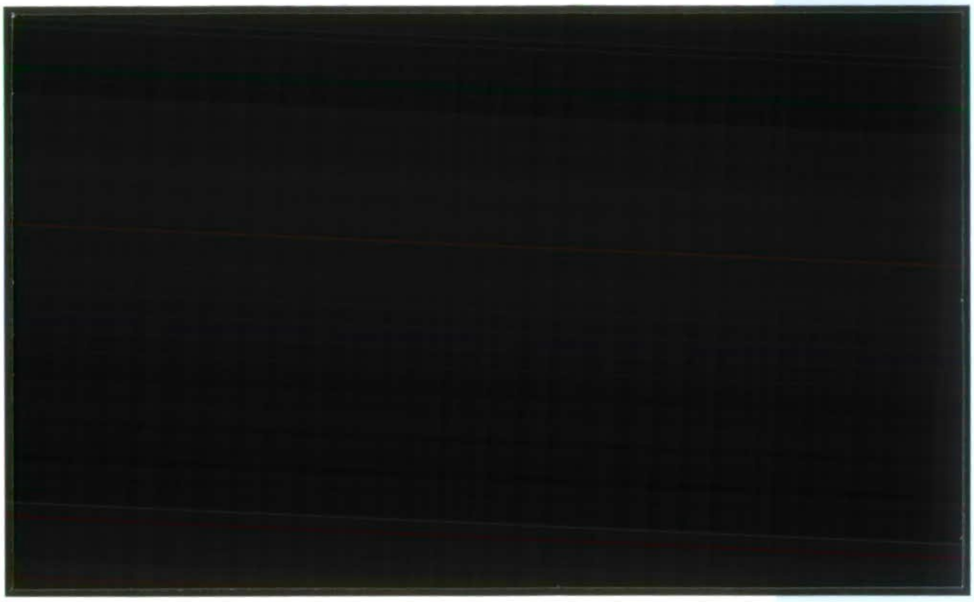
The

Centre for Ecology & Hydrology



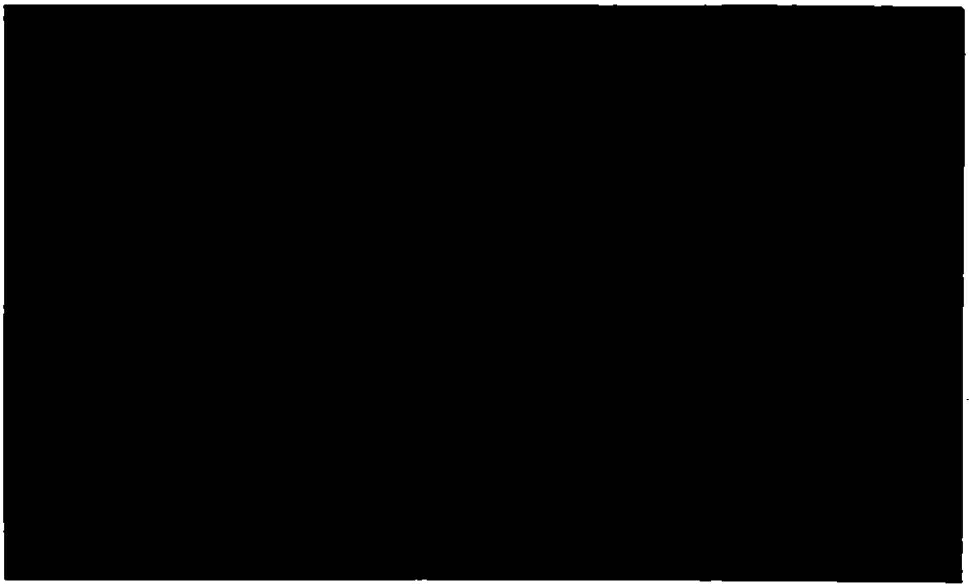
Centre for Ecology & Hydrology

NATURAL ENVIRONMENT RESEARCH COUNCIL

Formerly the Institutes of Hydrology, Terrestrial Ecology, Freshwater Ecology, and Virology and Environmental Microbiology

The **Centre for Ecology and Hydrology** is one of the Centres and Surveys of the Natural Environment Research Council (NERC). It was established in 1994 by the grouping together of four NERC Institutes, the Institute of Hydrology (IH), the Institute of Terrestrial Ecology (ITE), the Institute of Freshwater Ecology (IFE) and the Institute of Environmental Microbiology and Virology (IVEM). In 2000, the four component institutes were merged into a single research organisation.

Institute of Hydrology | Institute of Terrestrial Ecology | Institute of Freshwater Ecology | Institute of Virology and Environmental Microbiology



The CEH mission

- To advance the sciences of ecology, environmental microbiology (including virology) and hydrology through high-quality and internationally recognised research leading to a better understanding and quantification of the physical, chemical and biological processes relating to land and freshwater and living organisms within these environments

- To investigate, through monitoring and modelling, natural changes in the ecological, microbiological and hydrological environments, to assess both past and future changes, and to predict man's impact on these environments

- To secure, expand and provide ecologically and hydrologically relevant data to further scientific research and provide the basis for advice on environmental conservation and sustainable development to governments and industry

- To promote the use of the Centre's research facilities and data, to provide research training of the highest quality and to enhance the United Kingdom's research base, industrial competitiveness and quality of life.

Derivation and Testing of the Water Poverty Index Phase 1.

Final Report May 2002

Volume 3- Technical Appendices II

Dr C. A Sullivan, Dr J.R Meigh & Mr T.S Fediw

Centre for Ecology & Hydrology
NATURAL ENVIRONMENT RESEARCH COUNCIL

DFID Department For International Development

Derivation and Testing of the Water Poverty Index Phase 1.

Final Report May 2002

Volume 3- Technical Appendices II

Volume 3- Technical Appendices II

Contents

Appendix 9.1

Defining the Ecosystem Component of a Water Poverty Index

Mike Acreman[1] and Jackie King[2]

1. Introduction

It has become increasingly recognised since the Bruntland Report, *Our Common Future,* (WCED, 1987) that the lives of people and the environment are profoundly inter-linked and that ecological processes keep the planet fit for life providing our food, air to breathe, medicines and much of what we call "quality of life" (Acreman, 2001). It is clear that any loss of ecosystem benefits represents an important potential contribution to poverty. The Dublin Conference in 1991 - a preparatory meeting for United National Conference on Environment and Development (Rio Earth Summit of 1992), concluded that "since water sustains all life, effective management of water resources demands a holistic approach, linking social and economic development with protection of natural ecosystems" (ICWE, 1992). For example, upstream ecosystems need to be conserved if their vital role in regulating the hydrological cycle is to be maintained. Well-managed headwater grasslands and forests reduce runoff during wet periods, increase infiltration to the soil and aquifers and reduce soil erosion. Downstream ecosystems provide valuable resources, such as fish nursery areas, floodplain forests or pasture lands, but these must be provided with freshwater and seen as legitimate water users. In addition, water is an essential feature in many religions. For example, many Hindus believe the River Ganges is sacred: a dip in it will purify the soul and scattering the ashes of a cremated body on the water will aid rebirth in a higher existence.

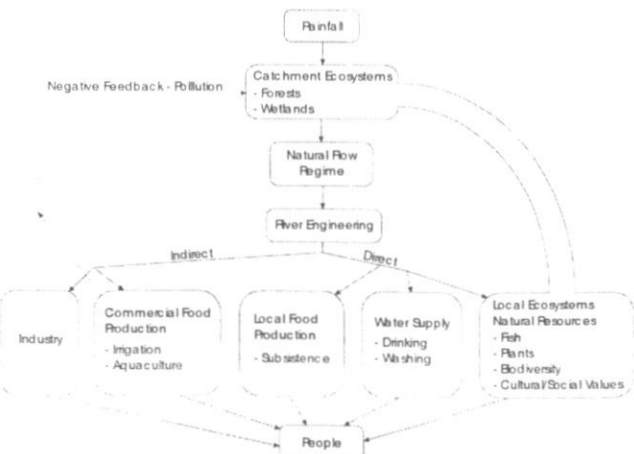


Figure 1 Direct and in-direct water use by people

At the Rio Conference itself, it was agreed that "*in developing and using water resources, priority has to be given to the satisfaction of basic needs and the*

1 CEH Wallingford, Crowmarsh Gifford, Wallingford, Oxfordshire OX10 8BB, UK
2 Freshwater Research Unit, Zoology Department, University of Cape Town, Rondebosch 7701, South Africa.

safeguarding of ecosystems" (Agenda 21 chapter 18, 18.8). Thus, whilst people need access to water directly to drink, irrigate crops or supply industry, providing water to the environment means also using water indirectly for people (Figure 1). Indeed, the aquatic ecosystem is the resource from which the commodity of water is derived, rather than a competing user of water. This concept is so basic that it has permeated all aspects of water resource management, such as the new Water Act of South Africa, whose principle 9 states that: "the quantity, quality and reliability of water required to maintain the ecological functions on which humans depend shall be reserved so that the human use of water does not individually or cumulatively compromise the long term sustainability of aquatic and associated ecosystems".

The implications of this concept are that people will be poorer if the ecosystem upon which they depend has been degraded by lack of water of appropriate quality. In this case, poverty is measured in terms of loss of benefits to people of the ecosystem. These benefits may be in terms of (1) products (i.e. natural resources), such as fish or aquatic plants, (2) functions (i.e. services), such as flood reduction, or (3) other attributes, such as spiritual or cultural ones. One may go as far as to say that the mere existence of a functioning ecosystem and its biodiversity provides intangible benefits to people, such as aesthetic beauty or potential benefits to current and future generations, such as undiscovered medicines, that should be recognised as valuable attributes. In this chapter we group the range of benefits of ecosystems to people under a general heading of "goods and services".

The natural ecosystem is often seen as making the most efficient use of scarce natural resources. Any changes will cause the system to be less efficient, leading to unpredictable and possibly several responses. In terms of sustainability, natural ecosystems retain the most options for future generations. The natural variability in the flow regime, including floods and droughts will impose considerable stress on the system, but this stress is key to sustaining the system in the long term. This analysis would suggest that any alteration of an ecosystem from its natural state might give rise to some level of poverty. However, we also recognise that, at least locally, management of ecosystems may produce improved benefits of certain goods and services. For example, management of the flow regime of a river by eliminating droughts may lead to increased abundance of fish, or engineering of a floodplain may improve flood water retention. Acreman (2001) has depicted this situation as a trade-off between benefits from the natural system and benefits from a managed system (Figure 2).

As natural systems are modified more and more, the benefits of the natural system and thus the options for future generations decline (solid line in Figure 2); eg. hydrological functions, products and biodiversity are lost. At the same time, benefits from the highly managed system increase (dotted line); eg. food production rises. It is suggested that the benefits from the highly managed systems reach a plateau, whilst the benefits of the natural system will decline to zero at some point. The local gains from the managed system may not be sustainable and may be acquired at the expense of other parts of the system. For example, ecosystem management may require the use of non-renewable resources, such as fossil fuels for production of infrastructure or running of pumps. This implies that the shape of the curve for the managed system is scale dependent. Whilst it may reach a plateau at the local level, at a global level (taking into account all resources used) it may decrease. The total long term benefits (dashed line) can be calculated by adding the benefits of the natural and highly managed systems. The total rises to a maximum before declining. It is at this point that the balance between naturalness and level of management is optimised. There is no temporal dimension to this graph, but as non-renewable resources are depleted the shapes of the curves may change. They may also change due to increased resource use efficiently with technological innovation. The value that society places on goods and services and ethical considerations will determine the exact form of these curves. Nevertheless, it shows that society will choose a target ecosystem that is not natural and it is this social choice that will prevail (Maltby *et al*, 1999).

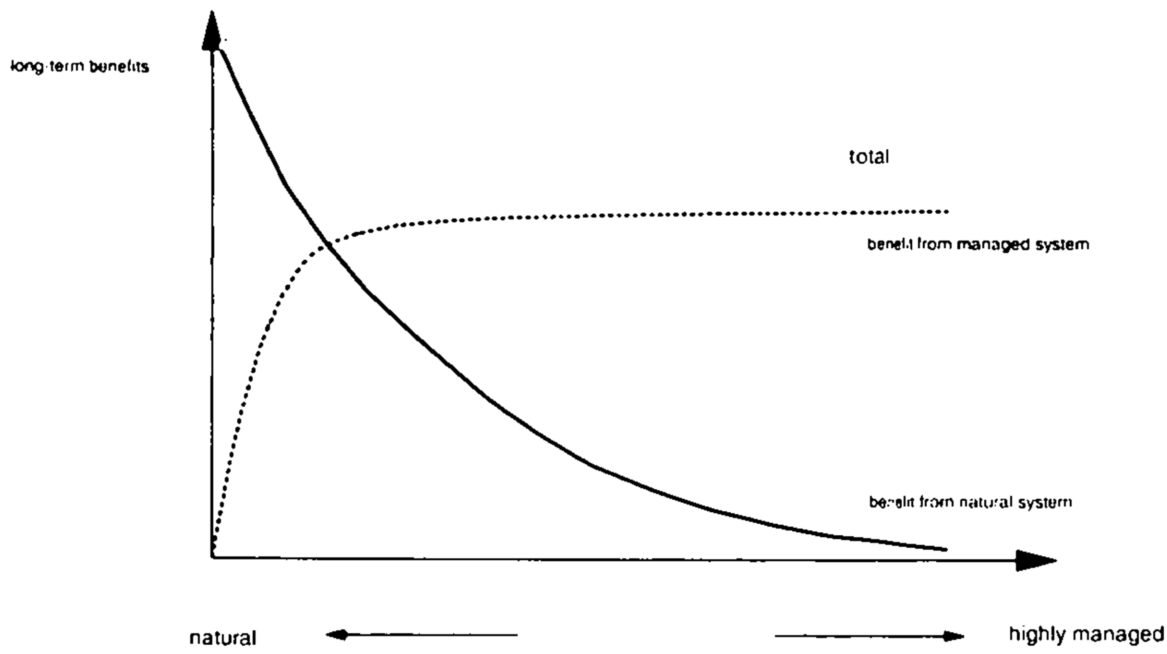


Figure 2 *Maximising benefits from ecosystems (after Acreman, 2001)*

In this chapter, we focus on the natural goods and services of ecosystems and not on any benefits from managed systems, such as irrigation or aquaculture.

2. The ecosystem component of a Water Poverty Index

A comprehensive water poverty index should include the contribution to poverty that people experience as a result of the amount of water reaching an ecosystem and providing natural goods and services. This is relatively straightforward in terms of the products or goods produced by ecosystem. For example, people may use plants or catch fish directly from a river, lake or wetland, or their cattle may graze on floodplain grasses. They will be poorer if the fishery, pasture or aquatic plants are degraded due to changes in the quantity or quality of water that supports them.

Assessment of wetland hydrological functions is more difficult. Whilst intuitively, healthy forests and wetlands, for example, are assumed to regulate the hydrological cycle, reduce floods and augment low flows, and anecdotal evidence is widely quoted, there is inadequate scientific verification of which ecosystems perform which services under which circumstances (eg. Kaimowitz, 2001). Tropical forests and wetlands are also known to be important stores of carbon and their destruction can lead to increased atmospheric carbon levels and potential climate change, but the link between ecosystem degradation and poverty is not easy to quantify.

A water poverty index should also cover the level of cultural or spiritual importance and existence value of ecosystem, but again there is little quantitative information on which to base this component of the index.

In this chapter we therefore make the assumption that the higher the productivity of the ecosystem, the greater will be the goods and services provided to people. Three factors can be identified that need to be quantified for the index: productivity of the ecosystem in its natural state; the degree of degradation from natural; and the population dependent upon the system.

Productivity of natural systems Natural ecosystems vary enormously around the world. Tropical rain forests and wetlands provide more goods and services than deserts and can thus support the needs of more people. The productivity of the system depends on many factors and their interactions, with water being only one component. Wilson (1992) concludes that the main driving variables for diversity of species, which is related the range of goods and services an ecosystem provides, are energy, stability and area. The ESA theory. The more solar energy, the greater the diversity; the more stable the climate, the greater the diversity; finally the larger the area the greater the diversity. Nutrient levels are another important controlling variable, but tend to vary locally and in a complex way depending on factors, such as geology. Given an equal amount of nutrients, the hottest and most humid places are also the most productive in terms of quantity of animal and plant tissue grown each year. Where there is great season to season variability, productivity may be high if the climate is consistent from year to year. For example the Inner Niger delta in Mali supports a very prolific fishery, even though the climate is very seasonal with a summer flood and winter drought.

Emberger (1955) used the principle that wetness and warmth are the main variables driving ecosystem productivity in his bio-geographical classification scheme:

$$Q = 200R/(M^2-m^2)$$

Where R = average annual rainfall (mm)

M = mean temperature for the hottest month (Kelvin)

m = mean temperature for the coldest month (Kelvin)

Degree of degradation The degradation of any ecosystem will mean loss of goods and services. Thus the degree of naturalness must also be included as a factor in any index. This factor would have its maximum value when the ecosystem is natural and its minimum value when the ecosystem has been completely degraded. For rivers and wetlands, ecosystem naturalness can be indexed by the hydrological regime. Maintenance of a natural river, lake or wetland ecosystem requires a natural hydrological regime and any alternation from a natural regime will result in changes in the ecosystem. In this case, an index can be based on the departure of the hydrological regime from natural. However, the form of the relationship between the hydrology and ecology is rarely understood. A small change in the hydrological regime may result in a major change in the ecosystem, or vice versa. In addition, there may be some threshold regime which marks a sharp boundary between a healthy and degraded system. Nevertheless, the advantages of this kind of approach are that hydrological data are more widely available than ecological data, and considerable research has been undertaken on water needs for maintaining aquatic ecosystems. For terrestrial ecosystems, such as forests or grasslands, data on loss of key species, such as IUCN Red Lists of Threatened or Endangered Species, or maps of deforestation may be used to quantify degradation.

Dependent populations Natural ecosystems have finite goods and services and will in many cases fail to supply sufficient, say fish, to support a large population, even when resource use is closely regulated by traditional or modern laws. In this case, the dependent community should be considered poor with respect to the natural ecosystem. The index must therefore include some measure of the carrying capacity of the ecosystem. This element of the index could be further refined by inclusion of other factors. First, not all people will use all ecosystem goods and services, or be dependant on them. Everyone will use the oxygen-maintenance function, but not every one catches fish. The poor may have little choice than to use natural resources, whereas alternative for most goods can be purchased at a price. Using the total population in an area indexes the *option* for everyone to use resources, which is related to the sustainability concept. Restricting the population figures to those dependent on the ecosystem is an alternative, but data are rarely available. Second, the ability of people to access the ecosystem's goods and services should also be included. People living further from a river or wetland may be considered to be poorer than those living close to it if use of the goods and services means long travel time. However, construction of a suitable index would mean a complex integral of where individuals live and their distance to the ecosystem.

There are three scales at which an index can be developed. First, the global scale which includes the ecosystem services, such as oxygen maintenance that are utilised by the world entire population. Second, the macro scale, where indices are based on widely available statistics or mapped data including rainfall, temperature and population. This allows rapid calculation of the index at any place and thus comparison between different areas or catchments. Third, the micro scale that involves assessing directly the benefits to people of various goods and services of an ecosystem. This could be based on a full environmental assessment. However, assessing objectively the goods and services provided by an ecosystem is a major task. Alternatively, the micro-scale index can be based on questioning local people about ecosystem benefits. It must be accepted that the respondents may have imperfect knowledge of the state of their environment, so general questions concerning ecosystem services may not be appropriate. In many cases, it may be more pragmatic to focus on direct use of natural resources from an ecosystem, which can be assessed by questions about use of the river, lake or wetland resources. For example, fishermen may have data on fish catches. The problem is that the cause of any decline will not necessarily be known and in such cases it will be impossible to separate ecosystem degradation due to changes in water availability or quality (thus contributing to water poverty) from that caused by, say, over-exploitation (eg. over-fishing). Likewise information about aesthetic, cultural or spiritual attributes can be determined by questionnaire. But, as with fisheries, the loss of these attributes may not be a result of water issues.

In summary, two elements seem to be key to an ecosystem index.

(1) The capacity of the ecosystem to provide goods and services

(2) The number of people who would wish to use the goods and services.

The capacity of the ecosystem might be indexed by two elements (i) the capacity of the ecosystem in its natural state and (ii) its degradation from natural.

This ecosystem index will indicate if people are environment rich or poor. To develop a water-ecosystem index, the contribution of water to defining the ecosystem index needs to be emphasised.

It is important to note that this index is focusing on the availability of the resource to people. It does not index the value of the resource. For many services, such as flood reduction, one person's use does not affect anyone else's use. However, for products such as fish, they may be in competition. It this case, the more people competing for a given resource the higher the price. Where the number of people wishing to use ecosystem goods and services is high compared to the availability of the resource, there will be poverty.

3. Methods of calculating an index

In this paper, we focus on two levels at which a water ecosystem component of the WPI can be calculated: the macro level (regional or catchment) and micro level (local).

3.1 Macro level

3.1.1 Terrestrial ecosystems

We first consider large scale terrestrial ecosystems, such as grasslands and forests that are fed by rainfall and not significantly by river flows or groundwater. The natural productivity of these ecosystems and thus their capacity to provide goods and services is controlled by many variables, but two key drivers that can be obtained from maps are:

(1) Rainfall; and
(2) Temperature

The actual capacity of the ecosystem will depend on its naturalness and hence a third variable is:

(3) Degree of degradation

The level of ecosystem poverty will then be determined by a fourth component:

(4) Population density (number of people wishing to use the goods and services and their access to them).

(1) *Rainfall.* Rainfall gives a general indication of the availability of natural foods and other products. Dryland farming stops at less than about 400 mm per year. Below that figure, landscapes are quite dry.

(2) *Temperature.* Natural systems, even with significant precipitation, will not be productive if the temperature is too low or day-length too short for plants to grow. Latitude is a potentially a good index as it covers, broadly, temperature and daylight hours. However, altitude can significantly influence temperature, such as in Lesotho. Winter minimum temperature has been selected as this indicates if plants are restricted by frosts. Temperature and day length are highly correlated.

(3) *Degree of degradation.* Natural ecosystems will provide more goods and services than degraded ecosystems. Degradation from natural, such as through deforestation, urbanisation or development of intensive agriculture, can be assessed from land use maps or statistics on loss of species.

(4) *Population density.* Although natural systems in high rainfall, warm areas will provide goods and services, high population densities may mean that they insufficient in terms of per capita provision (e.g.Mekong).

For calculation of the index, each category is divided each five classes. The range in each class and the score is very provisional and needs to be refined following detailed case studies.

Class		**5**	**4**	**3**	**2**	**1**
Degree of degradation	Type	Pristine	Near-pristine	light land use	intensive land use	Urban
	Score	5	4	3	2	1
Rainfall - average annual (mm)	Type	>800	600-800	400-600	200-400	<200
	Score	5	4	3	2	1
Temperature - winter minimum (°C)	Type	>20	12-20	4-12	0-4	<0
	Score	5	4	3	2	1
Population density (ppkm^2)	Type	< 0.1	0.1-1	1-10	10-100	>100
	Score	6.6	5	4	2	0.5

The Ecosystem Poverty Index for terrestrial ecosystems (EPI_{terr}) is calculated as follows

EPI_{terr} = (degree of degradation + rainfall + temperature) x population density

The index ranges from 1.5 (considerable ecosystem poverty) to 99 (no ecosystem poverty). To demonstrate the use of the EPI_{terr} , five areas of the world are considered.

- Lesotho (above the tree line, v cold in winter);
- London;
- Sumartra forest;
- Namib desert.

Note that the values used are very approximate. EPI_{terr} for each area would be:

	Degree of degradation	Rainfall	Temperature	Population density	EPI_{terr}
Lesotho	3	4	1	4 (5)	32
London	1	4	2	1 (0.5)	3.5
Sumatran forest	4	5	4	4 (4)	53
Namib desert	4	1	3	5 (6.6)	53

London scores worst as it has no natural systems to support people, but a dense population. Lesotho is too cold and the Namib desert too dry to produce many natural resources. However, the Namib in particular has few people depending on natural resources, so score quite highly. For a few people who rely on the trees fed by occasional rainfall natural resources are available. The Sumatran forest which is broadly natural has many resources but increasing population also scores quite high.

It must be remembered that although London has a low score, this does not cause poverty in a broader sense as the vast majority of people do not rely on natural resources and earn sufficient money to buy resources brought in from outside.

To distil from EPI_{terr}, an index related purely to water-ecosystem poverty, it is necessary to remove the other non-hydrological drivers. Thus the $WEPI_{terr}$ is derived simply from rainfall and population density.

$WEPI_{terr}$ = rainfall x population density

	Rainfall	Population density	$WEPI_{terr}$	EPI_{terr}	% EPI_{terr} caused by lack of water
Lesotho	4	4 (5)	20	32	37
London	4	1 (0.5)	2	3.5	43
Sumatran forest	5	4 (4)	20	53	62
Namib desert	1	5 (6.6)	6.6	53	88

By combining these two indices ($WEPI_{terr}$ and EPI_{terr}), the degree to which environmental poverty is caused by insufficient water can be calculated (see final column in above table). It can be seen that in the Namib desert the majority of the poverty is caused by lack of rainfall, whereas in Lesotho, it is caused primarily by low temperatures and ecosystem degradation.

Calculating the index at different times can provide information on whether water-environment poverty is increasing or decreasing. Burning of fossil fuels and other human activities have increased green house gas concentrations in the atmosphere and changed the global climate. Therefore, water-environment poverty may increase or decreased with time because of changes in the amount of rainfall.

3.1.2 River and wetland catchments

This section focuses on rivers and wetlands. The capacity of these aquatic ecosystems to provide goods and services is controlled by many variables, but the main drivers are similar to those for the terrestrial ecosystems with the addition of area and nutrient levels:

(1) Rainfall
(2) Area
(3) Temperature
(4) Degree of degradation
(5) Population density (number of people wishing to use the goods and services and their access to them)
(6) Nutrients

(1) *Rainfall* In regions with an average annual rainfall less than 400 mm, rivers tend to run very low in the dry season, or are ephemeral.

(2) *Area.* The quantity of water reaching a rivers and wetlands will be dependent to a large extent on rainfall and catchment area. "Wetter" systems with higher flow or will be more productive.

(3) *Temperature.* This is also an important driver for aquatic systems. If the temperature is too low production will be low, particularly if there is ice or snow in the winter. Water temperature records may not be available, but average catchment air temperature can be used instead.

(4) *Degree of degradation.* Natural ecosystems will provide more goods and services than degraded ecosystems. Degradation can be assessed from the difference between the actual hydrological regime (flow in rivers or water levels in wetlands) and the natural regime (Annex A). The number of dams and abstraction points may be used as a surrogate where hydrological records are not available). Degree of naturalness should also include water quality, such as levels of oxygen, phosphates and heavy metals (Annex B).

(5) *Population density*. As with terrestrial ecosystems, high population densities may mean that they are insufficient in terms of per capita provision of goods and services.

(6) *Nutrients* In natural systems, nutrient-rich rivers have generally higher productivity than nutrient-poor rivers, where nutrient status may be related to geology. However, there is not a clear relationship between the two on which to base an index.

For calculation of the index, each category is divided into five classes. The range in each class and the score is very provisional and needs to be refined following detailed case studies.

Class		5	4	3	2	1
Degree of degradation	Type	Natural regime	Near-natural regime	Minor impacts on regime	Significant impacts on the regime	Severely impacted regime
	Score	5	4	3	2	1
Rainfall - average annual (mm)	Type	>800	600-800	400-600	200-400	<200
	Score	5	4	3	2	1
Catchment area (km^2)	Type	>10,000	1000-10,000	100-1000	10-100	<10
	Score	5	4	3	2	1
Temperature - winter minimum (°C)	Type	>20	12-20	4-12	0-4	<0
	Score	5	4	3	2	1
Population density ($ppkm^2$)	Type	< 0.1	0.1-1	1-10	10-1000	>1000
	Score	5	4	3	2	1

The Ecosystem Poverty Index (EPI_{aqu}) is calculated as follows

EPI_{aqu} = (degree of degradation + rainfall + area + temperature) x population density

The index ranges from 4 (considerable ecosystem poverty) to 100 (no ecosystem poverty). To demonstrate the use of the EPI, five areas of the world are considered.

- rural lower Mekong;
- Okavango delta (Botswana);
- small river in Rio de Janeiro
- small river in Baluchistan, Pakistan

Note that the values used are very approximate. EPI_{aqu} for each area is given in the following table.

Interpretation: Rio de Janeiro score worst as its water quality is poor, it is a small river and the population density is high. The Okavango scores highest as this is semi-natural lush aquatic ecosystem with low population density). Mekong scores lower because although there are many resources, there are tens of millions of people using them. Pakistan scores quite high because there are few people and the temperature is hot, even though rainfall is low and some degradation (through over grazing and groundwater abstraction) has occurred.

Location	Degree of degradation	Rainfall	Area	Temperature	Population density	EPI_{aqu}
Mekong	2	5	5	4	2	32
Okavango	4	4	5	4	4	68
Rio de Janeiro	1	5	1	4	1	11
Baluchistan	2	1	2	5	4	40

As with EPI_{terr}, to produce an index related purely to water-ecosystem poverty, it is necessary to remove the other non-hydrological drivers. Thus the $WEPI_{aqu}$ is derived simply from rainfall, area and population density.

$WEPI_{aqu}$ = (rainfall + area) x population density

Location	Rainfall	Area	Population density	$WEPI_{aqu}$	EPI_{aqu}	% EPI_{aqu} caused by lack of water
Mekong	5	5	2	20	32	37
Okavango	4	5	4	36	68	47
Rio de Janeiro	5	1	1	5	11	55
Baluchistan	1	2	4	8	40	80

By combining these two indices ($WEPI_{aqu}$ and EPI_{aqu}), the degree to which environmental poverty is caused by insufficient water can be calculated (see final column in above table). It can be seen that in Baluchistan the majority of the poverty is caused by lack of rainfall, whereas in the Mekong, it is caused primarily by ecosystem degradation.

3.2 Micro (village) level

This section, data collected from the village surveys in Sri Lanka, Tanzania and South Africa as part of the Water Poverty Index Phase I study are assessed.

In South Africa and Tanzania, the only question asked about natural resource use was whether or not specific types of resources were used ie:

Do you use the river for anything else than water ?

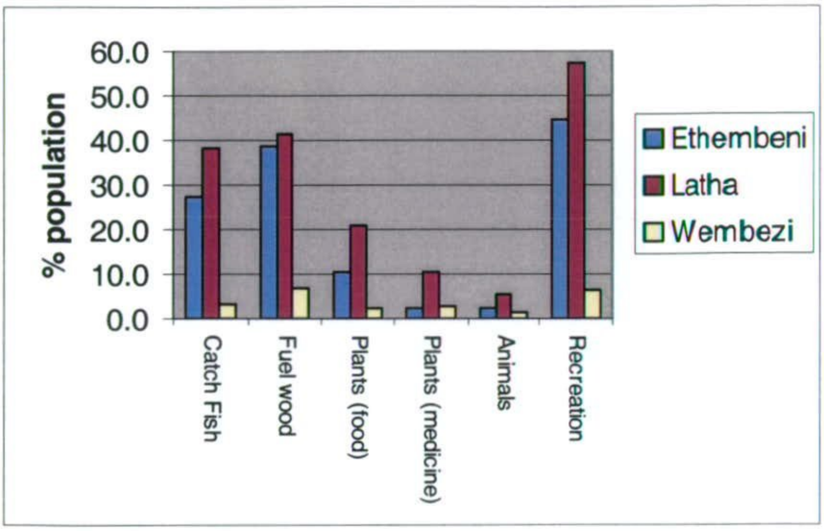


Figure 3 Percentage of population interviewed using natural resources in South African village case studies

Data for villages surveyed in South Africa are shown in Figure 3. It can be seen that large numbers of the population at Ethembeni and Latha use the river for recreation, some use it for fishing and fuel wood collection, but few collect plants or other animals. It is clear that natural resource use is much more important in Ethembeni and Latha than in Wembezi.

The only conclusion that can be drawn in terms of a Water Poverty Index is to adopt percentage of the population using resources as a direct indicator of poverty, ie. 0 is water poor, 100 is water rich. The indices for the South African case studies would be:

Village	Index (% using natural resources)
Ethembeni	68
Latha	77
Wembezi	18

Figure 4 shows the data for Latha divided according to whether the interviewee was male or female. It is evident that women make far more (on average six times) use of the river for natural resource use and recreation than men, even for fishing which is in some regions a male pursuit.

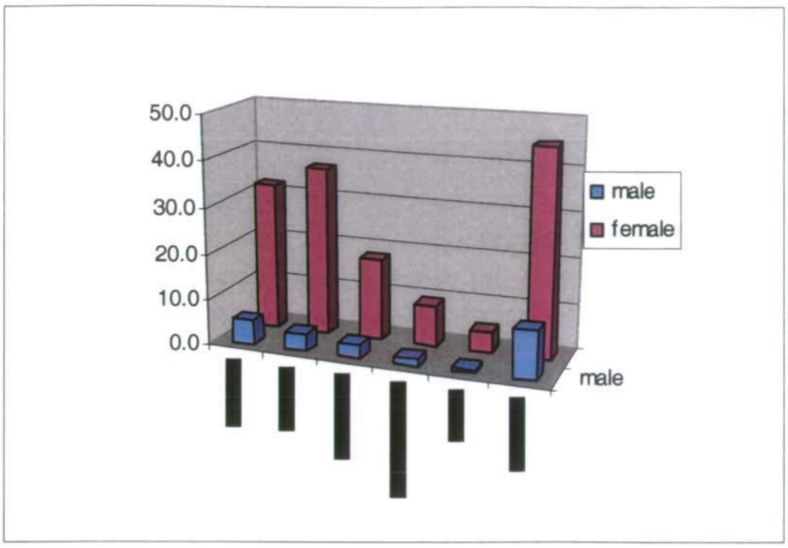


Figure 4. Natural resource use by gender at Latha

In four villages in Tanzania, the same question was asked. It can be seen that very little use is made of natural resources, apart from some cattle grazing. Application of the environmental component of the WPI is difficult because the reason for the lack of use is not known.

Village	Index (% using natural resources)
Nkoaranga	0
Samaria	19
Majengo	0
Kijenge	0

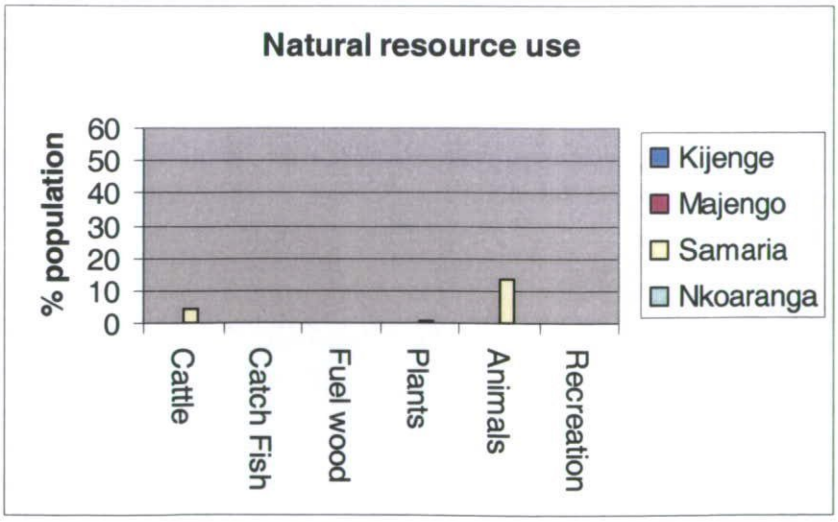


Figure 5 Natural resource use in Tanzania

For the village case studies in Sri Lanka, a slightly different question was posed.
Do you use wild animal and plants for everyday living?

This includes non-river wild resources that could include plants and animals from forest areas. It is thus more difficult to relate use to lack of water reaching the ecosystem.

Village	Index (% that use wild plants and animals)
Agarauda	32
Tissawa	68

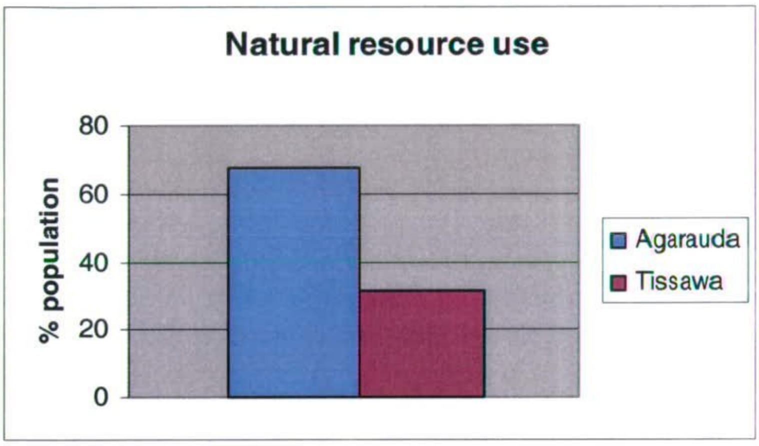


Figure 6 Natural resource use in Sri Lanka

No data were available for natural resource use from the surveys in the other two villages of Tarawatta and Avarakotuwa in Sri Lanka.

Developing the questionnaire

Three elements are key to developing an environmental index from questionnaires: (1) use of goods and services; (2) the importance of goods and services and (3) the adequacy of goods and services.

The questions will provide a different focus than the index developed at the macro scale. At that larger scale, it was assumed that all the population would want to use (or have the option to use) environmental goods and services. At the micro level we try to differentiate those that use goods and services and how important they are. At the macro level we assessed the provision of goods and services from a natural ecosystem plus its degree of degradation to determine availability. At the micro-level we can assess the adequacy of goods and services directly by targeted questions. The poorest, in terms of the index, would be those who want to use goods and services, consider them important, but find their availability inadequate.

Specific questions would be:

1. Do you use wild plants or animals (including fish) Yes=2. No =1.
2. How important are they for your livelihood (food or goods that can be sold).

No importance = 1; Little importance = 2; Medium importance = 3; Very important = 4; Principal means of livelihood = 5.

3. Would you use more if they were available? Yes=1. No=2.

These scores would need to amalgamated to form an index (ranging from 1 to 100) where high scores are good (low poverty) and low scores are bad (significant poverty). The problem with these questions is that inadequate availability may not be due to lack of water reaching the ecosystem, which is the key tenet of the Water Poverty Index. This could only be achieved by an assessment of the causes of the poverty level scored. If flow data for rivers, or water level data for wetlands were available, this assessment could be based on any changes in water availability to the aquatic ecosystem.

We recommend that the indices for the macro-scale index (rainfall, temperature etc) are used to define potential level of goods and services from the ecosystem, with the population factor replaced by response to the above questions concerning actual use.

References

Acreman, M.C. 2001 Ethical aspects of water and ecosystems. *Water Policy Journal*, 3, 3, 257-265.

Emberger, L. 1955 Projet d'une classification biogeographique des climates. In: *Les divisions ecologiques du monde*. Centre Nationale de la Recherche Scientifique (CNRS), Paris. pp 5-11.

International Conference on Water and the Environment 1992 *The Dublin Statement and report of the Conference*. 26-31 January 1992. World Meteorological Organization .

Kaimowitz, D. (2001) *Useful myths and intractable truths: the politics of the link between forests and water in Central America*. Research Paper. Center for International Forest Research, San Jose, Costa Rica.

Maltby, E., Holdgate, M., Acreman, M.C. & Weir, A. (Eds) 1999. *Ecosystem management; questions for science and society*. Sibthorp Trust.

Organization for Economic Cooperation and Development 1999 *Environmental Data Compendium*. OECD, Paris.

Wilson, E.O. 1992 *The diversity of life*. Allen Lane Penguin Press, London.

World Conference on Environment and Development 1987 *Our common future*. Oxford University Press, Oxford, UK.

World Conference on Environment and Development 1987 *Our common future*. Oxford University Press, Oxford, UK.

World Economic Forum 2002 *Pilot Environmental Performance Index*. Global Leaders of Tomorrow Environment Task Force. Yale Centre for Environmental Law, New Haven, USA.

Annex A

Degradation of the hydrological regime

One of the key elements of the ecosystem component of the Water Poverty Index is the degree of naturalness or degradation of the hydrological regime. However, this requires quantification of a simple measure of the difference between the natural regime and that its current state.

In natural ecosystems, river flows, wetland water levels and groundwater levels vary continuously, with periods of stability, rises, falls, floods and droughts. Other components of the ecosystem, including plants, animals and sediment/nutrients dynamics are all adjusted to these variations. Any change in the hydrological pattern will lead to changes to the ecosystem. It is not possible to prescribe a single index that encapsulates the entire hydrological regime. In practice, measures of low flow, such as Q_{95} (the flow that is exceeded for 95% of the time), are often used to index river flow regimes, since it is during dry periods when flows are low that water is normally most needed and withdrawals of water have their maximum impact on the rivers. However, Q_{95} in semi-arid regions may be zero, so another flow statistic may be used, such as mean flow. The mean flow has the advantage that it can be more readily calculated from a water balance approach to the catchment. The disadvantage is that the hydrological regime may be considerably altered, whilst preserving the mean. For example, if a flow equal to the mean flow, may be released continually from a reservoir the mean will be the same as the natural flow, but all variations about the mean (floods and low flows) will have been eliminated.

Other practical problems also exist with this approach. Even in situations where the actual river flow, groundwater table or wetland water level is measured, calculating the natural flow regime requires records of abstractions and discharges from and to the system. In most cases these will not be recorded. Estimation of the natural regime often relies on reference to near-by or similar hydrological systems that are natural.

The simplest index of degradation, in the case of river flow, is:

$$FR_{r,n} = RMF / NMF$$

where
RMF = recorded mean flow
NMF = natural mean flow

For cases where the recorded mean flow equals the natural mean flow, the index will equal 1. The index could exceed 100 where discharges to the river results in recorded mean flow exceeding the natural mean flow.

Since many river, wetlands and aquifers have significant wet and dry seasons, a more sophisticated index could have two components:

Annex B

Water quality

There are a wide variety of determinands that influence the quality of water including nutrients (eg. nitrates, phosphates), metals (eg. copper, zinc, lead) and pesticides.

The OECD has published data at a national level for a range of water quality parameters. These have been used in environmental indices such as the Environmental Performance Index (WEF, 2002). They three water quality measures: dissolved oxygen, phosphorus concentrations, biochemical oxygen demand using data for 22 countries.

Other national indices are available, such as the Surface Water River Ecosystem Classification (NRA, 1994), which classifies the quality of rivers into 5 groups.

River Ecosystem Class	Dissolved Oxygen % saturation 10 percentile	BOD mg/l 90 perc	Total ammonia mg N/l 90 perc	Un-inonised ammonia mg N/l 95 percentile	pH 5 perc 95 p	Hardness mg/l Ca CO_3 90 perc	Dissolved copper pg/l 90 perc	Total zinc pg/l 95 perc
1 Very good – suitable for all species	80	2.5	0.25	0.021	6 – 9	<10 >10 - 50 >50 - 100 >100	5 22 40 112	30 200 300 500
2 Good - suitable for all species	70	4.0	0.6	0.021	6 – 9	<10 >10 - 50 >50 - 100 >100	5 22 40 112	30 200 300 500
3 Fair – suitable for high class coarse fish	60	6.0	1.3	0.021	6 – 9	<10 >10 - 50 >50 - 100 >100	5 22 40 112	30 200 300 500
4 Fair – suitable for coarse fish	50	8.0	2.5		6 – 9	<10 >10 - 50 >50 - 100 >100	5 22 40 112	300 700 1000 2000
5 Poor – likely to limit coarse fish	20	15.0	9.0		6 – 9	<10 >10 - 50 >50 - 100 >100	5 22 40 112	300 700 1000 2000

Table B1 Water quality standards for UK rivers (NRA, 1994)

Appendix 9.2
Which Water are we Indexing and Which Poverty?

Tony Allan
SOAS, University of London. tony.allan@soas.ac.uk

'While water shortages do not determine the levels of poverty or prosperity enjoyed by a community, communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes and for secure livelihoods.'

Summary

The purpose of this analysis will be to contextualise the water poverty index activity by providing a review of some important underlying concepts. The discussion of these concepts will also assist in defining the scope of the study. **First**, it will be shown that communities can endure water shortages with poverty. They can also experience water shortages and enjoy prosperity. **Secondly**, it will be shown that while water shortages do not determine the levels of poverty or prosperity enjoyed by a community, communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes as well as for secure livelihoods. Poverty is a socially and politically determined phenomenon. Poverty is not environmentally determined. **Thirdly**, it will be shown that the long term challenge of allocating and managing adequate, sufficient and safe water is fundamentally associated with the creation of secure livelihoods. Secure livelihoods enable access directly to the small volumes of water needed for drinking and domestic purposes and indirectly to the water intensive commodities that are also necessary for life and well-being. **Finally**, it will be emphasised that in attempting to ameliorate the problems of those enduring water poverty priority will always have to be given to how to address the social and especially the political circumstances - local and external - that have led to the impoverishment of a community.

Water poverty is an element of poverty. The elimination of the political and socio-economic circumstances that consign a community to poverty will also enable the elimination of water poverty. As a result one of the features of this project will be its focus on communities that are poor in socio-economic terms. Regions that endure low rainfall or lack surface and sub-surface fresh water will not be the prime focus.

soil water. These fresh waters may be local in origin or they may have been moved by gravity from sources thousands of kilometres away.

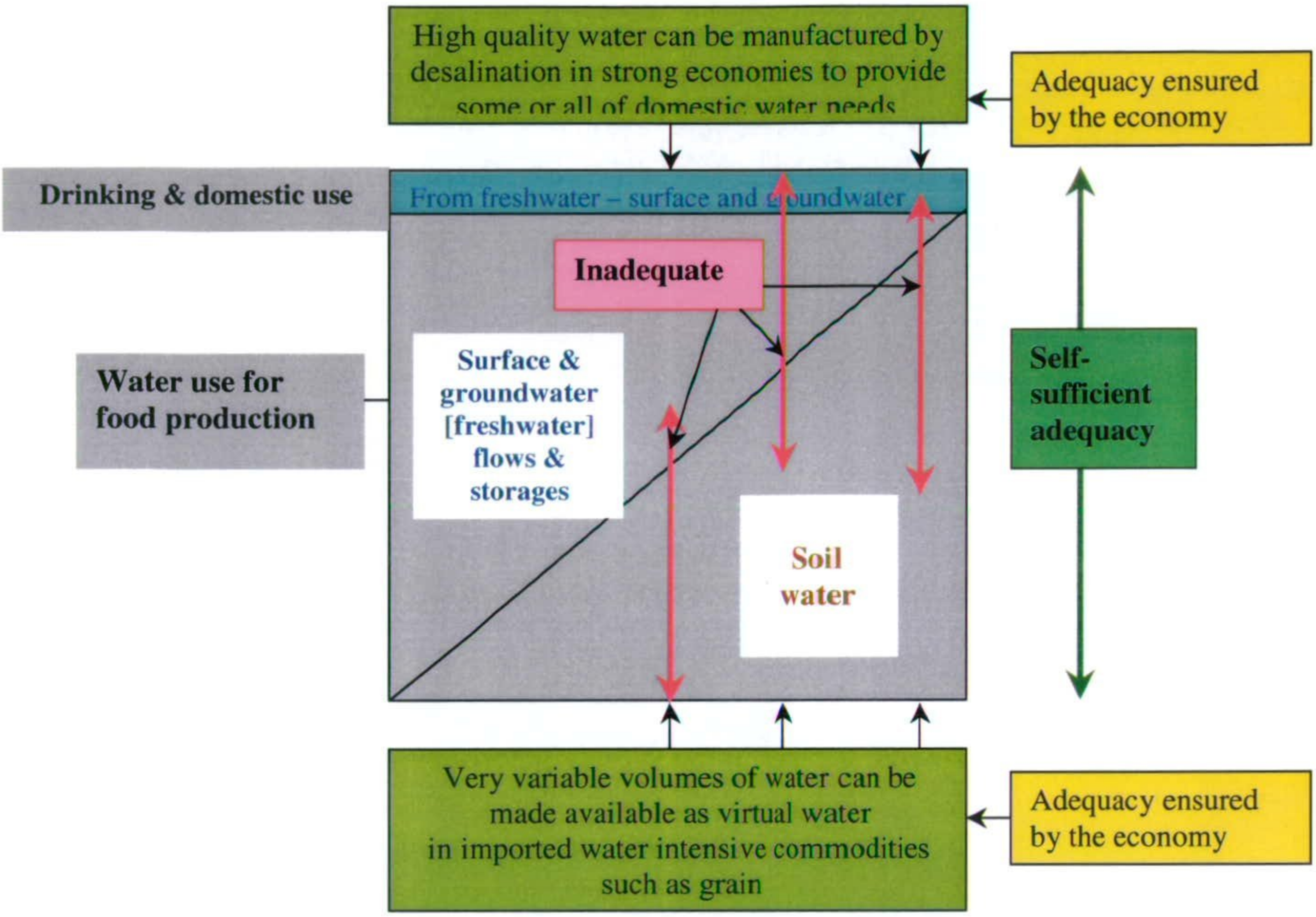


Figure 1: Water needs and the diverse combinations of sources which satisfy need. The diagram shows that the water supply system is not a closed one for a community in a particular tract. Both technology and trade can provide potential solutions for water supply deficiencies. It is the impoverished circumstances of poor communities that prevent them accessing the 'supplementary' manufactured water and the traded virtual water.

Demand and availability: identifying the proportions of the competing demands for fresh water and for soil water: scarcity can be naturally or socially determined

Individuals and communities need water for food, for domestic use including for drinking and cooking, for livelihoods and for the maintenance of environmental services. Very little water is needed for domestic purposes and for most livelihoods outside agriculture. The main competition for water for human use is between big volumes of water diverted from the environment for food production and the even bigger volumes of water in the environment that sustain environmental services. All water used by human systems is diverted from water flows and storages that, before human intervention, were in the environment.

In brief, an individual needs about one cubic metre of high quality water per year for drinking; a quantity of between five and 100 cubic metres per year for domestic purposes; and a quantity of between 500 and 1000 cubic metres per year for the production of their annual food needs.

In industrialised economies the levels of domestic water use, including drinking water, are about 100 cubic metres per person per year. In the poor economies of Africa the levels of domestic water use are at the low end of the range – about five cubic metres per person per year - because water for domestic consumption may have to be carried by the family from remote sources.

Levels of water use for food consumption also vary widely. People in industrialised economies enjoy diverse diets including high proportions of animal products. This pattern of consumption accounts for a high level of per person use of about 1000 cubic metres per year of water. The diets of poor communities are not diverse and they generally consume few animal products. As a result the water needs for food could be as low as half of the levels of those in industrialised economies.

Water for food consumption is a complex issue in that the water used for crop production may be available naturally in the soil profile. In some locations the naturally occurring soil water may be supplemented by freshwater diverted and/or pumped from surface and ground waters. In arid, rainless, regions all the water used in agriculture may come from surface and/or groundwater.

In the light of these numbers it is evident that the concept of available water is complex in that a community may derive ninety per cent of its water needs from the soil profiles surrounding their dwellings. [See Figure 1] Soil water is not available for drinking and domestic use yet it usually provides the bulk of the water needed for survival. Any attempt to design a water poverty index that indicates the status of the water available to a community in relation to the levels of water needed for survival must be capable of distinguishing between different types of water shortage.

First, water shortages may relate to the inadequate availability of the small volumes of water needed for drinking and domestic purposes. Secondly, water shortages may result from inadequate water availability for crop and livestock production in low rainfall areas. Thirdly, water shortages may result from the local absence or inadequacy of fresh surface water and groundwater to supplement, or serve instead of,

Poverty and water poverty

Communities can face water shortages in economies enduring poverty. They can also face and overcome water shortages in circumstances of prosperity. The inadequacy of the water availability can be ameliorated by accessing water for drinking and domestic purposes via technology and trade. The small volumes of water needed for domestic purposes can be manufactured – by for example by desalination. The big volumes of water associated with food production can be accessed via trade in water intensive commodities. This water is often referred to as virtual water. (Allan 2001) [See Figure 1]

It is the inability of poor communities to access technology and trade that consigns them to water poverty. Local deficiencies in freshwater and soil water availability cannot be addressed successfully by the poor. The communities for which the proposed water poverty index will be relevant are those that do not have the option of accessing manufactured water or traded virtual water.

In this study the focus is on the communities and economies that are poor and therefore lack the means to fully ameliorate their water shortages. Either water is not locally available or the communities lack the technical and economic capacity to access available local water. They also cannot access water available outside their locality either by technology or via trade.

Water poverty has two dimensions. Ohlsonn (1999) has usefully shown that there are two orders of water scarcity. First order scarcity is the shortage of water itself. Second order scarcity is that of social adaptive capacity. The poor lack social adaptive capacity. The absence of second order social adaptive capacity is many times more important than first order water shortage.

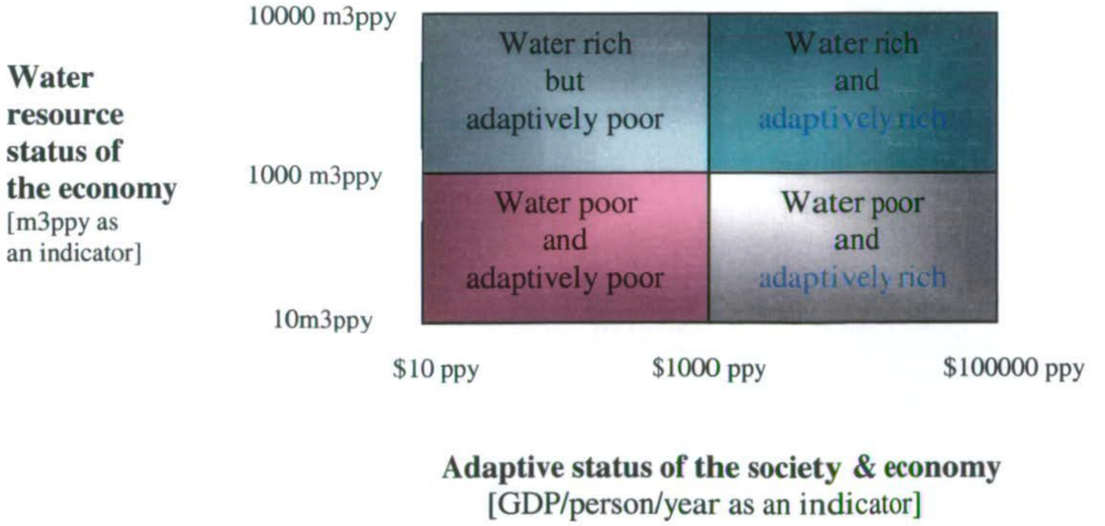


Figure 2 The two dimensions of water poverty and the two ameliorating factors – the water status and social adaptive capacity

The focus of the study is on the impoverished communities who currently lack the ability to ameliorate their water supply problems. Communities that lack the ability to ameliorate their water shortages lack 'social adaptive capacity'. (Turton and Ohlsson 2000)

Determining factors and water poverty

There is a tendency to assume that water shortages will determine poor economic outcomes. Such environmental determinism has long been discredited. Shortages of water do not determine the levels of poverty or prosperity enjoyed by a community. Figure 3 conceptualises water resource determinism. Figure 4 and Figure 5, however, show that water resource endowment does not determine socio-economic development outcomes

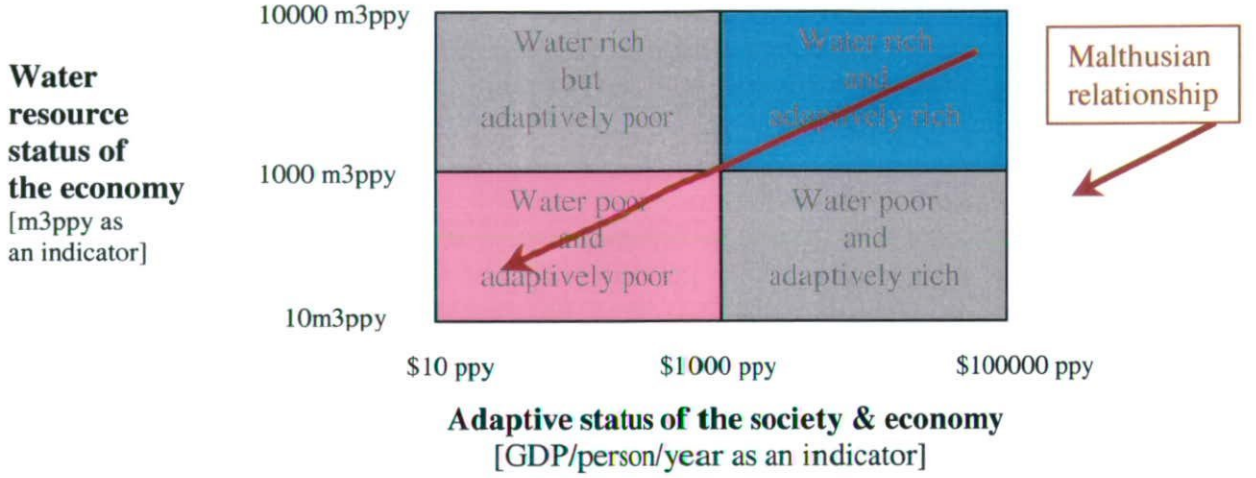


Figure 3 Showing the relationship predicted by Malthusian analysts. Natural resources would determine that would determine economic outcomes and the deterioration in the natural resource status would impoverish communities and political economies.

Figure 1, Figure 2 and Figure 3 illustrate the two dimensions of water poverty. The diagrams also show clearly that water poverty is not static. The status of the water resource for individuals within a nation or region tends to worsen as populations rise and the availability of freshwater and soil water tend to remain unchanged.

Communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes and for secure livelihoods. Poverty is a socially and politically determined phenomenon. Poverty is not environmentally determined. A community or economy can move from a poor position in terms of poverty and water scarcity to a position of prosperity through creating diverse livelihoods. A strong and diverse economy enables access to water and water intensive commodities. See Figure 4.

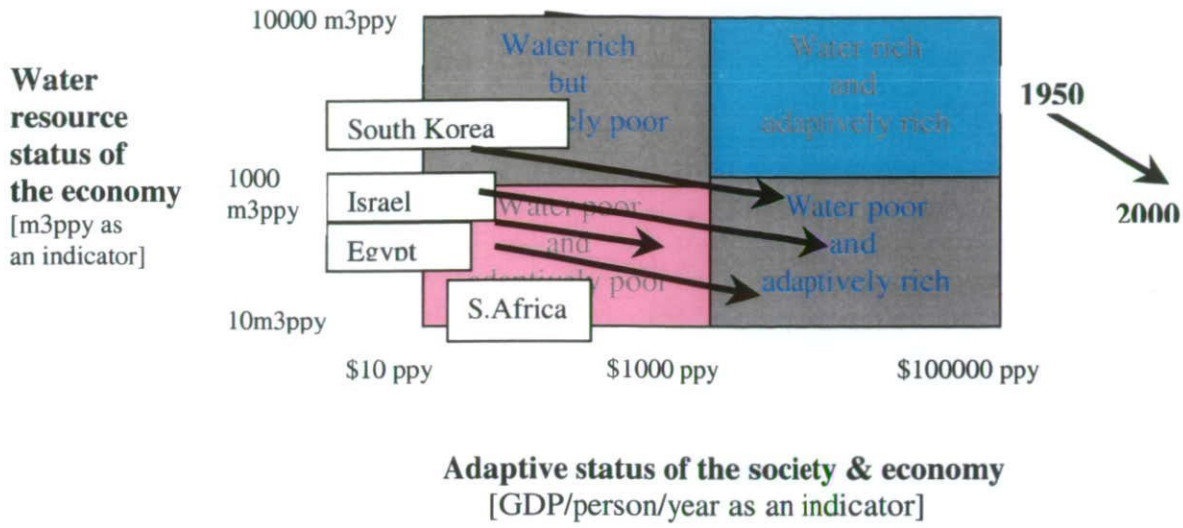


Figure 4 Both the water status and the social adaptive capacity are dynamic. Communities and political economies have trajectories reflecting worsening local water resource availability – because of rising populations, and reducing poverty – because of adaptive amelioration.

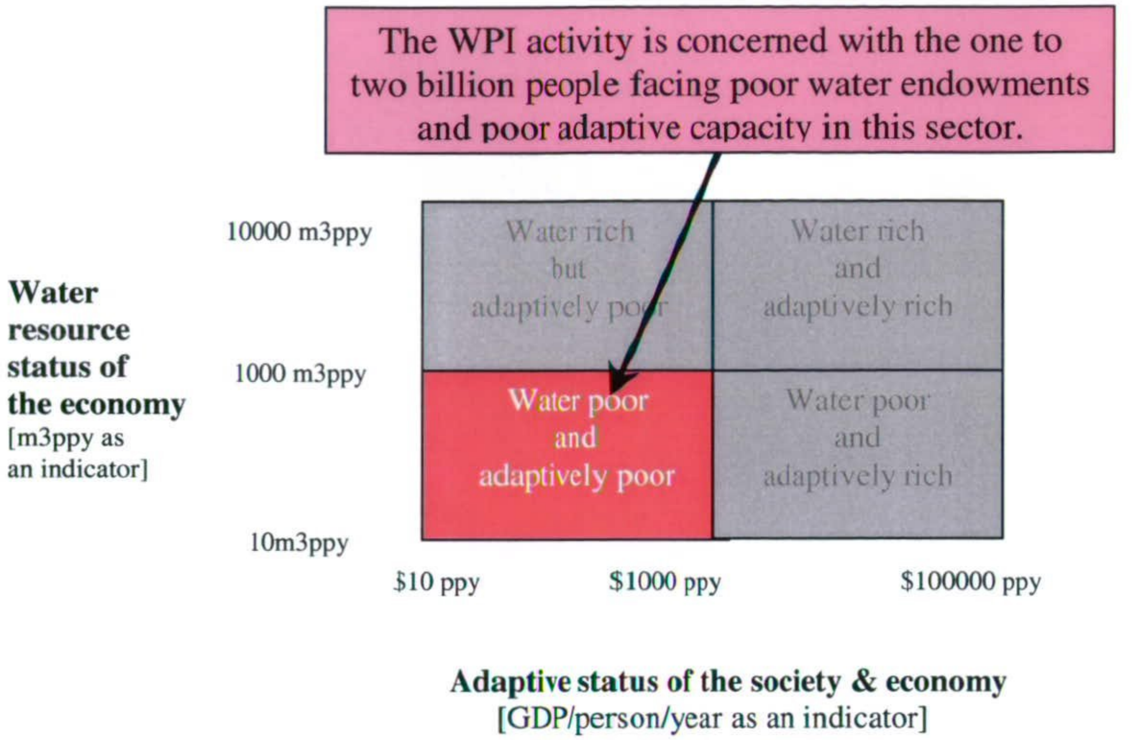


Figure 5 Diagram defining the communities for which the Water Poverty Index can be a relevant analytical tool and where re-allocative policies, investment and technology should be devoted

Secure livelihoods ameliorate water poverty

The long term challenge of accessing, allocating and managing adequate sufficient and safe water is fundamentally associated with the creation of secure livelihoods. Secure livelihoods enable access directly to the small volumes of water needed for drinking and domestic purposes and indirectly to the water intensive commodities that are also necessary for life and well-being. Evidence that economies which generate diverse and secure livelihoods can overcome water shortages was clear in Figure 4.

The creation of livelihoods is achieved by the mobilisation of local human and social capital. These are just two of the five capitals associated with the creation of livelihoods. Figure 6 is a diagram showing the five capitals. Impoverished communities are by definition short of all the capitals. Their local environmental, human and social capital have not been mobilised to create manufactured and financial capital.

The focus of this study is on communities that lack the adaptive capacity to mobilise their environmental, human and social capital to escape poverty. They have created little manufactured capital and cannot access financial capital.

Ideally a composite water poverty index will be weighted by the availability of the local capitals – environmental, human and social.
For planning and policy purposes it will be helpful to have information on the status of local manufactured capital and financial capital and on trends in availability.

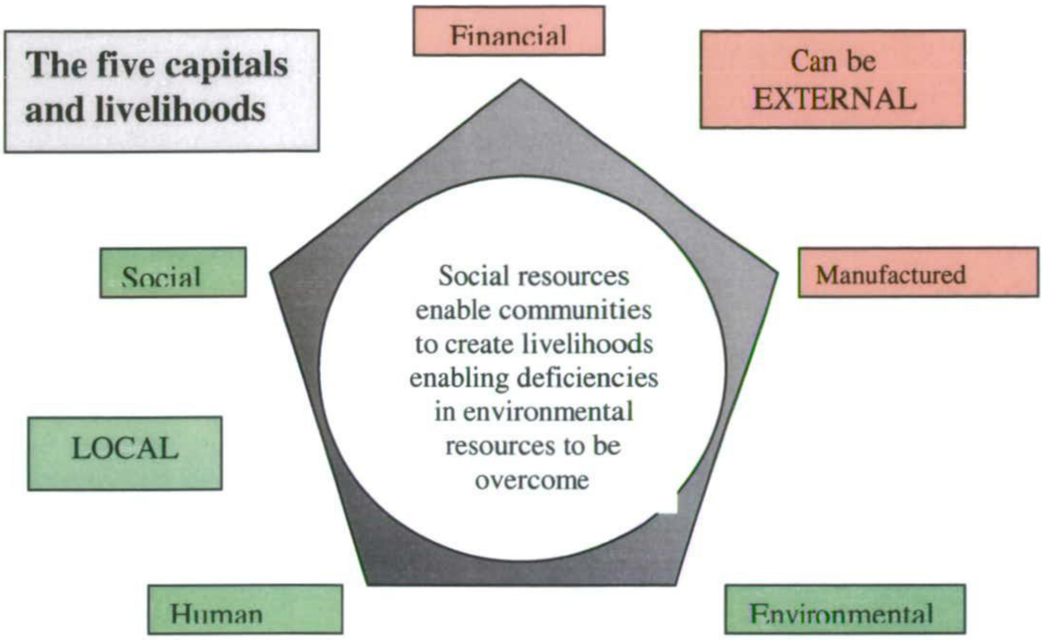


Figure 6 The five capitals and the creation of livelihoods that ameliorate environmental resource deficiencies.

Politics and governance: the diverse contextual factors which influence existing water management options and their potential for change and reform?

'Any attempt attempting to ameliorate the problems of those enduring water poverty must attempt to take into account the political and governance dimensions that explain water poverty and the poverty to which water poverty is subordinate.'

The most difficult factors to measure and evaluate in the area of poverty and water poverty incidence are those of governance and politics.

Governance is defined as the formal and informal institutions and arrangements that affect the relationship of a community with its resources, including its water resources, and with competing users. Such arrangements can advantage or disadvantage particular communities.

Politics is defined as the power relations between those who have allocative power over resources, such as water, and those whose access is affected by such power relations.

Politics is about the 'who'; governance is about the 'how' – in the definition – 'Politics is about who gets what, when and how'. (Laswell 1956)

Any attempt attempting to ameliorate the problems of those enduring water poverty must attempt to take into account the political and governance dimensions that explain water poverty and the poverty to which water poverty is subordinate. Appropriate priority should be given to the social and especially to the local and external political circumstances that have led the impoverishment of a community.

Conclusion

All indexes of social and economic activity are attempts to simplify the extremely complex. The above analysis is intended to demonstrate that the group of interdisciplinary environmental and social scientists, engineers and water resource professionals were aware of the complexity and the circumstances which make simplification challenging.

References

Allan, J. A., 2001, *The Middle East water question: hydropolitics and the global economy*, London: I. B. Tauris.

Laswell, x, 1956, *Who gets what, when and how,* xxx

Ohlsonn, L., 1999, *Environment, scarcity and conflict – a study in Malthusian concerns,* Göteborg (Sweden): University of Göteborg, Department of Peace and Development Research

Turton, A. R. and Ohlsonn, L., 2000, The turning of the screw: social resource scarcity as a bottleneck in adaptationto water scarcity, Occasional Paper 19, SOAS Water Issues group, Website – http://www2.soas.ac.uk.geography.waterissues

Appendix 9.3
Resource & Socio-economic Contexts- Contribution to Training Material

Tony Allan, SOAS, University of London

Water Poverty Index

Resource context and the socio-economic context

Training manual

WPI - concepts and contexts 1

'While water shortages do not determine the levels of poverty or prosperity enjoyed by a community, communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes and for secure livelihoods.'

WPI - concepts and contexts 2

Purpose

The purpose of this analysis will be to contextualise the water poverty index activity by providing a review of some important underlying concepts.

WPI - concepts and contexts 3

First, the water needs of individuals are defined and the diverse types of water shortage that a community can face.

Secondly, it will be shown that communities can endure water shortages with poverty. They can also experience water shortages and enjoy prosperity.

WPI - concepts and contexts 4

Thirdly, water shortages do not determine the levels of poverty or prosperity enjoyed by a community.
Communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes as well as for secure livelihoods.
Poverty is a socially and politically determined phenomenon. Poverty is not environmentally determined.

WPI - concepts and contexts 5

Fourthly, it will be shown that the long term challenge of allocating and managing adequate sufficient and safe water is fundamentally associated with the creation of secure livelihoods. Secure livelihoods enable access directly to the small volumes of water needed for drinking and domestic purposes and indirectly to the water intensive commodities that are also necessary for life and well-being.

WPI - concepts and contexts 6

Fifthly, it will be shown that attempts to ameliorate the problems of those enduring water poverty, ppriority will always have to address the social and especially the political circumstances - local and external - that have led to the impoverishment of the community.

WPI - concepts and contexts 7

Water poverty is an element of poverty.

The elimination of the political and socio-economic circumstances that consign a community to poverty will also enable the elimination of water poverty.

As a result one of the features of the WPI activity has been its focus on communities that are poor in socio-economic terms.

Regions that endure low rainfall or lack surface and sub-surface fresh water will not be the prime focus.

WPI - concepts and contexts 8

Water needs and types of water shortage

Water needs

Individuals and communities need water for food,
for domestic use including for drinking and cooking,
for livelihoods and for the maintenance of environmental services.

WPI - concepts and contexts 9

Very little water is needed for domestic purposes and for most livelihoods outside agriculture.

