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Three Strategic Water Quality Challenges that Decision-Makers Need to Know About and How the CSIR Should Respond

Keynote Address: A Clean South Africa

Presented at the CSIR Conference
"Science Real and Relevant"
18 November 2008
Pretoria

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South Africa is a fledgling democracy with a turbulent history. That history is a cocktail of good and bad, of success and failure, but it has provided us with a rich incubator for ingenuity.

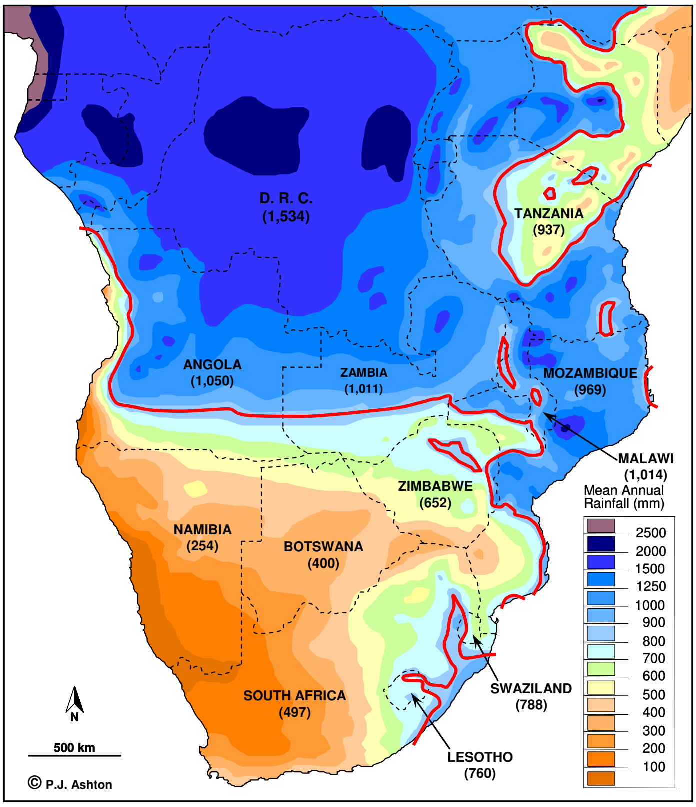
To me the simple question is what role should a National Science Council like the Council for Scientific and Industrial Research (CSIR) play in South Africa's fledgling democracy?

While this question seems simple at first glance, it is in fact highly complex, so it is my intention to unravel that complexity in a way that creates space for a fruitful debate in the near future. I will start that process by focussing on certain fundamental drivers that impact on every citizen of this country, in the belief that by understanding those drivers, we can collectively make sensible decisions about answering the question I have posed above.

For purposes of my argument I intend to focus on three fundamental drivers that we all need to be aware of. I will present an argument for the preservation of our capacity to generate ingenuity. This logic will then be filtered through a conceptual tool that has been developed at the CSIR called the Trialogue Model, in order to gain sufficient insight for us to collectively answer the question I have posed, but more specifically, to identify three strategic water quality issues that decision-makers need to know about.

The current social and economic wellbeing of South Africa has three fundamental drivers that have shaped the processes of development to date, and will continue to shape those processes as we move into the future. These three drivers are things we simply cannot change. They are so powerful that if we fail to recognize them, then all of our efforts at solution-seeking will mount to naught (at least in my professional opinion).

Driver No. 1: Dilution Capacity. The most important driver is the climate, and in particular our precipitation patterns. Map 1 shows the Mean Annual Precipitation (MAP) for the entire Southern African region. A few important aspects immediately become evident when one examines the data on that map. The most striking feature is the spatial distribution patterns of rainfall, with a steep gradient from north to south and from east to west. A more subtle feature is the global average of 860 mm/yr, shown as a thick red line on Map 1. Significantly, three of the most economically developed countries in the Southern African Development Community (SADC) mainland region – South Africa, Botswana and Namibia – are all on the "wrong" side of this global average. Even more subtle is the national average, shown in parenthesis under each country name on the map. South Africa has a paltry 497 mm/yr, marginally better than Botswana with 400 mm/yr and somewhat better than Namibia with a mere 254 mm/yr. This has led me to conclude that water scarcity is a fundamental developmental constraint, not only to South Africa, but also to the entire SADC region (Ashton & Turton, 2005; 2008; Turton, 2008a; Turton & Ashton, 2008).



Map 1. Mean Annual Precipitation (MAP) in the Southern African region (courtesy of Prof. Peter Ashton).

The situation becomes more interesting than this however, because it is not only the availability of water that is a constraint, but also the allocation of it. In this regard South Africa has allocated around 98% of the national water resource at a high assurance of supply (NWRS, 2004). This is highly significant, because the data used in the National Water Resource Strategy was from 1998, making it somewhat outdated, and I am on record as saying that I do not believe we can measure these things as accurately as this (Turton, 2007). In essence then, for purposes of the argument being presented here, South Africa simply has no more surplus water and all future economic development (and thus social wellbeing) will be constrained by this one fundamental fact that few have as yet grasped.

