The Impact of Climate Change on Water Resources in Southern Africa: What Policy Makers Need to Know

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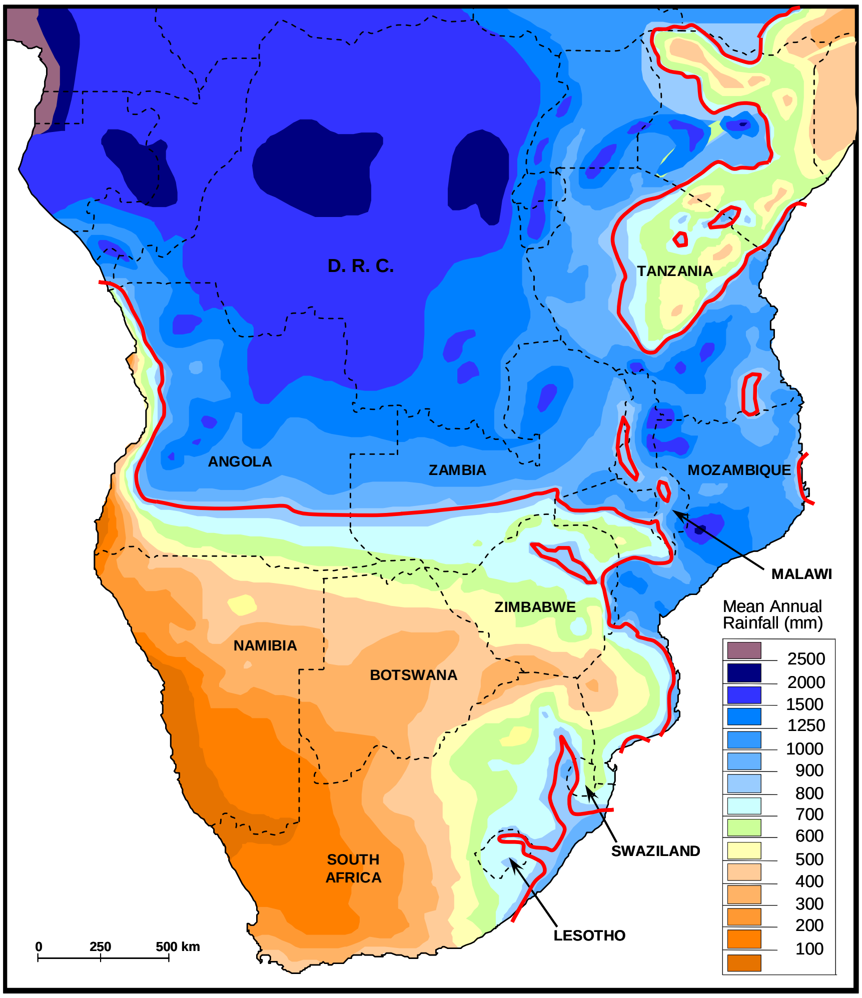
Introduction

Africa in general has major development challenges. In a globalizing world, one of the specific developmental impediments is the availability of water resources at an assurance of supply level sufficient to sustain a modern economy. The World Bank (2006) has published a document entitled *Water for Responsible Growth*, which has shown that most industrial countries have harnessed their hydrology. That document makes a case for Africa, specifically where growth is held hostage to hydrology, by showing that assurance of supply is a fundamental platform of sustained economic development. So what about Southern Africa, where the four most economically developed countries – South Africa, Namibia, Botswana and Zimbabwe – have all reached a point where available water poses potential limitations to future economic growth and hence political stability (Ashton & Turton, in press)? This paper explores the situation in what the author has labelled the Southern African Hydropolitical Complex, by looking at hydrological issues that policy-makers need to understand if they are to support any future sustainable development initiative.

Is Southern Africa a Hostage to Hydrology?