WPI - concepts and contexts 10

The main competition for water for human use is between big volumes of water diverted from the environment for food production and the even bigger volumes of water in the environment that sustain environmental services.

All water used by human systems is diverted from water flows and storages that, before human intervention, were in the environment.

WPI - concepts and contexts 11

Individual water use

For drinking One m3/person/year

For domestic use 100 m3/person/year

For food 1000 M3/person/year

Figures are lower for poor communities

WPI - concepts and contexts 12

Poor communities in the South tend to have less diverse diets - especially with less animal products - and as a result have lower water demands for the production of their food.

WPI - concepts and contexts 13

Self-sufficiency and types of water shortages

Water for food consumption is a complex issue in that the water used for crop production may be available naturally in the soil profile.

WPI - concepts and contexts 14

In some locations the naturally occurring soil water may be supplemented by freshwater diverted and/or pumped from surface and ground waters.

In arid, rainless, regions all the water used in agriculture may come from surface and/or groundwater.

WPI - concepts and contexts 15

First, water shortages may relate to the inadequate availability of the small volumes of water needed for drinking and domestic purposes.

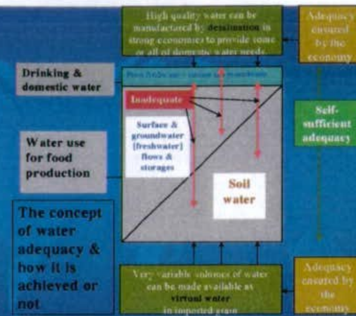
Secondly, water shortages may result from inadequate water availability for crop and livestock production in low rainfall areas.

WPI - concepts and contexts 16

Thirdly, water shortages may result from the local absence or inadequacy of fresh surface water and groundwater to supplement, or serve instead of, soil water.

These fresh waters may be local in origin or they may have been moved by gravity from sources thousands of kilometres away.

WPI - concepts and contexts 17



WPI - concepts and contexts 18

The diagram conceptualising water adequacy shows the diverse combinations of sources which satisfy need.

The diagram also shows that the water supply system is not closed for a community in a particular tract.

WPI - concepts and contexts 19

Both technology and trade can provide potential solutions for water supply deficiencies.

It is the impoverished circumstances of poor communities that prevent them accessing the 'supplementary' manufactured water and the traded virtual water.

WPI - concepts and contexts 20

Poverty and water poverty

Communities can face water shortages in economies enduring poverty.

They can also face and overcome water shortages in circumstances of prosperity.

WPI - concepts and contexts 21

The inadequacy of the water availability can be ameliorated by accessing water for drinking and domestic purposes via technology and trade.

Poor communities cannot ameliorate their water shortages in these ways because they cannot import virtual water and they cannot mobilise the engineering solutions.

WPI - concepts and contexts 22

It is the inability of poor communities to access technology and trade that consigns them to water poverty.

Local deficiencies in freshwater and soil water availability cannot be addressed successfully by the poor.

WPI - concepts and contexts 23

Relevance of the WPI

The communities for which the proposed water poverty index will be relevant are those that do not have the option of accessing manufactured water or traded virtual water.

WPI - concepts and contexts 24

Relevance of the WPI

The communities for which the proposed water poverty index will be relevant are those that do not have the option of accessing manufactured water or traded virtual water.

WPI - concepts and contexts 25

In this study the focus is on the communities and economies that are poor and therefore lack the means to fully ameliorate their water shortages.

WPI - concepts and contexts 26

Either water is not locally available or the communities lack the technical and economic capacity to access available local water.

They also cannot access water available outside their locality either by technology or via trade.

WPI - concepts and contexts 27

In this study the focus is on the communities and economies that are poor and therefore lack the means to fully ameliorate their water shortages.

Either water is not locally available or the communities lack the technical and economic capacity to access available local water.

They also cannot access water available outside their locality either by technology or via trade.

The two dimensions/orders of water poverty

Water shortages do not determine the levels of poverty or prosperity enjoyed by a community.

Communities that endure poverty will in almost all circumstances face problems in accessing sufficient safe water for domestic purposes as well as for secure livelihoods.

Poverty is a socially and politically determined phenomenon.

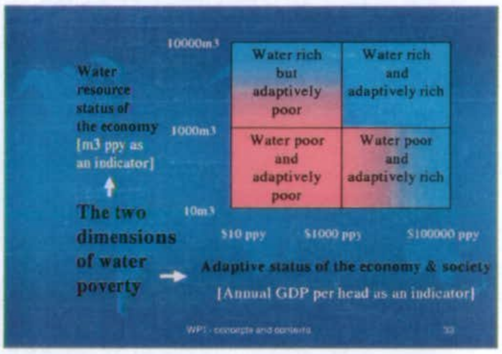
Poverty is not environmentally determined.

Water poverty has two dimensions.

First order scarcity is the shortage of water itself.

Second order scarcity is that of social adaptive capacity. The poor lack social adaptive capacity.

The absence of second order social adaptive capacity is many times more important than first order water shortage.



The focus of the WPI activity is on the impoverished communities who currently lack the ability to ameliorate their water supply problems.

Communities that lack the ability to ameliorate their water shortages lack 'social adaptive capacity'. (Turton and Ohlsson 2000)

Determining conditions and water poverty

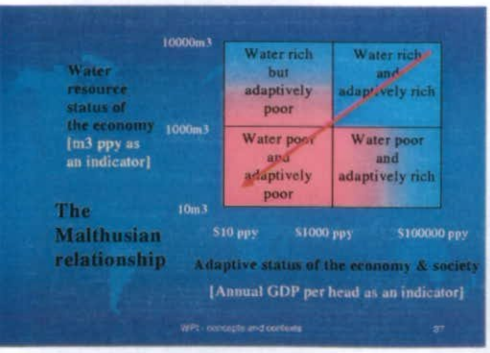
There is a tendency to assume that water shortages will determine poor economic outcomes.

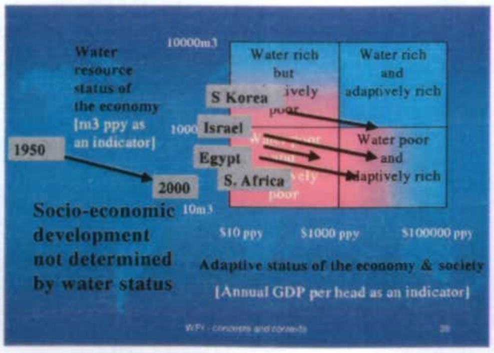
Such environmental determinism has long been discredited.

Shortages of water do not determine the levels of poverty or prosperity enjoyed by a community.

The following figures conceptualise:

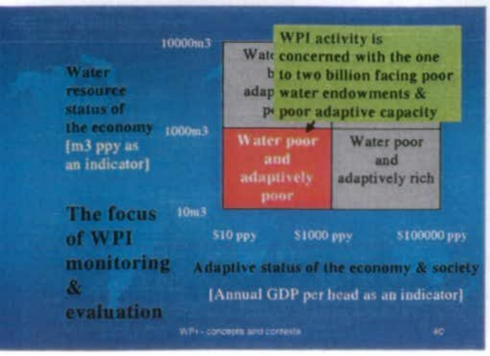
- water resource determinism.
- the next figure shows that water endowment does not determine socio-economic development outcomes





Both the water status and the social adaptive capacity are dynamic.

Communities and political economies have trajectories reflecting worsening local water resource availability - because of rising populations, and reducing poverty - because of adaptive amelioration.



Secure livelihoods ameliorate water poverty

The long term challenge of accessing, allocating and managing sufficient and safe water is fundamentally associated with the creation of secure livelihoods.

Secure livelihoods enable access:

- directly to the small volumes of water needed for drinking and domestic purposes
- indirectly to the water intensive commodities that are also necessary for life and well-being.

Economies which generate diverse and secure livelihoods can overcome water shortages.

Secure livelihoods enable access:
· directly to the small volumes of water needed for drinking and domestic purposes
· indirectly to the water intensive commodities that are also necessary for life and well-being.

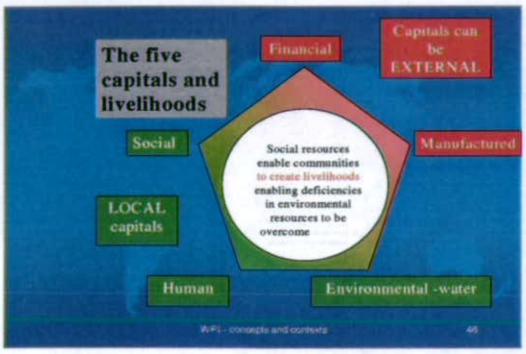
Economies which generate diverse and secure livelihoods can overcome water shortages.

The creation of livelihoods is achieved by the mobilisation of local human and social capital.

These are just two of the five capitals associated with the creation of livelihoods.

Impoverished communities are by definition short of all the capitals.

Their local environmental, human and social capital have not been mobilised to create manufactured and financial capital.



The focus of this study is on communities that lack the adaptive capacity to mobilise their environmental, human and social capital to escape poverty.

They have created little manufactured capital and cannot access financial capital.

Ideally a composite water poverty index will be weighted by the availability of the local capitals – environmental, human and social.

For planning and policy purposes it will be helpful to have information on the status of:
- local manufactured capital
- financial capital
- on trends in their availability.

Politics and governance

The diverse contextual factors which influence:
- **existing water management options and**
- **their potential for change and reform?**

'Any attempt to ameliorate the problems of those enduring water poverty must take into account the political and governance dimensions that explain water poverty and the poverty to which water poverty is subordinate.'

The most difficult factors to measure and evaluate in the area of poverty and water poverty incidence are those of governance and politics.

Governance is defined as the formal and informal institutions and arrangements that affect the relationship of a community with:
- its resources, including its water resources
- competing users.

Such arrangements can advantage or disadvantage particular communities.

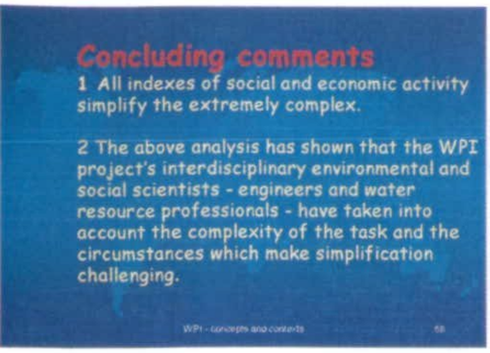
Politics is defined as the power relations between those who have allocative power over resources, such as water, and those whose access is affected by such power relations.

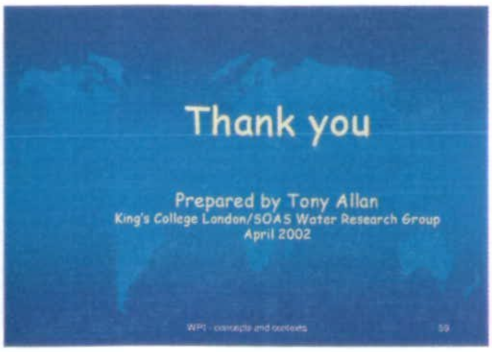
Politics is about the 'who'; governance is about the 'how' – in the definition:

'Politics is about who gets what, when and how'. (Laswell 1956)

Any attempt to ameliorate the problems of those enduring water poverty must to take into account the political and governance dimensions that explain water poverty and the poverty to which water poverty is subordinate.

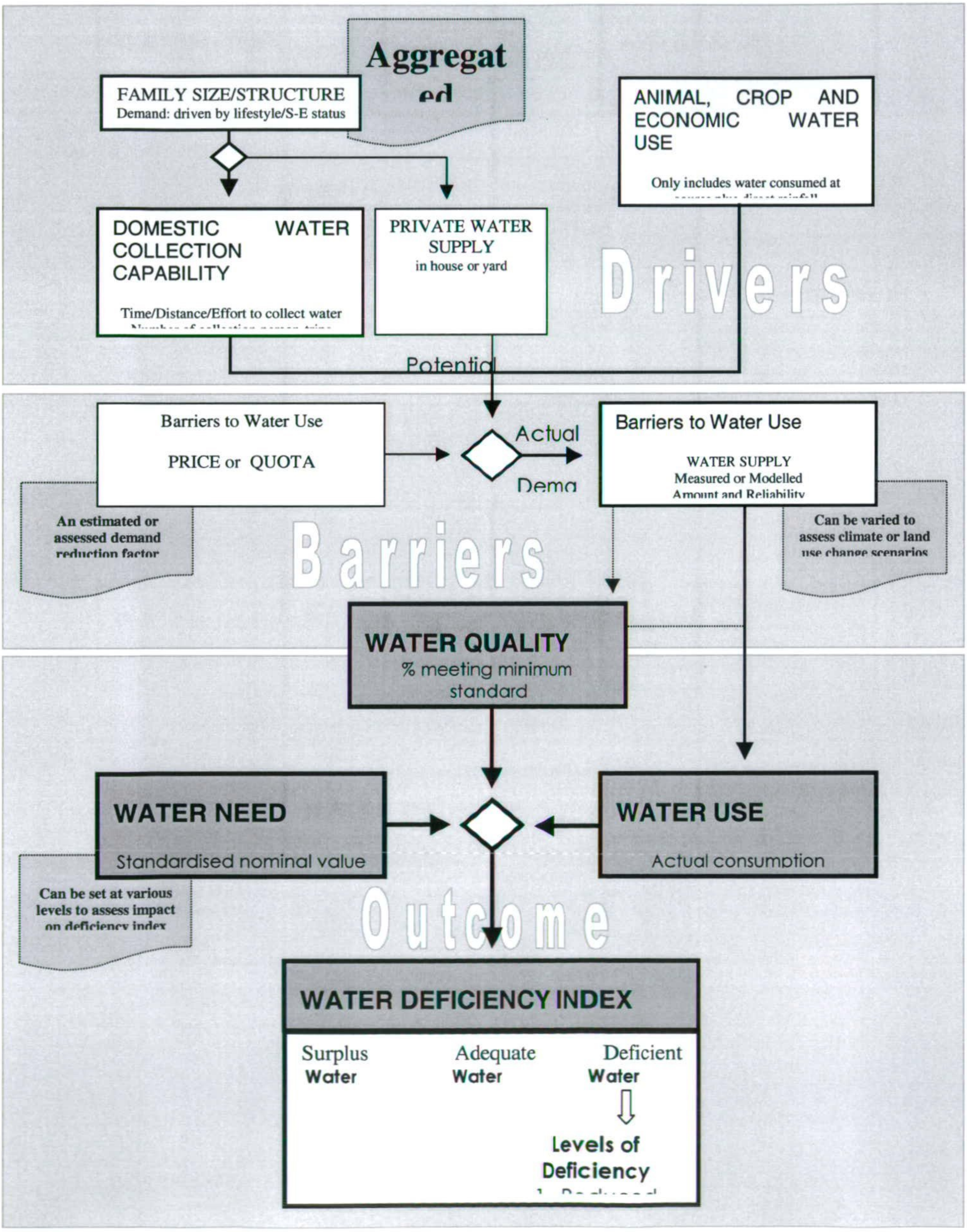
Appropriate priority should be given to the social and especially to the local and external political circumstances that have led to the impoverishment


Concluding comments
1 All indexes of social and economic activity simplify the extremely complex.
2 The above analysis has shown that the WPI project's interdisciplinary environmental and social scientists - engineers and water resource professionals - have taken into account the complexity of the task and the circumstances which make simplification challenging.
WPI - concepts and contexts
58


Thank you
Prepared by Tony Allan
King's College London/SOAS Water Research Group
April 2002
WPI - concepts and contexts
59

Appendix 9.4
A Water Deficiency Index for Primary Water Use

Michael Clark



A Water Deficiency Index for Primary Water Use

CRITERIA	Indicator Number	INDICATORS	Question Number
1. WATER USE Demand is driven by lifestyle/S-E status	1.1	*Per capita* daily water use [I]	
	1.2	N° water trips x container size [I]	
	1.3	N° livestock x average use (at source) [I]	
	1.4	Economic activity water use (at source) [I]	
	1.5	Private water supply (in house or yard) [I]	
	1.6	Number of people (age structure) [N]	
2. WATER QUALITY A potential barrier to water use and a driver of the deficiency index	2.1	% index based on proportion of water use (1.1) that meets minimum water quality standards (measured or perceived) *NB The assumption that only good water is used will under-estimate the actual use unless the index is weighted for this variation*	
3. PRICE or QUOTA A potential barrier to water use	3.1	% index based on estimated reduction of actual use over potential demand caused by imposition of a price or quota system	S/N
4. EFFORT COST The opportunity cost barrier of the time taken to collect water	4.1	% index based on estimated proportion of 12-hour day represented by total time of water trips for each individual concerned.	
	4.2	Effort includes a terrain and climate energy loss multiplier of the time or distance	S
5. WATER SUPPLY Potentially represents a limit on water collection and use	5.1	River flow in excess of whichever is the greater of (1) in-stream ecological requirement and (2) delivery flow requirement	S
	5.2	Groundwater availability	
	5.3	Dam + pond water availability	
	5.4	Capacity of piped water supply	
	5.5	Roof water harvesting	
	5.6	Water availability from vendors	
6. WATER NEED A driver of the deficiency index	6.1	Standardised nominal *per capita* need [I]	N

Water deficiency is the extent to which actual use of good-quality water matches assumed needs

S = Surrogate Data N = Nominal/standard Data

Calculation of Deficiency Index for Primary Water Use

Water deficiency is the extent to which actual use of good-quality water matches assumed needs

WATER DEFICIENCY = (WATER USE x WATER QUALITY) / WATER NEED

Strictly the index should be discounted by the opportunity cost of collection trip effort (4.1).

Variations could be calculated incorporating potential water use enhacements produced by modelling the addition of new or improved water supplies – thereby reducing the effort cost multiplier (4.1) and the supply limit (5).
NB The index could be separately calculated for dry/wet season and aggregated *pro rata*.

WATER USE = 1.1

Or	(1.2 + 1.3 + 1.4) x 2.1 x 3.1	(standardised to *per capita* using 1.6)
Or	(1.5 + 1.3 + 1.4) x 2.1 x 3.1	(standardised to *per capita* using 1.6)
Or	(1.6 x 6.1) x 4.1	(standardised to *per capita* using 1.6)

NB The alternative estimating routines may need standardising by a general or nationally-derived factor. This could be tested in Phase 1

Appendix 9.5
Poverty & Indicators Literature Review

Tim Fediw, CEH Wallingford

9.5.1: Definitions of Poverty

The study of poverty can be traced back at least as far as medieval times in England when poor laws were codified, however, empirical studies did not first come about until the turn of the century when pioneering studies were made by Booth in London and by Rowntree in York. Rowntree's study of 1901 was the first to develop a composite poverty standard, which included estimates for individual families based on estimates of nutritional and other requirements3. Since this time, approaches to poverty have changed and the scope of poverty studies expanded such that there are a number of interpretations of the meaning of poverty, accompanied by an even greater number of ways to calculate it.

The literature on poverty is so vast as to be impossible to list. Some of the key issues on poverty which have been examined include work on gender (Rosenhouse, 1989), definitions of poverty in the context of development (CDP,UNDP 2000; Sen, 1995; van der Gaag,1988), poverty thresholds (Orshansky, 1969), poverty measurement (World Bank 1996a; Lipton, 1988; Desai, 1995) poverty and welfare (World Bank, 1998) poverty and food (Malseed, 1990) poverty and politics (Uvin, 1994) poverty and health (WHO, 1992), poverty and vulnerability (CDP, 1999) and many more issues. While a lot of these issues may touch on the importance of water, very few attempts make the link explicitly between water and poverty, although the WHO/UNICEF Joint Monitoring Program does attempt to assess progress in the provision of clean water and sanitation.

Methods currently in use to assess poverty need to be considered in any attempt to link water resource assessments with poverty to form a Water Poverty Index. There are a number of approaches to this, including the *Poverty Line*, the *Headcount Index*, and the *Poverty Gap*. The *Poverty Line* is a consumption-based measure comprised of an element representing the minimum level of expenditure required for basic necessities, plus an extra amount for that required to participate in the everyday life of society. This varies considerably throughout the world, but for developing countries it is thought to range from $275 per capita per annum, to $370 per capita per annum. This measure indicates that over 1 billion people fall below the poverty line, roughly one third of the total population of developing countries. The *Headcount Index* expresses the number of poor, as defined by the poverty line, as a percentage of the total population. In a large country like China, a relatively low Headcount Index can actually mean very large numbers of people. The *Poverty Gap* is sometimes called the *Average Income Shortfall*, an assessment of the amount of money that would be necessary to bring every poor person up to the poverty line. This is expressed as the aggregate income shortfall of the poor, as a percentage of aggregate consumption.

All of these approaches are based on national income figures, and as averages, are not very representative of regional variations. As a result, they often fail to accurately

3 **Maxwell .S (1999)**

represent the levels of poverty experienced in different communities. Importantly, measures of per capita income are recognized to be inadequate to represent human wellbeing. While money measures may provide some means of comparison of economic activity, they take no account of non-monetary attributes of human wellbeing, nor of the value of women's household labor, nor indeed of depreciation of natural capital.

Henninger (1998) points out that *"no universally agreed upon definition of poverty has been established"*. However, he goes on to define poverty as being unable to secure a minimum standard of well-being or when peoples choices and opportunities to lead a tolerable life are denied or restricted. Henninger refers to eight broad components of poverty as identified by Jazairy et al (1992) These are; material deprivation which can include inadequate food supplies, poor health, lack of education, clothing, housing or fuel. Lack of assets, geographic isolation, alienation, dependence, or lack of decision making powers are also components of poverty. Additionally, vulnerability to external shocks such as floods or drought and insecurity in terms of the threat of being exposed to physical violence are also identified.

Poverty is therefore multidimensional and similar factors have also been identified when local people are asked about poverty. Issues such as being free of obligations to make children work for others or the ability to decline demeaning jobs are two examples of elements that were often identified.

Maxwell (1999) identifies what he calls nine *"fault lines in the poverty debate"*. Firstly, poverty can be measured at an individual or household level depending on what the study aims to highlight. Poverty is often defined in terms of private consumption, however, the inclusion of publicly provided goods and services may be more realistic. Some measures of poverty are restricted to monetary measures. A clear fault line is said to exist between such measures and those that include factors such as self-esteem or participation. Fault lines also exist between snapshot or time-lines measures, actual and potential measures, stock or flow measures, absolute or relative poverty, input or output measures and objective or subjective perceptions. Whilst there is no right or wrong answer, it is commonly agreed that welfare obtained from public provided and common properties should be included. Additionally, it should be noted that poverty affects individuals, it is therefore necessary to involve these individuals when it comes to defining poverty.

Rowson (2001) points out that *"a focus on income is not always helpful when we are trying to think of ways to tackle poverty"*. Rather, one should look at what it means to be in a state of poverty such as access to health services, clean water and sanitation, education and mortality rates. A measure of poverty that includes these factors is therefore broader than a basic income measure. This measure is known as Human Poverty as appose to Income Poverty and might include factors such as lack of income and assets, isolation, physical weakness, powerlessness and vulnerability.

The definition of poverty that is frequently adopted in the UK is based on the European Union working definition of poverty which defines it as: *"Persons, families and groups of persons whose resources (material, cultural and social) are so limited as to exclude them.* This definition is one of relative poverty, rather than absolute poverty as it defines poverty in terms of derivation, from a certain standard. In this sense, the standard of living that constitutes poverty will be far higher in a developed country than in one which is less developed.

Absolute poverty describes poverty *"without reference to social context or norms and is usually defined in terms of simple physical subsistence needs but not social needs"*. Furthermore *"absolute definitions of poverty tend to be prescriptive definitions based on the 'assertions' of experts about people's minimum needs"4*. The World Bank employs an absolute definition of poverty in the form of a poverty line. The poverty line, or minimum income required, is deemed as (US)$1 per day and any person living on less than this per day is seen to be in poverty. Such a definition does not therefore encompass social factors.

Gordon and Spicker (1999) summarise a number of contributions that have been made to the argument between the merits of absolute and relative descriptions of poverty. Sen (1983) argues that *"there is an irreducible absolutist core in the idea of poverty. If there is starvation and hunger then, no matter what the relative picture looks like- there clearly is poverty"*. Townsend (1985) though, claims that this core is itself relative to society.

Fonkem (1999) points out that an absolute definition of poverty may be insufficient as it does not take into account what is a *"reasonable and acceptable as a style of living"* in a particular place or at a particular time. Circumstances normally change from place to place and from time to time. For this reason two standards of poverty as put forward by Townsend should be employed. A "national-relational" measure should be used based on relative poverty according to a particular society along with a "world-relational" measure based on more absolute standards. This method allows poverty between different societies to be better compared. The argument between these too broad definitions is arguably less important than the need to identify those in need and to identify the issues that lead them to be in a deprived state.

The Canadian Council on Social Development {CCSD} (2001) recognises that *"virtually all measures of poverty are relative"* as whether or not someone is seen as poor depends, to some extent, on society norms. For this reason, from 2002 onwards, CCSD is introducing what it terms the Market Based Measure (MBM) for defining poverty in Canada. As well as encompassing basic, absolute, human needs, this measure also includes factors that represent what is needed to achieve "creditable" community norms.

This method has come in for criticism, as its calculation will involve large subjective judgements being made on the part of government officials, in particularly when it concerns what factors should be included in the basket measure. For this reason, it is recommended that the formation of the MBM should have a participatory and transparent approach.

Boyle (1999) attempts to show that there is a satisfactory resolution to the long standing argument between absolute and relative definitions. O'Boyle begins by renaming these definitions as "minimum living standard" and "income distribution standard" respectively as these terms more accurately reflect what each definition is

---

4 **Gordon .D, Spicker .P (1999)**

explaining. He believes that a great improvement in the way poverty is defined and measured can be achieved if more consideration is given to the reason why poverty is two-dimensional.

To this end, O'Boyle suggests that a single definition of Poverty can be achieved which encompasses both the minimum living standard and the income distribution standard definitions. Furthermore, this improved definition should be convenient. consistent, direct, comprehensive and widely acceptable.

From this a three-part classification of "poor" can be created. Those who are found to be poor under both the income distribution and minimum living standard definitions are defined as "poor". Those who are identified as poor under one or other of the definitions are identified as "marginally poor", whilst those who qualify under neither are "non-poor". This system helps to address the depth of income poverty and has been shown to be widely accepted by the public as it confirms to their values regarding the nature of poverty, which is essential for it to work.

In addition to this, O'Boyle cites the cause of controversy over definitions as being down to the mutual failure of the advocates of absolute and relative definitions to recognise the premises they have used in shaping their definitions. This failure leads the advocates of both camps failing also to recognise those of the other party.

There are numerous variations of the definition of poverty and arguments relating to which one is most relevant. It seems clear though from this literature review that any meaningful quantification of poverty should include both aspects of absolute and relative definitions. In absolute terms, there is always a minimum level of certain resources that people need in order to survive. Access to water resources is likely to be a major determinant of absolute poverty. Additionally though, it is necessary to place things in a cultural and more localised context if the definition of poverty is to be meaningful to both the researcher and the very people that it is defining.

9.5.2: Indicators & Techniques of Creating Them

Indicators provide a convenient method of summarising large amounts of data into a single value, which can then be compared over time or between countries and regions to reveal changes and differences. They also provide a means of communicating information about progress towards a goal (such as sustainable resource management5) in a significant and simplified manner. In the U.K. the Consumer Price Index (Retail Price Index) provides a good example of an indicator. Data is collected on the price of goods and services by measuring "baskets of goods" that are representative of consumer spending patterns. The items in each basket are known as price indicators and are combined together to produce the index, which gives an average measure of the change in prices of goods and services. Thus, the indicator provides a picture for the change in overall prices based on a selection of goods only.

How an indicator is constructed can be illustrated with a simple example. Take a basket with three goods: bread, meat and salt for two years:

Prices in (£) pounds per kg:

	1990	2000	% Change
Bread	0.75	1.05	40
Meat	5.00	6.00	20
Salt	0.25	0.40	60

Suppose that in 1990 the typical consumer bought 100kg of bread, 200kg of meat and 4 kilos of salt:

Cost of 1990 basket is:	100*0.75+200*5+4*0.25=	£1076
Cost of 1990 basket in 2000 is:	100*1.05+200*6+4*0.4=	£1306.6

The total increase in the cost of the 1990 basket is 21.4%, which is much lower than the average price increase. This is because although meat went up in price by the lowest percentage, it is the most important item in the basket and carries the greatest weight of total spending. Hence, an indicator can reflect the weights given to the different aspects that make it up.

Single indicators such as the Consumer Price Index can be used alone, however, some indicators are more useful when used together. The OECD, for example, uses a working set of core indicators in measuring development progress. Indicators covering a large range of factors that contribute to development such as education, health access to safe water and environmental sustainability are used to measure overall development progress. The Human Development Index is an average of three separate indicators and is calculated annually based on the relative performance of each country in human development. The Water Poverty Index can be constructed in a similar way, bringing together information on resources, access, capacity, use and environment for each country to allow comparison internationally.

5 For more information on indicators and natural resource management, see Walmsley, J (2002)

There is a considerable literature on the use of indicators (Anderson, 1991,DoE. 1996, Hammond et al, 1995, Rennings and Wiggering, 1997 Rogers et al., 1997, Salameh. 2000, Streeten, 1996, World Bank, 1998) While many of these allow policy makers and funding agencies to monitor progress for environmental change or poverty elimination, those of the Committee for Development Policy of the United Nations are particularly of use. None, however, recognizes the unique importance of water to all forms of life. Without adequate and efficient water supplies, i.e. where there is *'water poverty'*, any measures to reduce income poverty are unlikely to be successful.

The challenge of a good indicator is to be able to create an index or an alternative form of representation, which is characteristic of a whole country or region using a relatively small sample. *"Indicators must simplify without distorting the underlying truth (and) reduce the complexities of the world to a simple and unambiguous message"*6Thorough design of the indicator is therefore essential in order to ensure that the indicator achieves this accurately. A number of examples of different approaches to the creation of indicators, in particular regarding poverty, will be discussed below.

As part of the project *"Improving Methods for Poverty and Food Insecurity Mapping and its Use at Country Level"* the FAO, CGIAR, UNEP and GRID, in Henninger (1998), have sought to construct poverty maps, based on survey data, to provide an indicator of the levels of poverty *(http://www.povertymap.net/)*. The data used can come from a variety of sources each of which have advantages and disadvantages.

Whilst census data allows a fine resolution map to be created, information is often out of date. Bottom-up approaches have the advantage of allowing participants to introduce their own criteria but lack of structured questions can make it hard to extrapolate results and compare information. Household surveys to some extent provide a compromise although they produce maps of only adequate resolution.

These Maps are constructed using GIS and can deliver clear information on the spatial distribution of poverty. The use of maps to represent poverty was found to have a number of benefits. Use of GIS made it easier to integrate data from various sources and disciplines, which, if a conventional index approach had been used, may have been harder. This mapping technique also allowed geographic areas suffering from poverty to be clearly identified. Using this information, the allocation of resources can be improved and used to target anti-poverty programmes.

Using a map rather than figures has distinct advantages when it comes to developing countries, as they are more easily understandable to a wider audience. Mapping therefore provides a powerful tool for decision makers. Additionally, poverty mapping allows the limits of analysis to be expanded to include ecological factors and allow new variables to be included which were not part of the survey.

Mapping can help provide new insights into the causes of poverty that could not be found by conducting a household survey alone. Identifying physical isolation is one example. Mapping also has the advantage that it can be applied at the national and

6 World Health Organisation: Environmental Health Indicators.

sub-national level. High-resolution maps can be used to support efforts to localise decision-making.

Henninger (1998) also recognises that poverty indicators can be grouped into three major dimensions of economic, social and enabling environment. Under the economic dimension either current consumption expenditures, income or wealth can be used. Social aspects of well-being can include measures of nutrition, energy, sanitation and water availability, family planning or education. Such indicators have the advantage that they can be used as a proxy for the constraints of human welfare but have the problem that they can be hard to aggregate. Although less used at present, enabling environment indicators can provide important information. These can include level of empowerment, governance, participation and transparency of the legal system.

The United Nations7 (1995) use Multiple Indicator Cluster Surveys (MICS) as a method of producing indicators about the population when other data such as census data or sample survey data is not available. MICS involve surveying groups or clusters of households within the population to produce a nationally or sub-nationally representative picture.

Good survey design is essential to ensure that the correct data is collected and that questions are unambiguous. As part of this design it is necessary to ensure that the interviewers are trained to a high standard so that all interviewers conduct the survey in the same way. Pre-test questionnaires should always be carried prior to the main survey. This can highlight a number of problems such as if respondents are willing to answer questions in the form they are presented, whether questions are misinterpreted and whether or not the questionnaire has been effectively translated. This can also give an indication about the time it will take to carry out the survey and any additions that may need to be made to the questionnaire.

A number of problems can occur with MICS. Large and small communities may have an equal chance of being selected when in fact the larger community should have more chance. A technique called "Probability Proportional to Size" can be used to overcome this. Similarly, key groups with special needs may happen to be excluded from the survey as a result of randomness. This can be overcome by stratified sampling. Due to clustering, not all households are selected independently of each other and may therefore have similarities. This is known as design effect and can be overcome by increasing the sample size.

The effectiveness of MICS was later evaluated by UNICEF (1997) who concluded that, additional training and technical assistance was required, lack of language skills were a problem and that further capacity building within countries is required.

The World Health Organisation (WHO)8 recognise that environmental health indicators must satisfy a number of different criteria to be effective. They must provide a meaningful summary of the conditions for non-experts as well as being testable and scientifically sound. Indicators need to be sensitive to real changes but also must not be affected by "noise" to any great extent. When these criteria are

7 UNICEF (1995)
8 World Health Organisation: Environmental Health Indicators:

added to the need for cost effectiveness, the types of indicator that can be developed are limited to a certain extent. One of the greatest conflicts is balancing the need for current, high resolution data with the cost of collecting. Furthermore, different indicators demand different qualities from data, data is therefore often not interchangeable. It is also vital to ensure that indicators do not stand still, they must be adapted over time to reflect the changes that are happening in the world.

Whilst different indicators need to be developed for different situations, it is not wise that everyone develops their own indicators as this may result in a duplication of effort and ambiguity over which indicator to use. The paper therefore sets out some clear guidelines on indicator design and provides a summary list of environmental health indicators. Of particular relevance to the construction of the Water Poverty Index are "access to basic sanitation", "access to safe and reliable supplies of drinking water", "connections to piped water supply" and "outbreaks of water borne diseases".

The World Resources Institute (2001) identified similar problems when developing indicators to assess the extent of risk to health that people face from environmental threats. National level data is often lacking or incomplete which necessitates the use of less accurate proxy measures. Similarly, Gustavson et al. (1999) find that *"the poor quality, inaccessibility and irrelevance of existing data are pervasive constraints to reliable indicator modelling"*. Greater focus is therefore required on modelling frameworks that can use incomplete data sets or qualitative information, and linking this to existing quantitative models.

Elbers, Lanjouw and Lanjouw (2000) attempt to reconcile these problems with data by exploiting the beneficial attributes of two different types of data. They combine the detailed information about living standards available from small household surveys with the comprehensive coverage of census data. Elbers, Lanjouw and Lanjouw show that by combining the strengths of each of the above, the estimator of welfare that they are constructing, can be used at a disaggregated level. This approach leads to a result that can be clearly interpreted and can be expanded in a consistent way to any welfare measure.

The technique employed is to use the detailed household survey data to estimate a model of per-capita expenditure. The parameters that result are then used to weight the census based characteristics of a target population in determining its' expected welfare level. Simulation, numerical integration and distributional approximations are used to convert census data into usable figures.

Using this method on data from Ecuador, some welfare measures are derived which are found to be very reliable for populations varying in size from 5,000-500. Although it has been suggested that chance may have it that there is an especially good overlap between data in Ecuador, research elsewhere suggests that Ecuador is not a special case. Employing such a method may therefore provide useful welfare indicators for other countries.

Hentschel and Lanjouw (1998) investigate the use of total consumption as a household-level welfare indicator. This method has often been criticised, as it does not take into account the differing access to, and cost of publicly provided services. Hentschel and Lanjouw discuss how adjustments can be made to this indicator to take these factors into account. Careful analysis and correction of markets for basic services must be undertaken when deriving welfare measures due to some markets being highly subsidised. Meaningful welfare values can be obtained if this is carried out.

Degreene (1994) points out that many economic indicators have lost their predictive capability and that most social indicators are collected outside of a theoretical framework. Instead, Degreene argues that ecological and large scale natural environment indicators can *"provide more immediately powerful and convincing evidence of instability and structural change"*.

References

Anderson, V. (1991): *Alternative Economic Indicators*. Routledge, London and New York.

Canadian Council on Social Development (2001): at: Ccsd.ca/pubs/2001/povertypp.htm. October 2001.

Degreene .K. B (1994): *The Rocky Path to Complex-Systems Indicators*. Technological Forecasting and Social Change, Vol 47(2). Oct. 1994.

Department of the Environment UK (1996) *Indicators of Sustainable Development for the UK*. HMSO, London.

Desai, M. (1995): *Poverty, Famine and Economic Development*. Edward Elgar, Aldershot.

Elbers .E, Lanjouw .J.O, Lanjouw .P (2000): *Welfare in Villages and Towns*. Tinbergen Institute Discussion Paper, TI 2000-029/2.

Fonkem .R.N (1999): *In Cameroon, a Female-Centred Organisation Works to Conquer the Poverty of Rural Women*. United Nations Chronicle, Vol. XXXVI, No.1,1999. (http://www.un.org/Pubs/chronicle/1999/issue1/0799p70.htm)

Gordon .D, Spicker .P (eds) (1999): *The International Poverty Glossary*, Zed Books, London.

Gustavson .K.R, Lonergan .S.C, Ruitenbeek .H.J (1999): *Selection and Modelling of Sustainable Development Indicators: a Case Study of the Fraser River Basin, British Columbia*. Ecological Economics, Vol.28(1). Jan 1999.

Hammond, A., A. Adriaanse, E. Rodenburg, D. Bryant, and R. Woodward (1995): *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*, Baltimore: World Resources Institute.

Henninger (1998): *Mapping and Geographic Analysis of Human Welfare and Poverty- Review and Assessment*. World Resources Institute, Washington, D.C, U.S.A

Hentschel, .J, Lanjouw P.(1998): *Household Welfare Measurement and the Pricing of Basic Services*. World Bank, Washington D.C

Jazairy .I, Alamgir .M, Pannuccio .T (1992): *The State of World Rural Poverty, An Inquiry into Its Causes and Consequences.* New York University Press for International Fund for Agricultural Development, New York.

Lipton, M. (1988): *The Poor And The Poorest.* World Bank, Washington, DC.

Malseed, J. (1990): *Bread without dough: understanding food poverty.* Horton, Bradford.

Maxwell .S (1999): *The Meaning and Measurement of Poverty.* Overseas Development Institute, http://www.odi.org.yk/breifing/pov3.html

O'Boyle (1999): *Toward an Improved Definition of Poverty.* Review of Social Economy, Vol. LVII, No.3, September 1999.

OECD: *Measuring Development Progress, A Working Set of Core Indicators,* http://www1.oecd.org/dac/Indicators/htm/slides.htm

Orshansky, M. (1969): How poverty is measured, *Monthly Labor Review*, Vol. 92, No. 2, pp. 37-41

Rennings, K. and H. Wiggering (1997): 'Steps towards indicators of sustainable development: Linking economic and ecological concepts', *Ecological Economics* 20, 25-36.

Rogers, P.R., Jalal, K.F. Lohani, B.N. Owens, G.M., Chang-Ching Yu, Dufournaud, C.M and J.Bi (1997): *Measuring Environmental Quality in Asia.* Harvard University Press, Harvard.

Rosenhouse, M. (1989): *Identifying the Poor: Is Headship a Useful Concept?* LSMS Working Paper No. 58. World Bank, Washington, DC.

Rowson (2001): *Poverty and Health.* The Student British Medical Journal. June 2001.

Salameh, E. (2000): Redefining the Water Poverty Index. *Water International* 25 no.3 Pp 469-473

Sen .A.K (1983): *Poor, Relatively Speaking..* Oxford Economic Papers, No.35.

Streeten, P.P. (1996): Human Development – the Debate about the Index, *International Journal of the Social Sciences*

Townsend .P (1985): *A Sociological; Approach to the Measurement of Poverty: A Rejoinder to Professor Amartya Sen.* . Oxford Economic Papers, No.37.

UNICEF (1995): *Monitoring Progress Toward the Goals of the World Summit for Children: A Practical Handbook for Multiple-Indicator Surveys.*

UNICEF (1997): *Evaluation of Multiple Indicator Cluster Surveys: Division of Evaluation, Policy and Planning.*

Uvin, P. (1994): *The International Organisation of Hunger.* Kegan Paul, London.

Van der Gaag, (1988): *Confronting Poverty in Developing Countries: Definitions, Information and Policies.* LSMS Working Paper No 48. World Bank, Washington, DC.

Walmsley, J (2002): *Overview: Sustainability Indicators for Catchment Management in South Africa.* Water Research Commission, South Africa.

World Bank (1996a): *Poverty Monitoring and Analysis Systems.* World Bank, Washington DC.

World Bank (1998): *Standardised Welfare Indicators* World Bank, Washington DC.

World Health Organisation (1992): *Health for All Database.* WHO, Geneva.

World Health Organisation: *Environmental Health Indicators: Framework and Methodologies*, p2. See: http://www.northampton.ac.uk/ncr/who/index.html

World Resources Institute (2000): *Linking Environment and Health: Indicators of Environmental Threats to Health.*

Appendix 9.6.1
Taking the WPI Further

Ms Anna Maria Giacomello & Dr Caroline Sullivan, CEH Wallingford

The structure of the composite approach is very similar to the multi-criteria approach. As the MCA various elements (criteria) of different unit are aggregated together by first scoring them and then adding them using a weighting system.

Unlike the MCA, no costs are included in the aggregation. WPI values the impacts that a certain policy could have on the criteria such as Access, Use, Capacity and Environment, but it does not consider the cost of this policy.

However, Governments do not need only an instrument that helps them to identify which villages are more water poor, they would also like to know the most cost effective way of reducing water poverty in these villages.

A way of aggregating the costs of schemes and the WPI results it is to do a cost effectiveness analysis.

The WPI is calculated for each of the villages as follows:

$$WPI_{i,t} = w_{r,i}R_{i,t} + w_{a,i}A_{i,t} + w_{c,i}C_{i,t} + w_{u,i}U_{i,t} + w_{e,i}E_{i,t} \qquad (1)$$

where

$WPI_{i,t}$ is the WPI for the village i at the year t;
$w_{i,j}$ is the weight associated to the criterion j for the village i;
$X_{i,t}$ is any of the five component for the village i in the year t.

In the way the weights have been used in the formula, they do not change over time; however this is arguable as preference actually changes over time. An interesting way to structure the weights is to express them in function of time and the level of the criterion they are associated to. The weights could be calculated as follows:

$$w_{i,x} = f(t, X) \qquad (2)$$

The equation above captures the fact that the weight given to a criterion is very dependent on the state of the criterion. If we ask people to give weights to the five composite components and the current state of the environment is very bad, they would give much more weight to it than they would have done if the state of the environment was better.

The cost effectiveness can be constructed in the following way:

$$CEA_t = \frac{\sum_{t=0}^{n} \frac{c_t}{(1+r)^t}}{\sum_{t=0}^{n} \frac{WPI_{t,i}}{(1+r)^t}} \tag{3}$$

where

c_t is the cost of the scheme in year t; these are discounted using the discounting rate r.

It could be argued the fact that the WPI has been discounted in the cost effectiveness formula (3). In reality not all components would be discounted, the number of people suffering from diarrhoea would not be discounted, whereas the component wealth would be discounted.

In order to calculate the cost effectiveness of a scheme we need to predict the impacts that a scheme has on all the WPI components. In fact, when a scheme is implemented to improve one of the components (for example, access), it has also an indirect effect on the other components.

It would be very interesting to identify a list of possible schemes that could be applied to reduce water poverty and then estimate the impact that these schemes could have on the WPI components over a certain period of time. This would allow us to identify the scheme that is more cost effective in reducing water poverty in a village.

From WPI towards water pricing

How we have seen, the WPI (Water Poverty Index) is a very effective tool to prioritise villages and countries on the base of their water poverty/scarcity. This index is able to flag out the areas that are more in need of water to reduce significantly the level of poverty. So the WPI can be used to identify the villages/country that are unable to achieve the minimum standard of living which better water provision would be able to improve.

Once a reasonable water consumption level is achieved by a household, it is essential to allocate water among various uses in the most efficient way if sustainable development is to be achieved. Agriculture, industry, domestic use, environment compete all together over the water use. At this stage the WPI cannot be used to allocate water across users, to do that we need to give to water a price that reflects its effective value.

Value of water

Water is an essential and irreplaceable resource on which our life support system depends. Its value has long been the subject of philosophical debate which, within the economic discipline, has been described in the '*diamonds and water paradox*', which arises due to changes in the levels of marginal utility associated with different levels of consumption. Values in society are based on utility and preferences, and while we may have a low level of marginal utility for extra units of water, we all have high utility for the initial levels of consumption associated with the basic human water requirements. Nevertheless we all agree that the price of water is lower than the price of diamonds. This demonstrates the fact that price, value and cost are not the same thing. This is particularly important when it comes to thinking about water management, and water pricing.

The value of water varies considerably from place to place and also from use to use. For example, for a given quantity of water, the use value from use for navigation may be much less than that from use in a textile plant. For irrigation, the value of the water may be much higher if the crop grown is carrots than if it were wheat. Crop selection has a big impact both on the use value of water, and also on the level of water use itself. Since agricultural water use takes the largest share of water allocation in most economies, the value generated from it needs to be investigated, and methods introduced to regulate its use

One accepted way of valuing water is through an examination of what values other alternative uses could generate. This is known as the *opportunity cost* value of water, and can be used as way of improving water allocation decisions. Unfortunately this is not straightforward, as it is often the case that such calculations would suggest that the cultivation of higher value (non-food) crops would lead to a reallocation of water for that purpose. If this is taken to the extreme, then water would be allocated in such a way as to act as a disincentive for food production, causing a problem of food security. Nevertheless, the opportunity cost methodology does give some insight into the value of water.

Water pricing

For long time water has been considered a free good and sometimes still is. This has led to overexploitation of water resources and aquifers in some areas, causing serious environmental damage, and possibly leaving future generations with problems of water availability. To remedy this situation, payment for water services is now seen as an essential instrument in achieving sustainable use of water resources. In fact, water pricing has the potential to reduce water scarcity as it creates incentive on water demand to conserve and allocate water efficiently.

The issue of water pricing is a very controversial one, with much debate arising over both the ethics and practicalities of pricing water. Water pricing should be set to accomplish two roles: *financially*, it should be the main mechanism for cost recovery; and *economically*, it should be able to signal the scarcity value and opportunity cost of water and allocate water efficiently within and across water subsectors.

In many countries water users pay for water, but water rates are often set at a level which is both too low to cover the cost of the water supply, or to encourage efficient use of water. This is often due to a combination of subsidised water rates to some sectors, and the use of 'flat rate' instead of 'volumetric' price systems. States that subsidise water rates effectively create negative distortions in the water market. Often irrigation and domestic water supply systems are provided at subsidised rates, because in so doing, they deliver public goods in the form of secure food supplies, public health, or legitimacy for the government. A problem arises however when low water charges and poor cost recovery lead to declining funds available for investment in water infrastructure, and poor maintenance of existing systems. This leads to inefficient water allocation, and growing conflicts between those with and without access to water, and to the problem of unaccounted-for water. Unaccounted for water is one of the major problems for organisations trying to develop financially sustainable water delivery systems. Better understanding of patterns of water use will help to address this.

The costs of establishing a volumetric water delivery structure in rural areas is often prohibitive, especially in large and spatially distributed surface systems serving many smallholders. As a results, in most irrigation systems, area-based fixed rates are dominants. In urban environments, the problem of setting a water price or tariff on a volumetric system is relatively simple. In such a situation, it is usual that a system of graduated water rates is introduced (a block tariff), and this usually means that the first volume of water used is priced at a very low level, ensuring that the needs of the poor are met. At higher consumption levels, a higher tariff can be applied. In this way, it will be possible for large scale users to subsidise the cost of small scale ones, and so in some way compensate them for any 'social costs' associated with water provision schemes.

How to estimate water rates

The main four characteristics we should look for in calculating a water pricing are the following:

1. If it creates economic efficiency
2. If it allows cost recovery
3. If it minimises transaction costs
4. If it fulfils social objectives (such as recreational and environmental services provided by water).

The problem is that these objectives are not always easy to reconcile with one another. For example, the use of marginal costs will led to an efficient allocation of water, but will not always lead to cost recovery. On the other hand, a uniform national tariff might rule out the possibility of allocating water efficiently among various users. Inevitably, a trade-off is required and no single method of water pricing is necessarily the optimum. The appropriate pricing methodology will depend, among other things, on the structure of society and industry, and on the availability of appropriate data and information for both the water providers and regulatory authorities.

Since, the financial role of water pricing is to permit a water provider to recover the cost of supplying water to the users, all the supply costs should be used to calculate the water rates, including the operation and maintenance costs, and capital costs of constructing the system.

The economic and allocative role of water pricing requires water rates to capture the *scarcity value* and to equalise the *opportunity cost* of the resource (the value of water in its next best use) for the various uses. In order to achieve such goals it is essential to include all the environmental and social cost/benefits associated with supplying water to the users.

Alternative ways to set a price level for water

To estimate the water rates, certain types of costs can be used:

Average costs. When using these as a guide to price setting, it is assumed that the cost of the next unit of water will be the same as the average cost of water currently supplied. The problem with this technique is that it fails to capture the scarcity value of water risking market failure and consequently inefficient water allocation. This method will ensure cost recovery.

Marginal costs In order to achieve allocative efficiency, price should be based on marginal costs (the cost of the last unit provided). However, marginal costs are an abstract concept, in practice, marginal costs are measured as *incremental costs*, which can be defined as the forward looking additional costs caused by the provision of a defined increment of output (this is not the same as a unit). A distinction is also made between short and long run incremental costs (SRIC and LRIC). The SRIC is used in practice to calculate the short run marginal cost (SRMC) and LRIC is used to calculate the *Long run marginal costs (LRMC)*. The problem in using the SRMC pricing is that the cost of providing the next unit of water from a given supply system uses only operational costs. It does not include the long term investment in the industry, and therefore underestimates the true costs of any additional cubic metre of water provided.

The LRMC is measured over a long period to allow the firm to adjust the volume of all of its factors of production, so as to supply the additional increment of output at minimum cost. In theory, by using LRMC water will be efficiently allocated over time, and among its various users. So water pricing should ideally be based on the LRMC. In practice, the major problem with *LRMC pricing* is that much, well organised information and data is required to accurately estimate the LRMC for a water distribution network. If the method is to be used, particular care should be given to calculating the LRMC, in order to ensure that all supply costs are recovered.

Price reform can be effective and practical only with the necessary institutional and technical conditions that enable cost recovery and allocative roles for water pricing policy. Institutions conditions include independent water pricing agency and regulatory body, and clearly defined water rights. Technical conditions include volumetric delivery and infrastructure to move water over space and type of use.

Conclusions

WPI and water pricing could be used in combination. With the WPI we will be able to target the areas more in need of water and identify the most cost effective way of reducing water poverty. Once the minimum water requirement for living is achieved, water pricing should be used to allocate water in a more efficient way among its users.

Appendix 9.6.2
Calculation of the Composite Index Approach at the Micro Level

Ms Anna Maria Giacomello and Dr Caroline Sullivan, CEH Wallingford

The full text for this background paper is contained within Appendix 1.2

Appendix 9.7
Water and Conflict: Background Notes for the Water Poverty Index Assessment

Peter H. Gleick 9

The issue of environmental security has been debated now for more than a decade, beginning as the Cold War began to wane, and the importance of the environment and resources to international politics began to be recognized. The argument and focus of this debate has now shifted from "whether" there is a connection to "when," "where," and "how" environmental and resource problems will affect regional and international security. There is also a long way to go before nations or regions produce a common policy agenda or set of initiatives that truly incorporate environmental and resources issues into approaches to reduce the risk of regional and national conflicts. Nevertheless, there is a new framework under construction that permits scholars and policymakers to apply new tools, to set new priorities, and to organize responses to a range of environmental threats to peace and security.

This framework is particularly well developed in the area of water resources. In the past several years there has been considerable progress in both understanding the nature of the connections between water resources and conflict and in evaluating regional cases where such connections may be particularly strong (Gleick 1993, 1994, 1996; Klötzli 1993, 1994; Böge 1993; Homer-Dixon 1994; Libiszewski 1995; Kelly and Homer-Dixon 1995; Wolf 1997). There has also been progress in trying to identify policies and principles for reducing the risks that freshwater disputes will lead to conflict and to better understand mechanisms for promoting cooperation and collaboration over shared freshwater resources.

Progress has been more than academic. In October 1994, for example, Israel and Jordan signed a peace treaty that explicitly addressed water allocations, sharing water information, and joint management policies for the Jordan River Basin. In 1996, India and Bangladesh signed a formal treaty that moves toward resolving their long-standing dispute over the Farraka Barrage and flows in the Ganges/Brahmaputra system. In 1997 the International Law Commission, after nearly three decades of negotiations, drafting, and discussion, finalized the Convention on the Non-Navigational Uses of Shared International Watercourses, which was approved by the General Assembly in April (UN 1997a). And countries like Brazil, South Africa, and Zimbabwe are incorporating mechanisms and principles for resolving conflicts over shared waters in their new water laws.

9 Parts of this paper are modified from Ehrlich, A.H., P.H. Gleick, and K. Conca. 2001. "Resources and environmental degradation as sources of conflict." In R. Hinde and J. Rotblat (editors). Pugwash Occasional Papers: 50th Pugwash Conference: Eliminating the Causes of War. Vol. 2, No. 3, pp. 108-138.

Conflicts over Resources

There are many different ways to categorize the connections between resources and conflicts. Resources have been military and political goals. Resources have been used as weapons of war. Resource and systems for managing or using resources have been targets of war. And inequities in the distribution, use, and consequences of resources management and use have been a source of tension and dispute. Gleick (1993, 1998) describes these categories for water resources.

It is important to note the distinctions between the scales at which resource conflicts may occur. Such conflicts can occur at local, subnational, and international levels – indeed, one of the most important changes in the nature of conflicts over the past several decades has been the growing severity and intensity of local and subnational conflicts and the relative de-emphasis of conflicts at the "superpower" level.

Resources as Military and Political Goals

Where resources are scarce, competition for limited supplies can lead groups, communities, and even nations to see access to resources as a matter of highest concern. This aspect falls into the most traditional Cold War/realpolitik framework where resources can be a defining factor in the wealth and power – and in the economic and political strength – of a nation. In the past, much of the security literature has focused on energy resources and, to a less extent, mineral resources, as potential sources of tensions and disputes. Access to resources may serve as a focus of dispute or provide a justification for actual conflict. While it may never be the sole reason for conflict, history suggests that it has already proven to be an important factor.

Resources are unevenly distributed throughout the world. Water resources are especially unevenly distributed, with some regions receiving enormous amounts of rainfall or river flow, while others are extremely dry. Human factors, such as high population densities or intensive industrial development may cause conditions of "relative" scarcity.

The problem of shared resources complicates the problem of scarcity. When a resource base extends across a political border, misunderstandings or lack of agreement about allocations are more likely. Fresh water is very widely shared because political borders rarely coincide with watershed boundaries. At the international level, over 260 river basins are shared by two or more nations (Wolf et al. 1999). But even countries with few or no internationally shared rivers or aquifers often have internal water disputes among states, ethnic groups, or economic classes trying to gain access to additional water supplies.

If there are great disparities in the economic or military strength of the parties involved, unilateral and inequitable decisions are more likely. A weaker party will rarely provoke or initiate military action – and even more rarely prevail – against a stronger adversary, but if a weaker nation either controls a resource or is dependent on resources from an outside source, disputes and conflicts may occur. The heavy dependence of the industrialized nations on imports of petroleum has always been a source of political and military concern. When adversaries are equally matched economically or militarily, negotiation and cooperation are more common outcomes (Wolf 1997).

Finally, if there are few technologically or economically attractive alternative sources of supply, the potential for conflict is higher. If water is scarce and shared, but there exist alternative sources such as alternative suppliers, other rivers, groundwater aquifers, or even expensive desalination, conflicts are less likely to occur. There is a high economic, social, and political cost to conflicts: they are likely to be avoided if acceptable substitutes can be found.

History provides a wide range of examples of this kind of conflict in the area of shared water resources. Forty-five hundred years ago, the control of irrigation canals vital to survival was the source of conflict between the states of Umma and Lagash in the ancient Middle East. Twenty-seven hundred years ago, Assurbanipal, King of Assyria from 669 to 626 B.C., seized control of wells as part of his strategic warfare against Arabia (see Gleick 1994 for a chronology of water-related disputes in ancient times). In the modern era, the Jordan River Basin has been the scene of a wide variety of water disputes. In the 1960s, Syria tried to divert the headwaters of the Jordan away from Israel, leading to air strikes against the diversion facilities (Falkenmark 1986, Lowi 1992). The 1967 war in the Middle East resulted in Israel winning control of all of the headwaters of the Jordan as well as the groundwater of the West Bank. In these cases, water was certainly not the sole issue precipitating conflict, but it was an important factor in both pre- and post-1967 border disputes.

Water remains an important factor in the politics of the region. The multilateral and bilateral peace talks conducted in the 1990s, which led to the interim agreement between the Israelis and the Palestinians and to the peace treaty between Israel and Jordan, explicitly included negotiations and agreements on the shared water resources of the Jordan River. Israeli and Syrian concerns over the Banias, which originates in the Golan Heights, remain an important unresolved issue. Jordanian concerns about Syrian dams on the Yarmouk, the major tributary to the Jordan, are still unanswered.

Disputes over the allocation of water occur at the subnational level as well, and have the potential to turn violent. In California in the mid-1920s, farmers repeatedly destroyed an aqueduct taking water from their region to the urban centers of southern California. The governor of Arizona called out the local militia in the 1930s to protest the construction of water diversion facilities on the Colorado River between Arizona and California (Reisner 1986). This dispute was eventually resolved in court.

Court decisions do not always successfully end disputes. An interim court decision in India to allocate additional waters from the Cauvery River – which originates in the state of Karnataka – to Tamil Nadu actually precipitated violent conflicts resulting in the deaths of over 50 people (Gleick 1993). In 1997, the World Court issued a decision in the dispute between Hungary and Slovakia over the Gabcikovo-Nagymaros project on the Danube, effectively refusing to decide and returning the dispute to the two parties for more negotiation (Klötzli 1993; Lipschutz 1997). As populations continue to grow, regional water scarcity may lead to more frequent examples of this kind of dispute and conflict.

Resources as an Instrument or Tool of Conflict

The usual tools and instruments of war are military weapons. But the use of resources, such as water, as both offensive and defensive weapons has a long history. One of the earliest accounts is an ancient Sumerian myth from 5,000 years ago, which parallels the biblical account of the great flood. In this myth, the Sumerian deity Ea punishes humanity's sins by causing a great flood. In 695 BC, Sennacherib completed the destruction of Babylon by diverting irrigation canals to wash over the ruins of the city. Herodotus wrote in 400 BC about Cyrus the Great's successful invasion of Babylon in 539 BC by diverting the Euphrates River into the desert and entering the city along the dry riverbed (Gleick 1994). In 1503 Leonardo da Vinci, in one of history's oddest collaborations, worked with Machiavelli on an unsuccessful project to divert the Arno River away from Pisa during the war between Florence and Pisa (Honan 1996).

In recent years, newer examples suggest that the use of water as a weapon continues to be considered. North Korea announced plans in 1986 to build a major hydroelectric dam on the Han River upstream of South Korea's capital, Seoul. The project would provide electricity to the North, but is viewed by South Korea as a potential weapon. South Korean hydrologists calculated that the destruction of the dam by the North and the sudden release of the reservoir's contents would destroy most of Seoul. While the project currently remains on hold due to serious political and economic difficulties in North Korea, South Korea has built a series of levees and check dams above Seoul to defend against any such threat (Chira 1986, Koch 1987).

Another use of a large dam and reservoir as a weapon of war was proposed during the Persian Gulf War. The allied coalition arrayed against Iraq discussed the possibility of using the Ataturk dam in Turkey on the Euphrates River to shut off the flow of water to Iraq, which is highly dependent on flows in the Euphrates for water supply. No formal request to Turkey was ever made, and Turkey subsequently stated that it would never use water as a means of political pressure, but the possibility remains a concern in the region (Gleick 1993). Both Syria and Iraq continue to have an ongoing dispute with Turkey over the operation of Ataturk and the level and quality of flows in the Euphrates reaching both downstream countries.

In 1997, a fresh dispute arose between Singapore and Malaysia. Singapore has never been self sufficient in water because of its high population density and small size and it depends on piped water from Malaysia for nearly half of all its needs (Zachary 1997). In addition, Singapore imports water from Malaysia that it then treats and sells back under an agreement signed in 1965 (Dupont 1998). Relations between the two countries have long been clouded by economic competition, and religious, political, and ethnic differences that have flared periodically since their separation in 1965. In early 1997, these relations soured again after comments were exchanged by senior politicians about mutual concerns, leading to Ahmed Zamid Hamidi, the head of the youth wing of Malaysia's ruling party urging the government to review the basis of water agreements with Singapore (Lee 1997). Chief Minister of Johor state in Malaysia went further, suggesting that they appropriate two of the three water-purification plants operated by Singapore in Johor (Jayasankaran and Hiebert 1997). Singapore is clearly worried that Malaysia might use water as a political and strategic weapon against Singapore – a point made to Malaysian Prime Minister Mahathir Mohamad by Singapore's Prime Minister Goh Chok Tong: "an agreement by Malaysia to meet Singapore's long-term water needs beyond the life of the present water agreements would remove the perception in Singapore that water may be used as a leverage against Singapore" (Straits Times 1997, Dupont 1998). Singapore has also launched a campaign to increase water supplies and to reduce consumption through an aggressive conservation program. Among their supply plans are new desalination plants that would produce water at about eight times the cost of current supplies (Zachary 1997).

Resource Systems as Targets of Conflict

Where resources and resource-supply systems have economic, political, or military importance, they become targets during wars or conflicts. The city of

Babylon in ancient times was often a subject for conquest, as described above, and around 720 BC Sargon of Assyria destroyed the irrigation systems of the Haldians of Armenia. In modern times, energy plants, dams, and hydroelectric facilities have regularly been bombed as strategic targets. The United States targeted irrigation levees in North Vietnam. Syria tried to destroy Israel's National Water Carrier while it was under construction in the 1950s. The Persian Gulf war saw several examples of this problem: the Iraqis intentionally destroyed the oil-production system and water desalination plants in Kuwait and in turn suffered from the destruction of their energy- and water-supply systems by the allied forces assembled to liberate Kuwait. In February 2000, for tactical or strategic reasons that are not entirely clear, Israel destroyed three power plants in southern Lebanon in response to attacks on northern Israel from members of Hezbollah (Fahmy 2000).

Water and Poverty: Inequities in Resource Distribution, Use, and Development

Tensions and conflicts may also result from such indirect factors as the inequitable distribution, use, and development of resources. Energy, water, food, minerals, and other resources are shared by two or more nations, unevenly distributed, or inequitably used. Water provides a good example. Approximately half the land area of the world, and perhaps 70 percent of inhabitable land area, is in an international watershed, where river flows or lakes are shared (Wolf et al. 1999). These include the Nile, Jordan, Tigris, Euphrates, and Orontes rivers in the Middle East, the Indus, Mekong, Ganges, and Brahmaputra rivers in Asia, the Great Lakes, and the Colorado, Rio Grande, Amazon, and Paraná rivers in the Americas, and Lake Chad and the Congo, Zambezi, Lake Chad, the Niger, Senegal, Okavango, and Orange rivers in Africa, to name only a few. This geographical fact has led to the geopolitical reality of disputes over the uneven distribution of shared waters.

Equally uneven is the level of water use. Many industrialized nations and nations with extensive irrigated agriculture withdraw more than 1,500 cubic meters of water per person annually for all uses. At the other extreme, nations with limited supplies or low levels of economic development may use fewer than 100 cubic meters per person per year. Table 1 lists the 15 countries that use the most water per capita and the 15 countries that use the least. A low level of water use has direct and undesirable human consequences, including adverse impacts on health, the inability to grow sufficient food for local populations, and constraints on industrial and commercial activities.

One of the most important water constraints facing many regions is insufficient water to grow food. Sandra Postel (1997) suggests that as annual water availability drops below 1,700 cubic meters per person, domestic food self-sufficiency becomes almost impossible and countries must begin to import water in the form of grain. Table 2 lists countries where annual renewable water supplies are below 1,700 cubic meters per person per year. The number of countries in this category will continue to rise with population growth and overall dependence on grain imports will deepen and spread. Food insecurity is a political concern and can lead to economic weakness and other regional problems.

Finally, there are often adverse consequences of water development and use, and people who do not receive the benefits from water projects may feel these consequences. Examples include contamination of downstream water supplies or groundwater aquifers, dislocation of people because of dam construction, and the destruction of fishery resources that support local populations.

Summary

What is the connection between these issues and conflict? For the most part, inequities will lead to poverty, shortened lives, and misery, but perhaps not to direct conflict. But in some cases, they will increase local, regional, or international disputes, create refugees that cross, or try to cross, borders, and decrease the ability of a nation or society to resist economic and military aggression (Gleick 1993, Homer-Dixon 1994). Even local governments may experience unrest and controversy over equity-related issues. In February 2000, one person was killed and over 30 hospitalized in Bolivia when public protests over water privatization and increased costs of service were met by 1000 police and army units (Schultz 2000).

Table 1
Countries with the Largest and Smallest Reported Per-capita Water Withdrawals (a)

Country	Withdrawals ($m^3/p/yr$)	Country	Withdrawals ($m^3/p/yr$)
Congo, DR (formerly Zaire)	9	Suriname	1,181
Bhutan	15	Pakistan	1,277
Guinea-Bissau	17	Australia	1,306
Solomon Islands	18	Bulgaria	1,600
Comoros	18	Chile	1,625
Burundi	20	Madagascar	1,638
Congo	20	Korea DPR	1,649
Uganda	20	Afghanistan	1,702
Papua New Guinea	25	Canada	1,752
Central African Rep.	26	Tajikistan	2,065
Benin	28	United States of America	2,162
Togo	28	Iraq	2,367
Gambia	29	Kyrgyzstan	2,527
Cameroon	31	Turkmenistan	6,346 b
Equatorial Guinea	31	Guyana	7,616 b
Lesotho	31		

a These data include only reported water use. Data on rainfall used in agriculture and unreported water use are not available.
b These numbers are reported by FAO but may be in error.

Table 2
Countries with Per-Capita Water Availability Below 1,700 m3/p/year (as of the mid-1990s)

Country	Per-capita Water availability m3/p/year
Kuwait	10
Malta	46
United Arab Emirates	94
Libya	132
Qatar	143
Saudi Arabia	170
Jordan	219
Singapore	221
Bahrain	223
Yemen Dem Rep	350
Israel	467
Tunisia	504
Algeria	573
Oman	657
Burundi	658
Djibouti	732
Cape Verde	811
Rwanda	870
Morocco	1,197
Kenya	1,257
Belgium	1,269
Cyprus	1,286
South Africa	1,417
Poland	1,463
Korea Rep	1,542
Egypt	1,656
Haiti	1,690

Countries with less than 1,700 cubic meters per person per year will be unable to maintain full domestic food self-sufficiency reliably.

References

Carnegie Commission. 1997. Preventing Deadly Conflict. Final report of the Carnegie Commission on Preventing Deadly Conflict. Carnegie Corporation of New York, New York.

Chira, S. 1986. "North Korea dam worries the South." The New York Times, (November 30), p.3.

Crow. B. 1985. "The making and the breaking of agreement on the Ganges." In J. Lundqvist, U. Lohm, and M. Falkenmark (editors). Strategies for River Basin Management. D. Reidel Publishing, Dordrecht, the Netherlands, pp. 255-264.

Crow, B. A. Lindquist, and D. Wilson. 1995. Sharing the Ganges. Sage Publishers, New Delhi, India.

Dupont, A. 1998. The Environment and Security in East Asia. Adelphi Paper, forthcoming. Research School of Pacific and Asian Studies, Strategic and Defence Studies Centre, Australian National University, Canberra, Australia.

Ehrlich, A.H., P.H. Gleick, and K. Conca. 2001. "Resources and environmental degradation as sources of conflict." In R. Hinde and J. Rotblat (editors). Pugwash Occasional Papers: 50th Pugwash Conference: Eliminating the Causes of War. Vol. 2, No. 3, pp 108-138.

Fahmy, M. 2000. South Lebanon, peace, hit again by violence. Reuters News Service, February 9. (www.dailynews.yahoo.com/h/nm/20000209/ts/israel_lebanon 15.html, see also israel_lebanon_21.html)

Falkenmark, M. 1986. "Fresh waters as a factor in strategic policy and action." In A.H. Westing (ed.) Global Resources and International Conflict: Environmental Factors in Strategic Policy and Action. Oxford University Press, New York, pp. 85-113.

Gleick, P.H. 1990. "Environment, resources, and international security and politics." In E.H. Arnett (ed.) Science and International Security: Responding to a Changing World. American Association for the Advancement of Science (AAAS), Washington, D.C. pp. 501-523.

Gleick, P.H. 1991. "Environment and Security: The Clear Connection." Bulletin of the Atomic Scientists (April), pp. 17-21.

Gleick, P.H. 1993. "Water and conflict." International Security 18, No. 1, pp. 79-112 (Summer 1993).

Gleick, P.H. 1994. "Water, war, and peace in the Middle East." Environment 36, No. 3, pp.6-on. Heldref Publishers, Washington.

Gleick, P.H. 1996. "Conflict and cooperation over freshwater in Southern Africa: Background to the issues." Working Paper of the Pacific Institute for Studies in Development, Environment, and Security (prepared for the Carnegie Commission for the Prevention of Violent Conflict).

Gleick, P.H. 1997. "Water and Conflict in the Twenty-first Century: The Middle East and California." In D.D. Parker and Y. Tsur (eds.) Decentralization and Coordination of Water Resource Management. Kluwer Academic Publishers, Massachusetts. Pp. 411-428.

