PART ONE: INTRODUCTION, BACKGROUND TO THE LHWP AND RELATED LITERATURE

CHAPTER I - INTRODUCTION

1.1 The Setting

Water is scarce in many regions of the world: the Middle East, Eastern and Southern Africa, and parts of Latin America. But even in countries with an overall abundance of water resources like Australia, Brazil, China, Mexico, and the United States, demand exceeds supply in many areas. To overcome water deficits, water is often imported through inter-basin transfers at international, national, regional and local levels to meet increasing demands in agriculture, industry, hydropower, and household sectors. Such transfers can have enormous impacts on the riverine ecology in the exporting area, the importing area, and the path linking the two areas.

The exporting area can experience reduced flows, changed seasonal hydrology, or reduced dilution, all of which can negatively impact on the riverine ecological resources that provide direct and indirect benefits to populations residing in the area. For example, reduced dilution can negatively impact on the quality of water and thus the health of people and animals using the water. The importing area can experience flooding of rivers; changed water temperature, chemistry and quality; and water logging, which may impact negatively on aquatic ecosystems. Imported water can also exacerbate scouring and erosion in the receiving rivers. The erosion may alter the flows necessary to inundate floodplains/wetlands and impact negatively on agricultural productivity and floodplain/wetlands ecosystems. Water transfer schemes have evident benefits in water deficient areas, but if not carefully assessed, instream ecological effects of such transfers can have serious socio-economic and environmental impacts on downstream riparians[1] in both the exporting and importing areas. For instance, too much water than optimal, could be transferred to the importing area at a high opportunity cost for lost ecological resource/biodiversity values and hence reduced social welfare. It is, therefore, important to integrate instream ecological considerations into sectoral management of water

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[1] Rriparians refer to people living downstream, and directly affected by water projects.

resources in order to maximize the direct and indirect social benefits of water resource use.

In many countries policies used to manage inter-basin waters are usually based on sector-by-sector development approaches aimed at meeting economic sector's deficits (Hirji, 1998; Duda et al., 2000). These approaches do not integrate riverine ecological considerations into water management programs and hence, often lead to fragmentation rather than integration sought by socially and environmentally sustainable development[2].

Environmental Impact Assessments (EIAs) for inter-basin transfer schemes is one example where instream ecological effects of such schemes are left out. Such assessments are also often done after important projects' elements have been designed (Hirji, 1998). The Lesotho Highlands Water Transfer Scheme, popularly known as the Lesotho highlands water project (LHWP), is one good example. Recently, the Lesotho Highlands Development Authority (LHDA) commissioned a study to determine Instream Flow Requirements (IFRs) necessary to sustain riverine ecology of rivers downstream the dams of the scheme in Lesotho (LHDA, 2002a). However, this was done after important elements of the scheme had been implemented, e.g., part A of the first phase of the project had already been completed and part B had already commenced.

The main objective of the Lesotho IFR study was to assess negative impacts of modified flows of rivers downstream LHWP dams in Lesotho on riverine ecology. The study was also aimed at determining compensation required for lost values by riparians and to determine mitigation measures required. The said study assessed four IFR scenarios including the IFR in the project's treaty and design of the dams. Hydrological, biophysical and ecological impacts and dam yield of each scenario as well as resultant compensation and mitigation costs were assessed. These however, merely represented policy options available for the LHDA and the estimated costs have not been mitigated or

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[2] South Africa (SA) has been one of the forward thinking countries in this regard. Its new water law shows promise for improving the integration of ecological considerations into sectoral management of water resources.

compensated yet. The present research therefore intends to contribute to improved methods of assessing benefits of inter-basin water transfer schemes by integrating ecological considerations into sectoral or economic benefits' assessments of such schemes, using the Orange River inter-basin transfer scheme between Lesotho and SA (LHWP) as a case study. Because of their magnitude, inter-basin water transfers do not only impact directly related sectors, but also the general economies of related countries. As such, this study uses an economy-wide modeling approach to assessing the economic and ecological impacts of the LHWP. Building on the results of the IFR study, this study investigates and measures the extend of direct (economic) and indirect (ecological) impacts of the LHWP as well as their induced impacts, through multiplier effects, focusing on water allocation for direct and indirect uses, in the project areas in Lesotho and SA. A multi-country ecological social accounting matrix (MC-ESAM) framework that accounts for economic and ecological uses of water and that shows direct and indirect impacts of economic sectors on sectors, sectors on ecology and countries on countries is developed and used to conduct the analysis.

1.2 Background to case study area

The LHWP is one of the biggest water transfer schemes in the world. The project started in 1986 with the signing of the treaty between the governments of Lesotho and SA. The prime objective of the project is to transfer water from the highlands of Lesotho, through gravity, to the water deficient Vaal region in SA. In the process, the water will also produce hydropower electricity for Lesotho. The Vaal region is the industrial heart and an important region for the South African economy. The region produces 40% of the country's GDP, more than 50% of its industrial output, and supports more than 30% of the total population (King, 2000).

Despite it's importance, the region has few natural water resources. It has been projected that, with industrial and urban demand, the region would be facing a water deficit of $1.8 m^3/s$ by 1995, growing to $106.7 m^3/s$ by 2030. Clearly, SA needs more water for continued industrial development and to meet increasing urban water demand. SA could have impounded the water it gets from Lesotho from within its borders. But the LHWP was found to be a cheaper alternative for the country (See Chapter II). SA pays the full cost of the project, except for the hydropower component. The total cost of Phase 1, which is binding between the two countries according to the treaty, is R11 billion (current prices). This is split between Phases 1A and 1B as R8 billion and R3.3 billion, respectively. On completion of the project, SA will also pay an average of US$45 - 47 million per annum in royalties to Lesotho for water delivered by all parts of Phase I (World Bank, 1998).

Water transferred to SA generates hydropower in Lesotho, giving Lesotho some security in hydropower as Lesotho was a net importer of hydropower from SA before the project. The sale of water brings valued foreign earnings to Lesotho. Already the royalties comprise a large percentage of the government's non-tax total revenue (40% in the second quarter of 2000) (Central Bank of Lesotho, 2000). From this money, a revenue fund has been established through which employment opportunities were created for local communities, with the prime objective of poverty alleviation. The LHWP creates jobs as well as many other indirect employment and development opportunities. However, these apparent economic benefits conflict with ecological benefits to riparians in the project areas forgone as a result of the project.

IFRs studies have demonstrated that downstream the Orange River system in Lesotho is a host of ecological resources, which depend on instream flows of the river system. These resources have economic value to 150 000 riparians who derive livelihoods from them (LHDA, 2002a). IFR studies have shown that the current transfer of water will negatively impact on most of these resources, thus affecting the welfare of riparians. In South Africa significant ecological impacts are expected on the ecology of receiving rivers. It is expected that the water from Lesotho will alter water flow, temperature, chemistry and biology of these rivers and the Vaal dam. Ecological impacts of these biophysical disciplines were studied by Chutter et al. (1990) and Chutter (1992, 1998), but were never quantified like in the IFR studies for Lesotho. Nevertheless, the studies revealed several important ecological implications of water transfer within the reaches of these rivers. The major impact is expected to result from increased flow of the rivers, with resultant impact on the inundation of floodplains and wetlands, as well as on the biota of the rivers. Details of the LHWP, including benefits of the project, are provided in Chapter II.

Evidently, the LHWP is of paramount importance because of the significance of the water from the scheme for economic development in both Lesotho and SA, i.e., for industrial and urban development in SA, and hydropower and royalty generation in Lesotho. It is also evident that the water allocated to generate these direct economic benefits carries an additional cost to riparians in terms of loss of benefits from various ecological services due to modified flows of rivers downstream the LHWP dams. While the ecological losses emanating from the project may be small relative to the project's benefits, they may be significant for riparians. It is therefore critically important to value ecological impacts of the project and determine the extend to which related populations are affected by these impacts so that the losses can be mitigated against or compensated to ensure sustainable development.

The LHWP is a huge scheme that affects both the economies of Lesotho and SA. Because of the inter-linkages that exist between sectors directly affected by the project and the rest of the sectors in each country, and the strong economic linkages between the countries, the project is expected to have far reaching income and distributional effects within and between the two countries. In the same token, ecological effects of the project are expected to have economy-wide income and distributional implications within and between the economies of both SA and Lesotho. However, the extend of economic and ecological costs and benefits of water allocated in the scheme and their induced impacts, through multiplier effects, on the wide-economies of the project areas and the rest of the exporting and importing countries is not known. For an important and huge scheme like LHWP, which does not only impact on economic sectors, but also on the ecology of rivers and peoples' livelihoods, it is important to have a holistic management approach and to understand the full implications of allocating a cubic meter of water in the scheme to direct uses relative to indirect uses. This should provide information direly needed by the scheme's managers for informed policy making.

1.3 Study Rationale

The motivation of this study was spurred on two fronts. Firstly, it is important to know the extent of both environmental and economic impacts of the LHWP in the two countries involved. This holistic approach to impact analysis of the scheme is critically important at this point because the other phases of the scheme are yet to be negotiated. The results produced by the study should help the scheme's managers make informed decisions concerning further phases of the scheme.

The second motivation lies in the desire to bridge the gap in the literature. As mentioned, EIAs for inter-basin transfer schemes usually leave out instream ecological effects of such schemes and, as such, decisions on water developments involving diversion of water from streamflows mainly focus on direct economic water benefits, ignoring ecological benefits derived from such flows. Hence, the major objective, and contribution, of this study is to develop a general methodology that can be used to integrate environmental sustainability aspects into economic development in the case of exploiting water resources through inter-basin transfers.

Because the emphasis in this study is on income effects of the LHWP, especially welfare concerns of lost ecological services, the general equilibrium, and especially the SAM, approach is appropriate because the SAM is an important tool for analyzing social and distributional concerns. SAMs emphasise origins and distribution of income, as well as distribution of expenditure. They also emphasize disaggregation of households to study origins and distribution to different socio-economic groups of households. The SAM is particularly important in this study because one of the main objectives is to analyse the extend of ecological implications of the LHWP on the welfare of households. Because most ecological resources are non-marketed, their values are not readily available. Thus, the measurement of ecological values is critical to quantifying values that need to be integrated in the SAM model to develop an integrated environmental-economic model.

1.4 Objectives of the study

The prime objective of this study is to develop a general methodology that can be applied to integrating environmental sustainability aspects into economic development planning in the case of exploiting water resources through inter-basin transfers. Using the LHWP as the case, this study investigates and measures the economic and ecological benefits of the scheme. The study further determines the extent of direct, indirect and induced (through multipliers) effects of economic and ecological impacts of the scheme. To assess the full benefits of the scheme, the analysis covers both Lesotho and the SA.

The following specific objectives are pursued under the prime aim:

- Identify ecological resources that are likely to be affected by modified instream flows of rivers downstream the LHWP dams and their benefits to riparians.
- Using hydrological, ecological, social and economic information from IFR studies, measure the value of water allocated to the production of ecological resources (instream flow benefits) and riparian welfare changes due to modified instream flows.
- Identify the direct economic benefits of the scheme to both Lesotho and SA.
- Develop a broad social cost-benefit-analysis framework that takes into account the combination of all the said effects using a multi-country ecological social accounting matrix (MC-ESAM).
- Use the developed MC-ESAM to analyse the direct, indirect and induced benefits/costs of economic and ecological effects of the scheme on Lesotho and SA.
- Use the MC-ESAM to analyse the distribution of benefits among affected people and countries as well as welfare changes for different income groups and employment categories in both countries.
- To provide benchmark information on the total benefits and sustainability implications of the water resource involved.

- To provide better information for improved management of the LHWP and future water development plans between SA and Lesotho.

1.5 Approach and methods of the study

This study uses the multi-country ecological social accounting matrix (MC-ESAM) to measure economic and ecological effects of transferring water from the highlands of Lesotho to the Gauteng region in SA. Development of ESAM requires integration of ecological values related to water transfer in the SAM. This study adopts the utilitarian approach to valuing ecological resources. This means that only those resources whose change will affect riparian welfare are valued. Productivity/cost measures are used to value those ecological resources that riparians use directly or sell in formal or informal markets, and where instream water serves as an input in their production.

For streamflow health and cultural services, mitigation and transport costs, respectively, are used to value the services. The data for the development of the multi-country SAM comes from the country SAMs of South Africa and Lesotho for the year 2000. Valuation of ecological resources requires information pertaining to hydrological, ecological and biophysical changes resulting from modifications of streamflows. It also requires socio-economic information pertaining to the riparians who use ecological resources and prices of those resources that are sold in the market place. For health and culture related services, mitigation costs of diseases and transport costs to cultural sites are required. This study uses primary data that was collected by LHDA for IRF studies (LHDA 2002a, b, c and d).

1.6 Organisation of the study

The thesis is divided into three parts. Part One gives the general background to the case study area and forms the general motivation of the study and comprises three chapters. Chapter I introduces the study while Chapter II provides background to the LHWP. Chapter III links the study to the existing literature. It comprises review of approaches employed in assessing impacts of inter-basin water transfers: normative, positive and economy-wide approaches. Part Two covers analytical procedures followed in the thesis and consist of 3 chapters. Chapter IV provides a discussion on the general SAM analytical framework. Chapter V develops the model that integrates ecological and economic values, and the ecological social accounting matrix (MC-ESAM) is derived, and finally, in Chapter VI techniques used to value ecological services are discussed. Part Three, which provides the empirical results of the study has three chapters. Chapter VII gives the empirical model for the study area and Chapter VIII presents the empirical results of the study. Finally, conclusions, policy implications and recommendations for further research are given in Chapter IX. References and Appendices conclude the thesis content.

