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AFRICA EARTH OBSERVATORY NETWORK

EARTH STEWARDSHIP THROUGH SCIENCE

H_2O-CO_2-ENERGY EQUATIONS FOR SOUTH AFRICA

PRESENT STATUS, FUTURE SCENARIOS AND PROPOSED SOLUTIONS

STEPHANIE DE VILLIERS AND MAARTEN DE WIT

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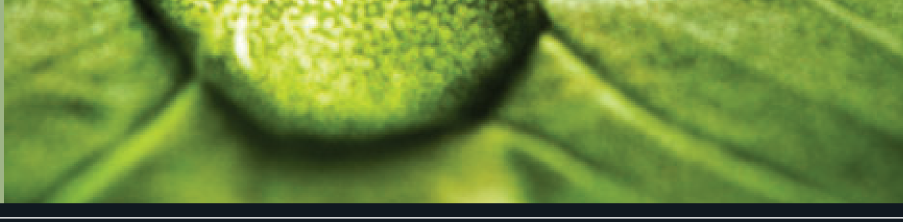

Abstract

South Africa is an arid country endowed with extraordinary mineral wealth. The first century of mineral exploration has brought with it economic development unrivalled on the African continent.

Continued exploitation of these resources, however, may invoke a turning-point in the historic positive relationship between mineral and economic wealth. This anticipated change in fortunes is predicated on the impact mining activities have had and will continue to have on South Africa's most precious and scarce natural resource, water.

A critical assessment of South Africa's future water balance paints a picture of a bleak future characterised by severe water shortages. The country's economic hubs and three main urban areas, Johannesburg, Cape Town and Durban, will be the most severely affected, with predicted water demand exceeding availability by a factor of about two by 2025.

This report demonstrates that consideration of climate change and water quality deterioration, both currently excluded from models used to forecast South Africa's official water outlook scenarios, predicts water shortages of 19 to 33% of requirements for the country as a whole by 2025, significantly larger than official estimates of 2 to 13% shortages by 2025. An estimated R360 billion, or about 15% of South Africa's present GDP, is needed within the next 15 years to secure South Africa's water future, primarily for maintaining and increasing water treatment plant capacity.

It is also demonstrated that the main contributor to increasing water quality deterioration will be acid mine drainage, resulting from the mining of coal to generate cheap electricity, and the mining of gold made possible by South Africa's cheap coal-based electricity. It is shown that the cost of water remediation necessitated by coal mining activities, and future carbon capture and storage cost resulting from proposals to increase South Africa's reliance on coal-fired power stations, have to be added to derive at the actual cost of the country's "cheap" carbon-intensive energy economy.

Quantification of these costs demonstrates that continued investment in coal-based energy supplies will bankrupt the country, and that external costs associated with water remediation and climate mitigation will dwarf the R385 billion sought by Eskom to fund its current coal-fired power plant expansion plans.

It is also demonstrated, however, that a dramatic move away from South Africa's current coal-based energy trajectory, towards a massive investment in renewable resources such as solar energy, can negate these bleak water and energy future scenarios. In fact, it appears that not doing so is not an option.

*Author for correspondence: E-mail: steph.devilliers@gmail.com

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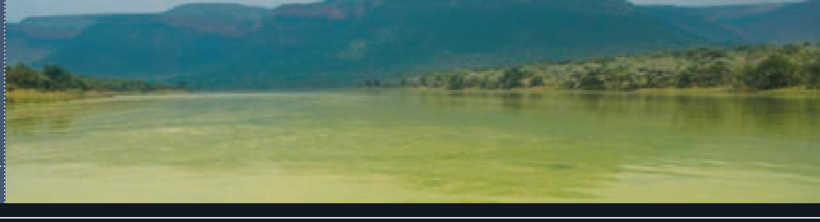

Foreword

SOLVING SOUTH AFRICA'S INTERLINKED ENERGY, CLIMATE AND WATER PROBLEMS.

The earth is a very complex system. Biologically modern humans (homo sapiens) have been part of this system for only around 250,000 years, arising during the Pleistocene when global temperatures fluctuated between ice ages and brief interglacial warm periods.

Humans in permanent settlements have existed as part of this system for only around 10,000 years, arising during the Holocene, an extended warm and stable interglacial period. A massive fossil fuel based global economy, megacities, and a human population in the billions arose only in the last 100 years. During this period, human activities have begun having such a massive impact on the functioning of the earth system that it has been labeled a new geologic era: the Anthropocene (Crutzen and Stoermer 2000).

Humans have always had a major influence on the ecosystems of which they were a part and which supported them. Pleistocene hunter/gathers used fire to radically modify their environment for their own advantage, and may have hunted several species of megafauna to extinction (Flannery 1994, 2006). Holocene farmers and city builders radically altered their local environments, with massive clearing, planting, and irrigation works. These civilizations also often collapsed by overextending themselves and losing resilience (Redman 1999, Diamond 2005, Costanza et al. 2007).

But the scale of change and impact in the Anthropocene is unprecedented. Human civilization is now so interconnected globally that if a collapse comes it will have a global affect.

During all of human history the primary drivers of development and change have been energy, water, and climate. In the Pleistocene current solar energy captured by natural ecosystems was simply gathered or hunted, while climate and water availability directed food availability and migration patterns. During the Holocene, ecosystems were domesticated, water was controlled to an extent, and climate could be moderated using the built environment. In the Anthropocene, current solar energy is being supplemented by aeons of past solar energy stored in fossil fuels. Water flow is highly manipulated and is being used to its limits, while climate is not only being adapted to, but also significantly changed by the massive burning of fossil fuels.

This report looks at these critical, society-shaping linkages in South Africa over the next 15 years. It is unique in its integration of climate change, water quality deterioration, and dependence on coal-based electricity in projecting South Africa's water supply future to 2025. It looks at the effects of global warming on evaporation rates in water short South Africa and the effects of decreasing water quality. Adding these two elements gives a much bleaker scenario for future water availability. It then estimates the costs of water treatment and purification, including these effects and the "external" costs of the impacts on valuable ecosystem services. For example, the destruction of the ecological integrity of river catchments has led to the loss of ecosystem services of water supply and regulation, and created additional costs to replace these services. The report shows clearly that when these costs are included, coal-based electricity is not cheap and continued investment in coal-based energy supplies will bankrupt the country.

Societies have collapsed before. Societies have also avoided collapse by adapting to changing conditions. Both South Africa and our global society are at a critical decision point. We require a transformation of our integrated worldviews, technologies, and institutions if we are to successfully adapt to the "full world" Anthropocene (Beddoe et al. 2009).

This report lays out part of the path to a successful South African adaptation to the challenges it now faces. South Africa needs to move away from its current coal-based energy system and invest in renewable resources such as solar energy. For example, placement of solar collector "lids" on many of the open reservoirs in South Africa would help solve both the energy problem and reduce evaporation enough to help solve the water problem. These types of creative, integrated technical solutions are a key part of the transition.

But South Africa (and the world) also need to change their worldviews to emphasize quality of life and equitable distribution rather than "growth at all costs," and develop more collaborative "commons" institutions that can bring about and implement the required changes (Costanza 2008).

While worldviews and visions of the future often seem the most difficult to change, they are often the key ingredient and the strongest leverage points in changing complex systems (Diamond 2005, Meadows 2010). South African society has already changed dramatically in recent decades, partly driven by the creation of a unique shared vision during the "Mont Fleur" workshop process (Kahane 2007). That kind of reenvisioning is needed again to deal with the looming, interlinked energy, climate, and water crisis outlined in this report.

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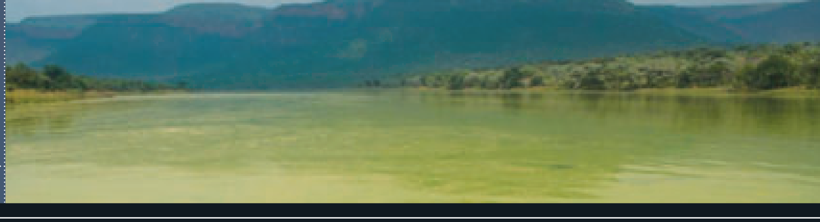
ROBERT COSTANZA:

University Professor of Sustainability and Director, Institute for Sustainable Solutions (ISS), Portland State University, Portland, Oregon, USA

www.pdx.edu/sustainability
Robert.Costanza@pdx.edu
Editor in Chief, Solutions (www.thesolutionsjournal.org)



1. Introduction

The status of climate variability and irreversible change as the defining environmental challenges of the 21st century are undeniable. The key environmental parameter in question is carbon dioxide (CO_2).

Emission targets (and the controversial carbon credits) are calculated in relation to the amounts of CO_2, or the CO_2 equivalents of other greenhouse gases, released into the atmosphere. The amount of CO_2 in the atmosphere is also the key environmental parameter used in climate models, which are used to predict the geographic areas where climate change will negatively impact on, and where therefore climate adaptation (i.e. combating the negative effects of climate change) will be the most needed.

Global CO_2 emission trends, combined with climate model predictions, suggest critical timeframes within which the global community has to act to reduce the impact that global warming will have (see box below).

"There is high confidence that many semi-arid areas (e.g. …southern Africa) will suffer a *decrease in water* resources due to climate change. Drought-affected areas are projected to increase in extent, with the potential for adverse impacts on multiple sectors, e.g. agriculture, water supply, energy production and health."

"At lower latitudes, especially in seasonally dry and tropical regions, *crop productivity* is projected to decrease for even small local temperature increases (1 to 2°C), which would increase the risk of hunger."

"The *health* status of millions of people is projected to be affected through, for example, increases in *malnutrition*; increased deaths, diseases and injury due to extreme weather events; increased burden of diarrhoeal disease; increased frequency of cardio-respiratory diseases due to higher concentrations of ground-level ozone in urban areas related to climate change; and the altered spatial distribution of some *infectious diseases*."

"*Poor communities* can be especially vulnerable, in particular those concentrated in high-risk areas."

"Approximately 20 to 30% of plant and animal species assessed so far are likely to be at increased risk of *extinction* if increases in global temperature exceed 1.5 to 2.5°C."

"Especially affected systems, sectors and regions:

***Africa*, because of *low adaptive capacity* and projected climate change impacts."**

In Africa, "By 2020, between *75 and 250 million of people* are projected to be exposed to *increased water stress* due to climate change." "By 2020, in some countries, yields *from rain-fed agriculture could be reduced by up to 50%*. Agricultural production, including access to food, in many African countries is projected to be severely compromised. "

Intergovernmental Panel on Climate Change (2007) [1]

For example, climate models suggest that global emissions have to be cut to 80% of 1990 levels by 2050, to prevent global warming exceeding the predicted critical threshold value of 2°C [1].

Despite the dire predicted impact that global warming will have, particularly for developing countries, there is no sign of a downturn in global CO_2 emissions and little commitment from governments and industry towards mitigation (i.e. the adoption of cleaner sources of energy to reduce CO_2 emissions) of the scale and within the timeframe required. The failure to reach agreement on emission targets and the financing of climate change impacts at COP15 (United Nations Climate Change Conference 15th Conference of Parties) held in Copenhagen in December 2009, again demonstrated this.

Concern about the implications of a repeat of this failure to reach consensus at COP16, to be held in Cancun in December 2010, has prompted the British government to produce an interactive Google Earth Map highlighting some of the changes that will occur if global average temperature increases by 4°C, that is double the threshold value of 2°C [2]. The predicted changes for southern Africa are dire, including: temperature increases of 7°C, a 70% reduction in water run-off, a factor of two increase in the frequency of droughts, and a 40% reduction in maize yields.

Key to reducing global warming trends is the reduction of anthropogenic 2°C emissions. Global power production from fossil fuels, which accounts for 55% of global anthropogenic CO_2 emissions, is projected to grow by 50% by 2030 [1]. At the heart of this increase in power production lays an unabated growth in global energy demand and a concomitant increase in consumption of fresh water to meet new living standards. Africa has the lowest per capita

TABLE 1

COUNTRY	TOTAL CO_2 EMISSIONS			CO_2 EMISSIONS FROM COAL		
	2007 TOTAL*	WORLD RANK	CHANGE 1990-2007	2007 TOTAL*	CHANGE 1990-2007	% OF TOTAL CHANGE (RANK)
JAPAN	1 263.3	5	+ 16%	444.8	+ 124%	88.0 (1)
SOUTH AFRICA	345.8	18	+ 36%	283.0	+ 36%	82.1 (2)
CHINA	6 071.2	1	+ 171%	5 033.3	+ 163%	81.5 (3)
FINLAND	64.4	45	+ 18%	29.0	+ 150%	78.4 (4)
INDIA	1 324.0	4	+ 125%	895.0	+ 120%	66.5 (8)
USA	5 769.3	2	+ 19%	2 114.8	+ 18%	35.6 (20)

The top four countries in the world in terms of increased CO_2 emissions derived from coal combustion. The biggest emitter of CO_2, China, also shows the biggest increase in CO_2 emission since 1990 (171%), but is surpassed by both Japan and South Africa in terms of the increasing contribution of coal to CO_2 emissions. Also provided are data for India and the U.S.A. (* indicates million tons of CO_2, data from [5]).

consumption of energy and water in the world, as reflected in its lowest national GDP's and highest poverty levels in the world [3]. Yet Africa is predicted to bear the brunt of the consequences of climate change [3] resulting from the excessive consumption of energy in the developed world (that includes Africa's oil, gas and coal reserves, most of which are now exported to the developed world, India and China), and predicted to result in severe non-linear depletions to its surface water supplies [4].

A critical and often overlooked feature of increasing CO_2 emission trends is that, in most cases, it is fuelled predominantly by increased coal usage [5]. Globally, of the 1 326.7 GW of energy generating capacity installed since 2000, 31.4% derives from coal, 33.9% from natural gas, 3.6% from oil, 2.2% from nuclear, and 17.4% from carbon-free sources (wind, solar, hydro, geothermal) [6]. In the case of countries such as Japan, South Africa, and China, increased CO_2 emissions derive almost exclusively from coal (Table 1). A more recent expressed concern is the fact that the IPCC CO_2 future emission scenarios to not "explicitly quantify" the inertia associated with existing energy and transportation infrastructure, and its implications for realising future emission targets [6].

The data shown above shows that South Africa, Africa's powerhouse, is punching above its weight when it comes to CO_2 emissions. South Africa has also committed itself to an almost doubling of its use of coal as its primary source of "cheap" energy over the next couple of decades [7], at a time that crippling water shortage are looming locally [8-12]. In doing so, it has also compromised the role it can play in negotiating the global policies needed to reduce the impact that global warming will have on vulnerability communities elsewhere in Africa.

The continued and increasing reliance on coal and the persisting narrow "carbon-minded" view of the environmental consequences of the use of coal and other fossil fuels, in South Africa and globally, have something critical in common: a complete lack of integration of water and energy issues. Whilst policy makers are indulging in carbon accounting schemes [13], including CO_2 sequestration [14], excessive coal-based energy consumption is silently leaving its destructive footprints in the most critical of our natural resources - H_2O. The evidence for this is nowhere more compelling than in South Africa and as the data presented in this report shows, South Africa has added itself to the following list of countries [8]:

"We are now on the verge of water bankruptcy in many places with no way of paying the debt back. In fact, a number of these regional water bubbles are now bursting in parts of China, the Middle East, the south western US and India; more will follow. The consequences for regional economic and political stability will be serious."

(World Economic Forum Water Initiative Report, 2009 [8]).

THE ALARMING FACTS THAT STATEMENTS SUCH AS THE ABOVE ARE BASED ON INCLUDE THE FOLLOWING (FROM [5]):

- Globally, 70% of freshwater withdrawals are used for agriculture.
- Globally, a doubling of food production is required in the next 40 years.
- Countries such as China, Saudi Arabia and South Korea have already required land in water-rich African countries, for the sake of their own food security.
- In China, 60% of the 669 cities already suffer from water shortages.
- In southern Africa, the Orange River has been dammed to such an extent that total reservoir storage exceeds annual flow.

This report presents an overview of the current status of South Africa's water resources, and outlines scenarios of what the future will look like if South Africa continues to dig up coal to feed its power stations. The results make the powerful argument that discussions, globally and in South Africa, about the future use of fossil fuels have to be about more than CO_2, it has to also be about H_2O. It demonstrates why climate policy forums must include discussion about the direct impact CO_2-liberation has on restricting scarce H_2O resources - the indirect environmental impacts of industries fuelled by coal-based energy. This report also demonstrates what the future can look like, and what it will look like, without coal.

2. The Water Cycle

2.1 THE GLOBAL WATER CYCLE

Only 2.6% of the water present at the Earth's surface is fresh water, and the majority of this is locked up in the polar ice caps [15] (Table 2, Figure 1). Humanity is sustained primarily by the 0.001% of water that is confined in river systems.

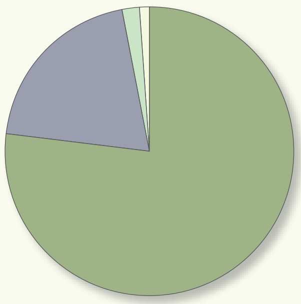
Exacerbating this fragile dependence of 21st century economies, let alone life on a trickle of water is the very dynamic nature of the water cycle. The average residence time of water in a particular reservoir can be obtained by dividing the amount of water in that reservoir (Table 2) by the magnitude of the flux in or out of the reservoir (Table 3). For example, the residence time of atmospheric water with respect to continental precipitation is given by:

$$(1\ 300\ km^3)/(111\ 100\ km^3/year) \approx 4\ days$$

$$\text{RESIDENCE TIME} = \frac{\text{AMOUNT IN RESERVOIR}}{\text{STEADY STATE FLUX IN (OR OUT)}}$$

Similarly, the average global residence time of river water with respect to continental runoff is only 15.6 days. In comparison, the residence time of an atmospheric CO_2 molecule, with respect to uptake by continental biomass, is more than a decade [16]. The relative rapid cycling of water between different Earth surface reservoirs implies that the amount of fresh water available to humans is very susceptible to large changes, on very short timescales. Ironically, this fact is far more visible in the overabundance of water during rapid flood events, than in the prolonged absences of water during droughts.

