CHAPTER 9

Ephemeral and endoreic river systems: Relevance and management challenges

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Abstract

Ephemeral and endoreic rivers are located in arid, semi-arid and dry sub-humid drylands of the earth. Climate variability, strongly correlated with aridity, is a major factor influencing ecological, economic and social sustainability of ephemeral and endoreic rivers (Molles et al 1992). Ephemeral rivers, with temporary surface flow that varies between seasons and years, nevertheless support ecological systems that have been used by people and wildlife for millennia. Endoreic rivers, which may be perennial or ephemeral, are also a focus of use and development in otherwise arid landscapes.

Growth in human populations and changing lifestyle expectations of people living in arid environments have led to greater pressure on ephemeral and endoreic rivers globally, while at the same time attracting more tourism, based on biodiversity and scenery. Commonly, policy guidelines are missing and information to aid management is incomplete, as these rivers tend to occur in remote areas. Nevertheless, examples of mismanagement and non-sustainable use of ephemeral and endoreic systems are legion, and provide salutary lessons to those responsible for management of the Okavango River and its water resources. Potential exists for policy and management options, both traditional and innovative, to ensure continuing supply of water and associated benefits to human and biotic riparian communities and their inland neighbours.

The major management challenge for the Okavango River and similar ecosystems is to balance rights, expectations, responsibilities and opportunities of local people, many beset by poverty in a harsh, arid landscape, with requirements of the ecosystem to maintain these desired services and with expectations and aspirations of the global community. The latter recognise the potential value and opportunities represented by the unique but diminishing assets supported by these dryland ecosystems, but are not required to sustain their own livelihoods from them.

Introduction

Growing human populations worldwide and concomitant increases in use of natural resources have led to increased recognition of the importance of biodiversity, climate change and the threat of increased desertification among the global community (WECD 1977; UNCBD 1992; UNFCCC 1992; UNCCD 1996).

The Okavango River is a perennial endoreic river with some ephemeral tributaries supporting a unique ecosystem with diverse opportunities for use and development for a variety of local, regional and global communities. For a number of reasons, the three Okavango basin states – Angola, Namibia and Botswana – have not extensively used the landscape or waters of the river or delta for development, although many divergent ideas and plans have been mooted over the past century. To date, the middle reaches of this ecosystem and the delta have been put to limited use by local populations for livestock grazing and harvest of natural products, and for a growing, lucrative tourism industry. As a consequence, it remains one of few, relatively untouched perennial endoreic rivers in the world's drylands that supports a varied and diverse biota in a relatively pristine and spectacular landscape.

Experience from elsewhere in the world has shown that endoreic rivers, occurring as they do in drylands, are in a relatively fragile state of hydrological and ecological balance, easily and often subject to degradation. The Aral Sea in central Asia supported a thriving fishing industry that has been entirely destroyed by use of its source rivers for irrigated cotton farming. Even if the entire inflow was to be restored to its original volume, neither the water body nor fishery could be restored to their former levels (Goldman 1994). Climate change is also affecting water bodies, and Lake Chad, located in the Sahel, has diminished in size by over half its surface area during the last century, apparently due to natural causes. Peace and potential development in Angola, source of the Okavango River, and use of water from its middle reaches to support the burgeoning and urbanising population of arid Namibia, could produce a similar effect to that of the Aral Sea. If combined with predicted increased aridity in the area due to climate change, the future of a perennial Okavango delta could be in jeopardy. This would negatively affect ecosystem services provided to the local population (among others, clean water) and their direct use of natural resources (such as fish and wood), as well as globally important biodiversity in the area and income generated from tourism.

Namibia is one of the Okavango basin states with a significant percentage of its population dependent upon water from ephemeral rivers. About 20% of the country's surface area and 20% of the population depend on 12 westward-flowing ephemeral rivers (Jacobson et al 1995). Another 50% of the people live along the endoreic, ephemeral wetlands of the Cuvelai system in north-central Namibia, while another 20% depend on other ephemeral systems and groundwater. Only 10% of Namibia's population uses perennial river water to support their livelihoods. These proportions emphasise the importance of ensuring development and use of very localised, fragile but important ecosystems in a socially, economically and environmentally sustainable manner. In Botswana, the Okavango Delta supports a population of approximately 30,000 (2% of the national population) while the

remainder depend mainly on groundwater and a few surface impoundments on ephemeral rivers.

Ephemeral and endoreic rivers

In an ephemeral river, water flows sporadically and for short periods following heavy rain or snow melting in its catchment during spring. Water may flow for hours or even days, but rarely longer. Jacobson (1997) defines an ephemeral river as one in which measurable discharge occurs for less than 10% of the year. Over time, a particular river can change from perennial (where water flow is continuous) to ephemeral, or vice versa, depending upon climatic and environmental circumstances. Another important feature of an ephemeral river is that, although the river channel's surface may remain dry for most of the year, there is usually a significant volume of water stored beneath the channel (Jacobson et al 1995).

An endoreic, or closed water system, ends its journey inland rather than flowing into the ocean. Most endoreic systems terminate as a lake or a sea or, as in the Okavango River system, as a delta. Both ephemeral and perennial systems can be endoreic, and paleohydrological evidence from around the world often shows that a system has changed from exoreic (flowing to the sea) to endoreic due to geological, climatic or environmental factors.

Location

Ephemeral rivers are located throughout the drylands (see map 1). These areas are centred along the tropics, north and south of the equator, where over a billion people in 110 countries try to make a living on more than 30% of the earth's surface (Turnbull 2002). In Africa alone, 35% of these drylands are degraded with over 70 million hectares strongly degraded according to figures provided by the United Nations Environment Programme (UNEP). Twenty African countries have more than 90% of their productive lands in vulnerable drylands, an illustration of the human dimensions of the issue (Turnbull 2002). Very few perennial rivers cross these drylands, with the Nile being one example, and none have their origins there. Ephemeral rivers, as a consequence of their variability, have a higher per capita importance than their volume of water would indicate.

Endoreic rivers are also located mostly in dryland areas of the world between the northern and southern margins of desert zones in both the northern and southern hemispheres. Most endoreic rivers are located far inland from the sea. They tend to have their origins in better watered areas and their endpoints in the drylands. As is the case with dryland ephemeral rivers, endoreic rivers often serve as a focus of activity for people and wildlife and for agricultural and urban development. Endoreic rivers also often have a higher per capita importance than their volume of water would indicate, despite sometimes containing water of lower quality than exoreic water bodies.