CHAPTER II - THE ECONOMIC AND ECOLOGICAL SIGNIFICANCE OF THE LHWP

2.1 Project area Description

The LHWP is one of the biggest water transfer schemes in the world. The project started in 1986 with the signing of the treaty between the governments of Lesotho and SA. The prime objective of the scheme is to transfer water from the highlands of Lesotho through gravity, to the water deficient Vaal region in SA.

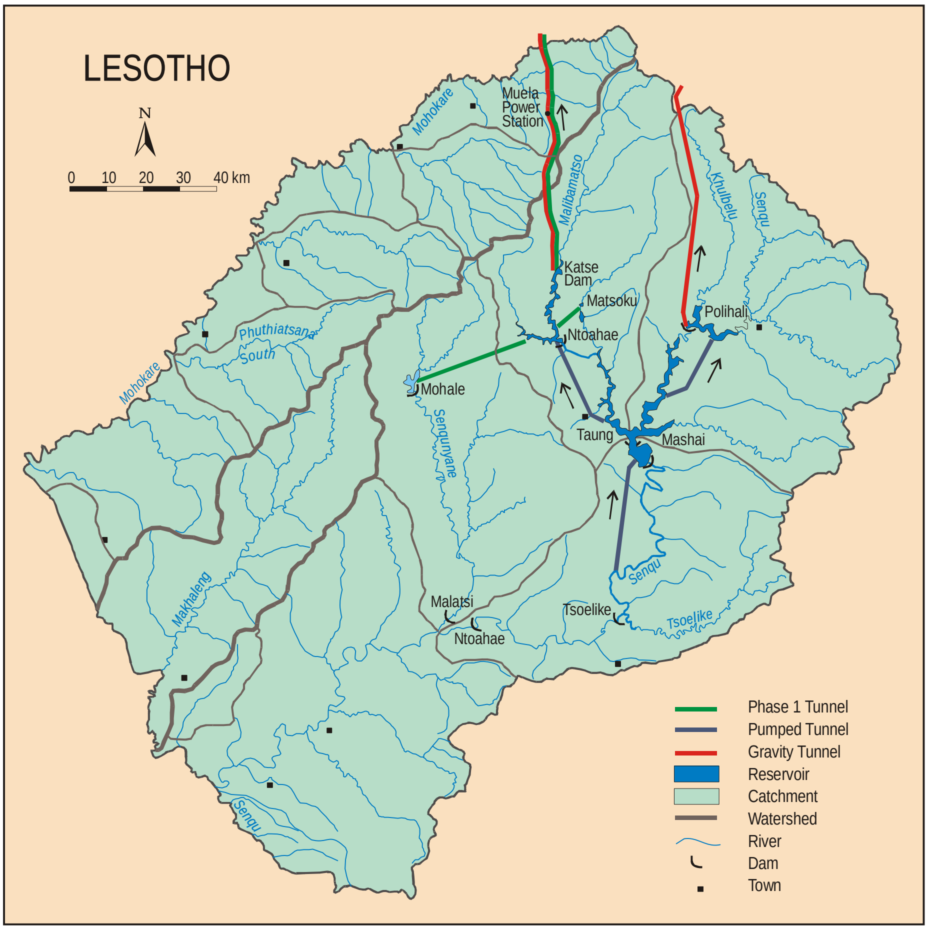
The project consists of an interlinked system of dams and tunnels designed to regulate the flows of the upper Senqu (Orange) River basin in Lesotho, to store water in Lesotho and deliver it to the Vaal River Basin in SA. The river system of the basin, namely, Makhaleng and Mohokare Rivers and their respective tributaries, flow into SA, becoming the Orange River. South Africa could have impounded water from the Orange River within its boarders through the scheme known as the Orange Vaal Transfer Scheme (OVTS). But this water is already too far south by the time it passes from Lesotho to be easily accessible to the Vaal Region. South Africa then found transporting water from the highlands of Lesotho through gravity as a cheap alternative.

Implementation of the LHWP was planned in four phases: phase IA and B, phases II, III and IV. Phase IA comprised of 180m storage dam at Katse site, construction of hydropower scheme within Lesotho, the Muela hydropower plant, with a capacity of 72 megawatts (MW), 45 km gravity transfer tunnel from Katse reservoir to Muela hydropower plant; 37 km gravity delivery tunnel - Trans Caledon Tunnel - from the Muela tailpond to the upper reaches of the As River in SA. This stage of development allowed the transfer of 18 m^3/sec. Phase IA is complete and water is already being transferred to SA, since 1998. Phase IB comprises 140m high storage dam at Mohale site and 30 km long gravity transfer tunnel from Mohale reservoir to Katse reservoir. It also includes construction of a diversion weir on the Matsoku River and a 6 km gravity tunnel connecting the weir and Katse reservoir. Construction of phase 1B has already started and has a completion date of 2004. On completion, this phase is expected to yield 11 m^3/sec of water and about 38 MW of hydropower. In total, the 'Muela hydropower will yield 110 MW of hydropower in Phase 1.

Phase II comprises a 170m high storage dam, a pumping station, a 19 km long conveyance between Mashai and Katse reservoirs and a conveyance system from Katse reservoir northwards to the Vaal River System. The phase is expected to yield 25 m^3/s. Phase III involves construction of a 160m high storage dam at Tsoelike site, a pump station and a 4 km conveyance system connecting Tsoelike and Mashai reservoirs. Incremental yield from this phase is expected to be 10m^3/s. Lastly, phase IV includes 125 m high storage dam at Ntoahae site, a pumping station and a tunnel connecting Ntoahae and Tsoelike reservoirs, with incremental yield of 5 m^3/s. The whole project is expected to provide 70 m^3/sec by 2021, which is the expected date of the project completion. The present Treaty however, commits the two countries to Phase 1 only. Figure 1.1 below shows the layout of the whole project.

The water of Phase I is supplied by the following river system: Malibamatso, Senqu, Matsoku and Senqunyane. From Katse reservoir the water passes through the 'Muela hydropower plant to generate power. Afterwards, the water is transferred by the Trans-Caledon Tunnel into the upper reaches of the As River in SA. From the tunnel outlet, the water flows northwards via Saulspoort Dam, the Liebenbergsvlei River and the Wilge River to Vaal Dam (see Figure 2.2), where the water is impounded for industrial and municipal use in the Vaal region.

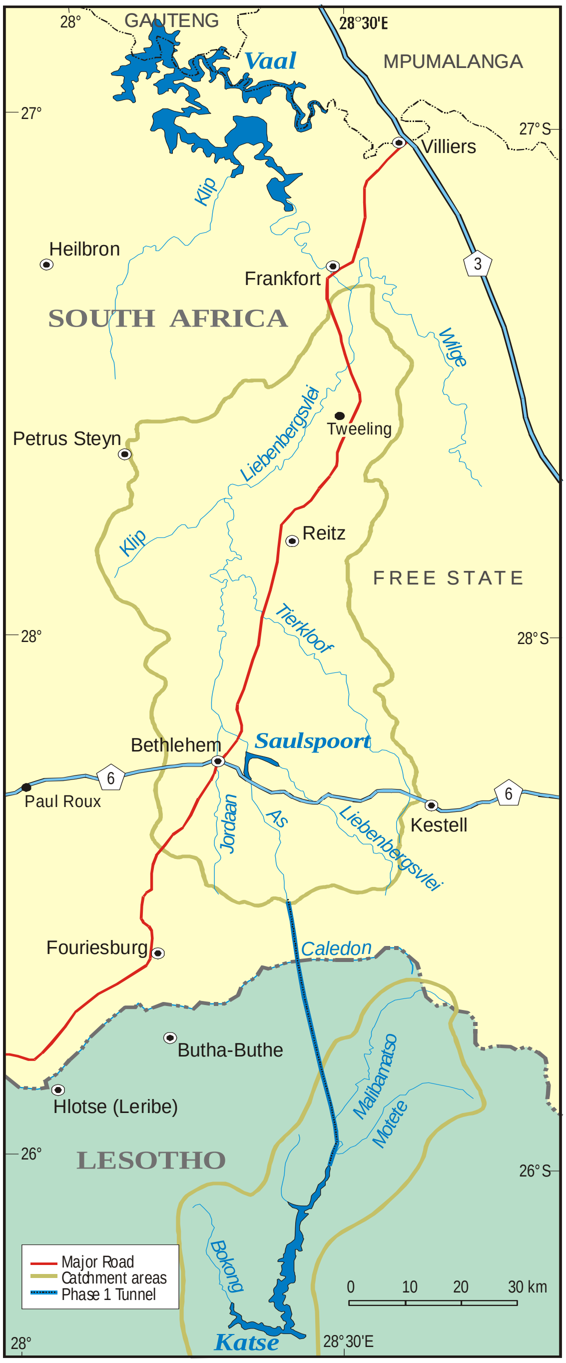
FIGURE 2.1: The Lesotho Highlands Water Project



Source: TAMS Consultants (1996)

The project area includes the main catchments of Malibamatso, Senqunyane and upper Senqu rivers in Lesotho and other areas to the north of those catchments, that are affected by project works in Lesotho and South Africa (see Figures 2.1 and 2.2). The project area in Lesotho falls into two ecological zones, the mountains, and the foothills/lowlands. The main reservoir sites are in the mountain zone. The project area in Lesotho is located in the districts of Butha-Buthe, Leribe, Mokhotlong, Thanbatseka and Qacha's Nek. The population of these districts is reported in Table 2.1 below.

FIGURE 2.2: The river system in SA connecting Katse and Vaal dams



Source: Adapted from Chutter and Ashton (1990)

TABLE 2.1: Population in Project area in Lesotho classified by District and sex

District	Males	Females	Total
Butha-Buthe	38 552	39 6333	78 185
Leribe	89 858	92 614	182 472
Mokhotlong	27 359	28 186	55 545
Thaba-Tseka	32 132	32 915	65 047
Qacha's Nek	50 518	54 085	104 603

Source: BOS (1996)

Land use patterns mainly comprise grazing/grasslands and cropping land, which is characterised by subsistance farming. Traditional form of land tenure prevails under the authority of chiefs. There is communal access to grazing and open water, with arable land traditionally allocated to farmers by chiefs and headmen. Many households are dependent on wage remittances from one or more workers, mainly in South African mines. However, this source of income has been declining over the years with depreciation in gold prices and resultant retrenchments in South African mines. The land in South African portion of the project is primarily used for mixed agriculture. Cultivation takes place in the flatter valley bottoms, while the steeper slopes offer grazing for livestock. The main crops in the area are maize and wheat. All land is privately owned, The largest urban center in the area is Bethlehem which has a total population of aproximately 59 800 (2004 estimates).

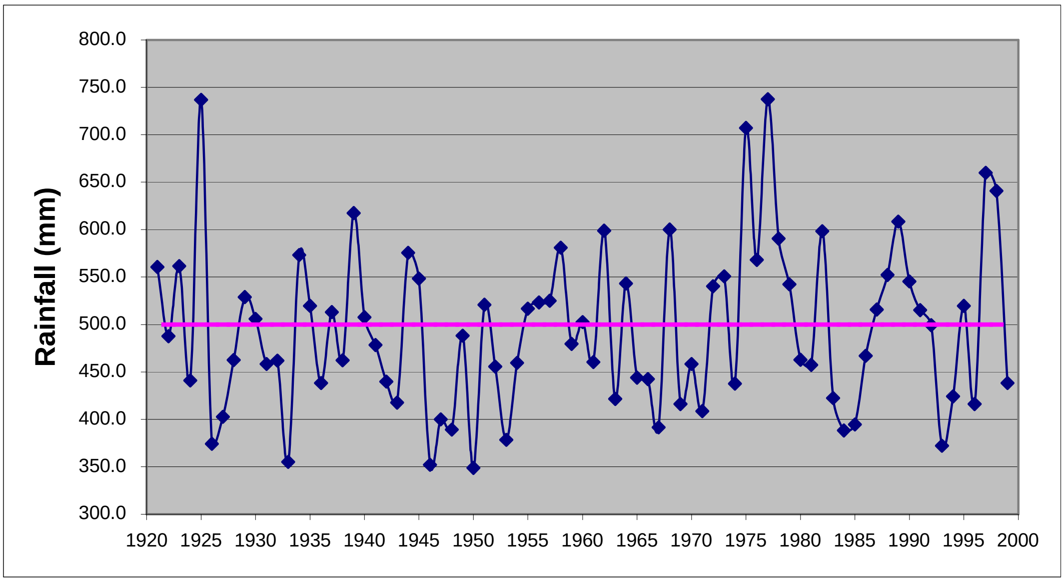
2.2 Water Resources in Project areas

2.2.1 Water resources in South Africa

South Africa is located in the semi-arid part of the world. In global terms, its water resources are scarce and extremely limited in extent. The average annual rainfall is 500mm compared to the global average of 800 mm and it has high temporal (Figure 2.3) and spatial variability. On the contrary, the mean potential evaporation varies between 1100mm to 3000mm, exceeding the annual rainfall substantially (Crafford et al., 2001).