An important implication of this fundamental fact is that **South Africa has lost its dilution capacity**, so all pollutants and effluent streams will increasingly need to be treated to ever higher standards before being discharged into communal waters or deposited in landfills. This gives us a very hard set of choices that need to be made. Either we need to change our current developmental trajectory and accept that the targets specified in the Accelerated and Shared Growth Initiative for South Africa (ASGISA, 2006) are simply unobtainable; or we have a radical rethink about how to mobilize the science, engineering and technology (SET) capacity of the South African 'nation' in a concerted effort designed to support the targets specified in ASGISA. The decision is not actually difficult to make, because if we accept the former option, then we can say, with a reasonable degree of certainty, that social instability will grow and South Africa will slowly slide into anarchy and chaos (see Johnston & Bernstein, 2007 for an example). The recent xenophobic violence is, in my professional opinion, but a foretaste of things to come, if we follow this trajectory (Johnston & Wolmarans, 2008; Sibanda, 2008). So the former is simply not an option. This leaves us with the alternative of radically rethinking how we should mobilize the national SET capacity as a matter of strategic priority. Embedded in this issue is the notion of comparative advantage, because the South African economy is already at a global disadvantage, so if we add additional costs to production, then we are faced with a double-whammy!

Driver No. 2: Spatial Development Pattern. Another fundamental driver is the unique spatial pattern of development in South Africa as a country, but also within the mainland SADC region as a whole. In this regard the uniqueness arises from the fact that all of the major centres of economic development, and thus cities and urban conurbations, are located on watershed divides. Nowhere else in the world is this pattern evident to the best of my knowledge. The global norm is for large cities to be located on rivers, lakes or the seashore. But not so in our part of the world, where we have Johannesburg/Pretoria as one massive urban conurbation in South Africa, Gaborone and Francistown as smaller cities in Botswana, Windhoek as a sizeable city in Namibia and Bulawayo and Harare in Zimbabwe – all located on, or very close to, watershed divides (Ashton *et al.,* 2008; Turton *et al.,* 2006; Turton, 2008a). The significance of this fact is twofold:

- It has taken major engineering and technology to mobilize the water needed to sustain these industrial and urban conurbations.

- It now means that effluent return flow out of these major industrial and urban conurbations is a major threat to future economic development, simply because the quality of the water is so degraded that it becomes unfit for human and industrial consumption (Coetzee, 1995; Coetzee *et al.,* 2002a; 2002b; 2005; 2006; Dalvie *et al.,* 2003; IWQS, 1999; Kempster *et al.,* 1996; Oberholster & Ashton, 2008; Oberholster *et al.,* 2004; 2005; 2008; Slabbert *et al.,* 2007a; 2007b; Toens *et al.,* 1999; Wade *et al.,* 2002). This is driving growing concerns from the public that will need to be addressed if social stability is to be maintained, if investor confidence is to be restored and if the legitimacy of the government is to remain intact (Bega, 2008a; 2008b; Johnston & Bernstein, 2007; Tempelhoff, 2008).

This makes the SET we develop (or fail to develop) a profoundly political act, and to ignore this factor, simply because scientists labour under the daily illusion that all they do "is the science", will be to our peril, both as a Council and as a 'nation'.

Driver No. 3: Historic Legacy. The most insidious, but potentially more volatile of these fundamental drivers, is our historic legacy. In this regard the country we call South Africa was forged out of the extreme violence of the Second Anglo-Boer War (Mills & Williams, 2006; Turton *et al.,* 2006). This was an event so traumatic that it sowed the seeds of the subsequent quest for Afrikaner Nationalism as a vehicle for recovery of a nation smashed, not on the field of battle, but by the gross injustice of the Scorched Earth Policy that targeted non-combatants, and the resultant squalor of the British Concentration Camps, in which Africans, women and children died of dysentery, cholera, starvation and despair (Hasian, 2003; Hobhouse, 1901; 1907; Van Reenen, 2000; Van Rensburg, 1980). The social pathology caused by this one historic event, which gave birth to our country as a legal entity, merged with three other sets of significant social trauma from the pre-statehood era, the combined effects of which are still being felt today:

- the plight of the amaXhosa after a century of war, which culminated in the Great Cattle Killing that reduced that great nation after 1857 to wage earners unable to sustain themselves (Meer, 1990; Peires, 2003; Welsh, 2000);
- the ethnic cleansing in the 1820's and 1830's of many non-Zulu tribes during the *Mfecane* that laid the hinterland of the country waste, creating the vacuum into which the Trekboers moved during the Great Trek (Edgecombe, 1986; Turton *et al.,* 2004; Welsh, 2000);
- and the destruction of the amaZulu as a hegemonic nation at the Battle of Ulundi, in response to their defeat of the British at the epic Battle of Isandlwana in 1879 (Mills & Williams, 2006; Welsh, 2000).