FIGURE 1



The relative distribution of Earth's freshwater between the different reservoirs.

TABLE 2

WATER RESERVOIR	*VOLUME (km³)*	*%*
EARTH total (ocean + freshwater)	1 385 978 000	100
EARTH FRESHWATER	35 978 000	2.600
Polar ice caps/glaciers	27 500 000	1.984
Groundwater	8 200 000	0.592
Lakes	205 000	0.015
Soil moisture	70 000	0.005
Rivers	1 700	0.001
Atmosphere	1 300	0.001

Global water facts (from [15]).

The continent of Africa occupies a uniquely challenged place in the global water balance, with an annual runoff of only 114 mm, making it the driest of the seven continents (Table 3). Although the total annual precipitation for Africa is second only to that of Asia and South America, the latitudinal positioning of this landmass results in more than 83% of this precipitation being lost through evaporation. Warmer air temperatures resulting from climate change will further increase evaporation rates [1]. Areas with predicted future decreasing rainfall trends as a result of climate change, such as southern Africa [3], will see a further reduction in the amount of precipitation that is converted to river runoff [4]. Climate change will result in Africa becoming even drier than it already is.

TABLE 3

LOCATION	% CONT AREA	PRECIP km³/a	EVAP km³/a	RUNOFF km³/a	RUNOFF mm	% CONT RUNOFF	RUNOFF/ PRECIP
GLOBAL (continents + oceans)		496 100	100 496				
CONTINENTS - Total	100.0	111 100	71 400	39 700	266	100	0.36
AFRICA	20.0	20 743	17 334	3 409	114	8.6	0.16
ANTARCTICA	9.4	2 376	389	1 987	141	5.0	0.84
NORTH AMERICA	16.2	15 561	9 721	5 840	242	14.7	0.38
AUSTRALIA	6.0	7 144	4 750	2 394	269	6.0	0.34
ASIA	29.6	30 724	18 519	12 205	276	30.7	0.40
EUROPE	6.7	6 587	3 761	2 826	282	7.1	0.43
SOUTH AMERICA	12.0	27 965	16 926	11 039	618	27.8	0.39
SOUTH AFRICA	0.8	576 (a)	527 (b)	49 (c)	40 (b)	0.12	0.09

Global water balance (unless stated otherwise, values from [15]).
(a) From Table 1; (b) Calculated from combination of other values; (c) From Table 4

2.2 SOUTH AFRICA'S WATER BALANCE

South Africa is the undisputed powerhouse of Africa, specifically in regards to economic activity and energy generation and consumption. On a global stage it also ranks very high in terms of its exploitable natural capital, particularly commodities such as coal, gold, platinum and many other metals. However, it is the one of the poorest countries in the world in terms of water resources. South Africa has an annual runoff of only 40 mm, almost a factor of seven lower than the global average of 266 mm (Table 3). Also, South Africa represents 4% of the surface area of Africa, but its runoff is only 1.4% of the total for Africa (calculated from values in Table 3).

Less than 9% of South Africa's precipitation is converted to river runoff. Most of the rest of the rainfall evaporates.

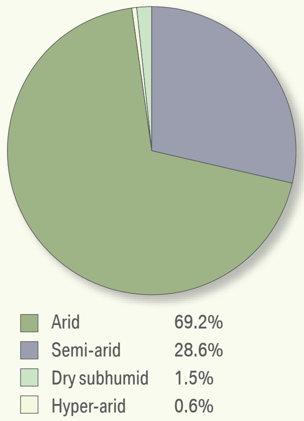
Only about 1.5% of South Africa is not classified as arid (including semi- and hyper-arid) [17] (Table 4, Figure 2). Even the savannah and grassland biomes of South Africa, respectively, so lush in the aftermath of summer rainfalls, are considered arid and semi-arid ecosystems. The critical factor that determines aridity is not precipitation, but the relative role of evaporation. Mean annual precipitation (MAP) values of 661 mm/a, for South Africa's grassland biome for example [18], is almost equivalent to the global average and may sound impressive, but only if evaporation is not taken into account.

Mean annual potential evaporation (MAPE) is the amount of water that could evaporate if there was sufficient water available. It is an indication of the amount of energy available for evaporation, in the case of South Africa amongst the highest incidences of solar radiation in the world, 220 W/m^2 [19]. MAPE far exceeds MAP in every part of South Africa (Table 4). The ratio MAPE/MAP is also called the aridity index [17]. In South Africa, only the small Indian Ocean Coastal Belt biome and the Forest biome are not classified as arid, but even in these areas evaporation is significantly greater than precipitation.

The implications of climate change for water availability in South Africa are profound. Temperatures are predicted to increase by 2 to 5°C across Southern Africa by 2050 [3]. Given a 5% increase in evaporation per °C increase in temperature [3], it implies a 10 to 25% future increase in surface water evaporative loss. Areas that are predicted to undergo reductions in precipitation as a result of climate change will become even more arid, that is most of southern Africa [3]. Areas that are predicted to undergo increases in precipitation will still see most of this increased water supply disappear through evaporation, and increased precipitation patterns will not necessarily translate into greater surface water availability. The ratio MAPE/MAP in South Africa's climatic conditions is simply too large, everywhere.

The above numbers illustrate how small and fleeting the amount of fresh water available on Earth is, and in South Africa in particular. Given that there are few places on Earth where the pressure on water to convert from liquid to its atmospheric vapour form is as overwhelming as in the hot, dry climatic conditions of South Africa, it raises a critical question. **The answer bears on every aspect of the well being of a society - what is the status of its small trickle of fresh water?** How is available fresh water in South Africa distributed geographically, how is it used, is it abused, and what does the future look like?

FIGURE 2



The percentage of South Africa's surface area covered by biomes, according to the UNESCO classification scheme (also see Table 4), demonstrating the extensive occurrence of arid climatic conditions in the country.

TABLE 4

BIOME	AREA km^2	MAP mm	MAPE mm	MASMS %	MAP km^3	MAP/MAPE	UNESCO CLASSIFICATION
1. SAVANNA	412 544	495	2 393	80	204	0.2	arid
2. GRASSLAND	354 594	661	1 991	75	234	0.3	semi-arid
3. NAMA-KAROO	248 279	208	2 583	84	52	0.1	arid
4. FYNBOS	83 946	483	2 047	72	41	0.2	arid
5. SUCCULENT KAROO	83 284	168	2 516	81	14	0.1	arid
6. ALBANY THICKET	29 128	431	2 025	77	13	0.2	arid
7. INDIAN COASTAL BELT	14 282	985	1 737	66	14	0.6	dry subhumid
8. DESERT	7 166	-	-	-	-	-	hyper-arid
9. FOREST	4 731	943	1 739	-	4	0.5	dry subhumid
TOTAL	1 237 954				576		

South Africa's water balance, as distributed across the biomes.
MAP = mean annual precipitation; MAPE = mean annual potential evaporation;
MASMS = % of days when evaporation demand is more than double soil moisture content;
MAP, MAPE and MASMS data from [18].

2.3 WATER AVAILABILITY IN SOUTH AFRICA

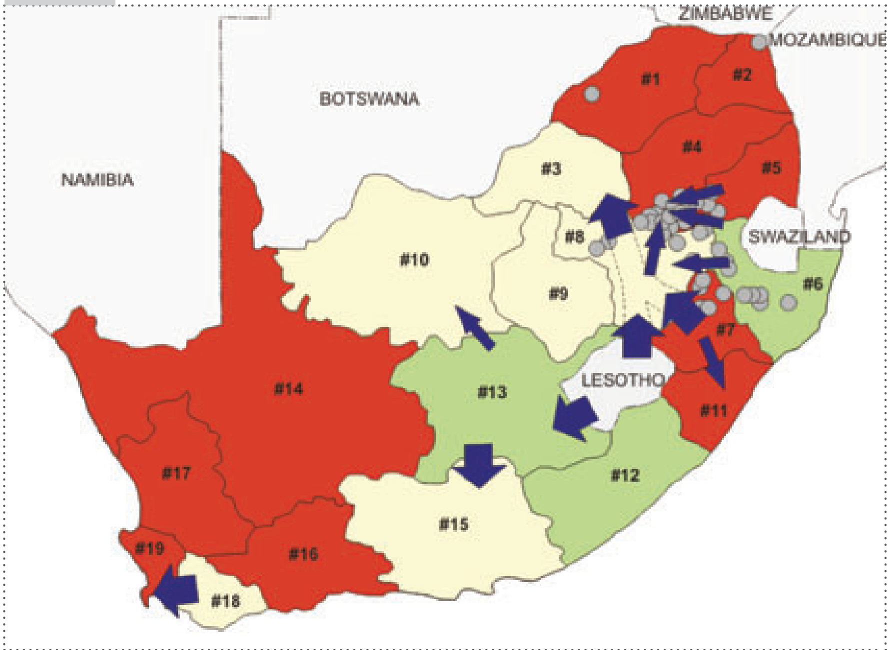
The National Water Resource Strategy [20] provides a broad overview of water availability in South Africa and its 19 Water Management Areas (WMA's), and values presented in this section are from the NWRS [20] (Figure 3; Table 5; Figure 4).

A critical evaluation of the robustness of these values for South Africa's surface and ground water resources, and the implications of the uncertainties in these values, are presented in the next section.

2.3.1 SURFACE WATER AVAILABILITY IN SOUTH AFRICA ACCORDING TO THE NWRS

South Africa's total natural river runoff is about 49 040 Mm³/a (million m³ per year). This includes 4 800 Mm³/a from Lesotho and 700 Mm³/a from Swaziland, which are generally accounted

FIGURE 3



Location of South Africa's 19 Water Management Areas (named in Table 5). WMA's with water balances presently in deficit [20] are shown in red, WMA's with substantial positive water balances at present are shown in green, and WMA's with marginal water balances are shown in yellow. Also shown are the location of active coal mines (grey circles), and the most volumetric water transfers between WMA's (or from Lesotho). Broad blue arrows indicate water transfers in excess of 400 Mm³/a, narrow blue arrows indicate water transfers of 30 to 100 Mm³/a (Table 6).

TABLE 5

WATER MANAGEMENT AREA	NATURAL MAR	ECOL RES	DAM STORAGE	LOCAL RELIABLE YIELD 2000	LOCAL RELIABLE YIELD 2025B	LOCAL RELIABLE YIELD 2025HI	LOCAL REQUIREMENTS 2000	LOCAL REQUIREMENTS 2025B	LOCAL REQUIREMENTS 2025HI	BALANCE 2000	BALANCE 2025B	BALANCE 2025HI	DEVELOP POTENTIAL
1. LIMPOPO	986	156	319	281	281	295	322	347	379	-23	-48	-61	8
2. LUVUVHU/LETABA	1 185	224	531	310	404	405	333	349	351	-36	42	41	102
3. CROC WEST/MARICO	855	164	854	716	846	1 084	1 184	1 438	1 898	41	125	335	0
4. OLIFANTS	2 040	460	1 078	609	630	665	967	1 075	1 143	-194	-242	-281	239
5. INKOMATI	3 539	1 008	768	897	1 028	1 036	844	914	957	-258	-197	-232	104
6. USUTU/MHLATUZE	4 780	1 192	3 692	1 110	1 113	1 124	717	728	812	319	311	238	110
7. THUKELA	3 799	859	1 125	737	742	776	334	347	420	-103	-111	-150	598
8. UPPER VAAL	2 423	299	5 725	1 130	1 229	1 486	1 045	1 269	1 741	17	-42	-764	50
9. MIDDLE VAAL	888	109	467	50	55	67	369	381	415	8	9	6	0
10. LOWER VAAL	181	49	1 375	126	127	127	643	641	703	31	57	70	0
11. MVOTI/UMZIMKULU	4 798	1 160	827	523	555	614	798	1 012	1 436	-241	-423	-788	1 018
12. MZIMVUBU/KEISKAMMA	7 241	1 122	1 115	854	872	886	374	413	449	480	459	437	1 500
13. UPPER ORANGE	6 981	1 349	11 711	4 447	4 734	4 755	968	1 059	1 122	332	88	-43	900
14. LOWER ORANGE	502	69	298	-962	-956	-956	1 028	1 079	1 102	-9	-7	-12	150
15. FISH/TSITSIKAMMA	2 154	243	739	418	456	452	898	988	1 053	95	71	52	85
16. GOURITZ	1 679	325	301	275	278	288	337	353	444	-63	-76	-157	110
17. OLIFANTS/DORING	1 108	156	132	335	335	337	373	370	380	-35	-32	-40	185
18. BREEDE	2 472	384	1 060	866	869	897	633	638	704	38	36	-2	124
19. BERG	1 429	217	295	505	568	602	704	829	1 304	-5	-67	-508	127
TOTAL	49 040	9 545	32 412	13 227	14 166	14 338	12 871	13 401	15 509	186	-234	-2 044	5 410

Current water availability and storage capacity, as well as current (i.e. 2000) and predicted future (2025B and 2025HI) yield, requirements and balances in South Africa's Water Management Areas, taken from the most recent NWRS assessment [20]. All values in 10^6 m³/a. The two future growth scenarios presented in the NWRS, 2025B and 2025HI, are elaborated on in the text. (Natural MAR = Natural Mean Annual Runoff)

for by South Africa as 'local yield' which strictly speaking they are not. An estimated almost 20% of the natural runoff is required to maintain ecological flow requirements, termed the "Ecological Reserve", i.e. water that is to be reserved specifically for meeting ecological water requirements. South Africa's total dam storage capacity, at present, is 66% of the natural runoff, an indication of the enormous extent to which the country's river systems have been dammed over the last couple of decades, and how strongly society depends on them today.

Rainfall and runoff vary from year to year and with that the reliable yield, that is the amount of water that can be abstracted without failure, on average 98 out of 100 years [20]. An estimated 11 328 Mm^3/a of the total reliable yield for the country derives from combined surface and groundwater yields - this is 23% of natural runoff and 35% of dam storage capacity (Table 5, Table 6).

The ecological reserve, combined with the surface and groundwater yield, represent 43% of the natural mean annual runoff. Assuming the remainder of the natural runoff is lost through evaporation from river channels and storage reservoirs (dams), it implies a 57% loss through evaporation. Such a magnitude of water loss through evaporation is consistent with high the MAPE/MAP ratios for South Africa (Table 4). Evaluation of river water chloride levels, as a first-order proxy for the extent to which water has undergone evaporation [21], confirms evaporative losses of this order in South Africa's river catchments (Table 7).

Evaporative losses also contribute significantly to the low yield/dam storage capacity observed in South Africa. The magnitude of these losses is instructive, particularly in regards to the viability of increasing yield in future by increasing dam storage to an even more significant extent. First of all, if the Ecological Reserve is maintained, the unexploited potential for increased dam storage is only 14.4% of the natural runoff, or 7,083 Mm^3/a. If the increased yield that will be derived from this with increased dam storage is only 35%, then the maximum amount by which the reliable surface water yield in South Africa can be increased by in future is 2 479 Mm^3/a. According to these estimates the maximum reliable natural yield (not including recycled water or return flows) potential in South Africa is 13 807 Mm^3/a and **the current reliable surface water yield is at 82% of its maximum capacity**.

TABLE 6

WATER MANAGEMENT AREA	RELIABLE LOCAL YIELD				TRANS	LOCAL REQUIREMENTS							TRANS	BALANCE	
	SURFACE	GROUND	RETURN	TOTAL	IN	IRRIG	URBAN	RURAL	MIN+IND	POWER	AFFOREST	TOTAL	OUT	NWRS	REVISED
1. LIMPOPO	160	98	23	281	18	238	34	28	14	7	1	322	0	-23	-123 (a)
2. LUVUVHU/ LETABA	244	43	23	310	0	248	10	31	1	0	43	333	13	-36	
3. CROC WEST/ MARICO	203	146	367	716	519	445	547	37	127	28	0	1 184	10	41	
4. OLIFANTS	410	99	100	609	172	557	88	44	94	181	3	967	8	-194	
5. INKOMATI	816	9	72	897	0	593	63	26	24	0	138	844	311	-258	-280
6. USUTU/ MHLATUZE	1 019	39	52	1 110	40	432	50	40	91	0	104	717	114	319	294
7. THUKELA	666	15	56	737	0	204	52	31	46	1	0	334	506	-103	
8. UPPER VAAL	599	32	499	1 130	1 311	114	635	43	173	80	0	1 045	1 379	17	
9. MIDDLE VAAL	-67	54	63	50	829	159	93	32	85	0	0	369	502	8	
10. LOWER VAAL	-54	125	55	126	548	525	68	44	6	0	0	643	0	31	
11. MVOTI/ UMZIMKULU	433	6	84	523	34	207	408	44	74	0	65	798	0	-241	
12. MZIMVUBU/ KEISKAMMA	776	21	57	854	0	190	99	39	0	0	46	374	0	480	
13. UPPER ORANGE	4 311	65	71	4 447	2	780	126	60	2	0	0	968	3 149	332	
14. LOWER ORANGE	-1 083	25	96	-962	2 035	977	25	17	9	0	0	1 028	54	-9	
15. FISH/ TSITSIKAMMA	260	36	122	418	575	763	112	16	0	0	7	898	0	95	
16. GOURITZ	191	64	20	275	0	254	52	11	6	0	14	337	1	-63	
17. OLIFANTS/ DORING	266	45	24	335	3	356	7	6	3	0	1	373	0	-35	
18. BREEDE	687	109	70	866	1	577	39	11	0	0	6	633	196	38	
19. BERG	403	57	45	505	194	301	389	14	0	0	0	704	0	-5	
TOTAL	10 240	1 088	1 899	13 227		7 920	2 897	574	755	297	428	12 871	170	186	39 (b)

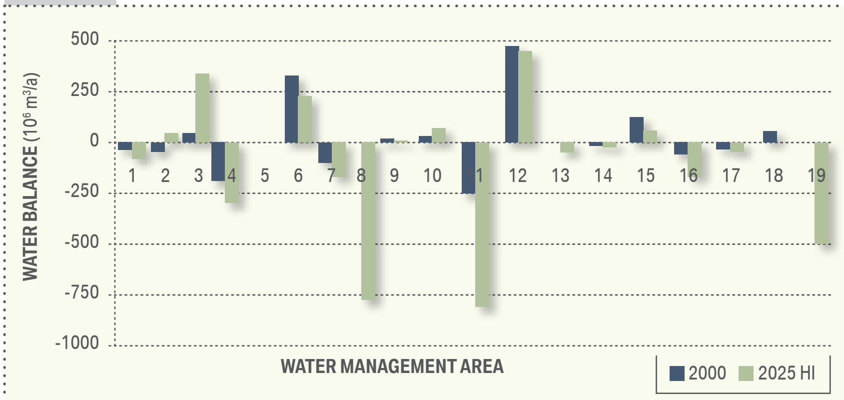
Detailed breakdown of current water yield and availability in South Africa, as given in the most recent NWRS assessment [20]. All values in 10^6 m^3/a.