Figure 2.3 shows that South Africa's rainfall is highly variable and unpredictable. In addition to the temporal variation in rainfall, the country has a wide spatial rainfall with the Eastern part of the country receiving the lowest amount (less than 200 mm/year on average), and the Southern part receiving the highest amount (grater than 800 mm/year on average).

FIGURE 2.3: Temporal distribution of rainfall in South Africa (1922 – 1999)



Source: SA weather Bureau (2000) (in Crafford et al., 2001)

This clearly shows an uneven distribution of rainfall, and thus natural water resource availability across the country. Additional to the unpredictable and uneven nature of rainfall in SA is the poor groundwater resources. The country is mainly underlain by hard rock formations which, although rich in minerals, do not contain any major groundwater aquifers which could be utilized on a national scale (DWAF, 1986). As a result of all these water deficient problems, South Africa is classified as a water scarce country. In many parts of the country, available water supply does not meet water requirements[3] (Basson et al., 1997). Table 1.2 shows the water balance picture of South Africa according to geographic regions.

TABLE 2.2: South Africa Water Balance – 1996 estimates (million cubic meters)

Region	River basin	Maximum yield	Water requirements	Balance available
North region	Crocodile/Limpopo	1117	1732	-615
	Olifants	1449	1641	-192
Eastern inland region	Komati	2252	1401	851
	Maputu	2582	919	1663
Eastern coastal region	Umfolozi	1531	933	418
	Tugela	2900	813	2087
	Umgeni/Umzimkulu	4122	1941	2181
	Umzimvubu	2635	934	1701
	Mbashe/Kei	2191	983	1208
Southern coastal region	Great Fish	263	580	-317
	Sundays	164	407	-243
	Gamtoos	801	347	454
	Gouritz	565	434	131
South Western region	Breed/Berg	2508	1891	617
	Olofants/Doring	585	491	94
	Buffels	2	14	-12
Karoo region	Senqu	4481	21	4460
	Orange to Vaal confluence	1533	700	833
	Orange below Vaal confluence	0	1834	-1834
Central Region	Vaal	1789	2029	-240
South Africa		33290	35320	-2030

Source: Adapted from Basson et al. (1997).

From the table it is notable that in many regions water supply falls short of water requirements. On average, South Africa has an annual short fall of 2030 million cubic

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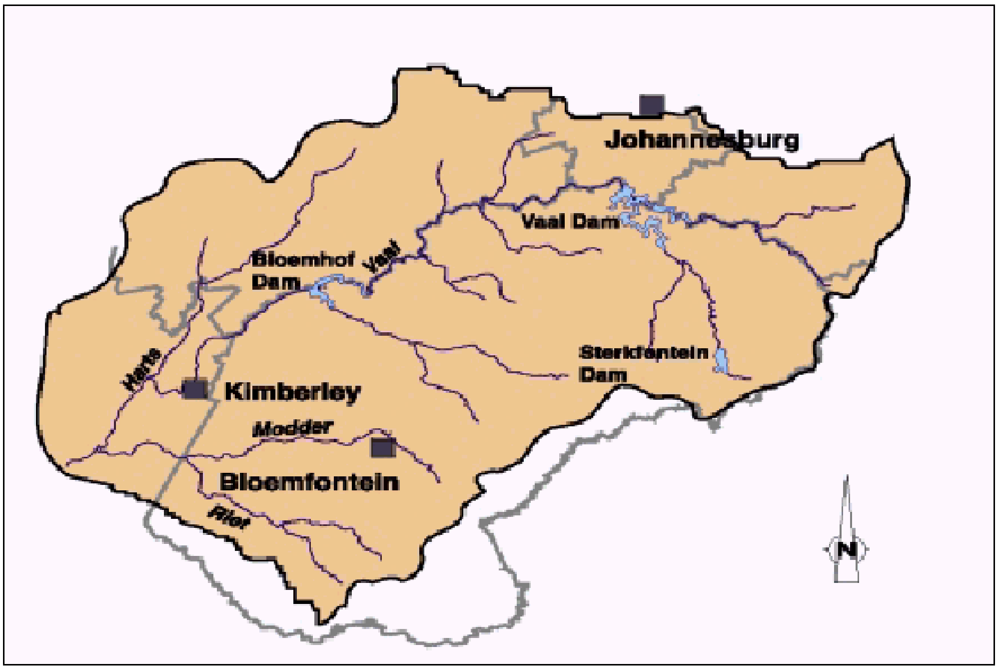
[3] Though it is not clear from the original source what the term 'requirements' mean in the context of water needs in SA.

meters of it's water requirement, and it is estimated that by the year 2030 this figure will have increased to 106.7m^3/s due to population growth and industrial expansion (King, 2000). Because of water deficits, SA has embarked on major dam constructions and inter-basin water transfer projects to augment water supplies in water deficient regions. The inter-basin water transfers and dam constructions have created the storage capacity of about 27 000 x $10^6 m^3$ for the country of which 40% is contributed by the LHWP (CSIR, 1999; King, 2002).

The LHWP is specifically aimed at augmenting water supply in the Vaal basin to specifically supply Gauteng/Vaal region and its vicinity. The Vaal Basin comprises the total Vaal River catchment with its tributaries. It drains part of Mpumalanga, Free State, Gauteng, North West and Nortrhern Cape (See Figure 2.4). The Vaal River is the most developed and regualted river in South Africa and the River System supports about half of the economic activity in South Africa (Basson et al., 1997). The river system is regulated by major dams constructed to provide water resources to different groups of users. These comprise:

(i) Vaal Dam, for serving Gauteng and Vicinity;
(ii) Vaal Barrage, for water quality management;
(iii) Grootdraai Dam, for serving the industrial and mining areas of Mpumalanga;
(iv) Bloemhof Dam, for irrigation purposes;
(v) Sterkfontein Dam, a major reserve storage reservoir fed by pumping from the Thukela River;
(vi) Several other dams on tributaries of the Vaal, for water supply to municipalities and irrigation. These include Saulspoort, Kopies, Boskop, Allemanskraal, Erfenis, Groothoek, Krugersdrift, Kalkfontein, Taung and Spitskop.

FIGURE 2.4: The Vaal Basin Jurisdiction



Source: Basson et al. (1997).

Water use in the basin is currently dominated by irrigation (66 %). By far the dominant growth in water requirements is foreseen in the domestic, urban and industrial sectors and is largely driven by population growth together with the concomitant urbanisation, increased standard of living and services as well as the supporting economic growth and industrialization (Basson et al., 1997). In this respect it is estimated that, should current growth trends and usage patterns prevail, the total requirements for water in these sectors will approximately double over the next 30 years, or will grow at roughly 3 % per annum (Basson et al., 1997). The water balance for the basin without inter-basin transfers is as follows:

TABLE 2.3: Water Balance for the Vaal Region

		1996		2030	
River Basin	Maximum yield (106m3/yr)	Water requirements (106m3/yr)	Balance available (106m3/yr)	Water requirements (106m3/yr)	Balance available (106m3/yr)
Vaal Basin	1789	2029	-240	3830	-2041

Source: adapted from Basson et al. (1997)

Evidently, the Vaal region already has the water deficit of 240 million cubic meters and it is projected that it will have the deficit of 2041 million cubic meters by the year 2030 (Basson et al., 1997). To augment water supply in the Vaal Basin, inter-basin water transfer schemes have been built and these include:

- Thukela-Vaal
- Buffalo-Vaal
- Assegaai-Vaal
- The Lesotho Water Highlands Transfer Scheme (LHWP)

Table 2.4 below shows the amount of water transferred by each scheme. From the Table the LHWP contributes more than 40% of total inter-basin imports and is aimed at supplying Gauteng and its vicinity with fresh water.

TABLE 2.4: Key details of existing Vaal Basin inter-basin transfers schemes

Source basin	Recipient basin	Average current transfer (10^6 m^3/yr)	% of total transfers	Use
Assegaai	Vaal	81	6%	Industrial, domestic
Buffalo	Vaal	50	4%	Industrial, domestic
Tugela	Vaal	630	47%	Industrial, domestic
LHWP 1A*	Vaal	574	43%	Industrial, domestic
Total		1335	100	

*Water from Phase 1B is not yet transferred to SA.

Source: adapted from Basson et al. (1997).

2.2.2 Water Resources in Lesotho

Unlike SA which is water scarce, Lesotho has bountiful water supply. Mean annual rainfall ranges from less than 600 mm in the lowlands to over 1 000 mm along the main mountain ridges. Inter-annual variations in rainfall are significant and are characterized by persistence levels which results in cyclical droughts. The whole country of Lesotho falls within the Orange River basin/catchment and the mountains/highlands of Lesotho provide the source of the basin. Although the mountains/highland region of Lesotho constitutes only about 5% of the total catchment of the Orange River (excluding the Vaal system), it provides about 50% of the total catchment run off. The water originating from the highlands of Lesotho is characterized by relatively good chemical quality and lower sediment content than water originating from other parts of the Orange River catchment (LMC and OSC, 1986).

The distinct geological feature of Lesotho is that all rivers flow in the same South-westerly direction, due to lower strata of sand stone being uniformly laid in a North-easterly to South-westerly plan (TAMS Consultants, 1996). All the rivers flow into South Africa. The thee river basins making up the surface water course system of Lesotho are the Senqu (Orange), Mohokare (Caledon) and the Makhaleng. These rivers leave Lesotho at an elevation of approximately 1 400 meters above sea level. The watershed between the Drakensberg and the Maluti constitutes the headwater of the Orange River, which is the largest catchment in South Africa. The mean annual flows of the river systems are shown in Table 2.5 below. Like the country's rainfall, the river flows are highly seasonal.

TABLE 2.5: Mean annual flow of main river systems in Lesotho

Basin	Mean Annual Flow
Senqu (Orange)	$105.5m^3/s$
Mohokare (Caledon)	$26.5m^3/s$
Makhaleng	$16.7m^3/s$

Source: TAMS Consultants (1996)

Lesotho is also endowed with ground water resources, both dynamic (renewable) and static though this comprises only seven percent of total available water. Despite the fact that Lesotho abounds in water, it only uses a very small percentage of total available water. Table 2.6 below shows water availability and requirements in Lesotho between 1995 and 2025. Domestic consumption in the table (i.e. Rural and Urban) also includes commercial, industrial, schools and government consumption of water. For 1995 data, agricultural consumption figures are also included.

TABLE 2.6: Total water requirements and resources by basin in 1995 and 2025 (m^3/s)

Basin	**1995**		**2025**			**Resource Availability**	
	Rural	Urban	Rural	Urban	Agriculture	Surface water	Ground water
Upper Mohokare and Hololo	0.02	0.07	0.03	0.21	0.00	4.59	0.37
Hlotse	0.02	0.04	0.03	0.15	0.16	8.59	0.38
Middle Mohokare	0.02	0.20	0.03	0.69	0.09	1.39	0.50
Puthiatsana North	0.02	0.04	0.04	0.12	0.11	6.12	0.43
Phuthiatsana South	0.03	0.15	0.04	0.90	0.04	4.79	0.47
Lower Mohokare	0.04	0.05	0.06	0.19	0.01	1.00	0.93
Upper and lower Makhaleng	0.05	0.02	0.08	0.09	0.32	16.71	1.24
Upper Senqu	0.02	0.00	0.06	0.00	0.00	52.00	2.49
Senqunyane	0.02	0.00	0.03	0.00	0.00	24.42	1.11
Middle Senqu	0.02	0.00	0.05	0.02	0.00	18.90	1.09
Maletsunyane, Qhoali, Ketane and Senqu	0.04	0.03	0.08	0.07	0.36	10.18	1.83
Total	**0.29**	**0.61**	**0.54**	**2.44**	**1.10**	**148.70**	**10.83**

Source: TAMS Consultants (1996).

From the table it can be noted that even with future possible water demand, total water demand in 2025 will only be 4.08 m3/s out of the total available water of 159.52 m^3/s. This means Lesotho will only require about three percent of its total water in 2025.

2.3 *Economic significance of the Project*

2.3.1 Economic costs and benefits to SA

The LHWP water is aimed at supplying the Gauteng region, which is the industrial heart of SA. Gauteng is the economic heartland of South Africa. It is formed by the Pretoria, Witwatersrand and Vereeniging (PWV) complex of the former Transvaal. It borders the Northern Province, Mpumalanga, the North West and the Free State to the south. It is spatially the smallest province, covering 21 025 km^2 or 1,7% of the total surface area of South Africa. It's population is 7,8 million (1994 estimates), and it is the second highly populated province after Kwazulu Natal with 8,9 million. It comprises 18% of total South African population. The population grows at 2, 18 percent (1994 statistics) (DBSA, 1998). Despite the fact that Gauteng is the smallest province in South Africa, it contributes the highest to the countries GDP compared to other provinces. In 2000, the province's geographic gross product (GGP) was R303 242 million at current prices compared to the country's GDP of 888 059 million Rands (DBSA 1998). Gauteng therefore contributed approximately 34% to the GDP, which was by the far the largest contribution, with Kwazulu-Natal a distant second at 15,5% (See Table 2.7 below.

Deleted:)

TABLE 2.7: SA Provincial Gross Geographic Product (GGP) for the year 2000

Provinces	GGP	% Contribution
Western Cape	125 957	14,2
Northern cape	72 471	8,2
Free State	17 558	2,0
Eastern Cape	49 225	5,5
Kwazulu-Natal	137 758	15,5
Mpumalanga	64 916	7,3
Northern Province	62 853	7,3
Gauteng	303 242	34,1
North West	54 079	6,1
South Africa	**888 059**	**100**

Source: Statistics South Africa (2002).