The World Bank refers to Africa as being a hostage to hydrology, but what is actually meant by this? A non-hydrologist needs to understand some fundamental science in order to appreciate the significance of this statement. Stated simplistically, Southern Africa is constrained by the available water defined in terms of both time and space. Spatially, water is unevenly distributed, with high rainfall in the northern parts centred on the Democratic Republic of Congo (DRC), tapering off in a dramatic gradient to the south. Map 1 presents this visually, with the global average of 860 mm/yr being shown as a red line. Two important development constraints are evident in this diagram. Firstly, the unequal distribution is patently obvious, often with the less developed countries having higher rainfall than the more developed countries. Secondly, and probably more importantly, the four most economically developed countries – South Africa, Namibia, Botswana and Zimbabwe – are all on the "wrong" side of the global average of 860 mm/yr. What is not shown in this map is another very important fundamental constraint to development. The rainfall is highly erratic, and "normal" conditions are measured in terms of their deviation from a norm, but that coefficient of variability is so extreme that one respected water scientist repeats *ad nauseum* that "means are meaningless" for planning purposes. Thus for example, we have distinct periods of cyclicity to rainfall where volumes falling could deviate by as much as 140% above what the "norm" should have been, to around 70% of what the "norm" should have been (O'Keeffe *et al.*, 1992:281). So these different physical elements – spatial, temporal and cyclicity factors - constitute what the World Bank refers to as difficult hydrologies.



Map 1. Spatial distribution of rainfall over Southern Africa showing the extreme gradient from north to south. The red line shows the global average of 860 mm/yr with the four most economically developed countries – South Africa, Namibia, Botswana and Zimbabwe – all having future development constrained by this hydrological fact. (Map courtesy of Pete Ashton, CSIR).

But this only part of the story. Another piece of the policy-related puzzle is associated with a fundamental conversion equation. Known technically as the ratio of Mean Annual Precipitation (MAP) to Mean Annual Runoff (MAR), this is a fundamental defining factor in Southern Africa's 'difficult hydrology'. In layman's terms, this refers to the annual average rainfall (remembering that average is a wildly variable concept for reasons noted above) that eventually makes its way as streamflow in rivers, and can thus be harnessed for economic growth and development. Some authors refer to this as Blue Water. The layman needs to understand some basics in this regard. Water is a fugitive resource, flowing in time and space as a flux. National economic planners think of water resources as a stock, which is reflected in statistical data such as flows of a given river expressed as so many cubic kilometres per year. But in reality this is a flux, changing in both space and time, being recycled in what is known technically as the hydrological cycle. Within that hydrological cycle, water falls to earth as precipitation, and a number of things happen to it. A fraction of that volume gets intercepted by foliage and evaporates almost immediately after the rainfall event. Another fraction falls to ground where it is either absorbed as groundwater, evaporated as evapotranspiration (what some call Green Water), or becomes runoff that finally makes its way into rivers that can be economically harnessed (what some call Blue Water). The MAP:MAR ratio is thus a critical indicator of sustainable development potential, referring to that small fraction that falls as rain and eventually becomes water flowing in rivers. The current reality is presented graphically in Figure 1.