(a) Revised balance, based on revised groundwater yield and requirement values [22]
(b) Adjusted as a result of changes in (a).

2.3.2 GROUND WATER AVAILABILITY IN SOUTH AFRICA ACCORDING TO THE NWRS

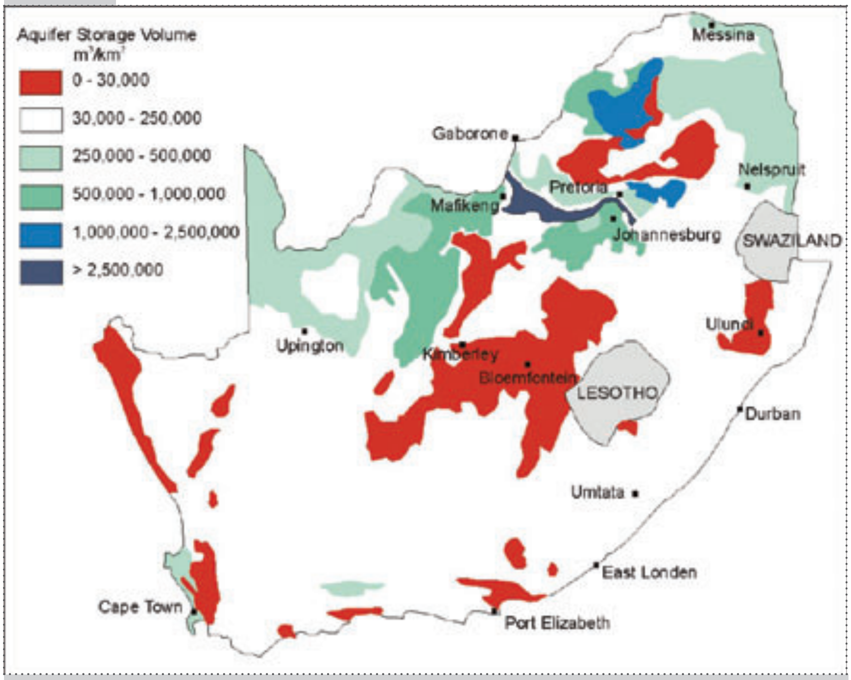
An estimated total volume of 235 000 Mm^3 of water is stored in South Africa's groundwater aquifers [23].

FIGURE 4



Graphic representation of the water balance in the nineteen Water Management Areas (see Table 5 and Figure 3) in the NWRS's present (2000) and future (2025HI) scenarios.

FIGURE 5



Areas of highest and lowest groundwater availability in South Africa (simplified from Figure 13 in [23]).

Almost 79% of this occupies low-yielding shallow (average 33 m thick) aquifers, associated with weathered and fractured-rock geological formations (Figure 5). High-yielding groundwater systems are restricted to dolomitic and quartzitic formations in the northern and southern parts of South Africa, respectively.

Unlike surface water reservoirs, which are recharged after every significant rainfall event, groundwater recharge can take months, years or even centuries. Knowledge of the rate of groundwater recharge is critical if over-abstraction is to be prevented. The national total recharge rate is currently "officially" estimated to be 30 520 Mm^3/a [24], which is 5.3% of MAP, i.e. this is the amount of groundwater that can be abstracted sustainably. However, not all of this is exploitable. Poor groundwater quality restricts exploitation potential. This can result from either natural factors, such as high dissolved solid load yielding lithologies, or pollution. Another important factor is that most of South Africa's groundwater aquifers are low-yielding systems with questionable economical exploitation potential.

"Educated guesstimates" of the total amount of exploitable groundwater available in South Africa range from early values [25] of 2 500 Mm^3/a, to much higher recent estimates of 19 000 Mm^3/a [26] and 10 000 Mm^3/a [27]. The National Water Resource Strategy (NWRS) assessment opts for the highest of these values, 19 000 Mm^3/a, but with an acknowledgement that the sustainable yield may only be 6 000 Mm^3/a [20]. This lower value, 6 000 Mm^3/a, is also the amount that the Ground Water Division of the Geological Society of South Africa suggests as the maximum quantity of groundwater that can be developed economically (e.g. reserves) (www.gwd.org.za/content/groundwater-resource-more-valuable-gold). The Millennium Ecosystem Assessment for Southern Africa [3] suggests an even lower value of 4 800 Mm^3/a. There is clearly a fair amount of uncertainty around the magnitude of South Africa's exploitable groundwater potential.

2.4 HOW RELIABLE ARE SOUTH AFRICA'S WATER AVAILABILITY ESTIMATES?

2.4.1 SURFACE WATER AVAILABILITY

Imbedded in the NWRS [20] water balance numbers and the instructive but simplistic back-on-the-envelope-type calculations presented above are many uncertainties.

These uncertainties are critical to sustainable water management, but they rarely get mentioned. In, for example, the NWRS assessment [20] all water balance values are given as absolute values (called "statistics"), with no stated uncertainties.

It deserves mention that the water availability data contained in the NWRS derives from assessments reports outsourced to various groupings of a total of 14 different consulting firms [22, 28-45]. The different data reporting methodologies, and presumably different data collection methods, used by different consulting firms may be problematic. Generally speaking, it is not clear for most of the Internal Strategic Perspective (ISP) documents, to what extent estimates for surface water balances are derived from updated versions of previous data, or recycled old data. Some of the ISP's construct water balances based on outdated 1995 estimates [33, 35, 38].

The Limpopo Water Management Area (WMA) deserves special mention in regards to data reliability and availability. The local water yield and requirement for the Limpopo WMA are given as 281 and 322 Mm^3/a in the NWRS [20], respectively, with a water balance deficit of -23 Mm^3/a. The final version of the ISP for this WMA [22], produced subsequent to finalisation of the NWRS report, contains some interesting data amendments. These amendments are based on previously unavailable data for registered groundwater use, and new estimates of groundwater yield potential. The updated data suggests local yield and requirement values for the Limpopo WMA of 453 and 595 Mm^3/a, respectively [22]. These values amount to changes of +60% and +85% to the previous estimates (i.e. the values given in the NWRS [20]). The updated water balance for the Limpopo WMA is then -123 Mm^3/a (transfers in and out remained unchanged); the revised water balance results in a water deficit exceeding the NWRS estimate by a factor of more than five. The implication is that NWRS data for other WMA's may similarly contain very large margins of error and uncertainty, which have yet to be uncovered.

2.4.2 GROUNDWATER AVAILABILITY

The uncertainty regarding the status of South Africa's groundwater resource is even more pronounced than that for surface water.

For example, the NWRS assessment suggests a total current groundwater use in South Africa of 1 088 Mm^3/a (Table 6). This value is about the same as the 1 095 Mm^3/a estimate from 1970 (calculated from 3 Mm^3/day) [46]. It is almost a factor of 2 lower than the current use value of 1 770 Mm^3/a published by independent scientists [47]. Groundwater abstraction is known to have increased significantly over the last couple of decades, and the suggestion is that the data used to produce the NWRS may be significantly underestimating this vital component of the water balance. The implication of such a high level of uncertainty is well illustrated by the dramatic amendments to the water balance values for the Limpopo WMA [22], discussed earlier, brought about by more realistic groundwater resource estimates.

It needs to be acknowledged that groundwater recharge estimation is a difficult science and one that has been notably neglected in South Africa in the past [26]. A complex set of factors determine the magnitude of groundwater resources and recharge rates, including climatic conditions, geology, vegetation, and probably

most importantly, the soil moisture regime [48]. Current estimates of groundwater recharge rates in South Africa are based primarily on conventional methods such as the chemical chloride mass balance (CMB) approach, numerical approaches based on empirical rainfall/recharge relationships, and GIS-based physical models [23, 24]. The continued reliance on these conventional methods, almost exclusively, perpetuates the uncertainty regarding the status of South Africa's vital groundwater resource.

Physical water balance approaches have been shown to be of limited use in arid and semi-arid regions, because of the huge margin of uncertainty associated with the large evaporation/rainfall ratios in these regions [48]. Additionally, the rainfall/recharge relationship applied in South Africa [23, 24] suggest an average value for total recharge of more than 5% of MAP. This value is higher than the upper end of the range in the global relationship for groundwater recharge in arid and semiarid regions of 0.1 to 5% of MAP [48]. If this range of values is applied to South Africa's MAP of 576 000 Mm^3/a, it suggests a total recharge rate of 580 (or 0.5 mm) to 28 800 Mm^3/a (or 28.3 mm), compared to the 30 500 Mm^3/a estimate adopted by the NWRS [20]. Another estimate for total recharge can be derived from the global relationship between recharge rate and precipitation in arid and semiarid regions ($y = 0.03*MAP - 2.60$, $R^2 = 0.46$) [48], which suggests an estimated total recharge rate of 15 Mm^3/a (or 12 mm/a) for South Africa. The latter value compares well with the only published 3H measurement-based estimate of groundwater recharge in South Africa of 13 mm/a in the savannah's of the North-west Province [49]. The latter study also applied the CMB method, which yielded much lower recharge values of 1.7 to 4.9 mm/a.

The CMB approach is the other conventional method widely applied in South Africa to estimate groundwater recharge. Like the conventional physical approach, CMB application in arid environments like South Africa is very problematic, because of decoupling between the solute and solvent during evaporation [48]. It should also be kept in mind that recharge rates across South Africa may vary by a factor of about 50, in accordance with observations globally for arid and semiarid regions [48], and that the few actual measurements of groundwater recharge rates in South Africa are skewed towards areas with anticipated high recharge rates.

All these uncertainties feed into the about factor-of-three uncertainty (6 000 to 19 000 Mm^3/a) associated with the magnitude of South Africa's exploitable groundwater yield, discussed above. If South Africa's exploitable groundwater yield is as low as 6 000 Mm^3/a, then a current use value of almost 2 000 Mm^3/a [47] would suggest the following worst-case scenario: a third of the sustainable groundwater yield is already used, with only 4 000 Mm^3/a remaining. If the calculated 2 267 Mm^3/a remaining surface water yield to be exploited (at great infrastructure development cost) derived earlier is a realistic estimate, then South Africa's total unexploited total surface and groundwater yield is 6 267 Mm^3/a. The NWRS's [20] estimated total amount of water that remains to be exploited in South Africa is even lower, 5 410 Mm^3/a (Table 5).

TABLE 7

RIVER CATCHMENT (MONITORING SITE)	$[CL]_{high}/[CL]_{low}$	ESTIMATED EVAPORATIVE LOSS
ORANGE RIVER (lower reaches, Pella)	2.07	52%
ORANGE RIVER (middle, Vanderkloof Dam)	1.69	41%
VAAL RIVER (downstream of Vaal Dam)	1.89	47%
HARTS RIVER (Mount Rupert)	2.08	52%
RIET RIVER (Kalkfontein Dam)	2.97	66%
OLIFANTS RIVER (Loskop Dam)	1.44	30%
OLIFANTS RIVER (Kruger NP)	3.43	71%
KOMATI RIVER (Sterkloop)	3.18	68%
LIMPOPO RIVER (Beit Bridge)	9.46	89%
TUGELA RIVER (upper reaches)	1.89	47%
PONGOLA RIVER (Ndugune NR)	1.88	46%
MZIMVUBU RIVER (upper reaches)	1.58	37%
GREAT KEI RIVER	3.13	68%
KEISKAMMA RIVER	2.13	53%
GROOT RIVER	1.69	41%
KEURBOOMS RIVER	1.39	28%
BERG RIVER (upper reaches)	1.29	23%
BERG RIVER (lower reaches)	2.33	57%
BREEDE RIVER (upper reaches)	1.67	40%
BREEDE RIVER (lower reaches)	4.60	78%

First-order estimated evaporative water losses from South African river systems, calculated from the ratio of the maximum and minimum chloride levels during the annual cycle, at long-term monitoring stations. Chloride data obtained from DWAF.

2.4.3 THE ECOLOGICAL RESERVE AND THE BASIC HUMAN NEEDS RESERVE

Last, but not the least important, is the amount of water allocated to the environment, termed the "Ecological Reserve".

The almost 20% of the natural runoff allocated to this is a significant amount of water, equivalent to almost 75% of the total amount of water required for the population and the economic activities that sustain their lifestyles. The right of the environment to this water is enshrined in the National Water Act of 1998 [50]. The environment is one of only two entities with a right to water in South Africa, the other entity is the human population with its "basic human needs reserve". All other water requirements are subject to authorisation, and such authorisation can only be granted if usage does not come at the expense of the "basic human need reserve" and the "ecological reserve". The amount of water considered to be sufficient to fulfil the "basic" needs of a South African is a paltry 25 L per day [20]. The current domestic water use (rural + urban = 3 471 Mm^3/a, Table 6) suggests that the per capita water consumption in South Africa (for the 85% of the population of 48 million people who has access to it) is 233 L per day. The comparative daily per capita water consumption is 150-180 L in the UK, 262 L in the USA, and 350 L in Australia [51].

The origin of the 20% of South Africa's total natural runoff (values vary from 12 to 30% across the country) currently allocated to the environment is the following: "Owing to a lack of better factual data it has provisionally been assumed that provision of the ecological water requirements in the lowest reach of the river will be sufficient to meet estuarine freshwater requirements as well" [20]. In other words, the "Ecological Reserve" values used in the NWRS water balances (Table 5) are the minimum amounts of water present in the river catchments, after decades of extensive dam construction and abstraction and the flow reductions that resulted from that. Numerical models have been developed to estimate the magnitude of the "Ecological Reserve" [52]. However, the expert developers of these models themselves admit that these models are not "based on a strong scientific analysis of the relationship between hydrology and ecological functioning", and that "the data to undertake such an analysis do not exist" [52].

Nationwide, site-specific, eco-hydrological studies and economic valuation of ecosystem services are needed, as a matter of urgency. Without such studies, the scientific credibility and defensibility of the "ecological reserve" are in serious doubt. This leaves the "ecological reserve", i.e. the environment, open to exploitation or, at best, to have only its minimum requirements respected, as is also the case for the country's previously disadvantaged people and their "basic human needs reserve". The linkages between human well-being and the services supplied by healthy ecosystems, above all water and food, cannot be overemphasised. Globally, about 60% of ecosystem services are used unsustainably, notably fresh water [3]. Since degradation of ecosystem services are borne disproportionably by the poor, it enhances inequities and cause social conflict and is already a barrier to achieving the Millennium Development Goals [3].

GOLF COURSE WATER USAGE

An average 18-hole golf course is estimated to use 1.2 to 3 Ml/day (www.ewt.org.za and www.panda.org.za), which is equivalent to 4.38 to 10.95 Mm^3/year per golf course. There are about 500 golf courses in South Africa. If each of them uses the amount typical for a golf course, then it adds up to a total water use of 2 190 to 5 474 Mm^3/year nationally. This range of values is equivalent to the total national domestic water consumption and almost equal to that required for irrigation (of presumably agricultural products only).

This simplistic calculation suggests that the typical amount of water usage per golf course quoted above is most possibly an overestimate for the average South African golf course. However, the numbers are significant enough to legitimately question the socio-economic benefits so often used to motivate the development of golf estates, particularly in severely water stressed golf-tourist towns along the south coast's Garden route.

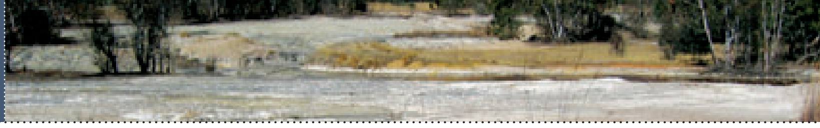
THE MAGNITUDE OF 3. Future water shortages - ACCORDING TO THE NWRS

According to the NWRS [20] South Africa currently has a slight amount of excess water of 186 Mm^3/a, which is 1.4% of the estimated "reliable local yield" (Table 5). On the whole, South Africa's current water requirements are therefore about equal to the amount of water available.

These numbers hide the enormous water deficits prevailing in the country's industrial centres, compared to the excess amounts of water present in undeveloped areas like in the Mzimvubu WMA in the Eastern Cape (Table 5, Figure 4). These numbers also hide the enormous amount of water transferred between water management areas, at great infrastructure and energy expense (Table 6). These numbers, particularly the "Ecological Reserve" estimations, also hide the fact that in most WMA's the ecological reserve has not been implemented yet [20].