Gauteng is the most industrialised and urbanised province in SA. It produces more than 50% of the country's industrial output, and employs more than 30% of the total population (King, 2000). Despite it's importance, the region has few natural water resources (see Table 3). It has been projected that, with industrial and urban demand, the region would be facing a water deficit of 1.8m^3/s by 1995, growing to 106.7m^3/s by 2030 (King, 2000).

Clearly, SA needs more water for continued industrial development and to meet increasing urban water demand. The direct benefits of the scheme to SA are, therefore, water for industrial development and municipal/urban use. SA pays the full cost of the project (R11 billion for Phase 1, current prices), except for the hydropower component. It will also pay an average of US$45 - 47 million per annum in royalties to Lesotho for water delivered by all parts of Phase I (World Bank, 1998). This is equivalent to R0.19/m^3 (1995 prices) (Conningarth Economists, 2004). To pay for the Lesotho Highlands Water Project costs, the Trans-Caledon Tunnel Authority (TCTA), responsible for managing the SA part of the project, sells the project water to DWAF at 69c/m^3 (1995 prices) (conningarth, 2004). SA also benefits in terms of OVTS opportunity cost.

Indirectly, SA benefits from employment opportunities generated by the scheme. Already many South Africans are working in the project as engineers, consultants and in other establishments. The economy of SA is benefiting from increased economic activity spurred by increased project related exports to Lesotho, e.g., more than 80% of the project related exports came from SA (LHDA Annual Reports 1988/89 – 1997/98)

2.3.2 Economic costs and benefits to Lesotho

Economic costs and benefits of the LHWP to Lesotho can be divided into two groups: permanent and transitory/transitional benefits. Permanent benefits are defined as benefits accruing as a result of the water transfer. These include benefits from water sale and hydropower generation, permanent infrastucture and benefits arising from compensation and mitigation programmes for environmental and social losses associated with the project. Transitory benefits relate to benefits which dissipate with the completion of construction activities, e.g., employment creation.

2.3.2.1 Permanent benefits

The primary permanent benefit of the project to Lesotho is water royalties paid by SA. These are Lesotho's share in the 'benefit' of the LHWP. The project's treaty defines the 'benefit' as the opportunity cost of the Orange Vaal Transfer Scheme (OVTS) which would transfer water from Lesotho to SA, but be entirely located within the borders of SA. This opportunity cost is defined as the cost difference between the LHWP and OVTS. According to the treaty, this benefit should be shared between SA and Lesotho on a 0.46:0.56 ratio, and the Lesotho's share is to be paid by South Africa as royalties over a fifty-year water delivery period.

The treaty provides for two monthly royalty components, namely:

- Fixed monthly payments representing the saving in capital costs of the LHWP compared to OVTS. This payment is calculated over the whole project and does not vary with project phases.
- Variable monthly payments in two parts, both being expressed as a rate per cubic meter of water delivered: (i) representing the saving in pumping costs of the LHWP compared to the OVTS and (ii) representing the saving in normal operation and maintenance costs (LHDA, 2003).

The treaty makes the provision that the royalty payments should be indexed to the RSA production price and electricity prices. This ensures that true economic value of the royalty payments is preserved and is not eroded by inflation or devaluation of the Rand. Therefore, SA pays Lesotho a fixed index-linked annuity per month and a variable royalty for each cubic meter of water delivered to SA. The first fixed royalties began in January 1996 and will continue until all project costs have been redeemed and Lesotho' share of the benefit has been paid in full. The variable royalties continue for the lifetime of the treaty, which is indefinite (LHDA, 2003). Table 1.8 below reports royalty payments for Phase IA from the year 1996, when fixed royalties commenced, to the year 2002.

TABLE 2.8: LHWP annual royalties for the period 1996 – 2002 (current million Maloti)

Year	Water Royalties for Phase 1A	GDP	% of GDP
1996	130.5	4 053.7	3.2
1997	81.8	4 719.5	1.7
1998	129.2	4 920.7	2.6
1999	146.9	5 564.9	2.6
2000	153.2	6 238.5	2.5
2001	174.8	6 478.3	2.7
2002	210.5	7 610.7	2.8

Source: LHDA (2003).

Table 2.9 below reports projected royalties for Phase 1A and 1B between 2003 and 2020 in 1995 prices. The Phase 1B royalties were scheduled to commence in 2003 when the transfer of water from the Mohale Dam to SA begins (LHDA, 1997). However, the Mohale Dam was only impounded on the first of November, 2002 and this process is expected to end by the end of 2003. If this happens the water from Phase 1B (and thus royalties from SA to Lesotho) will start flowing on the first of January 2004.

TABLE 2.9: Projected water royalties for Phase 1A and 1B (1995 million Maloti)

Year	Water Royalties for Phase 1A	Water Royalties for Phase 1B	Total Water Royalties for Phase 1
2003	98.5		98.5
2004	98.5	4.6	103.1
2005	98.5	20.8	119.3
2006	98.5	23.4	121.9
2007	98.5	26.7	125.2
2008 – 2020	98.5 annually	29.2 annually	127.7 annually

Source: LHDA (1997)

The water transfer royalties make a direct contribution to total government revenues which will then indirectly have a positive influence (through government expenditures and capital transfer) on domestic income. The royalties bring valued foreign earnings to Lesotho. Already the royalties comprise a large percentage of the government's non-tax total revenue (40% in the second quarter of 2001) (Central Bank of Lesotho, 2001). From this money, a revenue fund (first, the Lesotho Highlands Water Revenue Fund (LHWRF), and second and current, the Lesotho Fund for Community Development (LFCD)) has been established through which employment opportunities are created for local communities, with the prime objective of poverty alleviation. The LHWRF was established in 1991 to channel LHWP proceeds to various social projects in the communities. By 1998 M189 million (current prices) had been committed for community-based public works programs countrywide. This saw 138, 000 people getting employment. However, the fund collapsed due to mismanagement (LHDA, 2003). In 2001 the LFCD was launched with the mandate of implementing the following community-based projects: roads, footbridges, small earth-fill dams, forestry and soil conservation works. To date the total cost of projects approved by the fund exceeds M251 million (current prices).

The other permanent benefit is the hydropower. Water transferred to SA generates hydropower in Lesotho, giving Lesotho some security in electricity. Lesotho used to be a net importer of hydropower from SA before the completion of Phase 1A of the LHWP. The water flowing from Phase 1 will flow through the Muela hydropower station, which for Phase 1 has a rated capacity of 72 MW. On completion, Phase 1B will add about 38 MW of hydropower. Already, Lesotho is enjoying the benefits of locally produced electricity from Phase 1A. On the 11th November 1993, LHDA and the Lesotho Electricity Corporation (LEC) signed a Power Sales Agreement. The agreement allowed the two parties to collaborate in the national interest in installing, operating and maintainig facilities forming part of the hydropower component of the LHWP, and the sale of electricity from LHDA through the 'Muela Hydropower (LHDA, 2003). Since September 1998, when 'Muela hydropower was commissioned, LHDA started selling electricity to LEC. To date LEC has purchased 1, 072, 775 MW of energy from LHDA and this has saved Lesotho about 152 million Maloti in electricity imports (LHDA, 2003). Hydropower sales will have a lasting positive effect on Lesotho's economy, through contributions to domestic factor income and reductions in electricity imports. Other permanent benefits of the project include infrastructure created in support of the project. These include access roads to the central highlands of the country. Key features of permanent infrastructure include roads, housing and services at Katse, Mohale and ‘Muela new towns, electricity power substations and transmission lines, and telecommunications. For Phase 1B alone these amount to approximately M1527 million in current prices (LHDA, 2003). This will be particularly important in the development of regional tourism and commerce.

Tourism has been singled out as one of possible job creation activities in the highland areas of Lesotho by many studies. The road network that has been built because of the project will enhance this activity. Already there is evidence of increased tourism in the project areas. About 3000 visitors visited the Katse Information Center every month during the Katse Dam and site construction phase (LHDA, 1997). Phase 1B construction site has also been receiving number of tourists over the years. Table 2.10 below shows the number of tourists visiting the Mohale construction area from 1998 to 2001.

TABLE 2.10: Number of tourists that visited the Mohale Construction Area

Year	1998	1999	2000	2001	Total
Number of tourists	2324	7191	7626	10393	27534

Source: LHDA (2003).

Projects of this magnitude often result in enormous environmental and socio-economic losses to people residing in project areas. The final category of permanent benefits emanate from expenditures on compensation and mitigation programs aimed at environmental and social impacts of the project. The main socio-economic losses associated with the project were land, houses and other economic resources. To mitigate against these losses, both short- and long-term measures were taken. Short-term measures included direct compensation of households and communities for lost productive assets. On the other hand, long-term measures were aimed at facilitating the development of alternative sustainable livelihoods for affected communities and households. Three programs were used to achieve this:

- Production program – including livestock and range management, mountain horticulture, fisheries, forestry and land-use-planning

- Education program – including skills and income generation training and the establishment of necessary facilities.
- Infrastructure program – including feeder roads and reservoir crossings, water supply and rural sanitation, construction communities, and visitor information and tourism. Already, M241 million (current prices) has been spent on resettlement, compensation, development, and public health programs related to Phase 1B only (LHDA, 2003).

Additionally, the people of Lesotho have also benefited in terms of training and capacity building. Skills developed by workforce during construction period will permanently improve employment prospects and earning potential of the workforce. Rural Skills Development Program has been established to enhance skills and employment potential of people directly affected by the project in the project areas. Beneficiaries of this program will acquire skills that are expected to sustainably raise their income earning potential. Benefits arising from environment and socio-economic changes will also accrue to people directly affected by the project in project areas.

2.3.2.2 Transitory benefits

Transitory benefits are short-term and occur during the construction phase, which then dissipate following completion of the project. The most important transitory (transitional) benefits are labour earnings and government revenue through project related SACU receipts, both of which contribute to Lesotho's economic growth. A study that was commissioned in 1996 to analyse the economic impact of Phase 1A, and to make projections for Phase 1B, came up with the following important findings:

- Phase 1A accounted for about 14% of Lesotho's GDP and 400 % of value-added in the building and construction sector in 1994.
- Government revenue increased. In 1994 alone the government experienced a surplus of 156.3 milliot Maloti (1995 prices) compared to 136.6 million Maloti (1995 prices) deficit that the government would have realised without the project. The study estimated that this would have balloned to nearly 800 million Maloti (10.9 % as large as GDP) by the year 2002.

- In 1998 when Phase 1A rounded up, the project accounted for 13,6 % of Lesotho's GDP, 13% GNP, 35.3% value-added in building and construction and 27.8 % in government revenues (Dogget, 1996).

The microeconomic impact study of Phase 1B by the LHDA, Economics section, showed that the phase has created 8 000 jobs, amounting to 22 000 person years, while M250 million (current prices) worth of contracts and sub-contracts have been awarded to Basotho companies according to preliminary figures up to December, 2000 (LHDA, 2003). In 1998 Phase 1B accounted for 6.5 % of the county's GDP, 5.6 % of GNP and 21.4% of value added in the building and construction sector. Additionally, the Phase accounted for 7.4 % in total government revenue. Table 2.11 below summarises these benefits for the years 1998 and 2002.

TABLE 2.11: Phase 1B impact on Lesotho's macro-economy

Item	**Amount accounted for by Phase 1B (millions of 1995 Maloti)**		**Economic share due to Phase 1B (%)**	
	1998	**2002**	**1998**	**2002**
GDP	260.2	183.0	6.5	3.9
GNP	290.4	178.1	5.6	3.6
Building and construction	178.1	111.7	21.4	12.3
Government revenue	144.4	196.5	7.4	9.3

Source: Adapted from LHDA (2003).

2.4 Ecological Implications of the project

2.4.1 Introduction

Section 2.3 has demonstrated important economic benefits of the LHWP. However, as explained in the introductory chapter, the natural water in stream/rivers has important ecological benefits and if inter-basin water transfer developments compromise the ecological reserve for water, the result may be deleterious effects on the ecological resources and services. This may be true for both the exporting and importing rivers of the development. This section discusses ecological implications of the LHWP in both the exporting and importing countries (i.e., Lesotho and SA, respectively).

2.4.2 Impacts in the exporting country (Lesotho)

IFR studies conducted by LHDA have demonstrated that downstream the Orange River system in Lesotho is a host of ecological resources, which depend on instream flows of the river system (LHDA 2002a and b). The studies demonstrated that grasslands and shrublands, with occasional wetlands, dominate the vegetation. Vegetation zones along the rivers typically have a higher proportion of woody vegetation consisting of both indigenous and exotic species. In general, the following non-cultivated resources are found:

(i) Thatch grass provides an important thatch material for highlands riparians.

(ii) Crafts grass is used by riparians either to make a variety of crafts or sold unprocessed to crafts' makers.

(iii) Wild vegetables are eaten or sold in urban areas by riparians.

(iv) Shrubs and debris comprise an important source of fuel for riparians.

(v) Trees are used by riparians for construction and fuel purposes.