The combined effect of these four events has created a historic legacy that is based on violence and the disrespect of human rights that still lives with us today. These historic events have given us a country without a coherent sense of nationhood (Buzan, 1991; Thompson & Lamar, 1981). **Our science is embedded in this legacy, whether we choose to acknowledge it or not.** In the context of the topic at hand, this means that all decisions taken at a strategic level need to be fully cognizant of **three vitally important consequences of our historic legacy**.

- The propensity to resort to mass violence when expectations exceed the capacity of the government to deliver (see Image 1a).

- The legacy that has left a country with no coherent sense of nationhood, prone to popular rhetoric that reflects crudely defined racial stereotypes, a manifestation of which is a majority of citizens who are mired in endemic poverty, with little prospect of escaping that trap, without massive government planning and support.

- The systematic erosion of investor confidence, punctuated by bouts of extreme violence such as the recent xenophobic attacks (see Image 1b), which cause great harm to the perception of the international financial community that South Africa is a viable destination for foreign direct investment.

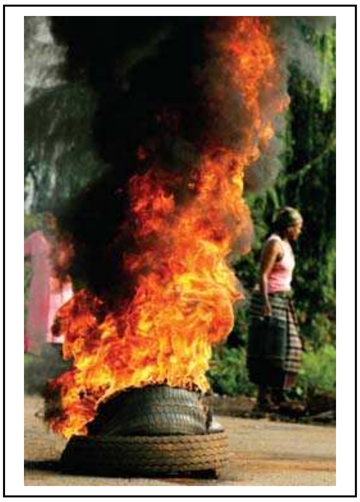



Image 1a (left) shows the extreme anger of people during riots in Phumelela and Merafong City in 2004, driven by a 'failure of service delivery', 'poor governance' and 'lack of capacity', fuelling perceptions of an uncaring and corrupt government (Johnston & Bernstein, 2007: 4 & 24). Image 1b (right) reflects the anger of people arising from failed immigration policies during the xenophobic violence that occurred in 2008 (image courtesy Ogrish.com). The propensity to resort to mass violence, when public expectations exceed the capacity to deliver, cannot be ignored in South Africa (Percival & Homer-Dixon, 1995; 1998; 2001). This violence is both unpredictable and unanticipated, which can be regarded as a manifestation of a failure to mobilize sufficient Social Ingenuity (see Homer-Dixon, 1996; 2000). Could this type of anger be unleashed in response to perceptions of deteriorating public health as a result of declining water quality?

So, if these three drivers are of strategic importance – our loss of dilution capacity caused by the over-allocation of national water resources, our unique pattern of spatial development, and our historic legacy – then we need to take cognizance of them if viable solutions are to be found. It is to this that we now turn our attention.

In the recent past a Canadian scholar named Thomas Homer-Dixon looked at the world and was struck by one observation that seemed to be repeated in a number of different geographies. That observation was that poor countries seemed to be locked into poverty from which little prospect of delivery seemed likely, whereas developed countries seemed to be able to become richer. This sparked a significant research program in which a number of startling discoveries were made, all of which are directly relevant to our current discussion (Barbier & Homer-Dixon, 1996; Homer-Dixon, 1994; 1995; 1996; 1999; 2000; Percival & Homer-Dixon, 1995; 1998; 2001). What Homer-Dixon discovered are in essence two profound causal relationships.

- Richer countries seem to be in a position to avoid most debilitating crises, when compared to poorer countries, because of their capacity to create solutions to complex problems. In order to give this concept a name he called it Technical Ingenuity, which he defined as the capacity of a nation to develop technical solutions to problems being driven by exogenous changes. This is obviously relevant in a global change context, but it is equally relevant to South Africa as a water-constrained political-economy.

- In order to develop Technical Ingenuity, a necessary pre-condition is what Homer-Dixon called Social Ingenuity, which he defined as the capacity of a nation to generate incentives that create the institutional environment in which Technical Ingenuity could be generated.

Now the argument becomes interesting, because if one analyses this whole issue of ingenuity, one is struck by the fact that problems facing society in general have a propensity to become more complex over time. This is driven in part by the unintended consequences of our technological solutions. This means that as we develop Technical Ingenuity, we set in motion a chain reaction that will almost always result in an unanticipated consequence. This is what Tenner (1996) called a "revenge effect". In the South African case we have many classic examples. We develop antibiotics to counter infection and over time we breed drug-resistant bacteria. We manage water scarcity by engineering dams and inter-basin transfers and over time we create an ideal environment in which toxic Cyanobacteria bloom (Harding & Paxton, 2001; Hunter, 2003; Oberholster & Ashton, 2008; Pitois *et al.,* 2000). We apply chemicals to kill mosquitoes and we reduce the potency of human gametes (Aneck-Hahn *et al.,* 2007) and create urogenital defects in unborn infants (Bornman *et al.,* 2005).