The NWRS predicted 2025 water outlook for South Africa is summarised in Table 5. The "2025 BASE" scenario is based on a low growth scenario of a 1.5% per year growth in gross domestic product (GDP), and the "2025 HIGH" scenario is based on a 4% per year growth in GDP. The NWRS regards the BASE scenario "as the more probably", and the HIGH scenario as "as an upper extreme" [20]. The upper scenario is also "intended to serve as a conservative indicator to prevent the occurrence of possible unexpected water shortages" [20]. The water balance for the BASE scenario predicts a water deficit for South Africa of -234 Mm^3/a by 2025, and the HIGH scenario predicts a deficit of -2 044 Mm^3/a by 2025. Even the most conservative NWRS estimate of South Africa's future water balance, therefore, is for a deficit of 2% of requirements by 2025. Even a relatively modest economic growth rate of 4% will result in a probably insurmountable water balance deficit of 13% of requirements, by 2025. It is important to emphasise that these estimates are based on the presumed availability of a "reliable yield". The occurrence of even a single year with a yield lower than the assumed "reliable yield" will exacerbate the water deficit situation, as presently dramatically illustrated in the drought-stricken Eastern Cape. This and the fact that 10 of the 19 WMA's are already experiencing water shortages (Table 5, Figure 4), contradict claims that there is not a water crisis in South Africa yet and that it would require a dry spell of several years to induce a crisis [9].

It is important to emphasise that the values above and those quoted in the media [8] represent water deficit values for the country as a whole. If individual WMA's are considered, the present and anticipated water deficit scenarios are much more pronounced, including in several WMA's critical to the economy (Table 5). WMA's for which water deficits are predicted to exceed 20% of requirements by 2025, according to the BASE scenario, include the Olifants (23%), the Inkomati (22%), the Thukela (32%) and the Mvoti to Umzimkulu (42%). Under the HIGH scenario the water deficit is predicted to exceed 20% of requirements by 2025 for the following WMA's: the Olifants (25%), the Inkomati (24%), the Thukela (36%), the Upper Vaal (44%), the Mvoti to Umzimkulu (55%), the Gouritz (35%) and the Berg (39%). The HIGH scenario, i.e. a minimum economic growth scenario that the South African government is aiming for, therefore predicts that by 2025 water requirements will exceed availability by a factor of about 2 in the WMA's that serve South Africa's three largest metropolitan areas, the Upper Vaal (Johannesburg), Mvoti to Umzimkulu (Durban) and Berg (Cape Town). Today these three metropolitan areas serve a total of



more than 12 million people or 25% of the South African population, most of the country's economic activity, and are positive population growth hotspots, primarily as a result of increased migration from rural to urban areas (www.statssa.gov.za). This is the bleak outlook of the most conservative estimates of the national government department tasked with projecting future water availability scenarios.

The above water deficit values are calculated assuming the "reliable yield" required by the NWRS is realised and that the expected rather modest increases in requirements are realistic (Table 5). If the yields do not increase as required or future requirements exceed expectations, then the water deficit values will be correspondingly larger. Under the BASE scenario, the largest increases in water requirements are expected in the Mvoti/Umzimkulu WMA (27% over 25 years), followed by the Crocodile West/Marico WMA (21%) and the Upper Vaal WMA (21%).

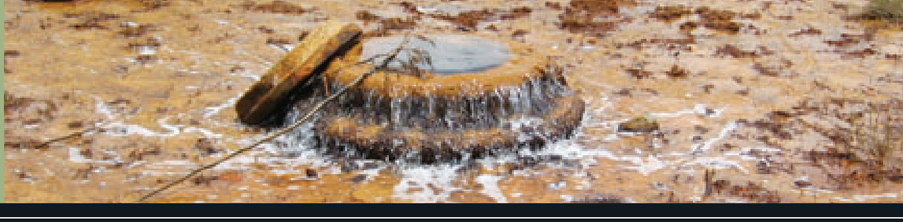
The latter two WMA's serve the industrial heartland of South Africa - Johannesburg/Pretoria urban and industrial areas, as well as platinum and gold mining activities, in the Rustenburg area and the Witwaterwatersrand basin, respectively [34]. Their combined contribution to the national GDP is 44%. The water to meet their increased requirements will be partly met by increased transfer of water from Lesotho. The cost for this expensive infrastructure project was justified by the economic importance of the Crocodile West/Marico and Upper Vaal WMA's. Under the HIGH growth scenario, the largest increases in water requirements are expected in the Berg WMA, which serves Cape Town (85% over 25 years), followed by the Mvoti/Umzimkulu WMA (80%), which serves Durban.

The BASE and HIGH scenarios require "local reliable yield" increases, compared to 2000 values, of 7% and 8.5%, respectively. Nationwide, increased yield is expected to derive primarily from increasing South Africa's already very extensive dam storage capacity and increased groundwater use. A "rough" estimate for developing just the "development potential" of the Mzimvubu WMA in the Eastern Cape is R20 billion [38]. If building cost escalates at 10% per year, this will cost R216 billion by 2025. This does not include the infrastructure that will be needed to transport this water to mining and industrial areas in the northern provinces, if need be.

RESULT

It seems clear from the NWRS's own projections that water shortages are going to occur on a large scale in South Africa, even if the country follows a no-to-very-slow economic growth path. The most optimistic outlook for 2025, a -234 Mm³/a deficit, is reliant on considerable increases in water transfer between WMA's, increased storage capacity in dams and groundwater use, and increased water recycling. All of these will come at a considerable, but unspecified, cost.

What follows in the rest of this assessment is, in our view, a more realistic evaluation of South Africa's water future, than that provided in the NWRS and discussed so far.



4. Parameters missing

FROM THE NWRS'S WATER BALANCE EQUATIONS

THE NWRS CONTAINS TWO FUNDAMENTAL OMISSIONS THAT IMPACT ON SOUTH AFRICA'S FUTURE WATER SUPPLY:

- Consideration of climate change, especially variations in evaporation rates.
- Documented evidence for exponential decreases in water quality.

4.1 GLOBAL WARMING AND CHANGES IN EVAPORATION RATES

The NWRS acknowledges that climate is one of the factors that influence water requirement, but dismisses its importance in the "future water requirements" section, based on the assertion that "climate has in the past been a relatively stable factor" [20].

It also acknowledges that climate models predict "continental warming of between 1°C and 3°C", "reductions of the order of 5 to 10 per cent of current rainfall", "greater evapo-transpiration" and that "South Africa could realistically expect to experience a decrease in runoff of up to 10 per cent in some areas". The following statement then follows these acknowledgements: "It must be emphasised that these conclusions are not predictions or forecasts. They are at best projections of how the global climate system may possibly evolve in the future, and how such changes may affect climate on a local scale." The NWRS also makes the following statement in regards to climate change: "A balance will have to be sought between preparedness and overreaction, to prevent valuable resources being wasted." Not surprisingly, neither of the NWRS 2025 scenarios (Table 5) includes assessment of the effect that climate change will have in future on precipitation, river runoff, water yields or requirements.

It is prudent at this point to reiterate some of the points made earlier. South Africa is an arid country; less than 9% of precipitation is converted to river runoff, as a result of excess evaporation over precipitation. Every primary school child in South Africa knows that if you hang a wet T-shirt outside in the sun it will dry, and on a warmer (or windier) day it will dry faster.

The implications of climate change and global warming for South Africa (and most of Africa) is that simple: water reservoirs and rivers are going to run dry and they will do so faster and to unprecedented low levels. Rainfall patterns and amounts will also change and the models used to predict these changes are complicated, and there are uncertainties associated with these predictions. However, these uncertainties about how much it is going to rain, and where, should not be allowed to distract from the more important point: most of the water that rains down on us evaporates back into the atmosphere. In a warmer world, even more of the water that rains down on our arid landscapes will evaporate, and we will have less water 'to drink'.

4.2 DECREASING WATER QUALITY

Deteriorating water quality, in addition to limited water supply, are considered the biggest threats to development in Southern Africa [3]. In South Africa the evidence for deteriorating water quality is overwhelming [53-69].

The amount of water available should only feature in water balances if it is of good enough quality to meet user requirements, whether this user is the environment, humans, including agriculture, or industry. Yet, there is a complete lack of integration of water quality issues and its impact on water availability in the NWRS's water quantity assessments and future outlook scenarios. Water quality in South Africa is deteriorating rapidly as a result of the activities of three dominant sectors: agriculture, municipal waterworks or the lack thereof, energy production and mining.

Nutrient loading, in addition to climate change, are predicted to become the most severe drive of ecosystem change in Southern Africa [3]. Nutrient levels exceeding recommended water quality guidelines for aquatic plant life are observed in almost all of South Africa's rivers [53]. Statistically significant increases in dissolved phosphate levels are found in almost 60% of South Africa's rivers, with exponential increases over the last 20 years in some cases (Figure 6, adapted from [54]). This eutrophication of South Africa's river ecosystems is the result of uncontrolled discharge from dysfunctional sewage works, sprawling unsewered human settlements around urban areas, and excessive application of fertilizers by the agricultural community [53,54,56]. Toxic cyanobacterial blooms, one of the problems resulting from eutrophication, have become a recurring problem in major water reservoirs in Gauteng in particular [56,57], including the Hartbeespoort, Roodeplaats and Vaal dams. The extent to which nutrient pollution has filtered down to groundwater aquifers is unknown. The fertilizer-equivalent costs of these nutrient fluxes are estimated to exceed several hundred million rand annually [53]. The cost to the environment and its ecosystem services, and human health, has yet to be quantified, but is likely to be billions of rands.

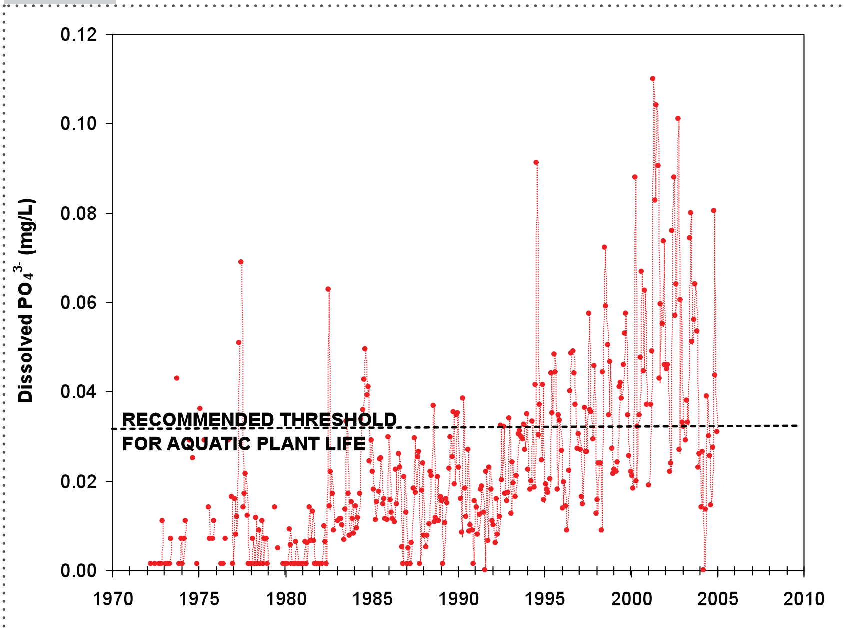
The most serious threat to South Africa's water resources (and economic growth) is dramatic worsening of H_2O quality resulting from wash-off and leaching from mining wastes, known as acid mine drainage (AMD) [58-63]. A graphic illustration of this is the increasing levels of dissolved sulphate in the Loskop Dam on the Olifants River in Mpumalanga (Figure 7), located downstream of the epicentre of South Africa's coal mining activities [64]. AMD results from the oxidation of sulphides, minerals such as pyrite, either during mining or subsequent to the closure of mines. The acidic fluids generated in the process promote the dissolution of toxic heavy metals, resulting in the pollution of surface and groundwater reservoirs. It typically results in water bodies becoming sterile i.e. the death of aquatic species such as fish, and renders H_2O unsuitable for consumption and irrigation purposes.

AMD is not exclusively associated with coal mining, but a problematic feature of the mining of mineral resources such as gold, platinum, base-metals etc. as well [58,61], because these metals are naturally embedded mostly in sulphide minerals from which they need to be chemically liberated before they can be used. In addition, the negative impact of mining on water resources is well illustrated by historical developments in the Witwatersrand goldfields. An extensive network of underground shafts, constructed to reach the rich gold deposits of the world's largest and deepest mines (2-4 km), have historically been prevented from flooding by dewatering of an exceptionally large overlying dolomitic karst aquifer [70]. Over the course of a century, dewatering has resulted in an estimated loss of 3 500 Mm^3 of water from one of Southern Africa's largest natural underground aquifers, a volume of water exceeding the storage capacity of the Vaal Dam [70]. The impact of deep-level gold mining on water resources not only have had dire consequences for agricultural activities for almost a century, but resulted in two of the three largest karst springs in the Southern Hemisphere drying up [70]. South Africa's glory days of gold mining, however, have come to an end, as was forecasted some 20 years ago [71]. Production in this biggest known gold field in the world peaked around 1970 and about 95% of the Witwatersrand goldfields now are uneconomic

and/or exhausted [72]. Gradual cessation of active underground mining activities since the 1990's, including pumping out of water to keep underground workings dry, have resulted in these underground voids being filled with naturally inflowing water again. The first surfacing of this water, termed mine decant, was observed in 2002 on the West Rand [70]. The chemical toxicity of this water that has been in contact with remaining sulphides and mine wastes dumped in the karst voids, and pollution of surface water bodies resulting from the decanting of such large volumes, is threatening the future of the very city built on and with this gold, Egoli [63], and will leave large parts of Gauteng awash with toxic water [70,73]. Now that the gold mining has largely run its course, extensive platinum mining, the new life-line of the South African mining industry, and now South Africa's major mineral earner, is likely to follow a similar path across the northeast provinces if left unchecked.

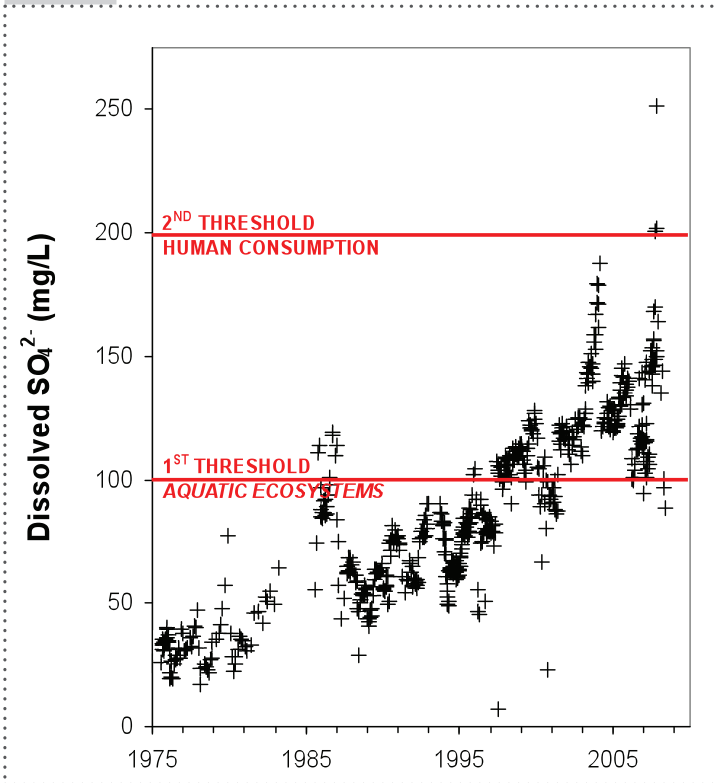
The environmental degradation resulting from more than a century's worth of gold mining activities is an indirect consequence of coal mining activities. The South African mining industry, the lifeblood of the southern African economies (SADC countries) for generations [74], has been powered by "cheap" coal-based energy and together with energy-intensive mining-related industries, consumes almost 50% of the total output supplied by the national energy supplier, ESKOM [75]. The dramatic deterioration of water quality in the Olifants River catchment, therefore, is the result not only of local coal mining, but gold and energy-intensive mining-related industries elsewhere in the country. AMD is manifesting in the Olifants River catchment despite the fact that coal mines in this area are still in production and relatively well-maintained. AMD in coal mining areas will become much more pronounced when mines close [76], as dramatically demonstrated in the West Rand gold mines already [58]. Exacerbating the outlook for water quality in South Africa's mining areas is a commitment by government to increase the country's reliance on coal. This will necessitate a dramatic increase in coal mining activities, in the Mpumalanga and Limpopo coalfields (Figure 3).

FIGURE 6



Long-term trend in dissolved phosphate levels in the Berg River, at the Dal Josafat (Paarl) DWAF monitoring station. Adapted from [54]. Exponential and linear fits to the data yield r^2 values of 0.44 and 0.36 respectively.

FIGURE 7



Long-term monitoring of dissolved sulphate levels at Loskop Dam on the Olifants River, adapted from [64]. Exponential and linear fits to the data yield r^2 values of 0.75 and 0.72, respectively.

4.3 ADDING WATER QUALITY + EVAPORATION TO THE WATER BALANCE EQUATION

If climate change results in a very moderately estimated 5% reduction in water yield by 2025, it will result in a 942 Mm³/a water deficit (7% of requirements) if added to the NWRS's 2025-BASE scenario (Table 8). If added to the 2025-HIGH scenario, the resulting water deficit will be 2 761 Mm³/a (18%) by 2025.

It should be remembered that the two NWRS future scenarios assume increased yields of 7% and 8.4%, respectively, which will require massive infrastructure development and financing. If these yield increases are not realised, but requirements increase as expected, then a 5% climate change impact will result in water deficits of -1 834 Mm³/a (14%) and -2 983 Mm³/a (19%), respectively.