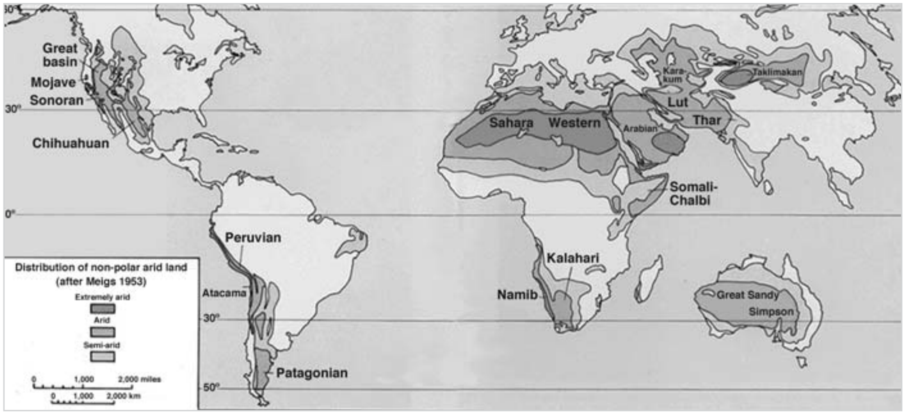
Relevance for the Okavango River

The Okavango River is a perennial, endoreic river with ephemeral tributaries (see map 2). With ongoing and expected increased development in the Okavango River catchment, the possibility exists that main river flow could become more variable within and between years resulting in only intermittent flow. This trend could be exacerbated by predicted regional climate change. Some perennial tributaries, particularly those flowing through sandy substrates, could also become ephemeral as aridity increases. Although figures vary, greater variability and lesser volumes of rainfall are expected in Southern Africa (Tarr 1999) as a result of climate change. Examining and understanding characteristics of ephemeral rivers, including their social, ecosystem and economic aspects on both a local and global basis, are thus of significance to those contemplating either conservation, or development and increased diversion of Okavango River water.

The Colorado River is an example of a perennial, exoreic river, flowing from high rainfall areas into an arid region, which has been converted into an endoreic system with little or no flow in its delta, due entirely to anthropogenic development. Much of this development occurred in the guise of progress during the first half of the 20th century. Regulations and agreements between the United States and Mexico and

Map 1

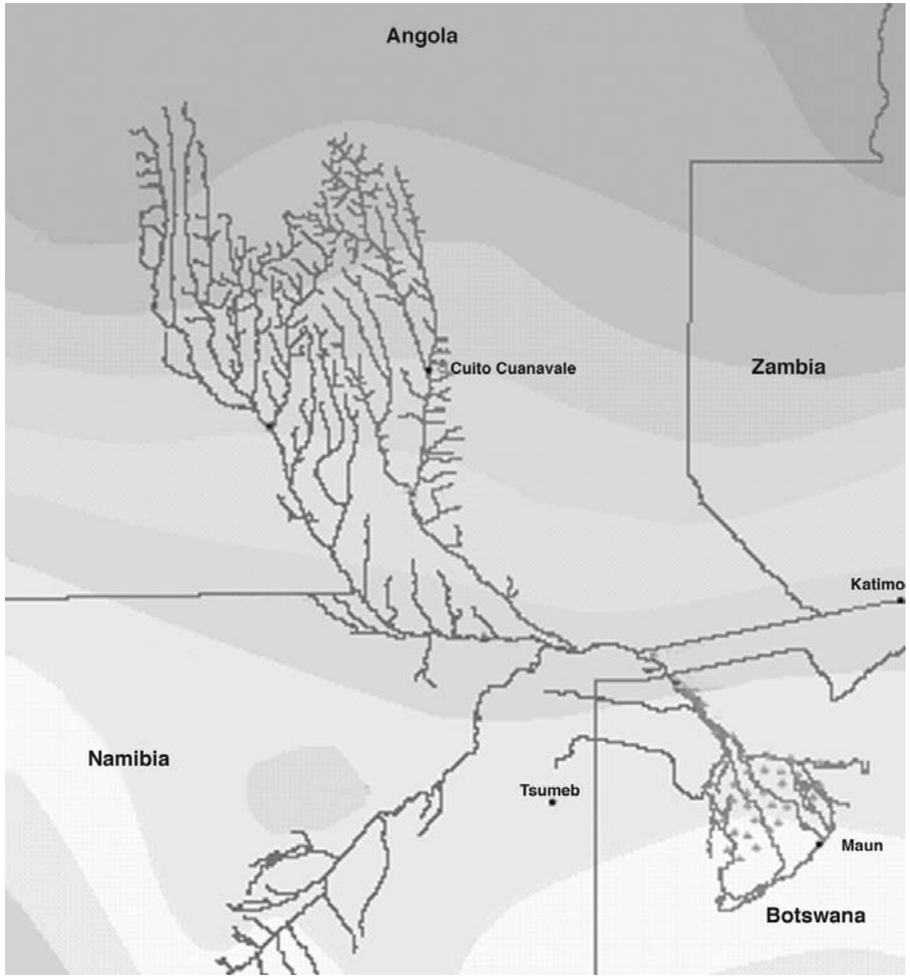
Arid and semi-arid areas of the world



Source: <ag.arizona.edu/OALS/IALC/About/aridlands_map.html>.

Map 2

Okavango River system



Source: el Obeid & Mendelsohn 2001.

among US states contribute to continued exploitation of this river, thus entrenching its endoreic nature.

Geographical characteristics of ephemeral and endoreic rivers

Ephemeral rivers, large and small, are predominantly found in the world's drylands. These rivers may be ephemeral in their lower reaches with some perennial flow in their upper reaches or where a rocky substrate forces groundwater to the surface in localised areas. Many ephemeral rivers are also endoreic, that is, they do not flow into the sea even during the highest rainfall. This may be the result of insufficient water in their upper courses, for example, in ephemeral rivers associated with mountains of the Sahara, the Tibesti or Agghar. Alternatively, this may be the result of sand dunes or other obstacles blocking their course, for example, the ephemeral Tsauchab River flowing into Sossus Vlei in Namibia. Other ephemeral rivers flow into the sea during high flows, or could, if developments had not diverted their surface flows. In Namibia, 10 of the 12 major westward-flowing ephemeral rivers flow into the sea on occasion, and the southward-flowing ephemeral Fish joins the perennial Orange that empties into the southern Atlantic Ocean. Namibia's perennial rivers also have ephemeral, endoreic tributaries that, although considered part of the basin, rarely flow. These include the Nossob, a tributary of the Orange, and the Omatako connected to the Okavango.

The geology through which ephemeral rivers flow also has an effect on their regimes and classification. The Nossob, for example, flows through the sandy Kalahari while the Fish River flows through hard rock areas along most of its length. Changing geomorphological conditions may also influence river classification as ephemeral and endoreic or as ephemeral and exoreic. In Namibia, the ephemeral Hunkab River of the northern Namib was considered endoreic, damming up against the Skeleton Coast dunes. In 1995, a large, localised downpour in its headwaters caused the river to cut through the dunes to the sea for several days (Jacobson et al 1995). This event uncovered evidence that surface flow to the sea had happened previously. Within a few years, any sign of dune disturbance was obliterated.

Aridity and its associated rainfall variability are key factors determining ephemerality of rivers, as is the very high rate of evaporation. In the western ephemeral catchments of Namibia, evaporation is more than six times greater than mean annual rainfall in the inland headwaters and more than 100 times greater in the arid west (Jacobson et al 1995). Evaporation leads to rapid loss of rainwater from the system. Where surface water is present at springs and wetlands, high evaporation frequently results in very saline soils. Because of limited water flow, salts build up and the only types of vegetation that can survive around these springs and wetlands are salt tolerant species. The efficiency of dams in drylands is also seriously affected by the high rate of evaporation.