Given the first two fundamental drivers noted earlier (the loss of dilution capacity and our spatial development patterns), we have mobilized masses of Technical Ingenuity to move water from distant river basins and mine minerals from ever greater depths. But these have caused second-order problems – the so-called revenge effects – such as loss of ecological integrity in aquatic systems arising from inter-basin transfers (IBTs) (Basson, 1995; Blanchon & Turton, 2005; Davies & Day, 1998; Heyns, 2002; Snaddon *et al.,* 1999) and increased levels of pollution from radionuclides, heavy metals and sulphates arising from mining (Cobbing, 2008; Coetzee, 1995; Coetzee *et al.,* 2006; Hobbs & Cobbing, 2007; Hobbs *et al.,* 2008; Oelofse, 2008a; 2008b; Oelofse *et al.,* 2007; Wade *et al.,* 2002). It is here that the analysis becomes really interesting. Clearly we have mobilized masses of Technical Ingenuity over time with which we have developed our national economy to the level of diversity we have, in the face of such significant constraints as water and energy, but we are again at the threshold of a new set of challenges. Development, like life, is a journey and not a destination! We have not yet arrived and indeed never will. What we have learned in the past is not necessarily relevant to the future, because of the propensity to greater complexity over time. We cannot base tomorrow's solutions on yesterday's experiences and today's science (Turton, 2007).

So the question now shifts to a new focal point using Homer-Dixon's logic. If we have mobilized that much Technical Ingenuity to give us economic development in the face of such environmental scarcities, can we continue to do so? The answer to that, I am afraid, is a chilling no, all things remaining equal (the economic principle of *ceteris paribus*). Why is this so? My argument is based on the fact that South Africa is the most economically developed country in Africa. I argue that this is so, because we have six National Science Councils, all of which have mobilized the necessary Technical Ingenuity on which that economic growth and development has been predicated. Yet the viability of some of these councils is no longer guaranteed. For example, the recent analysis by Walwyn & Scholes (2006) shows quite convincingly that the CSIR is in trouble (Figure 1).

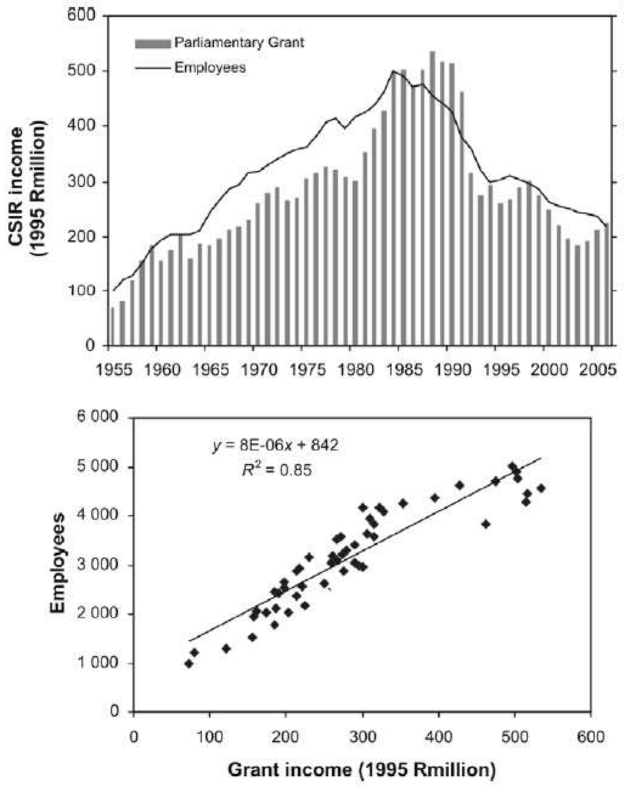


Fig. 4. CSIR employees and grant income. Employee numbers appear to correlate only with grant income; contract income does not retain research capacity.

Figure 1. Trends in funding and staff turnover at the CSIR (Walwyn & Scholes, 2006:241). Program-styled funding builds national capacity but contract-driven funding does not retain that capacity.

The cause of that loss of viability is a shift from a grant-based model to a mixed-income model. This research shows quite convincingly that SET capacity was developed at a national level before 1985, when massive programs were in place (see Figure 1). Those programs generated high quality science, such as the isolation of the molecule that makes up the toxin known as microcystin (CSIR, 1984:114), which is found in growing quantities in our national waterways today (Oberholster & Ashton, 2008). A recent article published in *Water Wheel* gives some insight into this era of science:

> "Until the mid-1980's, South Africa was a world leader in research in the field of eutrophication. Unfortunately, this advantage has since been lost due to eutrophication being afforded lower priority status by government, which led to the termination of funding for research in this field. Many of the researchers involved in early eutrophication research have since moved into better research fields, into consultation or have emigrated. As

> a result, appropriate management strategies directed against eutrophication have been seriously constrained by widespread lack of understanding of the problem, particularly at the decision-making level" (Van Vuuren, 2008:15).