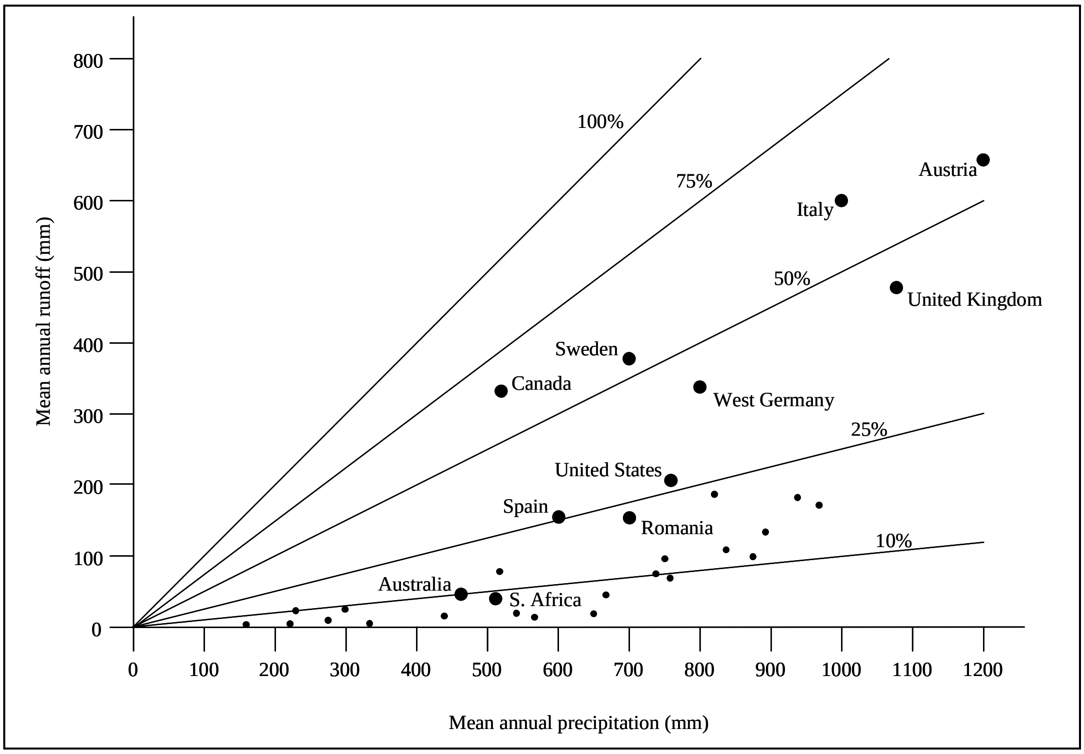


Figure 1. In the real world, only a small fraction of water that falls as rainfall (horizontal axis) becomes streamflow in rivers (vertical axis). The lines radiating from the nexus are percentile conversions, with the large named dots representing average conditions for the specific country concerned. The un-named smaller dots clustered around the tenth percentile represent different rivers in Southern Africa. (Redrawn from O'Keeffe *et al.*, 1992:281).

Figure 1 tells a powerful story about the 'difficult hydrology' of Southern Africa. South Africa as a country receives on average a similar volume of precipitation as Canada does (a bit over 500 mm/yr on average). However, the conversion of that precipitation to runoff differs remarkably. In Canada, that 500+mm/yr translates to around 325 mm/yr of runoff, whereas in South Africa, it becomes a paltry 25 mm/yr. And therein lies the basic developmental dilemma. Southern Africa and Australia have the lowest conversion of MAP to MAR in the world, and that is a fact that simply cannot be ignored when it comes to planning future economic development policies.

In order to better understand this fundamental constraint, a few more facts are needed. Rivers pulse as the cyclicity of flood and drought takes its natural rhythm from nature. Dams are needed to smooth this pulsing. In technical terms this is called yield. A dam therefore holds back floods, clipping off the peaks, storing that water for use in the ebbs of the “normal” hydrograph, thereby being harnessed as yield.

There are limits however, and a physical threshold kicks in at around 60% of the streamflow that has been captured as yield. Beyond that threshold, it starts to become economically prohibitive because the size of the structure is disproportionally large that the feasibility is reduced exponentially. Significantly, South Africa has currently captured around 62% of the available streamflow (O’Keeffe *et al.*, 1992:278), so we are sitting right on that threshold already. Beyond that threshold, it not only becomes increasingly uneconomic to harness the water resources, but it also becomes ecologically destructive. Rivers support ecosystems, and these perform helpful functions in society by cleaning up the waste caused by human habitation. Every water treatment process harnessed by engineers at a cost merely mimics what is done by nature for free. The preservation of ecosystem integrity is what prevents a work-horse river from becoming an open sewer. Ecologically intact rivers act as environmental sinks, saving money for a variety of actions such as assimilating our waste, and reducing the cost of treatment that would otherwise be passed on to society. The relevance of this becomes evident when one understands that given the natural variability of Southern African rivers, the ecology within each river basin has evolved over millions of years to survive variability. In fact variability is the biophysical trigger that causes major events such as spawning to occur (Junk *et al.*, 1989). Once dams are included into the system, variability decreases and with the loss of the flood pulse, biodiversity crashes in a magnitude that is disproportional to the degree of actual physical change. This is known technically as non-linearity, and it is a fundamental component of the so-called precautionary principle on which the very notion of sustainable development is built.