Drought, the result of variable rainfall in arid environments, is another factor correlated to ephemerality of rivers in drylands. Although drought is a normal

occurrence in drylands, people are usually unprepared for it when it occurs. Periods of drought often result in increased pressure on surface and subsurface water.

Endoreic systems form as a result of interruption of surface water flow that arises from a balance between inputs (precipitation and surface flows) and outputs (evaporation and seepage). Because inflowing water subsequently flows into dry watercourses or is evaporated, minerals and other inflow erosion products concentrate within these water bodies. With a continuing mineral input, some endoreic water bodies typically become more saline than those that flow into the oceans. As evaporation plus seepage are the major water outflow pathways, endoreic water bodies also tend to be more sensitive to pollution than those that flow into the oceans (UNEP 2000).

Endoreic water bodies include some of the world's largest lakes. The Aral Sea, a large terminal lake, presents the most disrupted endoreic system in the world (Goldman 1994). Its two major inflow rivers, the Amu Darya and Syr Darya, previously maintained the lake within acceptable boundaries of water quantity and quality for many beneficial water uses. A thriving commercial fishery employed over 60,000 residents in the catchment before the two rivers were more or less completely diverted to irrigate cotton in desert areas of Kazakhstan and Uzbekistan during the mid-20th century. This diversion led to the reduction of the Aral Sea to two-thirds of its original size and the threefold increase in salinity from evaporation. Remaining inflow is loaded with agricultural and industrial pollutants. The catchment is now beset with excessive fertiliser and pesticide use, as well as salinised soils causing serious health risks to local residents. It has furthermore led to extinction of 24 fish species and other aquatic species, ruin of the fishing industry and unemployment. Of particular significance is the fact that devastation of this ecosystem took place within the timeframe of a single human generation. It provides an example of unsustainable socioeconomic development of a catchment with the serious, unplanned environmental, economic, ecosystem, human health and social consequences that arise.

Mono Lake in eastern California is an endoreic ecosystem that was partially destroyed when its catchment water was diverted directly from the Sierra Nevada mountain runoff to Los Angeles. Reversal of this diversion is slowly allowing natural restoration of this remarkably scenic saline lake. The endoreic Oanab River in Namibia was thought to dissipate into the Kalahari sands after a flood until a dam was built across its lower reaches. Now, as the nearby artesian aquifer level decreases, possible connection with the Oanab River comes into question. Endoreic systems in arid environments still hold surprises for those wishing to develop their water resources.

Environmental characteristics of ephemeral and endoreic rivers

Ephemeral rivers have long been of importance to people and wildlife living nearby, representing linear oases or riparian corridors through otherwise dry landscapes (Jacobson et al 1995). Today they represent focal points of human development and natural biodiversity in drylands.

Ephemeral rivers are not only important for their water resources, but also for the vegetation and other biota that they support. Structure, productivity and spatial distribution of biotic communities are strongly affected by flow patterns. Altering flow negatively affects this fragile balance and reduces overall productivity. Soils in most ephemeral rivers are relatively poor and thin and have little potential for irrigated agricultural production. These same soils, however, support dense stands of trees and other woody vegetation, which provide essential fodder for livestock and wildlife. In evaluating potential benefits of any development, various factors must be considered such as poor drainage, high salinisation potential and particularly the great volumes of water required for irrigation (Jacobson et al 1995; Jacobson et al 2000).

Flooding is an important element in the structure and maintenance of ephemeral river ecosystems. Jacobson (1994) vividly describes a flood in the Kuiseb River:

> "The leading edge of the flood was nearly a meter high and looked more like lava than water as it rolled rapidly down the channel. The water was loaded with sediments and organic material, including seeds, sticks, logs, grasses and animals of various shapes and sizes. The water itself contained high amounts of nutrients and dissolved organic carbon. All of this material was carried downstream and deposited within the desert reach of the Kuiseb River."

Floods in ephemeral rivers are usually produced by heavy downpours that leave little time for water to infiltrate the soil (Jacobson et al 1995). The rate of water flow, or discharge depends upon the volume and pattern of rainfall in the catchment and where it is measured (see, for example, figure 1). Discharge increases until the combined effect of evaporation and infiltration causes a decrease in water level. Infiltration, the seepage of water into the channel bed, is the main factor contributing to downstream decline in discharge. Infiltration and evaporation are so great that discharge often stops before the flood reaches the river end. Large flood variations, coupled with a limited record of past floods, provide a serious barrier in understanding the resource base in ephemeral rivers, as well as to their sustainable management.

Presence of fish in ephemeral rivers usually depends on presence of perennial water somewhere along the river's course. This is one of few ecological systems where it is sustainable to remove all fish. They die as the river dries up and regenerate from perennial river sections.

Terminal water bodies of perennial or ephemeral endoreic river systems are varied. In the Kalahari basin, the Okavango River forms a perennial delta of varying size controlled by tectonic movements in the area. In the Cuvelai basin of north-central Namibia, the extensive, saline Etosha Pan receives water only occasionally, the last big inflow dating back to 1971 (Berry et al 1973). Sensitivity to salinity and pollution are characteristics of all endoreic systems, although some are already so saline – the Etosha Pan, Mono Lake – that increasing salinity is not currently a

relevant factor. Fish are an important economic asset in some endoreic systems, but salinity or other factors preclude them from others. Waters of the Okavango Delta are not as saline as might be expected given that evapotranspiration accounts for about 96% of water loss. Transpiration dominates over evaporation especially in the permanent swamps, and resulting saline water seeps away in groundwater flow. This coupled with bacteria in peat swamps, which absorb salts, prevent formation of saline surface water (McCarthy 1992). How the system would react to increasing levels of pollutants remains to be seen.