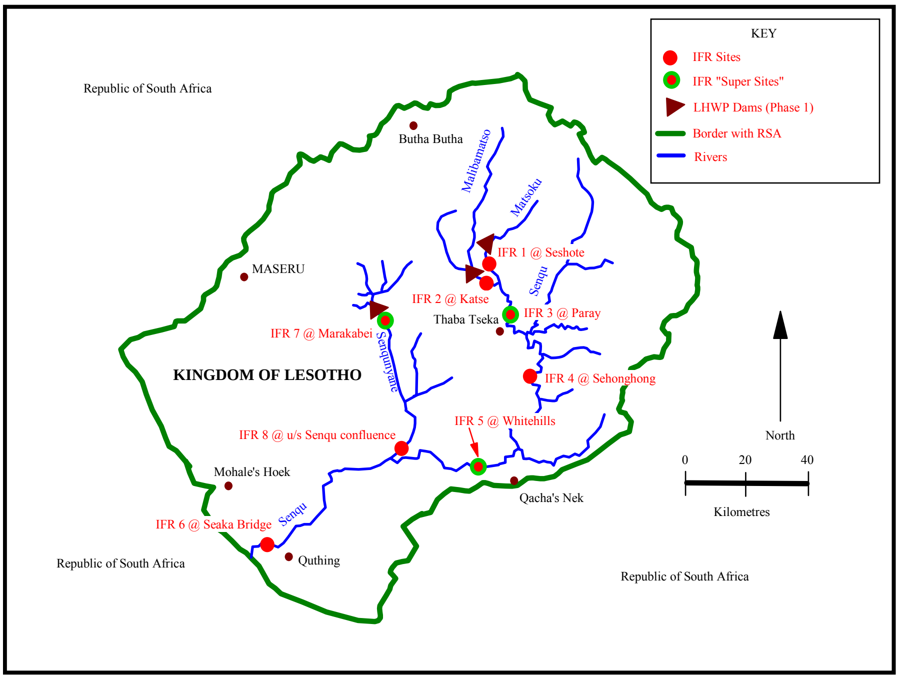
(vi) Medicinal plants are used locally by riparians, or traded regionally (i.e., in Lesotho, or in SA) (LHDA 2002c).

Other than vegetation, wildlife communities are found and are highly distinctive with several endemic species, though densities are low due to heavy exploitation (LHDA 2002a). Instream the river system, different varieties of fish (Smallmouth Yellowfish, Rock Cat Fish and Rainbow Trout) are found. These provide an important source of protein to riparians.

The human population downstream of the LHWP structures (i.e. dams and weirs) within Lesotho is about 155, 000. Most of these people live in small villages, with a small proportion living in larger settlements such as Marakabei. Lack of formal education and high unemployment are characteristic of most communities. Rural people are heavily dependent on ecological resources for their livelihood, while foreign employment (South African mines) represents an important but declining source of income. The value of ecological resources and services used by the human population downstream the dams was estimated to be R46.3 million annually (2000 prices) (LHDA, 2002d).

Cultivated agriculture is another important source of livelihood though agricultural lands are constrained in size by topography and soil depths. Figure 2.5 below shows areas in the villages likely to be affected by modified river flows downstream the LHWP dams in Lesotho. These are areas labeled IFR sites in the map.

FIGURE 2.5: Areas affected by modified river flow downstream LHWP dams



Source: LHDA (2002a).

The IFRs study (LHDA, 2002a) identified several biophysical impacts of the modified flows of the Upper Orange River system as well as the Population At Risk (PAR) as a result of the project. IFRs study covered impacts on the vegetation, fishery, geomorphology, hydrology, hydraulics, and water quality. The IFRs biophisical component of the study revealed that the biophysical changes identified will lead to reduction in a significant number of the ecological resources identified above, thus leading to a welfare loss to riparians. It is therefore critically important to value ecological losses of the LHWP to determine the extend to which the project will erode the riparians welfare.

2.4.3 Impact in importing country

Significant ecological impacts are expected on the As, Liebenbergsvlei and Wilge Rivers and Saulspoort Dam. The additional water from Katse Reservoir is expected to alter the flow, temperature, chemistry and biology of these rivers and dams. The ecological impacts of these biophysical disciplines were studied by Chutter and Ashton (1990) and Chutter (1992, 1997), but were never quantified as in the IFR studies for Lesotho. Nevertheless, the studies revealed several important ecological implications of water transfer within the reaches of these rivers. The major impact is expected to result from the increased flow of the rivers, with resultant impact on the inundation of floodplains and wetlands, as well as on the biota of the rivers.

The As and the upper Liebenbergsvlei River valleys have narrow floodplains which are often inundated during floods. These floodplains and wetlands contribute significantly to agricultural productivity in the valley, and also serve as an important habitat for wild vegetation and animals (birds). There are also several wetlands located in the Liebenbergsvlei valley, which are important in the ecology of the Highveld geese and duck. Jackson (1987) estimated that about 50% of the spurwing goose and 40% of the yellow bill duck and Egyptian goose populations of the whole Highveld mould are in the Eastern Orange Free State, which is where these wetlands are located. It is expected that increased flows of the As and Liebenbergsvlei Rivers will lead to high erosion of the river beds and this will alter the flows necessary to inundate riparian floodplains and will probably destroy existing wetlands (Chater et al., 1990). The increased flows are also expected to increase the size of the rivers, which is expected to impact positively on the diversity of riverine biota. Rainbow trout, and other riverine plant and animal species present in both the Malibamatso and Nqoe Rivers in Lesotho are expected to be transferred through the Trans Caledon tunnel to the As River. This is expected to displace the present fauna further downstream, but no major negative impacts on the indigenous fish are expected from this change. While it is equally important to estimate ecological values in this case, the estimation is not performed since the corresponding biophysical changes have not been quantified. The next chapter reviews literature related to this study.

CHAPTER III - REVIEW OF RELATED LITERATURE

3.1 Introduction

Interbasin water transfer (IBWT) projects have been used to transfer water from water abundant to water deficient areas/regions since about 50 years ago. The transfers are mainly aimed at augmenting supply to meet offstream demands for water in agriculture, industry, hydropower and household sectors with ultimate objective of boosting economic growth and society's welfare in water deficient regions. Accordingly, the economic and social desirability of such transfers have been traditionally based on the direct net benefits realized in offstream uses that the transfers are planned for. One problem with this approach to evaluating IBWT projects is the fact that it does not consider the economy-wide (indirect) effects of these changes. Moreover, such transfers can leave insufficient water to support the many instream ecological services of water in the exporting area. Instream water services include sustenance of ecosystems by regulating floods, water chemistry, temperature, quality and logging as well as sand deposists within rivers; and by supporting survival and growth of aquatic resources like fish and wild vegetation among others.

The external ecological costs associated with altering the volume and quality of water within a basin due to the transfers are often ignored. Even when included, they are usually done as adhoc assessments once the transfers have been implemented (e.g. LHDA, 2002a). This situation is perhaps due to the challenge involved in evaluating instream benefits of water. While it is relatively easy to evaluate offstream benefits of water typically used for producing marketed commodities, it is difficult to evaluate instream benefits because many of the involved ecological services of water are usually not traded in markets (Hassan and Lange, 2004; Freeman, 1991; Acharya and Barbier, 2000). Accordingly, the literature on assessment of IBWT can be grouped into the following four approaches:

(i) Studies evaluating net benefits of IBWT based on direct offstream uses of water in the importing region

(ii) Studies that consider indirect economy-wide impacts of changes in offstream supply and use of water as a result of IBWT

(iii) Studies evaluating external net benefits of ecological uses of water in the exporting region, and

(iv) A more recent thread of the literature representing studies that integrate instream with offstream net benefits of water in the importing and exporting regions

This chapter reviews the literature on the above listed four approaches to assessing IBWT and motivates modifications required to improve impact assessment of IBWT by integrating instream with offstream implications of such transfers into an economy-wide framework. Sections 3.2 and 3.3 review the literature on assessing direct and total (economy-wide) offstream effects of IBWT, respectively. In Section 3.4 the literature on assessing instream uses of IBWT is reviewed. Finally, Section 3.5 discusses the literature on studies that integrate instream with offstream benefits and costs of IBWT and provides the motivation for an integrated ecological-economic approach to assessment of IBWT through an economy-wide analytical framework to be adopted in this study.

3.2 Approaches to assessing direct offstream impacts of IBWT

The literature on IBWT schemes goes as far back as 50-60 years ago when the relatively older IBWT schemes were constructed in the United States and Australia. The fact that IBWT schemes were developed to meet water demand deficits in economic sectors has influenced the literature on the benefits of IBWT to be biased towards off-stream uses of water. As a consequence, the value of water in traditional off-stream uses is well documented, which include irrigated agriculture, industry, hydropower generation and household uses (Hassan & Lange, 2004; McKinney et al., 1999; Young, 1996; Gibbons, 1986). The earlier approaches only considered the direct impacts of IBWT on sectors that the transfers were intended for. Cost-benefit analysis (CBA) was the most common technique of project evaluation employed in assessing IBWT projects.

The CBA compares the discounted potential costs to benefits of IBWT and determines whether potential economic benefits of IBWT projects outweigh its costs, in which case the project is recommended for implementation (Gittinger, 1982). The costs normally consist of construction, operation and maintenance, relocation where people have to be relocated from project areas, opportunity cost of the land to be inundated, environment destruction as a result of a project and other costs associated with the schemes. Benefits usually include the value of tangible contribution to sectors the schemes are intended for, e.g. hydropower generation, flood control, irrigation, municipal and household water use. Most of the literature on CBA analyses of IBWT is found in unpublished technical feasibility studies and consultants reports, which are not easily accessible. A few examples of IBWT are provided below to show how CBA wass used in assessing IBWT.

Examples of IBWT include the old early 19th Century schemes in the US and Australia. In the US, examples include California, which has a variety of federal, state, and local IBWT developed over the past 85 years to meet rapidly growing demand. In 1913, the city of Los Angels built a 233-mile aqueduct to transfer water from the Owens valley in eastern Sierra Nevada. In 1937, a Central Valley Project (CVP) was funded by the federal government to divert water from the Sacramento-San Joaquin river delta to southern California (Howe and Easter, 1971). The scheme comprised 20 reservoirs, 11 power plants, 3 fish hatcheries, and 500 miles of canals. In a normal year, the scheme delivers 7 million acre-feet of water to irrigate 3 million acres of farmland and supply 2 million urban customers (Hirji, 1998). The CVP facilities were primarily constructed for river regulation, navigation, and flood control, but they also provide power generation and recreation.

The CVP was supplemented in 1960 by the State funded State Water Project (SWP), comprising 22 dams and reservoirs and a 444-mile aqueduct from the northern to the southern part of the state. Thirty percent of water from the scheme is used for irrigation in the San Joaquin Valley and 70 percent for residential, municipal, and industrial needs in the south (Howe and Easter, 1971). The benefits included in CBA analyses of these schemes focused on the improvement of the welfare of the farming communities, and the growth of cities and industries, as well as conservation benefits associated with relieved pressure on depleted groundwater aquifers, which had caused severe land subsidence.

In Australia examples include the Snowy Mountains hydroelectric scheme, which was constructed between 1949 and 1974. The scheme uses 16 major dams, 7 power stations, a large power pumping station, 245 km of tunnels, and 80 km of aqueducts to collect and divert 98 percent of the inflows to the Snowy Mountains into the Murray and Murrumidgee rivers for agricultural productivity and to meet urban demand in southeast Australia, including Sydney and Melbourne (Hirji, 1998). The CBA of this scheme assessed its benefits in terms of contribution of the scheme to annual energy requirements of southeast Australia and contribution of the scheme to agricultural productivity, regional output, income and employment. For example, the scheme meets 5 percent of the southeast's total annual energy requirements and provides 10-33 percent of flows in the Murray and 25-30 percent or regional output, income, and employment (Hirji, 1998). Like in the case of California, The CBA for this scheme did not derive the value of the water from the scheme for the multiple uses it was intended for.

These schemes were constructed at the time when there was little concern about the environment. As a consequence, their economic worthiness was based only on CBA analyses that did not pay much attention to ecological consequences of the schemes (Hirji, 1998). The result was serious unforeseen ecological consequences related to the schemes in all cases (see Hirji, 1998; and Howe and East, 1971 for details). To avoid this problem, today the economic viability of IBWT is also based on environmental impacts assessments (EIAs), which form an integral part of CBAs. EIAs may be defined as a formal process used to predict the environmental consequences of IBWT. They identify and measure all environmental costs of IBWT for inclusion in CBAs. EIAs therefore became an essential input to CBAs and the two assessments are complementary. As such, EIAs ensure that the potential environmental problems are foreseen and addressed at an early stage in the IBWT planning and design. More recent IBWTs have benefited from EIAs. Examples from developing countries include the Wanjiazhai Water Transfer Project (WWTP) in

China constructed in 1998 and the LHWP in Lesotho, Southern Africa constructed in 1987.