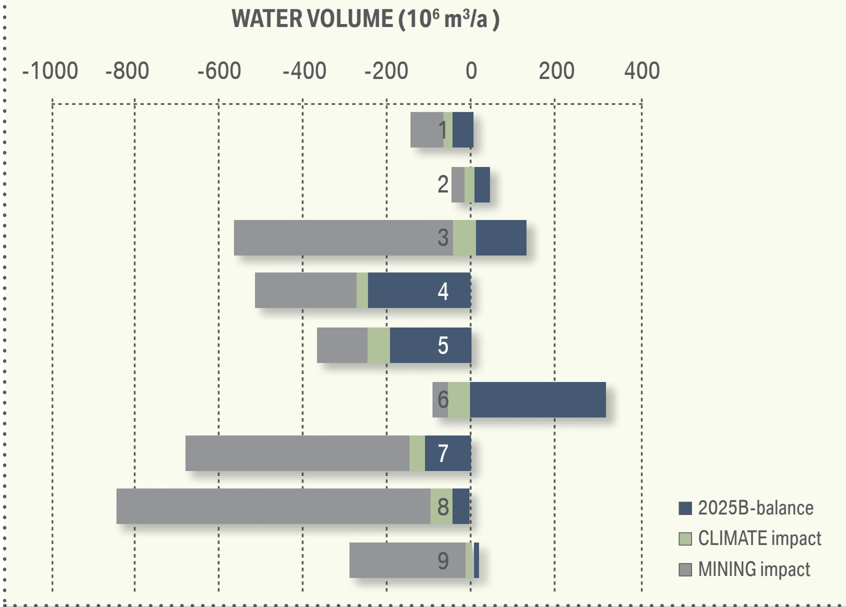
Suppose these conservative estimates of the impact of climate change on South Africa's water balance are left out of the equation, and water quality degradation related to mining activities only are considered. If mining is assumed to impact on the water quality of the yield derived from the catchments that drain mining areas only (i.e. propagation of pollution downstream and as a result of water transfers between WMA's are not taken into account) then a total amount of 2 590 Mm³/a of South Africa's water yield is at risk (Table 8). About 50% of this (1 315 Mm³/a) - the Upper Olifants, Upper Crocodile and Upper Vaal river catchments - is already severely contaminated [58-64]. If only this latter value, i.e. water already on the brink of becoming unusable, is added to the 2025-BASE scenario (n.b. without consideration of climate change impacts), it suggests a water deficit of 1 549 Mm³/a (12% of requirements) by 2025. It is just a matter of time before exponential decreases in water quality starts to manifest in other mining areas. Even the Vaal Dam, a massive water reservoir that should be well buffered against changes in water quality because of its sheer size, is showing definite signs of increased dissolved sulphate levels (unpublished DWAF data, S de Villiers).

Water quality deterioration will be accelerated by the massive increases in coal mining required to sustain South Africa's increased coal consumption trajectory. Even if coal mining activities do not expand, continued leaching of pollutants from existing active and dormant mines will result in the water draining from these areas becoming contaminated by AMD eventually [77]. An added concern is the decreasing quality of coal, which will necessitate that an increased amount of coal be mined, and washed, to produce an amount of energy equivalent to that obtained from higher quality coal. The high and increasing number of coal mines and prospecting companies that are operating without water licenses [67] and that are, in the absence of an approved national strategy for the rehabilitation of abandoned mines [78], being allowed to flaunt environmental legislation, is another serious concern.

4.3.1 THE MORE REALISTIC (THAN NWRS'S 2025-BASE) FUTURE SCENARIO

If a very modest 5% reduction in yield as a result of climate change (942 Mm³/a) and an equally moderate 1 315 Mm³/a reduction in yield as a result of water quality degradation from AMD is added to the 2025-BASE scenario, it suggests a water deficit of 2 491 Mm³/a, or 19% of requirements (Figure 8). We believe that this is a more realistic, yet

FIGURE 8



Graphic representation of the predicted impact climate and mining will have on the NWRS's projected 2025BASE scenario, as discussed in the text. Numbers 1 to 9 along the vertical axis represents the Water Management Areas that are predicted to be impacted on my mining, as summarised in Table 8.

TABLE 8

WATER MANAGEMENT AREA	NWRS-2025BASE		-5%: CLIMATE		MINING		CLIMATE +MINING		* ORIGIN OF IMPACT
	YIELD	BALANCE	YIELD	BALANCE	IMPACT*	BALANCE	YIELD	BALANCE	
1 LIMPOPO	281	-48	267	-62	-83	-131	184	-145	Coal in Mokolo catchment; 40% of SA reserves
2 LUVUVHU	404	42	384	22	-27	15	321	-5	Coal in Mutale catchment
3 CROCWEST	846	125	804	83	-336 -186	-397	282	-439	Gold-AMD in Upper Crocodile Pt mine dewatering in Apies/Pienaar
4 OLIFANTS	630	-242	599	-274	-238	-480	361	-512	Coal mining in Upper Olifants
5 INKOMATI	1 028	-197	977	-248	-118	-315	859	-366	Coal mining in Upper Inkomati
6 USUTU	1 113	311	1 057	255	-5 -33	273	1 019	217	Coal in Mfolozi catchment Coal mine decant - Mkuze
7 THUKELA	742	-111	705	-148	-398 -136	-645	171	-682	Coal mining in Upper Thukela Coal mining in Buffalo catchment
8 UVAAL	1 229	-42	1 168	-103	-184 -557	-783	427	-844	Upstream of VaalDam: coal, gold, Sasol, iron Downstream of VaalDam - gold
9 MVAAL	55	9	52	6	-142 -147	-280	-237	-275	Gold in Vaal catchment Gold in Sand-Vet catchment
10 LVAAL	127	57	121	51	0	57	121	51	
11 MVOTI	555	-423	527	-451	0	-423	527	-451	
12 MZIMVUBU	872	459	828	415	0	459	828	415	
13 UORANGE	4 734	88	4 497	-149	0	88	4 497	-149	
14 LORANGE	-956	-7	-1 004	-55	0	-7	-1 004	-55	
15 FISH/TSITS	456	71	433	48	0	71	433	48	
16 GOURITZ	278	-76	264	-90	0	-76	264	-90	
17 OLIFANTS	335	-32	318	-49	0	-32	318	-49	
18 BREEDE	869	36	826	-7	0	36	826	-7	
19 BERG	568	-67	540	-95	0	-67	540	-95	
TOTAL	14 166	-234	13 458	-942	-2 590	-2 824	10 738	-3 532	
WATER DEFICIT		-1.7%		-7.0%		-19.9%		-32.9%	

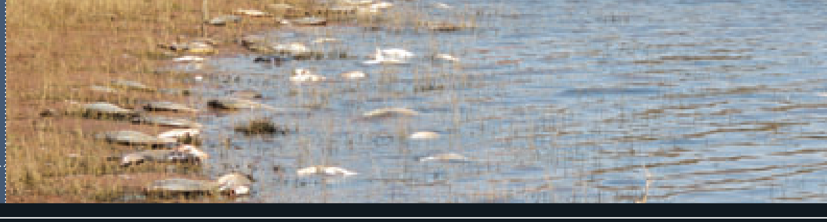
Predicted impact of climate change, coal and gold mining on future water quality and local yield (Mm^3/a) in South Africa's Water Management Areas, based on evidence for water quality degradation at existing and abandoned mines.
The total yield impacted on by coal mining adds up to 1 308 Mm^3/a (calculated from the sum of "Impact*" amounts in the "Mining" column with coal as the "Origin of Impact").

conservative estimate of South Africa's water balance by 2025.

4.3.2 THE MORE PROBABLE FUTURE SCENARIO

The increased water yields required by the NWRS future scenarios are unlikely to be realised for a variety of reasons, including water quality degradation related to nutrient pollution [53], not factored into the above calculations. Huge financial constraints imposed by increased development of the coal (and nuclear) energy sectors will severely limit the availability of funds that will be required to unlock South Africa's "unexploited" water potential, and doing so will come at great cost to river catchments and the ecosystem services they provide.

Both industry and government are already struggling to cope with the comparatively modest financial aspects of on-going water quality degradation. The same financial constraints will limit the availability of funds that will be needed to transform 2 590 Mm^3/a of water heavily contaminated by toxic chemicals, into water suitable for human consumption or for irrigation purposes. A more probably future scenario, therefore, consist of the following, still moderate, additions to the NWRS-BASE scenario: no increased yield compared to 2000, a 5% reduction in yield as a result of climate change, and a 2 590 Mm^3/a reduction in water yield as a result of AMD pollution. This, more probable, scenario suggests a water balance deficit of 4 424 Mm^3/a, which is 33% of the estimated 2025-BASE water requirements. South Africa will have even less water 'fit to drink'.



5. The estimated future

COST OF WATER TREATMENT AND PURIFICATION

5.1 ACKNOWLEDGED COSTS

In first-world countries "full cost pricing" is considered one of the seven pillars of sustainable water use [79], the other pillars being demand management, public education, linking water conservation to development and construction approvals, reduction of water system leakage, creation and implementation of bylaws promulgating the fitment of low-flow water fixtures in all new buildings, and water re-use, effluent treatment and storm water capture.

In a developing country such as South Africa, achieving "full cost pricing" arguable presents the biggest challenge to establishing these "pillars" for sustainable water use.

It is estimated that on the order of R100 billion is needed to address currently outstanding maintenance work on municipal water treatment plant and supply systems [9]. This is the minimum amount that needs to be spent to ensure that the country's future water yield will at least match current values, and to reduce the cost of pollution to the environment. The enormous increase in media reporting on water quality issues in South Africa over this last year in particular, is a stern warning sign of the magnitude of the problem and growing public concern regarding this problem [57,66-69,80].

The absence of access to proper sanitation facilities in informal settlements, for example, is resulting in pollution of not only surface water bodies, but also the groundwater resources South Africa is destined to become very reliant on. The call for huge financial injections to re-establish the functionality of municipal water treatment plants is motivated not only by the need to reduce nutrient and microbial pollution of surface and groundwater resources, but also the increased importance of water recycling in South Africa's future water outlook scenarios. Presently 14% (1 899 of 13 227 Mm^3/a, Table 6) of the total "Local reliable yield" derives from "Return flows".

These return flows constitute water used (i.e. these amounts are also counted as "Requirements"), which gets re-used after treatment, or released back into the environment. Most of this derives from urban water recycling (970 Mm^3/a), followed by irrigation (675 Mm^3/a) and mining & industry (254 Mm^3/a). It is envisioned that the required future increases in yield will partly be derived from increased water recycling [20].

Water recycling requires "sophisticated treatment processes and proper management" [20], and increased yield from enhanced water recycling will materialise only if the outstanding maintenance to existing infrastructure takes place, at an estimated cost of R100 billion [9], in addition to establishing the more sophisticated treatment plants needed to re-cycle water originating from the mining industry.

Desalination has long been considered too costly to be a viable means of increasing South Africa's fresh water yield. The fact that desalination plants are now being considered and constructed by several municipalities along South Africa's coast [81-83], despite the huge costs involved (Table 9), is proof of the increasingly challenged situation many municipalities are finding themselves in.

In Cape Town for example, provision of water from desalination of cold, nutrient-rich seawater will increase the production cost of water about 7-fold [82] (Table 9) to 15-fold [45]. Both the 2025-BASE and 2025-HIGH scenarios predict water shortages for the Berg WMA, the Cape Town metropole's main source of water, of 67 and 508 Mm^3/a, respectively (Table 5). If these shortfalls are to be countered with desalination plants, just the capital cost component (at R530 million

TABLE 9

TREATMENT OPTION	CAPACITY		CAPITAL COST		CAPITAL REDEMPTION	OPERATE+ MAINTENANCE	PRODUCTION COST
	Ml/d	Mm³/a	R million	R/Ml/d cap	R/kl	R/kl	R/kl
CONVENTIONAL [72]							
Rand Water (6 plants)	5 260	1 920	?	-	?	Estimated R100 billion needed for outstanding maintenance to existing infrastructure	2.53
City of Cape Town	various	-	?	-	?		1.05 - 1.25 (water only)
Amatola Water (rural)	various	-	?	-	?		3.39
DESALINATION [72]							
Groundwater	5	1.8	16.1 - 24.5	3 - 5	1.1 - 1.7	1.3 - 3.2	2.40 - 4.90
Seawater	5	1.8	40 - 63	8 - 13	2.8 - 4.4	3.0 - 4.0	5.80 - 8.40
	50	18	338 - 530	7 - 11	2.4 - 3.7	2.6 - 3.3	5.00 - 7.00
e.g. Sedgefield-seawater	1.5	0.5	16	10.7	3.8	~3.0	~6.76
MINE DECANT [62]							
Western Utilities Corp	150	55	1 500	10	?	= mineral recovered?	?
Anglo Coal	20	7	200	10	?	= mineral recovered?	?
EARTH	?	?	?	3 - 5	?	= mineral recovered?	?

Estimated costs of different water treatment options. Capital redemption cost is calculated assuming a 25 year plant life, and 12% annual interest rate [82].

per 18 Mm³/a capacity, Table 9) will be on the order of R2 to 15 billion.

In more remote locations, for example those served by Amatola Water in the Eastern Cape province, desalination of ground- or seawater will result in an increased production cost that is "only" up to 3 times current production cost, with production cost in such remote locations already almost 3 times that in urban areas (Table 9). The death of 131 babies in the Ukhahlamba district between January and April 2008, purportedly as a result of poor water quality in the area [80], is a stark reminder of the consequences of a lack of access to clean water, particularly in poor communities for whom the purchasing of bottled water or household water purification systems are not an option.

It should also be noted that methods that can be used to reduce evaporation of water in storage is actively researched as national priorities in dry countries such as Australia and in the Middle East [84-86]. This includes research into the relative effectiveness of different evaporation reduction strategy techniques, such as floating covers and objects versus shade structure. One of the important advantages of shade structures, for example, is that it does not significantly impact on water quality. Although evaporation control measures such as shade structures have been demonstrated to achieve up to a 70% reduction in water evaporation, the capital cost associated with installation is still prohibitive. There is much food thought for thought for South Africa in consideration of such technologies to improve the country's water requirements.

5.2 ESTIMATED COSTS OF TREATING MINE DECANT

Further evidence for South Africa's water crisis is to be found in proposals to purify water decanting from abandoned mines in the Witwatersrand area, also despite the minimum R2 billion estimated costs that will be involved [63,65,66].

Acid mine drainage and mine water decant require much more sophisticated water treatment processes than that used in conventional or desalination plants, primarily to remove toxic heavy metals, including radioactive elements such as uranium. Also, the very high acidity of these waters will result in higher operating costs, associated with the shorter life-time and more frequent replacement of consumables such as filters and ion exchange resins.

It is curious that, despite the more sophisticated chemical treatment required, the capital cost of treatment plants for mine water is estimated to be equivalent to or even lower than that of desalination plants (Table 9). Another interesting difference between desalination and the proposed mine water decant plants is the estimated production cost. In desalination plants the capital redemption cost is almost equivalent to operational plus maintenance costs, resulting in total production costs on the order of 2 to 7 times that of conventional plants depending on location and the chemical properties of the water to be treated (Table 9). The estimated cost of water derived from treatment of mine decant, however, is based on a pricing model that assumes that operational and maintenance costs will be covered by the money derived from recovered precious metals (Table 9), i.e. that production cost is equal to capital redemption cost only.

The financial viability of the proposed schemes to treat mine decant, and the extent to which such treatment options will come at the expense of the consumer, deserves greater scrutiny and has been rightly questioned [65].

5.3 UNQUANTIFIED EXTERNAL COSTS

Another critical factor that has to be considered is that the amounts of water used by the different sectors are much smaller than the amounts of water contaminated as the result of these uses.

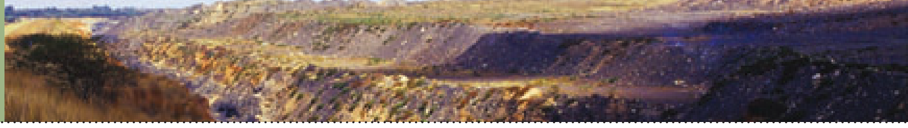
For example, the generation of electricity at coal-fired power stations currently requires 297 Mm^3/a, that is only 2.3% of total water requirements (Table 6).

However, acid mine drainage resulting from coal mining is already impacting on 1 038 Mm^3/a of total yield (Table 8), that is more than 3 times the amount of water used by power stations, and 8% of total current national water yield. Additionally, acid mine drainage from any particular mine will continue for decades [77], with a final cumulative impact on water yield (and quality) that will exceed the actual amount of water used during electricity generation, by at least a factor of 100.

The new Medupi coal-fired power station in Limpopo is a good example of the externality costs related to the impact of coal-based power generation, on water resources. Much has been made of the fact that Medupi will be the world's largest "dry-cooled" coal-fired power station [87]. However, the Medupi power station will still need an estimated 16 Mm^3/a of water [66].

The Limpopo WMA, in which it is based, already has a water deficit of 123 Mm^3/a, which is projected to increase to 148-161 Mm^3/a by 2025 (Table 5, Table 6). These water deficit values are the revised values discussed earlier. The magnitude of the revision (100 Mm^3/a) from published NWRS values is interesting in the context of the anticipated importance of the Limpopo province to increased coal mining and coal-based power in South Africa.

Clearly, there is not enough water in the Limpopo WMA to supply Medupi, and quite a lot less than the values stated in the NWRS, and reported on widely in the media, used to argue against the construction of Medupi [63]. Statements by government officials about transferring water from the Crocodile West/Marico WMA, which is already sourcing



most of its water through very expensive transfer schemes from Lesotho, have no cost estimates associated with it [66,87].

Also lacking in most of these discussions and commentary is mention of the fact that the coal for Medupi will be sourced primarily from the Waterberg area, i.e. this is the area where water quality degradation from acid mine drainage will eventually resemble the current situation in the Olifants River in Mpumalanga (Figure 7). Coal mining will not only have dire environmental consequences for the currently almost pristine Waterberg Biosphere area, but AMD resulting from it will eventually impact on yield in a WMA already under severe pressure from other human activities, such as agriculture and urban development. This is the one WMA in the country where there is clear evidence that groundwater is already over-exploited [20].

The construction of the Medupi power station, however, is about much more than the 16 Mm^3/a water it will need, and the impact coal mining will have on still pristine river ecosystems. If coal-mining in Limpopo increases as anticipated, the negative impact on the scarce water resources of this poverty-stricken province will very likely result in the decimation of valuable agricultural activities, as is observed in other coal mining areas [67], increased tension and competition over scarce resources between locals and refugees from neighbouring Zimbabwe, and mass migration of people from the province. That will be some of the unquantified socio-economic costs (presently still externalities) associated with the generation of an additional 4 800 MW of coal-based electricity.