This is the relevance of the so-called difficult hydrologies found in Sub-Saharan Africa insofar as surface water is concerned. Returning now to the earlier explanation of the hydrological cycle, let us focus for a few moments on the groundwater fraction. A small portion of the volume of rainfall that is not immediately evaporated, infiltrates into the earth. Of that fraction, a portion stays in the root zone as soil water, where it eventually becomes harnessed by the roots of plants and is evaporated after being converted to biomass. Some literature refers to this as Green Water. The other portion percolates down below the root zone where it eventually finds its way into aquifers as ground water. Let us dwell for a few movements on the physics at work here so we can begin to understand the relevance of groundwater to the economy.

The rate of infiltration into aquifers depends on a variety of factors, but in general this relates to the soil type, volume of water involved in the specific recharge event, duration of that event, and a host of other factors. Of significance to the current discussion, the rate of recharge is non-linear as shown in Figure 2. What this means is that another threshold needs to be understood in the context of sustainable development and global climate change. Figure 2 is a scatter plot showing measured recharge as a function of rainfall. When analysed statistically a trend becomes evident. That trend shows a relationship between precipitation and recharge that generally declines, so we get lower recharge from lower precipitation and *vice versa*. However, and of great significance, at around 500 mm of precipitation, a threshold is reached, with a dramatic change in this fundamental relationship. Below 500 mm of precipitation a non-linearity kicks in, becoming quite dramatic at around 400 mm.

Remembering that most of South Africa is way below the 500 mm/yr mark already (Map 1), this is of great relevance, specifically in the context of climate change.

