the vulnerability to drought will therefore require low growth. In this respect, the egalitarian context is less perilous than the hierarchist context, which, in turn is less risky than the individualist context. Growing competition between water users can become really fierce during a succession of dry years. For this reason, droughts constitute an opportunity for latent risks to become manifest. In this sense, droughts are a kind of early warning system. If a period of relatively wet years follows a disastrous period of drought, problems may seem to be solved, but they will probably return in a more severe form during the next series of dry years.

The question of which type of management increases the effects of future droughts and which reduces the effects is slightly more complex. The only advantage of the fatalist management style in this respect is the absence of water export to South Africa, because water export heightens the vulnerability to droughts considerably. On the other hand however, the fatalist management style lacks elements that improve water-use efficiency and it thus increases demand and vulnerability to droughts. In addition, the fatalist management style introduces other types of risk, related for instance to public health and water quality. The hierarchist management style focuses strongly on increasing water supply (through dams, supply infrastructure) rather than on reducing demand, which will result in relatively high specific water demands and an increase in society's vulnerability to drought. In this respect, the egalitarian and individualist management styles have the advantage of changing pricing structures more radically, thus reducing demands, which makes these types of management preferable to the hierarchist management style. With regard to the effects of droughts, the main disadvantage of the individualist management style is the export of water from the basin to South Africa. From the above, it can be concluded that the egalitarian context in combination with the egalitarian management style will reduce the vulnerability to drought most effectively. This would mean: low growth, no water export to South Africa and strong efforts to increase water-use efficiency through improving water-pricing structures and 'water education.'

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