Those programs in the 1980s also generated a cadre of PhD graduates who went on to become a foundation of the national-level SET capability. The shift to a contract-driven income model has had a catastrophic effect on our national SET capacity, at the very time when we are being confronted by revenge effects arising from our earlier application of Technical Ingenuity, to which we simply have no solution. This means that we are now flying blind as a nation. Significantly, we cannot import those technical solutions because, in the case if microcystin as an example, there are few other places in the world where there are similar levels of toxin in the national water resources (China is an exception), so there is simply no need in most countries to solve this specific problem with the same urgency that we are confronted by. Similarly, our need to reduce nitrogen and phosphate end-of-pipe loads by orders of magnitude at sewage works, if we are to mitigate the exponential growth in Cyanobacteria blooms that now threaten our national water security (Harding & Paxton, 2001; Humpage *et al.,* 2000; Oberholster & Ashton, 2008), will have to be home-grown solutions, because no other developed country faces this challenge. Likewise, we need to prevent the unchecked growth in numbers of babies being born with urogenital defects (Bornman *et al.,* 2005) and counter the loss of male fertility (Aneck-Hahn *et al.,* 2007), in both cases the result of endocrine disruptors caused by the use of chemicals to control malaria in some of the poorest communities in this country.

Using the conceptual lens of ingenuity provided by Homer-Dixon (2000), let us examine what the South African case has been in terms of water quality management at the national level over time (see Figure 2).

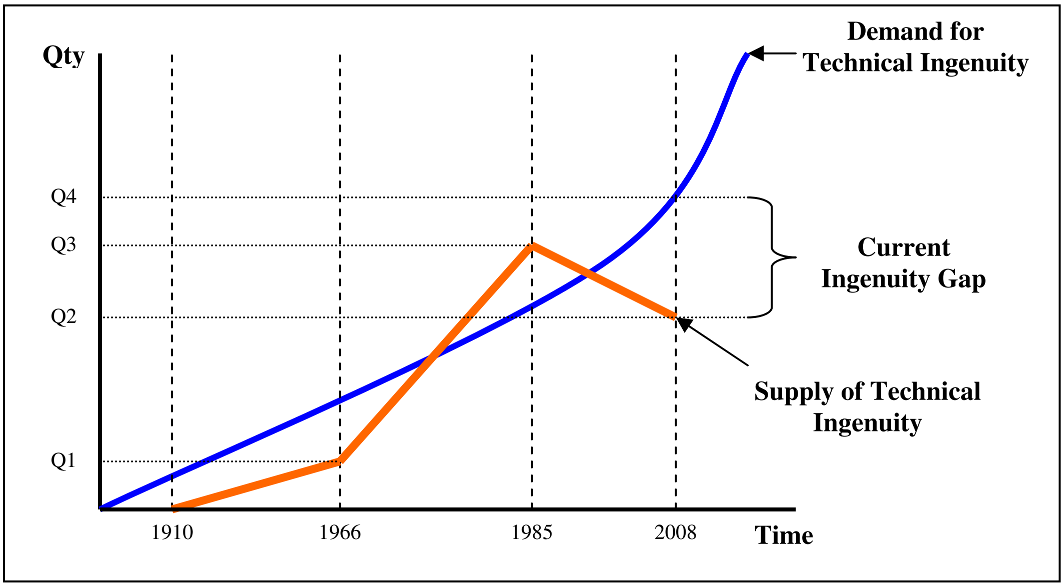


Figure 2. Schematic representation of the demand and supply of Technical Ingenuity in South Africa since the Act of Union in 1910 using the conceptual lens of an Ingenuity Gap as hypothesized by Homer-Dixon (2000).

The demand for Technical Ingenuity is presented as a blue curve, showing exponential growth over time as the level of complexity has increased at the national scale. The supply of Technical Ingenuity is presented as an orange line, which has three distinct phases to it. The first phase started in 1910 when the Act of Union formed the constitutional basis for what we today call South Africa. At the time of Union, the demand for Technical Ingenuity, mostly to sustain the mining industry, exceeded the supply, so there was an Ingenuity Gap that grew in magnitude to Q1 in 1966. In 1966 there was a *Commission of Enquiry into Water Matters*, which identified water as being a major constraint to future economic growth and national prosperity (Turton *et al.,* 2004; 2008). This established water resource management as a national strategic priority, with the Water Research Commission (WRC) being formed as a world first to fund the research needed to make that management more robust. The trajectory of the supply of Technical Ingenuity thus changed radically after 1966, growing to a point when it reached a peak (Q3) in 1985 (also see Figure 1 for the CSIR case). It must be noted that the supply of Technical Ingenuity probably exceeded the demand for Technical Ingenuity in 1985 (or was at least in balance). The year 1985 is important because that was when the CSIR reached its peak in staff numbers (see Walwyn & Scholes, 2006: 241 – Figure 1). It is significant that it was just before this date that the chemistry of microcystin became known for the first time (CSIR, 1984). The third phase in the supply of Technical Ingenuity saw the gradual demise of SET capacity in the CSIR to a point (Q2) where it is way below the current demand for Technical Ingenuity. This means that there is a current Ingenuity Gap in South Africa, with acute shortages occurring in the energy and water sector. The supply curve for Technical Ingenuity from 1966 to 2008 (Q1 – Q3 – Q2) coincides with the trajectory of the number of CSIR employees shown in Figure 1 (Walwyn & Scholes, 2006: 241). If we are to learn from the past, then what is needed is a new *Commission of Enquiry into Water Matters* in order to set new national priorities and align them with the SET capacity of the country (Turton *et al.,* 2008). **More significantly however, this decline started a decade before the birth of our democracy, so when the current government came to power they inherited a robust infrastructure but a declining level of Technical Ingenuity**. It is not their fault. This is part of their legacy, but it is they who have to deal with it now.