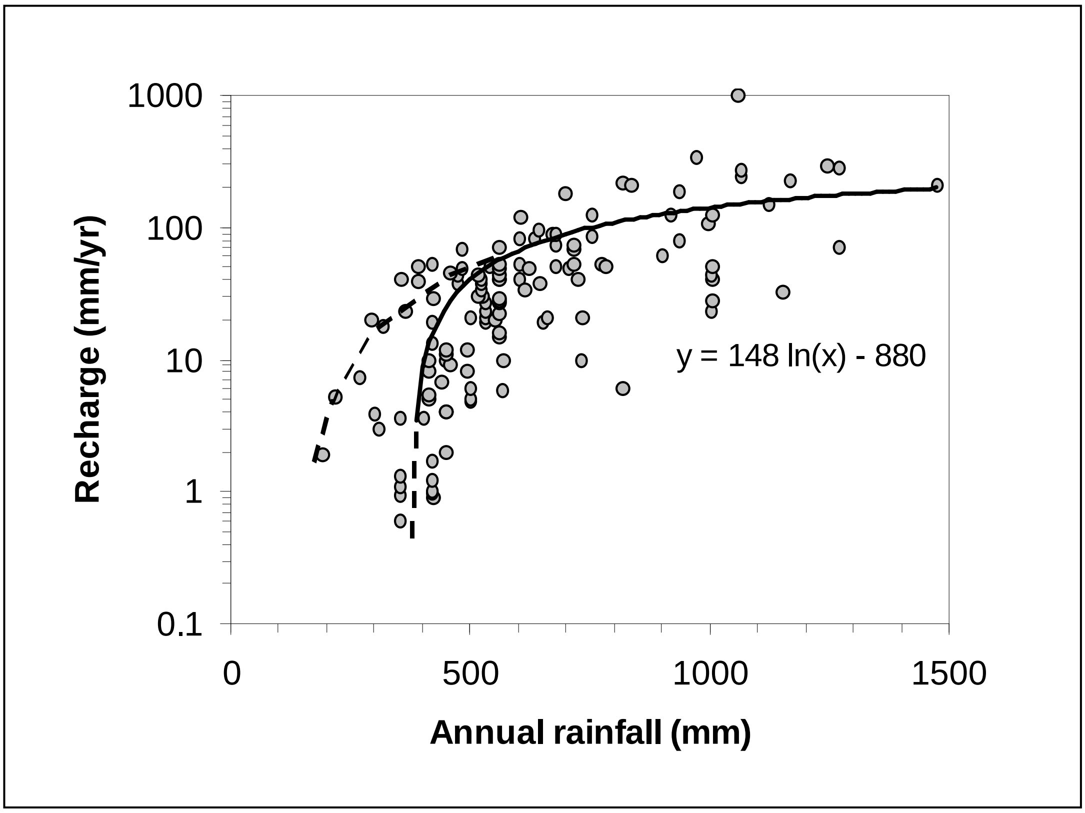
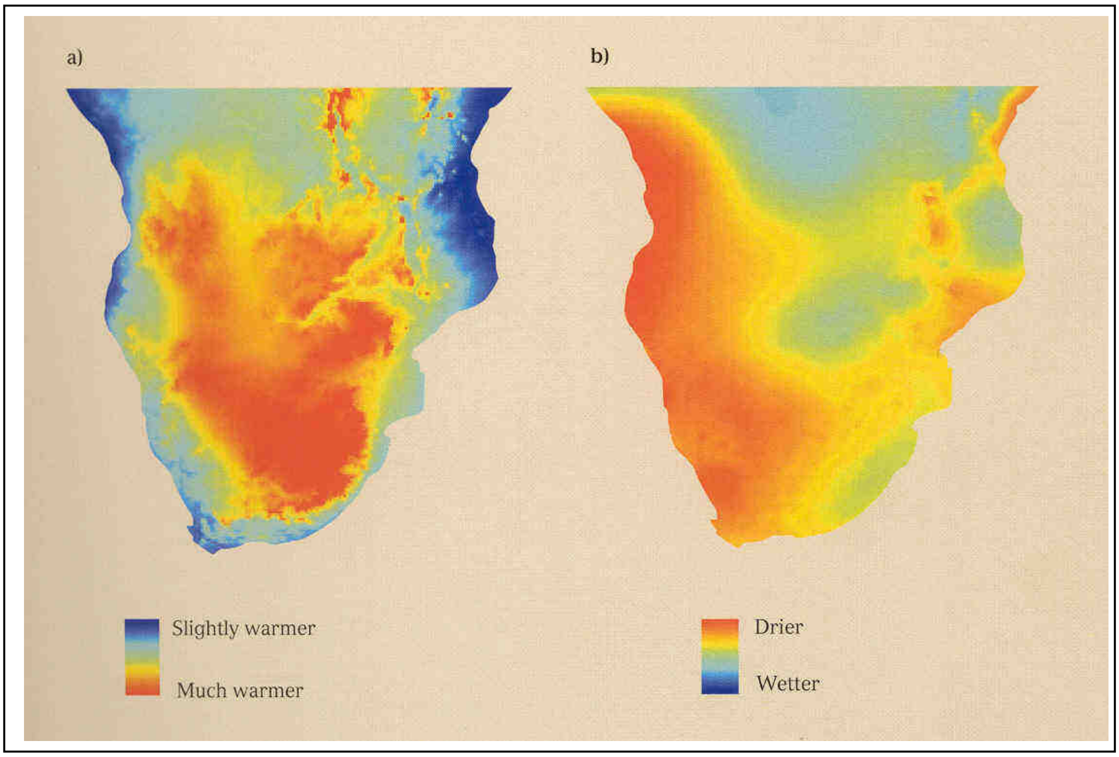


Figure 2. The relationship between rainfall (horizontal axis) and groundwater recharge (vertical axis) is non-linear in Southern Africa, with a major threshold occurring below the 500 mm mark (after Beekman *et al.*, 1996 and Cavé *et al.*, 2003:194).

To assess the significance of this, we need to understand firstly that large portions of Southern Africa have little reliable surface water availability, and are thus heavily reliant on groundwater. For example, Namibia has permanent rivers flowing only on her northern and southern borders, with the vast expanse of land in-between lying in so-called ephemeral river basins where rivers flow in events of short duration, punctuating long periods of non-flow, or sub-surface flow (Jacobson *et al.*, 1995). The same holds true for Botswana, where current energy shortages deriving from the collapse of the Southern African Power Pool, are driving the abstraction of deep groundwater for the generation of electricity at the Moropule Power Station.

It is in this context therefore that global climate change becomes such a key issue. While opinions vary on the actual nature of the cause of global climate change, convergence exists around the belief that the world is becoming hotter at a rate that natural causes cannot really explain. Stepping aside from the debate over anthropogenic drivers of climate change, significant convergence is occurring over the projected future of Southern Africa. The Hadley General Circulation Model (HADCM3) is a respected tool used by climatologists, of which Scenario A2 is considered by mainstream climate change scientists in Africa to be the most likely (Scholes & Biggs, 2004) (Map 2).