Homer-Dixon, T. 1994 "Environmental scarcities and violent conflict: Evidence from cases." International Security 19 (1), pp. 5-40.

Honan, W.H. 1996. "Scholar sees Leonardo's influence on Machiavelli." The New York Times. (December 8), p. 18.

Jayasankaran, S. and M. Hiebert. 1997. "Snipe, snipe: Malaysia-Singapore spat reflects growing economic rivalry." Far Eastern Economic Review (FEER), June 5, p. 24.

Kelly, K. And T. Homer-Dixon. 1995. "Environmental scarcity and violent conflict: The case of Gaza." The Project on Environment, Population, and Security. American Association for the Advancement of Science and the University of Toronto.

Klötzli, S. 1993. "Der slowakisch-ungarische Konflikt um das Staustufenprojekt Gabcíkovo." Environment and Conflicts Project Occasional Paper No. 7. Center for Security Studies and Conflict Research/Swiss Peace Foundation Berne, Switzerland.

Klötzli, S. 1994. "The water and soil crisis in Central Asia -- A source for future conflicts?" Environment and Conflicts Project Occasional Paper No. 11. Center for Security Studies and Conflict Research/Swiss Peace Foundation Berne, Switzerland.

Koch, N. 1987. "North Korean dam seen as potential 'water bomb'." Washington Post/San Francisco Chronicle. (September 30), p.3.

Lee, J. 1997. "KL uses water as political tool." The Jakarta Post, July 7.

Libiszewski, S. 1995. "Water disputes in the Jordan Basin region and their role in the resolution of the Arab-Israeli conflict." Environment and Conflicts Project Occasional Paper No. 13. Center for Security Studies and Conflict Research/Swiss Peace Foundation Berne, Switzerland.

Lipschutz, R. D. 1997. "Damming troubled waters: Conflict over the Danube, 1950-2000." Environment and Security Conference, Institute of War and Peace Studies, Columbia University, October 24.

Lonergan, S.C. and D.B. Brooks. 1994. Watershed: The Role of Fresh Water in the Israeli-Palestinian Conflict. International Development Research Centre, Ottawa, Canada.

Lowi, M. 1992. "West Bank water resources and the resolution of conflict in the Middle East." Project on Environmental Change and Acute Conflict, American Academy of Arts and Sciences and the University of Toronto. Occasional Paper No. 1, pp. 29-60.

McCaffrey, S. 1993. "International water law." In P.H. Gleick (ed.) Water in Crisis: A Guide to the World's Fresh Water Resources, Oxford University Press, New York, pp. 92-104.

Myers, N. 1989. "Environment and security." Foreign Policy, Vol. 74, pp. 23-41.

Postel, S. 1997. "Water for food production: Will there be enough in 2025?" Presentation at the International Water Resources Association IXth Congress, Montreal, Canada, 3-7 September.

Schultz, J. 2000. "A war over water." Democracy Center On-Line, Volume 31, February 4, http://www.democracyctr.org/newsletterstoc.html.

Straits Times. 1997. "PM Goh's speech in Parliament: I shall work for a new era of cooperation." The Straits Times, June 6.

United Nations. 1978. Registry of International Rivers. Centre for Natural Resources, United Nations. Pergamon Press, New York.

United Nations. 1997a. "Convention on the Law of the Non-Navigational Uses of International Watercourses." UN General Assembly A/51/869 (April 11). United Nations Publications, New York.

Wolf, A.T. 1995. Hydropolitics along the Jordan River: Scarce Water and its Impact on the Arab-Israeli Conflict. United Nations University Press, Tokyo, Japan.

Wolf, A. T. 1997. "'Water wars and water reality: Conflict and cooperation along international waterways." NATO Advanced Research Workshop on Environmental Change, Adaptation, and Human Security. Budapest, Hungary. 9-12 October.

Zachary, G.P. 1997. "Water pressure: Nations scramble to defuse fights over supplies." The Wall Street Journal, December 4, p. A17.

Appendix 9.8
Water, Poverty and Health

Caroline Hunt & Sandy Cairncross

November 2001

Introduction

Access to water supply can have wide-ranging long-term positive impacts beyond better health. These include improved livelihoods, better access to education, strengthened community management capacity and enhanced personal self-esteem.[i][10]

In terms of health impact, water can affect health in a number of different ways. A lack of water for hygiene, and consumption of contaminated water can result in disease, primarily diarrhoeal disease. Water, or the lack of it, can also have catastrophic health impacts through drought and flooding. Health is both directly and indirectly affected by environmental disasters. In the case of flooding, drowning is an immediate hazard and subsequent devastation to livelihoods and resources is often coupled with large-scale epidemics of diarrhoeal disease.

Water is also vital for agricultural production and for sustaining natural ecosystems that support human life. In some rural areas, abstraction of water for agriculture can mean less of the resource is available for domestic water supply. There are therefore many competing demands on water which in themselves can bring about health impacts.

There are clear examples where the green, *health of the environment*, agenda clashes with the brown *environmental health* agenda. For example in Peru, according to one source, before the catastrophic cholera epidemics of the 1990s, the national environmental movement had been able to affect the lowering of chlorine levels in piped water supplies because of the perceived damage to the natural environment caused by chlorination by-products. It seems likely that the subsequent water borne epidemics would not have been as explosive if chlorine levels in drinking water had been higher.[ii]

This paper focuses on the brown environmental health agenda and in particular the nature of the infectious disease health burden associated with domestic water supply for poor households.

How does water supply affect health?

The ways in which domestic water supply impacts on infectious disease health have been divided into four separate categories.[iii][iv] The categories are defined by the types of intervention which can control them, rather than by the types of organisms which

10

cause them. This model has proved helpful for engineers and public health professionals in working together.[v]

The categories relate to the four water-related routes for disease transmission:

- faecal-oral (water-borne and water-washed),
- strictly water–washed,
- water-based intermediate host
- and, water-related insect vector.

The first category, the faecal-oral diseases, includes infections which are transmitted by swallowing faecally contaminated matter containing pathogens (organisms causing disease). They can be caused by drinking contaminated water as well as through lack of sufficient water for washing. Diseases in this group include diarrhoeal diseases, typhoid, cholera and hepatitis A and E. This group of diseases is also closely linked to sanitation. A lack of access to adequate sanitation means that faecal materials are not safely disposed of away from human contact. Faecal pathogens can transmit faecal-oral diseases through contamination of fingers, food, water supplies and other means.

The second category is strictly water-washed. These are conditions that are exacerbated by lack of water for washing and hygiene. Diseases are largely related to skin and eyes, such as scabies, trachoma and conjunctivitis, or to body lice, such as louse-borne typhus.

The third category is water-based, with aquatic intermediate hosts. Aquatic organisms such as snails act as hosts to parasites, which then infect humans either by being swallowed or through contact in water (for example through entering the skin). Diseases include guinea worm and schistosomiasis.

The last category is diseases that are transmitted by water-related insect vectors. Some insect vectors, such as mosquitoes breed in or near water. They transmit disease to humans, for instance through bites. Diseases include malaria, filariasis, yellow fever, dengue and onchocerciasis (river blindness).

Scale of the problem

Approximately 90% of diarrhoeal disease cases are estimated to be attributable to environmental factors.[vi] Apart from water supply, sanitation and hygiene, diarrhoeal disease is also associated with a number of other risk factors including age, nutrition, lack of breast-feeding and seasonality.

Faecal-oral diseases, in the form of diarrhoeal diseases, are responsible for the greatest number of episodes of water-related illness and deaths worldwide as shown in Table 1 below (data are presented for WHO member state countries). It has been estimated that diarrhoeal disease represents 90% of the health impact associated with water supply and sanitation.[vii] Diarrhoeal diseases are estimated to kill more than two million people every year worldwide. The majority are children. There is some reason to believe that the number of deaths has fallen over the 1990s possibly in part due to increased use and success of oral rehydration therapy in preventing deaths.[viii]

However, it appears that the number of episodes of diarrhoeal disease has remained constant. This suggests that the causes of diarrhoeal disease have remained constant over time.

Table 1 also includes data for Disability Adjusted Life Years (DALYs) for the year 1999. These are 'the sum of life years lost due to premature mortality and years lived with disability, adjusted for severity'.[ix] The DALYs data are very high for diarrhoeal disease because the calculation takes into account the number of premature deaths which is high for diarrhoeal disease. The number of deaths from malaria is less than half that for diarrhoeal disease, at just over one million. Overall, pneumonia (and other acute respiratory infections) and diarrhoeal disease are the two leading causes of child deaths in The South. Despite this, the two diseases only represent 0.2% of total Health Research and Development spending worldwide.[x]

1. Water and sanitation related diseases

	Mortality estimates for 1999	DALYs estimates for 1999
Faecal-oral		
Diarrhoeal disease	2,213,000	72,063,000
Poliomyelitis	2,000	1,725,000
Water-washed		
Trachoma		1,239,000
Water-based		
Schistosomiasis	14,000	1,932,000
Water-related vector		
Malaria	1,086,000	44,998,000
Lymphatic filariasis		4,918,000
Dengue	13,000	465,000
Intestinal nematode infections	16,000	2,653,000

Source: data from the WHO World Health Report. WHO; Geneva. 2000

Why are the poor most at risk?

Determinants of health impact of water supply

The classification of water related diseases provides a broad overview of the ways in which water supply affects health. The likelihood of these diseases occurring will depend on a number of different factors, such as access to services, nature of use of services, maintenance of services and seasonality, amongst many others.

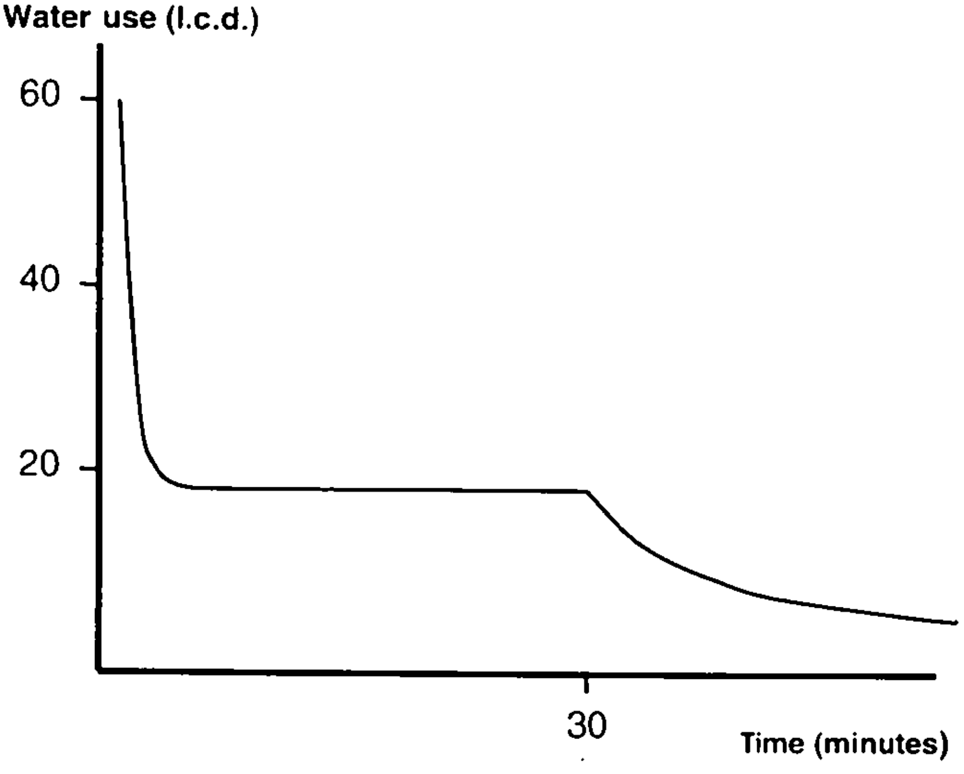
This section describes some of these determinants of health impact of water supply. Many of these determinants, especially those relating to access to services are most important for the poor who typically have lower levels of access to services, and quite often have to pay the highest prices for them. The poor also face a broad set of additional health risks. For millions of children under five, the combined effects of diarrhoeal disease, acute respiratory infections and malnutrition can be fatal. The poor are also often least able to cope with ill-health and the vital loss of livelihood that it can bring along with the potentially high costs of resulting health care.

Access and use

Distance to water source has been studied to look at the relationship between distance to source and consumption of water. Consumption of water is used as an indicator of hygiene (and therefore health impact).[xi] The relationship between distance travelled to collect water and the amount of water used is illustrated in Figure 1 below. In the absence of queuing, a 4 km/hour walking speed means that a water source one kilometre away roughly approximates a thirty-minute round trip. At distances less than that, the amount of water collected plateaus at around 15 litres per person per day. This consumption level depends on cultural and climatic factors, but can only be improved by introducing water supply within the household. This tends to double or treble the amount of water consumed per person per day.

This explains why researchers have often failed to find a health impact when consumers have merely been moved along the plateau.

Figure 1. The water use plateau



Source: Cairncross S, Feachem R 1993. Environmental Health Engineering in the Tropics; an Introductory Text. 2nd edition. Chichester: John Wiley & Sons, p. 63

Cost of services is another key factor which influences access to water supply and therefore health impact. High water costs are often paid out of the low-income household's food budget,[xii] with resulting health impacts. Studies have found that cost can be a critical factor in the take up and success of service programmes.[xiii] Engineering solutions need to be matched with local demand and preferably based on participatory planning.

Access to services can also be affected by local power dynamics. In some settings, a system of patronage exists around water supply. Villagers have to provide favours to secure access to water.[xiv]

Another important determinant of health impact is *who* uses services and *how*.

Treatment and maintenance

Treatment and maintenance are also key factors for the safety of water supply. Common challenges that face many piped water supply systems include contamination of source by industry, agriculture and municipal activities, old and deteriorating treatment works and distribution systems, demand for water outstripping supply, the increasingly recognised problem of treatment-resistant pathogens such as cryptosporidium and fear over toxicity of disinfection by-products.[xv]

Intermittent water supplies can result in water being effectively unavailable for hygiene purposes. Often households need to store water. Domestic water storage vessels are the main breeding sites for *Aedes aegypti* mosquitoes, the vectors of dengue and dengue haemorrhagic fever.

There is some evidence in the UK that disconnections of water supply may influence both the size of infectious disease outbreaks, as well as secondary infection rates.[xvi] Intermittence is also associated with changes in pressure within distribution networks which can lead to materials being drawn in through fractures in the pipes. This can then lead to secondary contamination of the water supply, depending on levels of residual chlorine.

Similarly, where water is collected from non-piped sources, the nature of water storage and treatment are both important. Many studies have investigated the links between public water supplies and household contamination of stored water.[xvii xviii xix xx xxi xxii] Findings have been rather mixed. There is a growing consensus that diarrhoeal disease pathogens originating within the home, as found in household water storage vessels, are less of a threat to household health than pathogens found in source water supplies (for example from public wells).[xxiii] This is largely because those pathogens already found inside the house would be transmitted by other routes within the household, regardless of water supply.

Therefore it appears more important for water quality interventions to safeguard the quality of the water source rather than to attempt to improve domestic water storage.[xxiv] Other commentators have suggested treatment of water within the household to improve quality of often-contaminated source water.[xxv] Routine household treatment of water in many cases often involves boiling. Boiling water will kill off most pathogens. Boiling, however, can be a rather expensive and time-consuming activity. It has been estimated that one kilogram of wood is needed to boil one litre of water for one minute.[xxvi] This may not be a choice for lower-income households where resources are limited.

Seasonality

Seasonality is a fairly well established determinant of the health impact of water supply. In many tropical and sub-tropical areas, the summer months are associated with peaks in bacterial diarrhoeal disease. These are believed to relate to enhanced bacterial pathogen multiplication in the summer because of moist, warm conditions, and possibly also because of increases in levels of water supply contamination associated with storms and heightened surface run-off. [xxvii] In contrast, cooler months, especially in temperate climates, are associated with peaks in viral disease infections.

Households may also change their source of water depending on seasonal availability of supply.

Pathogen specific factors

Further determinants of health impact are pathogen specific. Faecal-oral disease pathogens include bacteria, viruses, protozoa and helminths. The likelihood of infection by these pathogens relies on several factors. Firstly, the persistence of the pathogen is important, i.e. whether it can survive and / or multiply in the environment. Bacteria for instance are able to multiply both in the environment and inside their hosts. In contrast, viruses can only multiply inside their hosts.

Secondly, infective dose is a key factor about which relatively little is known. The infectious dose refers to the number of organisms necessary to cause infection. Viruses and protozoa for instance have very low infective doses, and in some cases just one protozoan cyst can cause infection. This makes transmission by water-washed routes relatively easy, as only a small number of organisms are needed to pass on infection from person to person. In contrast, many bacterial pathogens are thought to have much higher infective doses. In their case, direct consumption from either water supply or food may be the most likely route of transmission. Within these broad categories there are exceptions. Shigella for instance is thought to be relatively unusual as a bacterium, in its successful ability to transmit infection from unwashed hands. [xxviii]

There are further hypotheses about pathogen virulence and route of transmission. For instance, it has been suggested that pathogens which rely on water-washed transmission routes are less virulent because they need each human to be able to remain mobile and survive to pass on the infection.[xxix] In contrast, pathogens which transmit infection via host ingestion of water may be more virulent as they do not rely on person-to-person transmission routes.

A further factor is human host response, i.e. how well a host fights infection and whether they develop immunity. This is often related to factors such as age and general health status. As noted above, the majority of cases of illness and death due to diarrhoeal disease are in children under five (who are more likely to be encountering a given pathogen for the first time). Another group at heightened risk are the immunosuppressed.

Source of water

The source of water, i.e. either from the ground, surface or rain, may influence health risk. Several studies have collected microbiological water quality data to compare different types of source and technology.[xxx] It is often difficult to compare such studies, as water samples are not all collected and analysed in a standardised manner.

Surface water on the whole tends to be at greater risk of large-scale microbiological contamination than does groundwater. Untreated groundwater can nonetheless be the cause of disease outbreaks. Geology and land use patterns affect chemical and microbiological quality of groundwater as do water abstraction techniques. The nature of contaminants is also important. Most pesticides for instance are in the form of insoluble emulsions. This means that it is easier for them to stick to physical matter in surface water than it is for them to travel and remain in ground water. Chemical contaminants in groundwater will often be detectable by taste and as such this will often influence whether or not they are consumed. Arsenic and fluoride are naturally occurring exceptions to this rule and are the cause of serious contamination in a number of countries including Argentina, Bangladesh, Chile, China, India, Mexico, Taiwan, Thailand and the United States of America.

Attention is often focused on pit latrines and their impact on ground water quality. In general, a decision to protect ground water quality at the expense of sanitation is likely to have a negative impact on health.[xxxi]

Urban rural differences

Urban-rural differences in diarrhoeal disease prevalence, incidence and severity are not often investigated. Some evidence suggests that few differences exist between rural and urban diarrhoeal disease prevalence rates. For instance, a review of data from Demographic and Health Surveys from eight countries, reported that diarrhoeal disease prevalence in children under three years was similar in rural and urban areas, with one child in six experiencing diarrhoea during or just before the survey.[xxxii] The same study found that children's nutritional status was worse in rural areas. As a result, diarrhoea may be more severe in rural areas. Differentials in access to health care between urban and rural areas are also likely to play a role.

In urban areas there may be higher levels of environmental faecal contamination because of high-density populations living without adequate sanitation facilities. In addition, the much higher reliance on piped water supplies in urban areas may represent a higher risk of common source water-borne disease outbreaks. Events in Bangladesh and elsewhere have however, shown the devastating effects of chemically contaminated groundwater for large rural populations.

The evidence presented in this short review is subject to many methodological difficulties. Some of these are described in the following section.

Assessment methodologies and difficulties

Most of the difficulties in assessing health impact have been summarised elsewhere.[xxxiii] The majority of the epidemiological studies investigating the relationship between water supply, sanitation, hygiene and health are observational. This means that many of the factors that affect both exposure and health outcomes are not controlled for in the design of the study. For instance socio-economic status is strongly related to health status. It also often determines access to water supply.

Another difficulty is recall bias. Many of the studies rely on mothers or guardians of young children recalling episodes of diarrhoea over periods of up to two weeks. It appears that recall over periods longer than 48 hours is unlikely to be accurate. The choice of health outcomes or indicators used can also pose difficulties. For instance in the case of diarrhoeal disease, there is no accepted standardised definition of diarrhoea. [xxxiv]

The choice of exposure under study is also extremely important. Many studies look at water quality as this is relatively easy to measure and because many researchers have started from the assumption that water quality, rather than quantity and hygiene, is the key determinant of health impact. However, they do not always fully acknowledge and design for the multiple causes of diarrhoeal disease. Studies often only look at one part of a relationship between water supply or sanitation and health and as such can not allude to the full impact upon health. For instance, looking only at water quality discounts the existence and impact of secondary transmission from water-washed routes. Similarly, not enough studies investigate each of the steps within the casual pathway such as; use of certain facilities leads to exposure to pathogens and that in turn exposure to these pathogens leads to an identified health outcome. Commentators have highlighted such shortfalls of epidemiology in determining true transmission routes.[xxxv]

The body of scientific evidence illustrates that a large number of factors influence the health impact of services. The variety of specific local conditions in which studies are carried out makes it difficult to generalise the results of individual studies.

Monitoring water, poverty and health

The WHO / Unicef Global Water Supply and Sanitation Assessment 2000 has provided a vastly improved methodology for monitoring national service coverage levels.[xxxvi] The data contained in the report provide a consumer-based picture of service coverage. This is an improvement on the previous supplier based data provided by national Ministries of Health as reported by WHO. Data for national percentage access to water supply is used as part of the Human Development Index. As such access to water supply is accepted as a proxy for poverty. Information collected at national level from population-based sources such as the nationally representative Demographic and Health Surveys is able to inform us of progress within and between nations.

There is also a wider need for sub-national data to inform local actors of factors relating to access to water supply. Local information is needed to inform local actors and service providers of service gaps and needs. The information needs of municipalities may be very different to those of advocacy groups wishing to increase awareness of water supply issues.

Community based monitoring of water supply and other environmental services using indicators have been tested in different settings.[xxxvii] It has been found that scientific and / or health related evidence is not often an important factor in decision-making around provision of services.

If access to water supply is the best indicator of poverty, then health impact is closely related. When monitoring the health impact of water supply, factors such as distance to source are a good indicator as it provides an idea of how much water is used by the household. This will include both drinking water and water for washing and other domestic purposes. The amount of water available for washing and hygiene is very important in breaking the cycle of faecal oral disease transmission. For diarrhoeal disease, when looking beyond solely water supply, attention needs to be focused on access to and use of sanitation, handwashing practices and disposal of children's faeces.

Appendix 9.9
The potential for using Object Orientated approaches for data modelling and storage in the water sector, with particular relevance to the development and testing of the Water Poverty Index

Dr C. R Jackson, British Geological Survey
& Dr C A Sullivan, CEH Wallingford

1. WATER RESOURCES MANAGEMENT

1.1 Objectives

Given the pressures on water resources there is an obvious need to manage them so that they are not degraded. Environmental management becomes more important as the demand for water rises. It encompasses two separate but related aims. The first is to minimise the adverse impacts on and maximise the benefits to the environment. This requires that, whether developing a water resource or disposing of waste, the system should be managed to maintain or preferably to enhance the environment. The second aim is to minimise impacts on and maximise benefits to the resource itself. These aims must be balanced against the need to provide water for human consumption. Though conflicts arise, it is often through consideration of the needs of the environment that improvements in the water resources are identified. The rigour involved in the consideration of environmental impacts prompts the discovery of new and improved solutions.

The recent legislative act of the European Parliament, the Water Framework Directive, establishes a framework for the management of the water environment and is set to overhaul the management of the water environment in the UK. The Directive encompasses the aims described above and identifies an approach for the sustainable management of groundwater and surface water bodies. It specifies that strategic management plans must be defined for each river basin. This involves the detailed analysis of the pressures on water bodies and an assessment of their impact. A principal component of this assessment is the characterisation of surface-groundwater interaction. With regard to this specific task, numerical models will have an important role in developing the understanding of river-aquifer interaction. The framework also provides an opportunity to integrate all the components of the hydrological cycle. This will require conceptual models of groundwater systems to be extended to include the overground components of the hydrological cycle.

The approach of analysing individual components of the hydrological cycle in detail whilst broadening the system under consideration is important when considering the aim of sustainable water resource management. However, the representation of large systems by numerical models in which individual components are described in detail is currently a difficult task. However, a relatively new approach for the development of environmental modelling software offers the potential to construct numerical models that represent real world systems more closely.

1.2 Understanding of needs

Current simulation models of environmental systems are generally difficult to maintain, modify and integrate. However, advances in computing technology have resulted in the capability to develop numerical simulation models that can closely resemble the conceptual models of environmental systems. With regard to the need to construct models of extensive systems, such as coupled surface water-groundwater systems, the object-oriented approach offers many potential benefits. The approach enables models to be built on a framework of discrete components that represent individual features of real world systems. For example, by decomposing the features of the hydrological cycle into separate entities, complex models can be developed which are clear, easily modifiable, flexible and efficient. By hiding the complex behaviour of individual hydrological features in discrete objects the approach enables the development of models that more accurately represent hydrogeological systems. Much of the commonly applied groundwater modelling software is now based on outdated technology. The object-oriented approach can now be used to develop better modelling and management tools.

2. REQUIREMENTS FOR GROUNDWATER MODELS

Sustainability of a groundwater resource is linked to both the quantitative development of that resource and the protection of its quality. The consideration of the long-term is central to the principle of sustainability, however, the management of a resource is a dynamic and continually changing process. This is because the quality of a groundwater resource is affected by human activity though the hydrogeological setting and the climate determine the extent to which an action affects the quality of groundwater.

Management schemes have to change as a resource is developed due to the fact that groundwater systems are complex and their behaviour is nonlinear. However, the development of a scheme assumes that the factors influencing such impacts are understood. In order to manage the exploitation of a groundwater resource knowledge of these processes and their controls is essential. Without this, water resource engineers cannot make informed judgements about what action should be taken to manage the system for the benefit of both water consumers and the environment. One method by which a better understanding of the behaviour of a groundwater system can be gained is through the use of models. Models are powerful and widely used tools to investigate the behaviour of water resources systems in general and groundwater in particular. A systems analysis approach and the use of models are invaluable in the assessment of a sustainable management policy for a groundwater resource.

In groundwater resource management a model may be described as any device that provides an approximation to a field situation. Models have a number of purposes but these can generally be broken down into three categories. First, they are used as a tool to interpret a system, for example to improve the understanding of the flow within an aquifer. This often leads to a rapid identification of the need for data in areas where little exists. They are used for prediction, which is essential for water resource planning, and may form the basis of a decision making framework. Finally, they are used to investigate hypotheses, for example, the mechanism of river-aquifer interaction.

The development of digital models has allowed the numerical simulation of complex real world aquifers. Once such a model has been calibrated, through comparisons with historical hydrological data, it becomes a valuable tool for the prediction of the future behaviour of an aquifer under different stimuli.

2.1 Modelling objectives

Groundwater models fulfil several important roles in hydrogeology. They provide a framework within which improved understanding of physical processes takes place, they allow practical problems, such as resource allocation, to be addressed and they are an expression of what is currently known or assumed about an aquifer. Models are of fundamental importance in testing our understanding of aquifer systems. They provide the only means by which novel mechanisms can be examined quantitatively and confirmed or rejected on the basis of field evidence. Consequently, it is important that the model's design allows new processes to be formulated and added to existing models.

In the field of hydrogeology, scientific advances are made along a variety of paths. On might be termed the analytical route where a theory is explored by experiment leading to its adoption or rejection. There is also a contribution to be made by synthesis where information and technologies from different fields are harnessed to produce a unified view of some phenomenon. The development of models and their application to scientific and engineering problems falls into this second category.

As models move from development and use in research, they become the day to day tools of hydrogeologists engaged in the operation and management of aquifer systems. This process has highlighted the deficiencies in some modelling approaches and heightened awareness of the need for further development. In order to evaluate, which, if any, areas of a modelling methodology should be improved the following list of objectives might be considered. These are predominantly related to the development of a better regional groundwater model, with which this business and scientific case is concerned.

1. Does the model represent the hydrogeological mechanisms accurately and at the correct scale?
2. Does the model provide a framework that is adequate to improve the understanding of physical processes?
3. Does the model facilitate the evaluation of practical problems satisfactorily, for example resource assessment, the definition of borehole protection zone and particle tracking?
4. Does the model incorporate the required mechanisms/processes?
5. Can new mechanisms be incorporated easily as advances in the understanding of the physics of groundwater flow and solute transport are made? Is it extensible?
6. Does the model provide a satisfactory framework for research?
7. Is the model a sustainable platform for the future development of groundwater modelling over the medium to long term?
8. Can a model be modified rapidly and easily without changing the basic code?
9. Can areas of interest be added and removed dynamically? Is it flexible?
10. Is the model user and developer friendly?
11. Is data stored and managed satisfactorily by the model?
12. Is it easy to interrogate, manipulate and visualise the results?
13. Is the model efficient? Could advances in software development enable more detailed simulations to be run within a given time or cost budget?
14. Can new software development methods improve the representation of the hydrogeology within a model and improve its efficiency, flexibility and maintainability?

When considering the current state of groundwater modelling, the answers to many of these questions illustrate that significant improvements could be made to existing regional groundwater models. This is highlighted in the next section where a number of the deficiencies of current models are described.

2.2 Current deficiencies

Whilst the power of desktop computing has increased enormously in the last decade, with the exception of user interfaces, groundwater modelling technology has shown no significant advances. As described in more detail in the next section, currently most groundwater models are written in structured procedural programming languages, such as Fortran. In this approach the design of the model is based on the identification of the *algorithm*. The algorithm specifies the sequential steps that must be taken to achieve some result. In procedural programming the algorithm, or the models functionality is assigned significantly more importance than the *data* on which it acts. Consequently, many data are made common, which means that they are accessible to all parts of the models code. This means that great care must be taken when modifying the code, for example to implement a new mechanism.

The fact that data can permeate through much of a procedural program has serious consequences for the extensibility, modifiability and life expectancy of the code. For example, when a better description of a physical process is obtained, it is important to correct its representation in the model. Changes can also be required to test hypotheses about the operation of a particular physical mechanism itself. Unfortunately, it is often difficult to do this in existing groundwater models because data commonality means that alterations can transmit errors along a number of paths through the code. Consequently significant periods of testing are required to revalidate the model. Furthermore, because of the sequential nature of the majority of groundwater models a number of operations are performed at different locations within the code, which relate to a single mechanism, for example river-aquifer interaction. This repetition of similar tasks at different places within the program again complicates its modification when a new mechanism has to be incorporated in the model.

The new approach for the development of a regional groundwater model proposed in the next section of this document will eliminate many of these problems. By minimising the dependencies between parts of the code, it is envisaged that a model framework can be developed which focuses on mechanisms and not data. By localising effects within discrete areas of the code it will be significantly easier to modify or incorporate new hydrogeological mechanisms without causing errors in other parts of the program. Modelling practitioners will then be able to investigate mechanisms more easily instead of just modifying parameter values.

In addition to the lack of emphasis on mechanisms in current groundwater models, the representation of the geometry of hydrogeological units is difficult within the framework of a layered finite difference model, represented as a continuous three-dimensional array. Because layers have to be continuous across the model domain it is difficult to represent spatially discontinuous features. For example, the vertical shift in hydrogeological units across a fault, sinuous alluvial deposits in river valleys, spatially variable glacial drift cover and the thinning out of sedimentary layers are all example of spatially discontinuous hydrogeological features that are difficult to simulate.

An essential feature of a groundwater flow model is an ability to represent the aquifer features at different spatial scales. This is necessary both to focus on regions where there is particular interest and to maintain accuracy where the solution is highly variable. Because the behaviour of a numerical solution depends on the physical properties of the aquifer the hydrogeology must determine the discretisation of space and not the numerical technique. Unfortunately conventional finite difference methods have difficulty in fitting the mesh to the hydrogeology. Consequently, models generally contain additional nodes in regions where there is little interest and where they are not required for accuracy.

Telescopic mesh refinement is used to simulate aquifers more efficiently. However, this method has a number of drawbacks and is not always applicable. Whilst the method reduces the number of nodes involved in simulating an aquifer, the gains in computational efficiency are moderated by the need to determine boundary conditions for embedded models. It is often stated that the rapid gains in computing power and its reducing cost negate the requirement to improve the efficiency of numerical techniques. However, the demand to model more complex problems increases in parallel with improvements in computing. Consequently, novel methods to more accurately and efficiently simulate aquifers remain of benefit. An example of this is the need to be able to simulate the effect of groundwater abstraction on river flows. Currently, it is difficult to simulate in detail groundwater flow to wells and their influence on rivers or wetlands. It is envisaged that the approach proposed in the following two sections can address a number of these issues.

An important development in the field of geosciences is the application of database technology and graphical information systems for the storage, management and processing of data. These techniques offer significant benefits to groundwater modelling but it is only recently that they have been applied. The major benefit they offer is the capability to separate real data from models. Currently, this is not the case and significant amounts of information are bound up in individual models. For example, consider the spatial variation of hydraulic conductivity within an aquifer system. Information on this parameter can be obtained from a number of sources, for example from pumping test analyses, laboratory experiments or previous modelling investigations. This data is generally gathered by the hydrogeologist and transferred directly into a groundwater model. Parameter values are assigned on the model grid, which then acts as the store of this information. Consider then, that another modeller either wishes to construct a model which covers part of the area of the first or wants to modify the structure of the previous model. Because the model contains no information relating to the source of the data on which it is based, the user cannot be sure of its quality. Consequently, it is usually the case that the primary data must be collected again and re-examined. If the first model is to be modified, for example by refining the grid in the region of an abstraction borehole or river, new parameters values will have to be assigned manually. The drawback is that data is grid dependent but the grid is a feature of the model only and not reality. A better approach would be store data separately from the model and then allow the model to interrogate the data during its construction or modification.

In addition to data input, there are problems associated with the processing of model output. This has in part lead to the development of graphical user interfaces (GUIs), which facilitate post processing. In part the problem is due to the complexity with which model results are output during a simulation. For example, considering MODFLOW, the most commonly applied regional groundwater model, much of the output data is written in a binary format. The development of a suite of graphical user interfaces by commercial companies has simplified the post processing of this data. However, many of these still do not allow the rapid and simple interrogation of the raw data, which is often an important requirement. Consequently, individual modellers commonly spend time writing bespoke pieces of code to extract information from binary output files. The need for such interfaces could be questioned given the abundance of more generally applicable very high quality data processing software that is routinely used by hydrological modellers. These general software packages, such a spreadsheets, GIS packages and visualisation software are generally superior to those contained within an individual GUI. Their use could be facilitated by presenting model output in a clear, transparent and format independent way.

The object-oriented paradigm is a relatively new and powerful approach for developing software. In particular it offers significant benefits to the accurate representation of physical mechanisms in models. It can also greatly simplify the maintenance and development of a model as the understanding of the physics of groundwater flow improves. This is because real world objects are modelled by computational equivalents. Because objects are discrete and *encapsulate* their data and functionality it is easy to alter their behaviour without affecting other parts of the model. For example, both a river and an aquifer may be treated as objects. The objects may incorporate complex processes and it is only necessary to represent their interactions. This separation of concerns not only simplifies the program structure but also more importantly allows a better description of physical processes within the model.

REFERENCES

Bethers, U., Jekabsons, N. and Sennikovs, J. (1998). Object-oriented approach for coupling data assimilation, calculation and visualisation for groundwater flows. Proceedings ICHE'98. Cottbus, Aug 31 – Sep 3. 1998. Abstract in "Advances in Hydro – Science and Engineering", Vol. III, The University of Mississippi, (p. 285). Full text on CD "Cyber Proceeding 3rd Int. Conf. on Hydroscience and Engineering". ISBN 0 – 937099 – 09 – 0. Web page: http://www.modlab.lv/publications/publ6.htm

Desitter, A., Bates, P.D., Anderson, M.G., and Hervouet, J-M. (2000). Development of one, two and three-dimensional finite element groundwater models within a generalised object-oriented framework. Hydrological Processes. 14, 2245-2259.

Environment Agency. (1999). Representation of the variation of hydraulic conductivity with saturated thickness in MODFLOW. Commissioned Report.

Haitjema, H. (1999). Summary of OO-AEM meeting results. Web page: http://www.indiana.edu/~aem/reports/haitjema-may-99.html.

Hayes P.J. (1999). An r-theta co-ordinate numerical model, incorporating mesh refinement, for the investigation of pumping tests in heterogeneous aquifers. Ph.D. Thesis. University of Birmingham, Birmingham.

Hughes C. and Hughes T. (1997). *Object-oriented multithreading using C++*. John Wiley & Sons. New York.

Jackson C.R. (2000). A novel grid refinement method for regional groundwater flow using object-oriented technology. Ph.D. Thesis. University of Birmingham, Birmingham.

Jackson, C.R. (2001). The development and validation of the object-oriented quasi three-dimensional regional groundwater model ZOOMQ3D. British Geological Survey internal report IR/01/144.

Jackson, C.R. (2002). Development and validation of the implementation of vkd and particle tracking in the object-oriented quasi three-dimensional regional groundwater model ZOOMQ3D. British Geological Survey internal report IR/02/??.

Jacob, A. (1999). Development of object oriented frameworks for environmental information systems. Web page: http://fram.nrsc.no/~anita/ICSE99/onlineabs.html.

Khoshafian S. and Abnous R. (1995). *Object orientation*. John Wiley and Sons. New York.

Krabbe, H. and Matheja, A. (1997). Groundwater modeling using the random-walk method on top of distributed object-oriented systems. Proc. Sec. Int. Symp. on Environmental Software Systems. ISESS 1997. 28.4.-02.05.1997. Whistler. British Columbia. Kanada. In: Environmental Software Systems. Denzer. A.; Swayne. D.A.;

Schimak. G. (Eds.). Vol. 2. p. 327-334. http://www.fi.uni-hannover.de/~an/isess97/index_isess97.html.

Larrondo-Petrie, M.M. and France, R. (1995). Application of Object-Oriented Models. Databases, and Visualization Techniques in the Water Management Domain. Report I: Analysis of the Water Management Domain for South Florida. South Florida Water Management District report. http://www.cse.fau.edu/~maria/SFWMD/.

Liberty J. and Hord J.M. (1996). *Teach yourself ANSI C++ in 21 days.* Sams. Indianapolis.

McDonald M.G. and Harbaugh A.W. (1988). A modular three-dimensional finite-difference ground-water flow model. *Techniques of Water Resources Investigations.* **06-A1**. 576.

Ponnambalam K. and Alguindigue T. (1997). *A C++ primer for engineers. An object-oriented approach.* McGraw-Hill. New York.

Raterman, B.. Schaars, F.W. and Griffioen, M. (2001). GIS and MATLAB Integrated for Groundwater Modelling. ESRI User Conference Proceedings 2001. http://www.esri.com/library/userconf/proc01/professional/papers/pap600/p600.htm

Reitsma, R.F. and Carron, J.C. (1997). Object-oriented simulation and evaluation of river basin operations. Journal of Geographic Information and Decision Analysis. (1). 1. 9-24.

Rindahl, B. (1996). Groundwater Modelling and Analysis Using the USGS MODFLOW program and ArcView Abstract. ESRI User Conference Proceedings. http://www.esri.com/library/userconf/proc96/TO50/PAP042/P42.HTM

Sebhat, M., and Heinzer, T. (2000). The Use of ARC/INFO GIS in the Building and Development of a Finite Element Ground/Surface Water Model (WestSIM) in California's Western San Joaquin Valley. ESRI User Conference Proceedings. http://www.esri.com/library/userconf/proc00/professional/abstracts/a643.htm

Sydelko, P.J., Dolph, J.E., Majerus, K.A. and Taxon, T.N. (2000). An advanced object-based software framework for complex ecosystem modelling and simulation. 4th International Conference on Integrating GIS and Environmental Modeling (GIS/EM4): Problems. Prospects and Research Needs. Banff. Alberta. Canada. September 2 - 8. 2000. Web page: http://www.colorado.edu/research/cires/banff/upload/171/.

Tucker, G.E., Lancaster, S.T., Gasparini, N.M., Bras, R.L. and Rybarczyk, S.M. (2001). An object-oriented framework for distributed hydrologic and geomorphic modelling using triangulated irregular networks. Computers and Geosciences. 27. 959-973.

Appendix A Further discussion of the benefits of the object-oriented approach

Most groundwater models are written using procedural programming languages. Procedural programming is the forerunner to object-oriented programming. In this earlier method the system is decomposed into a series of operations that act on data, the most fundamental of which is the program statement. Consequently, the development of a procedural program involves the identification of the steps that are required to achieve some result; that is, the identification of the algorithm. In this approach, the data is separate from the procedures that act upon them and the important programming task is to ensure that the operation of the procedures is well understood. This means that the data should not be altered unexpectedly.

As procedural programming was applied to more complex problems it became difficult to understand the code and monitor the effect that procedures had on the data (Ponnambalam and Alguindigue, 1997). This drawback spawned the development of structured programming based on the concept of functions. In this case the program is simplified by breaking it down into smaller subprograms, each of which performs a subtask of the overall algorithm. The principle is one of divide and conquer. Any task that is too complex is decomposed into a set of functions, each of which is sufficiently small that it is easily understood. Structured procedural programming has been and still is a commonly used and successful approach for dealing with complex problems. This is particularly true for numerical computation applications. However, as Liberty and Hord (1996) state:

> *"... some of its deficiencies became all too clear. First, the separation of data from the tasks that manipulate the data became harder and harder. It is natural to think of your data and what you can do with your data as related ideas.*
>
> *Second, programmers often had difficulty structuring a program to solve a problem while solving the problem at the same time. It was a classic inability to see the forest for the trees. Instead of solving problems, they often spent their time reinventing new ways to fit the problem to the structure."*

The problem of the creation of a maze of algorithms when modelling complex systems spawned the development of the object-model. This is based on the principle that it is natural to think of data and the tasks that can be performed on that data as related ideas. Object-orientation is described by Khoshafian and Abnous (1995) as:

> *"... the software modelling and development disciplines that make it easy to construct complex systems from individual components.*
>
> *The intuitive appeal of object-orientation is that it provides better concepts and tools with which to model and represent the real world as closely as possible. The advantages in programming in data modelling are many."*

Conceptually object-orientation is based on the principle of abstraction to deal with complexity. Through the use of objects, which contain both data and the functions that operate on it, complex systems are decomposed into separate, discrete units. The maze of algorithms all acting on the same data that arises in procedural programs is transformed into a system of objects each with its own well-defined behaviour. Through the use of abstraction computational objects are designed to represent objects in the real world; a major advantage of the programming paradigm. Not only can classes, the templates for objects, be defined to have a similar structure to features in reality but they can also be designed to be manipulated in the same way.

The correspondence between user defined classes and real world objects also simplifies the translation of a problem from the design stage into a program. This is because a more consistent language can be used over the development life cycle of a program. Collaboration between the eventual users and the model developers is made easier because both can consider the same objects. Even though each group visualises the mechanics of an object differently, the use of a common language allows the parties to consider its behaviour jointly. This results in the development of programs that better fulfil the requirements of users, be they groundwater models or not. As Khoshafian and Abnous (1995) state:

"Object-orientation provides better paradigms and tools for interacting easily with a computational environment, using familiar metaphors."

Appendix B Literature review of object-oriented groundwater research

A number of investigators have used object-orientation to improve the implementation of numerical methods for solving groundwater flow problems. Desitter et al. (2000) examine the use of object-oriented techniques to overcome the problems associated with procedural programming methods. They state:

"Object-oriented programming and modem code development now enable the construction of a new generation of environmental modelling systems that offer the possibility of an open, easily maintained and easily extensible framework for code development. The speed at which new models can be developed or upgraded can be significantly increased by object-oriented programming and the confidence that can be placed in such codes is also higher as the basic building blocks are subjected to a greater degree of scrutiny."

They illustrate this by developing a generalised framework of finite element objects, which can be adapted easily to solve different systems of partial differential equations. They apply the model to solve Richard's Equations for unsaturated flow in one and two dimensions and use it to show the complexity of the code which can be developed in a short period of time.

Krabbe and Matheja (1997) develop an object-oriented framework for the development of a distributed transport model using the random walk method. To overcome some of the problems associated with the random walk technique the investigators propose the use of a significantly increased number of particles. For example, they state that meaningless concentrations may appear in parts of the models area with low particle numbers. To facilitate the management of a large number of particles they develop an object-oriented framework to manage the random walk process using multi-threading; a method by which computational effort can be split between multiple processors.
Tucker et al. (2001) also present an object-oriented framework for the simulation of hydrologic and geomorphic systems. They describe the representation of elements of a triangulated irregular network and their associated polygonal cells as objects. These are used to solve partial differential mass balance equations to simulate, for example groundwater flow. They state that the object-oriented approach provides an efficient means of both storing and interrogating the triangulation network. It is also concluded that the strategy enhances modularity and portability and has the potential to reduce software development time.

An organisation that has started to develop object-oriented models for the simulation of large regional surface-groundwater systems is the South Florida Water Management District, US. Larrondo-Petrie and France (1995) describe the application of object-oriented analysis in the development of a framework for the incorporation into the South Florida Water Management Model. This analysis is performed to describe the mechanisms, terminology and interactions contained in the current suite of models that are used to simulate surface water and groundwater water flow and quality and ecological processes in the area.

The motivation for the work is described by the investigators and is relevant to the development of a generic regional groundwater model proposed here. They state:

The current simulation models [for the South Florida Water Management District] are difficult to manage and maintain. New developments in technology and methodology, such as object-orientation, distributed processing, Graphical Information Systems (GIS), visualisation techniques, graphical user interfaces (GUI), electronic information sharing through the Internet and increases in storage and processing power, warrant the efforts to develop a comprehensive hydrologic regional simulation model. In doing so, the integration of other District and external models will be investigated to eliminate duplication of effort, increase usability and usage and make results more consistent and accurate.

Haitjema (1999) discusses the inception of a group of groundwater model developers who are investigating object-oriented methods. The group are examining the adoption of a set of standards for the construction of *analytical elements* objects, for example line sinks, used in the analytical element method (AEM) for groundwater flow simulation. One of the advantages of the approach is the ability to allow individual developers to more quickly implement a new model design through the use of the resulting well tested low level components: the *analytical element objects*.

In addition to the development of object-oriented models to improve the implementation of numerical methods, a number of investigators have used object-oriented techniques to develop frameworks for the coupling of software components, for example, the coupling of a river basin model with decision support system (Reitsma and Carron, 1997) and the construction of tools for data management, visualisation and modelling of environmental systems (Bethers et al., 1998; Jacob, 1999; Sydelko et al., 2000).

Appendix 9.10
The Water Poverty Index; A National Approach

Peter Lawrence, Jeremy Meigh and Caroline Sullivan

The full text for this background paper is contained within Appendix 1.5

Appendix 9.11
Derivation and Testing of a Water Poverty Index Contribution of the Commonwealth Science Council

Siyan Malomo and Silencer Mapuranga

Executive Summary

There is now a global concern about the availability of water for man, food and sustainable management of ecosystems in the next millennium. Global availability of fresh water per capita is steadily decreasing as population grows and water resources development has reached a ceiling in many countries. Some countries are already facing water scarcity and have had to resort to extreme measures to augment fresh water resources. Until fairly recently, water was considered to be an inexhaustible and cheap resource. This false notion has led to wasteful and inefficient practices in the use of water. Reduced availability of water has been the trend of much of this century.

The global population is projected to increase from the present 6 billion to nearly 8 billion in 2025. More than 80 percent of these people will live in developing countries. FAO estimates that more than 230 million people live in 26 countries which are classified as water deficient, of which 11 are in Africa. This number is likely to increase if the current pattern of water usage is continued unabated.

Currently about 1.3 billion people, nearly a quarter of the world's population, live in extreme poverty. Seventy percent of these people are women. They usually do not have access to adequate water and sanitation (see Eliminating poverty: A challenge for the 21st Century DFID 1997). The linkage between poverty and accessibility to water is generally known especially as it relates to health. The link between water scarcity and poverty nexus, i.e. water poverty, requires further examination.

Water stress leads to many socio-economic difficulties. These include less water available for food and fibre production, drinking water, sanitation and industrial development. The overall impact is reduced standard of living, lower quality of life, and less disposable income, especially in rural communities.

These factors lead to social and economic upheavals of rural communities, migration to urban areas, and increasing poverty in both the rural and urban areas. Low levels of national development, unemployment and poverty are some of the factors contributing to political instability. Another implication of water stress is that countries with riparian waters tend to be in dispute over the sharing of this riparian resource. There are conflicts over the sharing of riparian waters in many parts of the world.

Need for Action

The report on water scarcity (Water for Food and Rural Development) presented at the recent second World Water Forum, Hague 2000 highlighted the countries that are

facing imminent water shortages, those that will face shortages by 2025, and also those, which are relatively, water rich. The report showed that most of the water rich countries are in the developed world, especially North America, parts of Western Europe and Scandinavia. Countries that are in grave danger of freshwater availability, especially between now and 2025 are mainly in the developing world. The countries which will be most affected by water stress within the next 25 years are located in the Middle East, North Africa, parts of East and Southern Africa, Central Asia, regions of China, parts of South America and South Asia. Many of these are Commonwealth countries.

Generally few strategies exist to help policy makers and planners tackle the water and poverty link in a fundamental way. There is a pressing need for indicators that are developed on water scarcity and poverty nexus i.e. water poverty

There are several water-stressed countries within the Commonwealth. Water poverty is currently affecting the development of these countries, and will continue to do so in the foreseeable future. Commonwealth countries facing water poverty need to think about the impact on their economy and social fabric, and start on a path to dealing with the impacts.

Commonwealth Action

As a follow-up to the second World Water Forum, Hague, 2000 a number of initiatives are being implemented towards identifying the causes of world water scarcity and the extent such water scarcity is directly linked to existing and potential poverty. Commonwealth Science Council (CSC), London and the Brace Centre for Water Resources Management, Ste. Anne de Bellevue, Canada organised a workshop to discuss the issues of water poverty and scarcity. The objectives of the meeting *inter alia* were:

- To promote understanding of the water availability - poverty nexus and the long-term implication for the elimination of poverty.

- To develop a framework with which countries and institutions can respond to water poverty issues.

- To sensitise governments on the need for effective water conservation and demand management practices in order to avert future water crisis.

- To provide hands-on-training, to professionals and policy makers, in ways of considering water poverty issues as part of overall approaches to elimination of poverty

- To provide a forum for the exchange of ideas and to set up a Commonwealth Knowledge Network (CKN) on water poverty.

At that workshop, a paper was delivered on the topic of the development of a Water Poverty Index, (Sullivan, 2000[11]). Following the workshop, the CSC joined

11 Sullivan, C.A. (2000) *The Water Poverty Index*. Keynote presentation at the CSC/Brace Centre conference on Water and Poverty, Montreal, June 2000.

several national and international agencies and experts to work on a project to develop an index of water poverty and scarcity.

The Commonwealth Science Council, in collaboration with the Gender Affairs Department, is working on deriving and testing of a Water Poverty Index that can be used for measuring the extent such water scarcity directly relates to poverty. The derivation of this index is involving the establishing and testing of various models of water deprivation and the resultant influence on other economic and healthy problems. Three sites, Tanzania, Sri Lanka and South Africa are being used as pilot centres and these are providing a wide spectrum of factors that are causing water related poverty: gender mainstream issues, infrastructure capacity constrains, economic variables, usage conflicts, and water supply factors.

The main focus of this CSC exercise is to provide a generic index that will enable policy makers, water users and other stakeholders with an easy to use tool for assessing the degree of poverty caused by water access constrains. This index is critical in the evaluation and comparing regional differences and variables that are significant in each geographical area; and it would be a key index to complement the development problems derived through the Human Development Index.

The commitments on the proposal requires that the Commonwealth Science Council (CSC), through its extensive network of direct contacts with governments, institutions, personal experts and NGOs participate in the WPI project in the following ways:

1. contribute to the development and conceptualization of the WPI
2. provide inputs on components of a suitable index of social deprivation (similar to the Jarman index used in the National Health Service)
3. use the Commonwealth Knowledge Network for dialogue, discussions and as a strategy for dissemination of the results.
4. Possible assistance with small amounts of translation if needed (through networks) provide support for local workshops and some support for developing countries participants in pilot studies.
5. The Gender Affairs Department of the Commonwealth Secretariat will carry out gender sensitisation and analysis. It will use the Commonwealth National Women Machineries to support the pilot studies and help to ensure adequate gender sensitivity.

Items 1, 2 and 5 are described as current activities in this report. Items 3 and 4 will be implemented in the dissemination Phase 1 and as well as in other phases.

This report is a summary of the CSC contribution to developing the index. It describes the remit from the group of partners to the CSC and then describes some approaches to developing an index and later demonstrates how to developing a simple index using a commonly used index of deprivation – the Jarman Underprivileged Area Score.

Section 1 of the report describes models that can be applied in the derivation of the WPI, and section 2 proceeds to apply one particular technique, the Jarman

Deprivation Index (JI), on data from Tanzania. The third section (3) brings into the WPI debate the gender dimension of water poverty. As part of the ongoing exercise the gender issue should be integrated in the overall analysis of the water poverty challenges in developing countries.

Section 1 Water Poverty Index Models

Introduction

This report follows from the summary of the reports of the Arusha and Wallingford meetings. The report provides information on the sources of basic data and general information usable as input variables in the development of the water poverty index.
It caries out a critique of the proposed models and considers a methodology for deriving a composite measure of water deprivation, which is at once generic and flexible.

The identification of social factors has been described in the context of the WPI poverty models as discussed in the various meetings, including Arusha. The four models analysed and examined on the basis of sensitivity and robustness are the:

1. Composite (Multivariate regression) Index approach,
2. Matrix
3. Time series 0.measurement, and
4. Jarman Deprivation Index approach.

1.1.1 Composite (Multivariate regression) Index

This approach is similar to the Human Development Index (HDI) published annually by the United Nations Development Programme in the annual Human Development Report. It is based on aggregation of data from several social variables and it is easy to apply. Its simple in approach, and can be expanded to include more variables or their combination. It is however difficult to apply in lower level comparison of poverty, especially where household water poverty indicators should be input into the formulation of strategic water poverty alleviation policies.

In simple terms the water poverty index is depicted as a function of a number of social factors, as indicated below.

WPI*=F(wA+wsS+wt(1-T)/N

A=Adjusted water Availability as a %age of GW+SW+ USAGE
S=Population with access to safe water
T= Index to indicate time and effort to collect water. Could be modified to take into account gender issues
ws; wt; wa are weights given to each component of the index and they all sum to unity.
* Higher WPI= lower degree of water stress; i.e. less water poverty

Most of the factors used on this model can be computed from national censuses and dummy variables could be applied in dealing with particular attributes e.g. gender.

The weights applied in the variables are subjective except where they are based on empirical calculations. Therefore weights based on correlation of factors to variables should be applied in order that area specific differences of impact of factors can be captured in the computation of the WPI.

1.1.2 The Matrix

The Matrix is based on an overall resources gap between two major dimension of water related poverty: the gap between CAPACITY to generate adequate water and the basic water requirements (USE); and the social limitations impeding ACCESS to AVAILABLE water.

This is simply stated as

WPI=(C-U) + (Av-Ac).

This could be an important water poverty index if its focus is to measure the *differences* in the degree of deprivation, *extent* of water scarcity and *intensity* of water poverty across and within regions. The data demands or computation of **capacity** could be solved by defining components in economic terms, whilst **use**, **access** and **availability** are captured from surveys.

It is a complex index whose appropriateness will be determined by the scale used and the major concern is whether such a scale can be replicated, data permitting, in different geographical areas (regional, national etc). The collection of or availability of regional aggregated data or household survey data at low-level scales is a critical factor and may demand a lot of resources.

The computation of the **(C-U)** component of this model can pose a problem when used as a key input index to the composite WPI. This is because the varied capacity measurement and water usage levels that can be derived across areas are not restricted parameters. Therefore a simple capacity excess over utilisation is both indeterministic and also not a reliable comparative indicator. A useful variation of the equation can be presented in the form of:

WPI = (C/U) + (Av-Ac)
(Er) (Pr)

This equation combines the economic resource component (Er) with a physical resource gap (Pr). In simple terms the higher the use for a given physical resource gap the lower the index for specified capacity.

1.1.3 Time Analysis Approach

This is an index with very limited coverage of the fundamental social issues that have impact on water 'access' poverty. It is not multi-dimensional and given the varied water-point distance and volume parameters across regions and nations the weakness of this approach is clear. On the framework of a superior GIS based data collection and factor diagnosis this time -based computation of WPI could be difficult.

1.1.4 Water Deprivation (Jarman) Index

This approach is a combination of the GAP and the reverse of the HDI approaches. It integrates practical experiences and expert opinion into the weights of indicators. It has the advantage of simplicity and also draws attention to the distance a country still has to travel in order to reach the water access 'standard' per regional area. A major weakness of the method found elsewhere is that personal values, vested interests and bias that are applied through expert opinion.

This approach to deriving the WPI is flexible enough to allow for factor numbers and remaining consist in results, although disparities (outliers) in data could weaken its consistence. This can be overcome by standardising the data for each indicator.

$$\mathbf{WPI} = 1/n \sum_{i=1}^{n} Iij \,.$$

where index indicator **I*ij*** for each variable is defined as follows:

$$\mathbf{I}ij = \frac{Max(X_{ik})/k-(X_{ij})}{Max(X_{ik})/k-Min(X_{ij})/k}$$

Deprivation levels will range between 0 and 1. A more simplistic alternative to the computation of the WPI is the Jarman Deprivation Score method. This has similar indicator approach except that it does not involve standardisation by number of variables. Its formula is as follows:

$$WPIi = Jarman\ Index = \sum_{i=1}^{n} wx_{,}iXi$$

The Jarman Deprivation Index is an area-score whose value can range between 0 and 100%. This model is considered appropriate for discussing water poverty measurement because it produces multidimensional results. Its application in real life situations is described in the second part of this report (pages 8-13).

1.2 Data and variables operationalisation

The criteria used in selection of variables covered four data measurement requirements:

- Availability of national robust data for regions;
- Interpretability;
- Coverage of the domains of water scarcity (deprivation) as defined in Arusha; and
- Avoiding double weighting by indicators.

This approach is open to inclusion of numerous indicators and their contribution to an overall analysis of social factors that seek strength and depth of a generic WPI. This can been augmented by an examination of the structures of the underlying components of the indicators, through correlation and multivariate analysis (factor analysis and PCA) that focuses on a single-factor solution.
Given the limited small area data in developing countries the more robust approach is to seek a commonality of evidence across numerous indicators in the assumption that water poverty will be captured by the social factors

1.3 Variables and Factor selection

Based on the water scarcity dimensions that were agreed in Tanzania eight factors were identified from statistically significant variables that are deemed associated with water poverty. Table 1 below gives a summary of the factors and components applied on each WPI model.

Table 1 *WPI Factors and components*

			*Weight**	*HDI*	*GAP*	*Matrix*	*Time-Analysis*	*M/variate*
Factor	**Variable**							
Time	Distance			√		√	√	√
	Transport			√		√	√	√
	Volume						√	
Household	Gender			√	√	√		√
	Age			√		√		√
Usage	Domestic			√		√		√
	Ecosystem			√	√	√		√
	Agr. Irrig.			√	√	√		√
	Industry			√	√	√		√
Season	Dry/Wet			√		√		√
	Duration			√	√	√		√
Capacity	Physical	G-reliability		√	√	√		√
		S-reliability				√		√
		Adj-availab				√		√
	Social	Political		√	√	√		√
		Technology		√	√	√		√
	Behaviour	Harmony		√	√	√		√
		S-ownership		√	√	√		√
Source	B-hole			√	√	√		√
	Hse-connect			√	√	√		√
	S-pipe			√	√	√		√
	Pub-pipe			√	√	√		√
	P-spring			√	√	√		√
	P- well			√	√	√		√
Gender	F/M Divide	Water-Time		√	√	√		√

S/G= surface and ground water; B-hore= Borehole supply; S-ownership= water source ownership
Hse-conne= House connection; S-pipe= Standpipe; Pub-pipe= Public standpipe
* Weighting of the variables is based on their correlations with respective factors

The table above presents a somewhat comprehensive list of factors, some of which have been used in developing a WPI using the Jarman approach as described in sections 2.1 to 2.4 below.

Table 2 Variables and Sources of Data

Variable	Data Source	Country		
		S. Africa	Tanzania	Sri Lanka
Distance	Data available from Govern. National statistics and National censuses	√	√	√
Transport	Data available from Govern National Development Studies and Reports.	√	√	√
Volume	http://gnpswww.nima.mil/geonames/GNS/index.jsp; http://www.fao.organisation/aquastas;	√		√
Gender	National Development Studies and Reports. http://www.worldbank.org/data/wdi/pdfs/index.pdf	√	√	√
Age	http://www.childinfo.org/mics/Cntry_files ; Census	√	√	√
Domestic	http://www.poptel.org.uk/iied/agri/dowrv-intro.html; census	√1999	√1998	√2000
Ecosystem	http://www.poptel.org.uk/iied/agri/dowrv-intro.html; census	√1999	√1998	√2000
Agr. Irrig.	http://www.poptel.org.uk/iied/agri/dowrv-intro.html; http://www.fao.organisation/aquastas. census	√1999	√1998	√2000
Industry Use	http://www.poptel.org.uk/iied/agri/dowrv-intro.html; census	√1999	√1998	√2000
Dry/Wet	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report	√	√	√
Wet S. Duration	Data available from Govern. National statistics and National censuses	√1999	√1998	√2000
Capacity G-reliability	http://www.iied.org/agri/dowrv-institutional.html		√	
Capacity S-reliability	http://www.statssa.gov.za/default1; National Census.	√1999	√1998	√2000
Capacity Adj-availability	Data available from Govern. National statistics and National censuses; http://www.fao.organisation/aquastas;	√1999	√1998	√2000
Capacity –Political	http://www.measuredhs.com/. National Development Studies and Reports.		√	√
Capacity Technology	Government National statistics and Census	√	√	√
Capacity- Harmony	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report National Development Reports	√	√	√
Capacity S-ownership	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report National Development Reports. Censuses	√	√	√

Supply B-hole	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report National Development Studies and Reports.	√	√	√
Supply Hse-connect	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report. National Development Studies and Reports. Census	√	√	√
Supply S-pipe	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report. National Development Studies and Reports. Census	√	√	√
Supply Pub-pipe	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report. National Development Studies and Reports. Census	√	√	√
Supply P-spring	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report. National Development Studies and Reports. Census	√	√	√
Supply P- well	WHO &UNICEF JMP's Global Water Supply and Sanitation Assessment 2000 Report National Development Studies and Reports.	√	√	√
Gender: Water- Time	http://www.childinfo.org/eddb/water/africa/tanzania_water1.pdf; http://www.unicef.org/statis/Country_1Page170.html; http://www.worldbank.org/data/wdi;	√	√	√
Pop. Distr. density	http://www.measuredhs.com/data/start.cfm?	√	√	√
√ Indicates that the identified source has some data for that respective country and on that index indicator.				

Variable are described as summarised in Table 1 and all data source relate to those definitions in table 1. The sources (Table 2) cited above have provided initial statistics that can be used in the computation of the various factor indices. However other sources with more disaggregated data are still to be identified and in the meantime we can proceed to test the models, using more variables as data quality improves.

Section 2 The Jarman Index Approach: Application of Deprivation Scores in Water Poverty Index Derivation

Introduction

There is agreement that deprivation is generally a multi-dimensional concept. However there are conceptual disagreements over the use of particular indicators of poverty. The main point of difference in approach derives from the different objectives and models that are chosen to explain the causes of poverty. The choice of an indicator of poverty becomes a result of a trade-off between measurability of defined poverty and the complexity of factors that can be used in the analysis of that poverty. Therefore any model or derivation of poverty indices has to accommodate measurability and factor inter-linkage issues. This means we have to observe four model elements: measurable poverty; agreed/ identifiable components; time flexible indicators, and simplistic of application. However, added to these is the challenge of being able to identify the deprived persons using local indicators, and also being able to aggregate the results into meaningful national, or international figures. It is in this broad framework that the Jarman Index (JI) seems an appropriate tool for measuring water deprivation.

The Jarman index is social-factors based technique for measuring the (score) degree of deprivation that exists in a specific area. This Jarman Underprivileged Area Score was first applied in 1983, and constructed to measure factors affecting workloads of GPs. Subsequently it has been used in conjunction with other methods in the evaluation of levels of deprivation that beset a number of wards, districts and regions in England and Wales. It is now generally refereed to as the Jarman Underprivileged Area Score. Construction of this composite index requires a clear distinction to be made between the problem of the population served (social factors) and those of the services provided. We therefore observe these two conditions in using the JI technique for the construction of the Water Poverty Index (WPI). The Jarman Index (JI) and WPI terms are used interchangeably in the whole of this report.

2.1 Conception and Measurement of Water Deprivation

To date there is no agreement on what indicators are best measures of water deprivation and neither does literature provide reference to which measure is better than the other. In selecting indicators of water poverty it is important to distinguish direct and indirect measures. This is important in separating measures of incidence of deprivation and measures of vulnerable groups. In this WPI we opted to use the 'incidence indicator' because it covers those vulnerable who actually experience deprivation. Furthermore, we proceeded to define water deprivation in a way that divides the water poverty factors into 'first-order natural water scarcity' and second-order 'social resource scarcity' (adaptive capacity). The simultaneous existence of both dimensions defines water poverty. Using the adopted WPI concepts the following four core elements have been applied in making both the water scarcity and social adaptive capability dimensions integral to measurement and construction of area specific WPI.

Water Availability Factor: Measured availability of water in a location. This could be computed from survey data or through proxies such as per capita water availability.

Data for this factor is obtainable from national census and national hydrological statistics.

Access to Available water: This is the per capita access to available water. This definition of water access ignores the purpose to which such water is used.

Capacity: This is the overall ability of inhabitants to efficiently manage their water resources. Capacity embraces all 'water access' enhancing elements. This includes household financial ability, scientific and water knowledge exchange, knowledge to enhance management of sustainable water supplies, and infrastructure facilities for efficient water supply and its management etc.

Ecosystem balance: This is the integration of environmental factors into the water usage conflict analysis. In the background of concerted efforts to retain a balanced ecosystem the measurement of poverty has to include the level at which water availability, usage demands and management of its distribution affects the ecological balance. This is very important for areas that have high vagaries of rainfall changes, high density of livestock in small areas leading to intensified water competition, erosion and deforestation.

Within these four areas numerous factors can be identified for purposes of deriving the WPI:

- Household access to sanitation and water within 200-metre radius
- Time taken to access adequate water.
- Household characteristics,
- Usage competition (Domestic, Ecosystem, Agricultural Irrigation, and Industry,
- Adjusted availability and variations during dry/wet seasons and its duration,
- Capacity of the population to adapt/manage water scarcity challenges (Physical, Social, Behaviour),
- Source of water supply (Borehole, House connection, Stand-pipe, Public-pipe, Protected spring, Protected well).
- Gendered access to water.

Each of the above factors has variables whose components relate to more than one factor and some of them are correlated. For example, time to access water is inversely related to distance to sources of water *ceteris paribus*; capacity to regenerate or improve water access has elements that also relate to the water usage and its social conflict. At this point social capability issues must take into consideration factors that are a function of the 'water users' commitment to water supply sustainability. For example, factors that indicate any forms of resources capture, leading to instuitionalised water scarcity, can be built into the social capacity variables.

2.2 Construction of the Jarman Deprivation index

This construction starts from the premises that the indices are designed to be nationally comparable. In the case of Tanzania district of Dodoma the construction of

JI (WPI), done using secondary data, was designed to make the current and future analysis achieve the following objectives:

- Rural and Urban comparison within administrative districts;
- Identification of sectoral deprivation within regions;
- Region-by-region comparisons; and
- Country-by- country analysis.

The JI flexibility in factor substitution to accommodate national/regional/area WPI variables is similar to other methods. Table 3 below (Dodoma) illustrates the computations done for one region in the Republic of Tanzania. Results of each **JI** can be displayed in any shape, i.e. diamond, hexagon, etc. depending on significance of factors used in the construction of the WPI. The chosen level of area analysis will determine the shape number of factors taken into consideration or reporting matrix. In table 4 we illustrate the various levels at which the JI approach can be used for water poverty analysis.

As indicated in table 4 the causes of water poverty, as indicated by the derived JI (WPI), can be analysed from different positions depending on objectives and level of review. The advantage of using this JI technique is that its multi-dimension structure can enable diagnosis of the water poverty problem using village, district and national data. For example, in the Dodoma case JI reveals the impact of each water deprivation component and comparisons can be made on the significance of such factors within districts and across the urban and rural divide.

2.3 Jarman Index Calculations

The procedure for determining the Jarman Index is simple but requires inputs of various types of variables. The JI (score) is simply a summation of various factor values for each 'under privileged' area. The formula is

$$WPI_i = \text{Jarman Index} = \sum_{i=1}^{n} wx.iXi,$$

Where ***w*** and ***x*** are the weights and factor respectively, as applied in region ***i***.

Using the JI steps 1-5 indicated in Table 3 (Dodoma) the steps are as follows:

Step 1-2. Obtaining %age values from national census and decimalise them.
3 Obtain square root of the decimalised values.
4. Calculate ARCSINE for data angular transformation.
5. Standardise the value in 4 by the following formula;
$(M_d - M_n)$/std dev(n); where M_d and M_n is mean for domestic and national data respectively
6 Weight the standard values in 5 above.
7 Sum the values in 6 above.

2.4 Description of Variables

The factors used in the testing of the JI were based on two points: [1] conformity to the WPI focus, [2] level of correlations among the various factors and components indicated in Table 4 section 1.2 above. Factors used in the Dodoma were the following;

Water Access: Household units with water outside the 200m radiaus
Sanitation: Household units without sanitation facilities
Gender: Female headed household as a percent of total area population
Usage: Percentage water usage (Domestic 9%, Industry 2% and Agriculture 89%) based on annual per capita withdrawals (35 cubic metres per year for Tanzania).
Management: Population with above 'o' level education per district and area
House-hold Assets: Proxy used was the under five-mortality rate as an indicator of family capability.