Economic, social and environmental benefits

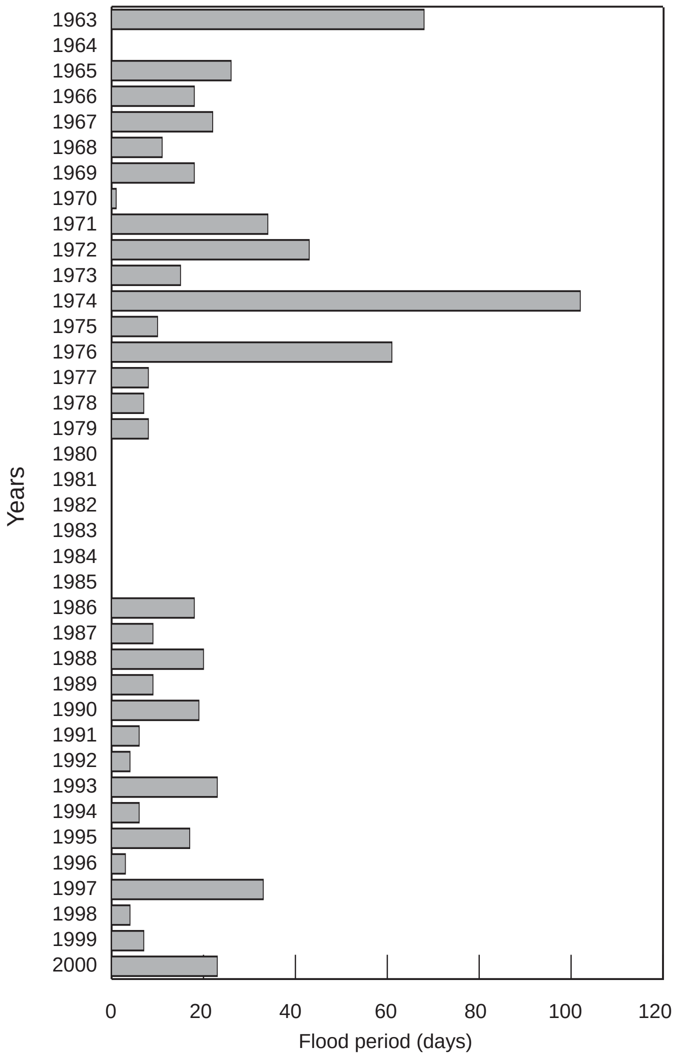
Perennial and ephemeral rivers have different users along their courses that share benefits and cause differential impacts. Perennial rivers usually originate as small streams that swell as water enters the system from numerous tributaries. Many large cities in temperate regions are located along the lower reaches and near the mouths of large perennial rivers. Ephemeral rivers, on the other hand, often have more water in their upper reaches, present for a longer time, than in the lower river course. Urban and large-scale agricultural developments dependent upon ephemeral rivers either use surface water captured in artificial dams, or groundwater stored in ephemeral aquifers. Sharing of water between upstream and downstream users therefore differs fundamentally between perennial and ephemeral rivers. Moreover, a greater proportion of water available in ephemeral rivers is consumed per capita than in perennial rivers. In the ephemeral Swakop River in central Namibia, the proportion of surface water impounded in its upper reaches has reached 100%, with consequent impact on productivity downstream, and is still insufficient to support Namibia's capital, Windhoek.

Sharing benefits between upstream and downstream users in endoreic systems is similar to that of ephemeral river systems because of the general landscape aridity and all that portends. As with ephemeral rivers, a great proportion of all water can be removed from endoreic systems short of their natural endpoints because of lack of inflow from surrounding arid landscapes.

Endoreic systems, whether perennial or ephemeral, contribute to groundwater recharge and support riparian ecosystems. Variable flood regimes are responsible for induction of germination and establishment of woody vegetation, and serve to recharge wetlands. Because of their function as linear oases or riparian corridors in drylands, they become a focus for urban centres, agriculture, irrigation, tourism and other human activities. Water may be directly abstracted from perennial endoreic rivers for domestic use or agriculture including irrigation. Impoundments may enhance human management and use of endoreic systems but, as with other arid zone water systems, there is a fine balance between benefit in the form of additional water and loss of alternative benefits, also dependent upon water, from the system.

Figure 1

Flow variability in the ephemeral Kuiseb River



Source: DRFN

Sharing upstream/downstream benefits and impacts

The Kuiseb River presents a good example of how water from an ephemeral river is shared among users. Over 100 commercial farms share the upper 63% of the catchment area (Jacobson et al 1995), each excavating from one to 20 farm dams, many of which have silted up in recent years (Angula et al 2001). Groundwater in the river's middle reaches supports wildlife of the Namib-Naukluft Park and Topnaar communal farmers. Meanwhile, the alluvial aquifer of the lower Kuiseb, which depends on recharge from occasional flooding, sustains the harbour and fishing town of Walvis Bay. In the recent past, the lower Kuiseb aquifer also supported the resort town of Swakopmund and Rossing uranium mine. As population of the coastal towns increases, along with increased fishing and harbour activities, greater use is made of the alluvial aquifer. At the same time, plans for a major dam in the middle reaches of the Kuiseb to support a new uranium mine are being pursued, which would reduce or eliminate recharge of the lower Kuiseb aquifer. Even now, accusations are made downstream that commercial farmers are withholding more than their fair share of water resources. Communal farmers accuse coastal towns of lowering the alluvial aquifer upon which their indigenous crops depend. Recent initiation of a basin management committee is one of the approaches being applied in an attempt to resolve issues and establish an agreed upon vision, shared by all users of this ephemeral river.

The Cuvelai system (map 3), which is endoreic as well as ephemeral, also presents an example of multiple use of an ephemeral wetland. In the headwaters, situated in Angola, little use is made of apparently perennial streams, although there is a proposal in hand to build a dam to recharge groundwater upon which a growing border town depends. Once the river crosses the border into Namibia, populations of people and livestock making use of the water increase significantly. Flow in the ephemeral wetlands recharges aquifers and traditional surface water sources, provides fish, supports indigenous vegetation and enhances water supply and grazing for livestock.

Where water accumulates in temporary pans, competition exists between fishers and livestock. It is only when flooding has been unusually high, as in 1971, that water flows down the entire course of these ephemeral wetlands into the end point, the Etosha Pan (Berry et al 1973). The Cuvelai basin, including the Etosha Pan, is currently the only ephemeral Ramsar site registered in Namibia (Barnard 1998).

Surface water

Flowing surface water in ephemeral systems is usually of little direct use to people because of the short duration of flow. It must therefore be impounded in artificial or natural dams and pans or recharge groundwater aquifers before it can be used by people. Flowing surface water is important, however, for germination and establishment of riparian vegetation as has been noted in the Kuiseb River (Jacobson et al 1995), and for redistribution of fish. Flowing surface water is also responsible for the dynamics of expansion, contraction and rejuvenation of ephemeral water courses and associated dryland systems (Friedman & Lee 2002).