The WWTP entailed construction of a large dam and a water transmission facility, as well as institutional reforms, pollution control measures, and an industrial waste management and waste wastewater collection and treatment strategy. The project's main aim was to supply the water stressed province of Shaxi in China by improving the water quality and supply and reducing groundwater overdraft and saltwater intrusion into coastal cities, in order to enhance economic growth and relief human distress in the province (Hirji, 1998). The LHWP was aimed at transferring water from the Highlands of Lesotho to the Gauteng province in SA. Details of this project have already been discussed in Chapter II. Both schemes benefited from CBA and detailed EIAs. Despite the advantage of the EIAs that these schemes had, ecological implications of the schemes associated with modifications of the river flows downstream the project dams were not included in the EIAs before the implementation of the projects (Hirji, 1998; LHDA, 2002a). Other IBWT examples from developing countries, drawn from SA, include the Komati scheme that transfers water from the Komati basin to the Olifants River Catchment to supply Eskom electricity power stations, and the Tugela-Vaal scheme that transfers water from the Orange river in the central parts of the country to the Sundays river in the eastern part of the country for irrigation purposes (Basson et al., 1997).

Like in the case of CBA analyses of the older schemes, assessments of above IBWT focused on tangible benefits in terms of economic growth and social development and not necessarily the value of water being transferred. Thus, CBA studies in the IBWT examples given above primarily compared the costs of IBWT projects to the tangible economic benefits generated by the various uses of the extra water supplied by these projects. The main purpose of such studies was not the determination of the value of water, but rather to calculate the economic worthiness and viability of planned IBWT projects and the economic activities to be supported. Because of the growing water scarcity world-wide and increasing costs of IBWT, as well as heightened interest in natural resource preservation, it has become important to measure the economic value of water to better understand the demand behavior of its users. Understanding the demand behavior of water users provides useful policy information to guide decision-making and strategic planning for IBWT and allocation of water resources towards the goals of efficiency, equity and environmental sustainability (Hassan and Lange, 2004; McKinney, Cai et al., 1999; Young, 1996; Gibbons, 1986).

The following sub-sections give an overview of the literature that has been dedicated to valuing and studying demand patterns in competing off-stream uses to assist water management and allocation decisions achieve their economic efficiency and other societal goals. Two analytical methods, positive and normative models were employed to evaluate water values and characterize patterns of demand for water. Positive models attempt to provide pragmatic explanation of water use patterns based on observed water demand and supply behavior information, employing econometric techniques for specification of demand and supply functions. These models are typically structured on the basis of underlying microeconomic theory of the behavior of water users and suppliers. On the other hand, the normative models are premised on assumptions, and judgments simulating respective demand and supply decision situations and commonly employing mathematical programming techniques to solve the simulated optimization decision problem.

3.2.1 Positive approaches to the assessment of IBWT impacts

Market- and non-market-based approaches have been used in the literature to value water in different offstream uses. Market-based techniques include: direct estimation of water value from observed water prices, the sales comparison approach, the land-value differential approach, the least-cost alternative approach, the production function approach, the residual value method and change in net income approaches (Hassan and Lange, 2004; McKinney, Cai et al., 1999; Young, 1996; Gibbons, 1986). In the direct estimation of water demand functions, observed prices and quantities of water are used to derive water demand functions, which are then used to measure the marginal value of water, or total value from consumer and producer surplus. Demand functions were used to analyse water users' behavior and infer various demand elasticities. Gibbons (1986) and Schneider and Whitlach (1991) have summarized substantial literature on estimation of household demand for water.

More recent studies estimating demand for water include those by Lyman (1992), Hewitt and Hanemann (1995), and Dandy et al. (1997). Arntzen et al. (2000) also used direct estimation of demand functions for water use in urban households of Botswana. Examples in South Africa include King (2002), Dockel (1973) and Veck and Bill (2000). King (2002) applied econometric techniques to cross-sectional and time-series data to directly estimate demand functions for water use in small agricultural holdings, households and industry in the city of Tswane. Dockel (1973) applied the macro-econometric model to cross-sectional data to estimate demand functions for water use in households for Alberton and Thokoza residential areas of Johannesburg, and Veck and Bill (2000) repeated the study, using the econometric approach, to estimate demand function for water use in Thokoza. However, their results were not statistically significant.

In impact assessment of water transfers, the direct estimation of water value from demand functions was applied to the case of Zambesi River. Hoekstra et al. (2001), Seyam and Hoekstra (2000), Chapagain (2000), Seyam et al. (2001) introduced the "value flow concept" for water in river basins where the analysis of water value is integrated with the whole water system rather than considering only *in situ* direct values of water. In this approach, water valuation is not only limited to water value at the spot where it creates a direct benefit, but also includes indirect benefits (i.e. values generated downstream) of water. Hoekstra et al. (2001) and Chapagain (200) employed measured demand and supply functions to determine the total value of water used up- and down-stream the Zambesi River as the sum of producer and consumer surpluses. Their value calculations were carried out on annual basis and had a static character. Seyam et al. (2000) extended this methodology in two later studies to include the dynamics of the water system within a year, thus allowing the assessment of values on a monthly basis. Seyam et al. (2001) extended this model by showing how water system dynamics can in various ways affect the value of upstream water. Both attempts to model water dynamics however, were theoretical and lacked empirical applications.

In the sales comparison approach, the value of water is estimated by real estate appraisal techniques that link water rates or fees exacted for water diverted for residential purposes to the market value of purchasing or selling water rights (Saliba and Bush, 1987). The sales comparison method compares the price of a particular water right to the prices of similar rights that had been recently sold in the market. This method of calculating water values results in a band or range of prices within which the value of the water right could possibly fall. The approach is often used in pricing municipal and irrigation water (Saliba and Bush, 1987, Moncur and Pollock, 1988; Young, 1996; McKinney et al., 1999). This approach is similar to the land-value approach, in which case the value of the water right is calculated as the difference in land values between land with and without access to water or rights (McKinney et al., 1999).

The least-cost alternative method hinges upon water development investments. The value of water supply scheme is estimated as the cost of the next best alternative water supply infrastructure. Alternatively, the value of existing water supplies is estimated as the cost of developing new water supplies. This is the opportunity cost-based approach. It estimates the equivalent costs of an alternative or alternatives to acquiring the rights to already developed water supply systems. These costs can be derived from the costs of recycling of water or construction of a new water supply. The approach is commonly used in pricing water for industrial purposes and in hydropower production, but can be extended to municipal uses if it can be established that consumers would be willing to buy water at the prices equivalent to the costs of developing new water source (Saliba and Bush, 1987; Moncur and Pollock, 1988; McKinney, 1999).

Where input demand for water is not directly observable (i.e. no data on purchases of water at different prices), but water enters the production process as intermediate input, the production function approach is used to estimate the value of water in production (Hassan and Lange, 2004; Young, 1996; Freeman, 1993). In this case the quantity of water used in production is combined with other relevant data to estimate the production function of the product in question to deduce the marginal value product of water. This technique is mainly used in irrigated agriculture and industry. Pazvakawambwa and van Der Zaag (2000) used the production function approach to estimate the value of water in maize production in the Nyanyadzi smallholder irrigation scheme, Zimbabwe. The production function which included maize yield, rainfall, irrigation water and soil moisture status, was estimated using econometric techniques generating marginal value of water estimates of US\$0.15/m^3 for total water and US\$0.19/m^3 for irrigation water.

Acharya and Barbier (2000) also used the production function approach to value the Hadeija Nguru wetlands in recharging aquifers that supply irrigation water to local communities during dry seasons. The authors estimated the total value of these wetlands at Naira 5.5 million for an average farmer in the production of wheat and vegetables collectively. The production function approach has also been applied to the valuation of industrial water. Examples include Wang and Lall (1999) who applied this method to value water in industrial production in China and Renzetti (1988 and 1992) who estimated the value of water in industrial production for British Columbia and Canadian manufacturing firms, respectively.

Like in the production function approach, the residual value method is also used to measure the value of water as intermediate input in production. However, in this case data on price and quantity of water required for direct estimation of water demand functions as well as physical quantities of inputs and output to support production function estimation are unobservable. This method uses only data on production costs and revenue to determine a shadow price for water calculated as the difference between the total value of output (TVP) and the costs of all non-water inputs to production (see Hassan and Lange, 2004; Young, 1996 for details). Examples of studies that applied this approach include Bate and Dubourg (1997), who estimated the residual value of irrigation water in 5 crops in East Anglia from 1987 to 1991 using budget surveys' data. The estimated value of water ranged from 13.45 – 1428.84 British Pounds per hectare for the 5 crops included in the analysis (winter wheat, barley, oilseed rape, potatoes and sugar beet). Schiffler (1998) calculated residual value for fruit and vegetable crops in Jordan, also based on farm budget surveys at 0.714 Dinar/m^3 in fruit crops and 0.47 Dinar/m^3 in vegetable crops. MacGregor et al. (2000) used the residual value method to value irrigation water from the Stampriet Aquifer in Namibia, deriving an estimate of N\$0.67/m^3 (where N\$ stands for Namibian dollar).

The change in Net Income (CNI) approach measures the change in net income resulting from a change in water input. The approach is often used to compare the value of water under present allocation to the value that would be obtained under alternative allocations of water (Hassan and Lange, 2004). Louw and Schalkwyk (1997) used the 'change in the net income' approach to value irrigation water in the Olifants River Basin in the Western cape, South Africa. In this case study water is transferred from the Olifants River to irrigate about 21 503 ha of land. The value of irrigation water was calculated as the difference between net value of agricultural output with and without irrigation divided by the amount of water transferred to agriculture. The value of water was calculated as R9 474 per ha.

The non-market approaches to valuation of water include inferential valuation or revealed preference methods and stated preference or contingent valuation methods (CVM). In the inferential valuation approach, the value of water is inferred from the behavior revealed by water users where the value is imputed from implicit prices such as expenditures incurred by individuals to use water, e.g. travel cost (typically applied to assess the value of water quality and recreation-based benefits but can also be used to estimate the value of residential water to consumers). Inferential valuation also employs the hedonic methods (Cropper and Oates, 1992).

The inferential valuation method relies on the notion that the price of marketed goods can be decomposed into its attributes, and that an implicit price exists for each of these attributes. The approach is often used for the aesthetic or quality valuation of water resources. Irrigation water supply has also been valued using this approach, through estimation of the effect of availability of water on the value of farmland (Young, 1996). Another method is mitigation/averting/avoidance/defensive costs, expenditures or technology, mainly used to value water quality. This method relies on the fact that in some cases purchased inputs can be used to mitigate negative environmental effects. For example, farmers can increase the irrigated area and other inputs used to compensate for yield decrease due to salinisation and consumers can take actions to avoid drinking polluted groundwater or mitigate the health effects of poor quality of water. In this case the value of water is estimated by the value of inputs used in mitigating water quality changes (Cropper and Oates, 1992; Lee and Moffit 1993).

Stated preference or CVM approach to water valuation elicits direct responses of potential users to structured questions regarding the amount they are willing to pay for water services. Examples include Thomas and Syme (1988) in which the CVM approach was used to derive the marginal value of residential water in the Perth metropolitan area of Australia and Veck and Bill (2000) who used CVM to estimate the marginal value of residential water in Thokoza and Alberton residential areas of Johannesburg, South Africa. Another approach similar to CVM is conjoint analysis which, unlike the CVM, focuses on the resource's attributes, e.g. water quality. Details of these techniques can be found in Hassan and Lange (2004), Mckinney et al. (1999), Young (1996), Gibbons (1986). The positive approach to valuation of water requires data which are often not available and hence econometric techniques can not be applied. This is when the normative approach is useful and can be used to estimate water demand functions under different policy and institutional settings than have historically existed.

3.2.2 The normative approach to assessment of IBWT impacts

The normative approach uses mathematical programming optimization techniques to value water with various forms of the supply and demand functions of water generally embedded within an optimization framework determining efficient allocation of water between different offstream uses. The general feature of optimisation models is to specify an objective function (usually profits or benefits maximization or cost or loss minimization) subject to several constraints including production functions, water availability, and other institutional and behavioral constraints. Optimisation models may be applied to one sector, for example agriculture in which the objective may be to determine optimal allocation of water between different crops or to a number of sectors within a water basin in which the objective may be to determine the optimal allocation of water to different water users within a basin.

IBWT have predominately been aimed at supplying water for irrigation purposes. As a result, most of available literature employed mathematical programming techniques to assess benefits of IBWT in irrigated agriculture. Most of reviewed studies focus on multiple crops. The common objective in this case has been to determine the optimal reservoir releases' policies and irrigation allocations to multiple crops (Vedula and Kumar, 1996; Vedula and Mujumdar, 1992; Dudley and Scott, 1993, Bryant et al., 1993). In all cases stochastic dynamic programming (SDP) approach was used in which reservoir release and field water allocation decisions were integrated in a modeling framework, taking into account soil moisture dynamics and crop growth at the field level. Reservoir inflow and precipitation were considered stochastic, and water allocation among multiple crops included.

Vedula and Kumar (1996) and Vedula and Mujumdar (1992) studied water allocation in the Malaprabha irrigation scheme in India which transfers water from the Malaprabha River and stores it in the Malapha reservoir for irrigation purposes. Dudley and Scott (1993) study was conducetd in the Gwydir irrigation scheme where water is transferred from the Gwydir River to farms in the Gwydir valley of northern New South Wales for irrigation (Dudley et al., 1993) and Bryant et al. (1993) considered irrigated farms in Texas High Plains of the US. Other studies in this category include Paudyal and Manguerra (1990) who used a two-step (deterministic and stochastic) dynamic programming approach to solve the problem of optimal water allocation in a run-of-river-type irrigation project. Ziari et al. (1995) developed a two-stage model in which they simultaneously considered multiple crops, stochastic water supply and demand, water application, and risk attitude in evaluating the economic feasibility of small impoundments for supplemental irrigation in the Blacklands region of Texas, USA.