Table 3 **Development of WPI for Dodoma using Jarman Index**

Jarman Procedural Steps	1 & 2		3		4		National		Weight	National		Dodoma				5	
	Urban	*Rural*	*Urban*	*Rural*	*Urban*	*Rural*	*Urban stats*	*Rural stats*		*Urban value*	*Rural wt value*	*Urban value*	*Rural value*	*Std Dev* Urban	*Std Dev* Rural	Urban	Rural
Variables																	
Access																	
Water access outside 200m	0.56	0.53	0.75	0.73	0.85	0.82	0.04	0.03	0.42	0.10	0.08	0.02	0.01	0.45	0.10	1.83	8.42
Households without sanitation	0.96	0.88	0.98	0.94	1.37	1.22	0.05	0.00	0.23	0.23	0.01	0.02	0.00	0.10	0.86	14.16	1.42
Gender												0.00	0.00				
Female headed household units	0.01	0.01	0.01	0.01	0.10	0.10	0.09	0.04	0.12	0.74	0.32	0.04	0.02	0.01	0.37	1.01	0.23
Use	**0.01**	**0.05**	0.07	0.23	0.07	0.23	0.02	0.04	0.01	1.90	4.09	0.01	0.02	0.00	0.02	0.65	9.5
Water usage -Domestic	0.00	0.01															
-Industrial	0.00	0.00															
-Agriculture	0.00	0.05															
Capacity																	
Managerial capacity potential	0.01	0.01	0.01	0.01	0.10	0.10	0.14	0.03	0.14	0.06	0.18	0.00	0.01	0.00	0.00	4.31	16.27
Household assets	0.41	0.26	0.64	0.51	0.69	0.54	0.03	0.08	0.08	0.42	1.01	0.01	0.03	0.00	0.24	2.89	2.13
WPI													**Jarman WPI**			**24.85**	**37.97**

Source: *United Republic of Tanzania: Population Census Vol. VI, 1982*

Table 4 **Application of JI at various levels**

Variables *Levels of Analysis*	**Villages**			**Districts**			**Countries**		
Access	*Rombo*	*Mbulu*	*Usambaa*	*Dodoma*	*Arusha*	*Tanga*	***Tanzania***	***S. Africa***	***Sri Lanka***
Water access outside 200m	5.56	5.53	30.75	10.28	8.85	7.15	X_{11}	Y_{11}	Z_{11}
Households without sanitation	12.96	18.88	5.26	16.46	11.20	0.72	X_{12}	Y_{12}	Z_{12}
Gender									
Female headed household units	20.85	10.05	15.20	1.83	2.15	3.50	X_{13}	Y_{13}	Z_{13}
Use	**20.01**	**30.05**	12.07	10.21	5.25	7.22	X_{14}	Y_{14}	Z_{14}
Water usage -Domestic	0.00	0.01							
-Industrial	0.00	0.00							
-Agriculture	0.00	0.05							
Capacity									
Managerial capacity potential	10.20	7.50	6.05	5.98	20.70	8.15	X_{15}	Y_{15}	Z_{15}
Household assets	8.41	4.40	3.68	5.02	10.15	6.25	X_{16}	Y_{16}	Z_{16}
WPI (Jarman Index)	**77.99**	**76.47**	**73.01**	**49.78**	**58.3**	**32.99**	$\sum X_N$	$\sum Y_N$	$\sum Z_N$

Note: In the absence of actual data figures used in the village areas are not confirmed published data. Only used for illustration of JI application levels.

Features of Jarman Underprivileged Area Index Matrix

- Targeted action plans can be effected at three levels.
- Intervention strategies can be designed to address specific area and factors causing water poverty.
- Similarities and variations in effects of causal factors can be ascertain across regions.

2.5 Methodological Challenges in Using the Jarman Index (JI)

There are methodological challenges that must be considered in applying the Jarman index. Deprivation indices are explicitly designed as indices of deprived areas and index scores thus relate to area poverty. Therefore any social deprivation analysis based on census data is not a person-by-person analysis and does not directly yield evidence of household water poverty. According to the JI approach geographical areas are given their nationally comparable scores of water poverty, using pre-determined variables. In some cases variables used include not only prevalent (economic) measures of deprivation but also variables that identify vulnerable groups (social class indicators and gender elements). However there is a weakness in including *at risk* group using pre-selected indicators. Some weaknesses include problems of double counting and over-counting. For example, people could be included under one component of deprivation (lack of transport) and yet also on another specific indicator of vulnerability (women). This is partly because the later (women) is counted as if they actually experience deprivation.

Therefore closely related to this area-based approach are two problems:

- danger of drawing inferences about individuals purely on the basis of aggregate spatial data; and
- the complexity of spatial geography of deprivation.

These two challenges are important in the designing of frameworks for water poverty analysis. For example, incidence of water poverty between men and women headed households cannot be revealed from spatial data, and the complexity of geography of deprivation is highly dependent on the scale at which this water poverty analysis is viewed. This may make JI score analysis of poverty difficult. Given the absence of small area data in developing countries the alternative approach is to seek a commonality of evidence across numerous indicators. This is on the belief that the very pervasiveness of key syndromes of water poverty will be identified in the recurring patterns of inequality to water access (e.g. urban versus rural water availability).

The third challenge is the synthesis of the JI factor indicators into a composite index, using a standard factor weighting approach. A number of indicator weighting can be applied. For example the Jarman Index for underprivileged areas made use of expert opinion. However the general criticism of personal values, vested interest and bias remains an issue with this expert opinion approach. The alternative, participatory survey, produces output faster and provides micro-level information on nuances of poverty that becomes very important when analysing causes of poverty. This survey data has to be augmented by further statistical analysis using techniques such as 'single factor' Principal Component Analysis. This introduces complex computation of data in order to derive values of the variables. The maths and statistical involvement is unsuitable to an untrained mind.

References

1. A.R. Turton 1999b. *Water Scarcity and Social Adaptive Capacity: Towards a Deeper Understanding of the Key Concepts needed to manage water scarcity in Developing countries. MEWREW Occasional Paper*
2. Anqing Shi. 2001. *How Access to Urban Portable Water and Sewerage Connections Affects Child Mortality. World Bank (Finance Development Research)*
3. Deaton, Angus S. 1987. *"The allocation of goods within the household: Adults, Children and Gender", mimeo. Princeton University, NJ.*
4. DUNCAN, O. D. (1969) *Towards Social Reporting: Next Steps. New York: Russell Sage Foundation*
5. Elias Salemeh, 2000. Redefining the Water Poverty Index. *Water International, Vol. 25(3) Sep*
6. Feitelson, E. 1999. *"Is the Commodification of Water Commensurate with Sustainability Notions", Paper presented at the Conference on Sustainability, Risk and Nature: The Political Ecology of Water in Advanced Societies. Oxford University, 15-17 April 1999.*
7. Gender in PRSPs: A Stocktaking. *World Bank Poverty Reduction and Economic Management Network Gender and Development Group, Aug. 2001*
8. Global Water Supply and Sanitation Assessment 2000 Report
9. **http://census.ac.uk/cdu/Dataset/1991_Census_datasets/Area.../Underprivileged_Area.ht**
10. http://popplanet.org/PopPlanet/issue.cfm?countryid=3&iid=5
11. http://www. worldbank.org/gender/assessment/gamethods.htm
12. http://www.africaonline.co.tz/madini/CountryInformation/pages3_b4.html
13. World Bank. 2000. *Interim Poverty Reduction Strategy Papers: Guidance on I-PRSPs and Joint Staff Assessment of I-PSRS, Sep. 2000*
14. Measurement and - Estimation. http://www.worldbank.org/research/peg/wps19/index5.htm
15. Menni Pradhan and Martin Ravallion. 1998. *Measuring Poverty Using Qualitative Perceptions of Welfare. World Bank (Working Paper 2011).*
16. Mike Combes. Simon Raybould. Cecilia Wong and Stan Openshaw. 1991. *1991 Deprivation Index: A Review of Approaches and Matrix of Results. HMSO Department of the Environment*
17. Payne and Hyde: Refuses of All Classes. http://scoreonline.org.uk/1/1/3.html
18. Policy Action Team18: *Better Information on Measuring Deprivation: A review of indices in Common Use*
19. Population Census. Private Household and Housing Characteristics. *Bureau of Statistics, Ministry of Planning and Economic Affairs. The United Republic of Tanzania, 1982, Vol. iv*
20. Sudhir Anand and Amartya K. Sen. 1994. *Human Development Index: Methodology and Measurement. UNDP Occasional Paper*
21. UNDP. 1998. Sri Lanka Report. *National Human Development Report: Regional Dimensions of Human Development.*
22. UpaliA. Amarasinghe. Lal Mutuwatta and R. Sakthivadivel. 1999. *Water Scarcity Variations within a Country: A Case Study of Sri Lanka, IWMI Report 32*

Section 3 Gender and Water Poverty

Background

The current and fashionable debate on gender work is gender mainstreaming. Gender mainstreaming seek to include gender issue not as a discrete component of development but more as a cross cutting issues in gender and development.

Gender mainstreaming is based on the recognition that gender inequality operates at all levels sectors in all of society, and needs to be addressed in the mainstream. It aims to ensure that women and men benefit equitably from all that society has to offer, and are equally empowered to affect its governance and decisions.

Gender mainstream rather like the environmental debate seeks to use and undertake the gender approach in all aspects of development. Mainstreaming is not only about ensuring that the situations of women are improved within existing frameworks as they are largely dominated by men. It is ensuring that the development process and frameworks are transformed in ways that ensure the participation and empowerment of women as well as men in all aspects of life and especially in decision-making structures [1].

The gender mainstream management initiative of the Commonwealth Secretariat aims to enhance and promote the participation of women on various levels of decision-making, planning and implementation of poverty alleviation projects.

The framework for a promotion of gender mainstreaming for Commonwealth countries was set and adopted at several high level meetings e.g. The Commonwealth Heads of Governments meeting Durban (199), the Sixth Women's' Affairs Ministerial Meetings, Delhi (2000).

Gender is being applied through the Commonwealth using a Gender Management System (GMS), a holistic and system-wide approach to gender mainstreaming developed by Commonwealth Secretariat for Government s, in partnership with other stakeholders including civil society and the private sector. It has been applied in such diverse areas as development planning, finance, education, science and technology etc

3.1 Commonwealth work in Gender mainstreaming

An example of work in the area is the use of National Women's Machinery (NWM) in government, identified by the Commonwealth governments as focal points to assist the targeting of general and women's poverty. A possible b, however not too useful approach is to extend the work to reduction in water poverty.

An another approach will be to identify constrains that directly or indirectly cause or trigger multiple incidence of water poverty and find means of addressing them For the latter a water poverty index that measures at once the extent of access, and at the same time capacity will be a useful tool in gender related interventions.

3.2 Gender and Water Poverty

A rational approach to gender and development requires that every section of the society including the disadvantaged be considered. A possible critique of the gender mainstreaming approach is that it may not pay specific attention to the issues of women deprivation.

The proposed Water Poverty Index (WPI) is a measure that indicates the wealth or poverty of an area's available water resources for domestic needs and for the demand of food production commensurate with the size of its population[xxxviii]. Whilst the national gender empowerment policies and gender budgeting approaches provide a framework for a macro level tool for addressing women deprivation it is inadequate. This model of state sponsored gender initiatives requires input from analysis of key water problem areas.

A useful starting point for a discussing of the true nature and impact of water deprivation on women is a definition and discussion of the two major tenets of water poverty. At this point water poverty is defined as the simultaneous existence of (1) natural water scarcity and (2) efficient management of scarce water resources (adaptive capacity)[xxxix]. These two dimensions are important in the identification and strategic analysis of plans being applied in reducing water poverty. In this respect we able to separates gender water access constrains by virtue of their origination:

(a) environment changes (Availability and Access problems),
(b) local inability to efficiently manage (Capacity and Use) the limited water resources availability.

The existence of structurally induced shortages in a national or regional water management scheme, leading to denial of water access to a specific user group, is an example of social capacity/use problem.

Whilst various economic and social indicators can measure efficiency in water management, women water scarcity still remains assessed by water time/trip constructs. These are gendered focused and are presented as a proxy for measuring time constrains to other women' economic activities. However these time/trip capture is an imprecise indicator of women water poverty problem because the time/trip is an endogenous household characteristics and not necessarily deterministic to level of poverty.[xl]

3.3 Gender as a Parameter for Water Poverty Index

Gender factors that identify managerial incapacity and those that influence access to water form two related groups of indices for water poverty, albeit they link differently. At present factors that indicate increasing participation (adaptive capacity) of women in political and regional decision units are showing incremental improvements. Forty countries of the Commonwealth have achieved more than 20% increase in placing women in areas of decision making. However the Poverty Reduction Strategic Papers (PRSPs)[l] of majority of these countries indicate that there is a knowledge gap between the decision making bodies and women user groups. However the CSC has not encountered disturbing inconsistence or major variations in both factors and their relationship with local water poverty. The main factors are the following:

1. Availability of water to women for domestic and economic activities;
2. Access infrastructure for water supply services, within economic means of women;
3. Capacity of local women to manage the limited water resources efficiently;
4. Usage conflict among the four major areas: domestic, irrigation, industrial, ecosystem;
5. Headship of household; and
6. Exposure to education and water usage knowledge

The core elements that are measured in assessing the degree of gender focus of the above factors are the level of Diagnosis, Monitoring, Public actions and Consultative Process.

3.3.1 Diagnosis

A gender-disaggregated analysis of water poverty and its causes is important for obtaining an understanding of how such poverty can be reduced. This analysis must include poverty incidence by gender of household, in addition to the other deprivation indices.

3.3.2 Monitoring

To ensure success of country driven water and gender process a monitoring measure can be applied. Using discrete dummy variables to indicate presence/absence of gender elements in water management processes enables organisations to monitor inclusion of gender elements in CKN programmes. The same indicators can be built into the WPI components that form the gender factor. This monitoring indicator does not show poverty but rather the consistency in the application of gender issues in the capacity development and knowledge exchange processes.

3.3.3 Public actions and Consultative Process

The promotion of the gender exercise, both within and outside the CSC gender projects, demands inter-agency networking. This has been achieved through support from national science councils and their home based government organisations. What has been important in this public relations argument is the level the various stakeholders (poor women included) are jointly and severally held accountable to the gender mainstream programme. Significant in this area of accountability is the level empirical data is used by each organisation in establishing priority actions. These priority action plans are not vague intentions but clear sectoral plans of action that relate to the water poverty reduction activities of other organisations[xli]. CSC provides an electronic network (CKN) and Decision Support System within which gender plans and information exchange is facilitated.

The national Poverty Reduction Strategy Policies have indicators of how gender is being used in the water poverty schemes. In the CSC such gender and water poverty factors include elements of the following:

- Water management Education
- Water safety nets
- Infrastructure facilities
- Governance, and

- Agriculture activities for women.

Therefore in assessing or developing a measure for local poverty these factors are serving as sectoral input that shed light into the success level of the women empowerment programmes. However the challenge is how sectoral indices on gender are integrated into the computation of WPI.

3.4 Disaggregation of WPI factors by Gender

In dealing with the gender issues attention is given to bringing men and women to the same level of access to water. Here there is an assumption that women need to 'catch-up' with their male counterparts. Consequently the gap between men and women can be used to construct disaggregated deprivation indices, using several factors, e.g. transport facilities, access to public versus private water wells/springs etc. In the background of the varied severity of scarcity and biased management of water poverty issues it is therefore imperative to distinctly ascertain the incidence of each component of deprivation and the degree to which they adversely affect women's access to adequate water. At regional (macro) level it easy to establish the incidence and impact of each of these components of water poverty. At individual household level the incidence level and impact is difficult to assess[xlii].

Analysis conducted in several projects shows that in any geographical area there is clear presence of difference in 'asset access' to water. This is arising from lack of household assets such as lack of transport to fetch water. Consequently analysis of poverty incidence does not treat women as a homogenous group or the gender attributes as immutable[xliii]. However both intra-and extra household differences are reflected in the level of involvement of women in management of water issues. water/trip time, and water consumption above survival water requirements. Therefore using possession of assets or lack thereof as proxies for fixing both minimum and maximum gendered access to water per household we able to establish the range of local deprivation. It must be emphasised that house data collection and collation for this process is difficult. Generally the evaluation of domestic asset poverty is often subsumed under that of the household and yet women's water poverty is differentiated from that of men: by biased water (resource) access and distribution. This is an element that has to be addressed.

Inevitably the estimating of the incidence of poverty using household data has been found to have serious flaws as it understates the actual incidence of water poverty on women. We have observed these problems in cases where the gender element is not well articulated in the surveys or when there is limited participation by the subjects of study. Various studies have shown that there is a strong association between female headship of household and poverty and this is common in Southern Africa and parts of Asia where culture norms deny female resources empowerment. It is thus CSC's approach that a gender diagnosis that deals with household analysis poverty analysis must have a built-in mechanism for gender data collection. This data collection must be organised to highlight key gender problems, the underlying causes of women marginalisation in water based economic empowerment. and the relationship between such problems and their causes.

At regional level evidence indicates that gender intervention programmes implemented under national gender budgets are not always effective in reaching to reduce water poverty in women headed households Neither are some technical assistance such as construction of dams managing to create a trigger for poverty reduction processes. It is also argued in various seminars that national strategies charting national policy response to gender-water equity requirements are not based on empirical data that relates to levels and nature of the current and potential gender-water poverty problem This is partly because the underlying causes of existing water poverty (natural and social elements) and the gender budgets policy prescriptions do not include grassroots knowledge of indigenous water management capabilities of women.

In the CSC initiatives SIWN and SIDS we seek to work with government organisations to reduce this knowledge gap between causes of and incidence of deprivation. For example, through the Commonwealth Knowledge Network (CKN) funding of a Sri Lanka project financial support specifically targeted science projects that dealt with involvement of women in an identified specific gender equity projects.

3.5 Integrating Gender into Enhanced Water Management capacity development

There is a prevalence of (asset) structural impediments to capacity development for water management and this is common in developing countries. This 'asset-related' constrains to water facilities include absence of irrigation infrastructure for women, lack of credit facilities for women that wish to embark on income generating activities, economic endowments denied to women by lack of knowledge, etc. Water distribution especially in the rural areas is mainly being decided on the basis of economic interests of the presiding male authority. These are generally endowed with the asset resources. This can easily be identified inside 'water use conflict' deprivation, in which the powerful have greater access to water at the expense of the poorer sections. Furthermore gender biased constraints to access credit for other water related projects, coupled with knowledge denial to women combine to restrict women's ability to respond to price signals and economic opportunities. These factors have increased women's water poverty exposure.

The envisaged use of a Water Poverty Index (WPI) stands to augments the national budget approach. The CSC collaborative work in gender and water issues has produced important insight on challenges confronted by number of gender and poverty reduction initiatives that have been undertaken to date. According to CSC two points must be advanced in the capability development through the gender/ water initiative. These are:

- women's participation in water industry based economic activities; and
- gender-culture conflict in water management issues.

At the broad regional level these two factors influence the incidence of water poverty at household level. As far as resolution of gender differentials is concerned these factors are additional to other social organisation of families and cultural norms that govern their interactions.

3.6 Gender and Culture conflict in Water Resources Management

The prevalence of men dominated organisations and their gender-water programmes are giving way to women managed water programmes. However the World Water Report 2001 indicates that in some countries man dominated cultural norms still exist as a challenge in the modern gender equity struggle. The reality is that even if these customs may not be a legal or *de jure* bar to water or land ownership there is a *de facto* situation whereby a lack of clarity over ownership and rights of access prevents women from realising the potential of farmland and water facilities. Evidence from parts of India and some parts of South Asian, as well as those of Sub-Sahara Africa give credence to this view and the Commonwealth Gender Mainstream initiative has sought to solve this problem through the gender budget approach. The process adopted in the NWM entails engaging local participation and educational networks that do not conflict with these cultural norms but empower women to partake projects that affect their water requirements.

Furthermore there is mounting evidence that shows that culture is an impediment to women's free right of access to water. In some cases this is a disadvantage that is created through the fact that some of these women rights still remain to be mediated through men. This is inherent in the culture relations and the CSC seeks to work along with the government programmes to reduce the culture limitations to gender inclusiveness in water-science projects. In CSC projects we have found that gender focusing can easily be achieved if the gender interests are addressed separately for men and women. This is partly because in some rural settings men are usually concerned with water access for irrigation or cattle (economic assets). The therefore play a greater role than women do in public decision making about water and sanitation issues. On the other hand women retain the role of collecting, use and management of water in the household.

3.7 The Way Forward

The nature and complexity of water/gender issues under implementation in developing countries is quite wide but very limited focus is placed on the measurement of water deprivation as related to women poverty. In short the whole gender debate revolves round a participatory framework of including women in water policy issues. This could include identification of the extent of the direct relationship between water deprivation and women's poverty. This should indeed not merely address policy and health issues alone. It must also embrace water as a key household factor for income-generating activities that will reduce household vulnerability to poverty.

The establishing of a relationship between water deprivation and women poverty is a fundamental step towards making strategic policy interventions that yield better understanding of the underlying factors and their effect. The current policy inspired attempts to deal with these issues has consistently escaped follow up evaluations. This is partly because there are limited pre-determined benchmarks that can assist implementers and project managers in the reviewing of the success/failure of gender and water-poverty initiatives.

CSC interventions on water and gender assessment indicate that diagnosis and follow-ups on the gender poverty and water issue is dealt with either at grassroots level but absent at the higher implementation level. In other cases it exists as a cursory budget issue with no input deriving from the water/poverty strategic plans from grassroots people. Therefore the CSC argues that mere inclusiveness of women in gender-water initiatives based on budget policies has limited effect on elimination of their relative poverty. It is necessary that such initiatives are based on analysis of gender factors such as management capacity development, usage conflicts effects potential, household characteristics, and water transport/infrastructure limitations. All these factors can form part of the gender budget input-output analysis. The CSC 's approach of a analysis of sectoral water poverty helps in three ways:

1. identification of gender-based differences in access to water resources, leading to prediction of the extent different household or members thereof are affected by the planned water-poverty interventions;
2. permits planners to set and measure high level effectiveness of interventions and the strategic application of future policies and programmes; and
3. development of a network facility that allows water access information exchange across and within members of the Commonwealth countries.

These three elements are fundamental in the understanding of and in dealing with the strategic gender needs, especially in addressing issues of equity and empowerment of women. This includes measuring the access of women, as a group compared with men, to resources such as water.

Appendix 9.12
Why include Livestock in a Water Poverty Index?
A presentation given by John Morton

Ref: King, John M.. - Livestock water needs in pastoral Africa in relation to climate and forage /. - Addis Ababa : International Livestock Centre for Africa, 1983. - (ILCA research report ; no.7

Despite myths and half-truths such as claims that they belong to the rich, destroy the environment and increase the risk of heart disease, livestock form a component of the livelihood of 70% of the world's rural poor:

- 194 million extensive graziers
- 686 million mixed farmers
- 107 million landless livestock-keepers

(LiD 1999)

Livestock provide:
- direct consumption (of protein and valuable micronutrients)
- cash
- security/investment
- fertility cycling
- draught power
- social capital
- a means to benefit from common grazing

Livestock water requirements are complex, and depend on; size, breed, physiological state, diet, activity, expected output, temperature, frequency of watering; etc. The science of water requirements appears still underdeveloped compared to animal nutrition.

Some indicative values: - litres/day for non-lactating adults under African **ranching** conditions

Species	Mean	Theoretical Maximum	"Practical Guideline for Development"	Salt-tolerance (% total salt)
Goat	2.0	5.4	5.0	1.5
Sheep	1.9	5.2	5.0	1.3-2.0
Cattle (Zebu)	16.4	56.1	25.0	1.0-1.5
Camel	18.4	34.0	30.0	5.5

(King 1983)

But more importantly, what (if any) household livestock holdings could be factored in to a water poverty index?

Some approaches (for brainstorming)

- farming-system specific (water to support number of animals locally associated with a poverty line) - cumbersome and dangers of circularity

- Water allowance for draught animals where DAP is prevalent form of farm power

- Notional water allowance for "small family milch herd/flock"
- e.g. 2 lactating goats @ 5 litres/day + 2 non-lactating @ 1 litre/day
- places value on milk as vital part of nutrition
- but values will be arbitrary

Water allowance for pastoralists mainly dependent on livestock

"Subsistence" herd sizes (hhold protein and caloric needs)

Species	Model	Literature
Cattle	50-64	20-36
Camels	28	10-25
Shoats	131-223	50-60

Hjort and Dahl 1983

but few pastoralists live entirely on their livestock

how to factor in labour and convenience?
pastoralists almost by definition must move themselves and their stock to water

how to factor in sustainability?
poorly planned year-round water can contribute to overgrazing and conflict

Defining an Index is not only a technical issue: it is ethical and political.

Appendix 9.13
Assessing the Water Poverty Index in a Context of Climatic Changes

Christel Prudhomme, CEH Wallingford

ABSTRACT

The Water Poverty Index (WPI) is a tool aimed at water managers to determine water-stressed areas, that can be estimated at a local, district or national level. It is briefly presented in this paper, with some suggested methods for its calculation. Its adaptability to incorporate climate change projections is discussed. A brief background on climate change modelling is provided, including a review of current climate modelling capacities from Global (and Regional) Climate Models (GCMs and RCMS). A summary of observed and projected changes in climatic variables and water-resources is provided for some regions of the world currently vulnerable to water-related poverty. Emphasis is given to two key elements of climate change modelling that must be considered with care in impact studies: scale and uncertainty. Currently, there are a number of limitations in climate change impact studies associated with climate change projections from GCMs, in particular of scale. To reduce uncertainties added with scale reduction techniques, it is recommended to undertake climate change impact studies at a scale consistent with that of climate change scenarios. For the WPI, future projections at a district or at a national scale are expected to be associated with lower uncertainties than those at local scale, and therefore recommended. An approach combining sensitivity analysis, climate change scenarios and hydrological modelling is proposed as a pertinent technique to identify threshold limits and impact of a range of projected changes on the WPI.

Key words: Water Poverty Index ; Water resources planning; Developing countries; Climate change assessment; Sensitivity analysis; Future projection; Water-poverty;

Introduction

Background on a Water Poverty Index

The Water Poverty Index is a new indicator developed at the Centre For Ecology and Hydrology in Wallingford, with the help of the funding from the British Department for International Development (DFID). Its concept emerged as a response to DFID after they identified that *"there is no generally acceptable quantitative measure for water assessment and the usual indicator is regarded as flawed for the purposes of rational, equitable and sustainable allocation"* (DFID, 2000). Integrated assessment of water stress and scarcity, linking physical estimates of water availability with socio-economic variables that reflect poverty, may offer some elements needed to find a more equitable solution for water allocation (Sullivan, 2001).

The Water Poverty Index is designed to capture those characteristics linking water and poverty, thus providing a water management tool to help determine where a water provision scheme is most needed. It is aimed to donor agencies and government departments, so that they can monitor progress and assess the impact of their work.

In a changing world, it is important to re-actualise this index regularly. It is also crucial to make future projections of the index, and to identify areas of potential increase of the water stress so that better medium to long-term planning can be made in time to implement adaptation procedures if necessary. This paper aims to provide some key elements on how to undertake assessment of what the WPI could become in the future.

The WPI definition

The Water Poverty Index evolves around five main themes (Sullivan, 2002):

- **Availability** of water resources (physical limitations and natural conditions);
- **Access** to that water, through human ingenuity and natural conditions;
- The **Use** made of that water by different economic sectors and social groups;
- The **Capacity** of society to manage the resource;
- The maintenance of **Ecological** integrity through allocation of adequate water supplies for ecosystem needs.

The ensemble of these indicators define the level of poverty attached to water resources. It is possible to monitor progress on each of these components, so that the state of water management can be assessed. For long-term water management planning, future projection of the WPI would need to be made, through future scenarios of the five indicators and re-calculation of the WPI under those scenarios.

Locations where the WPI would be most useful

There is a strong regional pattern in the geographical location of the world's poorest countries, as defined by their Gross National Income per capita. Of all the countries defined as 'low income' by the World Bank, 55% are from Sub-Saharan Africa, 8% are from South Asia, against only 14% from Eastern Europe and Central Asia (www.odci.gov/cia/publications/factbook). Regionally, this corresponds to a proportion of 73% of countries in Sub-Saharan Africa and 62% of the South Asian countries have a low income while 28% of Latin American countries are classified as having a low-middle income economy. A total of 76% of countries of low income are located between the tropics of Cancer and Capricorn (the inter-tropical zone), and most regularly endure some water-related disasters, such as dramatic flooding or severe droughts. In terms of climate, equatorial regions are marked by abundant precipitation, cyclones and typhoons in coastal areas. Sub-tropical regions show large regional variability with many of the world's largest deserts as well as regions with abundant rainfall (Lutgens & Tarbuck, 1992). Decadal cycles of extreme events are observed in the climate, such as long-lasting droughts or very severe flooding. Poor countries have generally a poor capacity to respond to problems, and a large population, thus are extremely vulnerable to climatic disasters.

If the WPI were to become an efficient, universal management tool, it should be designed to be flexible enough for an applicability in any part of the world where its need is perceived. The first phase of the feasibility of the WPI was conducted in three countries (South Africa, Tanzania and Sri Lanka) located in the inter-tropical zone (Fediw, 2001), where the combination of difficult climatic conditions and low state capacity makes then extremely unstable, and even more vulnerable to changes than most other areas. Examples of application of the WPI in these countries are shown in this paper.

Calculating the WPI

A number of approaches have been identified by a consortium of hydrologists, biologists, engineers, water managers, economists and sociologists that could be used to produce a Water Poverty Index. Two levels of definitions have been suggested, and their feasibility assessed: the *local level*, a 'bottom-up' type approach'; and the *national level* or 'top-down' approach. At the local level, values or parameters can be locally determined through surveys, local data collections etc... At the national level, information available in the public domain can be used. The approaches presented below could be applied at both levels, and have been developed during the first phase of the WPI project.

A composite index approach

The index is the weighted sum of set of variables that represent the five indicators. They could include:

- A: Adjusted Water Availability assessment (in %). It is the percentage of the water resource (surface and groundwater) that is available for ecological and human requirements (domestic and agricultural);
- S: population with safe access to water and Sanitation (in %);
- T: index (e.g. T between 0 and 100, but used in the form 100-T) that represents the Time and effort to collect the water, or the time of labour necessary to pay for the water.

The water access and time to collect the water are proxy data for socio-economic well being, while the water availability mainly represents the physical component. The different weights (or preferences) attached to each component should reflect which elements is thought to be the most critical in the region. For two regions with different characteristics but same preferences, such as for example, a region B with fewer people having access to safe water and spending more time to collect water than in region A, the WPI value is smaller for region B than for region A, thus highlights directly which region faces more water-related problems.

At a national level, the different components could represent the five key indicators of Resource, Access, Capacity, Use and Environment, and be assessed individually in a scale of 1 to 20 for example (20 being the most desirable state). The direct sum (with no weights) of those components would enable international comparisons of the Water Poverty Index value, with a lower score indicating problems (Table 1).

WPI Component	**Access**	**Use**	**Capacity**	**Resource**	**Environment**	**WPI**
Livelihood capital type	**ACCESS:Social capital, Financial capital**	**USE:Physical Capital, Financial capital**	**CAPACITY:Human Capital**	**RESOURCE:Natural Capital, Water resources**	**ENVIRONMENT: Natural capital**	**WPI**
Tanzania (WPI=43.0)	10.4	7.4	8.1	7.4	9.8	43.1
Sri Lanka (WPI=55.9)	10.1	14.5	12.5	7.5	11.3	55.9
South Africa (WPI=57.9)	12.1	14.7	13	5.6	12.4	57.8

Table 1 National WPI component values for three countries **(Source: Sullivan, 2002)**

The GAP method

The components of the WPI are compared to a standard (or target) value, defined to reflect the level that would exist if the resource was managed in a sustainable way. For each individual component of the WPI (e.g. ecosystem health, human health, community well being, and economic welfare), the empirical value, calculated from measurements, is compared to the pre-set standards, and the difference (or gap) between the two values indicates the level of water stress. The WPI is represented by the ensemble of gap values for each of the components – and not by a single value.

A matrix approach

The main characteristics associated with water stress and human welfare are combined in a two-dimensional matrix representing on one axis capacity and use; and on the other axis availability and access. This approach could be a graphical representation of a composite index calculation. A simple star diagram could also be used to display the results, for example the national WPI values of Table 1 are represented in Figure 1. This representation is closed to the 'Star Diagram' suggested by Lane *et al.* (1999) to represent a water resource index.

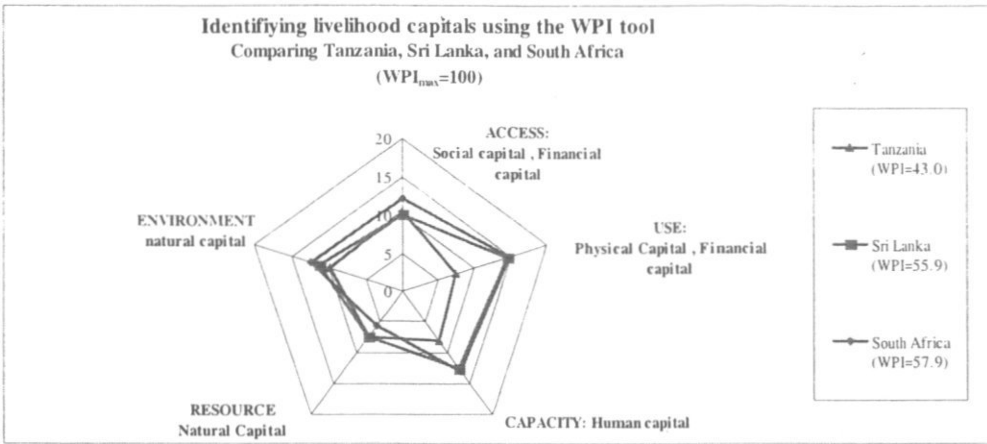


Figure 1 Comparing different countries using the WPI tool **(Source: Sullivan, 2002)**

Background on climate change modelling

In the recent past, human activity has lead to an increase in the concentration of greenhouse gases in the atmosphere by about 31% compared to levels of 1750, and the current rate of increase is believed to have been unprecedented for at least the past 20,000 years (IPCC, 2001a). Concomitantly, the global temperature has also been increasing, and is currently about 0.6°C warmer that it was 140 years ago.

The importance of taking into account the impact of change in climate in long-term planning is now widely recognised. However, it is crucial for managers to understand that any impact result is undoubtedly attached with large uncertainties, some of them due to aspects inherent to climate change modelling. In particular, it must be stressed that climate change scenarios are not predictions, but suggestions of what scientist think a plausible future may be. They are surrounded by number of assumptions and uncertainties and, thus, can only provide indications to be treated with caution. A rapid review of the main issues underlying any climate change impact study is provided here, with an overlook at their abilities but also their limitations.

Existing tools: Global Climate Models

The process governing the climate system is extremely complex, and not yet fully understood. Numerical Global Climate Models (GCMs) attempt to represent the physical processes in the atmosphere, ocean, cryosphere and land surface. They are currently the only credible tool available for simulating the response of the global climate system to increasing greenhouse gas concentrations, and provide estimates of climate variables (such as air temperature, precipitation, incoming radiation, vapour pressure, wind speed etc…) for the whole world (IPCC, 2001a).

Most GCMs are 3-dimensional models with generally one atmospheric and one oceanographic components coupled together. The Intergovernmental Panel of Climate Change (IPCC) Data Distribution Centre provides detailed information on several GCMs developed in Australia, Canada, Germany, Japan, the UK, USA, and scenarios of climatic variables derived from those models (http://ipcc-ddc.cru.uea.ac.uk).

Because the different processes representing the climate system are described by sets of complex equations, the geographical resolution of GCMs is typically around

~300 km. This means that some regional effects of the climate are masked by an over-smoothing of the elevation. Recently, Regional Climate Models (RCMs) have been developed to provide finer spatial and temporal details of atmospheric circulation, but they cover only limited areas of the globe (Hudson, 2002). The Hadley Centre's RCM has a nominal resolution of 0.44°x0.44°. An example is shown for Southern Africa (Figure 2), where the RCM is shown to provide a much more realistic representation of the elevation than the GCM (e.g. the Maloti mountains, in Lesotho). The RCM spatial resolution at those latitudes is roughly of 50 km by 150 km.

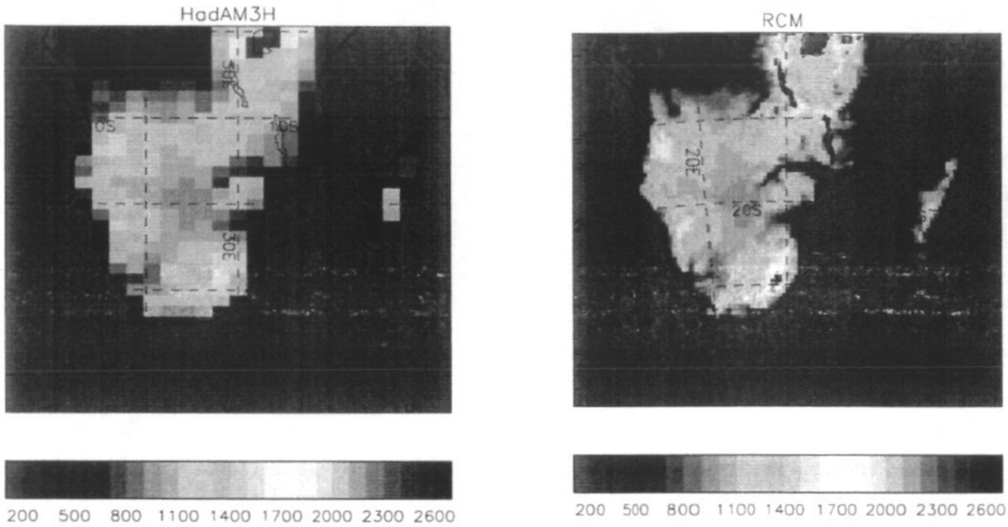


Figure 2: Distribution of orographic height (m) in the Hadley Centre's GCM (HadAM3H) and RCM. **(Source: Hudson, 2002)**

A number of different GCMs exist to simulate the global climate, and they don't always provide consistent results amongst themselves. No single particular GCM is at present recommended to use, but Smith and Hulme (1998) (after Hulme and Carter, 1999) suggest to impact modellers to chose a model as recent as possible, which performs well compared to local observations and whose spatial resolution is consistent with modelling requirements. Data availability and easy access are also important criteria. How well past and current climates are simulated provides guidance on how well the climatic processes are understood, and how much confidence can be given to future predictions. However, until progress is made in better replicating local features, and especially rainfall, scientists place more confidence in the differences in the signal than in the direct simulations.

Assumptions behind future projections

It is important to emphasise that GCM simulations are **not** predictions but are plausible futures. The assumptions behind climate scenarios include future trends in energy demand, emissions of greenhouse gases and land use change, as well as assumptions about the behaviour of the climate system over long time scales, and in particular the behaviour of the global air surface temperature. Two main forcing agents are used in future climate projections from GCMs:

(i) the **emission scenarios**, that are plausible projections of atmospheric concentrations of greenhouse gases and aerosols for the future. They are based on scenarios on demographic evolution, socio-economical development, energy demand and technical changes (IPCC, 2000); and

(ii) the **climate sensitivity**, that represents the increase in global temperature that the planet would endure (assuming the equilibrium is reached) when the CO_2 concentration in the atmosphere will be twice that of 1975. It depends on the GCM used to model the climate, but is usually assumed to range from 1.5 to 4.5°C (IPCC, 2001a).

Scale

Spatial scale

In hydrology, climate change impact studies are confronted with scaling issues as the scale of the processes is usually much finer than the scale of the Global Climate Models producing global climate series (cells of ~300km side). Different techniques have been developed to reconcile both scales, providing scenarios at finer spatial resolution than the GCM they are issued from. This mechanism is known as '*downscaling*'. Downscaling techniques range from very simple statistical methods (such as interpolation, multiple regression analysis etc...) to complex dynamical modelling such as the Regional Climate Models RCMs (Prudhomme *et al.*, 2002).

Temporal scale

Despite being run at sub-daily time steps, GCMs (and even RCMs) cannot yet capture sub-monthly climatic patterns, in particular variation in precipitation intensity. Prudhomme *et al.* (2002) compared daily series simulated from the Hadley Centre's GCM HadCM2 with areal daily rainfall series over the same area, in Wales in the UK. In particular, they observed that the annual maxima daily rainfall totals extracted from the GCM series were consistently lower than those extracted from the observed series. Series aggregated over time scales, such as annual or seasonal, however, generally mimic observations better than shorter time-step series, and are best used to assess climate change signals. Still, large differences sometimes exist when several model outputs are compared (e.g. Gates *et al.*, 1999), especially in the tropics (Adler *et al.*, 2001). Simulation of large-scale phenomenon, such as El Niño Southern Oscillation, has now improved (e.g. Meehl *et al.*, 2000a) - but it is still generally underestimated – so are the Monsoon cycles or the North Atlantic Oscillation. More extreme events are not yet completely satisfactorily simulated (e.g. Zwiers & Kharin, 1998; Jones & Reid, 2001).

Uncertainties

Uncertainty is a major concern in impact studies assessing future regimes (hydrological or others). A wide range of sources of uncertainties have been identified by Carter *et al.* (1999), including uncertainties in how to quantify and model a climate complex system not entirely understood, uncertainties in future emissions, uncertainties in how to interpret climate prediction and how to build them into downstream modelling (such as hydrological modelling). The use of multi-ensemble integrations run, that regroup several experiments done with a single model and under the same forcing, and the consideration of different GCM experiments are at present the recommended ways to reduce uncertainty (e.g. Barnett *et al.*, 1999; Dai *et al.*, 2001). In the UK, for example, the largest uncertainty in results of impacts of climate change on floods was from the type of GCM used, and not from the forcing scenarios used in the GCMs simulations (Prudhomme *et al.*, 2001).

Alternatives to GCM modelling

There are some alternatives to GCMs that could be used in climate change impact studies. Hypothetical scenarios, for example showing incremented changes in key variables, could provide a framework for a sensitivity analysis to be undertaken. They

could be derived either from extrapolation of observed trends, or be created to show a wide range of possible changes within which the plausible future changes are likely to reside (e.g. Panagoulia, 1991; Seidel *et al.*, 1998).
The analogue methods replicate part of historical series that show analogies with indications of changes (for example from GCMs, or from interpolation of observed trends) by the climate change factors compared to averaged conditions. The technique is to select some historical sequences (either month, or seasons) that show the same departure from the long term average as indicated by seasonal climate change factors, and to repeat this 12-month sequence - not necessarily from the same year in the original series – x times to construct an x-year long series.

Climate change assessment

Observed changes

Climatic trends

Trends in climatic variables, such as temperature or rainfall, are studied with interest all over the world as they could give evidence that our climate is changing, and a number of regional patterns have been observed. Sudan, for example, has experienced a significant upward trend in the annual and seasonal temperatures (Elagib & Mansell, 2000). In West and Central Africa, regional rainfall has decreased, but the deficit is larger in Western parts (Mahé *et al.*, 2001); step changes are characteristics of those regions, also observed in Nigeria (Tarhule & Woo, 1998). Heavy precipitation has been decreasing in Eastern Africa and Thailand, but increasing (both in terms of total precipitation and number of extreme events) in South Africa and China (Easterling *et al.*, 2000). Dai *et al.* (2001) showed increases in the overall areas of the world affected either by droughts or excessive wetness. However, climatic variability is large, and some trends could be erroneously highlighted if derived from short records, outside the context of natural multi-decadal variability (Robson *et al.*, 1998). In Africa, seasonal and interannual changes in rainfall are significantly greater than long-term trends and decadal cycles and this makes trends difficult to detect (Schulze, 2000).
In terms of modelling, most GCM are not yet able to satisfactorily capture and detect such changes, and thus to attribute them to enhanced greenhouse gases concentration (Barnett *et al.*, 1999), but Regional Climate models are starting to reproduce climate variability, for example in Africa where it is naturally large (Jenkins, 1997; Hudson, 2001).

Water resources trends

The water cycle is complex, and mainly driven by climatic conditions: as a first approximation, 'runoff' can be assessed as the difference between the input (precipitation) and the output (evaporative losses). However, this relationship is modified by numerous factors, either natural (vegetation with different water needs; varied infiltration due to variation in the geology and soil characteristics, soil moisture content, intensity and distribution of precipitation etc...) or unnatural (soil degradation, water abstraction, artificial streamflow channels, dams and reservoirs etc...). A highly non-linear, complex relationship results between rainfall and runoff or water resource, especially in regions of extreme climate such as Southern Africa. A dramatic example is found in South West Niger, where despite a significant decrease in the rainfall totals, the water table has risen, due to man-made land use changes and consequent soil degradation (Leduc *et al.*, 2001). Moreover, the combination of natural and human induced changes makes the observation and interpretation of changes in flow regimes difficult (Van Langenhove *et al.*, 1998).

Climate change projections

The IPCC recently published a report on the potential impact of climate change on the water cycle providing a general picture of possible changes briefly summarised here (IPCC, 2001b). Decreases in annual streamflow are projected to occur in central Asia, southern Africa, and the water stress is likely in be exacerbated. The water quality would be degraded by higher water temperatures, but changes in flow volume may modify the effect of temperature. Flood magnitude and frequency are likely to increase in most regions, and low flows are likely to decrease in many regions. For example, Indian Monsoon variability tends to increase, thus increasing changes of extreme dry and wet monsoon seasons (Meehl *et al.*, 2000a). Increased flood risk and wetland losses has been projected to happen in Southern Mediterranean, Africa, and vulnerability extremely increased in low-lying populated areas such as South and South-East Asia (Nicholls *et al.*, 1999). There is suggestion of an increase in the probability of extreme warm days, the greatest changes in the 20-year return period values of daily maximum temperature expected in central America, central and southeast Asia, tropical Africa (added to a decrease of the soil moisture content) and North Africa (Meehl *et al.*, 2000b).

Vulnerability to changes

Vulnerability in developing countries (in Africa, central America and Asia) is large, as the adaptive capacity is generally low due to lack of economic resources and technology. With a climate becoming more extreme, regions with high demographic (e.g. South Asia) increase freshwater resource expected to become highly vulnerable to changes. Other examples include the regression of glaciers in Latin America that would reduce water availability for irrigation, hydropower generation and navigation. Human health may also be at risk, the rise in temperature would extend disease vector habitats, and increase the frequency of water-borne diseases where sanitary structure is inadequate.

With one third of the world's population (1.7 billion) already living in water-stressed countries, this figure is projected to increase to 5 billion by the 2025. Demand for water is generally increasing, as a result of population growth and economic development. Larger withdrawals for irrigation and agriculture are likely also to be exacerbated by higher temperatures. The impact of climate change on water resources depends, in addition to changes in natural factors, to changing pressures on the system, and to the implementation of adaptive measures. It is possible that those non-climatic changes may have a greater impact on water resources than climate change.

Limitations and uncertainties

There is still large uncertainty in the projected changes in precipitation pattern from GCMs (Hulme *et al.*, 2001), and especially in low-latitudes (Gates *et al.*, 1999). Limitations in the ability of climate models to simulate precipitation, for example, arise from (i) small ratio between signal of change and noise due to natural variability; (ii) poor ability to account for influence of land cover changes on future climates; and (iii) poor representation in many models of the existing climatic variability extremely important, in particular for Africa. Despite those drawbacks, Hulme *et al.* (2001) suggest that "*climate change scenarios should nevertheless be used to explore the sensitivity of a range of African environmental and social systems, and economically valuable assets, to a range of future climate change*". It is therefore legitimate to envisage their use for future projections of the WPI.

Assessing the impact of climate changes in the Water Poverty Index

As seen in the first section, the Water Poverty Index is defined by a combination of five indicators, with each of them likely to be impacted differently to set changes. While this paper focuses mainly on changes due to the climate, the importance of other changes must be analysed in a complete impact study. Three main issues ar rise here: (i) which indicators are likely to be affected by such changes; (ii) what are the scales appropriate to assess the changes, and (iii) how to incorporate climatic changes efficiently.

The WPI indicators and the climate

From the five indicators identified as key to a water poverty index, not all have a direct link with the climate: the **availability** of the water resource will be modified by changes in precipitation and evaporation losses; the **use** of the water and the **environment** wealth will be conditioned by the temperature (e.g. hotter climate is likely to increase the domestic and agricultural demands; irrigation needs depends on rainfall patterns). **Access** to water depends mainly on the infrastructure, but the time to access the water may also be affected by temperature conditions.

Relevance of climate change impact studies for WPI future assessment

The scale issue

Climate change impact studies that use future climatic projections are constrained by the scale (spatial and temporal) at which climate change scenarios are available. GCMs models, with a ~300km grid cell mesh, do not provide estimates that can be used without further transformation – with the associated added modelling error and uncertainty. The recent development of Regional Climate Models, that provide simulated series for a grid of size under 100km, offers great scope to the impact community. Scenarios derived from RCM outputs describe more realistically spatial details of weather patterns of the order of 2,000 to 10,000 km^2. These scenarios would not necessitate the use of downscaling techniques if they were to be used at the same spatial scale, consistent with in macro-scale hydrological modelling.

The scale at which climate change scenarios are most relevant to the Water Poverty Index is the district level that is used in water management, and the coarser national level. The implementation of future assessment of the WPI at the local levels would require further assumptions on how regional estimates can be spatially distributed to give reliable local estimates of changes.

The modelling aspect

The definition of the Water Poverty Index requests estimates of the water resource available, combining natural availability (i.e. incorporating minimal human influence) and actual availability (accounting for infrastructure, pollution etc...). At present, GCMs or RCMs can only provide estimates of climate projections – and not of the water resource - and thus, modelling must be integrated in the WPI assessment exercise for future estimates of the water resources to be made. An unbiased evaluation of future changes of the water stress, as represented by the WPI, would require that a similar methodology should be used to calculate the WPI under present and changed conditions. Ideally, the modelling technique employed should be flexible enough to incorporate range of elements impacting on the water resource, natural or not, and to provide reliable estimates at a scale consistent with that of the input data.

Different approaches exist to model the water resource from climatic data, ranging from simple statistical methods to complex physically-based models through conceptually designed models. Simple statistical relationships request limited data.

but are not always very accurate. Moreover, in a context of climate change, there is no guarantee that those statistical relationships will remain true, and thus increasing the uncertainty in the future assessment. On the other hand, they provide immediate assessments, and request only very limited resources and data to be implemented. At the other end of the scale, physically distributed models demand large number of data (both climatic and physical) that are not always available, especially in developing countries where the scientific investment can be minimal. The scales at which they operate is often fine, and inconsistent with data provided by GCM or RCM scenarios. They cannot be used by non-specialists, and request sometimes large computing capacities.

Conceptual macro-models can often model the processes at a monthly time-step, and have the advantage to request a limited number of data. They have been a common approach to assess water resource at a continental or regional scale (Arnell, 1993), and thus are consistent with Global (or Regional) Climate Models scales. Whilst aimed at specialists, they usually demand less knowledge of the processes than more physically-based models. Two approaches exist: (i) the 'top-down' approach, consisting of simple conceptual models applied at a coarse scale gridded data (e.g. Vörösmarty & Moore, 1991; Servat & Dezetter, 1993; Kite *et al.*, 1994; Arnell, 1999; Meigh *et al.*, 1999); and (ii) the 'bottom-up' approach, with highly detailed models with fine spatial and temporal sales, but applied to large geographical areas (e.g. Kilsby *et al.*, 1999; Schulze, 2000). This last approach, like the physically distributed models, can sometimes be very data-intensive.

Assessing climate change impact

The Water Poverty Index is a complex index formed of separate elements, incorporating some 'un-quantifiable' data such as the perceived quality of the water, the sectorial allocation, method of transport of the water, right-of-use etc... Changes in each of them will have to be estimated for a future assessment of the WPI to be made. Sophisticated approaches may not be the most relevant when large uncertainties already exist in a stationary context. This section presents some methods that could be envisaged for an impact study on the WPI to be implemented.

Impact study: classical approach

The classical approach in climate change impact study is to run the model under "reference" and "future" conditions, and assess the difference. The level of sophistication of the method mainly concerns how the climate change scenarios are downscaled to the scale (temporal and spatial) relevant for the processes to be modelled. The type and number of scenarios used will condition quality of the results, and assessment of the uncertainty.

Climatic data. The majority of scenarios are provided at the GCM grid-scale (around 300 km side) and as monthly mean changes compared to a monthly mean baseline. The most extensive database is hold by the Intergovernmental Panel on Climate Change Data Distribution Centre, at http://ipcc-ddc.cru.uea.ac.uk, where at the time of writing, scenarios from seven GCMs are provided for the whole world. Data from RCMs are not yet publicly available, but could be obtained directly from the climate centres if available. It is highly recommended to undertake the modelling with a range of different scenarios obtained from different GCMs and forcing scenarios. For best planning decisions, it can also be envisaged to analyse the impacts for several time-horizons.

Other data. The IPCC-DDC provides socio-economic scenario information, that are compatible with the forcing scenarios used in the climate modelling (see also http://sres.ciesin.org/final_data.html). The socio-economic scenario data supplied follow the same assumptions than IS92 and SRES emissions scenarios. The variables should include population, Gross National Product (GNP), energy use, land use, and other socio-economic indicators. It is anticipated that pointers will be provided to the emerging work of the SRES.

The sensitivity approach: hypothetical scenarios

The sensitivity approach consists of analysing the impact of a series of changes for a set of relevant indicators regularly incremented concomitantly, thus analysing a matrix of hypothetical scenarios whose dimension equals the number of scenarios by the number of indicators. Indicators can be simple variables (e.g. rainfall, temperature and population) or complex variables (e.g. natural water resource, water demand, land use type or pollution level). Each of the four WPI elements should undergo a sensitivity analysis, with respective relevant factors and changes. This method is not very popular, but has been used in impact studies (e.g. Seidel *et al.*, 1998; Van Minnen *et al.*, 2000).

To avoid un-necessary computation, a 2-step approach is suggested. First, a pre-analysis with a limited number of changes (e.g. three changes) permits identification of which factors the WPI is most sensitive to. Second, a more in-depth study is carried out with only the pre-identified factors, but for an extensive range of changes. A maximum of three factors seems to be a manageable compromise.

An example of the approach is illustrated in Figure 3. It is taken from an analysis by Van Minnen *et al.* (2000) who evaluated the impact of changes in temperature and precipitation (the two pre-selected factors) on crop production, using Response Surface Diagrams. Those allow a graphical representation of the impact in a 3-dimension diagram, assuming a 2-component sensitivity analysis.

According to Strzepek & Yates (2000) "*understanding the role of water resources in each sector of the economy will help to determine the response of the economy to changes in water supply*". In that perspective, sensitivity studies are invaluable, because they are capable of incorporating adaptive capacities such as changes in the crop production or population movements, that would be difficult in a classical impact study if no scenarios exist on such factors.

The combined approach

A major drawback of the sensitivity approach is not to make reference to projected changes. While it is informative to assess how the system would respond to some changes, if those changes are unrealistic, there is no practical use in management, and the exercise becomes meaningless.

The combined approach is a way to encompass the simplicity of the sensitivity method while capturing the predictive information that resides within IPCC climate change scenarios. It is suggested as a three step method:

1. A pre-analysis defines the key factors whose changes will be considered in detail. If possible, no more than two or three factors should be selected;
2. A complete sensitivity analysis is undertaken with all the selected factors varying within a fixed range of changes, each varying regularly. All the combination of changes are to be analysed;
3. The changes indicated by the IPCC scenarios are highlighted in the sensitivity matrix. A range of several scenarios, combining different GCMs, climate sensitivity and emission scenarios should be considered to give an envelop of future projections.

A schematic representation of such a method is suggested in Figure 4. The matrix of impacts derived from the sensitivity analysis (Fig. 2) is accompanied by an envelop showing the impacts of (here hypothetic) climate change scenarios for a time horizon x.

The importance of thresholds

In addition to its simplicity and versatility, the combined approach enables identifation of a critical threshold beyond which the system response may becomeunacceptable. This notion of "threshold" is extremely important when analysing the consequences of changes in the water resources on the economy and poverty (Strzepek & Yates, 2000). Thresholds also exacerbate the non-linear response of the system to changes, such as the rate of change in runoff increases as the amount of rainfall change increases in semi-arid regions (Arnell, 2000). Arnell also stresses that *it's not the exceedance of the threshold which is generally important, but the frequency with which the threshold is exceeded*". The combined approach responds to this need, with climate change scenarios providing crucial complementary information to the sensitivity study. From this analysis, it is possible to assess (i) if the threshold is to be exceeded, (ii) when in the future it is likely to be exceeded for the first time, and (iii) what is the risk and frequency of being exceeded according to a number of climate change scenarios.

Conclusion

The Water Poverty Index is a tool designed for water managers so that they can assess the level of water-related poverty of specific sites. Its efficiency depends on (i) the range of indicators that it encapsulates, (ii) how comprehensive it appears, (iii) how understandable and direct it is perceived, (iv) its ease of calculation, and (v) its capacity in being used in long-term planning.

Recent scientific evidence suggests that the world's climate is changing at a rate accelerated by anthropogenic emissions. It results that efficient resource management necessitates long-term planning of the water resources, and cannot be dissociated from climate change projections any longer. The Water Poverty Index, if unable to account for changes, would have a somehow limited use, and it is crucial for its dissemination that it incorporates an element of changes. However, it must remain clear that limitations exists when undertaking climate change impacts studies, and in particular, uncertainty and scale issues are difficult to overcome.

Limitations exist in climate change impact studies due to the current abilities to simulate climatic series accurately. The best tools available at present are the Global Climate Models (and the most recent Regional Climate Models) but they only offer estimates at a spatial scale varying between 50 and 300km grid mesh. For those scenarios to be relevant for the future assessment of the Water Poverty Index, similar spatial scales should be considered. This means that the uncertainty associated with future projections of the WPI is expected to be lower when considering district and national levels than at a local scale. A sensitivity study undertaken for all elements defining the Water Poverty Index, combined with relevant scenarios obtained from GCMs and RCMs projections, would offer managers a framework useful for long-term planning.

Acknowledgements

The help of Sonja Folwell for the graphics is gratefully appreciated, and of fellow hydrologists for their useful comments and suggestions. This project was funded through the "Knowledge and Research" programme of the British Department for International Development (Research contract C24).

ReferenceS

Adler R.F., Kidd C., Petty G., Morissey M., Goodman H.M. (2001). Intercomparison of Global Precipitation Products: the third precipitation intercomparison project (PIP-3). *Bulletin of the American Meteorological Society*, **82**(7), 1377-1396

Arnell N.W.(1993) Data requirements for macroscale modelling of the hydrosphere. *In: Proc. Of the Yokohama symposium "Macroscale modelling of the hydrosphere"*, IASH, **214**: 139-149

Arnell N.W. (1999) The effect of climate change on hydrological regimes in Europe: a continental perspective. *Global Environmental Change*, **9**: 5-23

Arnell N.W. (2000) Thresholds and response to climate change forcing; the water sector. *Climatic change*, **46**: 305-316

Barnett T.P., Hasselmann K., Chelliah M., Delworth T., Hegerl G., Jones P., Rasmusson E., Roeckner E., Ropelewski C., Santer B., Tett S. (1999) Detection and attribution of recent change: a status report. *Bulletin of the American Meteorological Society*, **80(12)**: 2631-2659

Carter TR, Hulme M, Viner D (Eds.) (1999) *Representing uncertainty in climate change scenarios and impacts studies*. ECLAT-2 Report No 1, Helsinki workshop, 14-16 April 1999, CRU, Norwich, UK, 128pp

Dai A., Meelh G.A., Washington W.M., Wigley T.M.L., Arblaster J.M (2001). Ensemble simulation of twenty - first century climate changes: business-as-usual versus CO2 stabilization. *Bulletin of the American Meteorological Society*, **82**(11), 2377-2388

DFID (2000) Target Strategy Paper: Water Resources and Sanitation London

Easterling D.R., Evans J.L., Groisman P.Y., Karl T.R., Kundel K.E., Ambenje P. (2000) Observed variability and trends in extreme climate events: a brief review *Bulletin of the American Meteorological Society*, **81**: 417-425

Elagib N.A., Mansell M.G. (2000) Recent trends and anomalies in mean seasonal and annual temperatures over Sudan *Journal of Arid Environments*, **45**: 263-288

Fediw T. (2001) Derivation and testing of the Water Poverty Index Phase 1. South Africa, Tanzania & Sri Lanka household surveys. Preliminary analysis and observation. Report to DFID. Centre for Ecology and Hydrology, Wallingford, 35 pp

Gates W.L., Boyle J.S., Covey C., Dease C.G., Doutriaux C.M., Drach R.S., Fiorino M., Gleckler P.J., Hnile J.J., Marlais S.M., Phillips T.J., Potter G.L., Santer B.D., Sperber K.R., Taylor K.E., Williams D.N. (1999) An overview of the results of the atmospheric model intercomparison project (AMIP I). Bulletin of the American Meteorological Society, **80(1)**: 29-55

Hudson DA, 2001. Simulating present-day and future climates of Southern Africa using the Hadley Centre Regional Climate Model. DEFRA Report 2/5/01. Hadley Centre for Climate Prediction and Research, Met Office, Bracknell, UK

Hulme M. Carter T (1999) Representing uncertainty in climate change scenarios and impact studies Discussion paper 1. *In Carter & Hulme (Ed.), ECLAT-2 Report No 1*. Helsinki, 11-37

Hulme M., Doherty R., Ngara T., New M., Lister D. (2001) African climate change: 1900-2100. *Climate Research*, **17**: 145-168

Intergovernmental Panel on Climate Change (2000) *Special report on emissions scenarios*. Nakicenovic N, Swart R (Eds.). A special report of Working Group III on the Intergovernmental Panel on Climate Change. ISBN 0-521-80081-1, 612 pp

Intergovernmental Panel on Climate Change (2001a) *Climate change 2001 Scientific basis.* Contriibution of Working Group I to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge Uniuversity Press, Cambridge. UK. ISBN 0-521-80767-6. 881 pp

Intergovernmental Panel on Climate Change (2001b) *Climate change 2001. Impacts, Adaptation and Vulnerability.* McCarthy J.J.. Canziani O.F.. Leary N.A.. Dokken D.J.. White K.S. (Eds.). Contribution of Working Group II to the third assessment report of the Intergovernmental Panel on Climate Change. Cambridge Uniuversity Press. Cambridge, UK. ISBN 0-521-80768-9. 1032 pp

Jenkins G.S. (1997) The 1988 and 1990 summer season simulations for West Africa using a Regional Climate Model. Journal of Climate. 10(6): 1255-1272

Jones PD, Reid PA. 2001. Assessing future changes in extreme precipitation over Britain using Regional Climate Model integration. Intern. J. Climatol., 21: 1337-1356

Kislby C.G., Ewen J., Sloan W.T., Burton A., Fallows C.S., O'Connel P.E. (1999) The UP modelling system for large scale hydrology: simulation of the Arkansas-Red River basin. Hydrology and Earth System Sciences, 3(1): 137-149

Kite G.W., Dalton A., Dion K. (1994) Simulation of streamflow in a macroscale watershed using general circulation model data. Water Resources Research, 30(5): 1547-1559

Lane M.E.. Kirshen P.H., Vogel R.M. (1999) Indicators of impacts of global climate change on U.S. water resources. *Journal of Water Resources Planning and Management*, **125 (4)**: 194-204

Leduc C., Favreau G., Schroeter P. (2001) Long-term rise in a Sahelian water-table. the continental terminal in South-West Niger. *Journal of Hydrology*, **243(1-2)**: 43-54

Lutgens F.K., Tarbuck E.J. (1992) The *atmosphere: an introduction to meteorology (fifth edition).* Prentice-Hall, Englewood, New Jersey, USA, ISBN 0-13-051467-5. 430 pp

Mahé G., L'Hote Y., Olivry J.C., Wotling G. (2001) Trends and discontinuities in regional rainfall of West and Central Africa: 1951-1989. *Hydrological Sciences Journal*, **46(2)**: 211-226

Meehl G.A., Boer G.J., Covey C., Latif M., Stouffer R.J. (2000). The coupled model intercomparison project (CMIP) meeting summary. *Bulletin of the American Meteorological Society*, **81(2)**: 313-318

Meehl G.A., Zwiers F., Evans J., Knutson T., Mearns L., Whetton P. (2000b) Trends in extreme weather and climate events: issues related to modelling extremes in projections of future climate change. *Bulletin of the American Meteorological Society*, **81(3)**: 427-436

Meigh J.R., McKenzie A.A., Sene K. (1999) A grid-based approach to water scarcity estimates for Eastern and Southern Africa. *Water Resources Management*, **13**: 85-115

Nicholls R.J., Hoozemans F.M.J., Marchand M. (1999) Increasing flood risk and wetland losses due to global sea-level rise: regional and global analyses. *Global Environmental Change*, **9**:S69-S87

Panagoulia D. (1991) Hydrological response of a medium-sized mountainous catchment to climate change. Hydrol. Science Journal, 36(6): 525-547

Prudhomme C, Svensson C, Jakob D. 2001. Climate change and water management: managing European water resources in an uncertain future. Volume 4: changing streamflow in the UK. Report to the EU, project ENV4-CT98-0791, November 2001, CEH, Wallingford, UK, 84 pp

Prudhomme C, Reynard NS, Crooks S (2002) Downscaling of GCMs for flood frequency analysis: where are we now? *Hydrol. Processes*, **16**, 1137-1150

Robson A.J., Jones T.K., Reed D.W., Bayliss A.C. (1998) A Study of national trend and variation in UK floods. *International Journal of Climatology*, 18: 165-182

Schulze R.E. (2000) Modelling hydrological responses to land use and climate change: a Southern African perspective. *Ambio*, **29(1)**: 12-22

Seidel K., Ehrler C., Martinec J. (1998) Effects of climate change on water resources and runoff in an Alpine basin. *Hydrological Processes*, **12**:1659-1669

Servat E., Dezetter A. (1993) Rainfall-runoff modelling and water resources assessment in northwestern Ivory Coast. Tentative extension to ungauged catchments. *Journal of Hydrology*, **148**: 231-248

Strzepek K.M., Yates D.N. (2000) Responses and thresholds of the Egyptian economy to climate change impacts on the water resources of the Nile river. *Climatic change*. **46**: 339-356

Sullivan C. (2001) *Derivation and testing of the Water Poverty Index. Phase I*. Interim report to DFID. Centre for Ecology and Hydrology, Wallingford, 9pp+ annexes

Sullivan C. (2002a). *Calculating a Water Poverty Index*. Internal report, Centre for Ecology and Hydrology, Wallingford, UK, 24 pp

Sullivan C. (2002b). Using *the Water Poverty Index tool to achieve improved water management*. Internal report, Centre for Ecology and Hydrology, Wallingford, UK, 5 pp

Tarhule A., Woo M.K. (1998) Changes in rainfall characteristics in Northern Nigeria. *International Journal of Climatology*, **18**: 1261-1271

Van Langenhove G., Amakalli M., De Bruine B. (1998) Variability of flow regimes in Namibian river. natural and human induced causes. *In: Proc.* Abidjan'98 conference "Water resources variability in Africa during the XXth Century", IAHS 252: 455-462

Van Minnen J.G., Alcamo J., Haupt W. (2000) Deriving and applying response surface diagrams for evaluating climate change impacts on crop production. *Climatic change*, **46**: 317-338

Vörösmarty C.J., Moore B. (1991) Modelling basin-scale hydrology in support of physical climate and global biological studies: an example using the Zambezi river. *Surveys in Geophysics*, **12**: 271-311

Zwiers F.W., Kharin V.V. (1998). Changes in extremes of the climate simulated by CCC GCM2 under CO2 doubling. Journal of climate, 11, 2200-2222

Figure captions:

Figure 2. Sketch of sensitivity analysis presented with a Response-Surface-Diagram (adapted from Van Minnen *et al.*, 2000)
Figure 3. Same figure as Figure 1, but with a climate change envelop defined from hypothetical climate change scenarios (dark shade)

Appendix 9.14
Meso-Scale Indicators of Water Poverty in the Thukela Catchment South Africa, Under Baseline Land Cover Conditions

Roland E. Schulze and Dennis J. M. Dlamini

School of Bioresources Engineering & Environmental Hydrology
University of Natal, Pietermaritzburg, South Africa

Final Draft
Water Poverty Index Study
Thukela Catchment Report
April 2002

Disclaimer

While every reasonable effort has been made by the authors to obtain objective and realistic results in this study, neither the authors, the School of Bioresources Engineering and Environmental Hydrology, nor the University of Natal, nor any of their employees, make any warranty, express or implied, or assume any legal liability or responsibility for the accuracy, completeness or usefulness of any information, product or process disclosed by this report.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

Table 5.7 Statistics on monthly and annual simulated stormflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift

Table 5.8 Statistics on monthly and annual simulated baseflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift

1 PREAMBLE

The value of the results of water resources assessments is minimal if they are not linked to, or viewed in the light of, human welfare. Since the 1992 World Summit in Rio de Janeiro, several global initiatives (e.g. The 5th Global Forum of Water Supply and Sanitation Collaboration Council, 2000; 6th Session of the Commission for Sustainable Development) have highlighted the strategic importance of the water sector in poverty alleviation and the promotion of regional stability. This has resulted in the classification of countries and regions on the basis of water stress in order to implement interventions in crisis areas. At regional and national scales, Falkenmark's (1989) water stress index (while mindful of its limitations) has been used with considerable success for these categorisations. However, this method is too coarse for sub-national (provincial, small catchment or community) classification programmes. Furthermore, suitable methods or indices of water stress and poverty, in addition to having to be multi-disciplinary and having to link physical water availability (supply) with requirements of human population (demand), need to accommodate the population's capacity to access water and adapt to its shortage.

With funding from the Department for International Development (DIFID), the Centre for Ecology and Hydrology (CEH) at Wallingford in the UK is coordinating a multi-phased and multi-institutional research project aimed at deriving a tool for addressing the needs highlighted above. The tool will be known as a Water Poverty Index (WPI), and its utility will include:

- enabling the classification of regions on the basis of a quantifiable methodology which reflects both the physical availability of water and the human adaptive capacity to access it,
- facilitating an assessment of progress towards water related development targets,
- contributing towards prioritisation of water related needs, and
- monitoring the effectiveness of water related development projects.