5.4 THE COST OF THE "MORE PROBABLY FUTURE SCENARIO"

According to the "more probably future scenario", the country will have a water deficit of 4 424 Mm^3/a by 2025, 2 590 Mm^3/a of this resulting from the impact of AMD pollution on yield.

Suppose this deficit is countered as follows: (a) construction of specialised water treatment plants to clean a total minimum volume of 2 590 Mm^3/a of mine water, and (b) construction of desalination plants to produce 1 834 (4 424 - 2 590) Mm^3/a of potable water.

The capital cost required (if equivalent to that of a seawater desalination plant at R530 million per 18 Mm^3/a capacity, Table 9), will be (a) more than R76 billion and (b) R54 billion, respectively. If operational and maintenance costs is equivalent to capital expenditure (Table 9), it amounts to a total minimum water production cost of R260 billion (if the treatment plants have a 25 year lifespan). If the estimated R100 billion required for outstanding maintenance work on existing infrastructure is added to this, it amounts to a minimum amount of R360 billion that is needed to secure South Africa's water within a mere 15 years time.

This enormous cost is primarily the result of the destruction of the ecological integrity of river catchments, and the loss of the ecosystem services such as water supply and water quality, that are provided for free by healthy ecosystems. In urbanised areas water treatment plants provide the water cleaning services that healthy rivers provide, and buffer communities from changes in ecosystem services resulting from development [3]. When water treatment plants become dysfunctional, however, or their capacity is exceeded, the loss in ecosystem services is amplified and the financial cost associated with this loss becomes magnified. Wetland degradation and destruction in the Mpumalanga coal fields, for example, directly contributes to water quality degradation in river catchments such as the Olifants River.

The loss of the water purification services provided freely by healthy wetlands and river systems can be compensated for to some extent with water treatment plants, but the associated financial costs are very substantial, as calculated above, yet in line with predicted costs of the loss of similar ecosystem services on a global scale [88].

Interestingly enough, the minimum cost associated with securing South Africa's water future estimated above, is almost exactly the same amount that ESKOM requires to implement its envisioned increased coal-power generation capacity [7]. To this needs to be added indirect costs, such as the estimated minimum R30 billion needed to rehabilitate abandoned mines in South Africa [78]. South Africa is not alone in its lack of a national strategy to deal with the public health risks and environmental disasters resulting from AMD, as illustrated by a study in the UK [76]. Even more disturbing, however, is increasing evidence for the extent to which coal mining in particular is impacting on soil and water quality in agricultural areas, and therefore food security [67]. About half of South Africa's most productive agricultural land is underlain by coal reserves, and dramatically increased mining activity in these areas is allegedly threatening about 50% of the country's grain production [67].

6. Solving [ENERGY + CO_2 + H_2O] EQUATIONS FOR SOUTH AFRICA

IMPORTANT WATER-ENERGY PARAMETERS AND FACTS [8]

- Up to 3.0 m^3 of H_2O is required to produce 1 MWh of electricity from coal.
- Up to 6.5 m^3 of H_2O is required to produce 1 MWh of electricity from oil.
- 32.2 to 360.0 m^3 of H_2O is required to generate 1 MWh of electricity from biofuels.
- No H_2O is consumed during the production of electricity from solar or wind turbines.
- In the U.S.A. energy consumption accounts for about 39% of water withdrawals, and water consumption for energy production is expected to increase by 165% between 2000 and 2025 under business-as-usual scenarios.
- In the EU, the above numbers are 50% and 130% respectively.

6.1 SOLAR PV LIDS = GREEN ENERGY + CLEAN WATER

It is clear from the NWRS's conservative estimates of future water availability that South Africa will run into a permanent water deficit by 2025.

Inclusion of even moderate estimates of water yield reductions that will result from climate change and water quality degradation, suggests a bleak future with dramatic water shortages. What follows is a presentation of how South Africa can secure for itself a future with an adequate supply of water, and an adequate supply of energy, without having to excavate more coal.

A plan to solve South Africa's water and energy crises is at hand, and the discussion that follows demonstrates its feasibility. It will require massive investment in the manufacturing sector. For a country such as South Africa, with an official employment rate of 24.5% (www.statssa.gov.za), and with almost a million people purged from the job market in 2009 alone, many of them highly skilled mining and manufacturing industry workers, the technological challenges associated with this plan are not an obstacle. It is a fantastic opportunity. All that is required for this plan to be implemented, and for South Africa's water and energy security to be secured, is political will.

6.1.1 PUT A LID ON IT

It has been mentioned several times in this report that in South Africa's current climatic conditions most of the mean annual precipitation is lost through evaporation. The NWRS [20] estimates that 8% of South Africa's mean annual runoff is lost through evaporation from storage dams alone, that is 3 923 Mm^3/a of water (from MAR values in Table 5).

As discussed above, the chloride content of South Africa's fresh water systems suggests that more than 50% of mean annual runoff may be lost through evaporation in total (Table 7). These are large volumes of water, in the context of the water balance deficit values discussed earlier. The following calculations show that future water deficits can be overcome and water yield increased considerably, by reduction of evaporation of water in storage dams.

To reduce evaporation of water from a bowl left outside in the sun, one puts a lid on the bowl or places the bowl in the shade. South Africa has a "water bowl" storage capacity of 32 412 Mm^3, in the form of storage dams (Table 5). These storage dams have a combined surface area in excess of 2 000 km^2 (Table 10). Covering such a large area, or parts thereof, to prevent evaporation will be no small task. However, calculations show that the water yield to be gained from retaining as little as 8% of water in storage will be enough to secure South Africa's water future (Table 10). Undertaking such a huge task is well motivated by another consideration, the need to secure South Africa's future energy needs, preferably without the use of coal and certainly not at the expense of its water resources.

It has also already been mentioned that South Africa has a very high incidence of solar radiance, about 220 W/m^2. Solar photovoltaic panels have an energy efficiency conversion ratio of 10% to 20%, and efficiency will increase as technological advances are made [19]. An area of 2 000 km^2 of 10% efficient PV panels will produce 44 GW (44x10^9 W) of power; more expensive 20% efficient PV panels will produce 88 GW. South Africa's current annual power generation capacity is about 40 GW [89]. Solar power is estimated to generate 40 times more jobs per W than coal and other fossil fuels [90]. ESKOM employs 32 674 people [83]; 40 times that is more than 1.3 million new jobs.

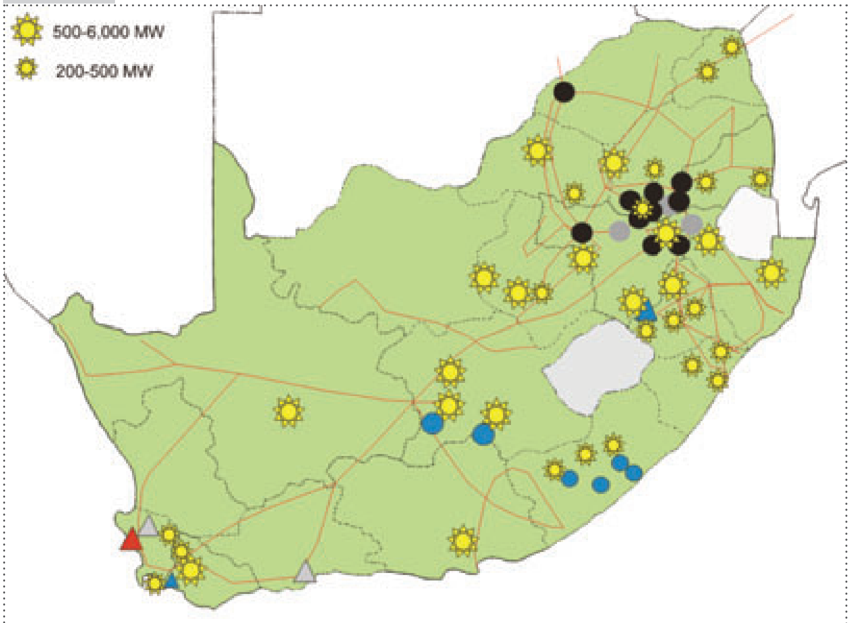
Solar power is viewed as critical to breaking the world's addiction to fossil fuel, but is still in many respects lacking in development, appropriate economies of scale and storage technology [6,91,92]. The South African government Department of Energy has proposed the concept of the country's first solar park near Upington in the Northern Cape, with up to 5 GW of peaking and base-load solar electricity to be phased in over a ten-year horizon [93,94]. However, it will need an estimated R150 billion in private investment, which will be challenging to obtain given ongoing uncertainty surrounding government guarantees for power purchase agreements with private producers [93,95]. Despite the challenges that remain to be overcome, this is a positive development and guaranteed to be a better investment than the abandoned pebble bed modular reactor (PBMR) project, which cost more than R9 billion rand [96]. Importantly, the concept of a solar park in South Africa mirrors other large solar projects, such as Desertec [19,97].

The goal of Desertec is to build huge solar farms in the Sahara, capable of producing 500 GW of electricity by 2050, to be transmitted to Europe. If this is realised it will meet 15% of Europe's energy needs by 2050 [97]. More than 200 bidders have already expressed interest in the first phase, a $9 billion, 10-year plan to build solar power plants producing 2 GW of power, in Morocco. It is envisioned that the power will be transmitted to Europe via high-voltage direct-current (HVDC) transmission, technology not currently in use in Europe, but already well established and in use in South Africa. Similar projects, on a smaller scale, are being considered or already in use in the U.S.A. and Australia.

Suppose then that we combine the concepts being developed in countries such as Australia to reduce water evaporation from storage dams, with the concept of large solar parks and the use of solar power as a viable primary source of energy, as envisioned by Desertec for example [97].

If we cover 75% of the surface area of South Africa's 6 largest storage dams with PV panels (Table 10), with enough space reserved for continued recreational activities, the reduction in water evaporation and increase in water yield resulting from this is estimated to be 1 379 to 3 448 Mm^3/a (Table 10). The electricity generated in the process will be equal to half or all (depending on PV panel efficiency) of South Africa's current power generation capacity. The result of this conceptual exercise speaks for itself. By integrating water and energy issues, i.e. by combining the concepts being developed internationally to safeguard a supply of both, and by looking beyond coal and towards solar, South Africa can secure its future water and energy needs. It is possible to have energy consumption everywhere (Figure 9), and enough water fit to drink.

FIGURE 9



Idealised view of the incorporation of photovoltaic "solar island" power stations into South Africa's existing national grid (red lines), taking into account the dams listed in Table 10. Also shown are current active (black circle) and mothballed (grey circles) coal-fired power stations, nuclear power (red triangle), open-cycle gas turbines (grey triangles), hydro-electric power stations (blue circles) and pumped-storage power stations (blue triangles). South Africa's power generation capacity (current and planned) is listed in Table 11.

6.2 DISUSED MINES = GEOTHERMAL ENERGY + CLEAN WATER

South Africa has the largest underground water storage capacity in the world, created manually by human capital and a lust for gold, beneath it largest metropolitan districts in Gauteng, notably beneath "Egoli" - Johannesburg and surroundings.

As discussed earlier, mine decant resulting from re-watering of abandoned and disused mines in the Witwatersrand goldfields poses a significant threat to surface water quality in South Africa's historical economic heartland. As also shown, the cost of treating this water to potable standards may be prohibitive with little guarantee for financial sustainability [63].

However, it has been argued recently that the end of traditional gold mining offers new opportunities for resource development and associated socio-economic economic upliftment, turning long-term financial liabilities of government and the mining industry into sustainable assets. Examples include the restoration of the karst aquifers to store large volumes of water using artificial groundwater recharge and harvesting, as well as underground generation of hydropower [70].

The costs and technical feasibilities of these ideas are well worth exploring, particularly within a framework of the well-recorded past-environmental wealth and agricultural/tourist potential of the region; and in light of the past self-serving political and economic arrangements imposed on the area by deep-level mining [98].

In addition, potable evaporation-free water storage in voids left by deep-level gold mining beneath the city of Johannesburg, with a population of over 10 million, could become a reality if nature's 'free' geothermal services are used as the source of energy.

6.2.1 GO UNDERGROUND

Shallow geothermal heat mining has been attempted successfully in many parts of the world where geothermal gradients are high, including in east Africa. More recently pilot studies in Europe and elsewhere are aimed at tapping shallow geothermal energy in areas of low geothermal gradients such as measured in South Africa.

By contrast, attempts at deep geothermal heat mining, especially those tapping hot geothermal fluids are less common. Ongoing experiments in Iceland have been particularly successful (www.iddp.is).

Here drilling at 2-5 km reach supercritical fluids from which energy can be economically mined [99]. Active drilling and testing in low enthalpy reservoirs at 2-4 km (similar to the depth of the Witwatersrand gold mines) for the generation of geothermal electricity are ongoing at Gross Schlönebeck, Germany (see International Centre for geothermal research at GFZ-Potsdam, Germany - www.gfz-potsdam.de). Drilling 2-4 km starting from the lowest levels in South African gold mines can reach depths of up to 6-8 km, in principle deep enough to simulate these studies.

Egoli's 'empty' gold mines - deep man-made cavities in hard quartzites that directly underlie the karst-pocketed dolomites - present potentially the world's largest artificial aquifer with a potential for hot aqueous mining. These cavities are so large and the gentle geothermal heat flow sustainable enough (51 mWm-2) [100] that they could provide significant energetic opportunities.

It should be possible to flood these cavities and simultaneously exploit the low geothermal gradient (ca.18°C/km) to help chemically cleanse the water and protect this and overlying aquifers, thereby preventing dispersal of mining related pollutants. The deep accessible excavations may allow for cost-effective sampling of deep circulating groundwater that can provide a source of potentially extractable metals and geothermal energy.

A sustainable solution to the remediation of gold mine acid mine drainage requires the development of the economic potential of the groundwater resource as treated raw water supply, as geothermal energy by heat transfer and perhaps even as a resource for the gold left-overs, and potential new resources beyond the depths of safe and economic manual mining that mostly have now been exceeded.

A theoretical thermodynamic scheme is being investigated to evaluate the use of the existing geothermal energy to sustain an aqueous biogeo-chemical exchange system, and if found feasible, a pilot project will be developed aimed at using this anthropogenic aquifer as a coupled reservoir/source of potable water reservoir and an energy source for the overlying mega-city.

If successful, there will be no evaporation loss from this underground storage of clean water. Internalising the energy costs saved by using natures own 'free' geotherm will bode well also for CO_2 emission reductions, and

TABLE 10

DAM (Province)	RIVER	STORAGE CAPACITY		SURFACE AREA		YIELD GAIN = 8% OF CAPACITY	YIELD GAIN = 20% OF CAPACITY	POTENTIAL POWER 10% EFFICIENCY +75% AREA	POTENTIAL POWER 20% EFFICIENCY +75% AREA
		Mm^3	Cumulative	km^2	Cumulative	Mm^3	Mm^3	MW	MW
Gariep (FS)	Orange	5 343	5 343	352	352	427	1 069	5 811	11 621
Vaal (FS/G)	Vaal	2 610	7 953	323	675	209	522	5 325	10 651
Bloemhof (NW)	Vaal	1 218	9 171	231	906	97	244	3 807	7 613
Vanderkloof (FS)	Orange	3 187	12 358	133	1 039	255	637	2 201	4 402
Pongolapoort (KZN)	Pongola	2 267	14 625	133	1 172	181	453	2 190	4 380
Sterkfontein (FS)	Nuwejaars	2 617	17 242	67	1 239	209	523	1 110	2 220
Rhenosterkop (LIM)	Elands	206	17 448	62	1 301	16	41	1 030	2 059
Teewaterskloof (WC)	Sonderend	480	17 928	51	1 352	38	96	839	1 677
Heyshope (M)	Assegaai	453	18 381	50	1 402	36	91	829	1 658
Vanwyksvlei (NC)	Vanwyksvlei	143	18 524	50	1 452	11	29	824	1 648
Brandvlei (WC)	Breede	301	18 825	41	1 493	24	60	679	1 357
Grootdraai (M)	Vaal	356	19 181	39	1 532	28	71	640	1 281
Kalkfontein (FS)	Riet	258	19 439	38	1 570	21	52	622	1 244
Molatedi (NW)	Marico	201	19 640	36	1 606	16	40	589	1 177
Ntshingwayo (KZN)	Nsama	195	19 835	34	1 640	16	39	568	1 136
Darlington (EC)	Sundays	188	20 023	35	1 675	15	38	570	1 139
Erfenis (FS)	Vet	212	20 235	33	1 708	17	42	542	1 083
Woodstock (KZN)	Tugela	373	20 608	29	1 737	30	75	481	961
Allemanskraal (FS)	Sand	179	20 787	26	1 763	14	36	437	874
Mthata (EC)	Mthata	254	21 041	25	1 788	20	51	419	839
Loskop (M)	Olifants	374	21 415	24	1 812	30	75	401	801
Albert Falls (KZN)	Umgeni	289	21 704	24	1 836	23	58	388	776
Hartbeespoort (NW)	Crocodile	195	21 899	21	1 857	16	39	341	682
Qedusizi (KZN)	Klip	133	22 032	20	1 877	11	27	323	647
Middle Letaba (LIM)	Middle Letaba	173	22 205	19	1 896	14	35	310	620
Driekoppies (M)	Komati	251	22 456	19	1 915	20	50	309	617
Kwaggaskloof (WC)	Wabooms	175	22 631	17	1 932	14	35	278	557
Voelvlei (WC)	Voelvlei	168	22 799	16	1 948	13	34	260	519
Nandoni (LIM)	Levuvuhu	164	22 963	16	1 964	13	33	259	518
Midmar (KZN)	Umgeni	175	23 138	16	1 980	14	35	258	516
Spioenkop (KZN)	Tugela	272	23 410	15	1 995	22	54	253	505
Inanda (KZN)	Umgenci	252	23 662	15	2 010	20	50	241	483
Ncora (EC)	Ncora	150	23 812	14	2 024	12	30	230	459
Xonxa (EC)	White Kei	121	23 833	13	2 037	10	24	213	425
Kwena (M)	Crocodile	159	23 992	13	2 050	13	32	206	413
Zaaihoek (M)	Slang	185	24 177	12	2 062	15	37	205	411
Witbank (M)	Olifants	104	24 281	12	2 074	8	21	200	400
TOTAL						1 951	4 876	34 184	68 369

Estimated increased water yield from South Africa's 37 largest dams water (representing 24 281 Mm^3 of the country's total 32 412 Mm^3 storage capacity), from reduced evaporative loss associated with surface coverage with PV solar islands. Also given are estimated power generation capacity, assuming use of photovoltaic panels with 10% energy generation efficiency, coverage of 75% of dam surface, and 220 W/m^2 solar power. Also shown is power generation capacity with the use of more expensive PV's with 20% efficiency.

could result in a long term positive legacy of South Africa's gold mining industry. It is an investment well worth considering, given the externality costs that the industry will have to come to terms with if the water pollution cost are passed on to them. It certainly makes little sense at this stage for government to nationalise these perceived assets and pass on the hidden costs to the people.