Map 2. The HADCM3 Global Climate Change model using the IPCC SRES A2 Scenario predicts a hotter (Map a) and drier (Map b) southern Africa by 2050 (Scholes & Biggs, 2004:4). This has serious implications for both streamflow and groundwater recharge, although the exact dynamics are still being debated.

While tools such as the Hadley General Circulation Model make useful predictions about the future, in general places that are likely to become hotter are also likely to become wetter for reasons of basic physics. A warmer environment simply evaporates more water so the linkage is elementary. This is not true for Southern Africa however, where due to a variety of other factors such as altitude, distance from the sea, ratio of sea surface to land surface, prevailing winds etc., a hotter Southern Africa, will also become a drier place (de Wit & Stankiewicz, 2006). This is relatively unique in global climate change predictions and is something we need to take very seriously from a policy-making perspective.

Why is this Important?

Global Climate Change is important because it is going to impact in a fundamental way on the future economic viability of the African continent. The nature of this impact will be to change the already ‘difficult hydrologies’ into ones of nightmarish proportions. These will be characterized by a number of significant changes, including the increase in the size, magnitude and duration of extreme events such as droughts and floods. Stated simplistically, droughts will become worse and stay for longer, floods will become more violent and extreme, and landscape desiccation will occur over large portions of the continent. Countries with hydraulic infrastructure such as dams and pipelines will be more “drought-proof” than those without, but even they will be severely impacted on as the result of increased siltation and flood damage arising from extreme events.

One particularly worrying aspect needs to be considered because of the unknown consequences, underscored by the generally under-researched nature of the fundamental physics involved. I refer here to mining, which is an economic foundation for large parts of Africa. What we know about mining is that when it ends, there are major environmental impacts. This is shown schematically in Figure 3, which represents time on the horizontal axis and value on the vertical axis. Three curves are shown. The first is the Development Cost Curve (DCC), representing the capital investment in developing the mine and maintaining it through its operational life. The second is the Revenue Curve (RC), which runs out of phase with the DCC because revenues flow after the initial costs of development have been incurred. The third curve is the Environmental Mitigation Curve (EMC), which only starts to become relevant way after mine closure occurs.

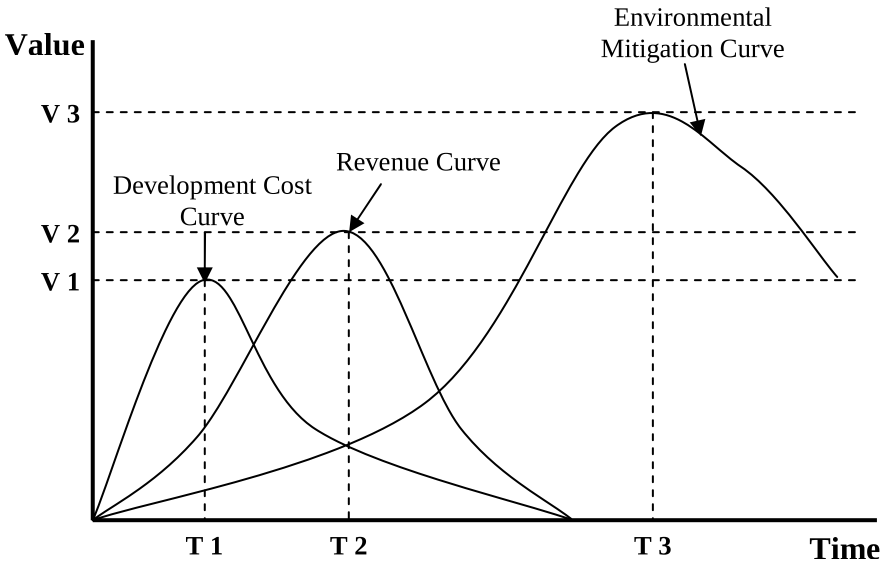


Figure 3. Conceptual representation of the cost of mining externalities such as environmental mitigation, which has a periodicity that differs from the Development Costs Curve and the Revenue Curve cycles that both terminate on mine closure. The Environmental Mitigation Curve is potentially greater in magnitude than the Revenue Curve, representing an externality posed on society, with specific consequences in a Global Climate Change scenario. (After Turton).