The WPI, the derivation of which was also identified during the 5th Global Forum of Water Supply and Sanitation Collaboration Council (2000) as a research need, is to be evaluated and tested by partner institutions in three countries, *viz.* South Africa, Sri Lanka and Tanzania. For the South African evaluation, the Thukela catchment of 29 035.9 km^2 in the province of KwaZulu-Natal was selected for a regional WPI study. Within the Thukela catchment two communities, at Keates Drift and Wembezi, were identified for more site-specific research on household water use.

The University of Natal's School of Bioresources Engineering and Environmental Hydrology (SBEEH) is one of the partner institutions in the research project. For the SBEEH, the objectives of Phase 1 of this study are:

- to provide an overview of the background hydrology of the Thukela catchment assuming baseline land cover conditions, i.e. land cover not influenced by human activities;
- in regard to water availability at the meso-scale, i.e. at the operational subcatchment level of 10s to 100s km^2 in area;
- in order to identify where, how much and how variable individual subcatchment flows as well as accumulated flows are; and furthermore
- to provide more specific detail on the background water availability at the two selected field sites within the Thukela, *viz.* at Keates Drift and Wembezi;
- by configuring the entire Thukela into relatively homogeneous operational subcatchments in order to undertake hydrological simulations under baseline land cover conditions using the *ACRU* agrohydrological simulation model; and
- to undertake preparatory work for an envisaged Phase 2 of this WPI study.

Chapter 2 presents background information on the Thukela catchment, focussing on aspects of its hydroclimatology, but also introducing elements of human influences on the landscape by briefly assessing present land use patterns as well as discussing the general poverty status within the catchment. The configuration of the *ACRU* model for hydrological simulations is discussed in Chapter 3, while overall and site-specific results are presented in Chapters 4 and 5 respectively. The report concludes with recommendations of work proposed for Phase 2 of the project.

2 THE THUKELA CATCHMENT: BACKGROUND

2.1 Location and Physical Features

The Thukela catchment extends latitudinally from 27E25' to 29E24'S and longitudinally from 28E58' to 31E26'E (**Figure 2.1**). It covers an area of 29 035.9 km^2. The Thukela River has its source in the Drakensberg mountain range in the west. The Drakensberg is a declared World Heritage Site which, in places, has altitudes exceeding 3000 m (**Figure 2.2**). It then flows eastward from a steep escarpment across low mountains of high relief, open hills of high relief and lowlands of low relief and thereafter through a deeply incised valley until it reaches the Indian Ocean approximately 85 km north of the city of Durban. The mainstem Thukela's major tributaries are the Little Thukela, Mooi and Bushman's Rivers which join from the southwest, and the Klip, Sundays and Buffalo Rivers flowing from the north.

2.2 Hydroclimatic Features

Mean annual precipitation (MAP) in the Thukela ranges from around 2000 mm in the Drakensberg to as low as 550 mm in the drier central regions (**Figure 2.3**). Most of the rainfall is received during the mid-summer months from December to February. Significant from the water poverty perspective is the relatively high inter-annual variability of rainfall, generally in the range of 20 – 30% (**Figure 2.4**).

The driest year in 10 records is only about 60% of MAP. Equally as important for WPI studies as its variability is the strong concentration of rainfall in the summer months. January's rainfall means range from 100 – 300 mm (mostly 120 – 150 mm) against July's means which over most of the catchment are < 5 mm (Schulze, 1997).

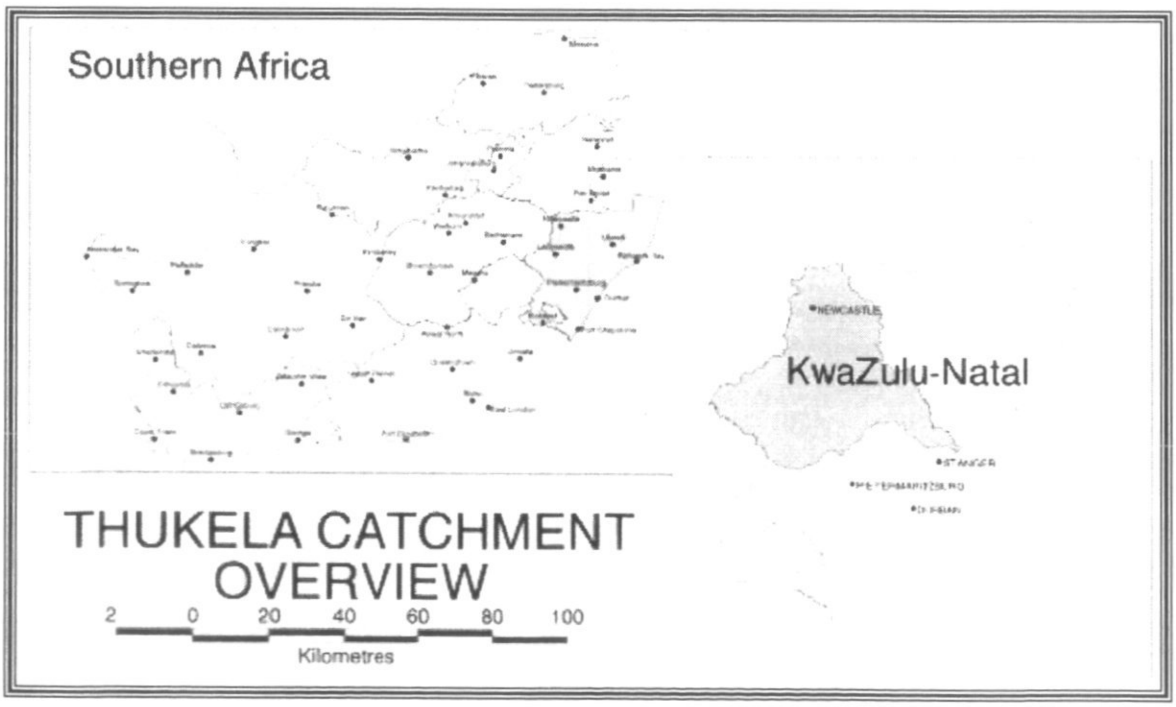


Figure 2.1 Location of the Thukela catchment

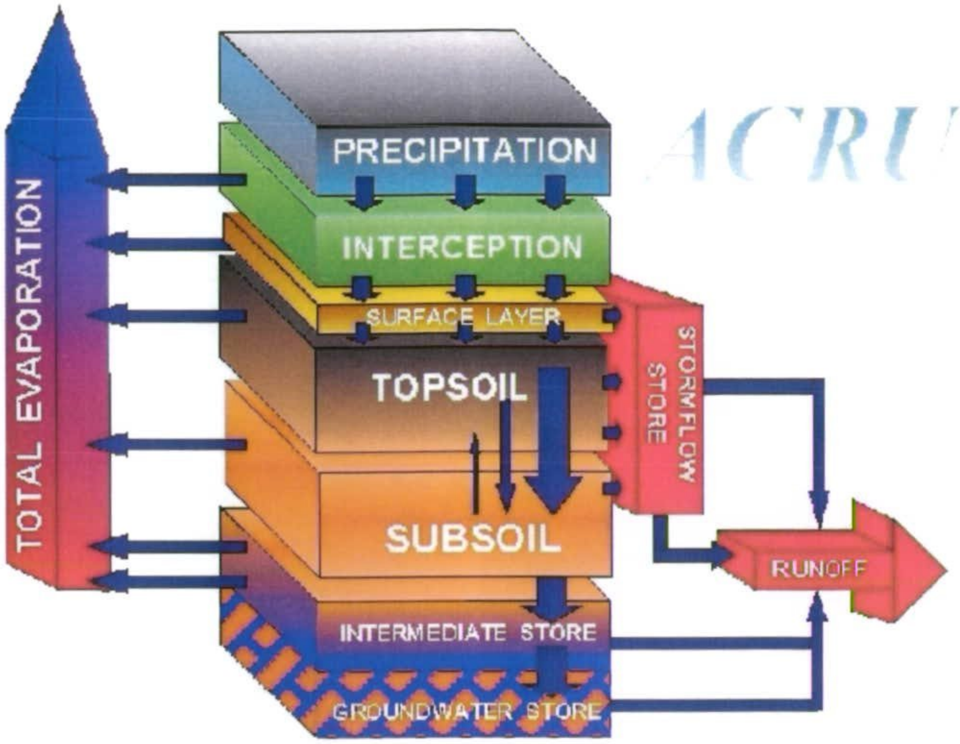


Figure 3.2 The *ACRU* agrohydrological modelling system: Structure (Schulze, 1995)

For large areas, or where complex land uses and hydrologically variable soils occur, or where streamflows in the channel have been modified by reservoirs/abstractions, the catchment is discretised into relatively homogeneous response zones, and *ACRU* then operates as a hydrologically cascading distributed cell-type model.

The *ACRU* model requires input of known and measurable spatial and temporal variables which characterise the catchment's hydrological behaviour. Catchment information may be classified by:

- climate, e.g. daily rainfall, temperature, potential evaporation;
- physical attributes, e.g. area, slope, hydrological soil properties;
- bio-physical characteristics, i.e. baseline land cover and present rainfed land uses and their hydrological properties; and other
- land use/management practices, including irrigation demand and supply, as well as domestic, industrial and livestock water abstractions from river runoff, as well as from reservoirs, and return flows.

Within the model, the input information is transformed to produce the eventual responses through the routines which represent the processes of each sub-system of the hydrological cycle (e.g. the rainfall, interception, infiltration, stormflow

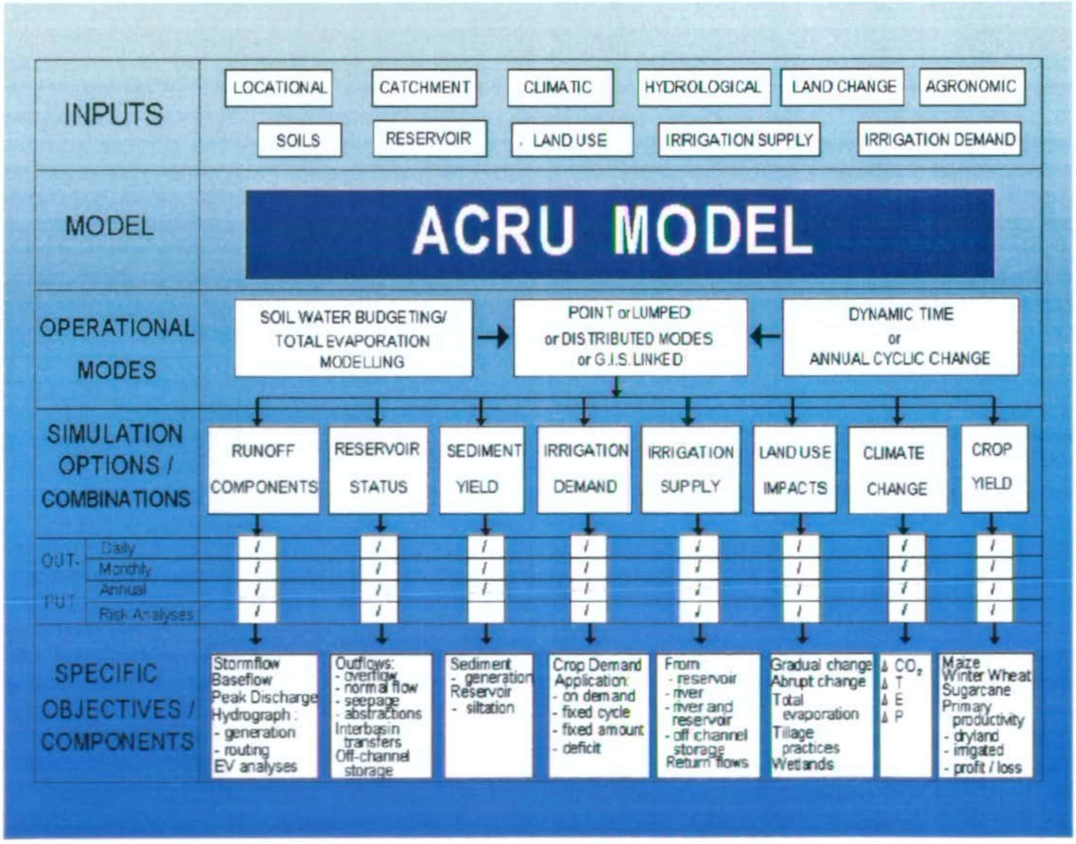
3 THE HYDROLOGICAL MODELLING SYSTEM

Owing to unavailability of observed records of pre-development streamflows over most of the Thukela catchment, simulation modelling was applied to estimate the catchment's baseline hydrological responses. The *ACRU* agrohydrological modelling system (Schulze, 1995; Smithers and Schulze, 1995; Schulze, 2001) was selected for this task.

3.1 The ACRU Agrohydrological Modelling System

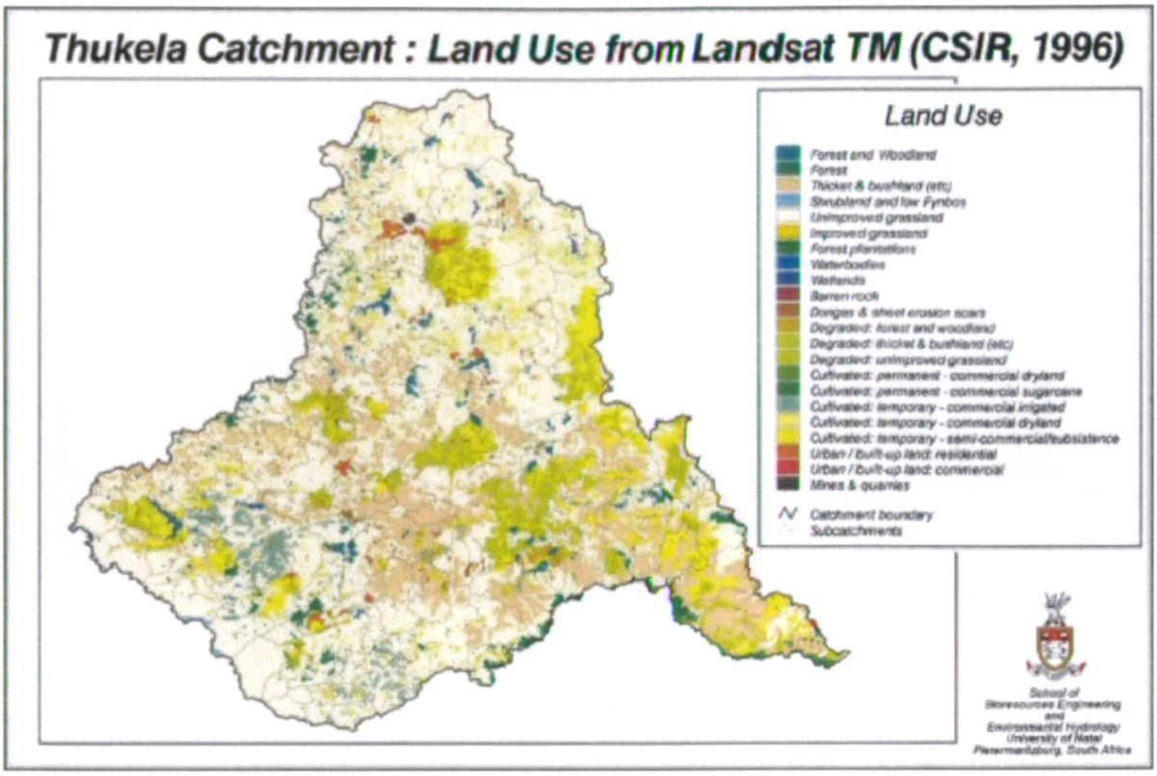
ACRU is a daily time step, physical-conceptual and multi-purpose agrohydrological modelling system (Schulze, 1995) with options to output, *inter alia*, daily values of stormflow, baseflow, peak discharge, reservoir status, recharge to groundwater, sediment yield, as well as irrigation water supply/demand and additionally having the facility to output seasonal yields of selected crops at any location within the catchment, either with or without irrigation (**Figure 3.1**).

The model revolves around multi-layer soil water budgeting concepts (**Figure 3.2**). It is structured to be hydrologically sensitive to impacts of different catchment land uses and changes thereof, including the impacts of reservoirs operations, run-of-river abstractions, irrigation practices, urbanisation, afforestation and of enhanced greenhouse gas induced climate change on catchment streamflow and sediment generation.

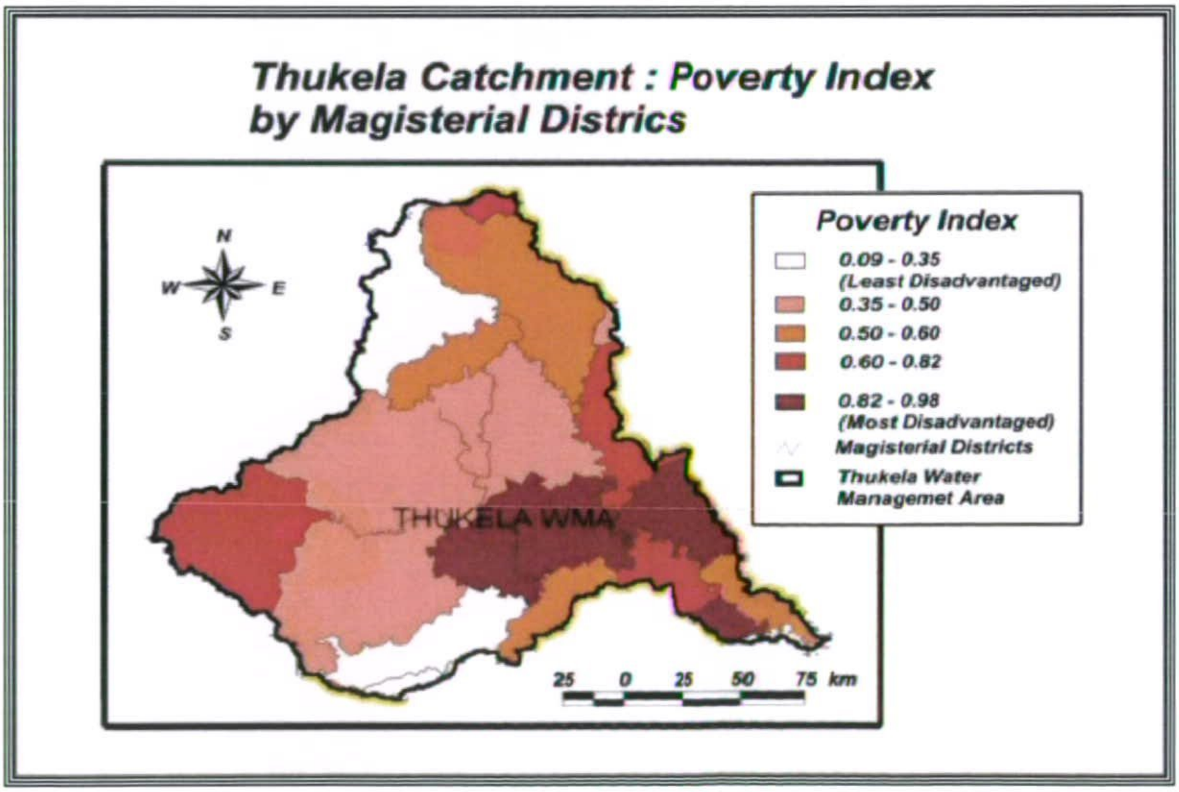


The *ACRU* agrohydrological modelling system: Concepts (Schulze, 1995)

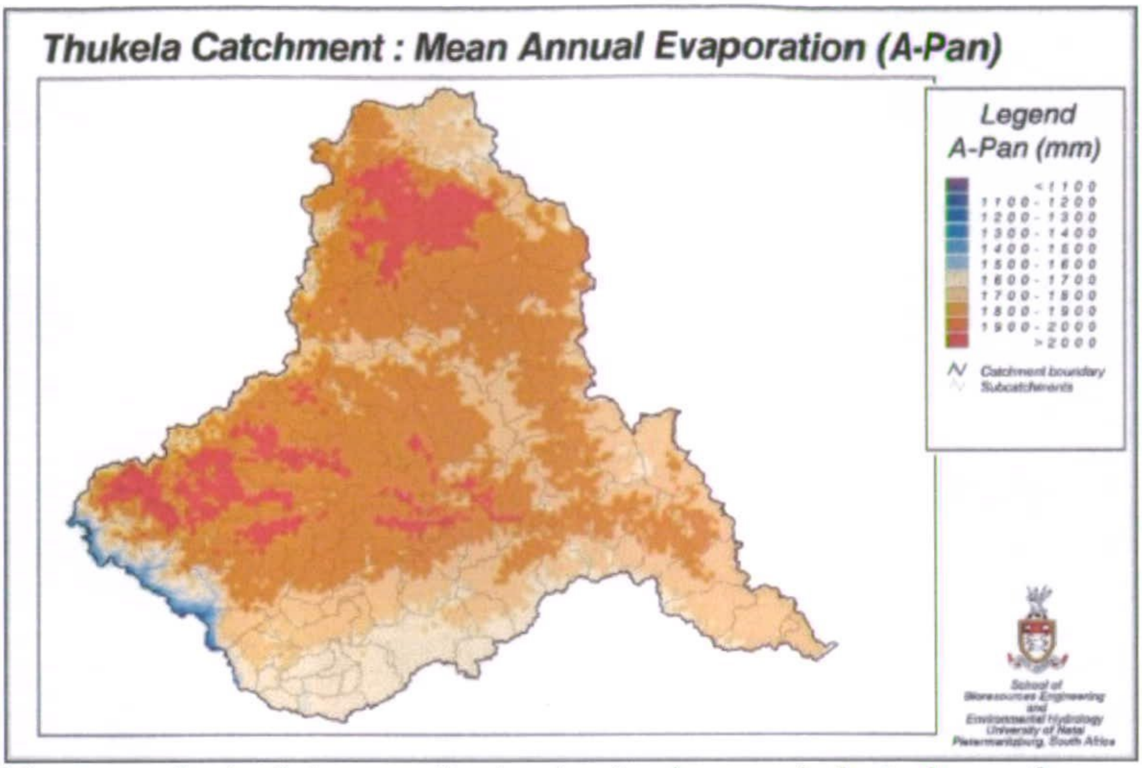
However, Phase 1 of the SBEEH brief concerns itself with the availability of water under baseline (i.e. non-anthropogenically influenced) land cover conditions; without taking cognisance of the 'human imprints', as an indicator of an area's natural endowment of water when quantifying a WPI. This brief is achieved by modelling streamflow characteristics at the meso-scale within the Thukela catchment. The meso-scale identifies subcatchments of 10s to 100s km^2 in area which are used as individual or as interlinked operational hydrological units in the planning and implementation of rural and small urban water supplies.



Present land use in the Thukela catchment (Source: CSIR,1996)



An overall index of poverty in the Thukela catchment (after Wilson, 2001)



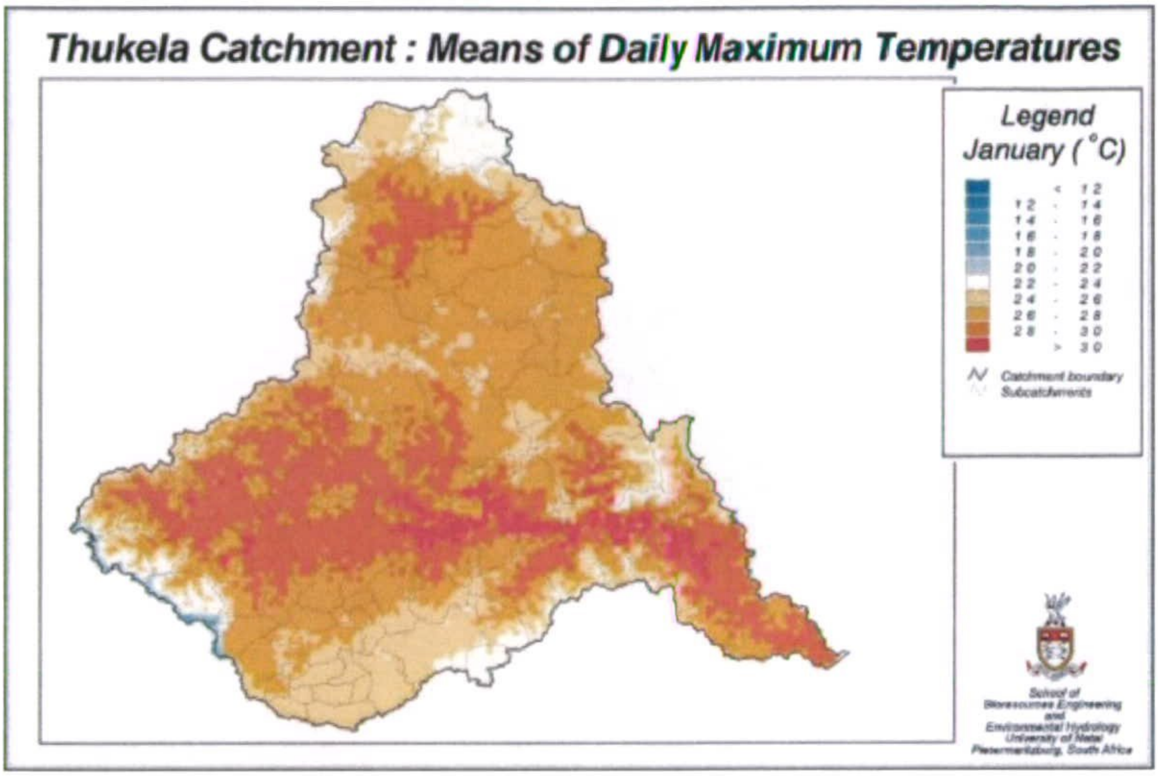
Mean annual potential evaporation (mm), using A-panequivalent values as the reference, in the Thukela catchment (after Schulze, 1997)

2.3 Human Imprints on the Thukela Catchment

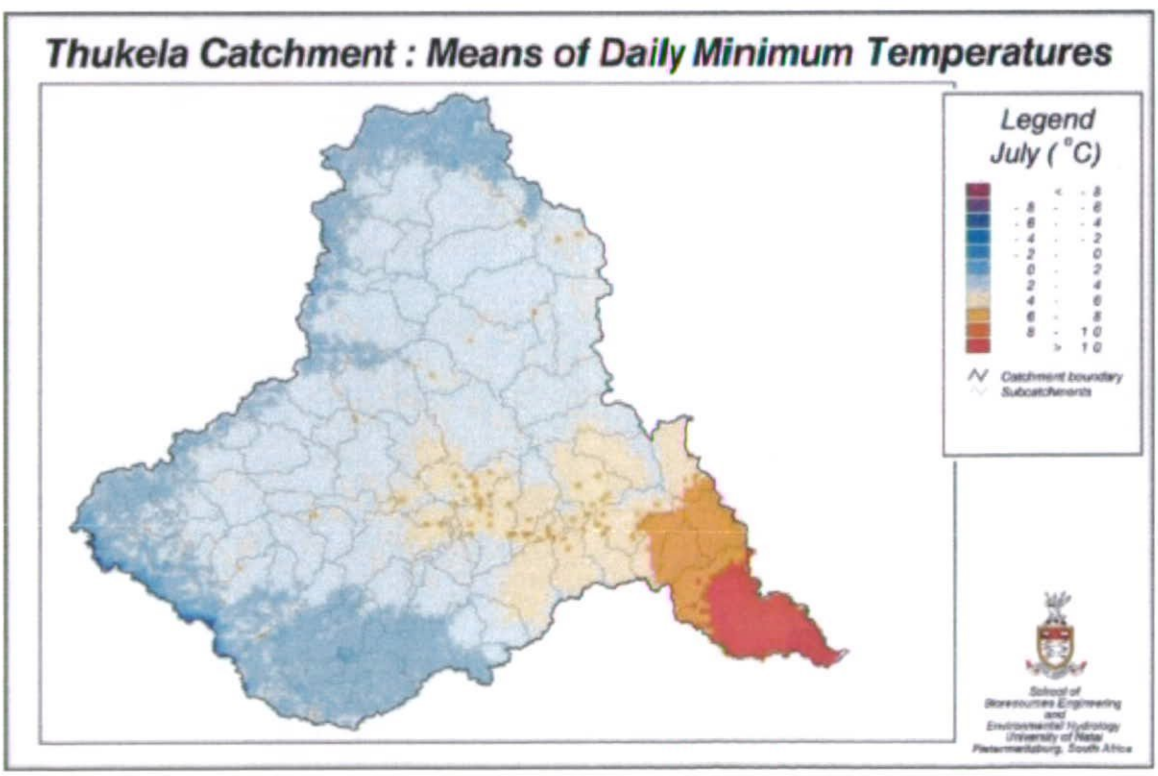
The Thukela catchment's natural land cover of mainly grasslands and savanna type bushveld (c.f. Chapter 3) has been highly modified and impacted upon by humans. This is illustrated clearly by the map of current land uses (**Figure 2.8**), which shows activities such as mining and urbanisation, as well as commercial agriculture, subsistence agriculture, irrigation and impoundments to be important. However, with regard to water poverty, the substantial areas of degraded grasslands, thickets, an bushveld (mainly through overgrazing) are first indicators of lack of sufficient water in certain areas.

That large tracts of the Thukela catchment are socio-economically not well endowed becomes evident from the perusal of an overall (not specifically water) poverty index, which is made up of indicators such as income, levels of education and access to adequate sanitation (**Figure 2.9**).

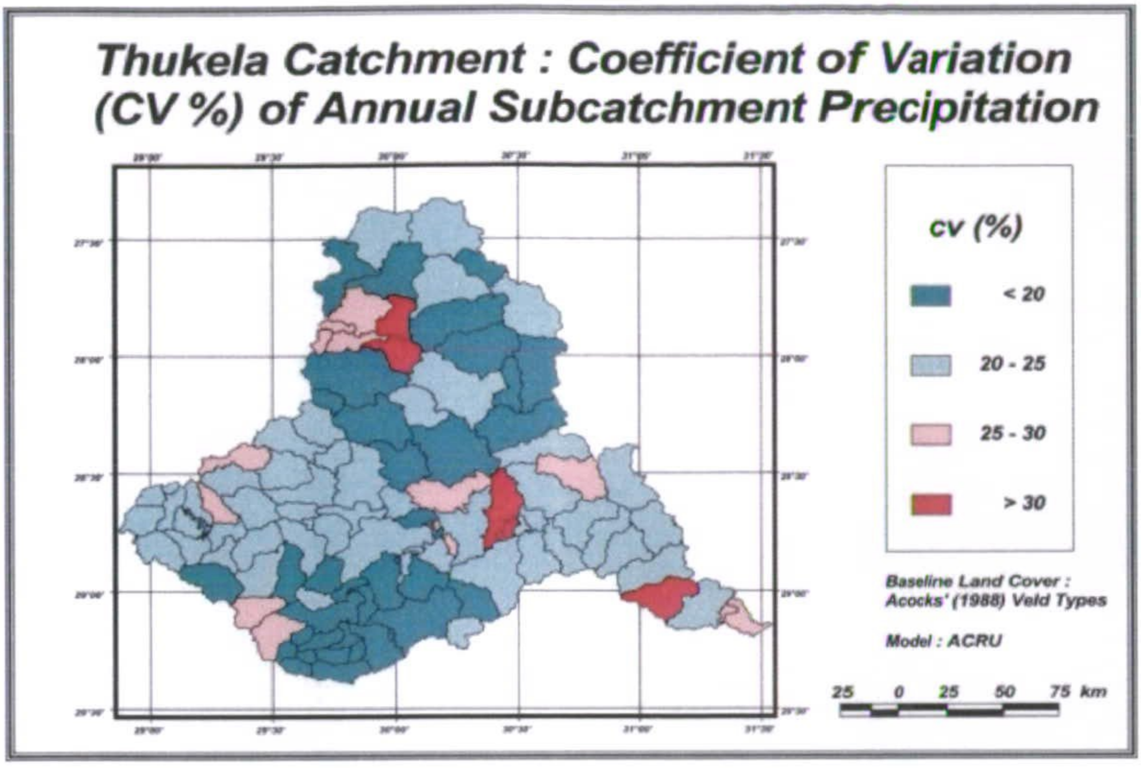
The above two examples of 'human imprints' on the Thukela catchment already point to a complex juxtapositioning of developed vs underdeveloped elements in the catchment, partially determined by the strong biophysical diversity described in Sections 2.1 and 2.2, but largely influenced also by the socio-political history of the area.



January means of daily maximum temperatures (°C) in theThukela catchment (after Schulze, 1997)



July means of daily minimum temperatures (°C) in the Thukela catchment (after Schulze, 1997)



Inter-annual coefficient of variation (CV %) of rainfall in the Thukela catchment (Schulze, 1997)

Monthly means of daily maximum temperatures of the hottest month, January, are generally between 26EC and 28EC with the highest means, (around 32EC), occurring in the incised eastern valleys and the lowest (below 20EC) in the high Drakensberg mountains (**Figure 2.5**). Winter (July) means of daily minimum temperatures range from 0EC in the Drakensberg mountains to 10EC at the coast (**Figure 2.6**). Illustrated in **Figure 2.7** is the distribution of average annual potential evaporation (E_p) using the A-pan as a reference. E_p is relatively high at between 1600 and 2000 mm per annum (Schulze, 1997). Highest monthly means of E_p (200 – 220 mm) coincide with high means of maximum temperatures in January and similarly the lowest values, still around 100 – 110 mm per month, occur in July (Schulze, 1997). In regard to a WPI, it is significant to note that the ratio of annual E_p to annual rainfall in the Thukela is 2-4, which classifies most of the area as semi-arid, despite the rainfall *per se* not necessarily being low everywhere.

Physiographically and climatologically the Thukela catchment is, thus, a highly diverse catchment, with first indications of water poverty already evident in the strong seasonality and inter-annual variability of its rainfall, exacerbated by a very high atmospheric demand which is expressed through the high values of potential evaporation.

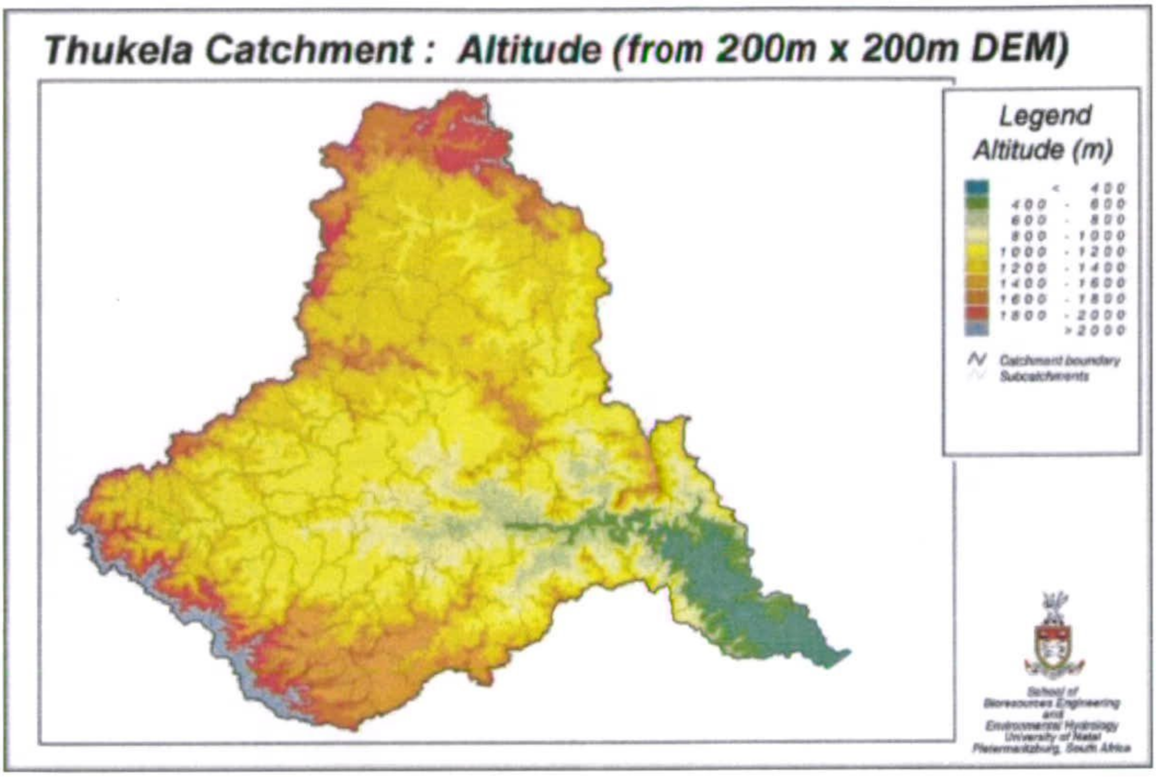


Figure 2.2 **Topography of the Thukela catchment**

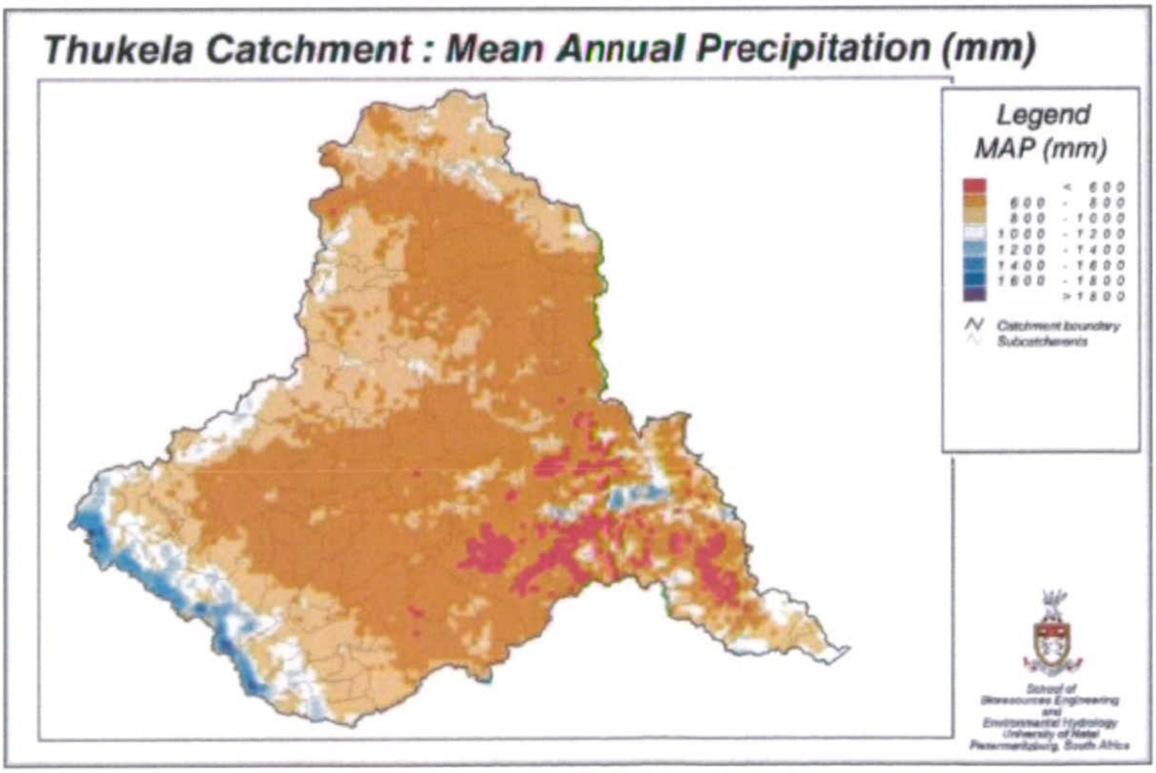


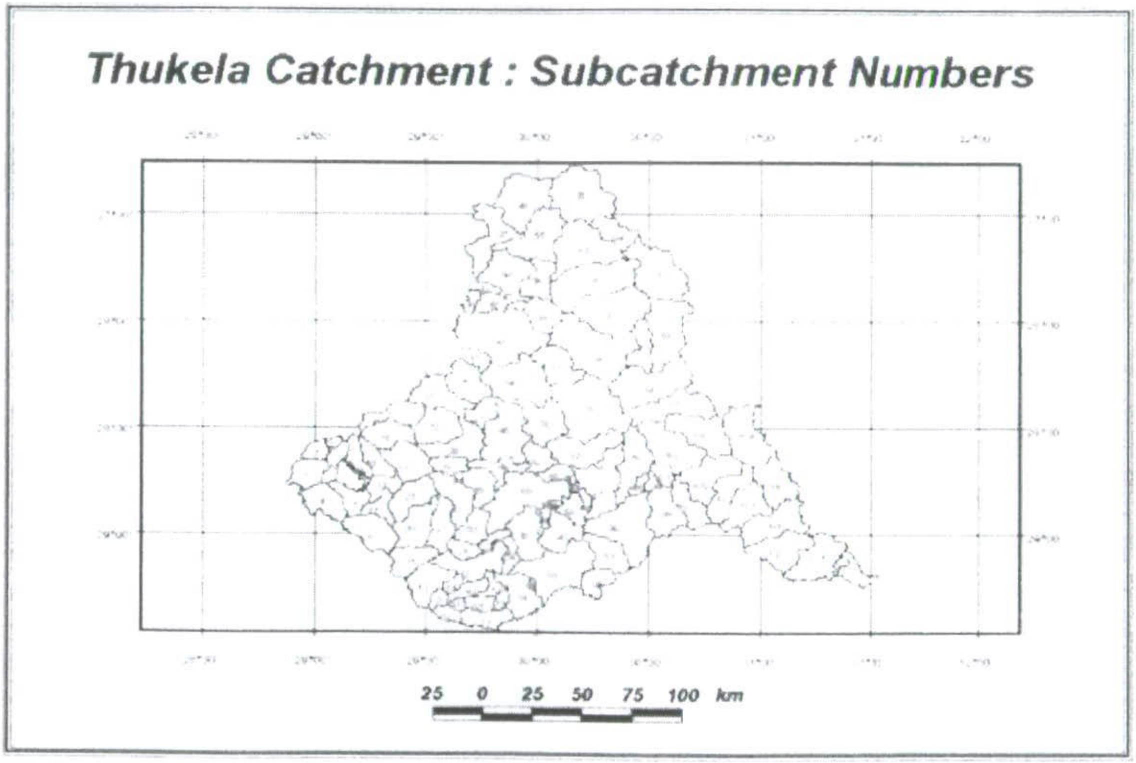
Figure 2.3 **Mean annual precipitation (mm) in the Thukela catchment (after Dent, Lynch and Schulze, 1989)**

generation or groundwater recharge sub-systems) and the manner in which they interact and are linked. The model also calculates thresholds at which catchment responses occur and response rates change.

3.2 Preparation of *ACRU* Model Input and Sources of Information

3.2.1 Layout and configuration of the Thukela catchment system for simulation purposes

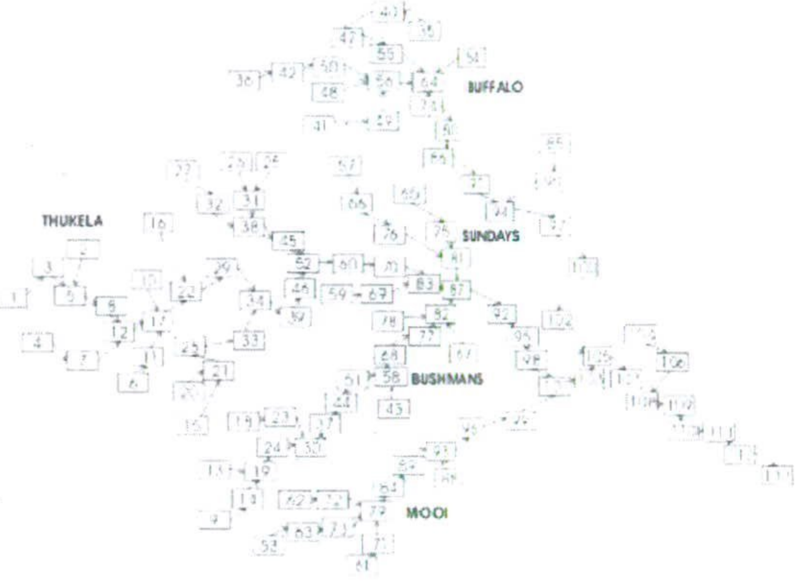
At 29 035.9 km^2, the Thukela catchment is a large system with marked spatial and hydrological heterogeneity. For simulation modelling purposes, the catchment was therefore discretised into 113 hydrologically relatively homogeneous subcatchments (**Figure 3.3**) on the basis of the Department of Water Affairs and Forestry's (DWAF) operational Quaternary Catchment (QC) delimitation which uses uniformity of soils, land uses and topography, as well as present reservoirs as criteria.



The 113 subcatchments delimited within the Thukela and their numbering system (after DWAF and Jewitt *et al.*, 1999)

Dwarf's initial official subcatchment delimitation of 86 QCs within the Thukela was extended by Jewitt *et al.* (1999), who considered Instream Flow Requirement (IFR) monitoring sites, critical reach sites as well as other locations in the channel such as water abstractions points and locations of proposed major dams where streamflows may be significantly modified; hence 113 subcatchment outlets. The manner in which the subcatchments were arranged and configured such that the simulated runoff would be routed through the system in a downstream direction is illustrated in **Figure 3.4**.

THUKELA CATCHMENT : SUBCATCHMENT CONFIGURATION



Subcatchment configuration and the routing of flows within the Thukela catchment

3.2.2 Climatic variables

Minimum climatic information required per subcatchment by the model is a time series of daily rainfall together with monthly means of daily maximum and minimum temperature and monthly totals of reference potential evaporation. Rainfall stations, in and adjacent to the Thukela catchment, with long records of daily rainfall were selected from the database maintained in the former Computing Centre for Water Research (CCWR) for an initial assessment of their data to "drive" the catchment's hydrological responses. Using a recently developed sophisticated technique (Smithers, 1998), missing daily records were in-filled for each of the rainfall stations before they were further screened using a utility known as *CALCPPTCOR* (Pike, 1999) to choose the most appropriate so-called "driver" station for each subcatchment. The *CALCPPTCOR* utility also calculates a precipitation adjustment factor which, when applied as a multiplier with the driver station's daily rainfall, is used to estimate a representative daily areal rainfall for each subcatchment. Using this selection procedure, 57 driver stations were eventually assigned to the 113 subcatchments (**Figure 3.5**), implying that many of the rainfall stations determined will "drive" the hydrological responses of more than one subcatchment, albeit with a different daily adjustment.

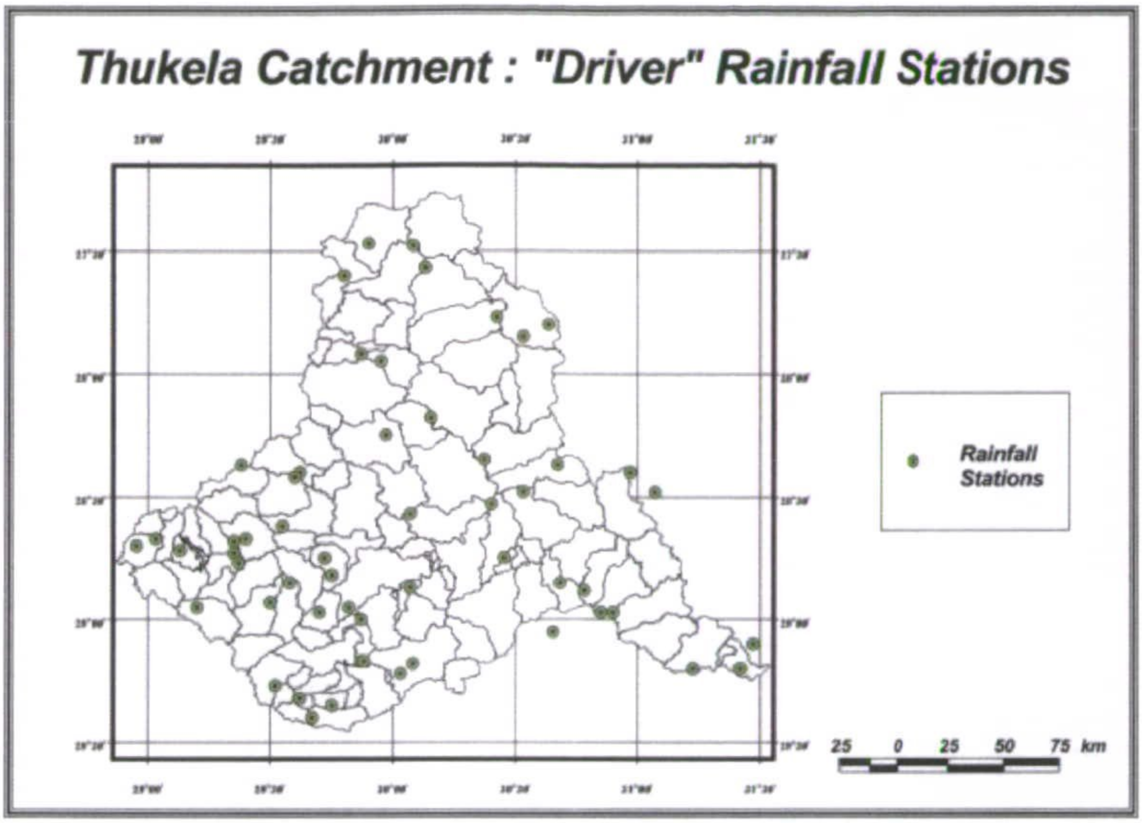


Figure 3.5 **Locations of the "driver" rainfall stations selected for this study**

For each subcatchment, representative values of monthly A-pan equivalent reference potential evaporation and means of daily minimum and maximum temperatures (c.f. **Figures 2.5**, **2.6** and **2.7**) were determined, based on input derived from one minute latitude by one minute longitude gridded surfaces that were developed by Schulze (1997). These are converted to daily values within the model by using a Fourier Analysis.

3.2.3 Soils information

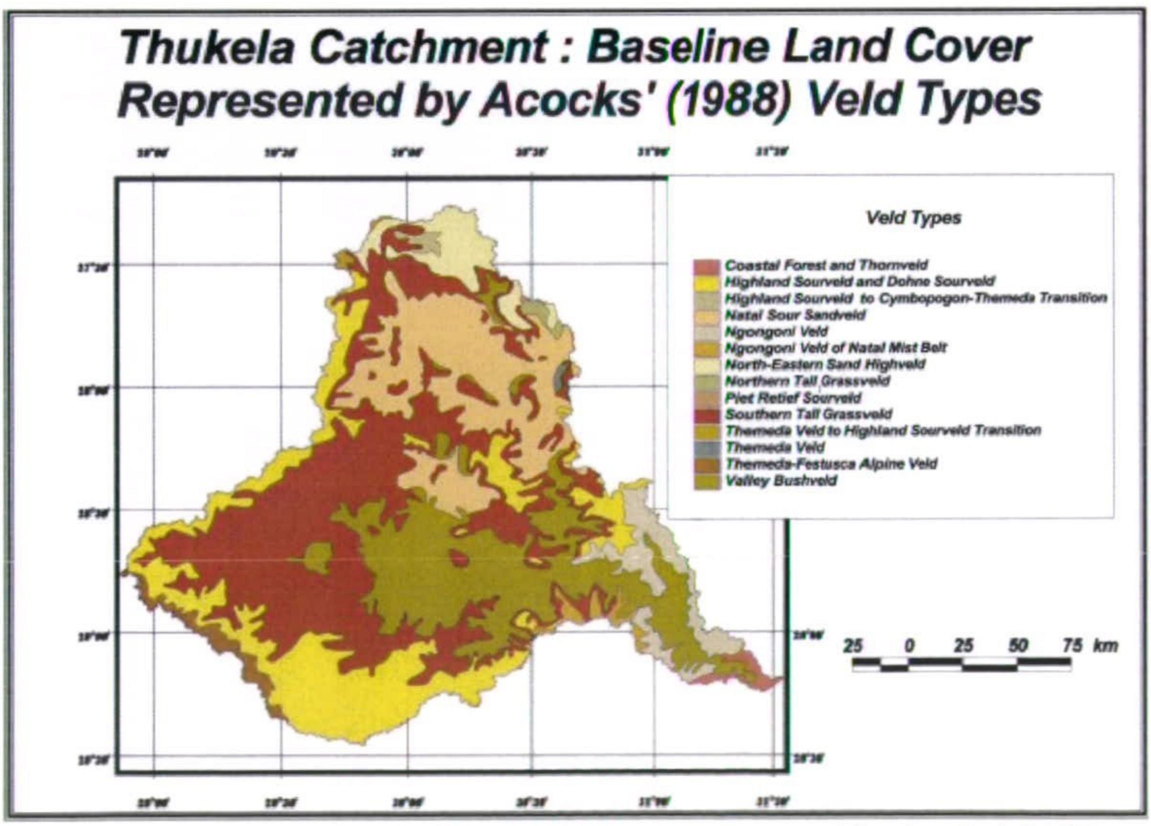
Soils play an important role as regulators of the rate and manner in which a catchment responds, hydrologically, to a rainfall event by

- influencing the rate of infiltration, thus dictating the timing and rate of stormflow generation;
- providing storage for soil water, which may become available for evapotranspiration;
- redistributing soil water, both within and out of the soil profile;
- controlling rates of soil water evaporation and transpiration processes; and
- influencing rates and amounts of drainage beyond the root zone and eventually into the intermediate/groundwater zone, which feeds baseflow.

A GIS coverage of soil mapping units called Land Types was obtained for the Thukela catchment from the Institute of Soil, Climate and Water (ISCW). The coverage provides detailed information on percentages of soil series making up individual terrain units, together with certain physical characteristics, for each Land Type. Using a soils decision support system known as *AUTOSOILS* (Pike and Schulze, 1995), these properties were translated into hydrological variables for a two-horizon soil profile, as required by *ACRU* (e.g. horizon thickness, critical water retention constants, drainage rates and saturated overflow areas).

3.2.4 Land cover information

Like soils, land cover and land use/management systems have profound influences on hydrological responses through seasonally variable canopy and litter interception amounts, surface water detention, evapotranspiration rates, provision of protective cover against soil particle detachment and loss from direct raindrop impact, as well as extraction of soil water by plant roots. For this Phase 1 of the WPI study, hydrological modelling is undertaken to evaluate streamflows under baseline land cover conditions to enable the estimation of primary water endowment, or natural water availability per subcatchment. Acocks' (1988) so-called Veld Types (**Figure 3.6**), which are assumed to represent natural vegetation classes, have become the standard land cover used for baseline hydrological studies in South Africa. The *ACRU*-related attributes of the Veld Types have been determined by Schulze (2001). The hydrological variables and associated values for the Veld Types found in the Thukela catchment are given in **Table 3.1**.



Baseline land cover in the Thukela catchment as represented by Acocks' (1988) Veld Types

Table 3.1 **Hydrological attributes of the Acocks' (1988) Veld Types, which represent baseline land cover in the Thukela catchment (Schulze, 2001)**

Veld Type	Variable	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Coastal Forest and Thornveld	CAY	0.85	0.85	0.85	0.85	0.75	0.65	0.65	0.75	0.85	0.85	0.85	0.85
	VEGINT	3.10	3.10	3.10	3.10	2.50	2.00	2.00	2.50	3.10	3.10	3.10	3.10
	ROOTA	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75	0.75
	COIAM	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.30
Ngongoni Veld - Zululand	CAY	0.70	0.70	0.70	0.65	0.55	0.50	0.50	0.55	0.60	0.65	0.65	0.70
	VEGINT	1.40	1.40	1.40	1.40	1.30	1.20	1.20	1.30	1.40	1.40	1.40	1.40
	ROOTA	1.40	1.40	1.40	1.40	1.30	1.20	1.20	1.30	1.40	1.40	1.40	1.40
	COIAM	0.20	0.20	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.20
Highland Sourveld and Döhne Sourveld	CAY	0.70	0.70	0.70	0.50	0.30	0.20	0.20	0.20	0.50	0.65	0.70	0.70
	VEGINT	1.60	1.60	1.60	1.40	1.20	1.00	1.00	1.00	1.30	1.60	1.60	1.60
	ROOTA	0.90	0.90	0.90	0.95	1.00	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Natal Mist Belt Ngongoni Veld	CAY	0.70	0.70	0.70	0.50	0.35	0.25	0.20	0.20	0.55	0.70	0.70	0.70
	VEGINT	1.50	1.50	1.50	1.30	1.10	1.10	1.10	1.10	1.40	1.50	1.50	1.50
	ROOTA	0.90	0.90	0.90	0.94	0.96	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Themeda Veld or Turf Highveld	CAY	0.65	0.65	0.65	0.50	0.40	0.20	0.20	0.20	0.35	0.55	0.65	0.65
	VEGINT	1.20	1.20	1.20	1.10	1.00	0.90	0.90	0.90	1.10	1.20	1.20	1.20
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
Turf Highveld to Highland Sourveld Veld Transition	CAY	0.60	0.60	0.60	0.52	0.40	0.20	0.20	0.20	0.35	0.50	0.60	0.60
	VEGINT	1.30	1.30	1.30	1.20	1.00	0.90	0.90	0.90	1.10	1.20	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
North-Eastern Sandy Highveld	CAY	0.62	0.62	0.60	0.50	0.35	0.20	0.20	0.20	0.35	0.50	0.62	0.62
	VEGINT	1.30	1.30	1.30	1.20	1.00	1.00	1.00	1.10	1.20	1.30	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15
Piet Retief Sourveld	CAY	0.70	0.70	0.70	0.55	0.45	0.20	0.20	0.20	0.50	0.60	0.70	0.70
	VEGINT	1.30	1.30	1.30	1.30	1.10	1.00	1.00	1.00	1.20	1.30	1.30	1.30
	ROOTA	0.90	0.90	0.90	0.90	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.25	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Southern Tall Grassveld	CAY	0.75	0.75	0.75	0.50	0.40	0.20	0.20	0.20	0.55	0.70	0.75	0.75
	VEGINT	1.60	1.60	1.60	1.60	1.50	1.40	1.40	1.40	1.50	1.60	1.60	1.60
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.20	0.15
Natal Sourveld	CAY	0.75	0.75	0.70	0.50	0.35	0.20	0.20	0.20	0.50	0.65	0.70	0.75
	VEGINT	1.80	1.80	1.80	1.80	1.60	1.40	1.40	1.40	1.50	1.70	1.80	1.80
	ROOTA	0.90	0.90	0.90	0.95	0.95	1.00	1.00	1.00	0.95	0.90	0.90	0.90
	COIAM	0.15	0.15	0.20	0.30	0.30	0.30	0.30	0.30	0.30	0.30	0.25	0.15

Legend:

CAY = water use (i.e. crop) coefficient

VEGINT = canopy interception (mm/rainday)

ROOTA = fraction of roots in the topsoil horizon

COIAM = coefficient of initial abstraction (i.e. infiltrability index)

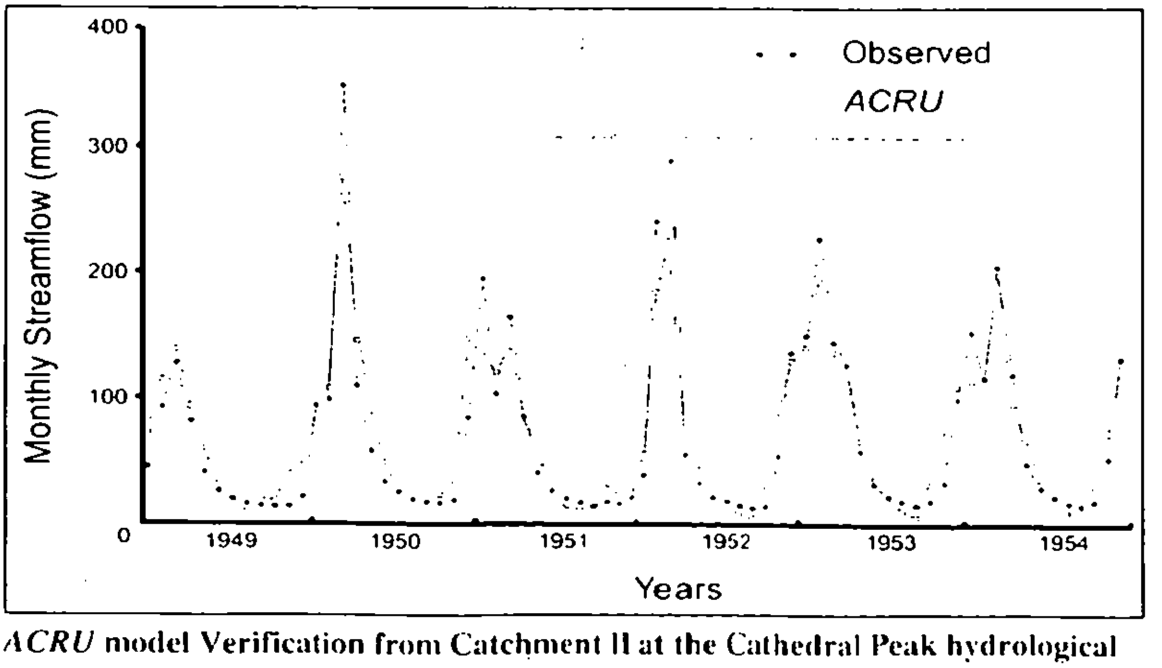
Monthly values corresponding to each Veld Type were weighted according to the percentage areas of the Veld Types found in each subcatchment. For this Phase of the WPI study, therefore, no land and water resources development was assumed to have taken place, and hence the impacts of land uses and abstractions/return flows of water from streams and reservoirs on streamflows were not considered.

3.3 Verification and Validation Studies of Streamflow Responses

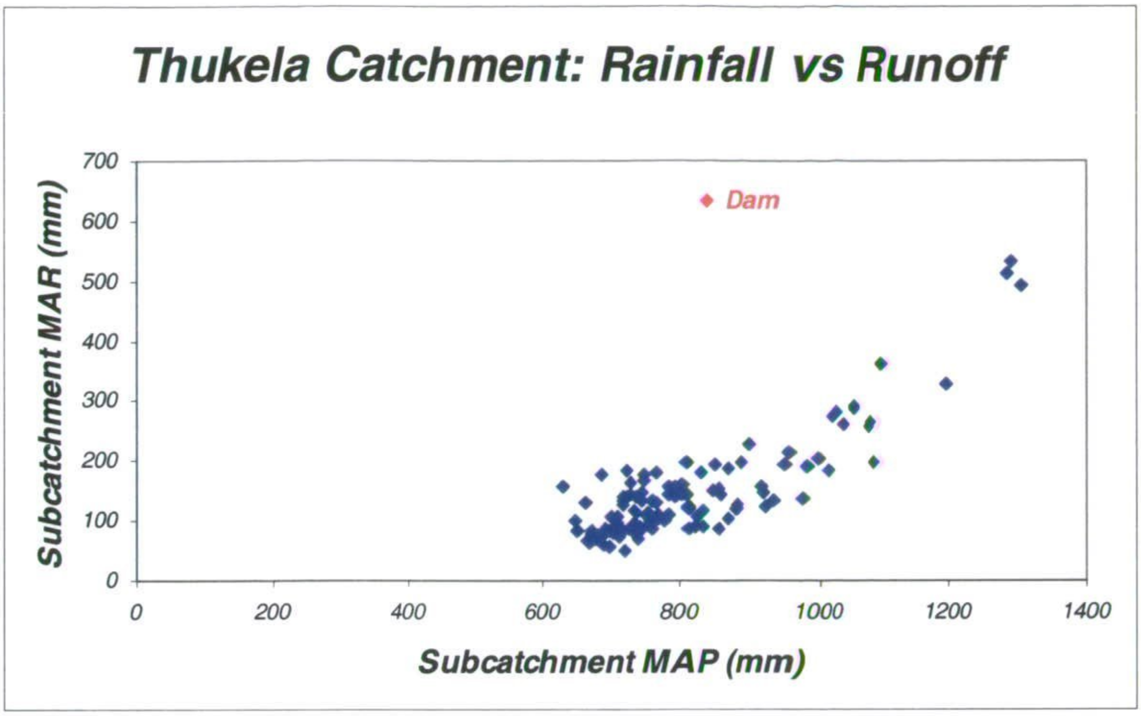
To engender confidence in the *ACRU* model's output of hydrological responses from baseline land cover conditions, verification studies have been undertaken on catchments under pre-development land cover conditions. An example from the Cathedral Peak hydrological research station's Catchment II (1.94 km^2), which is under natural grassland, is given in **Figure 3.7**.

However, owing to the unavailability of observed streamflow data from other catchments in the Thukela under baseline land cover conditions, a validation task was undertaken to visually check the overall plausibility of the model output. The results are illustrated in **Figure 3.8**, where simulated mean annual runoff, MAR, is plotted against MAP for each of the 113 subcatchments

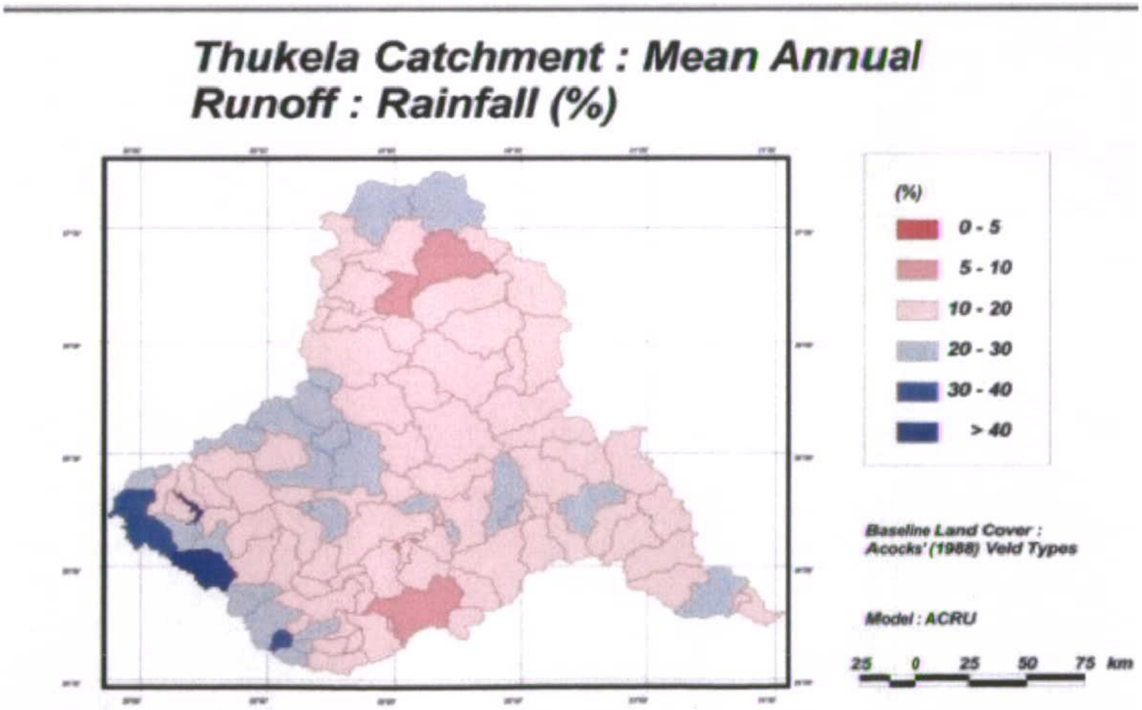
In accordance with hydrological theory, MAR increases curvilinearly with increasing mean annual rainfall. The trend is clearly evident in **Figure 3.8**. A map of subcatchments' rainfall-runoff ratios in **Figure 3.9** further highlights the above curvilinear trend. The trends in this validation are in accord with results from other studies conducted in the Thukela catchment (e.g. Schulze, 1979; Jewitt *et al.*, 1999). The above results are interpreted as an indication that representative results are produced by the *ACRU* model, thus lending credibility to the conclusions drawn from the simulation results, which are assessed in the next two chapters.



***ACRU* model Verification from Catchment II at the Cathedral Peak hydrological research station (after Schulze and George, 1987)**



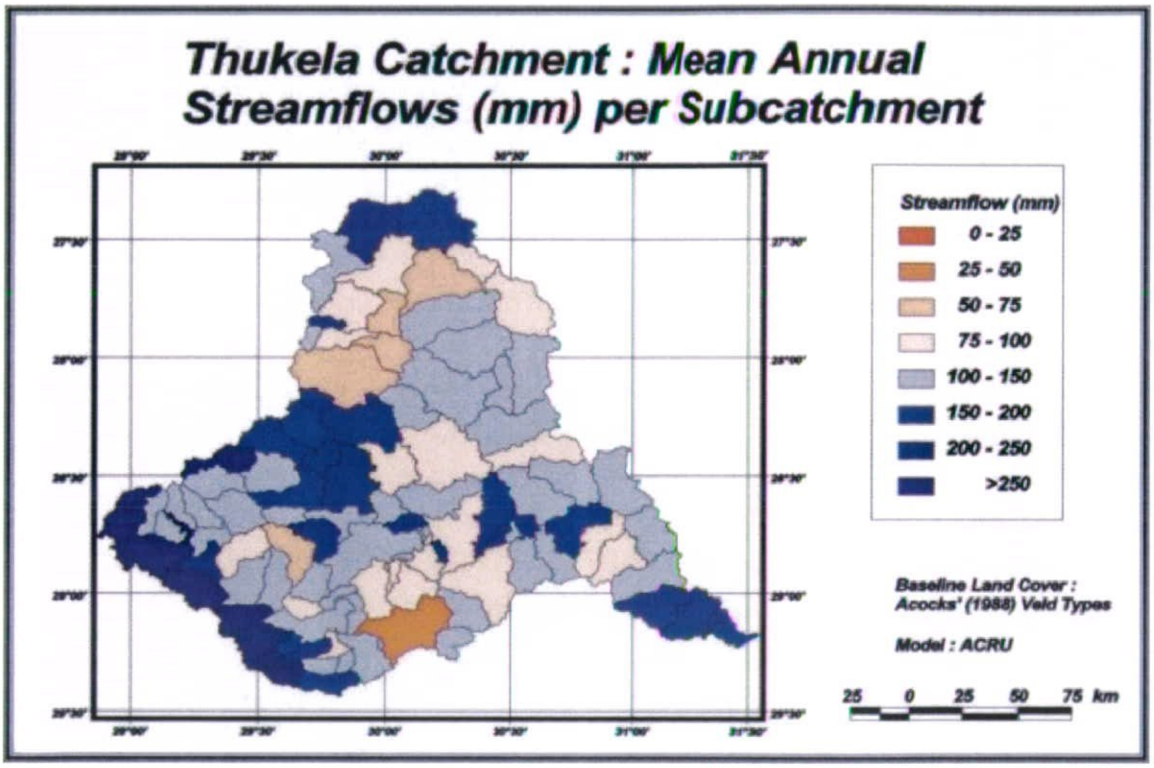
Relationship between *ACRU* model simulated MAR (mm) and MAP (mm) for the individual subcatchments within the Thukela



***ACRU* model simulated subcatchment MAR (mm) in the Thukela as percentage of MAP (mm)**

4 SPATIAL VARIATIONS OF STREAMFLOW CHARACTERISTICS WITHIN THE THUKELA CATCHMENT

The success of the verification and validation studies presented in Chapter 3 provides the all important confirmation of the *ACRU* model's output being considered realistic under baseline land cover conditions. The results of this study are presented in two chapters. In this chapter an analysis of baseline streamflow characteristics in the Thukela catchment in its entirety is presented, followed in Chapter 5 by an assessment of baseline streamflow characteristics at the selected WPI case study locations, *viz.* at Keates Drift and Wembezi.