Conradie and Hoag (2003) used a static linear programming model to assess benefits of water transferred from the Fish and Sunday Rivers for irrigation in the Eastern Cape, South Africa. The Fish-Sunday irrigation scheme is aimed at abstracting water from these two rivers for irrigation in the Eastern cape. The model focused on citrus and fodder farms and was used to determine the value of irrigation water within the scheme with and without water trade. Water demand functions for the two crops were explicitly estimated in the model. Results indicated that the value of irrigated water increased with trade from R0.0423/m^3 to R0.0681/m^3 .

Fang and Nuppenau (2003) used a spatial water allocation model (SWAM) to assess the impact of water use efficiency in transferring water from the water source (rivers) through canals to irrigated farms in the Li Quan, Shaanxi Province of China, as a case study. Fan and Nuppenau explicitly estimated demand function for water in the project area using econometric techniques. They then integrated these results in the spatial mathematical programming model to determine optimal spatial water allocation and corresponding water values taking into account individual farmer's adoption of modern water saving technologies and improvements in water transit, contributed by the public sector, from sources to end of canals. The main contribution of the study was optimizing water allocation and choices of irrigation technology for farmers in the case study area.

Other studies include Bowen and Young (1985) in which a linear programming model was used to derive estimates of financial and economic net benefits to irrigation water supply in northern Nile delta of Egypt. The authors formulated linear programming models of representative farms and in the study area and reported total, average, and marginal net benefit functions. Lee and Howitt (1996) developed a nonlinear mathematical programming model that optimizes river water quality, resources allocation, production levels and total expenditures for water control and applied it to the Colorado river basin.

One problem with the studies reviewed above is that they all leave out ecological values of water in their assessments. When environmental uses of water are left out, optimization approaches can lead to ill-defined policies when it comes to water conservation, especially for in-stream uses of water. Secondly, these models are based on partial-equilibrium analysis and hence provide a rather narrow approach to the assessment of IBWT that ignores linkages between sectors and activities in terms of the water transfers' impacts. This implies that influences through and on other sectors are insignificant such that the partial equilibrium model will tell the whole story about benefits and costs of IBWT. The next section discusses economy-wide modeling approaches developed to account for indirect impacts through multi-sector linkages and multipliers in assessing IBWT.

3.3 Economy-wide modeling approaches to impact assessment of IBWT

Economy-wide modeling approaches emerged from the pioneering work of Leontief (1951) leading to the development of input output (I-O) models. Following Leontief work on multi-sector analysis, his I-O framework has been extended to more comprehensive economy-wide structures such as the social accounting matrix (SAM) and computable general equilibrium (CGE) models (Johansen, 1960; Defourny and Thorbeck, 1984; Pyatt and Round, 1985; Adelman and Robinson, 1989). The three types of models rely on macro-economic data of a country. Because, for many years, macroeconomic data of countries excluded environmental concerns, economy-wide analyses have historically focused on pure economic accounts.

3.3.1 I-O based models used in impact assessment of IBWT

Application of input-output techniques to the study of resource and environment problems began in the 1970s. I-O studies range from those designed to influence water management and allocation decisions within water basins (Carter and Ireri, 1970; Thoss and Wiik, 1974) and those designed to assess the impact of IBWT (Xikang, 2000; Sheets, 1998). Carter and Ireri (1970) developed inter-regional input-output model to study water allocation between California and Arizona. At the time, the two states were embroiled in a legal conflict over water allocation rights from the Colorado River. In an attempt to provide information relevant for water allocation policies with respect to industrial and agricultural production for these two states, Carter and Ireri (1970) used the I-O model framework to study, among other things, the extent and nature of economic interdependence between California and Arizona, technical water requirements of different sectors in California and Arizona and how these requirements are related to economic activity within California and between California and Arizona, the magnitudes of water congealed in the product flows between California and Arizona and the direct and indirect water requirements of sectors in both regions in response to changes in final demand for products in each state. The results indicated that while both states have strong bilateral trade links, California production sectors had larger output multipliers compared to their Arizona counterparts. Arizona was more water intensive in agricultural production while California was water intensive in agricultural processing, manufacturing, mining and services. Arizona sectors use more water per dollar of final demand than corresponding California counterparts which is indicative of the fact that California sectors are more efficient in their water-use patterns compared to Arizona, and that California exports more water (congealed in exports) than Arizona.

Thoss and Wiik (1974) developed a constrained multi-regional I-O model to study management of water quality in the four regions representing the main industrial area within the Rhur basin in Germany. The objective of the model was to maximize production or gross regional income subject to permissible levels of water pollution and minimum required standards of consumption, capital investment and other physical conditions of the system. The results indicated that the manufacturing sector was the most water polluter in all the four regions. In addition, they highlighted regions producing at sub-optimal levels in terms of excessive pollution suggesting which sectors should cut or increase production to optimize gross profits and reduce pollution levels. The main conclusion that emerged from this study was that environmental policy should not be left to administrators or to engineers and that it needs to be determined using economic principles.

Despite the use of I-O models in the analysis of water allocation and management problems, its use in impact assessment of IBWT was recent. Xikang (2000) used the input-occupancy-output model to conduct an economic valuation of a water transfer project in the Shanxi province of China. The project, known as the Wanjiazhai Yellow River-Shanxi Diversion Project (WYSDP), transfers water from the Yellow River to the water defficient Shanxi province. The project provides water for three energy bases in Taiyuan, Datong and Pingshu and transfers the total of 1.2 billion m^3. Xikang's (2000) model had two distinct characteristics. First, the model divided the water sector into three sub-sectors: (i) freshwater, (ii) recycled water and (iii) waste water treatment. Second, Xikang (2000) added the occupancy section to the input section in the conventional input-output table, where the occupancy section included fixed assets, circulating assets, labour and natural resources. Although the study yielded useful results on how the Shanxi province can save water, it only focused on offstream uses of water (i.e. agriculture, industry and domestic) and ignored instream uses of water.

While the studies reviewed here used more powerful analytical tools than the partial equilibrium and sector-based studies reviewed in Section 3.2, they suffer from small multipliers criticism inherent in the limiting structure of I-O models. Among other things, the I-O model treats households consumption as exogenous, and as a result, income distribution to households and expenditure thereof (the demand side), are not allowed to feed back into the economic system. When the focus is on households like in this study, The I-O is seriously limited as an assessment of welfare/income effects of instream losses on different income groups of households cannot be performed with the I-O model.

3.3.2 SAM based Models used in impact assessment of IBWT

Compared to the I-O model, the SAM is more powerful in analysing socio-economic issues as it integrates demand sectors into endogenous accounts' structure and shows how income is generated and distributed in an economy. Thus, SAM-based models include feedback linkages from income generation, distribution and spending. The models also allow disaggregation of households into different income groups depending on the study objectives, which is advantageous when analyzing income effects of an exogenous change on different characteristics of households like is the case in this study. SAM-based models were used to study economic growth, income distribution and developmental issues, especially in developing countries (Adelman, 1975; Adelman and Robinson, 1989; Pyatt and Round,1985). However, their application to the assessment of IBWT remains scarce. Existing related literature on the use of SAM-based models mainly focuses on water management and are mainly single-country studies.

Because of chronic water scarcity in Thailand which threatens development, Kumar and Young (1996) developed an analytical framework for integrated water resources management to illustrate how Thailand SAM may be extended to incorporate water resources and give examples of what the supply and demand functions for water would look like. This framework was based upon an integrated approach to demand and supply management of water resources and the implications for water pricing policies. Kumar and Young (1996) concentrated on modifications and extensions of the social accounting matrix and on demand and supply equations for water that reflect the true scarcity of water for different uses and from different sources.

On the contrary, Daren et al. (1998) used a SAM framework to analyse water allocation options in the Truckee River Operating Agreement (TROA). They developed a SAM for the study area to estimate interlinkages between economic sectors in the study area and simulated different water allocation patterns to determine how to allocate water efficiently to different users in the study area. Although these two studies greatly depart from the objectives of this research, they were the closest from the available literature. Nevertheless, these studies confirm the significance of integrating water concerns into economy-wide planning. The only shortcoming of the studies is negligence of other uses of water not directly linked to economic production (i.e. water required for instream or ecological reserve).

Conningarth Economists (2000a and b) adopted a multi-region and multi-country approach to the measurement of water benefits for the Komati and Thugela water transfer schemes. In their analyses, they measured the extent to which water transfer from rivers in the two respective river basins (for agricultural use in the Komati Basin and industrial use in the Thugela Basin) would generate employment and lead to economic growth in general. Both analyses demonstrated the significance of sectoral linkages through induced multiplier effects. The analyses however, had the shortcoming of ignoring ecological considerations of water transfer schemes (instream impacts). As a result, benefits measured do not portray the full social costs and benefits of the schemes.

Although the SAM-based approach is an improvement over the I-O approach and single sector approaches reviewed under Sections 3.1 and 3.2, the approach is based on rigid assumptions of fixed coefficient production technologies, excess resources and thus fixed prices, and lack of input and output substitution. The following section reviews CGE-based models which relax most of these restrictive assumptions.

3.3.3 CGE models used in impact assessment of IBWT

Computable general equilibrium (CGE) models date as far back as the 1960s to the pioneering work of the Norwegian Leif Johansen (1960). In his dissertation 'A multi-sectoral study of economic growth', he presented a numerical model that came to be known as the "MSG model". The model was primarily intended to be a tool for long-term economic forecasting and economic policy evaluation and is generally seen as the first CGE model (Bergman, 2002). Unlike SAM-based models that are built with restrictive assumptions, CGE models use relatively more flexible supply and demand structures. The most commonly used specifications are the constant returns to scale technology and homothetic consumers' preferences (Bergman, 2002). CGE models endogenously determine relative product and factor prices and the real exchange rate. They are particularly aimed at quantifying the impact of specific policies on the equilibrium allocation of resources and relative prices of goods and factors.

Although CGE models started as early as the 1960s, environmental CGE models started only in the early 1970s and were predominantly energy models. The econometric CGE model for energy policy analysis of Hudson and Jorgenson (1974) is one such example. This turned out to be the first of a large number of models developed to analyse energy policy issues in the wake of the oil price increases in 1973 and 1979 (Bergman, 2002). At the beginning of 1990s the focus shifted from energy supply problems to climate change related problems (Burniaux et al., 1992; Hill, 2001; Murthy et al., 1992; Bussolo et al., 2002). Most CGE models today are designed to elucidate various aspects of climate change or in some cases, acid rain policies, e.g., pollution from energy use and climate change (Bergman, 2002).

Despite the fact that the application of CGEs to environmental problems started three decades ago, their application to water issues has been rare and available literature only focuses on agricultural water management policies (Diao et al., 2002; Decaluwe et al., 1999; Mukherjee, 1996; Robinson and Gehlhar, 1995; Goldin and Roland-Host, 1995). The skewed focus perhaps resulted from the growing water scarcity and increased population pressures that has prompted many countries to adopt water-pricing mechanisms as their primary means to regulate irrigation water consumption. The first CGE water model was presented by Berck et al. (1991) with which they studied the impact of investment policies aimed towards the distribution of water in the San Joaquim Valley of Carlifonia in the United States. The model was disaggregated into 14 production sectors, six of which were agricultural, and it measured the impact of changes in water available for agricultural production on the economy. The authors made a restrictive assumption that water was exogenously supplied and agriculture was the only consumer of water. A simulated reduction in water availability generated diversification in production away from agriculture to livestock, accompanied by a decrease in GDP, as well as a reduction in agricultural income and labour demand.

Other studies, all focused on agricultural water pricing in Morocco, include Goldin and Roland-Host (1995), Decaluwe et al. (1999) and Diao et al. (2002). Goldin and Roland-Holst (1995) studied the relationship between trade reform and water management in Morocco in a CGE framework. Their CGE had four production sectors, two of which were agricultural. They analysed the impact of two policy scenarios on water demand: (i) increased water tariffs for agricultural water use, (ii) reduction in import duties, and (iii) combination of the two policies. They concluded that the third policy scenario resulted in a reduction in water demand, an increase in GDP and an improvement in household income. They however, assumed a restrictive production function for agriculture that does not allow for substitution between water and other inputs. They also assumed fixed water endowment.

Decaluwe et al. (1999) relaxed these restrictive assumptions in analysing three pricing strategies (Marginal pricing, Boiteux-Ramsey Pricing (BRP), and arbitrary price increases in agricultural water) to determine which is more effective in achieving optimal agricultural water allocation, recovery of total costs related to agricultural water infrastructures and reduction in the growing water scarcity problem in Morocco. They used four types of agents: households, firms, government and the rest of the world. To account for spatial water distribution they divided the country into two distinct regions, north and south. They found the BRP, combined with a reduction in distorted production taxes to be the most efficient in reducing water consumption with a positive impact on efficiency in terms of use and cost recovery. Johanson (2000) gives detailed literature on similar studies.