South Africa thus presents today with a classic case of what Homer-Dixon (2000) calls an ingenuity gap. Our needs for technological solutions are growing exponentially while our capacity to create those solutions is declining exponentially. This is caused by a failure of Social Ingenuity – the capacity to create incentives for the continued creation of Technical Ingenuity – something we will need to address as a nation if we are to dig ourselves out of the hole we are sliding into. I therefore interpret the finding of Walwyn & Scholes (2006) as a classic example of what has previously been called a Second-Order Scarcity (Ashton & Haasbroek, 2002; Ohlsson & Turton, 1999; Turton, 1999; 2002) or a scarcity of Social Adaptive Capacity (Ohlsson, 1999). In essence **the mixed funding model is a manifestation of a shortage of Social Ingenuity - it is a failure to find the right incentives for the continued creation of Technical Ingenuity - and that is a national concern**, because of the implications to society at large.

How will we change this? In this regard I have endless optimism in South Africa as a ‘nation’. We have consistently dug deep into that intangible strength we have as a ‘nation’ when at the eleventh hour - often having our backs to the wall with collapse into chaos seeming imminent and unavoidable - we pull yet another rabbit out of the hat. That is what happened during 1994 when we faced our darkest hour as a 'nation', teetering literally on the very brink of full-scale civil war (Spitz & Chaskalson, 2000; Turton, 2006). This is what will happen again now, as the public realizes the role that the various National Science Councils play in delivering what I call "Science in the Service of Society" and as the various government departments start to realize that service delivery is a serious issue that they can no longer avoid.

After all, the Uhuru Decade came to an end with the electricity crisis in early 2008. This Uhuru Decade has been manifest all across Africa when a liberation movement has inherited infrastructure that works for about ten years before starting to break down through lack of investment in operation, maintenance and skilled human capacity. In South Africa's case that infrastructure was particularly robust so it has lasted a decade and a half, but it is now clearly under pressure and if left alone will collapse piece by piece, in the mid-term future. The trend in infrastructure investment for water at the national level shows this prognosis to be probable in a startling way (see Figure 3).