Simulated subcatchment MAR (mm) in the Thukela under baseline land cover conditions

4.1 Spatial Variations of Subcatchment MAR within the Thukela Catchment

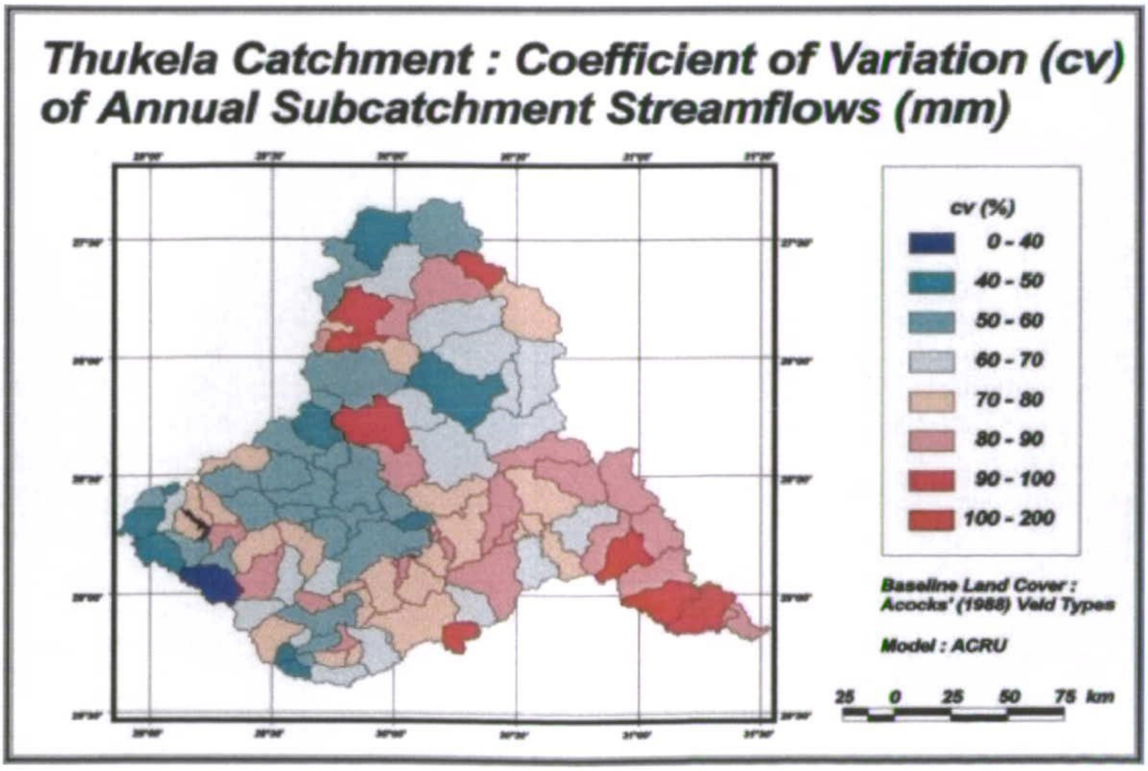
Figure 4.1 shows the spatial variations of individual subcatchment MAR within the Thukela catchment. The average MAR for the catchment is 136 mm. MAR values per subcatchment vary widely, from less than 25 to over 250 mm. High runoff values are simulated in the southwest and northern sections of the catchment which make up parts of the high Drakensberg range of mountains. Other high values occur in the southeastern tail of the catchment along the Indian Ocean, which has a maritime climate. Save for a few patches of MAR > 150mm, values ranging from 25 to 150 are simulated in the relatively dry central parts of the catchment.

These patterns have important implications on water resources development and water poverty. With most of the streamflows generated in the high altitude, rugged and sparsely inhabited western fringes, and less being produced in the lower lying plains and valleys which contain most of the farmlands, towns and especially the poor rural communities, it has become imperative that the mountain-fed main streams be impounded, also as a result of the strong seasonal nature of the flows, to ensure year-round sustained water supplies. Implications on rural communities will be discussed in the section outlining results at the two specific WPI survey sites.

4.2 Inter-Annual Coefficients of Variation (CVs) of Streamflows from Individual Subcatchments

Low CV values depict small year-to-year variations of annual runoff from the mean while the converse holds for high CVs. The spatial patterns of the CVs in the Thukela catchment (**Figure 4.2**) inversely mimic those of MAR. Subcatchments for which high MAR values are simulated portray correspondingly low values of CV, and vice-versa. The coastal stretch is an exception, as values of both MAR and CV are high. These high CVs of annual streamflows present a major challenge to planners in poor communities, many of whom are, as yet, without any reticulated water. The above picture of high inter-annual variability is exacerbated by the fact that

- most of the rural poor communities within the Thukela catchment live in those areas with high CVs,
- both intensification and extensification of land uses have been shown, to amplify streamflow variabilities in the Thukela catchment (Schulze *et al.*, 1997; Schulze, 2000), and
- the CVs depicted in Figure 4.2 are of the "mildest" form because CVs of streamflows for individual months are several times higher than those of annual flows (Schulze, 2000; also Chapter 5)



Inter-annual coefficient of variation (CVs) of individual subcatchment streamflows within the Thukela

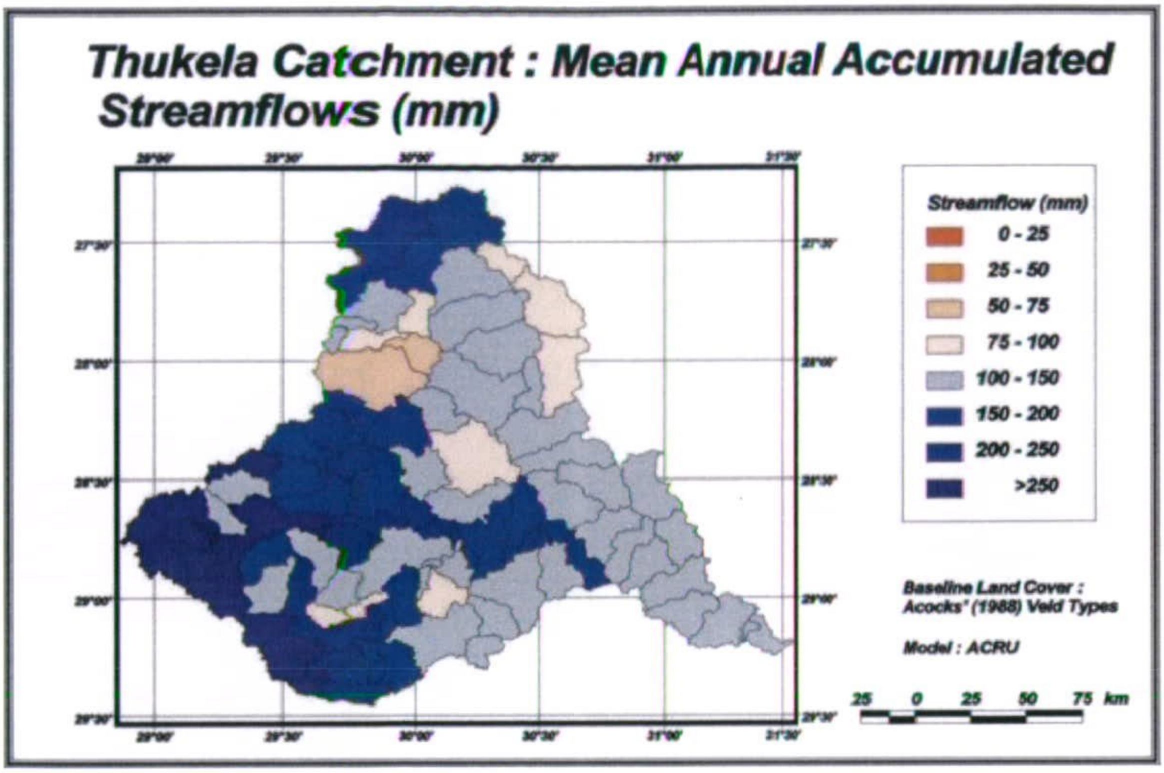


Figure 4.3 **Accumulated MAR (mm) in the Thukela catchment**

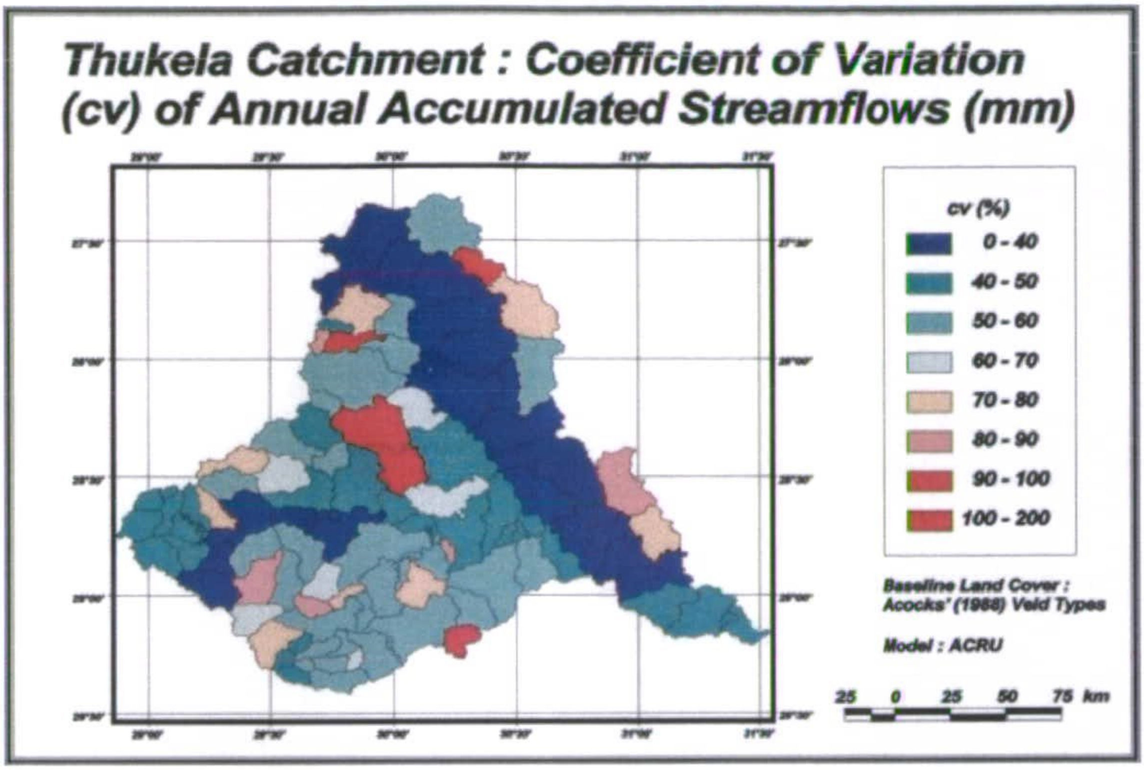
4.3 Spatial Variations of Mean Annual Accumulated Streamflows

Figure 4.3 shows means of annual accumulated streamflows in the Thukela catchment, where accumulated flows incorporate the (usual dampening) effects of all upstream flows, as well as flows from the subcatchment under consideration.

High streamflows are once again simulated in the Drakensberg region and also along internal subcatchments, i.e. those subcatchments that receive streamflow contributions from upstream subcatchments. These high runoff internal subcatchments are clearly those along the mainstem of the Thukela River and its major tributaries such as the Mooi, Sundays, Bushmans and Buffalo rivers. Other than in the Drakensberg, external subcatchments generally have the lower streamflow values than internal ones.

The implication of this pattern is that, although the Thukela catchment appears to have abundant available water, most of that water is concentrated along the major tributaries and the mainstem Thukela itself. It should, furthermore, already be noted at this juncture that most of the rural poor communities do not, however, live along mainstem rivers with high accumulated flows. There is a further constraint to indigenous rural communities not having ready access to available water, other than not being located along internal/mainstem rivers, and that is that within a subcatchment the communities/households tend to be located close to watershed boundaries where their supply of surface water would come from first order headwater streams which are frequently ephemeral in flow, rather than from second or third order streams with more consistent flows.

4.4 Inter- Annual Coefficient of Variation of Accumulated Streamflows



Inter-annual coefficients of variation (CV%) of accumulated streamflows within the Thukela

The CVs of accumulated flows (**Figure 4.4**) display inverse patterns to those of the accumulated flows themselves. Low CVs occur along the main channel and major tributaries, while high values occur in external subcatchments. This observation once again highlights the fact that water users who are located near the major tributaries are generally assured of more consistent supply than those who live in external subcatchments. This is of particular relevance in water poverty studies when considering those rural communities with no formal water supply schemes laid on as yet.

5 STREAMFLOW CHARACTERISTICS AT SPECIFIC W.P.I. CASE STUDY LOCATIONS IN THE THUKELA CATCHMENT

5.1 Background

As a central focus of the WPI project, in-depth case study surveys of household water use and accessibility were conducted at two locations within the Thukela catchment, *viz.* at Keates Drift and Wembezi (**Figure 5.1**). In South Africa, these surveys were carried out by Zulu speaking students from the SBEEH on behalf of the GeoData Institute from the University of Southampton in the UK. The sections which follow outline the objectives of the analyses, describe field survey locations and present results of the analyses of streamflows simulated for the subcatchments in which these sites are located.

5.1.1 Objectives of the hydrological analyses

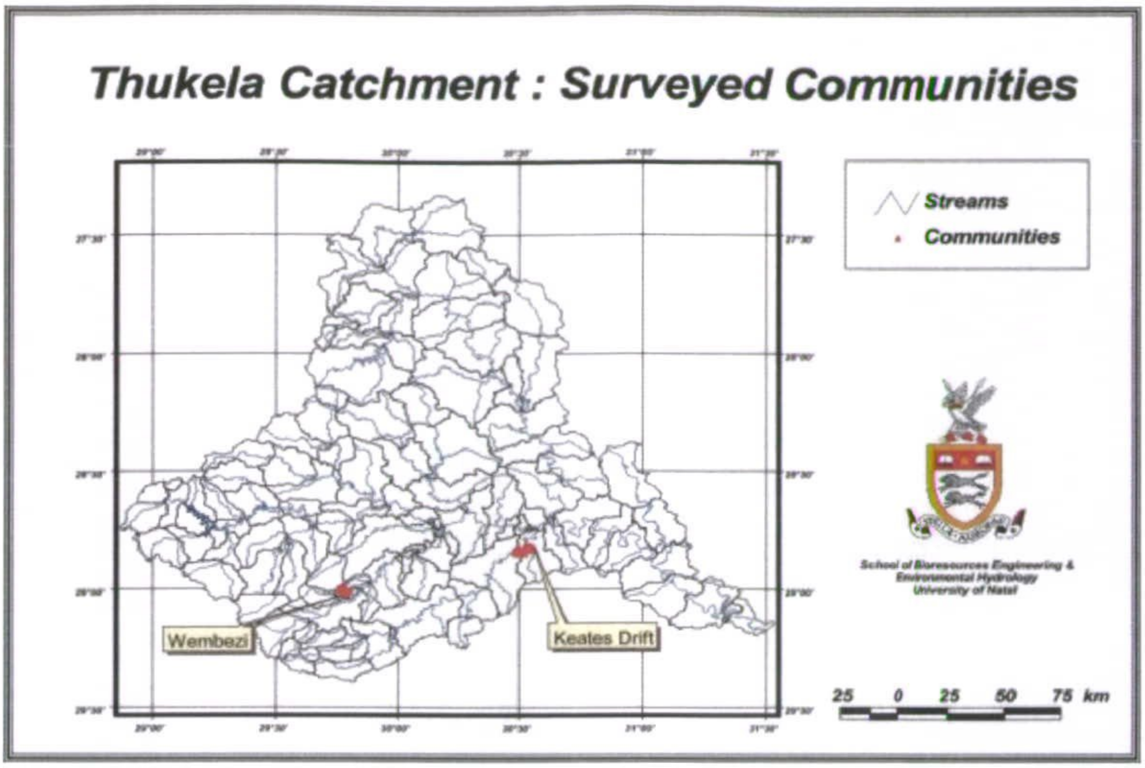
The objectives of the hydrological analyses which follow for Keates Drift and Wembezi are

- to present and interpret output statistics of simulated baseline flows, including flow variability, on a month-by-month basis rather than only as annual totals,
- to interpret time series of streamflows to establish patterns of flows, particularly during low flow months, and
- to evaluate flow duration curves for total, high flow month and low flow month conditions in order to establish patterns of flow at critical threshold occurrences,
- to distinguish between respective contributions of stormflows and baseflows to total streamflows.

5.1.2 Keates Drift

Keates Drift (KD) was selected to represent a poor rural indigenous community consisting of scattered non-nucleated households, where one section of the community, *viz*. Ethembeni, already has access to potable water from a pre-paid token (akin to debit card) system at scattered water points, while the other section of the community at KwaLatha has no water service provision as yet and water has to be collected from rivers and springs.

The Keates Drift communities are located close to the Mooi River along the Greytown-Dundee road at latitude 28E51'S, longitude 30E30'E and altitude about 700 m. The subcatchment in which these communities are located is SC99 (**Figure 3.3**) which has an area of 309.77 km^2, while the accumulated upstream area of the Mooi at Keates Drift is 2880.22 km^2.



Location of the case study sites within the Thukela catchment

5.1.3 Wembezi

Wembezi (WB) was selected to represent peri-urban township conditions. One section of the population, *viz.* at Depot, lives in formal housing with running water while the other, poorer community, Section C, lives more under shack conditions with no individual household water supply, but with communal standpipes approximately 150 m apart. Wembezi is a satellite township near Estcourt. Located at 29E03'S, 29E47'E and at an altitude of 1400 m, Wembezi flanks the Bushman's River. The subcatchment in which it is located is SC23 (**Figure 3.3**) with an area of 77.86 km^2 and the total catchment area upstream of WB is 195.55 km^2.

5.2 An Overview of Streamflow Statistics

The tables with streamflow statistics which follow all have mm equivalent flows as the unit rather than m^3, in order to represent flow equivalents per unit of area. The 10th percentile of flow exceedence represents flows in the driest month/year in 10, the 20th percentile the driest in 5, the 90th percentile the wettest in 10, and so forth. Also note that monthly percentile flows are computed for that particular month only and that the 12 monthly totals of percentile flows therefore do not add up to the annual total, which computed separately. Furthermore, note that because the *ACRU* model simulates a subcatchment's stormflows and baseflows explicitly (i.e. without recourse to baseflow separation curves), the statistics on stormflow and baseflow are available only for flows of an individual subcatchment and not for accumulated flows from upstream, in which case mixing of these two streamflow components has already taken place.

Table 5.1 **Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	17.5	19.2	12.0	3.8	1.8	0.7	0.7	2.7	9.3	7.5	9.5	16.0	100.7
Std. Deviation	18.8	22.4	14.1	4.6	2.7	0.9	1.3	5.7	28.0	12.2	9.6	15.7	75.5
CV (%)	107.8	116.8	117.5	121.4	149.9	131.2	176.4	210.6	302.2	161.0	101.4	98.1	75.0
Skewness Coef.	1.6	1.9	2.5	2.0	2.3	1.8	4.5	2.7	5.0	2.7	1.9	1.7	1.9
Kurtosis Coef.	2.3	3.8	7.0	3.9	5.1	2.9	24.8	6.7	27.2	7.6	4.4	2.9	5.4
10th Percentile	1.7	1.5	1.5	0.3	0.0	0.0	0.0	0.0	0.1	0.5	1.0	3.1	22.3
20th Percentile	3.1	2.5	2.1	0.6	0.1	0.0	0.0	0.1	0.2	0.9	2.7	3.3	46.3
50th Percentile	10.1	10.3	8.7	2.3	0.9	0.3	0.3	0.4	0.6	2.5	6.4	12.7	83.3
80th Percentile	29.8	37.1	18.1	6.2	2.3	1.1	1.2	2.6	7.9	10.3	15.2	24.7	147.0
90th Percentile	41.6	47.1	22.8	12.1	5.0	2.1	1.7	10.2	22.7	22.8	22.0	33.9	178.0

Table 5.2 **Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the accumulated area upstream of Wembezi**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	18.1	18.6	11.0	4.5	1.9	1.1	1.2	1.8	7.1	6.5	7.9	14.9	94.6
Std.	19.9	19.5	11.7	4.5	2.6	1.9	2.5	3.2	21.0	11.3	7.3	13.3	72.9
CV (%)	110.0	104.9	106.3	99.9	137.0	172.6	216.3	173.3	296.7	172.5	92.2	89.5	77.1
Skewness	2.1	1.7	1.8	1.2	1.9	3.5	4.5	2.7	4.9	3.2	1.5	1.4	1.7
Kurtosis	5.5	3.1	2.9	0.3	3.3	16.0	23.3	7.4	25.6	11.0	1.6	1.8	3.3
10th	2.7	1.7	1.8	0.7	0.0	0.0	0.0	0.1	0.2	0.7	1.0	2.5	23.1
20th	4.0	3.3	2.3	1.0	0.1	0.0	0.0	0.1	0.2	0.9	2.1	4.0	39.8
50th	9.4	15.1	6.3	2.3	0.9	0.4	0.4	0.5	0.6	2.0	6.4	10.9	80.6
80th	28.4	28.0	18.9	9.2	3.8	2.1	1.6	2.0	6.6	8.3	10.6	24.3	132.1
90th	43.2	42.6	24.4	11.6	5.6	3.0	2.7	6.6	15.0	13.3	18.9	35.8	194.5

Table 5.3 **Statistics on monthly and annual simulated stormflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	16.0	17.4	9.8	2.1	0.8	0.1	0.4	2.4	8.2	4.9	7.6	14.5	84.3
Std.	18.4	20.8	12.2	3.8	1.8	0.2	1.2	5.4	26.3	7.0	7.4	15.1	58.0
CV (%)	115.2	119.6	124.6	178.5	221.7	158.1	316.5	229.6	319.0	143.2	97.4	103.7	68.8
Skewness	1.7	1.8	2.2	3.1	2.9	2.2	5.6	2.8	5.2	2.2	1.9	1.8	1.9
Kurtosis	2.8	3.6	5.3	10.4	8.7	5.0	34.1	7.5	29.3	4.1	4.0	3.2	5.9
10th	1.5	1.4	0.7	0.1	0.0	0.0	0.0	0.0	0.1	0.4	1.0	1.9	21.8
20th	2.5	2.0	1.2	0.3	0.0	0.0	0.0	0.0	0.1	0.7	2.6	3.2	40.6
50th	9.4	8.3	5.2	0.6	0.1	0.0	0.0	0.2	0.4	1.8	4.7	8.1	75.1
80th	28.2	30.8	15.9	3.0	0.5	0.2	0.3	1.9	4.5	7.6	11.3	24.6	129.2
90th	37.9	42.4	22.8	4.5	3.0	0.3	0.8	9.9	22.7	14.8	19.3	29.4	140.2

Table 5.4 **Statistics on monthly and annual simulated baseflows generated under baseline land cover conditions from the individual subcatchment SC23 at Wembezi**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	1.4	1.7	2.2	1.7	1.0	0.6	0.4	0.4	1.0	2.7	1.8	1.5	16.4
Std.	2.6	3.0	4.1	3.0	1.6	0.9	0.6	0.7	2.9	8.3	4.7	2.7	24.1
CV (%)	183.3	173.8	184.8	177.2	158.3	154.6	154.6	191.6	275.1	313.4	252.7	185.4	146.5

Skewness	2.4	2.6	2.7	2.7	2.1	2.0	1.9	4.0	3.5	4.1	3.6	2.9	2.4
Kurtosis	5.9	8.3	6.9	7.4	4.6	3.4	3.3	19.8	11.7	17.3	13.2	9.1	5.8
10th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
50th	0.1	0.2	0.5	0.3	0.2	0.1	0.1	0.1	0.0	0.1	0.1	0.1	7.8
80th	1.7	3.2	3.3	2.5	1.6	1.0	0.6	0.6	0.5	0.4	2.2	2.4	22.5
90th	5.2	6.0	4.8	4.2	3.5	2.1	1.3	1.0	3.6	7.1	4.3	4.0	43.5

Table 5.5 **Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	28.7	24.4	15.9	4.2	3.3	0.9	1.8	4.2	9.4	9.1	10.1	19.6	131.5
Std.	34.0	33.6	21.6	7.0	11.3	1.8	5.0	9.4	36.2	14.8	12.0	28.4	82.4
CV (%)	118.7	137.8	136.1	166.5	343.0	197.7	281.2	224.1	386.6	162.3	118.6	145.3	62.7
Skewness	2.2	2.8	2.2	2.8	5.7	2.7	4.1	2.6	5.8	3.7	1.5	5.0	1.2
Kurtosis	4.3	9.5	4.9	8.8	34.8	6.9	17.7	5.5	36.0	16.6	1.4	28.8	2.0
10th	3.0	1.0	0.7	0.2	0.0	0.0	0.0	0.0	0.0	0.3	0.6	2.4	47.1
20th	6.5	4.3	1.2	0.3	0.1	0.0	0.0	0.1	0.1	0.6	1.2	5.8	66.6
50th	18.0	10.9	5.4	1.1	0.5	0.1	0.2	0.3	0.6	5.7	4.8	13.3	108.9
80th	38.5	41.4	25.2	5.9	2.1	1.1	1.2	2.8	7.8	13.2	18.0	25.4	201.0
90th	85.0	58.4	49.3	12.4	4.5	3.2	4.3	22.9	12.2	23.6	29.4	29.8	228.6

Table 5.6 **Statistics on monthly and annual simulated total streamflows generated under baseline land cover conditions from the accumulated area upstream of Keates Drift**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	20.8	18.1	14.5	5.5	3.4	1.7	1.2	2.7	7.2	7.6	10.2	18.5	111.4
Std.	14.3	13.2	12.6	4.7	4.5	2.5	1.5	4.3	24.2	12.1	7.6	9.7	62.0
CV (%)	68.7	72.9	87.1	85.3	134.7	145.3	128.4	158.5	335.2	158.7	74.8	52.5	55.6
Skewness	1.2	1.1	2.3	2.1	3.2	3.9	2.9	2.9	5.9	3.3	1.3	1.2	2.1
Kurtosis	1.0	1.2	7.3	5.1	12.8	18.7	10.6	10.0	36.8	11.6	1.5	1.3	5.1
10th	7.5	4.4	3.8	1.6	0.4	0.2	0.1	0.3	0.3	1.3	2.5	7.4	59.1
20th	8.8	5.7	5.0	2.2	0.7	0.5	0.2	0.3	0.4	1.7	3.3	11.5	67.3
50th	16.5	15.3	11.0	4.2	1.9	1.1	0.6	1.2	1.0	3.3	8.7	15.6	95.3
80th	32.0	29.7	22.3	8.2	4.8	1.9	1.9	3.5	4.8	8.6	13.8	24.6	128.7
90th	44.4	37.9	27.5	10.4	8.8	4.9	3.1	8.2	12.6	13.5	20.0	31.3	175.4

Table 5.7 **Statistics on monthly and annual simulated stormflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annual
Mean	27.4	23.1	14.8	3.2	2.4	0.3	1.2	3.6	8.1	6.5	8.0	18.0	116.6
Std.	33.5	33.5	20.8	6.3	10.5	1.4	3.8	8.7	35.1	8.3	10.6	26.8	68.7
CV (%)	122.1	145.0	141.3	198.3	430.4	394.8	326.0	245.1	435.5	127.2	133.0	148.8	59.0
Skewness	2.1	2.8	2.3	3.0	5.7	4.8	3.6	2.7	6.0	2.6	2.0	4.8	1.0
Kurtosis	4.0	10.1	5.6	10.0	34.7	22.9	12.1	6.8	38.0	9.0	4.0	26.9	1.6
10th	2.8	0.9	0.6	0.1	0.0	0.0	0.0	0.0	0.0	0.3	0.5	2.2	41.1
20th	5.3	2.6	1.0	0.2	0.0	0.0	0.0	0.0	0.0	0.6	0.7	5.6	65.1
50th	16.2	9.9	5.2	0.6	0.1	0.0	0.0	0.2	0.3	4.0	3.1	10.8	97.1
80th	38.5	40.4	24.8	3.8	0.4	0.2	0.2	1.4	3.3	10.3	14.0	24.1	164.9
90th	84.8	54.5	44.9	10.7	4.0	0.4	1.2	17.8	8.1	14.7	22.1	28.8	204.9

Table 5.8 **Statistics on monthly and annual simulated baseflows generated under baseline land cover conditions from the individual subcatchment SC99 at Keates Drift**

	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Annu
Mean	1.2	1.3	1.1	1.0	0.9	0.6	0.6	0.6	1.3	2.6	2.1	1.6	14.9
Std. Deviation	2.9	2.6	2.1	2.0	1.6	1.3	1.6	1.6	3.0	7.3	5.4	3.6	23.0
CV (%)	229.	206.	182.	194.	190.	220.	266.	252.	233.	283.	253.	230.	154.0
Skewness	3.6	2.9	3.1	3.4	2.4	3.6	4.7	3.4	2.5	4.1	3.5	2.9	2.1
Kurtosis Coef.	14.8	9.7	12.7	14.4	5.1	15.0	25.8	10.6	5.1	19.0	13.6	8.0	4.7
10th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20th	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
50th	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.5
80th	1.7	2.0	1.9	1.9	1.4	0.8	0.7	0.6	0.8	2.5	3.1	2.0	24.5
90th	4.4	4.2	3.9	3.4	2.7	1.6	1.6	1.3	5.0	7.1	5.7	4.8	48.8

The following may be gleaned from **Tables 5.1** to **5.8**:

- A strong seasonality of flows is evident at both sites, with very low winter month flows (June – August) compared with high summer month flows (November – February).
- Total streamflow is dominated by stormflows (83.7% of the total flows at Wembezi, 88.7% at Keates Drift), indicative of the episodic and pulsar nature of rainfall events in the Thukela, which often occur as thunderstorms.
- Streamflow variability from year to year for any given month is very high. For the individual subcatchments, at Wembezi 11 of the 12 months have CVs > 100%, at Keates Drift it is 12 out of 12.
- It is notable that median monthly flows (i.e. 50th percentile) are markedly lower than mean monthly flows, particularly in the low flow months (e.g. at Wembezi in August: 0.4 mm vs 2.7 mm). This non-normality of the flow distribution manifests in very high coefficients of skewness.
- While baseflows only make up 16.3% of the annual flows in the Wembezi subcatchment, and 11.3 % at Keates Drift, they do play an important role in the low flow season. For the period June to August, for example, baseflows make up 34 % and 26 % respectively of total flows at Wembezi and Keates Drift.
- According to the *ACRU* model simulations, baseflows are not generated at all in any month of the year, in the driest year in 5 or condition drier than that at Wembezi and in the driest year in 2 or drier at Keates Drift.
- Where a total upstream catchment is large, as is the case at Keates Drift, CVs of monthly (and annual) flows are considerably lower than those from an individual subcatchment. For example, CVs are < 100 % in 6 of 12 months for accumulated flows vs 0 out of 12 months for individual subcatchment flows at Keates Drift. This is

not the case with the small total area upstream of Wembezi, however, where accumulated flows are more variable than those of the local subcatchment.

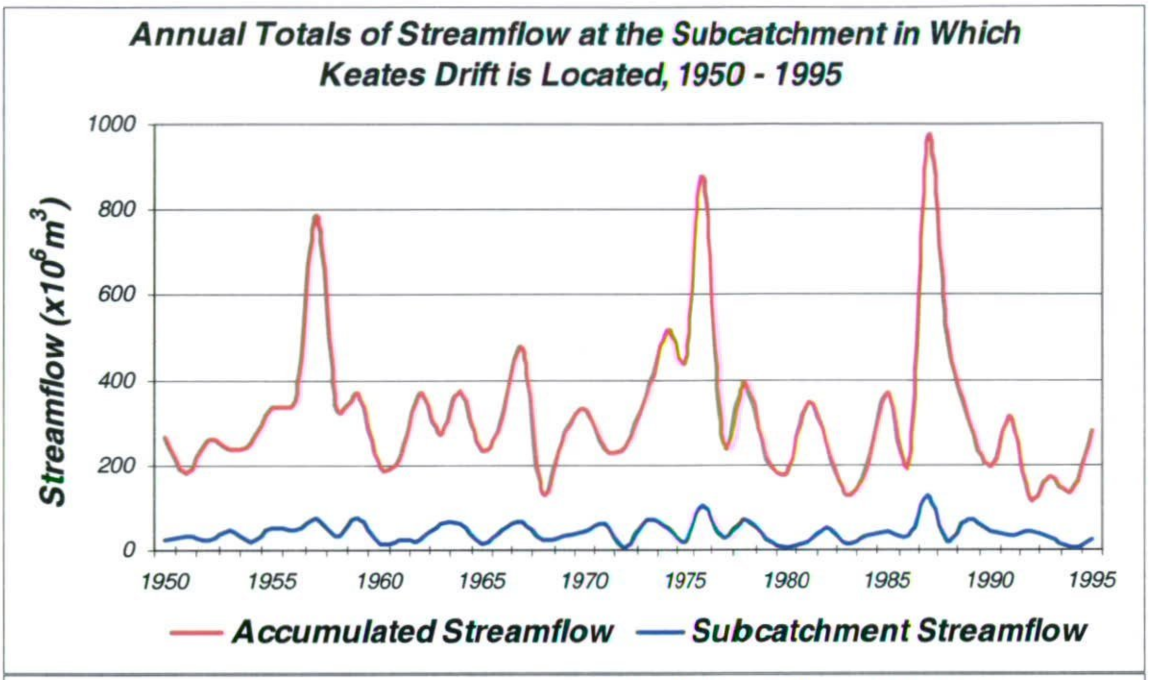
5.3 Interpretation of the Time Series of Streamflows

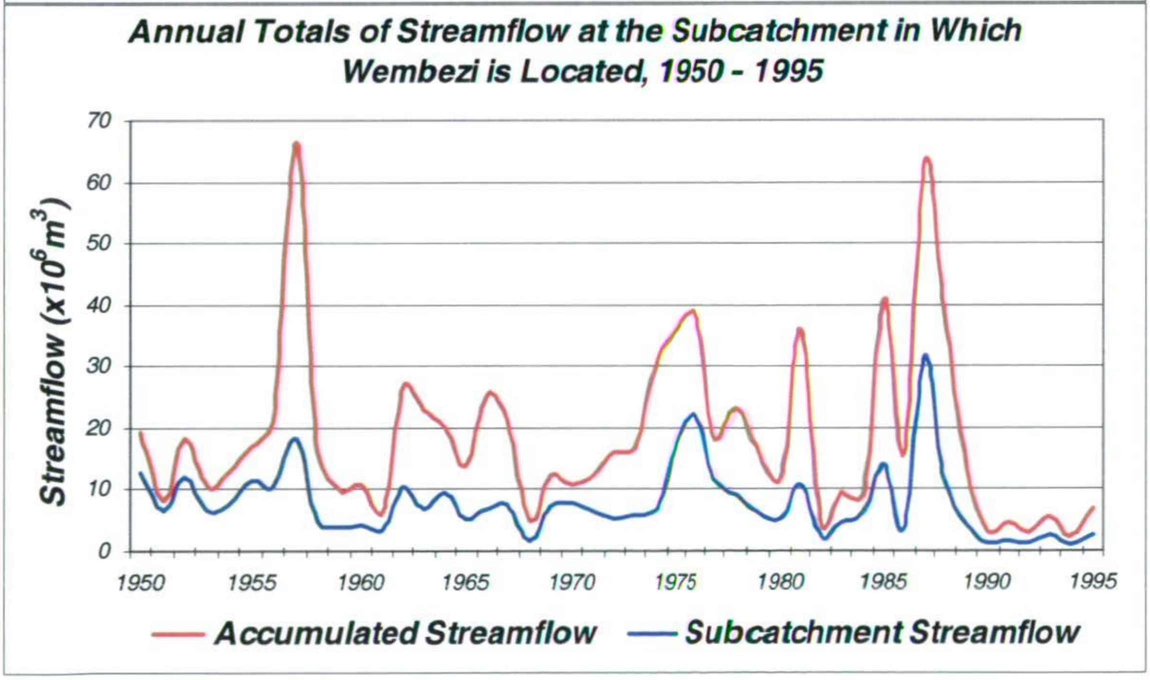
Visual interpretation of the time series of annual streamflows in the subcatchments in which Keates Drift and Wembezi are located (**Figure 5.2**) highlights the following:

- There is a high inter-annual variability of flows.
- More importantly from a WPI perspective is that, in addition to isolated years with very high flows (e.g. 1957, 1976, 1987 at Keates Drift), sequences or clusters of persistent annual high flows occur, as do sequences of years of persistent low flows. The persistent low annual flows of the early 1960s, 1980s and especially 1990s have well documented associations with strong El Ninõ events.
- Neither the isolated high annual flows nor the consecutive years of lows necessarily occur at the same time or at the same strength at the two locations, which are only 75 km apart. For example, the sequence of low annual flows at Wembezi in the early 1990s is much stronger at Keates Drift.
- The implications of persistent low annual flow sequences for a WPI are quite profound, in that any storage of water will have to be large enough to withstand hydrological droughts of several years' duration.

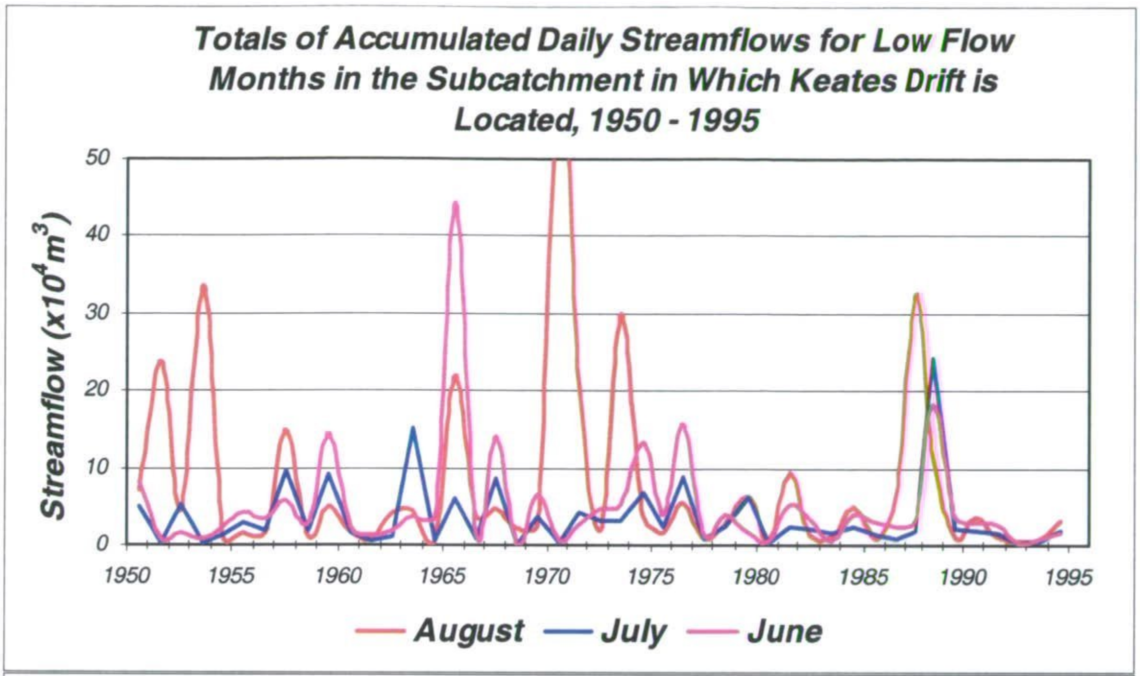
More significant for communities dependent on local surface water supplies are the patterns of the flow sequences in the low flow months, *viz*. June to August (**Figure 5.3**). The following may be oserved:

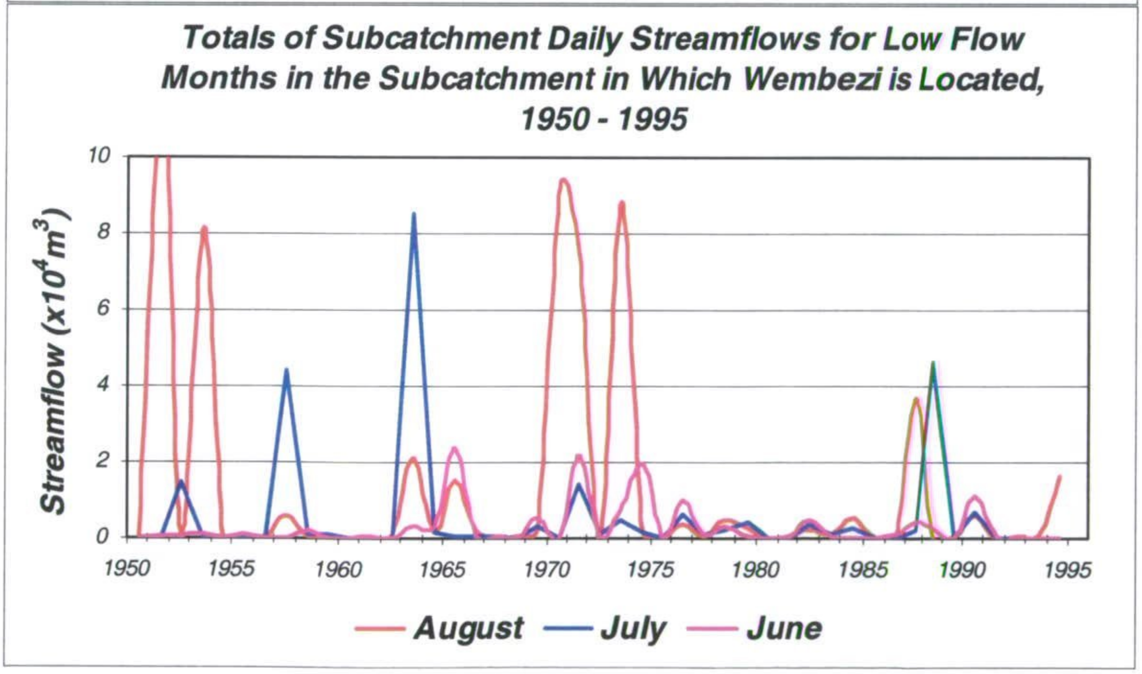
- Inter-annual comparisons for the specified low flow months display a much more jagged pattern than for annual flows, particularly in the late low flow season (July – August).
- Prolonged hydrological droughts, i.e. when all three months have below average flows for several successive years, can be pronounced, as in the early 1960s, late 1960s and the decade 1975 – 85 at Wembezi.
- Again, differences occur in the low flow season persistencies at the two locations.
- The time series analyses highlight the necessity for monthly to seasonal streamflow forcasting to be tested and applied as a planning and operational tool for water poor areas.





Time series of annual streamflows in the subcatchments in which Keates Drift and Wembezi are located





Time series of monthly flows for the low flow months June to August in the subcatchments in which Keates Drift and Wembezi are located

5.4 Evaluation of Flow Duration Curves for Year Round Flows and for High and Low Flow Months

Flow duration curves (FDCs) show the percentage of time that a specified flow is exceeded or not. When evaluated together with a population or development-driven water demand, a FDC can be used as an indicator of the proportion of time that water stress occurs, either in regard to too much water (low percentage exceedence) or too little water (high percentage exceedence).

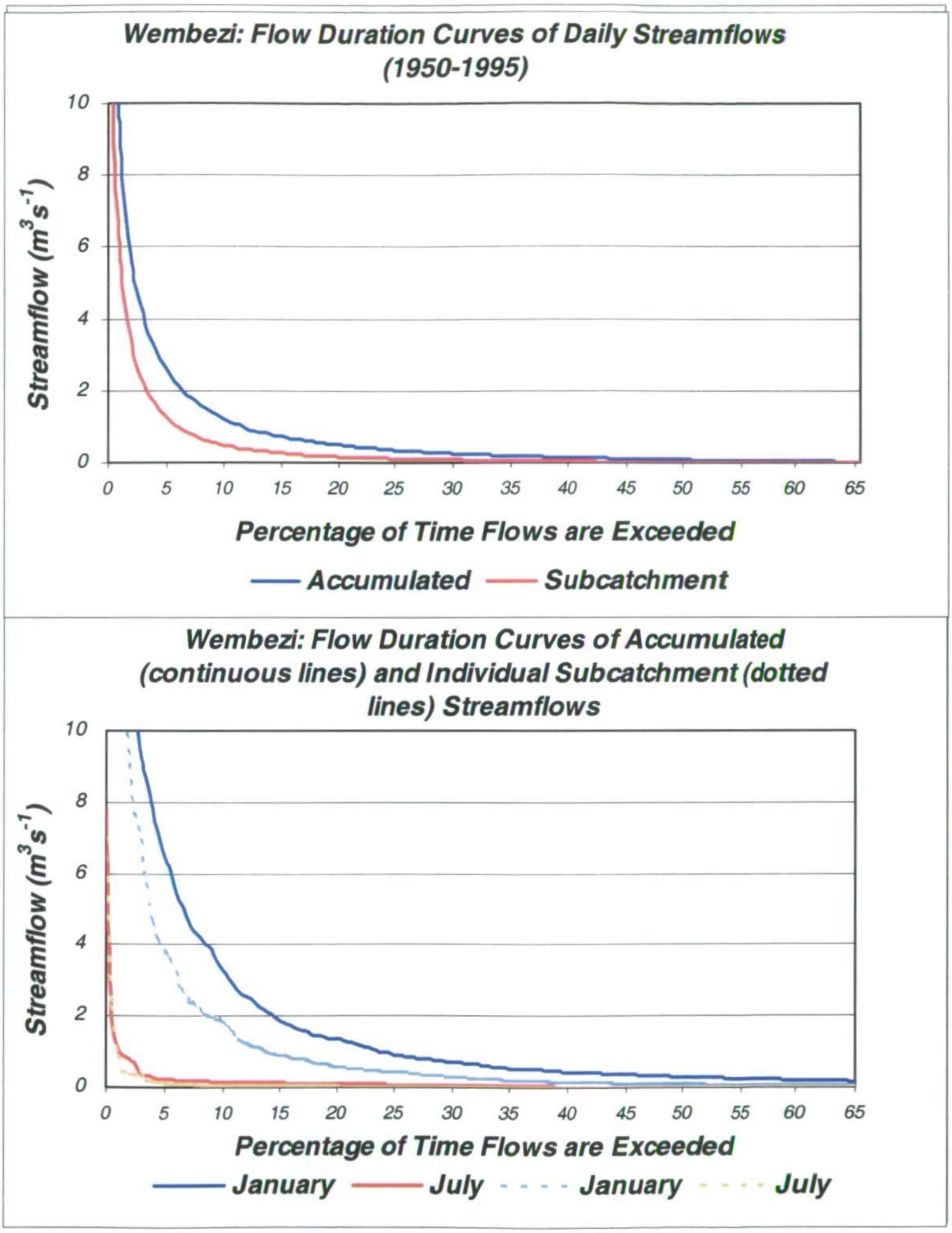
Figures 5.4 and **5.5** illustrate the following:

- In absolute terms (i.e. $m^3.s^{-1}$ of water available), the proximity of a mainstem river commanding a large upstream catchment area (as at Keates Drift) provides a much more sustained water availability than a smaller catchment would (**Figure 5.4** top vs **Figure 5.5** top). Unfortunately, the rural poor do not always have access to water from rivers with large upstream catchments.
- Secondly, sustained water yield above a critical threshold of flow in months with high streamflows (e.g. January) is just so much more readily available than in months with low flows, e.g. July (**Figure 5.4** bottom vs **Figure 5.5** bottom).
- While being informative on percentage exceedences of flows of a given magnitude, the FDC does not, however, address the issue of persistent sequences of high or low flows.

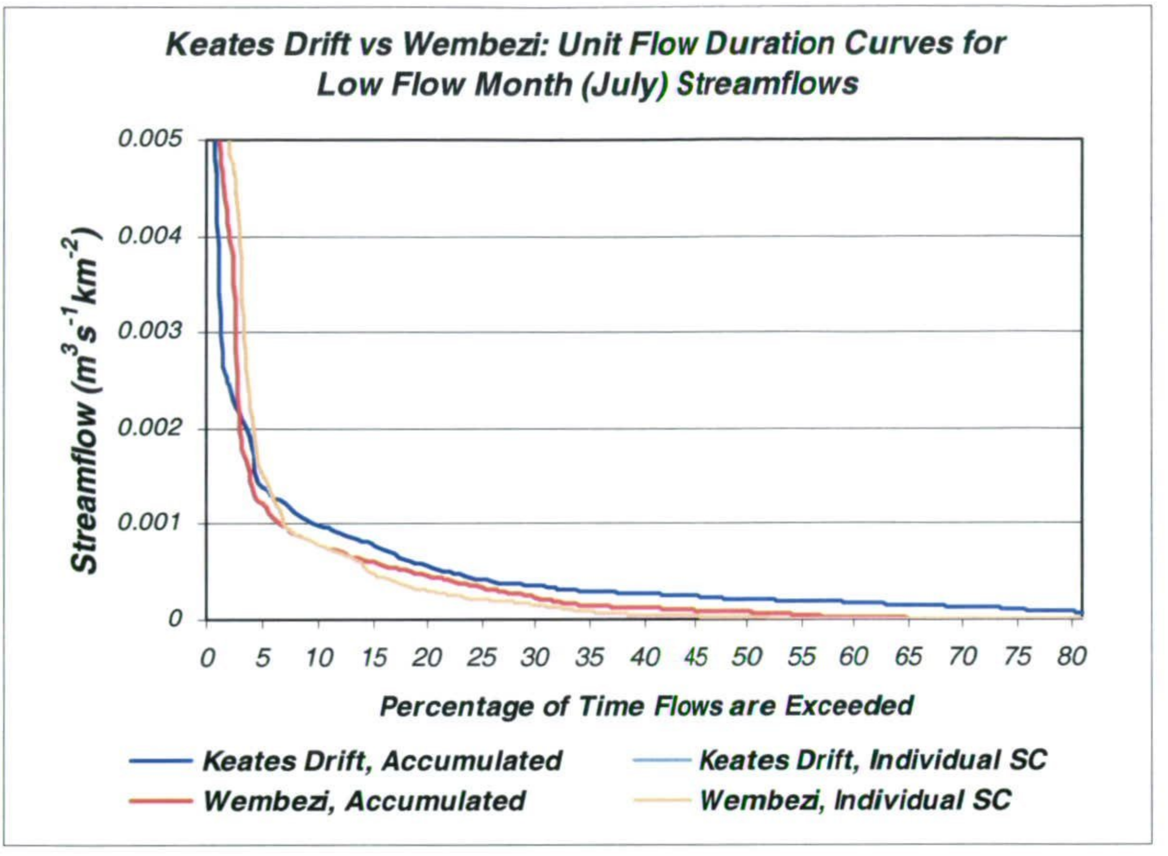
For the purposes of comparing streamflow generation from large vs small catchments, FDCs may be expressed in terms of a unit area, i.e. $m^3.s^{-1}.km^{-2}$. Such a comparison is made in **Figure 5.6**.

While results look deceptively similar, close scrutiny shows that from a WPI perspective, i.e. at the low end of streamflow generation for which flows are exceeded frequently,

- a unit of area upstream of Keates Drift generates considerably more streamflow than upstream of Wembezi and that
- an individual subcatchment may reverse a trend when its flows are compared with those of the accumulated flows of the total upstream catchment, as is the case at Wembezi for high flows occurring less frequently than 7 % of the times.



Flow duration curves for total flows as well as for high flows (January and low flows (July) months at Keates Drift

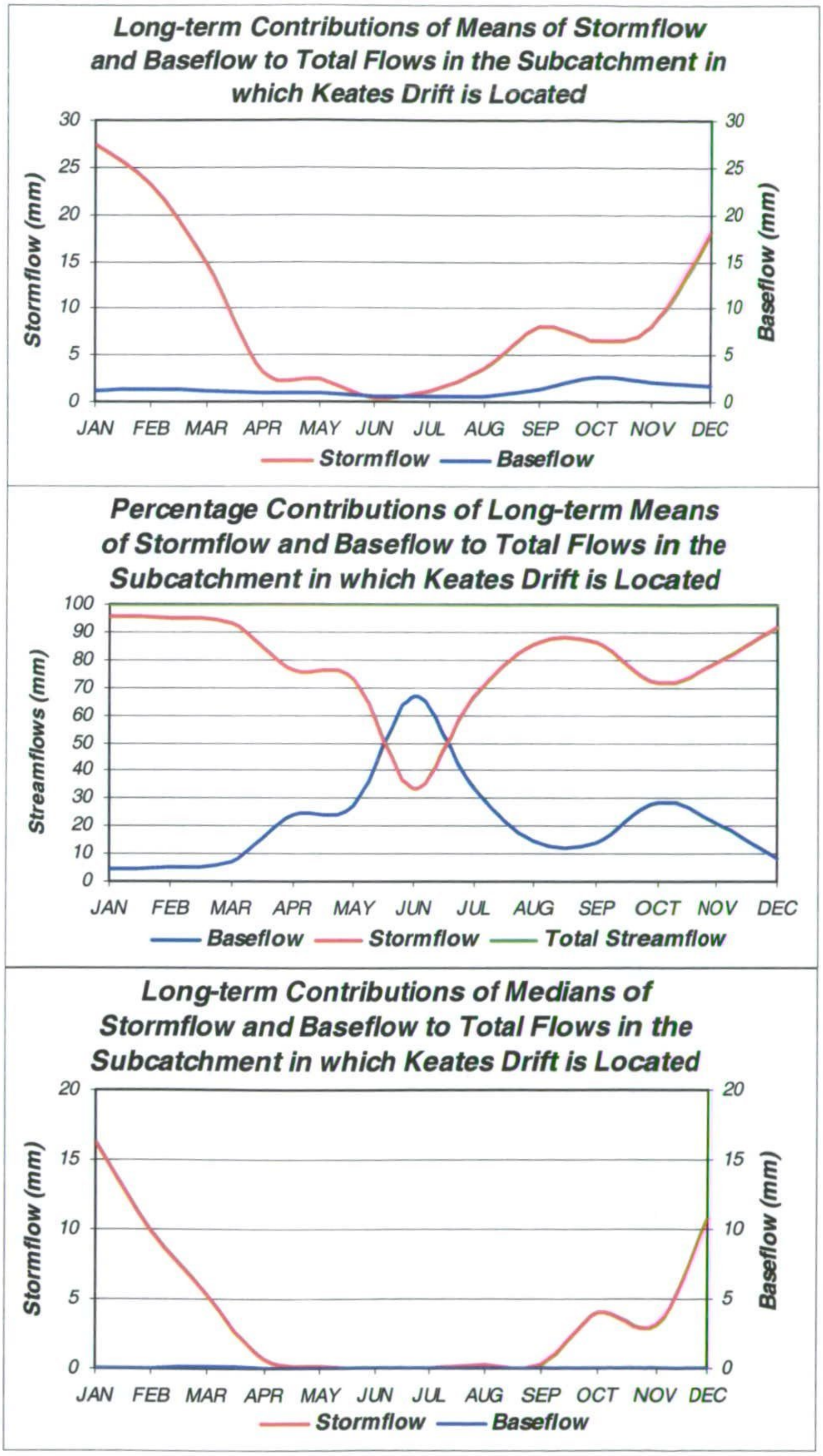


Flow duration curves per unit area ($m^3.s^{-1}.km^{-2}$) at Keates Drift and Wembezi

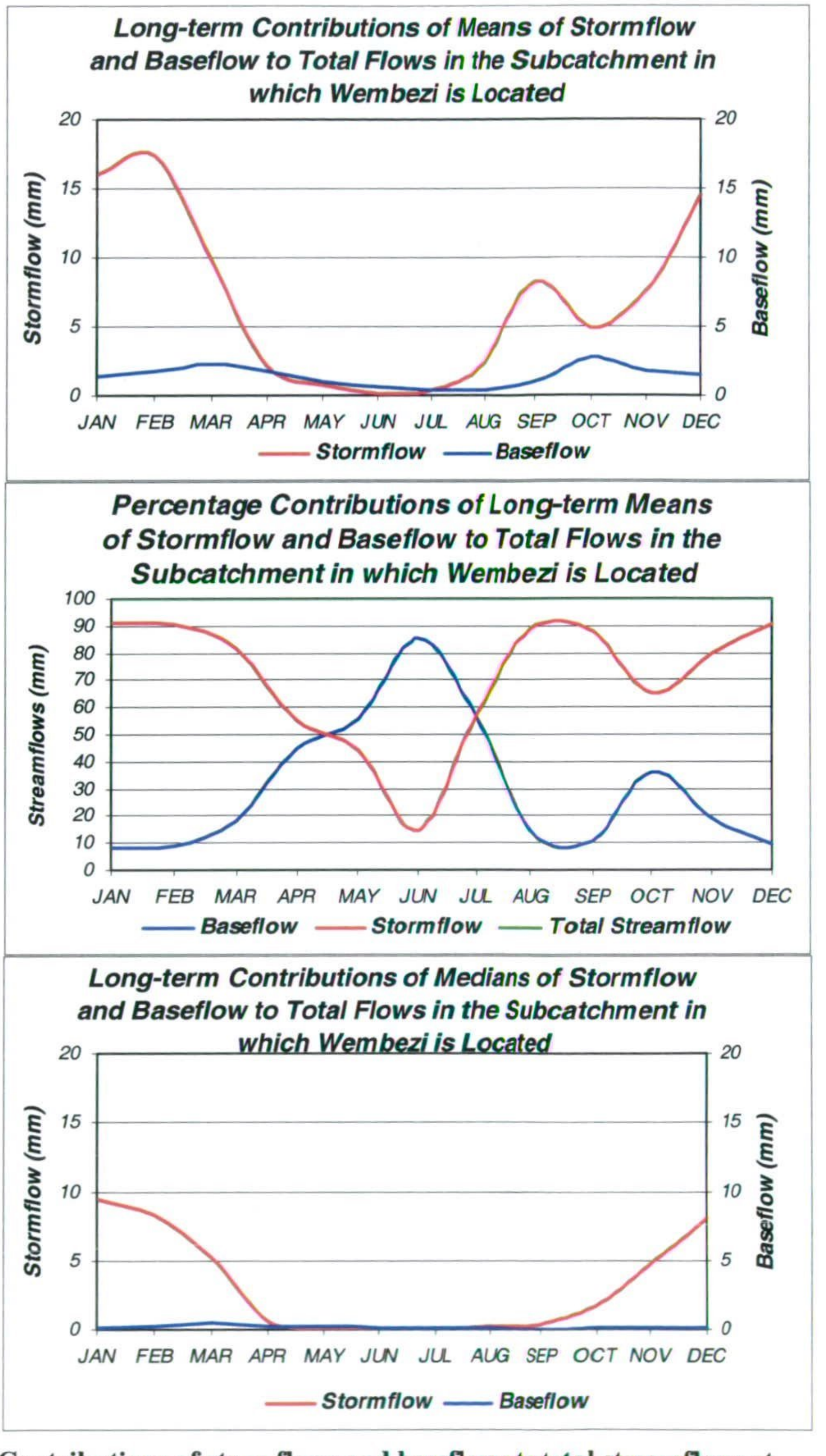
5.5 Contributions of Stormflows and Baseflows to Total Streamflows

The respective contributions to total flows of stormflows (Q_s) and baseflows (Q_b) are a reflection not only of the type of rainfall generating mechanism in a region, but have an influence also on water quality. For example, high stormflows are associated with high sediment and phosphorus yields; high baseflows have bearing on nitrate concentrations of streamflows.

The dominance of stormflows at both Keates Drift and Wembezi has already been emphasised. This is borne out graphically for the two case study locations in **Figures 5.7** (top) and **5.8** (top). In relative (percentage) terms, the middle diagrams of **Figures 5.7** and **5.8** show that only in June at Keates Drift and only from May – July at Wembezi, do baseflows contribute more to total flows than stormflows. The bottom diagrams of **Figures 5.7** and **5.8** illustrate that for median flows, the dominance of Q_s over Q_b is even greater than for means, because the means are influenced by extreme events which tend to produce more baseflows.



Contributions of stormflows and baseflows to total streamflows at Keates Drift



Contributions of stormflows and baseflows to total streamflows at Wembezi

6 LESSONS LEARNED AND THE ROAD AHEAD

6.1 Why Water Poverty Indicators at the Meso-Scale?

Water stress and water poverty indices tend to be developed for, and applied at, either macro-scales on a country or major catchment level, or on the other hand, at the micro-scale the individual rural communities. At the macro-scale little to no indication is given to where, when, how often, or for what duration water stress occurs at a given point of interest within the country, while at community scales in-depth studies tend to be undertaken in isolation of broader operational water resources issues.

This evaluation of indicators of water poverty under baseline conditions in the Thukela catchment has focussed on the meso-scale, i.e. at catchments in the range of 10s to 100s km^2 in area. Two reasons are forwarded for developing a WPI at this scale:

- It is at the meso-scale that the intra-catchment streamflow response differences can be identified, i.e. the where, when, how frequently or how persistently water is available at a location of interest.
- It is, furthermore, at the meso-scale that water resources planners operate and many decisions on integrated water resources management are made.

6.2 What Lessons Have Been Learned from the Thukela Catchment in Regard to the Development of Water Poverty Indices?

(i) Primary indicators of potential water stress occurrence within the Thukela may already be gleaned from simple hydroclimatic analyses such as those on mean annual precipitation and its spatial variation (**Figure 2.3**), the seasonality of rainfall, its inter-annual variability (**Figure 2.4**) and potential evaporation rates (**Figure 2.7**).

(ii) The amplification of any changes in rainfall patterns in hydrological responses cannot be over-emphasised. For example, a 3- to 4-fold range of MAP within the Thukela manifests itself as a 10-fold range in subcatchment streamflows, with MARs ranging from < 25 mm to > 250 mm (**Figure 4.1**).

(iii) The hydrological amplification is even more pronounced in the inter-annual variabilities, with CVs of annual rainfalls around 20% (**Figure 2.4**) converting to CVs of annual streamflows of 40 to 100% (**Figure 4.2**).

(iv) Variabilities of annual totals are the "mildest" form of assessing dispersion about the mean, with CVs of monthly streamflows being consistently and considerably higher than those of annual streamflows (**Tables 5.1** to **5.8**). To us it is imperative that this observation needs to be factored into a realistic WPI if it is to be applicable in rural areas with poor infrastructure.

(v) In the Thukela catchment, and probably in many other catchments in South Africa, the rural poor for historical reasons and more recently for more political reasons settled in those parts of the catchments characterised by higher climatic/hydrological variability. This renders rural poor communities even more vulnerable to water stress than had they settled more randomly throughout the catchment.

(vi) Mainstem rivers and large tributaries generally produce higher and more sustained flows and have dampening effect on flow variability when compared with flows from individual subcatchments (**Figures 4.3** and **4.4**; **Tables 5.1** to **5.8**).

(vii) However, the rural poor in the Thukela catchment tend not to live close to larger rivers. In fact, they often live close to watershed boundaries where streams are more prone to be ephemeral rather than permanently flowing. This observation needs quantification and verification, however.

(viii) Median (i.e. statistically expected) monthly and annual flows within the Thukela catchment are considerably lower than their corresponding means (**Tables 5.1** to **5.8**). This indication of skewness in the distribution of streamflows further exacerbates water stress and ideally needs to be accounted for in a WPI.

(ix) Time series of streamflows of the 46 year period of simulation display long sequences of years with persistent low flows, both for annual flows and the low flow months (**Figure 5.2**). These long sequences of low flows place a heavy burden on the water-poor communities.

(x) Long low flow sequences are closely associated with the well documented El Ninõ phenomenon in South Africa and if seasonal climate forecasting skills were to increase, rural communities concerned with water security would be important beneficiaries of such forecasts.

(xi) The low flow persistencies furthermore imply that any impoundments designed to store water have to be large in order to cope with frequent occurrences of low inflows and high demands.

(xii) Any water alleviation planning or WPIs should include flow duration curves as an input. In particular where local community planning is undertaken, the value of Unit FDCs (i.e. flows generated per km^2) should not be underestimated as a design tool (**Figure 5.6**).

6.3 The Road Ahead

The main objective of this study in the Thukela catchment has been to assess the primary natural endowment of streamflows under baseline land cover conditions at the meso-scale level, as an indicator of the potential availability of water and its constraints to development, with specific reference to contributing towards the quantification of a Water Poverty Index. A number of the streamflow attributes which were evaluated were found to have potential for inclusion in a WPI.

This first phase of the study has not, however, yet taken cognisance

- of present land use impacts on flow characteristics, through agricultural intensification or extensification, degradation, urbanisation, mining activities, or the major inter-basin transfers out of the Thukela system of over 600 x $10^6 m^3$ per annum out of a total water resource of 4000 x $10^6 m^3$ per annum,
- of the above impacts on water quality and recharge to groundwater, or
- of population distributions and their water demands.

In particular the distribution of where the "water poor" populations reside has to be identified, not only in which subcatchments they reside, but also with respect to where, within a subcatchment, they are located with respect to more local streamflow variability.

The above are the challenges to be considered in further phases of WPI studies.

ACKNOWLEDGEMENTS

This research has been funded with grants from the UK Department for International Development, through the Centre for Ecology and Hydrology at Wallingford, UK, and from the Water Research Commission of South Africa. Their financial support is acknowledged gratefully. The initial configuration of the Thukela catchment was undertaken by Dr Graham Jewitt, Ms Valerie Taylor and Messrs Jason Hallows and Mark Horan. Their inputs and the computing assistance from the Computing Centre for Water Research are acknowledged with thanks.

REFERENCES

Acocks, J. P. H. 1988. Veld Types of South Africa. Botanical Research Institute, Pretoria, RSA. Botanical Survey of South Africa, Memoirs, 57. pp146.

CSIR,1996. National LANDSAT TM Images. Environmentek, CSIR, Pretoria, RSA.

Dent, M. C., Lynch, S. D. and Schulze, R. E. 1989. *Mapping Mean Annual and other Rainfall Statistics over Southern Africa.* Water Research Commission, Pretoria, RSA. Report 109/1/89.pp 198 plus Appendices.

Falkenmark, M. 1989. The massive water shortage in Africa: why isn't it being addressed? *Ambio*, 18, 112-118.

Jewitt, G. P. W., Taylor V. and Hallowes J. 1999. Thukela Water Project : Hydrology Specialist Study. Report to Institute of Natural Resources, Pietermaritzburg, RSA. School of Bioresources Engineering Hydrology and Environmental Hydrology, University of Natal, Pietemaritzburg, RSA.

Pike, A. 1999. *CALCPPTCOR* – A rainfall selection and correction program. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, RSA.

Pike, A. and Schulze R. E. 1995. AUTOSOILS Version 3. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, RSA.

Schulze, R. E. 1995. Hydrology and Agrohydrology : *A Text to Accompany the ACRU 3.00 Agrohydrological Modelling System.* Water Research Commission, Pretoria, RSA. Technology Transfer Report TT 69/95. pp 552.

Schulze, R. E. 1997. *South African Atlas of Agrohydrology and – Climatology.* Water Research Commission, Pretoria, RSA. Technology Transfer Report TT82/96. pp 276.

Schulze, R. E. 2001. hydrological variables associated with Acocks' Veld Types. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, RSA. Available also from http://www.beeh.unp.ac.za/pike/acru/acru_default.htm.

Schulze, R. E. and George, 1987. A dynamic, process-based user-oriented model of forest effects on water yield. *Hydrological Processes*, 1, 293 – 307.

Schulze, R.E. 1979. Hydrology and Water Resources of the Drakensburg. Natal Town and Regional Planning Commission, Pietermaritzburg, RSA. pp 179.

Smithers, J. C. 1998. *Development and evaluation of techniques for estimating short duration design rainfall in South Africa.* Unpublished PhD. Thesis. School of Bioresources Engineering and Environmental Hydrology, University of Natal, Pietermaritzburg, RSA.

Smithers, J. C. and Schulze, R. E. 1995. Background, concepts and applications of the *ACRU* agrohydrological modelling system. *In:* Smithers, J. C. and Schulze, R. E. *ACRU Agrohydrological Modelling System : User Manual Version 3.00.* Water Research Commission, Pretoria, RSA. Technology Transfers Report TT 70/95. pp AM1-1 to AM1-18

United Nations 1998. The Sixth Session of the UN Commission on Sustainable Development (CSD-6 Decisions), 20 April - 1 May 1998 [Internet]. Available from http://www.iisd.ca/csd/csd6rep.pdf [Accesed 24 February 2002]

Wilson, A. J. 2000. *Thukela Water Management Area: Draft Situational Assessment.* Department of Water Affairs and Forestry, KwaZulu Natal Regional Office, Durban, South Africa. pp 70.

World Health Organisation 2000. Research needs identified during the 5th Global Forum of Water Supply and Sanitation Collaborative Council November 2000 [Internet]. Available from http://www.lboro.ac.uk/departments/cv/wedc/garnet/grtapplied.html. [Accesed 24 February 2002].

Appendix 9.15
Towards the sustainable management of water. The contribution of research in Green Accounting to the construction of a Water poverty Index.

Dr Sandrine Simon, Open University, Milton Keynes, UK

5.1 Introduction

There is no life without water. Water is absolutely central to our survival and to societal and environmental vitality. We are now realising the critical importance of the way in which we manage this resource. Its over-exploitation and its pollution beyond levels of abatement by natural ecosystems threaten the whole hydrological system, and hence the availability of safe water we can consume. The dimensions of the water crisis we are now experiencing are crucially important, and the need to address them only recently realised.