Groundwater

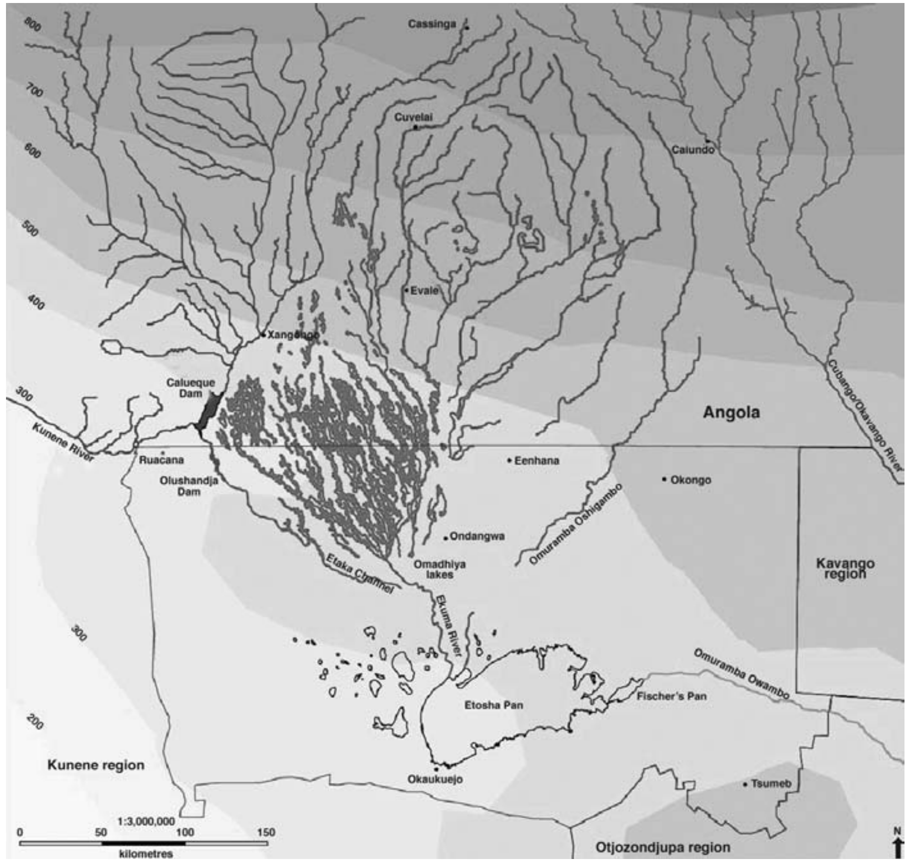
Groundwater recharge is one of the most important functions of floods in ephemeral rivers. As a flood travels down an ephemeral river, water infiltrates into the sandy and gravelly alluvial deposits of the channel beds. The degree of recharge depends on intensity, volume and duration of a flood (Heyns et al 1998).

When the groundwater table is just a few metres below surface following a flood, people and animals obtain access to groundwater by digging in the riverbed. Today, boreholes and pumps ensure year-long accessibility to water along ephemeral rivers. Permanent watering points enable formation of permanent settlements and facilitate sedentary livestock farming, irrigation and industry. This shift from a semi-nomadic to a sedentary livelihood has resulted in land degradation and even desertification in some areas. In Namibia, local communities keep vegetable gardens along the Omaruru, the Ugab, Hoanib and the Swakop rivers, while commercial crops are grown in the lower reaches of the Swakop (Jacobson et al 1995). Coastal towns of Swakopmund, Walvis Bay and Henties Bay derive their water supplies exclusively from alluvial aquifers in the Swakop, Kuiseb and Omaruru rivers (Heyns et al 1998). It is estimated that almost 100,000 coastal residents are dependent for their survival upon aquifer resources provided by Namibia's ephemeral rivers (Tarr 2002). In some Namibian rivers, such as the Kuiseb and the Swakop, a gradual decline in the groundwater table is being observed, despite some good floods in recent years. This is a first sign of unsustainable water consumption.

Constant availability of groundwater in ephemeral river channels allows for the presence and growth of woody riparian vegetation. In west-flowing ephemeral rivers dense stands of large woody trees (e.g. *Faidherbia albida* and *Acacia erioloba*) stand in contrast to the otherwise arid landscape. While constant groundwater availability plays a vital part in tree survival, occurrence of irregular, extreme floods plays a vital part in aquifer recharge, morphological reshaping of the channel and also in the age structure and spatial distribution of riparian trees (Friedman & Lee 2002). Riparian forests provide resources for people such as wood for construction and fuel, medicines and fruit, and essential fodder and shade for wildlife and livestock. Because of riparian forest and groundwater availability, ephemeral rivers are frequently referred to as the 'linear oases' of the Namib Desert (Jacobson et al 1995). Human groundwater use is in direct competition with water needs of riparian vegetation and water consumption should be carefully weighed against the value of the riparian vegetation. Furthermore, dam construction affects flood patterns of ephemeral rivers. Dams not only lower the watertable downstream, they also reduce flood size, which has a potential long-term impact on aquifer recharge, channel morphology and

Map 3

The Cuvelai water system



Source: <www.dea.met.gov.na/nnep/orientat3.htm>.

vegetation structure and distribution. The demise of most of the riparian woodland downstream of the Swakoppoort Dam in the Namib-Naukluft Park in Namibia provides a good example of this effect.

Groundwater-fed wetlands occur in Namibia's western rivers where subsurface flow is forced to the surface by bedrock. Such wetlands vary in flow rates, water chemistry and duration of flow. They provide water, food, shelter and a unique habitat for a great variety of plants and animals (Loutit 1991; Christelis & Struckmeier 2001). Archaeological evidence suggests that such wetlands have been used as human settlements for millennia and they are still frequented by local communities, their livestock and tourists today (Jacobson et al 1995).

Groundwater plays a role in both perennial and ephemeral endoreic systems, although the ecological and social importance of groundwater tends to be greater in ephemeral systems. Groundwater contributes to the baseflow of perennial endoreic systems, while it acts as an essential supply to humans, riparian vegetation and animals in seasonal systems (Parsons 2002).

Management challenges

Management challenges and, consequently, policy and legislation challenges presented by ephemeral rivers differ in kind and degree from those presented by perennial rivers flowing into the sea. Management challenges presented by endoreic systems, whether perennial or ephemeral, have more in common with ephemeral systems in that they occur in drylands. The primary factor influencing management actions on ephemeral rivers and endoreic systems is their variability of flow caused by the arid climates in which they are situated. When rivers flow for only a few hours or days in a year, the cost of a management intervention varies considerably depending on flow characteristics and the scale of the proposed intervention. Moreover, because ephemeral and most endoreic rivers are located in arid areas that are relatively sparsely populated and their flow is episodic, data and information are limited on which management interventions could be based.

Opportunities for use of surface water or groundwater of an ephemeral river vary greatly between upstream and downstream locations (Dausab et al 1994; Amoomo et al 2000; Angula et al 2001). The upstream section of an ephemeral river will have surface water present more frequently than the downstream section as it usually occurs in an area of higher rainfall. It is only larger, less frequent floods that reach the downstream water course. On the other hand, storage capacity in the form of alluvial aquifers may be larger in the lower reaches of an ephemeral river, as is the case in the 12 main westward-flowing ephemeral rivers of Namibia (Jacobson et al 1995). Consequently, long-term benefits from occasional ephemeral river flow may be greater in the downstream section of the river compared with upstream locations. Similarly, benefits to be gained from the end point of the endoreic system may be greater than those upstream in an unmanaged system, for example, in the Aral Sea at

the beginning of the 20th century. The reverse can be true with development of endoreic rivers upstream of their endpoints, the Aral Sea again being a profound example. Variations between upstream and downstream locations in terms of opportunities and benefits to be derived from ephemeral rivers, as well as from endoreic systems, cannot be easily generalised.