Once solved, the same principles can be applied even easier to deep, mined out platinum mines of the Bushveld Igneous Complex, where the heat flow (or geotherm) is significantly higher, and the potential for large scale chemical ion-exchange-for-clean-water can be achieved with greater ease to generate rural water supplies for the ex-mining communities. The disused mines would be converted from liabilities into assets, in which case their 'nationalisation' may well turn out to be profitable.

6.3 DOING THE SUMS: ENVIRONMENTALLY SOUND NATIONAL PLANNING = (ENERGY + H_2O − CO_2)

The most vociferous argument for a continuation of, and increase in, South Africa's reliance on coal-based energy production has always been that it is cheap, and cheaper than alternative sources of energy, particularly renewable sources such as solar.

Eskom's capital expansion budget is "R385 billion up to 2013 and is expected to grow to more than a trillion by 2028. Ultimately Eskom will double its capacity to 80 000 MW by 2026" (www.eskom.co.za /live/content.php?Item_ID=5981).

According to Eskom's current planned capacity expansion programme (summarised in Table 11), this R385 billion investment will yield an additional 6 984 MW of capacity, primarily from increased use of coal-based energy (5 650 MW). This amounts to a R55 billion capital investment per GW of additional capacity, and excludes the costs associated with the adaptation of clean technologies, such as desulphurisation and carbon capture and storage.

The first noteworthy observation is that the construction of "dirty coal" technologies in South Africa appears to be twice as expensive as "clean coal" technologies in the UK (Table 12). Concern has rightly been raised in the media about the hugely inflated cost of establishing power generation capacity in South Africa, compared to other countries. These inflated costs are not restricted to increasing coal-based energy generation capacity. The 40 MW "Tsitsikamma Community Wind Farm" project would cost about R1 billion [101], which is equivalent to R 25 billion/GW, i.e. almost twice the estimated cost of establishing wind farms in the UK [19]. Similarly, ESKOM's R5 billion spent on a 100 MW CSP pilot plant (www.eskom.co.za), equates to R500 billion/GW, more than 3 times the estimated cost in the UK [19].

A second important observation is that the R55 billion/GW capital cost calculated above, is almost equivalent to the per GW cost of constructing the photovoltaic farms ("solar lids") proposed in this manuscript as a solution to South Africa's future energy need requirements. Thus, coal-based energy is not cheaper than other options. Solar farms, such as those proposed in this report and already established in some parts of the world (e.g. Solarpark in Bavaria and similar plants in California) [19], are envisioned to become the primary future sources of energy in the world (www.desertec.org), and South Africa has amongst the highest solar energy potential globally [19].

The strongest (financial) argument against continued investment in additional coal-based power generation capacity, however, lies not in the direct capital cost factors discussed above, but in the costs associated with water pollution resulting from coal mining, and the carbon capture and storage technologies that will be required if climate change mitigation strategies are adopted.

If a volume of water equivalent to that already impacted on by coal mining is considered (a cumulative 1 222 Mm^3/a derived from the data in Table 8), a capital cost investment in water treatment plants on the order of R36 billion will be required to provide the capacity needed to treat this water to usable standards (at R530 million/18 Mm^3 capacity). If the annual operational and management costs of these plants are equivalent to a capital redemption cost of R4 billion/a (at 10% over 25 years), then **the total cost for water remediation in coal mining areas (capital cost redemption + operational and management) will be R80 billion/a by 2025** (Table 13). If a larger volume of water is impacted on (which will almost certainly be the case), the cost will be correspondingly larger.

This water remediation cost factor has to be added to the cost of coal-based energy to derive the true cost of energy in South Africa.

TABLE 11

POWER STATION TYPE	GENERATION CAPACITY (MWe)		EXPANSION PROGRAMME SCHEDULE							
	CURRENT	+ADDITIONS	2009/10	2010/11	2011/12	2012/13	2013/14	2014/15	2015/16	2016/17
CAPACITY EXPANSION BUDGET (from www.eskom.co.za)					**R 385 BILLION**					**> R 1 TRILLION**
COAL-FIRED PS										
1. ARNOT	2 100	+200	70	30						
2. DUVHA	3 600									
3. HENDRINA	2 000									
4. KENDAL	4 116									
5. KRIEL	3 000									
6. LETHABO	3 708									
7. MAJUBA	4 110									
8. MATIMBA	3 990									
9. MATLA	3 600									
10. TUTUKA	3 654									
11. CAMDEN	1 600									
12. GROOTVLEI	1 200	+800	800							
13. KOMATI	1 000	+750	125	325	300					
14. MEDUPI (NEW)		4 800				1 588	794	1 588	794(?)	
15. KUSILE (NEW)		4 800					1 600	800(?)	1 600(?)	800(?)
COAL TOTAL	37 678	48 892	38 673	39 028	39 328	40 916	43 310	45 698	48 092	48 892
(% INCREASE IN CAPACITY)		(30%)	(2.6%)	(3.6%)	(4.4%)	(8.6%)	(14.9%)	(21.3%)	(27.6%)	(29.8%)
NUCLEAR PS										
1. KOEBERG	1 930									
HYDROELECTRIC+PUMPED STORAGE SCHEMES										
1. DRAKENSBERG PS	1 000									
2. PALMIET PS	400									
3. GARIEP HYDRO	360									
4. VANDERKLOOF HYDRO	240									
5. INGULA PS		1 352								
6. TUBATSE PS		1 500	(on hold)							
HYDRO + PS TOTAL	2 000	4 852								
GAS TURBINE PS										
1. ACACIA	171									
2. PORT REX	171									
3. ATLANTIS	1 327									
4. GOURIKWA	740									
GAS TOTAL	2 409									
WIND PS										
1. KOEKENAAP		200	(on hold)							
TOTAL ALL	44 017	58 283								
% COAL	86%	84%								

ESKOM's build programme (summarised from www.eskom.co.za). Values under the coal expansion programme schedule marked with (?) indicates value that, if left out, will be consistent with a 30% reduction in future coal needs, and completion of only 5 600 MW of Medupi + Kusile's idealised final 9 600 MW capacity.

TABLE 12

TECHNOLOGY	R bn/GW CAPACITY
"CLEAN COAL"	30
SOLAR HOT WATER PANELS	432
PHOTOVOLTAIC FARMS	59
CONCENTRATING SOLAR PANELS (CSP)	128
NUCLEAR	20
WIND	15
PUMPED STORAGE SCHEMES (PSS)	7.5
WASTE INCINERATORS	45

The capital cost investment required for different energy producing technologies in the United Kingdom (from [19], adopting a R15 = £1 conversion factor), expressed in billions of Rand per GW of energy generation capacity.

The second cost factor that has to be included to establish the actual cost of coal-based energy, is that related to carbon capture and storage (CCS), i.e. climate change mitigation.

If South Africa's CO_2 emissions increase in accordance with Eskom's proposed coal-power station expansion plans (Table 11), emissions will by 2025 increase with 150x10^6 tonnes of CO_2 relative to 2000 levels, and about 207x10^6 tonnes of CO_2 relative to the 5% below 1990 levels stipulated in the Kyoto Protocol (Table 14).

Current technology captures CO_2 at a cost of around $150/tonne of CO_2, exclusive of transport and storage costs [102,103]. The prohibitive cost of current technology has resulted in most efforts at carbon capture in developed countries being abandoned [104]. It is predicted that future technological developments may bring the cost of CCS down to $50/tonne of CO_2 [103,105].

Assuming then a $50 to 150/tonne cost bracket for CCS, the estimated cost associated with coal-based energy generation in South Africa can be calculated.

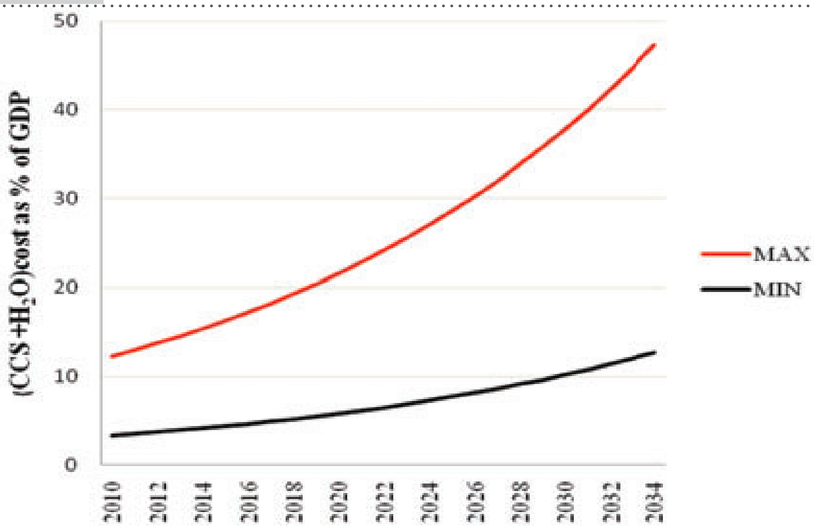
According to the recently released carbon storage atlas for South Africa [106], more than 98% of the country's storage capacity is located offshore. Offshore carbon storage represents the high end of the CCS cost bracket, i.e. the cost associated with it is much higher than onshore carbon storage options [102,103].

The predicted future CO_2 emission scenarios for South Africa, combined with the $50 to $150/tonne cost bracket, yield annual CCS costs on the order of **R82.720 to 248.160 billion per annum**, if Eskom's expansion programme is realised, and South Africa commits to CO_2 reduction targets in accordance with the Kyoto Protocol (Scenario 1 in Table 14).

A reduced reduction scenario (to 2000 emission levels), combined with a scaling down of Eskom's expansion programme, yields a CCS cost of **R45.480 to 136.440 billion per annum** (Scenario 2 in Table 14).

As mentioned in the previous paragraph, given that most of South Africa's carbon storage capacity is located offshore, the cost of CCS for South Africa is best presented by the high end of this price range.

FIGURE 10



Graphical representation of the minimum and maximum estimates of what CCS + H_2O will cost, as a % of GDP, according to the scenario detailed in Table 13.

TABLE 13

YEAR	CAPITAL COST DEBT (R billion)	REDEMPTION REDEMPTION (R billion/a)	CARBON CAPTURE + STORAGE (R billion/a) MIN	MAX	WATER REMEDIATION (R billion/a)	ANNUAL GDP (R billion)	($CCS+H_2O$) COST AS % OF GDP COST MIN	MAX
ANN INTEREST OR INCREASE	10%		10%	10%	10%	4%		
2010	385	43	45	136	8	1 600	3	9
2011	381	43	50	150	9	1 664	4	10
2012	376	43	54	165	10	1 731	4	10
2013	371	43	60	181	11	1 800	4	11
2014	365	43	66	199	12	1 872	4	11
2015	358	43	72	219	13	1 947	4	12
2016	351	43	80	241	14	2 025	5	13
2017	344	43	88	265	16	2 105	5	13
2018	335	43	96	292	17	2 190	5	14
2019	326	43	106	321	19	2 277	5	15
2020	316	43	117	353	21	2 368	6	16
2021	304	43	128	388	23	2 463	6	17
2022	292	43	141	427	25	2 562	6	18
2023	278	43	155	470	28	2 664	7	19
2024	263	43	171	516	30	2 771	7	20
2025	247	43	188	568	33	2 882	8	21
2026	229	43	207	625	37	2 997	8	22
2027	209	43	227	687	40	3 117	9	23
2028	187	43	250	756	44	3 241	9	25
2029	162	43	275	832	49	3 371	10	26
2030	136	43	303	915	54	3 506	10	28
2031	107	43	333	1 006	59	3 646	11	29
2032	74	43	366	1 107	65	3 792	11	31
2033	39	43	403	1 208	72	3 944	12	33
2034	0	43	443	1 340	79	4 101	13	35
CUMULATIVE TOTAL		986			788			

Estimated new coal power station capital redemption cost over a 25 year period, and long-term growth in annual cost associated with CCS (carbon capture and storage) and water remediation in coal mining areas. According to this, by 2025 the annual Captical Cost Redemption will be R43 billion and Water Remediation R33 billion (i.e. R76 billion combined), with CCS contributing an additional estimated R188 to R568 billion annually.

Based on the above, the most conservative estimate of the annual cost associated with water remediation and CCS is the following: R8 billion a year for water remediation (a minimum volume of 1 222 Mm3/a for water impacted on by coal mining only), and R45 to 136 billion a year for CCS (assuming a scaling down of Eskom's expansion programme, and CO2 reductions relative to 2000 levels).

These are current cost estimates, and combined they represent 3 to 9% of South Africa's gross domestic product (GDP), as illustrated in Table 13. These costs and GDP will increase over time, and in a country such as South Africa with an inflation rate much higher than economic growth, the value of the costs as a percentage of GDP will increase over time (Figure 10). If GDP increases by a healthy 4% per year until 2025, and the cost of water remediation and CCS increases 10% annually, then the most conservative current cost estimates (R8 billion for water and R45 to 136 billion for CCS) will increase to 13 to 35% of GDP by 2025. It is clear from all of these estimates that by 2025 the combined annual cost of water remediation related to coal mining, and CCS related to coal-fired power stations, will dwarf the annual capital redemption value of Eskom's current expansion programme, and exceed the total capital cost of this expansion programme by a considerable amount.

When the magnitude of these costs are considered in relation to the country's GDP, it is clear that South Africa cannot afford to invest in a coal- and carbon-intensive energy future, and that doing so will bankrupt the country and derail socioeconomic developmental plans.

TABLE 14

YEAR	CO_2 EMISSIONS (10^6 TONNES)*			TONNES	GDP	TOT PRIMARY	FUTURE CO_2 EMISSIONS (10^6 TONNE)	
	COAL	OIL	TOTAL	CO_2/CAPITA*	$ BILLION	ENERGY (PJ)*	SCENARIO 1	SCENARIO 2
1971	146.3	27.5	173.8	7.69	71.5	1 890	173.8	173.8
1990	208.3	46.4	254.7	7.24	110.9	3 804	254.7	254.7
2000	248.1	50.4	298.5	6.78	132.9	4 619	298.5	298.5
2007	283.0	62.7	345.8	7.27	178.0	5 624	345.8	345.8
2010							358.2	358.2
2015							419.5	412.2
2020							448.8	412.2
2025							448.8	412.2
COPENHAGEN SCENARIO:	**2025 CO_2 emissions @ 2000 levels (10^6 tonnes)**						150.3	113.7
	Carbon Capture and storage @ $50/tonne and R8/$ (R million/a)						60 120	45 480
	Carbon Capture and Storage @ $150/tonne and R8/$ (R million/a)						180 360	136 440
KYOTO SCENARIO:	**2025 CO_2 emissions = 5% lower than 1990 levels (10^6 tonnes)**						206.8	170.2
	Carbon Capture and Storage @ $50/tonne and R8/$ (R million/a)						82 720	68 080
	Carbon Capture and Storage @ $150/tonne and R8/$ (R million/a)						248 160	204 240

South Africa's CO_2 emissions from 1971 to 2007, with ancillary data (* from [5]), and projected CO_2 emissions based on ESKOM's proposed coal-fired power station build programme outlined in Table 11. Scenario 1 represents ESKOM's idealised (maximum) coal-fired PS capacity increase, and Scenario 2 represents a reduced coal-fired PS capacity increase, with only 5 600 MW of (Medupi + Kusile) final capacity, as outlined in Table 11. (Example of calculation to derive at cost estimates in lower right hand corner: 150.3x10^6 tonnes * $50/tonne * R8/$ = R 60 120 million = R60.120 billion).

NEW DEVELOPMENT

RELEASE OF IRP2010 DRAFT REPORT BY THE DOE ON 8 OCTOBER 2010 [107]

The much anticipated Integrated Resources Plan for Electricity (IRP2 or IRP2010) was released by the Department of Energy on 8 October 2010 (www.doe-irp.co.za). This government planning document is unquestionably key to South Africa's future, and the scenario planning presented in AEON Report 2 is directly relevant to the scenarios presented in IRP2010.

The primary objective of IRP2010 is "to determine the long-term electricity demand and detail how this demand should be met in terms of generating capacity, type, timing and cost. It aims to "achieve a balance between an affordable electricity price to support a globally competitive economy, a more sustainable and efficient economy, the creation of local jobs, the demand on scarce resources such as water and the need to meet nationally appropriate emission targets in line with global commitments".

KEY ASPECTS OF THE "LEAST-COST BASE CASE" SCENARIO IN THE IRP2010 ARE THE FOLLOWING:

- It supports an average 4.5% GDP growth trajectory over the next 20 years.
- It requires 41,346 MW of new capacity (excluding the capacity required to replace decommissioned plants).
- It assumes continuation of extraction and beneficiation of natural resources as a significant primary sector.
- The bulk of demand (for base-load) will be met by coal-fired power stations, with open cycle gas turbines (OCGT) providing peak energy. This is motivated by the "relative low direct cost" of coal-fired power stations and high domestic coal reserves, and mention of the fact that "externalities related to coal are not included".
- "While the Base Case Scenario indicates the least-cost alternative, these costs do not include the inherent externalities involved in coal-fired electricity production, in particular greenhouse gas (GHG) emissions and the impact on the environment as well as the security of supply imperative in diversifying the national energy base".