Following the statements and conclusions derived from the 1972 Stockholm conference on the Environment and Development, the 1977 Mar Del Plata Water Conference, the 1992 Dublin Statement, Chapter 18 of Agenda 21 from the Rio conference, the Global Water Partnership and many other international meetings, we are getting progressively ready to broaden water policy to include issues of *water sustainability*, *equity* and *security*. New definitions and concepts are needed to make us understand the dynamic behind water management in a more integrated and holistic way, but also to modify our water policies in such a way that the integrity of water resources and ecosystems and their environmental sustainability is maintained as a prerequisite for the achievement of the sustainability of human societies.

The construction of a Water Poverty Index acknowledges this need for a new approach, and will attempt to respond to it by providing *inter-disciplinary* and *integrated* information on *water and poverty* as well as *water poverty*. However, its *policy impacts* must also be addressed prior to its construction, in order to make sure that it does have a practical impact. This means that the index must contribute to our understanding of the practical implications of sustainability, and help policy makers to produce more sustainable policies for water management. This suggests that the insights derived from research into '*green accounting*' might be a useful contribution to the construction of a Water Poverty Index.

5.2 Representing sustainability. Why and how?

The representation of the concept of sustainability12, launched in the 1980s with the World Conservation Strategy and the final report of the Commission for Environment and Development (1987), is currently perceived as being a crucially important and useful first step in the direction of the *operationalisation* and *implementation* of a more secure future for human development on Earth. While numerous definitions of

12 Costanza et al. (1991:8) have defined sustainability as the 'relationship between human economic systems and larger dynamic, but normally slower changing ecological systems in which 1) human life can continue indefinitely, 2) human individuals can flourish, 3) human cultures can develop, but in which effects of human activities remain within bounds, so as not to destroy the diversity and function of the ecological life-support.

the concept exist, we need to overcome any rhetoric to identify some practical objectives which can be achieved through changes in human behaviour brought about by policy making for sustainable development.

It is important to highlight why it is necessary to *represent* interrelations between ecosystem functioning and economic activities as necessary prerequisites of sustainability. The main reasons why this interaction is important are as follows:

- **policy-makers need to understand better how ecosystems function and how economic activities impact on them.**

- **we need to adopt another approach towards economic policies and acknowledge the fact that our economic systems constitute a sub-system of larger natural environments upon which we depend. This implies a progressive shift in paradigm in economic and management thinking**

- **we need a clear and practical illustration of the meaning of 'sustainability' in terms of the links between economic activities and the environmental stocks and flows of goods and services.**

The representation of these interactions, if it is to respect the principles of sustainability and of the multi-dimensional importance of water, needs to be:

- **holistic and integrated, in order to include ecological, economic and social dimensions of sustainability;**

- **understandable - despite the complexity of the processes involved- hence not solely focused on scientific jargon;**

- **possible to integrate in the policy process and tools.**

Policy-makers are currently finding *indicators of sustainability* and *frameworks of indicators* particularly useful as a first step towards the operationalisation of sustainability. The literature on such indicators is abundant. A number of useful references concerning indicators of sustainability and frameworks of indicators are included in the references to this text.

5.3. Green accounting

Research into what has been called 'green accounting' has become crucially important in the debate on 'indicators of sustainability'. This is because our 'System of National Accounts' (SNA) provides us with *aggregate economic indicators* that policy makers very much rely on. GNP, for instance, is both used to determine the choice between alternative policies (if GNP is likely to increase as a result of the implementation of an option, this option will generally be preferred to others) and used to internationally rank countries depending on their economic performance.

The appropriateness of such indicator concerning the assessment of the sustainability of our policy choices MUST therefore be examined and questioned. Since the national accounting instrument and indicators derived from it are sufficiently powerful to *remain the main policy tools*, they will need to be adjusted to become *appropriate indicators of sustainability*. The objective of such adjustments, dealt with in 'research in green accounting', is that the reformed accounting instrument will help greening our economic policies and hence progressively help manage our societies in a more sustainable way.

Research in Green Accounting started a little more than 25 years ago. The rationale for such research was then focused on the shortcomings of the SNA (System of National Accounts), the problems these shortcoming generated, and the ways to correct them. This research was initiated in the context of an 'indicator crisis' which questioned the validity of the signals on which policy makers rely (in particular, signals such as the aggregate economic indicators generated from the SNA). These criticisms were based on the fact that important considerations, such as environmental degradation, were not correctly taken into account, since they were seen as increasing the value of our 'economic performance' but not denunciated for threatening our future life support base. The shortcomings (Anderson, 1991) of the SNA are listed below:

- The traditional SNA focuses on flows only and ignores stocks, be they environmental or cultural. People interested in environmental issues have realised that stocks have a great importance, and so is the way in which certain ecosystems stocks respond to external shocks.
- Negative externalities, such as environmental pollution or crime, are not taken into account in the assessment of economic performance and progress.
- Distribution and inequality issues are not taken into account in the current SNA either. For instance, the SNA uses average income per head in numerous analysis exercises focused on the performance of the economy.
- The SNA focuses on production processes that generate monetary exchanges solely. Hence, the use of services that do not involve monetary exchange (e.g. use of 'free' air or 'free' house work) are not considered as contributing to economic welfare.

For all of these reasons, it became clear that the current SNA gives the wrong signals and needs reforming. The rationale for Green Accounting therefore focused on the *correction of these shortcomings*, because the current SNA generates and encourages *unsustainable economic development*.

Research in green accounting has gone a long way. Different methods have been developed, and research is still evolving everywhere in the world. Some focus on shortcomings related to ecological considerations, while others on social considerations. Generally, green accounting methodologies have been essentially centring on the issue of valuation, and the main difference in approach has been between the construction of **'satellite accounts'** and that of **'adjusted indicators'** such as adjusted 'green' GNP. Advocates of the construction of a single aggregate feel that correcting the shortcomings of the SNA requires adding of what is missing from the GNP accounts and subtracting what is not supposed to appear. Advocates of the construction of satellite accounts feel that we need better understanding of the functioning of the environment upon which we depend, and they work on the construction of exclusively 'environmental accounts' that can be linked to the SNA in order to examine how economic activities impact on the environment. Satellite accounts are expressed in physical/ biological terms, while green GNP is expressed in monetary terms. There is a huge controversy around monetary valuation methods that allow to carry out the subtractions and additions that the construction of green GNP requires.

UNEP has identified the application of green accounting, adaptable to specific country needs and linked to their System of National Accounts (SNA), as a high priority in the future direction of development aid (UNEP, 1992). As Friend stressed: *'monitoring the state of resources, just after measuring poverty, is the most critical indicator of 'economic health' and (...) developing systems of Environmental Resource Accounting could also show how the overwhelming benefits of conserving natural capital to maintain regenerative capacity of the biosphere would provide the right political climate for the much needed (financial) resource transfer from the rich to the poor nations'* (Friend, in UNEP, 1992:11). Although there are some difficulties in developing environmental types of accounts in developing countries, some green accounting research has been carried out in an increasing number of developing countries. Some examples of this work includes a study on natural resource accounting for Indonesia (WRI, 1989) where physical accounts were compiled for petroleum, timber and soils. In Costa Rica, the Tropical Science Centre, with technical support from the World Resources Institute, compiled physical accounts for soils, fisheries and forests. In Mexico, a pilot case study was sponsored by the World Bank and UNSTAT to link environmental and economic information and investigate whether environmentally adjusted national income aggregates could be derived for that country. Other developing countries have also made a start at developing resource accounts, and these include Uruguay, Thailand, Tanzania, Slovenia, The Philippines, Papua New Guinea, Malaysia, India, El Salvador, Columbia, China, and Angola, and in the case of Brazil, water accounts have been constructed for the purpose of national accounting.

Friend (1993) identified three major obstacles to the development of green accounts in developing countries:

- **lack of political and institutional commitment and funding**
- **reluctance in shifting economic paradigm**
- **technical challenges: need for co-operation between ministries of the environment, development and panning and finance, as well and external financial and technical support.**

5.4. Strategic resources and the development of water accounts.

When reviewing most of the existing satellite accounting systems, one striking characteristic can be noticed immediately: many of these accounts have been constructed because they provide useful information on resources that have been qualified of *'strategic'* because of their economic importance. Thus, the UK Office for National Statistics has built accounts for oil and gas (Vaze, 1996), Canada constructed some physical accounts of sub-oil assets and forests (Born, 1998), Namibia's physical asset accounts provide information on fish stocks (Lange, 1998) and the combined asset accounts for manufactured and natural capital in Botswana have been constructed as a useful method to monitor progress towards diversification in a country highly dependent on mineral resources (Lange and Gaobotse, 1999).

Interestingly, *water* is also being progressively perceived as a 'strategic resource' and *water accounts* have now started being constructed in different countries in the world. Thus, for instance, Vaze and Schweisguth (1998) have recently constructed the UK Water Accounts. These stress the economic importance of water by showing the contribution of water supply and sewage treatment to the GDP and they display data for two in situ users of water, fishing and water transport, which also contribute to GNP. Generally, the UK water accounts describe issues such as water abstraction and emissions of substances into water and they also illustrate which economic actors and activities affect the water environment.

In the Netherlands, de Haan (1997) has recently constructed the NAMWA (National Accounting Matrix including Water Accounts) for the year 1991. It covers water availability, extraction by industries and emissions of nutrients, BOD and heavy metals, as well as information on expenditures related to the management of water. Other countries, such as Canada (Johnson, 1995), France (Babillot, 1995) and Namibia (Glenn-Marie Lange, 1998), have constructed water satellite accounts.

Although these water accounts can help in identifying problems related to the emission of pollutants and related to the general management of water, they do considerably limit our understanding of the real global importance of water. Social or political considerations are not taken into consideration, for instance - although they are very important in the context of water management in developing countries. Beside, the issue of water should not be isolated to issues such as waste management, land use, etc. All these economic and environmental considerations are very closely linked and should be considered as such if the management of our resources is to improve.

5.5 New insights in green accounting

Newer initiatives in green accounting have allowed us to progress in the sense of integration. Meanwhile, the United Nations has been publishing guidelines to construct green accounts and this subject of research is being more and more taken seriously and worked on. There are new important and useful insights in research on green accounting:

- **environmental valuation approaches**: monetary valuation approaches are being reformed and new (less technically or ethically controversial) suggestions are flourishing. Non-monetary valuation methods that now often include the participation of all stakeholders are also now evolving.

- Numerous green accounting approaches (in particular the successful Dutch example of the NAMEA (Keuning and de Haan, 1998) are based on the construction of a ***framework of indicators*** and have proved that policy-makers can still derive useful information when the green accounts expressed in physical terms rather than monetary terms.

- Environmental features (goods and services) were originally introduced in the national accounts framework on the basis that they contribute to production systems and can therefore be considered as 'natural capital' (Harrison, 1990). This notion of natural capital has presented some problems in that a) it assimilated the environment to an 'economic' good, hence ignoring ecological integrity and intrinsic values and b) it has provided us with a very 'static' perception of the environment, instead of encouraging a thorough understanding of the dynamic functioning of ecosystems. The notion of ***'Critical natural capital'*** (Berkes and Folke, 1994; Noel and O'Connor, 1998) pays attention to the functioning of ecosystems and stresses the fact that, for instance, some key buffer species, determine the way in which an ecosystem keeps functioning, or that the pollution of a certain habitat can have repercussions on other habitats and species, etc. The notion of CNC is therefore more focused on processes (be they ecological or economic) and can also greatly contribute to improving the construction of green accounts.

In an attempt to integrate these new insights, some new green accounting approaches have been developed as policy frameworks.

- The Dutch NAMEA provides a good example of a policy relevant framework of interrelated environmental indicators and themes. This framework illustrates the impact of economic activities on the environment and helps identify priorities which will direct policies towards sustainable development.
- The CRITINC accounting framework (Ekins and Simon, 1999; Ekins et al., 2000), partly based on the principles of the NAMEA, introduces further considerations such as social participation in policy making and valuation processes, and since it also attempts to extend the notion of 'natural capital' to that of critical natural capital, which helps understanding natural ecosystems in a much more dynamic and integrated way.

5.6 Conclusion

Different messages derived from this brief presentation on research into green accounting are directly relevant for the construction of a Water Poverty index. Some important points to bear in mind are:

- Any system developed to provide environmental information to policy-makers should be related to the policy-making tools and instruments that are currently in use, and are likely to continue to be in use in the future.
- To answer policy related questions, the tool must be holistic, *integrated, interdisciplinary* and *comparable on an international basis*
- Appropriate data must be collated from both the natural and social sciences, and collected on a regular basis to ensure the continued usefulness of the tool.

Overall, it is clear that the development of appropriate data to create a Water Poverty Index may well be the same data that would be needed to develop water accounts. If water management at a macroeconomic level is to be truly sustainable, it is essential that an appropriate accounting mechanism be put in place, and a monitoring tool such as the WPI could well provide the means to show that the natural and social capital values associated with water is indeed 'non-depleting'. If however, this was found to not be the case, appropriate mitigation strategies could then be introduced, bringing the economy and society back towards a more sustainable path. Such aspirations may seem a distant reality, but when considering the scope of human and technological development over the next 25 years, it is not unrealistic to conceive of a more optimal path for human progress. Already a paradigm shift is being seen in a number of disciplines, and within economics, it is certainly clear that important notions such as the *'nature of economic performance'*, *'economic progress'*, and the relation between our policy indicators and the notion of *welfare*, have been highlighted and debated as a result of the greening-of-the-accounts exercise. The development of a Water Poverty Index is an example of how these philosophical and ethical issues can be realistically addressed within the framework of economic development and environmental policy.

References

Aaheim, A. and K. Nyborg (1993), *'Green National Product: good intentions, poor device?'*, Statistics Norway.

Anderson, V. (1991) *Alternative Economic Indicators*. Routledge, London and New York.

Babillot, P. (1995) *Compte de l'eau sur le bassin de la Haute Loire*. IFEN, Orleans.

Berkes, F. and C. Folke (1994) Investing in natural capital for sustainable use of natural capital in A. Jansson, M. Hammer, C. Folke and R. Costanza (eds) *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*, Island Press, Washington D.C.

Born, A. (1998) 'Measuring Canada's natural wealth: why we need both physical and monetary accounts', in K. Uno and P. Bartelmus (eds), *Environmental Accounting in Theory and Practice*, Dordrecht: Kluwer.

Commission of the European Communities (1996), *Environmental Indicators and Green Accounting*. COM (94) 670 final, Luxembourg: CEC.

De Haan, M. (1997) *Water Accounts in the Dutch NAMEA: a 'NAMWA' for 1991*. Statistics Netherlands. Voorburg, The Netherlands.

Department of the Environment UK (1996) *Indicators of Sustainable Development for the UK*. HMSO, London.

Ekins, P. and Simon, S. (1999) The sustainability gap: a practical indicator of sustainability in the framework of the national accounts, *International Journal of Sustainable Development*, Vol.2 No.1: 24-58.

Ekins, P., Simon, S., Deutsch, L., Folke, C., de Groot, R. (2000) *A Framework for the Practical Application of the Concepts of Critical Natural Capital and Strong Sustainability*. Working Paper 1. CRITINC European project PL9702076, European Commission Environment and Climate RTD Programme.

Friend, A. (1993) Environmental and resource accounting in developing countries, in: Institute for Research on the Environment and the Economy *Ecological Economics: Emergence of a New Development Paradigm*. Ottawa.

Hammond, A., A. Adriaanse, E.Rodenburg, D. Bryant, and R. Woodward (1995), *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*, Baltimore: World Resource Institute.

Harrison, A. (1990) Introducing natural capital into the SNA, in Y. Ahmad et al. (eds) *Environmental Accounting for Sustainable Development*. A UNEP/ World Bank Symposium, Washington D.C.

Jesinghaus, J. (1998), *A European System of Environmental Pressure Indices*, First volume of the Environmental Pressure Indices Handbook: The Indicators. Luxembourg: European Commission.

Johnson, T. (1995) *Water Use in Economic and Domestic Activity*. Environmental perspectives 2 -Studies and Statistics, Statistics Canada, Ottawa.

Keuning, S. and M. de Haan (1998), 'Netherlands: What's in a NAMEA? Recent results', in K. Uno and P. Bartelmus eds), *Environmental Accounting in Theory and Practice*, Dordrecht: Kluwer.

Lange, G. (1998) Building physical accounts for Namibia: depletion of water, minerals and fish stocks and loss of biodiversity, in K. Uno and P. Bartelmus (1998) *Environmental Accounting in Theory and in Practice*. Kluwer, Dordrecht.

Lange, G. and D. Gaobotse (1999) The contribution of minerals to sustainable economic development in Botswana. Draft discussion paper No. 2. Botswana Natural Resource Accounting Programme National Conservation Strategy Co-ordinating Agency and Central Statistics Office: Gaborone, Botswana

Lutz, E. (ed) (1993), *Towards Improved Accounting for the Environment*, Washington DC: World Bank.

Noel, J.F. and O'Connor, M. (1998) Strong Sustainability and Critical Natural Capital in S. Faucheux and M. O'Connor (Eds) *Valuation for Sustainable Development: Methods and Policy Indicators*, Edward Elgar, Cheltenham.

Rennings, K. and H. Wiggering (1997), 'Steps towards indicators of sustainable development: linking economic and ecological concepts', *Ecological Economics* **20**, 25-36.

Sheng, F. (1995) Real Value for Nature. An Overview of Global Efforts to Achieve True Measure of Economic Progress. World Wide Fund for Nature International. Gland Switzerland.

United Nations Environment Programme (1992) *Workshop on ENRA. Summary record*. Environmental Economic Series 3. UNEP, Nairobi.

Uno, K. and P. Bartelmus (Eds) (1998), *Environmental Accounting in Theory and Practice*, Dordrecht: Kluwer,

Vaze, P. (1996), 'Environmental accounts: valuing the depletion of oil and gas reserves', *Economic Trends*

Vaze, P. and D. Scheiwsguth (1998) An illustrative water account for England and Wales, in P.

Vaze (ed.) *UK Environmental Accounts 1998*, London: Office for National Statistics.

World Commission on Environment and Development (1987) *Our Common Future*. Oxford University Press. Oxford.

Appendix 9.16

Poverty and Development: Laying the foundations for the capture of natural capital

Caroline Sullivan, CEH Wallingford

1. Introduction

According to the Brundtland Report, one of the prerequisites of real sustainable development is equity. In particular, this relates not only to equity amongst current resource users now, but also equity in the way resources are used over time. The issue of equity however is fundamental to the process of poverty and its alleviation, as it is certainly true that much poverty exists because of the currently inequitable distribution of resources and access to them.

There can be many approaches to the way we address poverty and inequity. In terms of macroeconomic planning, these may include a number of issues such as improving health and education, putting in infrastructure, and developing the financial services sector to provide access to credit. The development of better access to markets and improved post-harvest processing are other ways by which poor people can have improved returns to their labour, especially in the agricultural sector. It is now recognised that poorer households rely more heavily on natural resources than do those whose livelihoods may be more secure through receipt of wages or remittances (Sullivan, 1999; Redclift, 2000). Enabling these important values to be recognised and captured is therefore an important contribution to the achievement of sustainability.

Poverty is the result of a variety of factors, which can be summarised by the term 'capacity deprivation'. Without the basic domestic water requirement, described by some as 25 litres per capita per day, people are likely to have a reduced capacity to live a strong and healthy life. Without good health, economic efficiency is degraded, further reducing capacity to generate the economic growth and redistribution needed if the welfare of the poor is to rise.

The impact of a lack of water on the condition of poverty is something few would deny, but proving a causal relationship of statistical significance between the two is not an easy task. Lack of adequate and reliable data and a poor understanding of the complexities associated with both water and poverty, have led to an incomplete understanding of how best to manage the resource. To incorporate a rich reflection of the fundamentals of sustainability, it would mean that water would have to be managed to achieve the situation where all people in the world have adequate water to live in a dignified and self-sustaining way.

The achievement of such a goal is well within the current level of global economic development. Even taking a business as usual scenario, the capital investment requirement of meeting basic needs is likely to have a net positive impact on fiscal and monetary indicators, mainly due to increased labour efficiency. Improving the quality of the human and social capitals within communities creates a strong basis for macroeconomic growth, and the cost effectiveness of such a policy implementation is likely to surpass that of most other development strategies. As highlighted in the Hague World Water Forum, the actual amounts of water needed to provide for basic needs is so small that its cost impact in the wider global economy is of only marginal significance. This supports the contention that major developmental goals will be achieved more through awareness raising, capacity building and institutional strengthening.

Taking a longer term view, ensuring ecosystem integrity is the means of ensuring the maintenance of our own life support systems, and it should therefore be given appropriate significance in our strategic and economic planning and monitoring systems. The need to understand more about the complexities of effective resource management requires better, more integrated use to be made of available data, and data to be managed more effectively to take advantage of the full benefits offered by current and future levels of information technology. Ultimately, when ecosystem goods and services can be appropriately identified and accounted for, the costs of their use can be properly integrated into national accounts systems, and treated in the same manner as other income and capital flows. When this can be achieved, appropriate mechanisms can be developed to capture these values and bring about redistributional measures to ensure their efficient and equitable use (Roodman, 1999). In this way, sustainable development comes closer to being a reality.

2. Water and the natural capital services it provides

There is little doubt that the burden of water collection falls disproportionately on women and children. Women provide an important source of labour in subsistence households, and excessive time and effort spent in water collection reduces their potential productive contribution. The negative impacts of inadequate water availability include both the loss of human capital (through morbidity) and natural capital (through pollution from human contaminants). Both provide a constraint to welfare growth, and as a result, good water management has an important role to play in poverty alleviation in developing countries. In addition, improved availability can influence the potential for a household to generate different sources of income. Subsistence incomes which can be increased through better water provision include those from brick making, beer brewing and textile work such as batik and dyeing. In this case, water is used as a factor of production just like any other natural resource, and thus better understanding of how it can be accounted for will promote better long term management.

By widening our understanding of the links between water and ecosystem services, and conveying this information to the public, behaviour more conducive to the achievement of efficient water management may result. Through capacity building at the middle management level, we can empower decision makers to have more confidence in the validity of their decisions, as well as make the process of decision making more transparent. If the national education system can become more involved in water management issues, cross cutting benefits can occur. In every country, the already established education system provides a direct link to households, and by more explicitly including water into the educational agenda, we can not only raise awareness of the issues, but also perhaps develop a means of collecting key components of household information which can be of use for water managers. Furthermore, if this can improve cooperation between the water authorities and the education department, better provision of water in schools may result. If this occurs, increased female enrolment rates may be achieved, as it is often the case that girls prefer to miss school when there is no provision of adequate water and sanitation.

Due to its very site specific nature, water availability in terms of quantity, quality and reliability need to be understood at the local scale. However, such scales are relatively inappropriate for current hydrological techniques, so for the purposes of monitoring changes in water availability, mesoscale assessments are also needed This fits in well with the continued expansion of the application of integrated water resource management (IWRM) techniques in many national water strategies. Finer resolution hydrological data would enable more accurate assessment of local conditions, and perhaps future approaches to this problem may be assisted through the use of remotely sensed data that is currently available at resolutions at appropriate scales.

3. Linking WPI values to the Sustainable Livelihoods Framework

The concept of sustainable livelihoods (Carney, 1998; Scoones, 1998) is fundamental to our understanding of the development process. The WPI components can be related to livelihood entitlements, as a way of understanding more about what is needed to relieve poverty drivers. In any development process, there is clear overlap between some of the capital types, but using this approach provides at least some quantification of these can be achieved. Table 2 shows how the livelihood capital types may hypothetically be related to the WPI components.

Table 2. Linking national WPI components to livelihood capital entitlements

WPI component	Data source	Livelihood component
Resource	Freshwater withdrawals, groundwater, quality and reliability data	Natural capital, water component
Access	Access to domestic water supply and sanitation, access to irrigation	Physical and Social capital
Use	Water withdrawals, total and by sector	Financial and Human capital
Capacity	GDP, child mortality and education	Human capital
Environment	water quality water stress environmental regulation and management informational capacity biodiversity based on threatened species	Natural capital

Clearly there is much overlap between these different capital types, and naturally water provision will influence a number of different issues. Increasing social capital through institution building (e.g .in water authorities, statistical services etc.) will help to improve techniques of demand management, and identify areas for potential water redistribution. Furthermore, integration of relevant key issues into existing statistical processes will facilitate natural resource accounting procedures, and promote more effective long term planning.

There is little doubt that in addition to the basic water resources which are available in any location, effective and equitable water provision will depend on how easy it is to gain access to that water, and how it is distributed for use. The incorporation of our knowledge of these and other important issues into a standardised yet flexible framework enables us to highlight the possibility of achieving a more equitable outcome for millions of poor people. As a result, this in turn may increase the likelihood of influencing political will for change. By increasing social capital through institution building, and increasing financial capital through increased efficiency in the water sector, not only will better water management become more likely, but also better returns on capital investments in the water sector may be achieved.

4. Identifying natural capital

The idea of accounting for natural resource use is becoming more widely accepted, although there is still much resistance to it, especially from some sectors and in some countries. Serious attempts to develop and disseminate the techniques of natural resource accounting have been made since the early 1990s, and the World Bank and other organisations have produced a number of publications on the subject (Lutz, 1993, CEC, 1993, UNSO,1993). In order to effectively consider how such resource accounts can be developed, we need to first consider what exactly we are trying to account for.

5. Natural Capital - assimilation into national accounting strategies.

Capital can be defined broadly as a stock that yields a flow of goods and services into the future. *Natural Capital* can be defined as stocks of energy and resources, and the ecosystem characteristics from which these can derived. In order to incorporate issues such as intergenerational equity, ecological integrity and economic resilience the idea of maintaining a *constant natural capital stock* has become important.

To achieve genuinely sustainable water management, the natural capital values associated with water need to be identified. Attempts to integrate measures of natural capital into national accounting strategies are in the process of being developed in a number of countries, including the UK, the Netherlands and Norway. This is a complex process which involves not only the identification of values of the natural capital and the services generated from it, but the means by which these can be assimilated within the conventional national accounts on which macroeconomic planning is based.

Many of the concepts which have been used to develop natural resource accounts, (and water accounts), have been derived from earlier work on calculations of oil and gas depletion. In order to effectively account for water in national accounts, it is clear that we must consider water quantity and water quality, and as a result, considerable interdisciplinary work will need to be done to bring together the appropriate data for the development of such accounts. Within any long term planning strategy, it is important that these issues be addressed, in order to ensure that the concepts required for the development of natural capital accounts for water can defined on an holistic basis, and standardised to allow effective and reliable international measurements and comparisons.

6. Assessing the natural capital values of water

Water is an essential and irreplaceable resource on which our life support system depends. Its value has long been the subject of philosophical debate which, within the economic discipline, has been described in the 'diamonds and water paradox', which arises due to changes in the levels of marginal utility associated with different levels of consumption. Values in society are based on utility and preferences, and while we may have a low level of marginal utility for extra units of water, we all have high utility for the initial levels of consumption associated with the basic human water requirements. Nevertheless we all agree that the price of water is lower than the price of diamonds. This demonstrates the fact that price, value and cost are not the same thing. This is particularly important when it comes to thinking about water management, and water pricing.

The value of water varies considerably from place to place and also from use to use. For example, for a given quantity of water, the use value from use for navigation may be much less than that from use in a textile plant. For irrigation, the value of the water may be much higher if the crop grown is carrots than if it were wheat. Crop selection has a big impact both on the use value of water, and also on the level of water use itself. Since agricultural water use takes the largest share of water allocation in most economies, the value generated from it needs to be investigated, and methods introduced to regulate its use

One accepted way of valuing water is through an examination of what values other alternative uses could generate. This is known as the opportunity cost value of water, and can be used as way of improving water allocation decisions. Unfortunately this is not straightforward, as it is often the case that such calculations would suggest that the cultivation of higher value (non-food) crops would lead to a reallocation of water for that purpose. If this is taken to the extreme, then water would be allocated in such a way as to act as a disincentive for food production, causing a problem of food security. In some places problems such as this have occurred where cash crops such as cotton have been produced in preference to food crops, and when too many farmers made this choice, food shortages have arisen. Nevertheless, the opportunity cost methodology does give some insight into the value of water. There is still much work to do to refine and perfect techniques of quantifying any kind of natural capital, and to date, no widely accepted method of valuing water and the ecosystem services associated with it currently exists.

7. Integrating natural capital values into the macroeconomic framework

Water, and other natural resources, provide the raw materials on which production depends. It is clear therefore that the value of these materials needs to be counted in our national accounting systems, but this is in fact not always the case. We can illustrate the fact that water is important to economic development if we simply look at the rate of water use and the level of GDP per capita. While this is a superficial examination, it does demonstrate that water has an important value to an economy, and that value needs to be more explicitly appreciated.

Table 1. A comparison of per capita national income and national water use.

	GDP, US$, per capita	Annual Water withdrawals M^3	Annual Water withdrawals M^3	Annual Water withdrawals M^3
	1990	1970-87	1970-87	1970-87
		Domestic	Industrial and agricultural	Total
Tanzania	110	8	28	36
Sri Lanka	470	10	493	503

South Africa	2,530	65	339	404
United Kingdom	16,100	101	406	507
Sweden	23,660	172	307	479
United States	21,790	259	1,903	2,162

Source: World Bank. World Development Report 1992. Development and the Environment, Table 1 and 33.

One of the ways in which this problem can be addressed is through the introduction of a system of assimilating the value of natural resources in to the national accounts system. This is referred to as green accounting

8. Green accounting

Research into what has been called 'green accounting' has become crucially important in the debate on 'indicators of sustainability'. This is because our 'System of National Accounts' (SNA) provides us with *aggregate economic indicators* that form the basis of economic policy. For example, Gross National Product (GNP), has long been used to determine the choice between alternative policies (if a development option will increase GNP it is likely to preferred to others which do not), and used to rank countries internationally depending on their economic performance.

Many years ago, the World Bank and other international organisations were effective in implementing the System of National Accounts (SNA), which effectively standardised national accounting practices. There are however a number of problems with this approach, and one of the main issues of concern today is how the environment and its goods and services can be assimilated into this structure. This became more pressing in the context of an 'indicator crisis' which questioned the validity of the signals on which policy makers relied. These criticisms were based on the fact that important issues such as environmental degradation were not correctly accounted for, since they often resulted from activities which increased the value of our economic performance, yet at the same time, when taken to extremes, effectively threaten our future life support base. The shortcomings of the SNA are listed below (Anderson, 1991):

- The traditional SNA focuses on flows only and ignores stocks, be they economic, environmental or cultural. In the case of environmental capital in particular, stocks have a great importance, and the way in which certain ecosystems stocks respond to external shocks can be crucial and must not be ignored (due to the problem of 'ecological irreversibility').

- Negative externalities, such as environmental pollution or crime, are not taken into account in the assessment of economic performance and progress.

- Distribution and equity issues are not taken into account in the SNA. For instance, the use of average income per head is unsatisfactory as a true representation of how people live in an economy.

- The SNA focuses only on production processes that generate monetary exchanges solely. Hence, the use of services that do not involve monetary exchange (e.g. use of 'free' air or 'free' house work) are not considered as contributing to economic welfare.

For all of these reasons, it became clear that the current SNA gives the wrong signals and needs reforming. The rationale for Green Accounting therefore is focused on correcting these shortcomings, because the current SNA effectively acts as an indicator of unsustainable economic development.

Generally, green accounting methodologies require more effective methods of environmental valuation, and two different approaches have evolved: the construction of **'satellite accounts'** or of **'adjusted indicators'** such as adjusted 'green' GNP. Satellite accounts are expressed in physical/ biological terms, while *green GNP* is expressed in monetary terms. The production of adjusted indicators involves adding what is missing from the GNP accounts and subtracting what is not supposed to appear. There is a huge controversy around monetary valuation methods that facilitate the subtractions and additions that the construction of green GNP requires.

UNEP has identified the application of green accounting, adaptable to specific country needs and linked to their System of National Accounts (SNA), as a high priority in the future direction of development aid (UNEP, 1992). The relationship between poverty and natural resource availability, and the need to monitor this, is highlighted by Friend, who points out: *'monitoring the state of resources, just after measuring poverty, is the most critical indicator of 'economic health' and (...) systems of Environmental Resource Accounting could also show how the overwhelming benefits of conserving natural capital to maintain regenerative capacity of the biosphere would provide the right political climate for the much needed (financial) resource transfer from the rich to the poor nations'* (Friend, in UNEP, 1992:11).

Although most countries have still to develop any kind of environmental accounts, some research into green accounting in developing countries has been carried out in the last decade. These include:

- Indonesia (WRI, 1989) where physical accounts were compiled for petroleum, timber and soils.
- Costa Rica, the Tropical Science Centre, with technical support from the World Resources Institute, compiled physical accounts for soils, fisheries and forests.
- Mexico, where a pilot case study was sponsored by the World Bank and UNSTAT to link environmental and economic information and investigate whether environmentally adjusted national income aggregates could be derived for that country.
- Other developing countries have also made a start at developing resource accounts, and these include Uruguay, Thailand, Tanzania, Slovenia, The Philippines, Papua New Guinea, Malaysia, India, El Salvador, Columbia, China, and Angola, and in the case of Brazil, water accounts have been constructed for the purpose of national accounting.

9. Strategic resources and critical natural capital

Water is increasingly perceived as a 'strategic resource' and *water accounts* have now started being constructed which stress the economic importance of water. Although these water accounts can help in identifying problems related to the emission of pollutants and related to the general management of water, they do considerably limit our understanding of the real global importance of water. Social or political considerations are not taken into consideration, for instance - although they are very important in the context of water management in developing countries. Beside, the issue of water should not be isolated to issues such as waste management, land use, etc. All these economic and environmental considerations are very closely linked and should be considered as such if the management of our resources is to improve. The notion of *'Critical natural capital'* (Berkes and Folke, 1994; Noel and O'Connor, 1998) pays attention to the functioning of ecosystems and stresses the fact that, for instance, some key buffer species, determine the way in which an ecosystem keeps functioning, or that the pollution of a certain habitat can have repercussions on other habitats and species, etc.

Considering issues related to the development of a WPI, it is important to bear in mind that any policy tool being developed must be holistic, *integrated, interdisciplinary* and *comparable on an international basis*. Policy-making tools and instruments that are currently in use, and are likely to continue to be in use in the future must provide the means by which any new tools, such as the WPI, can become implemented in a country. To achieve this, appropriate data must be collated from both the natural and social sciences, and collected on a regular basis to ensure the continued usefulness of the tool.

Overall, it is clear that the development of data to create a Water Poverty Index may well be the same data that would be needed to develop water accounts. If water management at a macroeconomic level is to be truly sustainable, it is essential that an appropriate accounting mechanism be put in place, and a monitoring tool such as the WPI could well provide the means to show that the natural and social capital values associated with water is indeed 'non-depleting'. If however, this was found to not be the case, appropriate mitigation strategies could then be introduced, bringing the economy and society back towards a more sustainable path. Such aspirations may seem a distant reality, but when considering the scope of human and technological development over the next 25 years, it is not unrealistic to conceive of a more optimal path for human progress.

Already a paradigm shift is being seen in a number of disciplines, and within economics, it is certainly clear that important notions such as the *'nature of economic performance'*, *'economic progress'*, and the relation between our policy indicators and the notion of *welfare*, have been highlighted and debated as a result of the greening-of-the-accounts exercise. The development of a Water Poverty Index is an example of how these philosophical and ethical issues can be realistically addressed within the framework of economic development and environmental policy.

10. The need for capacity building

'Capacity building' encompasses the variety of methods that assist local communities to participate in, or even take responsibility for decisions which affect their neighbourhoods (Selman, 1996: 29).

The participation of various stakeholders in policy making and valuation methodologies, in particular, have been very much promoted, such as 'deliberative democracy' (Jacobs, in Foster, 1997) in the area of environmental valuation, and 'multi criteria appraisal' (Stirling, 1997) in the area of policy making. Deliberative democracy, like citizens juries, presents the advantage of animating a debate and hence environmental awareness amongst a community, and constitutes a combination of environmental education and the construction of environmental values that are then communicable to the policy-makers. The Water Poverty Index is an example of how this may be achieved, since, if it were to be implemented, it would not only have use as an immediate policy tool, but also have the more long term use of bringing about the development of more integrated accounts of water and the impacts of its use. In order to make this a real possibility, there is a significant degree of capacity building needed, although in most instances, this is very much a case of building on what already exists. In order to implement the WPI, a small core of trained personnel would be needed to put the framework in place and collate the data from various sources.

11. Conclusion

More effective water management is a major challenge faced by policy makers in the 21st century. There are uncertainties associated with water resource availability due to climate change, as well as demographic and lifestyle changes, which will have a significant impact on water demand. At the same time, many governments are trying to devolve responsibility for water management to more local levels, while skilled and experienced water managers are being attracted to more lucrative posts in the private sector both at home and abroad. This has given rise to the situation where more difficult decisions need to be made, and a more transparent process on which those decisions are to be based needs to be developed.

The maintenance of the long-term viability of our life support system is an essential prerequisite for ensuring the possibility of a sustainable future. Since water plays such a vital role in ecosystem integrity, its management needs to be effective and robust. One way in which this can be achieved is through better monitoring of water resources and their use, and through the integration of natural resource accounting into macroeconomic systems. If this can be brought about, accounts of any changes in natural capital will be incorporated into national accounting systems, enabling the full social costs and benefits of resource use to be identified and evaluated. By developing a more comprehensive dataset on water and its use, the WPI will contribute to the achievement of that more long-term goal.

A typical characteristic of poverty is lack of access to adequate water supplies, yet only small amounts of water are needed to meet basic human needs and to relieve the currently inequitable situation. This highlights the fact therefore that bringing about more effective redistribution of water to reduce poverty is not by any means an impossibility. Taking the water management problem as a whole however, allocations between sectors need to be examined, with the potential goal of highlighting current inefficiencies and inequities in sectoral water use. By highlighting such inefficiencies, attention can be drawn to weaknesses in the existing system, with a view to fine-tuning water management through its more equitable reallocation. By demonstrating the small degree of change needed to achieve real impacts on poverty alleviation, policy makers may be persuaded to adopt the appropriate political will needed to bring about real change.

If water is to be allocated more efficiently to reduce the capacity deprivation which characterises poverty (Sen, 1981;1995;1999), a more comprehensive, interdisciplinary approach to its evaluation is needed. If such an approach can be developed, then not only will water resources be better understood, but it will be possible for policy makers to identify those aspects of the water management problem which need the most attention, and to invest in them more effectively to improve the human condition.

References.

Aaheim, A. and K. Nyborg (1993), *'Green National Product: good intentions, poor device?'*, Statistics Norway,

Anderson, V. (1991) *Alternative Economic Indicators.* Routledge, London and New York.

Berkes, F. and C. Folke (1994) Investing in natural capital for sustainable use of natural capital in A. Jansson, M. Hammer, C. Folke and R. Costanza (eds) *Investing in Natural Capital: The Ecological Economics Approach to Sustainability*, Island Press, Washington D.C.

Carney, D. (ed.) (1998) *Sustainable Rural Livelihoods: What Contribution Can We Make*? DfID, London.

Commission of the European Communities (1996), *Environmental Indicators and Green Accounting.* COM (94) 670 final, Luxembourg: CEC.

Friend, A. (1993) Environmental and resource accounting in developing countries, in: Institute for Research on the Environment and the Economy *Ecological Economics: Emergence of a New Development Paradigm.* Ottawa.

Friend, A. (1993) Environmental and resource accounting in developing countries, in: Institute for Research on the Environment and the Economy *Ecological Economics: Emergence of a New Development Paradigm.* Ottawa.

Hammond, A., A. Adriaanse, E.Rodenburg, D. Bryant, and R. Woodward (1995), *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development.* Baltimore: World Resource Institute.

Harrison, A. (1990) Introducing natural capital into the SNA, in Y. Ahmad et al. (eds) *Environmental Accounting for Sustainable Development.* A UNEP/ World Bank Symposium, Washington D.C.

Jacobs, M. (1997) Deliberative Democracy. in Foster, J. (ed) Valuing Nature. Ethics, Economics and the Environment. Routledge, London.

Johnson, T. (1995) *Water Use in Economic and Domestic Activity.* Environmental perspectives 2 -Studies and Statistics. Statistics Canada, Ottawa.

Lutz, E. (ed) (1993), *Towards Improved Accounting for the Environment*, Washington DC: World Bank.

Noel, J.F. and O'Connor, M. (1998) Strong Sustainability and Critical Natural Capital in S. Faucheux and M. O'Connor (Eds) *Valuation for Sustainable Development: Methods and Policy Indicators*, Edward Elgar, Cheltenham.

Redclift, M. (Ed.) (2000) *Sustainability: Life Chances and Livelihoods*, Routledge, London.

Rennings, K. and H. Wiggering (1997), 'Steps towards indicators of sustainable development: linking economic and ecological concepts', *Ecological Economics* **20**, 25-36.

Roodman, D. (1999) *The Natural Wealth of Nations. Harnessing the Market and the Environment.* Earthscan, London.

Selman, P. (1996) Local Sustainability. Managing and Planning Ecologically Sound Places. Paul Chapman. London.
Sen, A.K. (1995) *Mortality as an indicator of economic success and failure* Discussion paper 66, London School of Economics and Political Science

Sen, A. K. (1999) *Development as Freedom*. Oxford.

Sen. A.K (1981) Poor, Relatively Speaking. *Oxford Economic Papers*, No.35.

Scoones, I. (1998) *Sustainable Rural Livelihoods: A Framework for Analysis*. IDS Working Paper no.72. IDS, Brighton.
Stirling, A. (1997) Multi Criteria Mapping. Mitigating the problem of environmental valuation in Foster, J. (ed) Valuing Nature. Ethics, Economics and the Environment. Routledge, London.

Sullivan, C.A. (1999) *Valuation of Non-timber Forest Products: A case study of three Amerindian Villages in Guyana*. Ph.D. Thesis. Dept. of Economics, Keele University, UK.

United Nations Environment Programme (1992) *Workshop on ENRA. Summary record*. Environmental Economic Series 3. UNEP, Nairobi.

United Nations Statistical Office (1993) Handbook of national Accounting. Integrated Environmental and Economic Accounting. Studies in Methods. Series F, No.61. United Nations Statistical Office, New York.

World Bank (1992) *World Development Report 1992. Development and the Environment*. Washington DC.

World Commission on Environment and Development (1987) *Our Common Future*. Oxford University Press. Oxford.

Appendix 9.17
Towards a Gender and Water Index

Barbara van Koppen
International Water Management Institute

1. Gender in the Water Poverty Index

The Water Poverty Index (Sullivan, 2002a and 2002b) seeks to link two major global challenges that, for too long, were addressed separately. One is the effective and ecologically sustainable management of freshwater resources, which become increasingly scarce as the demands by growing and increasingly wealthier populations augment. The other challenge regards the social uplift of the world's poor, who are still left out, living below minimum standards of wellbeing, especially in rural areas in the South. Water is an important asset in this process.

Gender issues are integrated in the Water Poverty Index in various explicit and implicit ways. Explicitly, gender-disaggregated data were collected in a study into domestic water provision to households without a house connection in South Africa (453 households), Tanzania (377 households), and Sri Lanka (411 households). The results are presented in this paper. Gender issues are also implicitly addressed by examining health and sanitation issues related to domestic water supplies among the poor (*cf* Hunt and Cairncross 2001; Sullivan 2002). Inadequate facilities are widely known to affect poor women even stronger than men. Women are not only primarily responsible for water supply but, as caretakers for children and the sick, women often bear a disproportionate burden of water-related disease. Moreover, better sanitation especially benefits women, who are more disadvantaged in this regard than men (Hannah and Anderson 2001). A better understanding of these and other relationships is of utmost relevance for poor women, who outnumber poor men (UNDP 1995).

The present paper further expands on the gender dimensions of the Water Poverty Index. One area to further add value regards gender issues in productive uses of water, especially irrigation, and in water resources management, such as catchment management. Below, some latest research findings are reported. Another addition is conceptual and methodological. This paper explores a methodology for the development of a specific Gender and Water Index for integrated water resources management. 'Gender' is taken as the very starting point, recognizing that gender and poverty are inter-related but yet *different* social phenomena. Developing a Gender and Water index is analogous to what the Water and Poverty Index developed for poverty.

Gender refers to the social and psychological dimensions of the relationships between men and women, articulating how these relationships are shaped by society and its history, norms, culture, institutions, education and socialisation, economy, laws, and politics. Biological differences between men and women as the two 'sexes' are obvious reality. However, the notion of 'gender' conveys the wide variation throughout history and across the world in which different societies attribute economic, cultural, and socio-political meanings to what is often people's strong identity of 'femininity' or 'masculinity'. Gender clarifies that 'sexe' is no natural destiny but human creation, subject to agency and change (Jackson 1998). Although gender, poverty, and water are intertwined –just like gender and other sets of social relationships are- this paper explores the route of analytical distinction, at least initially, before blending again into hopefully richer insights.

2. Rationale and Method for Gender and Water Index Development

The Gender and Water Index developed below is a decision-support tool that guides policy makers in ensuring greater gender equity in the basins governed, as relevant for integrated water resources management – the focus of our attention here. A Gender and Water Index allows characterizing and comparing basins from a gender perspective and monitoring the same basin over-time, for example to assess impacts of new policies. The policy relevance is the greater, if the indices relate more directly to integrated water resources management and give better direction for feasible and effective intervention to the policy makers, legislators, and implementers from governmental and non-governmental national and international organizations, for which the indices are meant to be a decision-support tool. Indices that aim to capture complex phenomena, as gender relations and other social phenomena typically are, comprise many components or 'attributes'. Attributes can be expressed as indicators and, then, indicators can be aggregated again into indices. Perhaps the clearest way to accommodate a lay audience about the meaning of indicators and indices is to express the indicator, and, after aggregating and weighting, the indices, as scores between 1 and 5. The value of the score would express the degree to which the socio-political goal of the users of the tool is achieved, or not, at a certain moment in time.

For gender relations, conform the Convention of Elimination of All Forms of Discrimination against Women (United Nations 1987) and the Platform for Action, formulated during the Fourth World Conference on Women in Beijing (United Nations 1995), one could come, for example, to the following agreement about the "gender performance of a basin". A basin would perform well from a gender perspective, if:

- both genders have equal access to water and benefit equally,
- both genders bear equal costs for using water,
- both genders participate equally in (paid and unpaid) water management and decision-making.

Such basins would receive a score of 5. The score of basins in which women are virtually completely excluded from benefits from water and decision-making, but still bear high costs, would be 1.

Although a score 5 for any river basin may seem utopian at this time in history, this does not challenge the rationale and method for the development of a Gender and Water Index as such. However, there is an important issue here: water management is only one aspect of the many factors that shape, change, or perpetuate the socio-economic, historical, cultural, and political relations between men and women. Gender equity requires more changes in society than only those depending upon ways of governing water. Nevertheless, the rationale and method for index development as such remain valid if one wants to compare river basins from a gender perspective. However, it warrants a better understanding of the multiple relationships between gender and water. Moreover, action only within a narrow water sector is insufficient to reach a higher gender score. We come back to this.

The modest aim of the present paper is to explore just the very first step of a Gender and Water Index, which is the identification of key attributes to be included in such Index. The attributes are a synthesis of key issues highlighted in global literature and debates on gender and water during the past decades. Each key attributes is researchable either in the conventional way or with a more participatory method. While some data may already be available, the collection of other data may require more or less effort. As for other basin characteristics, data tend to be available at other levels than basins. Regrouping of results according to river basin boundaries is still needed. While the methodological feasibility of measuring the attributes and hence their appropriateness for verifiable indices development need to be kept in mind, the single most important first step is consensus on the attributes. This is the basis for second steps, such as the conceptual development and empirical measurement of indicators of each attribute and their aggregation into one index.

We now come back to the nature of the relationships between gender relations and the natural resource of water. These relationships are more or less evident and strong. In this paper we highlight the more or less proven relationships. Attributes for which the relation with water use and management is clear and direct are called 'Direct Gender and Water Attributes'. Attributes that highlight underlying processes that indirectly, but often forcefully, impinge upon gender dynamics in water use and management are so-called 'Integrated Gender and Water Attributes'. The 'Integrated Gender and Water Attributes' have been identified in research, although hardly any quantification on the relationships has been undertaken as yet. Integrated attributes constitute important conditions or 'prior issues' that influence the more visible, direct relationships. Without addressing those prior issues, water policy makers risk just scratching a surface, without ever reaching even a score 2, or 3, let alone score 5, if we take the above-mentioned example in which score 5 expresses equal access to water, equal benefits and costs, and equal participation in paid and unpaid water management decision-making.

The less visible but yet important attributes are called 'Integrated Attributes', conforming the global recognition that a more comprehensive approach to water management, or Integrated Water Resources Management, is needed (Global Water Partnership 2000). However, up till now, Integrated Water Resources Management (IWRM) was interpreted in a limited way and confined to the physical and hydrological aspects of water management (quantity-quality; surface-groundwater; upstream-downstream; basin-boundaries). As we will show, it is both needed and fruitful to elaborate the concept of IWRM to also address complex relationships between the natural resource water and social relations, such as societies' gender relations and other socio-economic, class, caste, and ethnic relations. Underlying social processes can be better understood if the call for *Integrated* Water Resources Management is better applied to the social dimensions as well.

Basically, a more integrated approach is a matter of common sense. Even daily discussions on gender and water, especially water for productive purposes, quickly reach the point in which gender characteristics *not* obviously related to water seem more important, such as women's limited education or women's limited access to land. Education, land, and other factors emerge spontaneously as *prior* social conditions, or ultimate desired impacts, of effective Integrated Water Resources Management.

A review of literature, including ongoing debates in the global Gender and Water Alliance (Maharaj 2002), resulted in the following list of gender issues that have been identified as relevant, either as Direct or Integrated Gender and Water Attributes. They should, in any case, be included in a Gender and Water Index that assesses the performance of river basins from a gender perspective. All attributes are policy-relevant and can be measured empirically. The development of the method for the latter and its implementation can be taken forward once there is consensus about the list of relevant attributes.

Table 1. Overview of Direct and Integrated Attributes of a Gender and Water Index

DIRECT AND INTEGRATED ATTRIBUTES OF A GENDER AND WATER INDEX	
1. Minimum and Shared Intra-Household Costs for Domestic Water	
Attribute 1- Direct	Minimum Costs for Safe Domestic Water
Attribute 2- Direct	Shared Costs for Safe Domestic Water
Attribute 3 - Direct	Women's Equal Participation in Community Decision-making
2. Equal (Self-) Employment and Other Benefits from Water for Productive Uses	
Attribute 4 - Direct	*Women Farmers' Equal Access to Water for Productive Use*
Attribute 5 – Direct	*Women Farmers' Equal Participation in Water User Associations*
Attribute 6 - Integrated	Equal Access to and Control over Water-dependent Enterprises
Attribute 7- Integrated	Sharing in Water-related Employment and other Benefits
3. Equal Participation in (Unpaid and Paid) Water-related Decision-making	
Attribute 8 - Direct	Women's Equal Participation in Water-related Decision-making
Attribute 9 – Direct/Integ.	Gender-disaggregated Data
Attribute 10 - Integrated	Women's Equal Education and Inclusion in Public Governance

3. Minimizing and Sharing the Intra-Household Costs for Domestic Water

In poor households in which household water connections are still lacking, the task to provide water for household use is often gendered in the sense that men and women have different obligations to contribute to this aspect of family welfare (Van Wijk 2001). Water provision is one of the tasks integrated in the broader societal gender patterns in which unpaid domestic and income-generating tasks are divided. For example, men may be responsible for the digging and upkeep of public village tanks or wells, thus controlling the access to the resource, while women take up most of the laborious task of daily water fetching for their households. Elsewhere, for example in cultures where women's seclusion is strong, male kin may also take up these latter responsibilities, especially when it involves more sophisticated means of transport, like bicycles.

In the context of the Water Poverty Index, detailed comparative empirical research was carried out into prevailing divisions of household water provision tasks in villages in South Africa, Tanzania, and Sri Lanka, the results of which are summarized in Table 1, Table 2, and Table 3. Salient findings are the following.

In all villages in all three countries, women are the water carriers in the large majority of households, varying from 83% to 91%. Men and children are clearly less regular contributors, but the patterns vary considerably. In Tanzania, in 16% of the households only are men also providing water. In South Africa, this is 20%. In Sri Lanka, however, this varies substantively in the four villages studied. In Awarakotuwa, as many as 64% of the households have men who carry water, while this is only 17% in Tharawatta – similar to the African villages.

For children, the pattern is the reverse: African children contribute more often than their fathers to water provision, 37 and 42 % in Tanzania and South Africa respectively. However, in Sri Lanka, children contribute in less than 15% of the households. (In interpreting these data, one should note that the proportion of children of the defined age also differs). These patterns are also reflected in the averages for all households in the respective villages in terms of, first, number of household members by gender and age that regularly carry water and, second, in terms of the number of trips that the respective household members make, on average, and, third, in terms of volume of water contributed.

What is interesting in the African surveys in which this question was particularly asked, is that, if men carry water, they bring larger volumes of water than their female kin per trip. Children, on the other hand, bring less than both adult men and women.

Overall, the labor costs to provide water are huge, especially for women and in the dry season. In South Africa, women spend up to 119 minutes per day for this chore; in Tanzania, it is even as high as 416 minutes in the dry season. In Sri Lanka, the time inputs even for a normal day are high, varying from 97 to 221 minutes. Yet, the volumes of water available per person per day in all sample villages are still below or even way below the quantities recommended by the WHO of 50 liters per person per day. For South Africa the volume is even as low as 18 liters.

Table 1. Water provision by gender in South Africa (Ethembeni, Latha, and Wembezi) for households without connection*

Sample demographics			
number of households	453		
number of persons in sample	4346		
percentage adults	61		
percentage children	39		
Water provision			
wet season; time per trip (min)	35		
dry season: time per trip (min)	35		
households with women water carriers (no., %)	413 (91%)		
households with men water carriers (no., %)	90 (20%)		
households with children water carriers (no., %)	167 (37%)		
	women	**men**	**children**
average volume per trip (ltrs)	22	32	14
average number of persons per trip per day			
first trip	1.6	0.3	0.6
second trip	1.2	0.2	0.3
third trip	0.7	0.1	0.2
average number of trips per person per day	3.4	0.5	1.1
wet season average time per person per day (min)	118	19	37
dry season average time per person per day (min)	119	19	37
average volume provided per person per day (ltrs)	84	14	16
	average household		
total volume available per household per day (litrs)	115		
total volume available per person per day (ltrs)	18		

* 159 households have a household water connection, mainly in Wembezi

Table 2. Water provision by gender in Tanzania (Nkoaranga, Samaria, Majengo, Kijenge) for households without connection*

Sample demographics			
number of households	377		
number of persons in sample	2592		
percentage adults	52		
percentage children	48		
Water provision			
wet season; time per trip (min)	142		
dry season; time per trip (min)	164		
households with women water carriers (no., %)	312 (83%)		
households with men water carriers (no., %)	59 (16%)		
households with children water carriers (no., %)	158 (42%)		
	women	**men**	**children**
average volume per trip (ltrs)	45	66	39
average number of persons per trip per day			
first trip	1.1	0.2	0.4
second trip	0.8	0.1	0.2
third trip	0.6	0.1	0.4
average number of trips per person per day	2.5	0.3	0.9
wet season average time per person per day (min)	360	45	135
dry season average time per person per day (min)	416	52	156
average volume per person per day (ltrs)	85	14	28
	average household		
average volume available per household per day (ltrs)	127		
average volume available per person per day (ltrs)+A18	28		

*104 households have a household water connection

Table 3. Water provision by gender in Sri Lanka (Agarauda, Awarakotuwa, Tharawatta, Tissawa) in 411 households without connection

	Village			
Sample demographics	Agarauda	Awara-kotuwa	Thara-watta	Tissawa
number of households	65	120	83	143
number of persons	282	500	346	579
percentage of male adults	36	34	37	40
percentage of female adults	35	36	34	40
percentage of male children <14	13	14	13	11
percentage of female children <14	16	16	16	9
Water provision				
wet season; time per trip (min)	15	23	47	13
dry season: time per trip (min)	18	71	92	24
households with women water carriers (no., %)	57 (88%)	107(89%)	74 (89%)	120(84%)
households with men water carriers (no., %)	29 (45%)	77 (64%)	14 (17%)	79 (55%)
households with children water carriers (no., %)	10 (15%)	8 (7%)	6 (7%)	20 (14%)
average number of household members regularly providing water				
women	1	0.9	1.1	1
men	0.5	0.6	0.2	0.6
children	0.1	0.1	0.1	0.1
average volume per trip (ltrs)	25	24	26	25
average number of trips per normal day	7.3	6.4	4.7	7.5
average volume available per household per day (ltrs)	185	153	121	186
average volume available per person per day (ltrs)	43	37	29	46
total time per household per normal day (min)	105	147	221	97

The empirical findings of this research underline the need to include the following attributes in a Gender and Water Index.

Attribute 1- Direct: Minimum Costs for Safe Domestic Water
Consensus is broad that the extent to which especially poor women but also poor men are *liberated* from the former labor or excessive cash burdens, is a major manifestation of 'good gender performance' in a river basin. Obviously, better water supply is especially important for the poor whose access to facilities is weakest. Moreover, for them, cash costs, both absolutely and relatively as a proportion of the income, are often exorbitantly high. New facilities should be affordable for them. The latter goal incited, for example, the government of South Africa to provide the first 6000 liters per household per month for free, through cross-subsidization by higher-volume users who pay higher tariffs, and through state support. Domestic water supply projects by national and international governments and NGOs can significantly change and improve women's and men's wellbeing and gender relations.

Attribute 2- Direct: Shared Costs for Safe Domestic Water
Gender equity in the division of the remaining cash and labor obligations within households is another direct gender attribute, embedded in the social patterns in which men and women divide their contributions to household welfare. Empirical insight in

this issue is still limited. An anecdotic example in Niger tells that women continued taking the lion share of the new obligations after installation of a borehole, even when this required cash investments. In other situations where taps were newly installed, as in Mashabela, South Africa, the relative easiness of the new water points stimulated men to also fetch water, unlike before. However, most men did not change their overall contributions to the household expenditures in order to pay these new costs (Van Koppen and Makola forthcoming). Where house connections are full-fledged, gendered labor input for water provision has become irrelevant. The issue of the way in which men and women contribute to the cash costs is again a matter of intra-household patterns of obligations for expenditures for household welfare.

Attribute 3 - Direct: Women's Equal Participation in Community-level Decision-making

A third gender attribute in domestic water supply is community-level decision-making and the access to possibly new paid employment opportunities. Community decision-making in projects includes the site selection, technology choice, training and capacity building, membership rights and obligations, composition of the committee including the leadership positions, paid positions of operators and mechanics, etc. This attribute, in which agencies themselves play the major role, has been well studied. There is strong evidence in the water sector that women's inclusion in community-level decision-making on domestic water supply on the same footing as men's considerably enhances the efficiency and chances for sustainable adoption of the new facilities (*cf* Van Wijk-Sijbesma 2001; UNDP/SEED 2000).

4. Ensuring Equal (Self-) Employment and Other Benefits from Water for Productive Uses

Water is a also crucial input into income-generating activities, especially in rural areas. Self-employment for incomes in kind and cash in rural households in the form of gardening, cropping, livestock, fisheries, forestry, small industries, etc. critically depend upon water and, hence, the technologies to better manage water, mitigate periods of drought and protect against adversities like soil erosion, flooding, and increasingly pollution. As direct water users in such self-employment, both men and women require, in the first place, access to appropriate land and water management technologies to improve their access to water for the divers water-related enterprises. Second, once the physically available water resources are being committed and competition for the scarce resources increases, water allocations to female water users need to be as well protected, if not expanded, as water allocations to male water users.

Attribute 4 - Direct: Women Farmers' Equal Access to Water for Productive Purposes
Attribute 5 – Direct: Women Farmers' Equal Participation in Water User Associations
Direct Gender Attributes have been extensively documented for the case of irrigation. They follow from the need of women farm decision-makers to obtain access to water, on the same footing as men farm decision-makers, to improve the producitivy of their water-dependent enterprises. Worldwide, numerous cases have been documented in which women farm decision-makers were bluntly excluded in the construction of new irrigation schemes (Hangar and Morris 1973; Dey 1980; Zwarteveen 1994; Van Koppen 1998; Merrey and Baviskar 1998). Women farmers who, before the project, had strong local rights to land in the new command area or women who were well included in local arrangements to obtain water rights through participation in

construction works (Prins 1996), were simply expropriated, often from one day to the other, because of projects that were heavily biased in favor of men. This had negative impacts on the production in the new schemes, as women withdrew labor or even completely abandoned these sites by lack of own benefits (Jones 1986; Carney 1988).

These project failures raised awareness and sensitivity among irrigation professionals. Various more recent irrigation projects pioneered into including both men and women farm decision-makers from the design phase of the project onwards. They consequently achieved better productivity and equity. These projects proved to be more successful, in terms of canal maintenance, cost-recovery, and dynamism of Water Users Associations and their committees (Hulsebosch and Ombarra 1995; Arroyo and Boelens 1997; Van Koppen et al. 2001). So both for the purpose of gender equity and sustainable productivity, women farm decision-makers should be equipped with the same technical means to access water and be equally included in Water Users Associations as men, both as members and leaders.

In the above, we focused on the access to irrigation technologies and institutions for women *farm decision-makers*. Depending upon the local situation, which highly varies over the globe, a considerable proportion of farm decision-makers can be women. This is the case, for example, in areas with high male out-migration like in parts of Eastern and Southern Africa (Safiliou 1994; Van Koppen et al. 2000), but also in Latin America and Asia; or for specific agro-ecological environments like wetlands in West Africa (Richards 1986); or for homestead cultivation worldwide. Such farming systems with about equal or even more than, say, a two-third majority of women are called respectively 'dual' and 'female farming systems' (Safiliou 1988; Van Koppen 2002). The gender attributes discussed concern especially female or dual farming systems.

Male farming systems are defined as farming systems in which the majority of farm decision-makers, say more than two-third, are male. Male farming systems are found in areas in countries like India and Nepal, although, often unexpectedly, there may also be exceptions (Zwarteveen 1996). In areas with such male-dominated agrarian structure, women in most farm households are merely unpaid farm laborers, whose contributions are confined to the laborious, unskilled tasks. Irrigation is rarely a task for which women are primarily responsible. Core tasks like irrigation, which highly influence the success of the enterprise and often require specific skills, monetary investments, and contacts with outsiders, are monopolized by men as a gender. When the income status allows, female kin is replaced by male or female wage laborers.

The minority of women farm decision-makers in such male farming systems not only faces prejudices from the intervening agencies, as the case mentioned above, but also from gender-biased local arrangements. As a corollary, agencies seeking more gender-inclusiveness for this minority of women farm decision-makers have to challenge local norms and practices. Agencies are bound to counter male resistance in male farming systems, while in the dual and female farming systems mentioned above, agencies' just have to go with the rather equitable local gender relations, rather than introducing new gender exclusion (Van Koppen 2002).

Attribute 6 - Integrated: Women's Equal Access to and Control over Water-dependent Enterprises

In male farming systems, the majority of women face primarily the 'prior' gender issue that they lack control over own economic enterprises and their outputs. The fact that water is one input in comprehensive production systems makes water a special resource. Once women (or any other social category) are excluded from opportunities to manage own enterprises, it implies that it is rather meaningless to improve their access to just one input, water. Instead, the first issue is to get access to the range of factors needed for their own enterprise, such as access to land, other technologies, skills, and markets, *together* with access to water. Access to land, the key resource in agrarian societies, is probably the most important factor (Agarwal 1994).

The need for a broader, holistic perspective on economic opportunities rather than just one input in an enterprise, water, is not limited to the collective irrigation schemes and Water Users Associations. The same principle holds true for other water-related technologies for cropping, such as individual small-scale land and water management technologies, like treadle pumps, bucket drip irrigation, water harvesting, soil conservation, etc. Moreover, the same principles hold true for other water-dependent enterprises than cropping. Women's own access to and control over water-dependent enterprises is an Integrated Gender and Water Attribute[13].

Attribute 7- Integrated: Sharing in Water-related Employment and other Benefits

In the above, we discussed role of water in raising the productivity and profitability in self-employment for women and men as *direct* water users. There are other ways in which women and men can benefit from water. First and foremost, they can find wage employment in water-related enterprises, in a sense, as *indirect* water users. Wage employment is generated in farming, cattle rearing, fishing, forestry, mines, tourism business, etc. Second, women and men can benefit from hydro-power, navigation, and other functions of water in society.

The number and the types of jobs created for women compared to men in water-dependent enterprises is an important Integrated Gender and Water Attribute. For example, a basin in which a large proportion of water is used to create massive employment for poor women would have a Gender and Water Index with a higher score than a basin in which much water is used for tourism that generates benefits only for a small international tourist company and a handful of foreign tourists. 'Jobs per drop for (poor) women and men' is an Integrated Gender and Water Attribute that may influence allocation decisions regarding sectors that give most equitable employment. However, it also refers to realms beyond water management: gender-segregated job markets.

---

13 For the specific case of collective irrigation schemes, the International Water Management Institute developed a Gender Performance Indicator for Irrigation that captures the above-mentioned dynamics in further detail. It is based on nine comparative case studies in Asia and Africa. The Gender Performance Indicator for Irrigation is a generic decision-support tool for policy makers, interventionists, and researchers that accommodates huge variation in the gendered organization of farming worldwide. It gives the methodology to assess whether a farming system is a male, dual, or female farming system, and whether gender-based inclusion or exclusion from irrigation institutions takes place at farm, forum, and leadership level. This allows identifying realistic and effective action for gender-inclusive irrigation intervention or, as local reality requires, intervention for women's broader economic empowerment (Van Koppen 2002).

More research needs to be done on measuring 'jobs per drop' as an alternative for economic benefit calculation, expressed as just one overall figure of monetary profits made, ignoring the distribution of water-related wealth between men and women (or poor and non-poor, or any other categories of all citizens).

5. Equal Participation in (Unpaid and Paid) Decision-making

A last set of Gender and Water Attributes with both direct and integrated dimensions has received relatively ample attention: women's and men's equal participation in decision-making bodies on water issues. Above, we already mentioned the usually voluntary community-level drinking water committees and Water Users Associations for irrigation. Decision-making also encompasses other government and non-governmental organizations, both volunteers and professionals, non-profit and commercial. With a growing call for public participation in integrated water resources management from local to basin level, new networks and institutions are being created. Education, training, and research institutes are other bodies involved in decision-making, perhaps more indirectly. With increasing activities of commercial companies in the water sector, gender staffing becomes an important issue there as well. In all these organizations the issue of gender equitable participation arises.

Attribute 8 - Direct: Women's Equal Participation in (Paid and Unpaid) Water-related Decision-making
World-wide, considerable gender gaps have been observed in the composition of decision-making bodies in sector-based water management and integrated water resources management, although gaps are somewhat closing (Athukorala and Tortajada 1998; Schreiner 2001). Direct Gender and Water Attributes for equity in decision-making could encompass characteristics such as:

- the proportion of women in formal or informal institutions at the various levels of decision-making (members, management/leadership, technical staff)
- salary scales for equal work
- access to conventional and modem information channels and quality of information provision to men and women
- intensity of participation in decision-making which can range from just being listened to, to the ultimate decision-making powers.

These attributes would also encompass policies, laws, and other actions for change, and their enforcement, including:

- gender machineries for planning and enforcement at highest decision-making levels
- gender-specific and affirmative recruitment policies, such as quota systems
- capacity building and gender-awareness raising for women and men; networking and organization, exchange visits
- monitoring, evaluation, and other means for enforcement of gender-sensitive measures
- performance evaluation/rewarding of both men and women functionaries for the degree in which they perform their jobs or functions in a gender-sensitive way.
- NGOs for advocacy; movements and campaigns

Attribute 9 – Direct and Integrated: Gender-disaggregated Data
The availability of gender-disaggregated data is a crucial condition for any gender-equitable decision-making. It is also a performance indicator for research institutions and universities, whose primary task is to generate high-quality data. This is valid for general and water-specific data.

Attribute 10 - Integrated: Women's Equal Education and Inclusion in Public Governance
The following phenomena are essential conditions for equal participation in water-related decision-making (and often society's distribution of paid and unpaid tasks as well). They include attributes such as:
- Literacy, Languages, and School Enrolment, which are important for economic opportunity-creation, but also for leadership positions in governing bodies
- Mobility, Transport, and Communication Financial and cultural constraints negatively affect women's relative mobility and access to means of communication (telephone, email), which is often required to participate in decision-making
- Participation in Politics, Administration, Networks, etc. Decision-making in the water sector is embedded in international, national and local political bodies and government administration, so women's exclusion from these bodies is inevitably reproduced in the water sector. As a corollary, more gender-balance in general public governance spheres can support and cross-fertilize initiatives in the water sector. Especially NGOs are interesting in this regard. Women are well organized in, for example, NGOs in India (e.g. Self Employed Women) or Bangladesh (Grameen Bank, BRAC, Proshika). Such NGOs can be highly instrumental in the implementation of the attributes discussed: minimizing and equal sharing of domestic labor for water supply; ensuring equal employment and other benefits from productive water use; and in equitable decision-making in water-related decision-making forums

6. Conclusion

The totality of above-identified attributes for a Gender and Water Index would help assessing how well a river basin 'performs' from a gender perspective, and where further feasible policy and intervention is needed, in order to ensure that both genders have equal access to water and benefit equally; bear equal costs for using water; and participate equally in (paid and unpaid) water management and decision-making.

It is clear that direct attributes alone are insufficient to reach such broader goals. The integrated attributes identified, for which the relation between gender and water use and management is less visible but plausible, are also important. Yet, for a range of attributes that are manifestations of gender relations per se and that figure high on the world's gender agendas, it is yet to be clarified how they relate to the ecologically sustainable management of freshwater resources. Examples of such gender attributes are reproductive rights issues and fertility and women's and men's health and life expectancy (besides those health aspects related to drinking water, hygiene, and sanitation), dependency ratios for women and men providers, male-female ratios, gendered infanticide, violence against women, women's higher vulnerability for HIV/AIDS, etc. Intuitively, one would expect that such gender characteristics are also important underlying conditions for river basins to obtain a score 5. However, such relationships have not been explored as yet (except for health impacts of drinking water and hygiene, as at least partially addressed in the Water Poverty Index).