As populations increase and become more sedentary, more pressure is placed on ephemeral river basins (Marsh & Seely 1992). Not only do more people expect a share of the limited water available from an ephemeral river, but they also expect to use this water for more varied economic developments. Moreover, traditional livelihoods and attitudes tend to be based on the expectation of adequate water at little or no cost. These changing social and economic conditions place additional constraints on developing efficient and effective management approaches to ephemeral river basins and, similarly, to endoreic systems in arid environments.

Ephemeral and endoreic rivers are situated in drylands of the globe where poverty and underdevelopment often dominate. Although many countries in the Southern African Development Community (SADC) are currently revising their legislation (see NWRMR 2000a), policies, legislation and regulations needed to address efficient and effective water resource management are not well developed in countries where ephemeral or endoreic rivers predominate. Because of limited surface flow in the case of ephemeral rivers, they are often ignored by governments and water authorities. On the other hand, many countries involved have ratified the United Nations Convention to Combat Desertification in those Countries Experiencing Serious Drought and/or Desertification, particularly in Africa (UNCCD), the United Nations Convention on Biological Diversity (UNCBD) and the United Nations Framework Convention on Climate Change (UNFCCC), although implementation of these environmental conventions – and certainly their application to drylands and their water resources – lags far behind ratification.

Many ephemeral and endoreic rivers cross international boundaries or internal state jurisdictional boundaries (Pallett 1997). Few institutions and bureaucracies responsible for water resource management have appropriate mechanisms to handle issues associated with managing, developing or sharing ephemeral river resources (NWRMR 2000b). With the focus on decentralisation in many arid African states, capacity to manage water resources that transcend these new intrastate boundaries is limited (NWRMR 2000c). At the same time, devolution of responsibilities associated with rights over water resources is often not a part of the decentralisation process, although the UNCCD particularly promotes participation in management by resource users (see also NWRMR 2000c).

Vision and management objectives

Vision and management objectives for ephemeral and endoreic rivers in drylands must encompass sustainability of water resources as laid out in the Brundtland report

(WCED 1987), Agenda 21 (UNCED 1992) and the Dublin principles (1992), even though these instruments are often only considered, if at all, in the case of perennial rivers. Basin management approaches integrating ephemeral and perennial rivers, if they are present, surface and groundwater, endoreic and exoreic systems, and land as well as water could help to promote sustainable use of ephemeral river resources (Jacobson et al 1995; NWRMR Policy 2000a). As highlighted in the UNCCD (1996), participation by all resource managers and users is essential for appropriate and sustainable management. Partnerships among agencies and institutions, coupled with full participation and focused on integrated resource management, must be a part of the vision and management objectives for ephemeral and endoreic rivers throughout drylands (NWRMR 2000c). Results of such an approach would encompass enhanced livelihoods for those who depend on and use ephemeral and endoreic river resources, as well as the conservation of landscapes and the biodiversity they support.

Management of surface waters

Small-scale harnessing of ephemeral river water, such as rainwater harvesting, has been practised for millennia (Lovenstein & Stafford Smith 1994). Management of surface flow of perennial rivers in endoreic systems is well developed in many areas, with varying consequences.

Impoundments

The demand for readily available surface water in semi-arid and arid areas has led to the construction of some large and many small impoundments on ephemeral river systems. Commercial farmers in the upper catchment regions of pre-independence Namibia received government support to construct ground dams, and large impoundments were built to supply industrial areas in central Namibia (Jacobson et al 1995). Since independence and the withdrawal of subsidies, many of these ground dams have silted up, retaining little water even in the most abundant rainy seasons (Angula et al 2001).

Every flood carries large quantities of sediments, which provide nutrients to the river ecosystem and redefine the channel morphology (Friedman & Lee 2002). When the high sediment load of floods is intercepted by dams, it affects the functional time of a dam, and deprives the lower river reaches of nutrient materials (Agnew & Anderson 1992). In order to intercept a large volume of water flowing only occasionally, a dam on an ephemeral river must be large in relation to average inflow. There is a high risk of dam failure on ephemeral rivers due to high unpredictability of flash floods. In 2000, the Hardap Dam on the Fish in southern Namibia received rapid inflow. Authorities had to weigh up their actions quickly and carefully, based on three possibly conflicting priorities: to minimise dam failure, to ensure the safety of people living downstream, and to keep the dam as full as possible to ensure storage of

valuable water resources (Van Langehove 2002). The result was some flooding of the town of Mariental, situated nearby below the dam, but was overall an optimal solution to a difficult situation.

Surface waters in arid areas evaporate quickly. Losses due to evaporation are higher, the larger the surface area of the dam. The further up water retention is in the river, the more severely it affects flood intensity and volume in the lower reaches, which in turn reduces recharge in downstream aquifers (Agnew & Anderson 1992). Very difficult decisions have to be made when developments are planned for ephemeral rivers. Information is often limited and numerous factors, including differential land use, must be considered.

Pollution control of surface water

A water reservoir on an ephemeral river is at risk from at least three sources of pollution. Permanent surface water is at greater risk of direct pollution from the immediate surroundings (shores, air, acid rain) than the remainder of an ephemeral river, which has a layer of unsaturated soil to filter out some pollutants. The most common dam pollution occurs from materials carried downstream from the upper river. The Okapuka tannery near Windhoek in Namibia releases high concentrations of sodium chloride into a tributary of the Swakop River, and increased concentrations have been detected in the groundwater. Over time and with several floods, there is the risk that these pollutants will enter farm dams downstream and the Swakoppoort Dam, one of the key water sources for Windhoek (Roeis 2002).

Ephemeral floods naturally transport significant quantities of organic material and sediments, which accumulate in dry riverbeds during the dry season (Jacobson 1997). Accumulation of organic materials in impoundments can lead to increased nutrient levels and ultimately result in eutrophication. Decay of organic matter can cause temporary anoxic conditions in lower stratification layers of the dam, which affects aquatic life and requires constant adjustment of water abstraction depth for human consumption. High evaporation rates in arid areas also increase concentration of organic and inorganic compounds in dam water over time (Schachtschneider & Bethune 1997).

Integrated water resource management

The main aims of integrated water resource management are to supply adequate volumes of water for human use and economic development while also ensuring sustainable use of water resources for proper functioning of ecosystems and their use by future generations. In the case of alluvial aquifer resources in ephemeral rivers, sustainable use does not mean abstraction of the full aquifer storage potential, but rather the equivalent use of long-term annual recharge (Christelis & Struckmeier 2001). Appropriate management thus strives for a balance between water volumes entering the system, natural water requirements of the system and human water demand. This logical concept is difficult to quantify and implement, particularly in variable, arid environments. Of particular relevance to ephemeral rivers is occasional aquifer recharge while abstraction and use are constant.

Aquifer recharge rates are difficult to measure, as they are site-specific and depend on a number of variables, including rainfall intensity, soil conditions, surface topography, vegetation cover, land use, watertable and aquifer characteristics (Christelis & Struckmeier 2001). Calculations of water outputs need to take into account natural losses from alluvial aquifers through springs, groundwater flow down the catchment and evapotranspiration from riparian vegetation. Such losses are difficult to quantify accurately (Christelis & Struckmeier 2001). Water abstraction is determined though metering. Unfortunately, many developing countries either do not or only partially calculate water abstraction and water supply therefore cannot be accurately quantified.