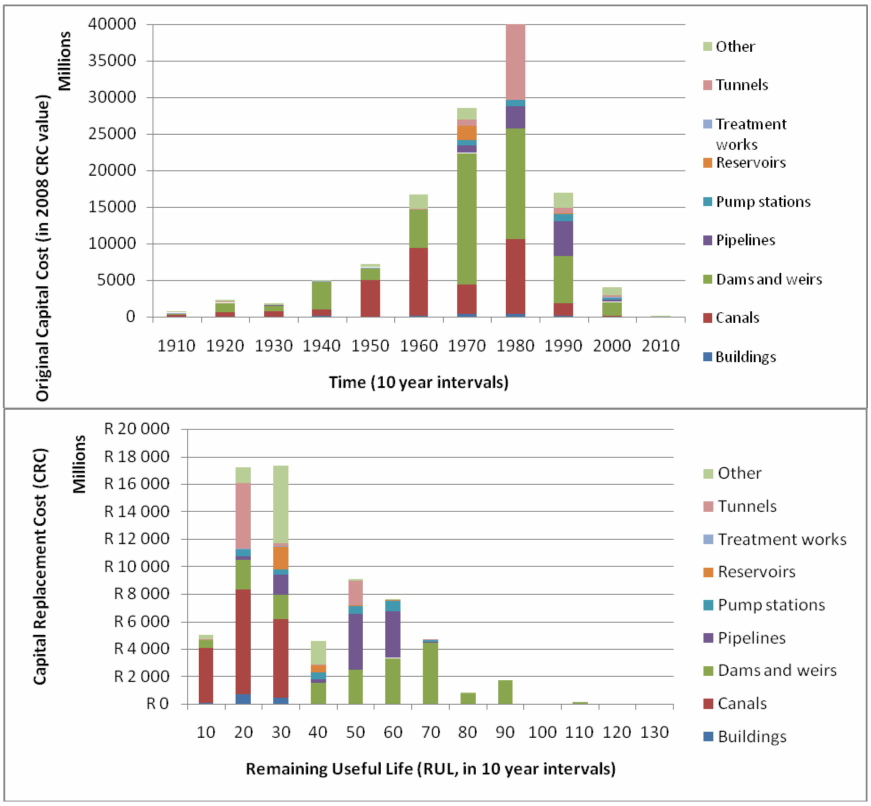
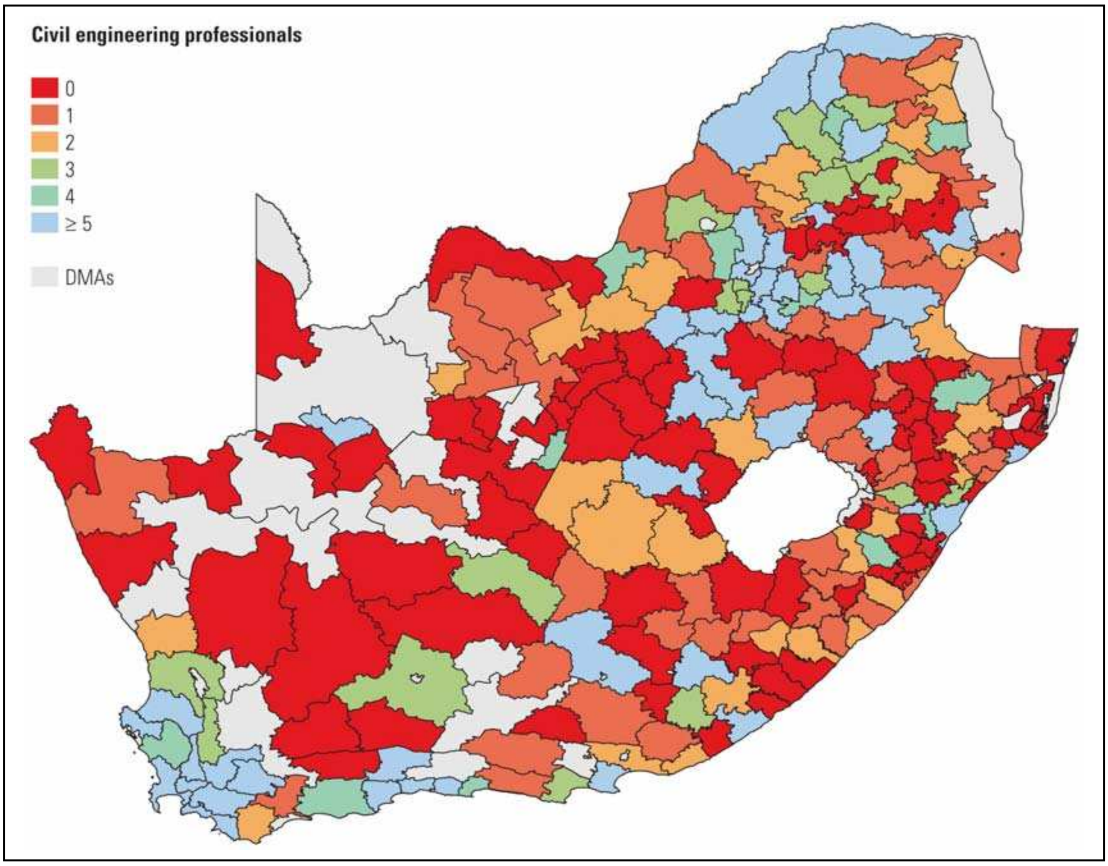


Figure 3. The age profile of assets currently on the books of the Department of Water Affairs and Forestry (DWAF) shows a peak period of capital investment in the 1980's followed by a dramatic decline (top). The remaining useful life of those assets shows a worrying trend (bottom). Both of these graphs have a similar pattern to Figure 1 suggesting a trend towards the erosion of the assurance of supply needed to grow the national economy in a sustainable manner. (Both graphs courtesy of DWAF, 2008).

If Figure 1 gives an indication of what is happening to our highly qualified human resources at a national level, and if Figure 3 gives an indication of what is happening to our physical infrastructure in the water sector, then it is not hard to conclude that we are heading for a significant crisis in the water sector. That crisis can best be understood as being driven by an ingenuity gap as described in Figure 2.

The impact of this conclusion is evident when tested again another alarming trend. The South African Institute of Civil Engineers (SAICE) did a presentation to the Parliamentary Portfolio Committee on the 4th of June, 2008. In that presentation they revealed a number of startling facts. One of these relates to the number of engineers per municipal area across South Africa (Map 2). It is evident from this map that a significant proportion of South Africa has no civil engineering professional support in a local authority. It is precisely these rural areas that are most likely to be affected by the deteriorating water quality arising from eutrophication in rivers and dams (see below for more details). It is also these local authorities that are the least capable of adapting water treatment processes and plant to remove Microcystins, Endocrine Disrupting Chemicals (EDCs) and Anti-Retroviral medication (ARVs) that are likely to arise from a population with a heavy burden of AIDS-related diseases (see below for more information).



Map 2. The number of civil engineering professionals per municipal area in 2005 has a distinct spatial maldistribution pattern to it (courtesy South African Institute of Civil Engineers, 2008). This suggests that the water quality crisis presented in this paper is more likely to occur unless a well designed and informed intervention takes place.