These three curves represent different cycles in the life of a mining operation. The significance is that the three curves have different durations and peaks. The DCC peaks early on (T1) at V1, followed later on in time (T2) but greater (hopefully) in magnitude by the RC (V2). The profit to the shareholders of the mine is crudely represented as V2 minus V1. This is not the whole picture however, with the cost of mitigating environmental damages arising from the mining operation occurring much later in time (T3), and also potentially at a greater magnitude (V3). This represents an externality that the mining operation imposes on society (V3 minus V2), which is fundamentally at odds with a key notion of sustainable development that shuns the need for future generations to pay the costs of previous generations' activities.

How is this relevant to global climate change? Recent scientific work has shown that gold mining activity is associated with uranium and radioactivity (IWQS, 1999; Coetzee *et al.,* 2002; Wade *et al.,* 2002; Coetzee *et al.,* 2006). While little is known of the extent of the problem, we do know that this radioactivity is trapped in the sediment of rivers downstream of gold mining activities. Furthermore, we do know that this radioactivity is generally prevented from spreading further by virtue of it being trapped in this sediment bed. This is a classic example of an environmental sink at work. What we do not yet know is how (or indeed if) this radioactivity enters food chains, say *via* irrigation water or normal ecological food webs. We also do not know what will happen if these sediments are dried out and allowed to blow around as dust particles, potentially contaminating other land, such as occurred in the case of the Aral Sea where toxins trapped in sediment became airborne after landscape desiccation.

What we can therefore expect under a possible climate change scenario, is for streamflow regimes to change in rivers, some of which have radioactive contaminants trapped in the sediment. During periods of prolonged drought, that radioactivity could conceivably become airborne in dust particles, whereas during periods of flood it could move downstream into dams and possibly irrigation systems, far distant from the mining activities. Radioactivity, and other pollutants, could also become concentrated in water due to the loss of natural dilution, further compounding the problem of treatment to potable standards. The simple truth is that as things now stand we just do not know enough about these dynamics, so the precautionary principle suggests we approach this problem with considerable prudence and apply our best scientific minds to solving the problem. We also need to hold public officials accountable for their actions in regulating such activities that could be harmful to society at large. Significantly, in South Africa, we are already working on this in the spirit of the new Constitution, so we have a healthy relationship between science, government and society, and regulating authorities are becoming more reflexive in their approach. This is encouraging.

Conclusion

Global climate change is something that the general public tends to dismiss as being the stuff bad movies are made of. For regions of the world that are already water stressed, this is a major concern. For regions where mining has been a major activity, this adds a new dimension that has moral, economic, social and other dimensions to it. In truth, we simply do not yet know enough about these complexities. What we do know thus far compels us to apply our collective minds further. We do know, for example, that development is constrained by what the World Bank calls 'difficult hydrologies', and we can realistically expect these to become more problematic in the future. We also know that we are approaching thresholds beyond which non-linearity kicks in and the outcome starts to become very scary indeed. Three of these non-linearity's confront us right now – the conversion of MAP to MAR, the ecological collapse after two thirds of the streamflow has been captured in dams, and the dramatic drop-off in groundwater recharge below 400 mm/yr. We know a bit about mine management, and we are starting to find out about externalities and the true cost of mining in the form of long-term environmental mitigation costs. What we know already suggests that these long-term costs could conceivably exceed the benefit derived from mining in the first place, as occurred with asbestos and potentially with uranium in the former East Germany. We do not yet know the true situation in the gold mining industry, specifically if radioactive waste that we know is found in some rivers, potentially moves through society as a direct result of the extreme events associated with global climate change. Combined, these suggest that we apply due diligence and investigate these in a responsible way in order to best inform the decision-makers, many of which are simply non-specialist politicians that are driven by a relatively short time horizon. Ultimately, as a society, we need to ask ourselves if this is commensurate with the spirit of sustainable development that is so deeply enshrined in the South African Constitution? If not, we need to take adequate measures to change things. This includes the effective resourcing of our national scientific institutions, and the holding of our regulatory authorities accountable for the unintended consequences of the actions of previous economic growth models.

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