A final complication in arid developing countries is the lack of long-term, regular groundwater monitoring data on which to base models and predictions. Sampling and monitoring are limited due to financial constraints and the remoteness of some ephemeral and endoreic systems (Jacobson 1997; Parsons 2002).

Water demand management

Sustainable groundwater use is difficult to compute both on local and catchment scale. The fall of water tables is frequently used as an indicator of overabstraction, although seasonal variations and long-term climate change need to be taken into consideration. Agnew and Anderson (1992) report cases of constant watertable falls of one to four metres per annum in arid regions of China and the US. In such cases, water is clearly being overabstracted and resource managers need to focus attention on regulating water demand. Water demand management seeks to improve efficient use of existing water supplies by reducing the water demand (Winpenny 1994).

Water demand increases with population growth, level of development and infrastructure, and increased standards of living. Water demand can be separated into two components: the basic volume of water required for survival and water demand for increased productivity/comfort (White & Fane 2001). The first is a constant volume required per capita for basic survival. It is the latter demand for the product or comfort produced through use of water that can be controlled and reduced through pricing, regulation and awareness creation. Technological measures can furthermore be applied to reduce the volume of water required to produce a specific product or comfort without affecting its quality. Examples include a switch from flood irrigation to drip irrigation or installation of low-flush toilets.

Water demand management is an emerging concept that is only now being implemented in Southern Africa (Allan 2001), but it faces many challenges. Semi-arid countries such as Namibia and South Africa have provided water supplies at highly subsidised rates in the past, creating a general attitude that water is a freely accessible resource (Turton 1999). As a consequence, there is a certain antagonism

towards water use regulation and water pricing, and the effects of water awareness creation are limited. This is exacerbated in Namibia and South Africa when combined with the post-independence expectations of improved livelihoods based on improved availability of natural resources. Developing countries often do not have a policy on water demand management and have limited markets for water-saving technology. Regulating institutions are often challenged to implement appropriate regulations, overcome antagonisms and to perform regular monitoring (Gumbo et al 2002). Despite its challenges, water demand management remains a very powerful and cheap method of resource management and should receive careful consideration especially in arid and developing countries typified by water and financial constraints.

For example, water for the coastal town of Swakopmund is supplied from alluvial aquifers in the ephemeral Omaruru River supplemented by the ephemeral Kuiseb River. Rising concerns over dwindling water resources led to the adoption of a water demand management strategy for the town. Inhabitants are exposed to ongoing awareness campaigns and water tariffs have been adjusted to discourage wasteful behaviour. Regulations prohibit certain inefficient activities and all wastewater is treated and recirculated for garden use. Water demand management will remain an important resource management tool for Namibia's coastal towns in the near future as development of a desalination plant has proven not to be financially viable for the moment (Schachtschneider 2002).

Conjunctive use of surface and underground water sources

Conjunctive use of different water sources is an important management tool to conserve water in arid environments, mainly by reducing evaporative losses. Conjunctive use of ephemeral surface water, perennial river water, groundwater and unconventional water sources can increase the yield and efficiency of an interlinked water supply system, save water, delay the need to incorporate additional water supply infrastructure at an early stage to augment existing water sources and can reduce the unit cost of water.

By linking groundwater sources to a water supply system that obtains water from dams on ephemeral rivers, a major contribution can be made to increase alternative strategies available for water supply management. When a groundwater source forms part of an integrated water resource system, the aquifer can be used at its long-term safe sustainable yield in normal years, but if there is a shortage of water from dams as a result of drought conditions, boreholes can be pumped at two to three times the long-term sustainable safe yield of the aquifer over short periods of time to bridge the drought period. When the drought is over, boreholes can be rested to allow water levels in the aquifer to recover during higher rainfall periods. An aquifer can also be recharged by banking surface water or by artificially recharging the aquifer with water that has accumulated in a dam after good runoff and recharge events.

The efficiency of a dam on an ephemeral river can be increased if water can be used at a higher yield but at a lower reliability. This can be achieved by using water as fast and as much as possible to reduce evaporation losses that would have occurred over a longer time. This mode of operation reduces reliability of the dam to yield water at a certain assurance of supply but, by linking either a reliable groundwater source or a perennial water source to a dam on an unreliable ephemeral watercourse, the more reliably stored groundwater or the perennial water source can be used to meet demand when there is a failure to supply water from the dam.

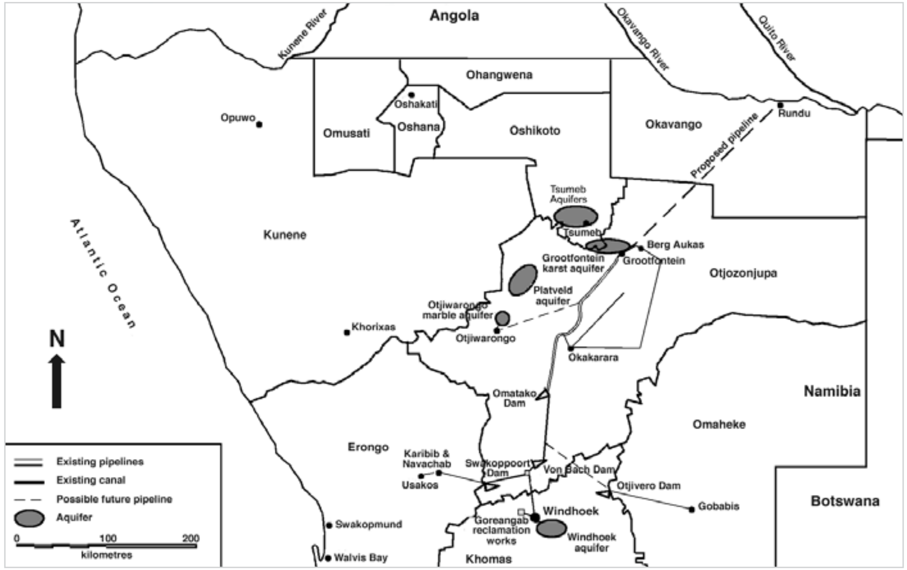
The Eastern National Water Carrier is an ambitious project that was proposed as part of the Water Master Plan of Namibia (see map 4). It is planned that the water carrier may eventually link the water sources in central Namibia to the perennial but endoreic Okavango River. The scheme has been under development for the past 33 years, and has been planned in phases over time as demand has increased and as new water sources have been incorporated.