In sum, therefore, if 'gender' is taken as starting point of index development, it not only corroborates the importance of attributes addressed in the empirical research of the Water Poverty Index in South Africa, Tanzania, and Sri Lanka. There is added value in at least three respects. First, this approach underlines the need to address a wider range of direct attributes, including those regarding productive water use and participation in decision-making in general. That implies fostering:

- Minimum costs for safe domestic water
- Shared costs for safe domestic water
- Women's participation in community decision-making
- *Women farmers' access to water for productive purposes at farm level*
- *Women farmers' participation in Water User Associations*
- Women's participation in water-related decision-making
- Gender-disaggregated data

Second, it highlights where a narrow focus on water alone would be misleading and where an integrated approach is needed if water policy makers want to be effective and realistic. This implies fostering:

- Women's Access to and Control over Water-dependent Enterprises
- Sharing in Water-related Employment and other Benefits
- Women's education and inclusion in public governance

Last but not least, starting with gender stimulates further analysis of the complex relationships between water and gender, even if a gender-equitable river basin, or society in general, remains utopia for the near future.

References

Agarwal, Bina. 1994. *A field of one's own. Gender and land rights in South Asia.* South Asian Studies 58. Cambridge, Great Britain: University Press

Arroyo, Aline, and Rutgerd Boelens. 1997. Mujer campesina e intervencion en el riego Andino. Sistemas de riego y relaciones de género, caso Licto, Ecuador. Quito: Servicio Holandés de Cooperación al Desarrollo (SNV), Central Ecuatoriana de Servicios Agrícolas (CESA) and Sistema de Capacitación en el Manejo de los Recursos Naturales Renovables (CAMAREN)

Athukorala, Kusum, Cecilia Tortajada, and others. 1998. Contributions of Women in the field of water management. Workshop 8. Proceedings Eight Stockholm Water Symposium. 10-13 August 1998. SIWI Report 3. Stockholm: Stockholm International Water Institute

Carney, Judith. 1988. Struggles over land and crops in an irrigated rice scheme: the Gambia. In: Jean Davison (eds). *Agriculture, women and land. The African experience.* pp 59 - 78. Boulder, Colorado: Westview Press
CEH Wallingford. 2001. Derivation and Testing of the Water Poverty Index Phase 1. Contribution to the Interim Meeting. Wallingford: DFID and CEH

Dey, Jennie. 1980. Women and rice in the Gambia: the impact of irrigated rice development projects on the farming system. Ph.D. thesis, University of Reading

Hanger, Jane, and Jon Morris. 1973. Women and the household economy. In: Chambers, Robert, and Jon Moris (eds). *Mwea: an irrigated rice settlement in Kenya.* Munchen: Weltforum Verlag

Hannan, Carolyn and Ingvar Andersson. 2001. Gender perspectives on water supply and sanitation: Towards a sustainable livelihoods and ecosystem-based approach to sanitation. Summary version of a paper prepared for the 97[th] Annual Meeting of the Association of American Geographers, February 27-March 3, 2001, New York.

Hulsebosch, Joitske, and Doris Ombara. 1995. Towards gender balance in irrigation management: experiences in Kenya South-west Kano Project. Irrigation and Drainage systems. 9. pp 1-14. Kluwer Academic Publishers Netherlands

Jackson, Cecile. 1998. Gender, Irrigation, and Environment: Arguing for Agency. In: Merrey, Douglas J., and Shirish Baviskar (eds). 1998. Gender analysis and reform of irrigation management: concepts, cases and gaps in knowledge. Proceedings of the Workshop on Gender and Water. September 1997. Colombo, Sri Lanka: International Water Management Institute

Jones, Christine W.. 1986. Intra-household bargaining in response to the introduction of new crops: a case study from North Cameroon. In: Moock, J.L. (ed). *Understanding Africa's rural households and farming systems.* Boulder, Colorado, USA: Westview Press

Maharaj, Niala. 2002. Email conference 'Gender Mainstreaming in Integrated Water Resources Management.' WATER@NIC.SURFNET.NL and Moderator.water@iiav.nl

Merrey, Douglas J., and Shirish Baviskar (eds). 1998. Gender analysis and reform of irrigation management: concepts, cases and gaps in knowledge. Proceedings of the Workshop on Gender and Water. September 1997. Colombo, Sri Lanka: International Water Management Institute

Prins, Djura. 1996. La dinámica de los derechos de agua en el contexto de la intervención 'el Proyecto Múltiple Laka Laka' en Bolivia. Un estudio sensitivo hacia el papel de la mujer en la intervención. MSc thesis. Department of Irrigation and Soil and Water Conservation, Wageningen Agricultural University

Richards, Paul. 1986. *Coping with hunger.* London: Allen and Unwin

Safiliou, Constantina. 1988. Farming systems and gender issues: implications for agricultural training and projects. Unpublished paper. Ministry of Agriculture and Fisheries of the Netherlands and the International Agricultural Centre. Wageningen

Safiliou, Constantina. 1994. Agricultural policies and women producers. In: Adepoju, Aderanti and Christine Oppong (eds). *Gender, work and population in Sub-Saharan Africa. International Labor Organization.* London: James Currey and Heinemann

Schreiner, Barbara. Water, gender, and poverty. Keynote address: Plenary session IV: Integrating gender perspectives: Realising new options for improved water management. Chief Director, Water Use and Conservation, Department of Water Affairs and Forestry, South Africa. International Conference on Freshwater, Bonn 6 December 2001

Sullivan, C. A (ed.). (2001a) *The Development of a Water Poverty Index: A Feasibility Study*. The Centre for Ecology and Hydrology (Wallingford)

Sullivan, C.A. (2001b) The potential for calculating a meaningful water poverty index. *Water International* Dec. 2001.

United Nations 1987. Convention of the Elimination of all forms of Discrimination against Women. New York: United Nations Department of Public Information

United Nations. 1995. The Beijing declaration and Platform for Action. Beijing: Fourth World Conference on Women, 4-15 September 1995. New York: United Nations Department of Public Information

United Nations Development Programme (UNDP) and SEED. 2000. Toolkit Gender and Integrated water resources management. Working Draft

Van Koppen, Barbara. 1998. *More jobs per drop: targeting irrigation to poor women and men*. Ph.D. Thesis Wageningen Agricultural University. Amsterdam: Royal Tropical Institute

Van Koppen, Barbara, Carien Joubert and Lizinda Grobbelaar. 2000. Gender and irrigation in the Tongwane Basin, South Africa. South Africa Working Paper. Unpublished Report. Colombo: International Water Management Institute

Van Koppen, Barbara, Rashmi K. Nagar, and Shilpa Vasavada. 2001a. Gender and Irrigation in India. The women's irrigation group of Jambar, South Gujarat. IWMI Working Paper 10

Van Koppen, Barbara. 2001b. Gender in integrated water management: an analysis of variation. Natural Resources Forum 25 (2001) 299-312. United Nations. United Kingdom: Elsevier Science Ltd.

Van Koppen, Barbara. 2002. A Gender Performance Indicator for Irrigation: concepts, tools, and applications. Research Report 59. Colombo: International Water Management Institute

Van Koppen, Barbara, and Nong Makola. Forthcoming. Local water tenure in Mashabela, South Africa. IWMI Working Paper

Van Wijk-Sijbesma. 2000. The best of two worlds? Methodology for participatory assessment of community water services. IRC Technical Paper Series 38. Delft, Netherlands: IRC International Water and Sanitation Center

Zwarteveen, Margreet Z. 1994. Gender issues, water issues: a gender perspective to irrigation management. Working Paper 32. Colombo: International Water Management Institute

Zwarteveen M., and N. Neupane. 1996. Free riders or victims: women's nonparticipation in irrigation management in Nepal's Chhattis Mauja Scheme. IIMI Research Report 7. International Irrigation Management Institute. Colombo, Sri Lanka: International Irrigation Management Institute

Appendix 9.18
Water and Poverty -an Econometric Approach

Ian Walker[14], Anna Maria Giacomello[15], Caroline Sullivan and Ian Walker[16]

1.1 Introduction

In our work on the development and testing of the Water Poverty Index, we felt that it was worthwhile to try to investigate the relationship between water and poverty using the more formal approaches of economic analysis, based on econometrics techniques. Econometrics can possibly help us to identify variables, which are most significant when determining the links between water and poverty. This could make the refinement of any survey questions for example, more carefully targeted towards the very specific bits of details, which may be having the greatest effect. More importantly, an econometric methodology allows us to *quantify* the *size* of the relationship between the consequences of water poverty and the factors that *cause* it.

To date we have only been able to make a preliminary investigation of this work, and we have made a start by looking at the WPI data from the point of view of how specific variables may influence specific outcomes.

The findings we have achieved so far are tentatively presented here, with the clear statement that this is very much work in progress and which needs to be taken much further before results can be taken to be definitive. For this reason, we present this material here in note format, in order to ensure that the reader bears in mind the exploratory nature of this part of the work.

Due to the nature of the problem, there are a number of alternative approaches that could be used to produce an index of how "water-poor" households are.

Motivation

We care about "water poverty" because low volume/quality and/or high price of water are associated with diseases and other bad *outcomes* for households. Some of these outcomes have externalities associated with them – such as the spread of disease. Moreover water supplies may be subject to high fixed costs and low marginal costs. Finally, water supplies may be difficult to establish *property* rights over.

For all of these reasons water may have, at least in part, the characteristics of a *public good* and hence we might expect water supplies to be "under-provided" by the workings of the market mechanism Thus, there are good reasons to believe that the *efficient* provision of water requires some form of government intervention.

14 Department of Economics, University of Warwick
15 Centre for Ecology & Hydrology, Wallingford
16 Centre for Ecology & Hydrology, Wallingford

Data

The aim is to relate measures of water quantity, quality, availability and reliability to household outcomes – disease etc and to relevant household characteristics (such as number of adults and children)

2.1 Desirable properties of a WPI

This WP index should be "aggregable" so we can move from a household index to to assess the degree to which an "area" is water poor. The index should tell us what to do to improve WP. Thus, if X_1 or X_2 are the factors that determine our measure of WP then we would like to know whether it would be best to improve X_1 or X_2? Should we improve WP in some areas and not others? The index should tell us when to stop improving it. That is, at what point does it cease to be sensible to stop reducing WP?

Methodology

The methodology is to quantify the outcome(s), Y, and relate it (them) to water measures and household characteristics, X. Then define the household specific degree of water poverty (WP) as, say, some "distance" measure (how poor), or an "indicator" measure (poor or not) of Y relative to some chosen (and maybe, arbitrary) benchmark for the outcome(s), $\bar{Y}$.

A simple example of this approach

Suppose there is some outcome measure Y and some observable X's. We estimate $Y_h = X_h\beta + e_h$ where e_h captures the unobservable determinants of Y for household h. Save the estimated $\hat{\beta}$'s.

Then define $\bar{Y}$ as the "threshold" level for Y so we can then define the set of combinations of X_1 and X_2 that yield a level of $Y = \bar{Y}$. Thence the "poor" are those households that are predicted to have a $\hat{Y}_h > \bar{Y}$

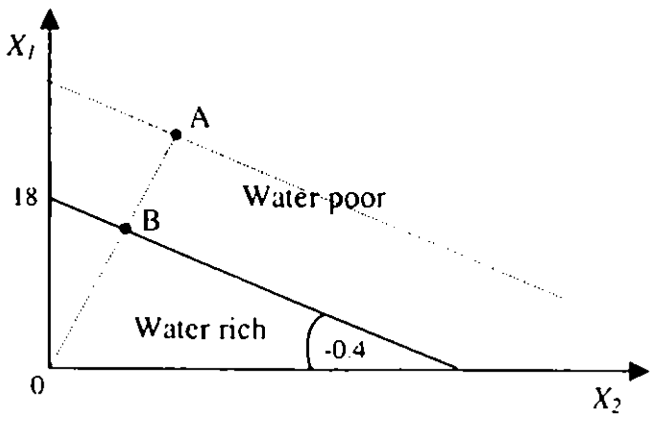
We can extend this idea so that the "depth of poverty" of a water poor households is the extent to which X_h (the factors that determine the outcome Y) needs to be reduced to achieve $\bar{Y}$.

A 2 - X, 1 - Y example

Suppose there are two factors that affects one outcome and we have estimated the relationship between them as

$$\hat{Y} = 10 + 5X_1 + 2X_2$$

Suppose we fix a poverty threshold as the level of outcome $\bar{Y} = 100$. Then $Y_h > 100$ if $X_{1h} > 18 - 0.4X_{2h}$. That is the diagonal line in the figure below defines the combinations of the X determinants that would just put a household in water poverty. Thus, household A is "poor" and its *depth of poverty* is 0A/0B.



3. Applying an ordered-probit model to the analysis of household welfare-water relationships.

3.1 Analysis of the Impact of Water Supply on Household Welfare

This section explores how water supply impacts on factors that are associated with household welfare or well-being. In particular, since we are concerned with policy towards water supply, we look at how the distance from the household to the water supply used (in both wet and dry seasons), the nature of ownership of the water supply used, and the quality of water supply used affect the incidence of diarrhoea and the time spent collecting water by the household.

Diarrhoea is an important problem 67% of households report "many" incidences16.

Table 1. Investigating what factors influence diarrhoea

How many times had diarrhoea?	Code	**Frequency**	**Percent**	**Cumulative**
Many times	3	1016	67.46	67.46
Occasionally	2	350	23.24	90.70
Never	1	140	9.30	100.0
Total		1506	100	

The relationship between this and the distance to water supply is important for planning the development of water availability. Below we estimate the relationship between the "probabilities of never/occasional/many diarrhoea" occurring using an "ordered probit" model.

MODEL 1 - Investigating the importance of distance from water source

This model is deliberately parsimonious to illustrate the ideas. The data used in the estimation are: the dependent variable is *Diarrhoea* data (3 = many times; 2 = occasionally; 1 = never) while the explanatory variables *are Distance from source in the Dry season, Distance from source in the Wet season, Number of children in the household*, and *Number of adults in the household.* The ordered probit estimates are:

Number of observations	1076
LR chi2(4)	25.36
Prob > chi2	0.0000
Log likelihood	-779.70738

16 It must be noted here that there are many difficulties in collecting health data, and the responses elicited by the questions used in the survey may be only a rough representation of the actual situation, but the object of using this data was to contribute to the process of testing the WPI methodologies on a level playing field (ie the WPI dataset). The reliability of this model should be verified using other more comprehensive datasets such as those provided by the WHO/UNICEF Joint Monitoring Programme. This could be incorporated into any work on the 2nd Phase of the WPI.

Pseudo R2 0.0160

Diarrhoea	Coef.	Std Err.	t	P>|z|	[95% Conf. Interval]
Distance dry	0043576	.0012881	3.38	0.001	.0018329 0068822
Distance wet	-.003921	.0014206	-2.76	0.006	-.0067052 -.0011367
Children	.0370508	.0166288	2.23	0.026	.004459 .0696426
Adults	.037013	.0170144	2.18	0.030	.0036653 0703606
_cut1	878732	.0789132		(Ancillary parameters)	
_cut2	1.811466	.0929859			

It seems that diarrhoea incidence is increasing with distance in the dry season (positive (coefficient of 0.0044) and statistically significant effect (its t value exceeds 2)) and negatively correlated to distance to water supply in the wet season (again statistically significant). This model controls for the number of adults and children - naturally we find that more people in the household is associated with more diarrhoea.

MODEL 2 - Refining the model for site specificity

The simple model above is very parsimonious. We might expect that people who live in the same village to be more similar than people in different villages – for example they experience the same weather. The results below add "village fixed effects" to control for any local effects that might be common to all households within each village. There are significant differences across villages - but the effects of distance remain significant.

Data used in the iterations are:

- Diarrhoea data (3 = many times; 2 = occasionally; 1 = never)
- Distance from source in the Dry season
- Distance from source in the Wet season
- Number of children in the household
- Number of adults in the household
- Dummy variables for each village:
  - village_12: it is 1 for KwaLatha and 0 for all the others villages;
  - village_13: it is 1 for Wembezi (informal) and 0 for all the others villages;
  - village_14: it is 1 for Wembezi (formal) and 0 for all the others villages;
  - village_21: it is 1 for Nkoaranga and 0 for all the others villages;
  - village_22: it is 1 for Samaria and 0 for all the others villages;
  - village_23: it is 1 for Kijenge and 0 for all the others villages;
  - village_31: it is 1 for Agarauda and 0 for all the others villages;
  - village_32: it is 1 for Avarakotuwa and 0 for all the others villages;

- village_33: it is 1 for Tharawaththa and 0 for all the others villages; and
- village_34: it is 1 for Tissawa and 0 for all the others villages.

The four Sri Lanka villages have been dropped due to collinearity. The ordered probit estimates are:

Number of observations	1076
LR chi2(11)	193.10
Prob > chi2	0.0000
Log likelihood	-695.84057
Pseudo R2	0.1218

Diarrhoea	Coef	Std. Err.	Z	P>|z|	[95% Conf. Interval]
Distance dry	.0049327	.0014186	3.48	0.001	.0021523 .0077131
Distance wet	-.0043009	.0014699	-2.93	0.003	-.0071819 -.0014199
Children	.0072095	.0175926	0.41	0.682	-.0272714 .0416904
Adults	.0184343	.0189898	0.97	0.332	-.018785 .0556535
Ivillage_12	.1179608	.1524627	0.77	0.439	-.1808606 .4167821
Ivillage_13	-1.251955	.1679063	-7.46	0.000	-1.581045 -.9228644
Ivillage_14	-1.219918	.1863104	-6.55	0.000	-1.585079 -.8547562
Ivillage_21	-.4576756	.1681073	-2.72	0.006	-.7871599 -.1281913
Ivillage_22	-.8175853	.2093206	-3.91	0.000	-1.227846 -.4073245
Ivillage_23	.0530689	.159247	0.33	0.739	-.2590496 .3651874
Ivillage_24	-.9685858	.189375	-5.11	0.000	-1.339754 -.5974176
_cut1	.1968619	.1577331			(Ancillary parameters)
_cut2	1.265174	.1630923			

As in the previous model *distance* to water supply in the *dry* season is positively correlated with *diarrhoea* incidence and it is statistically significant; also *distance* to water supply in the *wet* season is still statistically significant and the correlation with diarrhoea is negative. In addition to the previous model a dummy variable was included to represent the specific characteristics of each village. As it possible to observe (in the table above) most of the dummy variables used to represent villages are statistically significant; this indicates that there are local factors that might be common to all households within each village that are different across the villages and that can help to explain the diarrhoea incidence.

4. Econometric Complications

Use actual or predicted *Y*?

Depends on how you interpret e_{h}. These errors may indicate random measurement error (which should be set to zero to compute poverty) or may be permanent unobservable factors (which should be included in computing poverty). Ideally panel data would allow us to discriminate between the two.

Functional form

Y may not be *linear* in the *X* variables. One might use non-parametric methods to explore this.

Causality

Some of the *X*'s may be correlated with the *e*'s. So correlation between *Y* and one (or more) of the *X*'s may be *spurious*. That is, when you change the *X* you will find that *Y* does NOT change (in the way suggested by the estimated equation). This is an important issue and motivates some experimental design to evaluating the effects of water supplies on the outcome.

Y may be discrete rather than continuous

For example *Y* = 0,1 (corresponding to, say, bad or OK). In which case we could define a "latent" variable *Y** such that

$$Y = \begin{cases} 1 \text{ if } Y^* > 0 \\ 0 \text{ otherwise} \end{cases}$$

Or *Y* may be constrained (to be non-negative, say)
–e.g.

$$Y = \begin{cases} Y^* \text{ if } Y^* > 0 \\ 0 \text{ otherwise} \end{cases}$$

Y may be a "count" (say, 0,1,2,3,4..) or "ordered" (say, poor, OK, good) or unordered (red, blue, green)

In these cases appropriate estimation techniques have to be used.

5. Theoretical Complications

The conditions under which one might aggregate across housholds with a single Y are limited. A number of measures do satisfy the aggregation conditions. For example
***H* "headcount"**

This is the proportion with - $\hat{Y} > \bar{Y}$ This measure is bounded but has the undesirable feature that it assumes shallow poverty is equally as bad as deep poverty. Moreover, it ignores those just above the poverty line

***P* "Poverty gap"**

$$\sum \min(0, Y_h - \bar{Y})/H$$

This relates to average depth of poverty . The measure is unbounded. It ignores those above poverty line and produces an index that "weights" deep poverty more than shallow poverty.

A wide variety of other measures could be used.

Cost benefit analysis with single *Y*

It would be useful to be able to define objective function in money terms so we can address questions such as
- What is a unit reduction in Y worth?
- Value of life (i.e. risk of death)?
- Based on Marginal Benefit (MB)

Need to calculate marginal costs of reducing *Y* in each area

Bear in mind that cost of reducing X_1 may be different than cost of reducing X_2. Carry on reducing X's until they equate all Marginal Costs (MCs) of all X's in all areas with MB.

Multiple *Y's*

The objective function might be efined in terms of multiple indicators. We need to "weight" these together. Weights chosen by "social planner". Sensitivity testing should then be carried out.

Constrained budgets

Need to equalise MC's – to each other but not to MB

Summary

This summary gives the reader an idea of what has been considered here. It is premature to represent any conclusions. Our preliminary work has demonstrated that an econometric approach has the benefits that it can indicate which factors are significant in determining water povery. To date however we have not had the opportunity to take this work further, and we would suggest that this be included in the next phase of the project.

References

Deprivation indices

B Nolan and C Whelan *Deprivation and Poverty (in Ireland)*. Clarendon Press, 1997.

(Income) Poverty measures

G Lewis and D Ulph, *Poverty, inequality and welfare.* **Economic Journal** (1987)
P Lambert, **The Distribution and Redistribution of Income**, CUP 1989.

Estimating "efficiency" measures

S Grosskopf et al, *Budget constrained frontier measures of fiscal efficiency in schooling*, **Rev of Econ & Stats** (1997).

Value of life

K. Viscusi, *The value of risks to life and health*, **JEconLit** (1993)

References (Appendix 9.8)

[i] Adugna, A, Dery M, Gomme J et al. Looking back: the long-term impacts of water supply and sanitation projects. London: WaterAid, 2001.
[ii] Ghersi E & Naupari H. Dirty water: cholera in Peru. In. Mooney L & Bate R (ed.s) Third World Problems – First World Preoccupations. Oxford; Butterworth Heinnman, 1999.

[iii] White GF, Bradley DJ and White AU. Drawers of water. Chicago: University of Chicago Press. 1972.

[iv] Feachem R, McGarry M & Mara D. Water, Wastes and Health in Hot Climates (ed.s). Chichester; John Wiley. 1977

[v] Kolsky-PJ. Diarrhoeal disease: current concepts and future challenges. Water, sanitation and diarrhoea: the limits of understanding. Transactions of the Royal Society of Tropical Medicine and Hygiene. 1993 Dec; 87 Supplement 3: 43-6

[vi] Murray CJL & Lopez AD (ed.s) The Global Burden of Disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Harvard University Press, Cambridge MA 1996

[vii] Feachem R, McGarry M & Mara D. Water, Wastes and Health in Hot Climates (ed.s). Chichester; John Wiley. 1977.

[viii] Bern C et al. The magnitude of the global problem of diarrhoeal disease: a ten-year update. Bulletin of WHO. 1992;70(6)

[ix] Murray C & Lopez A. Global mortality, disability, and the contribution of risk factors: Global burden of disease study. The Lancet 1997;349:1436-42.

[x] Ad Hoc Committee on Health Research. WHO 1996.

[xi] Cairncross S. Health aspects of water and sanitation. Waterlines. 1988;7(1):2-5.

[xii] Cairncross S, Kinnear J. Elasticity of demand for water in Khartoum, Sudan. Social Science and Medicine. 1992 Jan;34(2):183-9.

[xiii] Saywell D, Hunt C. Sanitation Programmes Revisited. WELL Report number 161. WEDC and LSHTM. 1999.

[xiv] Hanchett S. Draft WELL reports (tasks 483 and 534) 2001.

[xv] Ford T. Microbiological safety of drinking water: United States and global perspectives. Environmental Health Perspectives. 1999;107(1):191-206.

[xvi] Middleton JD, Saunders P, Corson J. Water disconnection and disease. Lancet 1994 Jul 2;344(8914):62.)

[xvii] Kirchhoff LV, McClelland KE, Do Carmo Pinho M, Araujo JG, De Sousa MA, Guerrant RL.Feasibility and efficacy of in-home water chlorination in rural North-eastern Brazil. J Hyg (Lond). 1985 Apr;94(2):173-80.

[xviii] Quick RE, Venczel LV, Mintz ED, Soleto L, Aparicio J, Gironaz M, Hutwagnar L, Greene K, Bopp C, Maloney K, Chavez D, Sobsey M, Tauxe RV. Diarrhoea prevention in Bolivia through point of use water treatment and safe storage: a promising new strategy. Epidemiol Infect. 1999;122:83-90.

[xix] Deb et al. Studies on interventions to prevent el tor cholera transmission in urban slums. Bulletin of the World Health Organisation. 1986; 64(1):127-131.

[xx] Jonnalagadda and Bhat. Parasitic contamination of stored water used for drinking/cooking in Hyderbad. South-East Asian Journal of Tropical Medicine and Public Health, 1995;26 (4):789-794.

[xxi] Mintz et al. Safe water treatment and storage in the home. A practical new strategy to prevent waterborne disease. JAMA, 1995;273(12): 948-53.

[xxii] Jagals P, Grabow WOK, Williams E. The effects of supplied water quality on human health in an urban development with limited basic subsistence facilities. Water South Africa. 1997;23(4):373-378.

[xxiii] VanDerslice J, Briscoe J. All coliforms are not created equal: a comparison of the effects of water source and in-house water contamination on infantile diarrhoeal disease. Water resources research. 1993;29(7):1983-1993.

[xxiv] VanDerslice J, Briscoe J. All coliforms are not created equal: a comparison of the effects of water source and in-house water contamination on infantile diarrhoeal disease. Water resources research 1993;29(7):1983-1993.

[xxv] Mintz et al, 1995. Safe water treatment and storage in the home. A practical new strategy to prevent waterborne disease JAMA, 273(12); 948-53

[xxvi] Mintz et al, 1995. Safe water treatment and storage in the home. A practical new strategy to prevent waterborne disease. JAMA, 273(12); 948-53.

[xxvii] VanDerslice J, Briscoe J. All coliforms are not created equal: a comparison of the effects of water source and in-house water contamination on infantile diarrhoeal disease. Water resources research. 1993,29(7):1983-1993.

[xxviii] Esrey SA, Feacham RG, Hughes JM. Interventions for the control of diarrhoeal diseases among young children : improving water supplies and excreta disposal facilities. Bulletin of the World Health Organization. 1985,63(4):757-772.

[xxix] Ewald PW. The evolution of virulence and emerging diseases. J Urban Health 1998 Sep;75(3):480-91

[xxx] Feachem R. Bacterial standards for drinking water quality in developing countries. Lancet 1980 Aug 2;2(8188):255-6.

[xxxi] Cave B & Kolsky P. Groundwater, latrines and health. WELL study no. 163. WEDC & LSHTM. 1999

xxvii Esrey SA. Water, waste, and well-being: a multicountry study. American Journal of Epidemiology. 1996;143(6):608 622

xxviii Blum D, Feacham RG. Measuring the impact of water supply and sanitation investments on diarrhoeal diseases: problems of methodology. International Journal of Epidemiology. 1983; 12(3):357-365

xxix Baqui AH, Black RE, Yunus M, Hoque AR, Chowdhury HR, Sack RB. Methodological issues in diarrhoeal diseases epidemiology: definition of diarrhoeal episodes. International Journal of Epidemiology. 1991 Dec;20(4):1057-63.

xxx Briscoe J. Intervention studies and the definition of dominant transmission routes. American Journal of Epidemiology. 1984;120:449-455

xxxi WHO / Unicef Global Water Supply and Sanitation Assessment 2000. WHO / Unicef; Geneva 2000.

xxxii Hunt, C & Lewin S. Exploring decision-making for environmental health services: perspectives from four cities. Reviews on Environmental Health 2000, Vol.15, No.1-2, 187:206

References (Appendix 9.7)

xxxviii Elias Salemeh, 2000. Redefining the Water Poverty Index, *Water International, Vol. 25(3) Sep*
xxxix Feitelson, E. 1999. "Is the Commodification of Water Commensurate with Sustainability Notions". Paper presented at the Conference on Sustainability, Risk and Nature: The Political Ecology of Water in Advanced Societies, Oxford University, 15-17 April 1999
xl Measurement and Estimation, http://www.worldbank.org/research/peg/wps19/index5.htm
l Gender in PRSPs: A Stocktaking, *World Bank Poverty Reduction and Economic Management Network Gender and Development Group, Aug 2001*
xli Interim Poverty Reduction Strategy Papers: Guidance on I-PRSPs and Joint Staff Assessment of I-PSRS, Sep. 2000
xlii Deaton, Angus S, 1987, "The allocation of goods within the household: Adults, Children and Gender", mimeo. Princeton University, NJ.
Sudhir Anand and Amartya K Sen, 1994, Human Development Index. Methodology and Measurement, *UNDP Occasional Paper*
xliii Gender Analysis as a method for gender-based Social Analysis,
http://www.worldbank.org/gender/assessment/gamethods.htm
xliii Sullivan, C A. (2000) *The Water Poverty Index.* Keynote presentation at the CSC/Brace Centre conference on Water and Poverty, Montreal, June 2000.
l Taylor VA (1999). A quick guide to gender mainstreaming in development planning. Gender Management Series, Commonwealth Secretariat, London

Appendix 10
References

1993. Global Health Watch – Monitoring Impacts of Environmental Change. *Lancet*. NR 27, BP 1464, EP 1469, PG 6, VL 342.

Acreman, M.C. (1998) Principles of water management for people and the environment. In: de Shirbinin, A. & Dompka, V., *Water and Population Dynamics*. American Association for the Advancement of Science.

Ahmad, A.A. (1989): "Jordan environmental profile: status and abatement". *"State-of-the-Environment Reports"*. Amman, USAID.

Alcamo J., Döll P., Kaspar F. and S. Siebert (1997). Global change and global scenarios of water use and availability: An application of WaterGAP1.0. Centre for Environmental Systems Research, University of Kassel, Germany.

Allan, J.A. and M. Karshenas. (1995) *Managing Environmental Capital: The case of water in Israel, Jordan, the West Bank and Gaza, 1947 –1995*. Proceedings of the International Conference on water in the Jordan catchment countries. School of Oriental & African Studies, University of London.

Allan, J.A., 2001, *The Middle East water question: hydro-politics and the global economy*, London: I. B. Tauris.

Anderson, V. (1991): *Alternative Economic Indicators*. Routledge, London and New York.

Annual County Statistics & World Health Report Selected Indicators (2000). Grenada.

Arnell, N.W. and King R. (1998). Implications of climate change for global water resources. Report to Department of the Environment, Transport and the Regions by Department of Geography, University of Southampton, UK.

Baqui, A.H., Black, R.E., Yunus, M., Hoque, A.R., Chowdhury, H.R. & Sack, R.B. (1991) Methodological issues in diarrhoeal diseases epidemiology: definition of diarrhoeal episodes. *International Journal of Epidemiology*, **20**(4), 1057-63.

Batchelor, C., Rama Mohan Rao, M.S. and A.J. James (2000) *Karnataka Watershed Development Project Water Resources Audit*. Kawad Report 17, Bangalore, India.

Beckerman, W. (1995) *Small is stupid: Blowing the whistle on the Greens*. Duckworth, London.

Bell, S. and Morse, S. (1999) Sustainability Indicators: Measuring the Immeasureable. Earthscan, London.

Biswas, A.K. (1989) *Sustainable Water Development and Management. A Synthesis.* United Nations Environment Programme. Vol. 35, 1639-1655.

Biswas, A.K. (ed.) (1994) *International Waters of the Middle East: From Euphrates-Tigris to Nile.* OUP, Bombay, India.

Brouwer, F. and Falkenmark, M. (1989) Climate-induced water availability changes in Europe. *Environmental monitoring and assessment.* 13 (1), 75-98

Cairncross, S. & Kinnear, J. (1992) Elasticity of demand for water in Khartoum, Sudan. *Social Science and Medicine,* **34**(2), 183-9.

Cairncross, S. (1988) Health aspects of water and sanitation. *Waterlines* **7**(1), 2-5.

Canadian Council on Social Development 2001. Defining and Re-Defining Poverty: A CCSD Perspective.

Carmichael, J. J. and Strzepek, K. M. (2000): A Multiple-Organic pollutant simulation/optimization model of industrial and municipal wastewater loading to a riverine. *Water Resources Research.* BP 1325, EP 1332, PG 8, VL 36.

Carney, D. (ed.) (1998) *Sustainable Rural Livelihoods: What Contribution Can We Make?* DFID, London.

CEH (Wallingford), 2001 '*Developing a Water Poverty Index.*' Poster.

CEH (Wallingford) & The GeoData Institute & University of Southampton, 2001. *Water Poverty Index Conceptualisation Meeting – Arusha, Tanzania. Background Reading Documents.*

CEH (Wallingford), 2001. *Derivation and Testing of the water Poverty Index Phase 1.* (Interim Report). CEH Wallingford, Natural Environment Research Council.

Chambers, R. (1995) *Poverty and Livelihoods: whose reality counts?* IDS Discussion Paper 347. IDS, Brighton.

Chattergee, A. Abrams, L. Cleick, P. and Lane, J. (1999) *Vision 21* Water Supply and Sanitation Collaborative Council.

Coad, P. and Yourdon, E. (1990) *Object Orientated Analysis.* Prentice Hall, London.

Commission of the European Communities (1996). *Environmental Indicators and Green Accounting*. COM (94) 670 final. Luxembourg: CEC.

Committee for Development Planning (1989) *Elements of an International Development Strategy for the 1990s*. United Nations. New York.

Committee for Development Planning (1999) *Annual Report*. United Nations. New York.

Committee for Development Planning (2000) *Annual Report*. United Nations. New York.
Conducting Multiple Indicator Cluster Surveys (MICS) (1995) A Summary of the main points contained in the UN publication: 'Monitoring Progress Toward the Goals of the World Summit for Children. A Practical Handbook for Multiple Indicator Surveys

Cordonnier, J., Madiec, H., Ziegler, O., Soukatchoff, P. & Leroy, P. (2000): Diagnosis of old cast iron network and protection of the internal walls with water treatment. *Techniques Sciences Methods. Genie Urbain-Genie Rural*. No 11, pp 42-47.

Cosgrove, W.J. and Rijsberman, F.R. (2000) *World Water Vision: Making Water Everybody's Business*. World Water Council

Costanza, R., Cumberland, J., Daly, H., Goodland, R. and R. Norgaard. (1997) *An Introduction to Ecological Economics*. CRC Press, Boca Raton.

Court, J.H.O. & Allan, J.A. (1995). *Water in the Jordan Catchment Countries: A Critical Evaluation of the Role of Water and Environment in Evolving Relations in the Region*. SOAS Water Issues Group, SOAS Centres of Middle Eastern and African Studies and the Department of Geography.

Cunningham, W.P. (1994) *Understanding Our Environment: An Introduction*. WCB. USA

Curtis, V. (1986) *Women And The Transport Of Water*. Intermediate Technology Publications, London.

Daly, H (1999) *Ecological Economics and the Ecology of Economics*. Edward Elgar. Cheltenham.

Deaton, A. (1999) *The Analysis Of Household Surveys: A Microeconomic Approach To Development Policy*. World Bank, Washington DC.

Desai, M. (1995) *Poverty, Famine and Economic Development*. Edward Elgar, Aldershot.

Degreene .K. B (1994): *The Rocky Path to Complex-Systems Indicators*. Technological Forecasting and Social Change, Vol 47(2), Oct. 1994.

Department of the Environment UK (1996) *Indicators of Sustainable Development for the UK*. HMSO, London.

Desai. M. (1995): *Poverty, Famine and Economic Development*. Edward Elgar. Aldershot.

DFID & Centre for Ecology and Hydrology. (Natural Environment Research Council)

DFID (2000) *Target Strategy Paper: Water Resources and Sanitation* London

Dickenson, G. and K. Murphy (1998) *Ecosystems*. Routledge. London.

Edgeworth, F.Y. (1925) The Plurality of Index Numbers *The Economic Journal* 35:139:379-388

Elbers .E. Lanjouw .J.O. Lanjouw .P (2000): *Welfare in Villages and Towns*. Tinbergen Institute Discussion Paper, TI 2000-029/2.

Engelman. E. and P. LeRoy (1993): "*Sustaining water. Population and the future of renewable water supplies*". Washington, Population Action International.

Falkenmark. M. (1989): New attitudes needed to support semi-arid development. *Water International*. Vol. 14, No 3, pp 148-150

Falkenmark, M. (1989): The massive water scarcity now threatening Africa – why isn't it being addressed? *Ambio*. Vol. 18, No 2, pp 112-118

Falkenmark. M. (1990): "Rapid population growth and water scarcity: the predicament of tomorrow's Africa", in: "*Resources, environment and population*". (K. Davis and M.S. Bernstam, eds.). pp. 81-94. Supplement to "*Population and Development Review*". Vol. 16.

Falkenmark. M. (1995): Further momentum to water issues: comprehensive water problem assessment in the being. *Ambio*. Vol 24, No 6, pp 380-382

Falkenmark. M. (1997): Preparing for the future: Water for a growing population. *Water Supply*, Vol 15, No 4, pp 139-146

Falkenmark. M. (1998): Dilemma when entering 21st Century—rapid change but lack of sense of urgency. *Water Policy*. Vol 1, No 4, pp 421-436

Falkenmark, M. (1998): Water scarcity generates concern for future food prospects. *Stockholm water front*. No ½. 9

Falkenmark. M. (1999): Forward to the future conceptual framework for water dependence. *Ambio Stockholm*. Vol 28, No. 4, pp 356-361

Falkenmark, M. 1(991): The Ven Te Chow memorial lecture: environment and development urgent need for a water perspective. *Water International*. Vol. 16, No 4, pp 229-240

Falkenmark, M. and G. Lindh, (1974) *Impact of Water Resources on Population* Swedish contribution to the UN World Population Conference, Bucharest.

Falkenmark, M. and Lundqvist, J. (1992): Coping with multi-cause environmental challenges – a water perspective on development. *International conference on water and the environment: Development issues for the 21St Century*. pp 8, 1-8, 22.

Falkenmark, M. and Lundqvist, J. (1998): Towards water security: political determination and human adaptation crucial. *Water Resources Journal*. No 198, pp 12-28

Falkenmark, M. and R. A. Suprapto (1992) Population-landscape interactions in development: a water perspective to environmental sustainability. *Ambio*. Vol 21, No 1, pp 31-36

Falkenmark, M. and Rockstrom, J. (1993): Curbing rural exodus from tropical drylands. *Ambio*. Vol. 22, No 7, pp 427-437

Falkenmark, M. and Suprapto, R. A. (1992): Population-landscape interactions in development: a water perspective to environmental sustainability. *Ambio*. Vol 21, No 1, pp 31-36

Falkenmark, M. Lundqvist, J. and Widstrand, C. (1990): Coping with water scarcity: implications of biomass strategy for communities and policies. *International Journal of Water Resources development*. Vol. 6, No 1, pp 29-43

Falkenmark, M., da Cunha, L. Foerstal, H. and Mageed, Y. (1991): IWRA statement on water, environment and development. *Water International*. Vol. 16, No 4, pp 243-246

FAO (1995) *Country tables. Basic data on the agricultural sector*. Rome.

FAO (1996) *Control of water pollution from agriculture* FAO irrigation and drainage paper 55, Rome.

FAO (2001) *Crops and Drops: making the best use of water for agriculture*. Rome.

Feachem, R. (1980) Bacterial standards for drinking water quality in developing countries. *The Lancet*, 2(8188), 255-6.

Feachem, R., McGarry, M. & Mara D. (eds) (1977). *Water, wastes and health in hot climates*. Chichester. John Wiley & Sons.

Fisher, I. (1922) The Making of Index Numbers. *Journal of the American Statistical*

Association.

Fitzgerald, T. (). *'Poverty: Its Definition and Measurement'* Sociology Online – Social Theory.

Fonkem .R.N (1999): *In Cameroon, a Female-Centred Organisation Works to Conquer the Poverty of Rural Women.* United Nations Chronicle. Vol. XXXVI, No.1,1999. (http://www.un.org/Pubs/chronicle/1999/issue1/0799p70.htm)

Friend, A.M. (1993) Feasibility of environmental and resource accounting in developing countries. *Environmental Accounting: A Review of the Current Debate.* UNEP. Environmental Economics Series no.8. Nairobi. Kenya.

Garcia, L. A. Strzepek, K. M. and Podmore, T. H. (1994): Design of Agricultural drainage with adaptive irrigation management. *Journal of Irrigation and drainage engineering-ASCE.* BP 179, EP 194, PG 16, VL 120.

Gauthier, T., Bayle, J. and Leroy, P. (1980): Fluidization phenomena and technologies. *Oil & gas science and technology-revue De L Instiut Francais Du Petrole.* NR 31, BP 187, EP 207, PG 21, VL 55.

GEO-2000: Water, Water, Everywhere.

Gibson, C.C., Ostrom, E. and Ahn, T.K. (2000) The concept of scale and the human dimensions of global change: a survey. *Ecological Economics*, 32:2, 217-240

Gillis, M., Perkins, D., Roemer, M. and Snodgrass, D. (1987) *Economics of Development* (2nd edn.). Norton, New York.

Gleick, P. (1993) *Water in Crisis: A guide to the world's fresh water resources.* Oxford University Press, UK.

Gleick, P. (1997) Water 2050: *Moving Toward a Sustainable Vision for the Earth's Fresh Water.* Working Paper for the Pacific Institute for Studies in Development, Environment and Security, Oakland, California.

Gleick, P. (1997). Damping Down the Water Wars. *Water Bulletin.* No 759, pp 8-9.

Gleick, P. (2000) *The World's Water 2000-2001.* Island Press, London.

Gleick, P. H. (1993): *Water in Crisis: a guide to the world's fresh water resources.* New York. Pacific Institute for studies in development environment and security.

Godet, J. L., Leroy, P. 1998. Materials used in public water supply networks: their influence on the quality of water. *Techniques Sciences Methods. Genie Urbain-Genie.* Vol 93, No 2, pp 22-29.

Godet. J. L.. Rigal. S.. Leroy, P. (1994): Effects of materials in contact with drinking water intended for human consumption: influence of European standardization and prior research on national and European regulatory controls. *Techniques Sciences Methods. Genie Urbain-Genie*. Vol. 89. No 10. pp 557-561.

Godet. J-L.. Leroy. P. (1999): Sanitary Conformity of the Materials Used in Public Water Distribution Systems. *Techniques Sciences Methods. Genie Urbain-Genie*. No 12, pp 25-32.

Gordon .D. Spicker .P (eds) (1999): *The International Poverty Glossary*. Zed Books. London.

Gurnell. A.M and Montgomery. D.R. (eds.) (1999) *Hydrological Applications of GIS*. Wiley. London.

Gustavson .K.R, Lonergan .S.C, Ruitenbeek .H.J (1999): *Selection and Modelling of Sustainable Development Indicators: a Case Study of the Fraser River Basin, British Columbia*. Ecological Economics, Vol.28(1). Jan 1999.

Guyana. Mali, Nepal. Senegal, South Africa. Sri Lanka. Tanzania. 2000. World Bank.
http://devdata.worldbank.org/data-query/

Haines. A.. Epstein. P. R.. Mcmichael. A. J., Hughjones, M.. Kalkstein. L.S.. Lloyd. S. A.. Morse. S. S.. Nicholls. N., Parry. M., Patz. J. Postel, S.. Sherman. K. and Slooff. R.
Hammond. A.. A. Adriaanse, E. Rodenburg, D. Bryant. and R. Woodward (1995): *Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development*. Baltimore: World Resources Institute.

Hammond. A., A. Adriaanse, E. Rodenburg. D. Bryant, and R. Woodward (1995): Environmental Indicators: A Systematic Approach to Measuring and Reporting on Environmental Policy Performance in the Context of Sustainable Development. Baltimore: World Resources Institute.

Hanchett, S. (2001) Draft WELL reports (tasks 483 and 534).

Henninger (1998): *Mapping and Geographic Analysis of Human Welfare and Poverty-Review and Assessment*. World Resources Institute. Washington. D.C. U.S.A

Hentschel. J. Lanjouw P.(1998): *Household Welfare Measurement and the Pricing of Basic Services*. World Bank. Washington D.C

Howard. G. (2000). *A Reference Manual. Urban Water Supply Surveillance*. WEDC. Loughborough University. UK.

Hunt, C. & Lewin, S. (2000) Exploring decision-making for environmental health services: perspectives from four cities. *Reviews on Environmental Health*, Vol.15, No.1-2, 187-206

International Conference on Water and the Environment (1992) *The Dublin Statement and record of the Conference*. WMO, Geneva.

IPCC (2001a) *Climate change 2001 - The Scientific basis*. Report by the working group I of the International Panel on Climate Change.

IPCC (2001b) *Climate change 2001 – Impact, adaptation and vulnerability*. Report by the working group II of the International Panel on Climate Change.

Jazairy .I, Alamgir .M, Pannuccio .T (1992): *The State of World Rural Poverty, An Inquiry into Its Causes and Consequences*. New York University Press for International Fund for Agricultural Development, New York.

Kirchhoff L.V., McClelland K.E., Do Carmo Pinho M., Araujo J.G., De Sousa M.A. & Guerrant R.L. (1985) Feasibility and efficacy of in-home water chlorination in rural North-eastern Brazil. *J. Hyg. (Lond)*. **94**(2), 173-80.

Jacobs, M. (1994) The limits to neoclassicism. Towards an institutional environmental economics. in: M. Redclift and T. Benton (eds) *Social Theory and the Global Environment*. Routledge, London.

King, John M., (1983) *Livestock water needs in pastoral Africa in relation to climate and forage* International Livestock Centre for Africa. - ILCA research report ; no.7 Addis Ababa

Kneese, Allen, V. and Sweeney, James L. (eds) (1993):. *Handbook of Natural Resource and Energy Economics*. Amsterdam, New York, North-Holland. Elsevier Science Pub. Co.

Labbe, F., Ruelle, P. Garin, P. and Leroy, P. ( ). Modelling irrigation scheduling to analyse water management at farm level, during water shortages. *European Journal of Agronomy*. NR 17, BP 55, EP 67, PG 13, VL 12.

Lange, G. M.(1998) An approach to sustainable water management in Southern Africa using natural resource accounts: the experience in Namibia. *Ecological Economics* 26: 299-311.

Laswell, H. (1958) *Politics: who gets what, when and how*. World Publishing Company, New York.

Lee. N and Walsh. F. (1992) Strategic Environmental Assessment: An overview. *Project Appraisal.* 7:3. pp 126-136.

Leroy. P. (1999): Water Characteristics suitable for reducing corrosion of metallic materials of distribution networks. *Water Supply.* Vol 17. No 3-4. pp 419-424.
Leroy. P. (2001): replacement of lead pipes: What materials should be used? *Techniques Sciences Methods. Genie Urbain-Genie Rural.* No 1. pp 63-68.

Leroy. P., Bousquet. G., Martin. J., Ouvrad. J. (1995): Sampling Strategy for bacteriological quality monitoring in large distribution networks: implementation of hygienic controls in the Paris region. *Techniques Sciences Methods. Genie Urbain-Genie.* Vol 90. No 3. pp 184-187.

Lipton. M. (1988): *The Poor And The Poorest.* World Bank. Washington. DC.

Lohani. B.N. and N. Mustapha (1982) Indices for Water Quality Assessment in Rivers: A Case Study of the Linggi River in Malaysia. *Water Supply and Management* 6(6) 545-555

Lowi. M. R. (1993): Bridging The Divide – Transboundary Resource Disputes and the case of West-Bank water. *International Security.* NR 65. BP 113. EP 138. PG 26. VL 18.

Lowi. M. R. (1994): Oil Monarchies: Domestic and security challenges in the Arab Gulf States – Gause. FG. *International Journal of Middle East Studies.* NR 1. BP 610. EP 612. PG 3. VL 28.
Lowi. M. R. (1996): Oil Monarchies: Domestic and security challenges in the Arab Gulf states – Gause. F. G. *International journal of Middle East Studies.* NR 1. BP 610. EP 612. PG 3. 28.

Lowi. M. R. (1996): Rivers of Eden: The struggle for water and the quest for peace in the Middle East – Hillel. D. *International Journal of Middle East studies.* NR 1, BP 121. EP 123. PG 3. VL 28.

Malseed. J. (1990): *Bread without dough: understanding food poverty.* Horton. Bradford.

Maxwell .S (1999): *The Meaning and Measurement of Poverty.* Overseas Development Institute. http://www.odi.org.yk/breifing/pov3.html

May. P.. Burby. R., Ericksen. N.. Handmer. J.. Dixon. J. Michawls. S and Ingle Smith. D.(1996) *Environmental Management and Governance.* Routledge. London.

McConnachie. G.. Mtawali. A.& Young. R. (1994): Design Aspect of Hydraulic Flocculators. *Affordable Water Supply and Sanitation. Proceedings 20th WEDC Conference. Colombo. Sri Lanka.* pp 284-288.

Meigh, J.R., McKenzie, A.A., Austin, B.N., Bradford, R.B. and Reynard, N.S., (1998). *Assessment of global water resources – Phase II. Estimates of present and future water availability for Eastern and Southern Africa.* DFID report 98/4. Institute of Hydrology, Wallingford.

Meigh J.R., McKenzie A.A. and Sene K.J. (1999). A grid-based approach to water scarcity estimates for eastern and southern Africa. *Water Resources Management*, 13, 85-115.

Michaelides, G. Young, R. (1985): Provisions in Design and Maintenance to protect water quality from roof catchments. *International Journal of Environmental Studies*, vol. 25, No ½, pp 1-11.

Middleton J.D., Saunders P. & Corson J. (1994) Water disconnection and disease. *The Lancet*. **344** (8914), 62.

Mintz *et al*. (1995). Safe water treatment and storage in the home: a practical new strategy to prevent waterborne disease. *JAMA*, 273(12), 948-53

Morgan, J. and Falkenmark, M. (2000). Workshop 5 (Synthesis): Feminization of water security. Water Security for the 21st Century-Innovative Approaches, *Elsevier science Ltd*. Vol 43, No. 4

Morgan, J. and Falkenmark, M. (2000): Workshop 5 (Synthesis): Feminization of water security. Water Security for the 21st Century-Innovative Approaches, *Elsevier science Ltd*. Vol 43, No. 4

Moseley, W. G. (2001). *African Evidence on the Relation of Poverty, Time Preference and the Environment*. Elsevier Science BV. 38 (3), 317-326

Murray C & Lopez A. (1997) Global mortality, disability, and the contribution of risk factors: Global burden of disease study. *The Lancet*. **349**, 1436-42.

Murray C.J.L. & Lopez A.D. (eds) (1996) The Global Burden of Disease: a comprehensive assessment of mortality and disability from diseases, injuries, and risk factors in 1990 and projected to 2020. Harvard University Press, Cambridge, Massachusetts, USA.

Nogueira, V. P., Wilson, J. L. and Strzepek, K. (1981. River-Basin Simulation in Systems with Large response Times. *Journal of Hydrology (Amsterdam)*. Vol 51, No ¼, pp 159-168.

O'Boyle (1999): *Toward an Improved Definition of Poverty*. Review of Social Economy, Vol. LVII, No.3, September 1999.

O'Riordan. T. (ed.) (1995) *Environmental Science for Environmental Management* Longman. UK

OECD: *Measuring Development Progress. A Working Set of Core Indicators.* http://www1.oecd.org/dac/Indicators/htm/slides.htm

Ohlsonn. L. (1999) *Environment, scarcity and conflict – a study in Malthusian concerns,* Göteborg (Sweden): University of Göteborg. Department of Peace and Development Research.

Ohlsson. L. (1998) *Water and Social Resource Scarcity.* FAO issue paper. FAO. Rome. Organisation for Economic Cooperation and Development (OECD) 'Measuring Development Progress – A Working Set of Core Indicators'.

Orshansky. M. (1969) How poverty is measured. *Monthly Labor Review.* Vol. 92. No. 2. pp. 37-41

Park, C. (1997) *The Environment: Principles & Applications.* Routledge. UK

Patz. J. A., Strzepek. K., Lele. S, Hedden. M., Greene. S., Noden. B., Hay. S. I., Kalkstein. L., Beier. J. C. (1998): Predicting Key Malaria Transmission Factors. Biting An d Entomological Inoculation Rates. Using Modelled Soil Moisture. *Tropical Medicine and International Health.* BP 818, EP 827. PG 10. VL 3

Patz. J. A., Strzepek. K., Lele. S., Hedden. M., Greene. S., Noden. B., Hay. S. I., Kalkstein. L. and Beier. J. C. (1998): Predicting key malaria transmission factors. biting and entomological inoculation rates, using modelled soil moisture in Kenya. *Tropical Medicine and International Health.* BP 818, EP 827, PG 10. VL3

Pearce. D., Turner. K, O'Riordan, T., Adger. N., Atkinson. G., Brisson. I., Brown. K. and Powell. J. (1993) *Blueprint 3: Measuring Sustainable Development.* Earthscan. London.

Pigou (1920) *The Economics of Welfare.*Oxford.

Planning Office Evaluation and Research Office Programme Division. () Monitoring Progress Toward the Goals of the World Summit for Children – A Practical handbook for Multiple-Indicator Surveys.

Postel. S. (1990): Facing the crunch on efficiency. World Watch Institute. *World Water.* Vol. 12. No 11. pp 32-35.

Postel. S. (1992): Water Scarcity. *Environmental Science & Technology.* Vol. 26, No 12. pp 2332-2333

Postel. S. (1993): *The Politics of Water. World Watch.* NR 0. BP 10. EP 18. PG 9. VL 6.

Postel, S. (1999): Sweetwater Solutions. *Green Futures*, No 17, pp 22-25.

Postel, S., Polak, P., Gonzales, F. & Keller, J. (2001): Drip Irrigation for Small Farmers: A New Initiative to Alleviate Hunger and Poverty. *Water International*. Vol. 26, No 1, pp 3-13

Postel, S.L. (1992) Water Scarcity. *Environmental Science & Technology*. **26** (12), 2332-2333.

Postel, S.L. (1996). *Dividing the waters: food security, ecosystem health, and the new policies of scarcity*. Worldwatch Paper No. 132, P29. Worldwatch Institute, Washington DC.

Postel, S.L. (1998) Water for food production: Will there be enough in 2025? *Biosciences*, **28**, 629-637.

Proops, J. L. R. 1993. "A Proposed Alternative Approach to Integrating the Environment into the National Accounts," in E. Lutz (ed.), *Towards Improved Accounting for the Environment*. Washington, D.C.: World Bank.

Rennings, K. and H. Wiggering (1997). 'Steps towards indicators of sustainable development: Linking economic and ecological concepts', *Ecological Economics* **20**, 25-36.

Renwick, T. J. (1993). *A budget based definition of poverty with an application to single-parent families*. Journal of Human Resources.

Repetto, R. & W. Magrath & M. Wells & C. Beer & F. Ross. 1989. *Wasting Assets: Natural Resources in the National Accounts*. Washington, D.C.: World Resources Institute.

Rockstrom, J. Falkenmark, M. Folke, C. Barron, J. and Fox, P. (1999): Water harvesting for drought proofing of rainfed agriculture in semi-arid regions of Africa. *Regional Land Management*. Grid no 13, pp 10-11

Rogers, P.R., Jalal, K.F. Lohani, B.N. Owens, G.M., Chang-Ching Yu, Dufournaud, C.M and J.Bi (1997) *Measuring Environmental Quality in Asia*. Harvard University Press, Harvard.

Rosen, S. and J.R. Vincent, (1998) *Household Water Resources and Rural Productivity in Sub-Saharan Africa: A Review of the Literature*. Harvard Institute for International Development, Cambridge, MA.

Rosenhouse. M. (1989) *Identifying the Poor: Is Headship a Useful Concept?* LSMS Working Paper No. 58. World Bank. Washington. DC.

Rosenhouse. M. (1989): *Identifying the Poor: Is Headship a Useful Concept?* LSMS Working Paper No. 58. World Bank. Washington. DC.

Rowson (2001): *Poverty and Health.* The Student British Medical Journal. June 2001

Saby. S., Leroy, P., Block. J. C. (1999): Escherichia coli resistance to chlorine and glutathione sysnthsis in response to oxygenation and starvation. *Applied and Environmental Microbiology.* Vol. 65. No 12. pp 5600-5603.

Salameh. E. (2000) Redefining the Water Poverty Index. *Water International* **25** (3). 469-473

Schulze, R. (1999) *Transcending scales of space and time in impact studies of climate and climate change on agrohydrological responses.* Paper given at the GCTE Focus 3 Conference on Food and Forestry — Global Change and Global Challenges. Reading.

Scoones, I. (1998) *Sustainable rural livelihoods: a framework for analysis.* IDS Working Paper no.72. IDS, Brighton.

Seckler. D., Amarasinghe. U., Molden. D., de Silva. R., and R. Barker (1998) *World Water Demand and Supply, 1990 to 2025: Scenarios and Issues.* Research Report 19. IWMI. Colombo. Sri Lanka.

Selman. P. (1996) *Local Sustainability. Managing and Planning Ecologically Sound Places.* Paul Chapman. London.

Sen. A. K. (1983): *Poor, Relatively Speaking.* Oxford Economic Papers. No. 35.

Sen. A.K (1985) *Commodities and Capabilities.* North Holland. Amsterdam

Sen. A.K (1995) *Mortality as an indicator of economic success and failure* Discussion paper 66. London School of Economics and Political Science

Sen. A. (1999) *Development as Freedom.* OUP. Oxford
Shanahan. P. & Lantagne. D. (2002) *Indicators for Water Quality.* Paper presented at WWAP 'Indicator Workshop'. Rome February 2002.

Shiklomanov I.A. *et al.* (1997). Assessment of water resources and water availability of the world. Part of the *Comprehensive Assessment of the Freshwater Resources of the World.* World Meteorological Organization. Geneva.

Simon. S. (1999) A Framework for sustainable water management: integrating ecological constraints in policy tools in the UK. *Environmental Practice* 1: 19-30

Spash, C.L. (1998) Environmental values and Wetland Ecosystems: CVM, Ethics and Attitudes. In: *Social processes for environmental valuation*. The VALSE project final report, Versailles.

State of the Art Review of Environment, Security and Development Co-operation – Working Paper. (2000).

Steyl, L., Hutton, C. (2001). *Derivation and Testing of the Water Poverty Index Phase 1 – Summary of Meetings in South Africa and Tanzania*. GeoData Institute, Southampton
Stockholm Environment Institute, (1997) *Comprehensive Assessment of the Freshwater Resources of the World (volumes 1-8)* Stockholm.

Streeten, P.P. (1996): Human Development – the Debate about the Index, *International Journal of the Social Sciences*
Strzepek K. M. (2000). Responses and thresholds of the Egyptian economy to climate change impacts on the water resources of the Nile River. *Climatic Change*. BP 339, EP 356, PG 18, VL 46

Strzepek, K. M. & Chapra, S. C. (1990): Do The Right Thing. *Civil Engineering*. BP 54, EP 56, PG 3, VL 60.

Strzepek, K. M. & Marks, D. H. (1981): River Basin Simulation Models – Guidelines for their use in Water-Resource Planning. *Water Resources Bulletin*. BP 10, EP 15, PG 6, VL 17.
Strzepek, K. M. (2000): Responses and thresholds of the Egyptian economy to climate change impacts on the water resources of the Nile River. *Climate Change*. BP 339, EP 356, PG 18, VL 46.

Strzepek, K. M. Yates, D. N. & ElQuosy, D. E. (1996): Vulnerability Assessment of Water Resources in Egypt to Climatic Change in the Nile Basin. *Climate Research*. BP 89, EP 95, PG 7, VL 6.

Strzepek, K. M., Major, D. C., Rosenzweig, C., Iglesias, A., Yates, D. N., Holt, A. and Hillel, D. (1999): New Methods of modelling water availability for agriculture under climate change: The US Cornbelt. *Journal of the American Water Resources Association*.

Strzepek, K. M., Yates, D. N. (1997): Cimate change impacts on the Hydrologic Resources of Europe: A simplified continental Scale Analysis. *Climatic Change*. BP 79, EP 92, PG 14, VL 36.

Strzepek, K. Models for Assessment of Global Water Issues in 2025. In: *World Water Scenarios:Analysis*.

Sullivan, C. A (ed.). (2001) *The Development of a Water Poverty Index: A Feasibility Study*. The Centre for Ecology and Hydrology (Wallingford)

Sullivan, C.A. (2001a) *The Development and Testing of a Water Poverty Index*. Progress report to DFID, Centre for Ecology and Hydrology, Wallingford.

Sullivan, C.A. (2001b) The potential for calculating a meaningful water poverty index. *Water International* Dec. 2001.

Sullivan, C.A. (ed.) (2001) *The Development of a Water Poverty Index: A Feasibility Study*. Centre for Ecology and Hydrology (Wallingford)

Sullivan, C.A., Meigh J. R. and S. Mlote, (2002), *Developing a Water Poverty Index for Tanzania*. Conference paper for the Water Experts Conference, Arusha, January 2002

Sullivan, C.A., Meigh J. R. and S. Mlote, (2002), *Developing a Water Poverty Index for Tanzania*. Conference paper for the Water Experts Conference, Arusha, January 2002

Sullivan, C.A., Mutamba, M. and Kozanayi, W. (2001) *Water Use and livelihood Security: S A Study of Rural Households in Southern Zimbabwe*. Project report to DFID/NRSP, Sept. 2001, London.

Thompson, J. (2001) *Domestic Water Use and Environemntal Health in East Africa: Three Decades after 'Drawers of Water'* Project Summary, IIED, London.

Thurman, E. M., Squillance, P. J., Strzepek, K. M. & Garcia, L. (1988): Intelligent Data Analyser – Herbicide Transport in the Cedar River, Iowa. *Abstracts of Papers of the American Chemicla Society*, BP 5, EP ENVR, PG 0, VL 196.

Thurman, E. M., Squillance, P. J., Strzepek, K. M. and Garcia, L. (1988): Intelligent Data Analyzer – Herbicide Transport in The Cedar River, Iowa. *Abstracts of Papers of the American Chemical Society*.BP 5, EP ENVR, PG 0, VL 196.

Townsend .P (1985): *A Sociological; Approach to the Measurement of Poverty: A Rejoinder to Professor Amartya Sen.* . Oxford Economic Papers, No.37.

Turton, A. R. and Ohlsonn, L. (2000) The turning of the screw: social resource scarcity as a bottleneck in adaptation to water scarcity, Occasional Paper 19, SOAS Water Issues group, website – http://www2.soas.ac.uk.geography.waterissues

UNCED (1992) *Report of the United Nations Conference on Environment and Development*. United Nations, New York.

UNDP (2000) Overcoming Human Poverty. UNDP.

UNEP (1987): *"State of the environment: National reports"*. Nairobi.

UNICEF (1995): *Monitoring Progress Toward the Goals of the World Summit for Children: A Practical Handbook for Multiple-Indicator Surveys.*

UNICEF (1997): *Evaluation of Multiple Indicator Cluster Surveys: Division of Evaluation, Policy and Planning.*

United Nations Environment Programme (1992) *Workshop on ENRA. Summary record.* Environmental Economic Series 3. UNEP, Nairobi.

Uvin, P. (1994): *The International Organisation of Hunger.* Kegan Paul, London.

Valdes, J. B., Montbrundifilippo, J., Strzepek, K. M. & Restrepo, P. J. (1992): Aggregation-Disaggregation Approach to Multireservoir Operation. *Journal of Water Resources Planning and Management-ASCE.* BP 423. EP 444. PG 22. VL 118.

Van der Gaag, (1988): *Confronting Poverty in Developing Countries: Definitions, Information and Policies.* LSMS Working Paper No 48. World Bank, Washington, DC.

VanDerslice J. & Briscoe J. (1993) All coliforms are not created equal: a comparison of the effects of water source and in-house water contamination on infantile diarrhoeal disease. *Water resources research.* **29**(7), 1983-1993.

Vinciguerra, H., Audouin, C., Boussemart, G., Herman, A., Leroy, P., Maillot, H. (2000): Optimization of Urban Wasterwater System & Protection of Underground Water Resources for a Major French urban Community: *Techniques Sciences Methods. Genie Urbain-Genie.* No 9, pp 51-68.

Walmsley, J (2002): *Overview: Sustainability Indicators for Catchment Management in South Africa.* Water Research Commission, South Africa.

White GF, Bradley DJ and White AU. (1972). Drawers of water. Chicago: University of Chicago Press.

WHO (1992) *Health for All Database.* WHO, Geneva.

WHO (1996) Ad hoc committee on health research.

WHO/UNICEF (2000) Global Water Supply and Sanitation Assessment 2000. WHO / UNICEF, Geneva.

Wolf, A. T. 1997. "Water wars and water reality: Conflict and cooperation along international waterways." NATO Advanced Research Workshop on Environmental Change, Adaptation, and Human Security. Budapest, Hungary. 9-12 October.

World Bank (1992) *World Development Report 1992: Development and the Environment.* OUP.

World Bank (1994) *Social Indicators of Development*. World Bank. Washington DC.

World Bank (1996a) *Poverty Monitoring and Analysis Systems*. World Bank. Washington DC.

World Bank (1996a): *Poverty Monitoring and Analysis Systems*. World Bank. Washington DC.

World Bank (1996b) *A Guide to LSMS Surveys and their Datasets*. World Bank. Washington DC.

World Bank (1997) *Expanding the Measure of Wealth Indicators of Environmentally Sustainable Development*. Rio+5 Edition. discussion draft. World Bank. Washington DC.

World Bank (1998): *Standardised Welfare Indicators* World Bank, Washington DC.

World Bank (1999) *The World Factbook (1999* (www.odci.gov/cia/publications/factbook/).

World Bank (2001) *World Development Report 2001/2002: Attacking Poverty*. Oxford University Press

World Bank Group (2000) World development Report 2000/2001 — Attacking Poverty. New York. Oxford University Press, Inc.

World Bank. (1999). *World Development Report (1998/99*. Oxford University Press. New York.

World Bank. Various Papers including: '*World Bank. Social Indicators of Development*'

World Commission on Environment and Development (1987) *Our Common Future*. Oxford University Press. Oxford.

World Economic Forum. (2000) *Pilot Environmental Sustainability Index*. Yale Centre for Environmental Law and Policy. Yale

World Health Organisation (2002) http://www.who.int/water_sanitation_health/

World Health Organisation: *Environmental Health Indicators: Framework and Methodologies*. p2. See: http://www.northampton.ac.uk/ncr/who/index.html

World Resources Institute (1996) *World Resources* Oxford University Press. New York.

World Resources Institute (2000): *Linking Environment and Health: Indicators of Environmental Threats to Health*.

WWAP (2002) World Water Assessment Program. Information/Publications. http://www.unesco.org/water/wwap/

Yates, D. N. & Strzepek, K. M. (1998). An Assessment of Integrated climate change impacts on the Agricultural Economy of Egypt. *Climatic Change*. BP 261, EP 287, PG 27, VL 38.

Young, R. (1989). Roundtable: groundwater contamination issues. *Pollution Engineering*, vol. 21, No 4, pp 92-106

Young, R., budget, D. and Chatwin, C. (2001): Dynamic complex wave front modulation

Zhang, M., Baron, J., Leroy, P. (1995): Secondary consequences for water quality of the use of certain additives in cement-based materials. *Journal Europeen d' hydrologie*. Vol 26, No 2, pp 175-191.

Appendix 11
Further Documentation

11.1: Please see separate document:

Evaluating Your Water: A Management Primer for the Water Poverty Index

11.2: Please see separate document:

Water Poverty Index Implementation; An Introduction

11.3: Please see separate document:

Developing a Water Poverty Index, Poster

The Centre for Ecology and Hydrology has 600 staff, and well-equipped laboratories and field facilities at nine sites throughout the United Kingdom. The Centre's administrative headquarters is at Monks Wood in Cambridgeshire.

CEH Sites

CEH Directorate
Monks Wood, Abbots Ripton,
Huntingdon,
Cambridgeshire PE28 2LS
Telephone +44 (0) 1487 772400
Main Fax +44 (0) 1487 773590

CEH Oxford
Mansfield Road,
Oxford,
Oxfordshire OX1 3SR
Telephone +44 (0) 1865 281630
Main Fax +44 (0) 1865 281696

CEH Merlewood
Windermere Road,
Grange-over-Sands,
Cumbria LA11 6JU
Telephone +44 (0) 15395 32264
Main Fax +44 (0) 15395 34705

CEH Bangor
University of Wales, Bangor,
Deiniol Road,
Bangor, Gwynedd LL57 2UP
Telephone +44 (0) 1248 370045
Main Fax +44 (0) 1248 355365

CEH Wallingford
Maclean Building, Crowmarsh Gifford,
Wallingford,
Oxfordshire OX10 8BB
Telephone +44 (0) 1491 838800
Main Fax +44 (0) 1491 692424

CEH Dorset
Winfrith Technology Centre,
Winfrith Newburgh, Dorchester,
Dorset DT2 8ZD
Telephone +44 (0) 1305 213500
Main Fax +44 (0) 1305 213600

CEH Edinburgh
Bush Estate,
Penicuik,
Midlothian EH26 0QB
Telephone +44 (0) 131 4454343
Main Fax +44 (0) 131 4453943

CEH Windermere
The Ferry House, Far Sawrey,
Ambleside,
Cumbria LA22 0LP
Telephone +44 (0) 15394 42468
Main Fax +44 (0) 15394 46914

CEH Monks Wood
Abbots Ripton,
Huntingdon,
Cambridgeshire PE28 2LS
Telephone +44 (0) 1487 772400
Main Fax +44 (0) 1487 773467

CEH Banchory
Hill of Brathens,
Banchory,
Aberdeenshire AB31 4BY
Telephone +44 (0) 1330 826300
Main Fax +44 (0) 1330 823303

Further information about CEH is available on the World Wide Web at www.ceh.ac.uk

NATURAL
ENVIRONMENT
RESEARCH COUNCIL