THE IRP2010 PLAN, IN SUMMARY, INCLUDES:

- The continuation of Eskom's committed build programme, including the construction of Medupi and Kusile coal-fired power stations.
- A nuclear fleet strategy, commencing in 2023, contributing at least 9.6 GW by 2030 (6x1,600 MW).
- A renewable programme, from 2020, incorporating all renewable options (wind, CSP, solar PV, landfill, hydro) of 7.2 GW.
- Up to 5 GW of generic coal-based power generation (from 2027 to 2030), in addition to Medupi and Kusile.
- Up to 5,750 GW of peaking OCGT.

According to the IRP-2's so-called Revised Balance Scenario, South Africa's electricity mix would, by 2030, consist of: 48% baseload coal-fired power; 14% baseload nuclear; 16% renewable energy; 9% peaking OCGT; 6% peaking pumped storage generation; 5% mid-merit gas power generation; 2% baseload import hydropower.

The estimated cost associated with the different technologies and the energy mix of the each scenario is summarised below.

THE FOLLOWING SHOULD BE NOTED, AS A REMINDER THAT THE COSTS OUTLINED IN THE IRP2010 ARE DIRECT COSTS ASSOCIATED WITH THE INSTALLATION OF ENERGY INFRASTRUCTURE *ONLY*:

- 1. The estimated total cost for each scenario includes total capital, operating, maintenance and fuel cost, but excludes the cost of transmission infrastructure.
- 2. The "Emission Limit" scenarios **exclude** the cost associated with carbon capture and storage (CCS), which will have to accompany these scenarios.
- 3. The "Carbon Tax" scenario **excludes** the cost associated with the carbon tax itself.
- 4. The IRP2010 document contains the following important statement regarding nuclear energy: "There is a strong possibility that the costs could be higher than those assumed".

SCENARIO COST SUMMARY (current value estimates):

SCENARIO (all with Medupi and Kusile)	COST (R billion)	WATER USE (million L)
BASE CASE	789	266,721
EMISSION LIMIT 1.0	860	241,785
EMISSION LIMIT 2.0	835	241,091
EMISSION LIMIT 3.0	1,250	218,970
CARBON TAX 0.0	852	236,561
BALANCED SCENARIO	849	241,943
REVISED BALANCE SCENARIO	856	

TABLE 15 *TECHNOLOGY*	CAPITAL COSTS (R billion/GW)	WATER USAGE (l/MWh)
PULVERISED COAL WITH FGD	17.785	229.1
FLUIDISED BED WITH FGD	14.965	33.3
NUCLEAR AREVA EPR	26.575	6,000 (sea)
OCGT	3.955	19.8
CCGT	5.780	12.8
WIND	14.445	0
CONCENTRATED PV	37.225	0
FORESTRY RESIDUE BIOMASS	33.270	210
MUNICIPAL SOLID WASTE BIOMASS	66.900	200
PUMPED STORAGE	7.913	-
INTEGRATED GASIFICATION COMBINED CYCLE (IGCC)	24.670	256.8
CSP, 3 HRS STORAGE	37.425	250
CSP, 6 HRS STORAGE	43.385	245
CSP, 9 HRS STORAGE	50.910	245

The Capital Costs and Water Usage of different energy technologies, summarised from Table 13 in IRP2010.

NOTABLE FEATURES:

- 1. The total direct costs associated with the different Scenarios fall within a very narrow range, except for Emission Limit 3.0.
- 2. Seen against a current value GDP of R1,600 billion, the Revised Balance Scenario cost (R856 billion over 20 years) translates into 2.7% of GDP. This compares as follows to expenditure on total infrastructure (all, including energy):
- 2.4% of GDP in the USA, 5% in the European Union and 9% in China (www.moneymorning.com).
- 3. The importance of the fact that the costing of the different Scenarios in the IRP2010 is based on direct costs only and that it excludes costs associated with externalities cannot be overemphasised. As demonstrated in this AEON Report 2, the costs associated with externalities such as water purification and carbon capture and storage technologies will be substantial and will in fact exceed the direct costs provided in the IRP2010 by a factor of 2 to 5. External costs simply cannot be ignored as a crucial criteria for deciding on the most sensible future energy mix for South Africa.
- 4. The capital cost requirements of the Revised Balance Scenario, normalised against the capacity increased, translates to an expenditure of R20.7 bn/GW (from R856 billion/41.346 GW). In comparison, the Desertec [97] project, i.e. production of solar power in North Africa for transmission to Europe, will cost an estimated R4,000 billion rand (at R10 = 1 Euro) for the establishment of 500 GW of electricity. The latter is equivalent then to R8 bn/GW of capacity, almost a factor of 3 lower than the capital cost requirements of IRP2010. It is an open secret that infrastructure projects in Africa (including South Africa) cost a lot more in comparison with equivalent projects in developed nations. However, the economy of scale and the fact that much larger scale solar technology production plants, for example, will bring down the cost of solar technologies significantly, is an important factor in the relatively low cost of the Desertec project.

TABLE 16

	COMMITTED BUILD											*NEW BUILD OPTIONS*								
	RTS CAPACITY	**MEDUPI**	**KUSILE**	**INGULA**	**DOE OCGT IPP**	**COGNERATION, OWN BUILD**	**WIND**	**CSP**	**LANDFILL, HYDRO**	**SERE (WIND)**	**DECOMMISSIONING**	**COAL (PF, FBC, IMPORTS)**	**COGENERATION, OWN BUILD**	**GAS OCGT**	**OCGT**	**IMPORT HYDRO**	**WIND**	**SOLAR PV, CSP**	**RENEWABLES (ALL)**	**NUCLEAR FLEET**
2010	380	0	0	0	0	260	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2011	679	0	0	0	0	130	200	0	0	0	0	0	103	0	0	0	0	0	0	0
2012	303	0	0	0	0	0	200	0	100	100	0	0	0	0	0	0	0	0	0	0
2013	101	722	0	333	1020	0	300	0	25	0	0	0	124	0	0	0	0	0	0	0
2014	0	722	0	999	0	0	0	100	0	0	0	0	426	0	0	0	200	0	0	0
2015	0	1444	0	0	0	0	0	100	0	0	-180	0	600	0	0	0	400	0	0	0
2016	0	722	0	0	0	0	0	0	0	0	-90	0	0	0	0	0	800	100	0	0
2017	0	722	1446	0	0	0	0	0	0	0	0	0	0	0	0	0	800	100	0	0
2018	0	0	723	0	0	0	0	0	0		0	0	0	0	0	0	800	100	0	0
2019	0	0	1446	0	0	0	0	0	0	0	0	0	0	474	0	0	800	100	0	0
2020	0	0	723	0	0	0	0	0	0	0	0	0	0	711	0	360	0	0	800	0
2021	0	0	0	0	0	0	0	0	0	0	-75	0	0	711	0	750	0	0	800	0
2022	0	0	0	0	0	0	0	0	0	0	-1870	0	0	0	805	1110	0	0	800	0
2023	0	0	0	0	0	0	0	0	0	0	-2280	0	0	0	805	1129	0	0	800	1600
2024	0	0	0	0	0	0	0	0	0	0	-909	0	0	0	575	0	0	0	800	1600
2025	0	0	0	0	0	0	0	0	0	0	-1520	0	0	0	805	0	0	0	1400	1600
2026	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	600	1600
2027	0	0	0	0	0	0	0	0	0	0	0	750	0	0	805	0	0	0	1200	0
2028	0	0	0	0	0	0	0	0	0	0	-2850	2000	0	0	805	0	0	0	0	1600
2029	0	0	0	0	0	0	0	0	0	0	-1128	750	0	0	805	0	0	0	0	1600
2030	0	0	0	0	0	0	0	0	0	0	0	1500	0	0	345	0	0	0	0	0

New build options – as outlined in Table 4 in the IRP2010's Proposed IRP Revised Balance Scenario.

7. Summary
AND CONCLUSIONS

THIS REPORT DEMONSTRATES THAT:

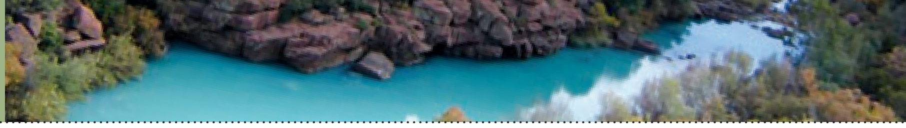
- South Africa's surface water yield is at an estimated 82% of its maximum capacity.
- Establishing South Africa's sustainable groundwater exploitation potential, using state-of-the-art geochemical techniques, has to be made a national research priority, before this critical resource becomes irreversibly over-exploited.
- The high level of uncertainty regarding the status of South Africa's water balance is an enormous cause for concern, particularly in regards to groundwater abstraction rates.
- The scarcity of eco-hydrological studies, as a robust scientific basis for estimation of the Ecological Reserve, is cause for concern.
- The National Water Resource Strategy's predicted future water shortages for the country as a whole are extremely conservative estimates.
- The NWRS's future scenarios for the country as a whole, hide its own predictions for severe future water shortages in South Africa's three largest cities, Johannesburg, Cape Town and Durban, and the factor of 2 by which demand will exceed availability in the WMA's that serve these cities, under a 4% economic growth scenario.
- The lack of inclusion of climate change scenarios in the NWRS, particularly the threat posed by increased evaporative water losses, demonstrates a disconcerting appreciation of the fact that South Africa is an arid country, and that the climatic conditions imposed on it by its mid-latitudinal geographic position puts it at greater risk of increasing water scarcity in a warmer world, than most other countries.
- Deteriorating water quality is arguably an even greater threat to South Africa's water security than climate change, and lack of consideration of water quality in the NWRS future outlook scenarios renders the NWRS predictions almost meaningless.
- Inclusion of climate change and water quality deterioration in the NWRS future scenarios result in estimated future water shortages on the order of 19 to 33% by 2025.
- An estimated R360 billion is needed to secure South Africa's future water supply, primarily to address outstanding water treatment plant maintenance issues, and to increase water treatment plant capacity by 2025.
- Other viable options for energy generation are open, particularly through solar and geothermal energy sources.
- The exclusion of externality costs in IRP2010, estimated in this report to exceed the capital cost of infrastructure by a factor of 2 to 5 in the long-term, is a grave omission that needs to be rectified.

> When all the facts are considered in detail, and not just the sanitised overview values presented in summary reports [9,20], it is difficult to argue that South Africa is not already in the grip of a water crisis.

It is difficult to reconcile statements by government officials, who consistently downplay the current state of affairs [57,108], with the facts contained in their own assessment documents, as illustrated in the appraisal of the NWRS presented in this report.

The proliferation of reports about water quality issues in South Africa, by high quality investigative environmental journalism primarily and unfortunately to a lesser extent by independent scientists and academics, is an indication of the growing extent of the problem, and mounting public concern. As shown in this report, water quality is only one aspect of South Africa's water crisis: the amount of water available versus that required is as important and should serve as additional motivation for water quality issues to be given the serious regard it deserves.

What is also clear is that South Africa's water crisis cannot be considered in isolation of its energy crisis and the repercussions of its carbon intensive economy. South Africa's energy intensive mining and related industries have sustained economic growth in South



Africa's for more than a century. However, the positive relationship between the wealth derived from mining activities, and the wealth and socio-economic prosperity of the country, is at a turning point. This turning point will result in continued coal mining and past gold mining impacting negatively on South Africa's economic growth, and the health of its people.

Added to the enormous costs that will be associated with the future water quality remediation measures needed to secure an adequate supply of water, will be the eventual cost of Eskom's dogged commitment to increase the country's reliance on coal-based energy. As illustrated in this report, the combined cost of water remediation and carbon capture and storage, if South Africa is to meet its international obligations towards mitigating against global climate change, will bankrupt the country. The South African government has pledged to commit to CO_2 emission reductions in future, conditional on international financial support for mitigation measures, while at the same time insisting that is has a right to develop its own "carbon space", i.e. increasing its reliance on carbon-intensive energy sources [109]. This is disingenuous, not least of all because CCS is not eligible for funding under the UN's Clean Development Mechanism (CDM). It also exhibits a remarkable lack of commitment and unwillingness to accept responsibility for the well-being of future generations of Africans. It also ignores the practical impossibility of implementing CCS in South Africa on the scale required, within the timeframe required [110], even if funding was available. On the other hand, it is clear that just consideration of the implications of continued and more extensive coal mining for South Africa's future water outlook scenarios is enough to motivate serious reconsideration of the country's carbon-intensive economy.

The current lack of integrated water and energy issues, globally, is manifested in the narrow carbon-minded view adopted in climate change treaty negotiations such as Copenhagen. Water, in itself, is added motivation for the recent suggestion [111] that policy makers should perhaps "leave aside the near-obsessive need to benchmark everything against the $2^{o}C$ target". To that can be added the obsession with using global warming trends as benchmarks for the urgency with which the world needs to act, rather than the water crises that are already manifesting globally [8].

Most of the increased future cost associated with both electricity and water supply will be passed on to the consumer. Not only domestic electricity, but also water accounts will have to increase several-fold within the next decade to fund the expenditure required. Imbedded in increased water tariffs will be the costs associated with the clean-up of water polluted by coal mining for energy generation. An interesting facet of the costs associated with water pollution resulting from coal mining is that water is sold by independent regional water suppliers, whereas electricity is still supplied by a single national provider, ESKOM. Will water consumers in WMA's impacted on by coal mining have to carry these costs on their own, or will the burden be shared by all users of electricity in the country? Currently, water distribution set-ups and legislation do not make provision for the latter, and water users in provinces such as Mpumalanga, Gauteng and Limpopo should be observant of that fact. Similar questions have to be asked about the increased cost of water associated with desalination treatment plants in water-stressed towns like Sedgefield, George and Mossel Bay. Will golf estates contribute their requisite fair share, or will the increased cost of water be shared by all consumers, across the socio-economic spectrum? These are some of the important questions that are not being asked yet and that will have profound implications for South Africa's socio-economic landscape.

This report, importantly, also outlines future scenarios for South Africa that promise positive economic growth scenarios, socio-economic benefits and a healthy population and environment. Realisation of these scenarios depends on a radical break by the South African government from its commitment to maintaining a carbon-intensive economy. Development of alternative and sustainable energy technologies, in particularly solar (which is eligible for funding under the UN's CDM), will guarantee: resolution of the energy crisis, an extensive low-carbon manufacturing and export industry, substantial job creation, sustainable GDP growth, healthier and wealthier people, and enough clean water to drink. One of the obstacles to integration of water and energy policies in South Africa, as elsewhere in the world, is its undermining by diffuse and confusing responsibilities by different government departments. The newly established National Planning Commission in the Presidency of South Africa, and the recently announced inter-ministerial committee on energy (State of the Nation address in Parliament, 11 February 2010), provide unique and exciting opportunities to overcome these historical obstacles, and provide platforms from which plans for a new energy outlook for South Africa can be launched.

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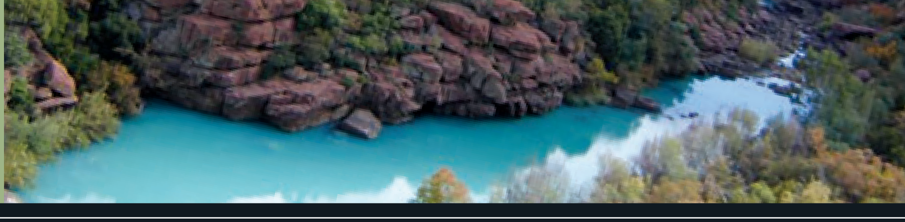

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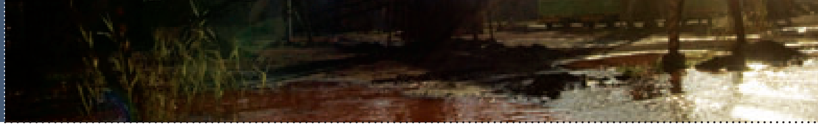

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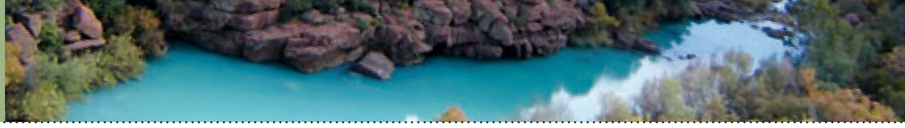

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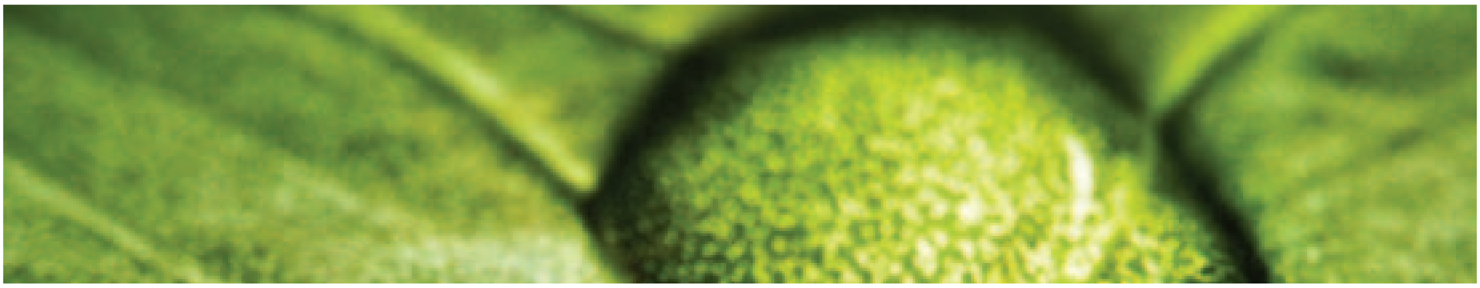

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