There are three major dams on ephemeral rivers in central Namibia that form part of the Eastern National Water Carrier. These dams are linked to one another by pipelines. It is therefore possible to use the dams on an integrated basis by transferring water from dams with less favourable evaporation characteristics to dams with more favourable conditions. The total 95% assured safe yield from the dams when utilised on an individual basis, is only 8 Mm^3/a, but by operating the dams on an integrated basis, evaporation losses can be reduced and the 95% assured safe yield of the three dams can be increased to 18 Mm^3/a. The dams are also linked to the Windhoek aquifer and groundwater sources in karstified carbonate rock aquifers at Grootfontein and Tsumeb in the karst area, some 400 kilometres north of Windhoek. Recent studies of the potential of the karst aquifers show that long-term sustainable safe yield is in the order of 20 Mm^3/a. However, up to 15 Mm^3/a can be abstracted additionally on a short-term basis of not more than three years as a backup if the dams should fail to supply. This can be done without adverse effects and allows the aquifers to recover during a rest period. When groundwater from karst aquifers is used in this way on a conjunctive basis with the dams, the 95% assured safe yield of the dams can be increased to 30 Mm^3/a. Recent studies have also shown that by banking surface water from dams in the Windhoek aquifer, additional security of supply can be obtained. The safe yield of the dams can be further increased to 45 Mm^3/a. When the carrier system is eventually connected to the perennial Okavango River, this will show the advantage of using various methods such as the conjunctive use of surface and groundwater, banking of surface water and integrated use of surface waters to increase efficiency of water sources connected to the carrier.

The project started in 1969 and was to be completed up to the Okavango River by 1983. However, a number of factors have delayed completion of the final 250 kilometres. These include addition of groundwater sources, implementation of a water demand management strategy that reduced water consumption, and conjunctive use of an integrated system of interlinked water sources. Yield of water from resources in the

Map 4

Eastern National Water Carrier system



Source: Department of Water Affairs, Ministry of Agriculture, Water and Rural Development

Eastern National Water Carrier has increased to such an extent that completion of the project may well be delayed until 2012.

Artificial recharge of aquifers

Evaporative losses from surface waters in arid areas can be as high as 70% of the total volume of water. One resource management option is to store water underground. Sand storage dams and ground weirs have been used in Namibia and other arid countries for more than a century (Christelis & Struckmeier 2001).

A sophisticated large-scale recharge scheme, the Omdel, lies on the ephemeral Omaruru River in Namibia. The Omdel Dam is a key water supply scheme for the coastal towns of Walvis Bay, Swakopmund and Henties Bay (Jacobson et al 1995; Heyns et al 1998; Christelis & Struckmeier 2001).

Before dam construction, the aquifer had an average mean annual recharge of 3.5 Mm^3, while abstraction was 6.3 Mm^3/a for the coastal towns. Groundwater abstraction exceeded recharge and a steady depletion of the aquifer occurred.

The Omdel Dam (figure 2) was built taking into consideration the fact that recharge of alluvial aquifers depends on turbulence of flow and the clogging effect of colloidal material suspended in floodwaters. During less turbulent flow conditions, a layer of very fine silt or clay material is deposited on the surface of the riverbed and this reduces or completely blocks penetration of water into the aquifer after a short period of time. Quantities of dissolved salts in ephemeral river runoff are normally elevated and are enough to cause flocculation of colloidal material in the water.

The dam is situated upstream of the aquifer and initial storage of turbid river runoff in the reservoir allows flocculation of fine, suspended sediment. Clear water is then fed into infiltration ponds. From there, high aquifer infiltration occurs due to absence of silt in the water and because the aquifer comprises coarse material. The recharge system was designed to transfer the contents of the reservoir to the aquifer during the dry season so that if there was a subsequent good rainy season with runoff, there would be storage space available in the reservoir to impound this runoff. In this way, storage potential of the reservoir and recharge to the aquifer could be maximised. Recharge after flood events has improved to 50% of runoff in comparison to 20% before dam construction. In 1996, the project received the prestigious Shell Environmental Award.

A totally artificial recharge process is currently being tested in Windhoek. Purified water from the surface storage Von Bach Dam on the ephemeral Swakop River is being pumped into the groundwater aquifer underlying Namibia's capital. To date, tests are proving its success and this may be a way to ensure water supply for several years even during times of little rain.

Pollution control in groundwater systems

Effective enforcement of policies with regard to biodiversity and ecosystem functioning is vital to control pollution of groundwater resources. Thorough environmental assessments are required to assess the risk of pollution from mining, industrial, agricultural and household activities (Christelis & Struckmeier 2001). There are several cases of alluvial aquifer pollution in Namibia, despite existing environmental policies, proving the importance of active regulation and monitoring. There are pollution reports from copper mining activities in the upper reaches of the Kuiseb River and of groundwater pollution in the upper Omatako catchment from inadequate sanitation in the Osire refugee camp (Roeis 2002).

Conclusion

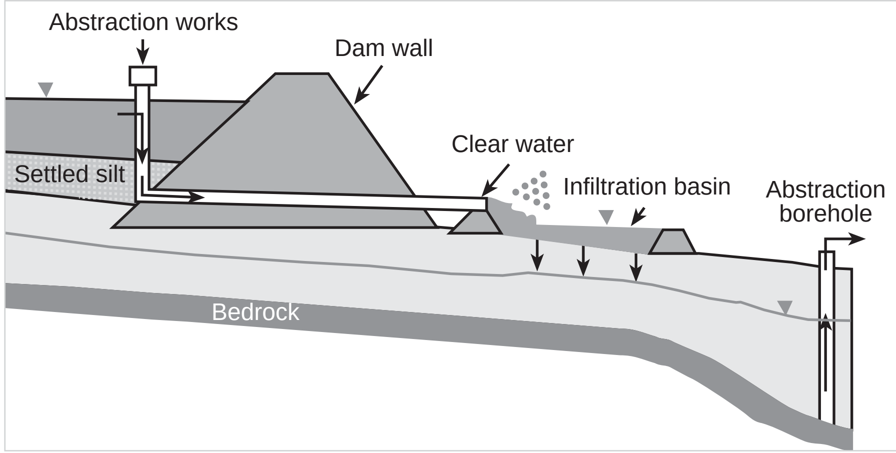
Ephemeral rivers and endoreic systems occur in drylands of the globe. Aridity and a variable climate are key overarching factors influencing their structure and functioning. As oases of water and vegetation in an otherwise arid landscape, they have attracted people and wildlife for millennia and continue to do so today. As a consequence of their location and character, all rivers in drylands, ephemeral or perennial, are subject to increasing human and development pressures. As another consequence of their location and character, all rivers in drylands are hydrologically fragile and alterations to their hydrological systems can have far-reaching ramifications.

Desertification is a major concern where ecologically, economically or socially sustainable use of scarce natural resources is secondary to unsustainable attempts at alleviating prevailing poverty. The unique and valuable ecosystem services and biodiversity supported by these water sources in drylands require attention that is also diverted by an unsustainable focus on poverty alleviation. On the other hand, while subjected to the environmental effects of poverty, drylands are also susceptible to climate change, and may become even more arid and variable.

Sustainable use and maintenance of the longevity of the world's dryland ephemeral and endoreic rivers require appropriate management of technical, social and economic solutions coupled with inclusion, participation and support of all stakeholders – from riparian communities to the international community.

Figure 2

The Omdel Dam



Source: Department of Water Affairs, Ministry of Agriculture, Water and Rural Development

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