Robinson and Gehlhar (1995) used an 11-sector CGE model to determine the magnitude of Egyptian agricultural resource base (land and water) strains resulting from further population and GDP growth. The study particularly focused on two distortionary policies that characterised the Egyptian economy in 1986-88 (i.e. large, sectorally variegated output taxes and subsidies), which included major input subsidies and zero charges for water in agriculture. The model combined an optimizing, programming model of land and water use in agriculture with a simulation model of the non-agricultural sectors. Empirical results indicated that 1986-88 Egyptian policies were biased against agriculture and led to a water-conserving structure of agricultural production. As such, land, not water, was the binding constraint. The results also indicated that policy reform would increase both aggregate welfare and demand for water. Given the inelastic demand for water, policy reform on the output side would strain the existing system of water distribution since water would become much more valuable than land to agricultural producers. Given the initial policy bias against agriculture, policy reform would favor rural employment and lead to reduced pressure of rural-urban migration.

Mukherjee (1996) used a “Watershed Computable General Equilibrium (CGE) model” to analyse water allocation policies in South Africa, using the Olifantsriver Catchment in the Transvaal as a case study. The main objective of this study was to analyse different water allocation policies that can result in efficient and equitable water allocation between productive (agriculture, mining, industry and tourism) and consumptive (human and ecological) uses of water in South Africa. Although all the users mentioned above were included in the model, agriculture was given a more detailed technical specification since it is the largest water user in South Africa. The important conclusion the study arrived at was that SA needs improved efficiency in administrative allocations, and that the potential efficiency gains from improved water policies do not appear to exact tremendous price from the disadvantaged sectors, though small and targeted investments that would improve these sectors' productivity are likely to have great impact.

Economy-wide models discussed above have an advantage over the positive and normative models as they analyse economy-wide implications of IBWT and hence provides a holistic approach to impact assessment of IBWT. Despite this strength over partial equilibrium models, the studies reviewed above suffer from the major criticism of leaving out instream uses of water. Lack of integration of ecological values into IBWT impact assessment studies reviewed so far suggests that valuation of instream impacts of IBWT continue to be a challenge. The next section reviews studies that evaluated instream/ecological uses of water.

3.4 Approaches to assessing instream impacts of IBWT

Unlike offstream impact assessment of IBWT that started about 50 years ago, explicit estimation of instream/streamflow economic benefits of IBWT only started in the late 1980s (Gibbons, 1986). As a result, instream flow reservations for maintenance of riverine ecology are still largely based on biological and hydraulic, rather than economic criteria.

Available literature on the streamflow valuation largely centers around recreational values. Economists have used biological and economic assessment methods to evaluate the recreational fishing benefits of incremental streamflow changes (Johnson and Adams, 1988; Hansen and Hallam, 1991; Duffield et al., 1992; Harpman et al., 1993). Other studies have analysed quality of whitewater boating (Brown et al., 1991) and stream aesthetics for general shoreline use (Brown and Daniel, 1991). The common objective of these studies was to compare the economic values of instream flow to the value of competing off-stream consumptive uses such as irrigation or municipal withdrawals. These uses are typically marketed commodities or inputs to marketed commodities and hence their values are relatively well understood. However, instream uses are generally not marketed, requiring novel approaches for estimating their economic value.

A Multistage bioeconomic framework has been commonly used for estimating recreational fishing streamflow value (Johnson and Adams, 1988; Hansen and Hallam, 1991; Daffield et al., 1992; Harpman et al., 1993). The first step of this type of analysis comprises of estimating a fish production model with respect to streamflow. The second step involves the use of contingent valuation methods (CVM) to elicit from anglers the amount of money that they would be willing to pay (WTP) for increments in fish quality or the amount they would be willing to accept (WTA) for decrements of fish quality. This method employs Hicksian compensating measures: compensating variation and compensating surplus (Freeman, 1993) to measure the value of streamflow. Despite the fact that they are the best available methods for valuing non-marketed resources, CVMs have many shortcomings, which are well documented in the literature (e.g., Blamey and Common, 2000; Tietenberg, 2000; Dixon et al., 1994; Hanemann, 1991; Branden and Kolstad, 1991; Hufschmidt et al., 1983).

Recently, there has been a shift in the focus of streamflow valuation from its original recreational flows to agricultural and biodiversity valuation, with the main objective of measuring welfare impacts associated with modified streamflows. The work done on Hadejia-Nguru wetlands of Nothern Nigeria (Hollis, 1993) is a notable example. Earlier studies on these wetlands largely focused on the impact of diverting water to upstream uses on the agricultural and biological diversity productivity of floodplains downstream, and resultant welfare implications on the downstream users. The work on these wetlands was motivated by dam and reservoir projects, built and proposed, which will divert water from rivers that inundate Hadejia-Nguru wetlands, to meet irrigation and industrial demands of water upstream. Studies that analysed direct linkage between flooding of these wetlands and wetlands productivity demonstrated that diversion of water to upstream uses resulted in reduced wetland productivity and thus reduced riparian welfare (Barbier et al., 1993 and Barbier and Thompson, 1998), and led to shifts in farming patterns by downstream farmers from high value crops (e.g. rice in west Nigeria) to low value crops (millet) (Adams, 1985).

While these studies demonstrated the value of floodplain products and the impacts of diverting water away, on floodplain productivity and on riparian welfare, they made no attempt to explicitly estimate the economic relationship between streamflow/flooding and floodplain agricultural and biodiversity productivity. Recent studies (Acharya and Barbier, 2000 and Acharya, 1999) made such an attempt. In the said studies, the value of wetlands in recharging groundwater was analysed, using the production and cost function approaches and drawing on the hydrological and economic evidence. The said studies showed that the indirect effects of changes in instreamflows, and thus flood extent would cause groundwater levels to fall within the wetlands, resulting in welfare losses from reduced agricultural productivity and wild resource availability. LHDA (2002d) and Klassen (2002) used the same framework of Acharya and Barbier (2000) to value streamflow impacts of the LHWP. LHDA (2000d) and Klassen (2002) drew on hydrological, biophysical, economic and socio-economic information to value the impact of the LHWP on the capacity of the Lesotho Highlands rivers to provide regulating and supporting services to the growth of wild vegetation and fish, and resultant welfare impact on riparians residing in the vicinity of the rivers. The studies further used transportation costs to value the cultural services of the rivers, and mitigation costs against human and animal health to value the change in the quality of rivers' water as a result of the LHWP.

The production function approach has been suggested in the literature as a good approach to measuring values of environmental goods or services used in the production of final consumption goods (Freeman, 1993). In this approach, an environmental service or good is treated as an input in the production of some measurable output (Ellis and Fisher, 1987; Freeman, 1991 and 1993; Mäler, 1992). For example, the service of floods to recharge aquifers in floodplains enters the production function of floodplain products indirectly as an input in the production of such products (Acharya and Barbier, 2000; Archaya, 1999). Since the aquifer recharge function of the floods can be said to reduce irrigation costs, this reduction in costs can be represented as a shift in the marginal cost or supply curve for the agricultural product along a given demand curve. An environmental improvement would then involve a downward shift (to the right) of the supply curve of the agricultural product and the theoretical welfare impact measure of this change, would be the combined consumer and producer surplus changes. Detailed valuation techniques of instream uses of water are given in Chapter VI.

While the studies reviewed above make a breakthrough in the valuation of streamflows and criteria for making instream water allocation decisions, they are premised on partial equilibrium analysis like studies reviewed in Section 3.2. Additionally, by focussing only on streamflow benefits of IBWT, the studies offer 'piecemeal' solution to impact assessment of IBWT. The next section reviews the thread of literature that integrates streamflow with economic benefits/costs of IBWT in an economy-wide framework and provides the motivation for this study.

3.5 Integrated assessment of IBWT

Although off- and in-stream impacts of IBWT have historically been assessed separately, a new approach that integrates both assessments has emerged. Available literature predominantly employs mathematical programming techniques in assessing off- and in-stream impacts of IBWT. Integrated hydrologic-economic models for river basin management are used to assess impacts of IBWT on off-stream uses, mainly agriculture and water quality problems (salinity) caused by agriculture (Cai et al., 2003 and 2002; Rosegrant and Meinzen-Dick, 1996; Lefkoff and Gorelick, 1990; Booker and Young, 1994). While this group of studies are an improvement over studies that only focus either on off-stream or in-stream uses of water, they narrowly concentrate on single uses, i.e., agriculture for off-stream uses and water quality for instream aspects of water. Watanabe et al. (1981) considered a number of off-stream uses of water and water pollution problems in assessing impacts of allocating water within a river basin. He used a spatial optimisation model to demonstrate how water use can be optimised in different off-stream uses at minimum water pollution levels using the Yamato-River basin as the case study. Like preceding studies, Watanabe et al. (1981) only focused on one aspect of instream concerns of water, i.e., water quality.

Brown et al. (2002) developed a broader approach which included a variety of off-stream uses: hydropower, irrigation and urban water supply. In their model in-stream uses included flood control and recreation. Their model is a computer simulation model called AQUARIUS and is devoted to temporal and spatial allocation of water flows among competing off- and in-stream uses in a river basin. The model employs mathematical programming techniques and allows for explicit estimation of water demand. The model offers significant contribution to integrated assessment of IBWT impacts. However, it lacks empirical application. In addition, it narrowly focuses on flood control and recreation as in-stream uses of water within a river basin. Other studies that also developed methodology for integrating instream and offstream uses of water include Griffin and Hue (1993) and Giannias and Lekakis (1997).

Griffin and Hsu (1993) developed a conceptual framework, based on a single country, for addressing interface between off-stream and instream uses of water. They considered a case where water from a river basin is used for both off-stream and instream uses, located at different points along a river. In their framework, off-stream users divert water from streams for use in agriculture, industry and household consumption. Some water is returned back to streams after use. This affects both quantity and quality of water available for instream uses. In their study, Griffin and Hsu (1993) developed a highly stylised theoretical spatial model to determine optimal allocation of water between offstream and instream uses for different regions along the river. Their model captured essential details of hydraulic interdependencies among water users and assumed the world sans of transaction costs. While this model offers a good insight into how to integrate environmental into economic concerns in planning water developments, it lacks empirical application.

Giannias and Lekakis (1997) on the other hand developed a conceptual framework presenting a simple economic-ecologic model which examines input-output controls, social input prices, bilateral water trade, a water market for all water users, and a fixed water allocation agreement, as possible water policies for cross border river sharing. They demonstrated that these policies can satisfy the conditions for maximum joint economic benefits, while simultaneously working towards maintaining the functional integrity of river ecosystems. Their study provides a good analytical framework for exploitation of transboundary water resources and demonstrates the significance of cooperation between countries sharing such resources. Although this study makes significant contribution to economic theory of exploiting transboundary water resources, it's weakness lies in the lack of empirical application, probably because of international lack of cooperation in the management of transboundary water resources. The LHWTS is a unique and probably one of the few transboundary water developments where there is already bilateral trade agreement between involved countries.

The studies reviewed above adopted a partial-equilibrium approach to assessing impacts of IBWT. Hence, they ignored important linkages between activity levels in different water-using and non-using sectors, which suggest that all decisions affecting sectoral production levels and processes invariably lead to repercussions (e.g. multiplier effects) in other parts of the economic system. Sheets (1998) employed an economy-wide approach, using the I-O technigue, to assess the impact of water transfer trom Turkey Creek Watershed into numerous dams. In his analysis he included both off- and in-stream uses of water. The Turkey Creek Watershed occupies 175, 700 acres and is located in Johnson and Pawnee Counties, Nebraska, and Marshall and Nemaha Counties in Kansa. The main objective of the water transfer was to abstract water from within the watershet and store it in 75 floodwater retarding dams with the aim of reducing floods and providing incidental recreation. The project would also reduce sedimentation, enhance wildlife habitat, enhance water quality, improve riparian health, and economic conditions by increasing incomes. Sheets (1998) used a multi-regional I-O model through the computer model he called IMPLAN to analyse regional impacts of the project with special emphasis on flood damage and recreation. The results showed that the project would yield tremendous benefits with respect to reduced flood damage and benefits accruing to incidental recreation. Although the study included instream uses of water, it narrowly focused on flood control and recreation services of streamflow only.

The review of related studies in this chapter has shown that offstream and instream impacts of IBWT have traditionally been assessed separately. Also, some attempts have been made towards integrating these impacts, which has contributed significantly to impact assessment of IBWT to ensure long-term sustainability of such transfers. Nevertheless, studies reviewed in this section only included a few instream aspects of IBWT (recreation, flood control and water quality). Many other aspects including instream resources like wild vegetables, medicinal plants, crafts grass, fuel wood, etc direly required for sustenance of riparians livelihoods in most cases were not included. In addition, most studies employed partial equilibrium techniques which only focus on direct benefits of IBWT. Even Sheets (1998) who integrated offstream with instream effects of IBWT in an economy-wide framework, used the I-O technique that suffers from the problem of small multipliers, and also narrowly focussed on flood control and recreational services of water as instream impacts of IBWT.

This study attempts to contribute to improved analytical approaches for assessing IBWT impacts by developing an ecological economy-wide framework using a SAM-based model that integrates ecological benefits of water. The model captures regulatory and supportive services of streamflows in the growth of wild vegetation and fish, cultural/recreational services of streamflows and the value of streamflows in maintenance of human and animal health (i.e. quality of streamflow). Because of the spatial and temporal nature of IBWT, the fact that they induce structural changes that affect relative prices, and because the LHWTS is a multi-country project, the dynamic multi-country ecological CGE or at-least, multi-country quasi-dynamic ecological CGE model would be appropriate for this analysis. However, because of data limitations, the multi-country ecological SAM (MC-ESAM) is a better substitute at this stage. The next chapter discusses the SAM analytical framework and details on the MC-ESAM follow in Chapter V.