When one considers that in 2004 South Africa had 15,000 engineers, technologists and technicians (SAICE, 2008), new insight is shed onto the notion of an ingenuity gap (see Figure 4). The age distribution of one sub-set of this larger category – certified professional engineers – shows a maldistribution in terms of race and age. There is a large bulge of aging white male engineers followed by a massive gap in the age group 35 – 49. This is the age group that has been most affected by affirmative action employment rules and sadly many of this cohort have left the country as a result. This is another manifestation of a failure to mobilize Social Ingenuity, because it has created a disincentive to the retention of skilled engineering staff at the national level to the detriment of the entire country.

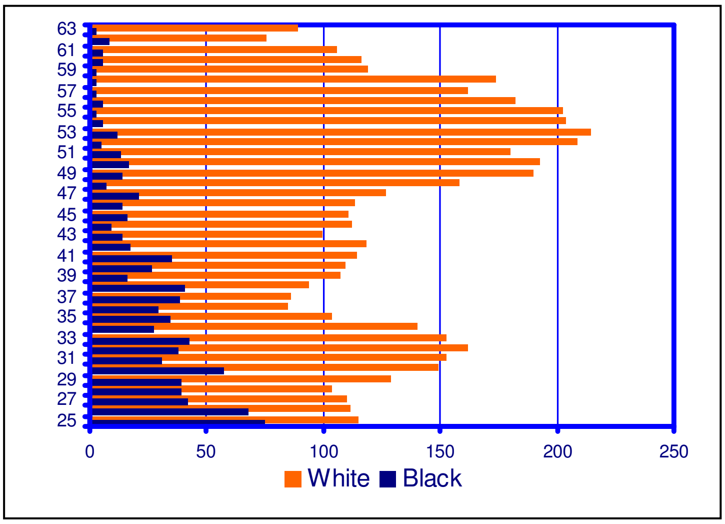


Figure 4. The age distribution of engineers in South Africa shows that we are producing fewer engineers than are leaving the profession (SAICE, 2008).

A similar trend is evident when one examines the distribution of the 15,000 engineers, technologists and technicians that South Africa had in 2004 (SAICE, 2008), presented in Figure 5.

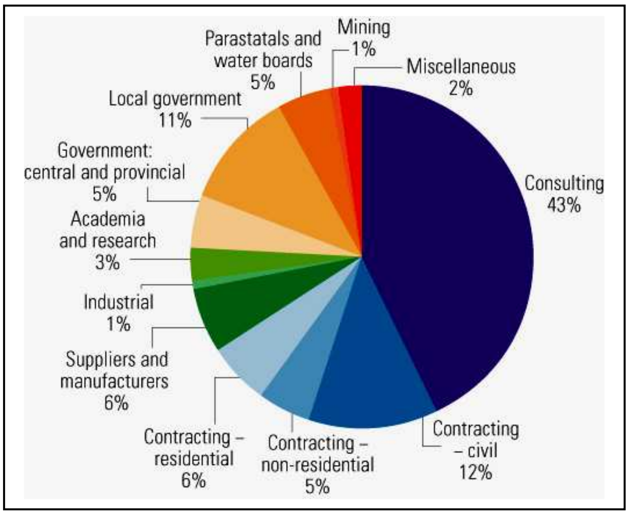


Figure 5. The distribution of the 15,000 engineers, technologists and technicians that South Africa had in 2004 shows that few are in research, national and provincial government, with most in private consulting firms (SAICE, 2008).

The distribution of engineering professionals shown in Figure 5 indicates that few are found in research, national and provincial government, while many are found in private consulting practice. This is again a manifestation of a scarcity of Social Ingenuity because the incentives have not been created to attract and retain qualified engineers to research councils, national and provincial government.

Which poses the question, what do we need to do about this at a national level? Do we wish to avert the water crisis before it happens, or are we to be content with the *status quo*, happy to deal with it after it has been thrust upon us like the electricity crisis was? Remember, alternatives to coal-fired electricity do exist, with disruptions to service delivery being at best a temporary disruption but at worst a slowdown of the economy and loss of jobs. But water is different. Chronic exposure to microcystins can cause human health impacts (Harding & Paxton, 2001; Humpage *et al.,* 2000; Oberholster & Ashton, 2008; Oberholster *et al.,* 2004; 2005; 2008; Pitois *et al.,* 2000; Ueno *et al.,* 1996), with fears of radioactivity and heavy metal contamination (Coetzee *et al.,* 2002a; 2005; 2006) becoming a new scare in which the panic factor makes the management of the process that much more volatile.

The CSIR has invested large amounts of financial and intellectual capital into the development of an internal thinking process that will prepare us for a new role in our fledgling democracy. This has resulted in what has been called the Trialogue Model, in terms of which the relationship between three actor-clusters – Government, Society and Science – is mediated by a set of complex interfaces in which partnerships are formed and feedback loops provide the signals necessary for all actors to modify their behaviour in response to specific stimuli (Turton *et al.,* 2007) (see Figure 6).

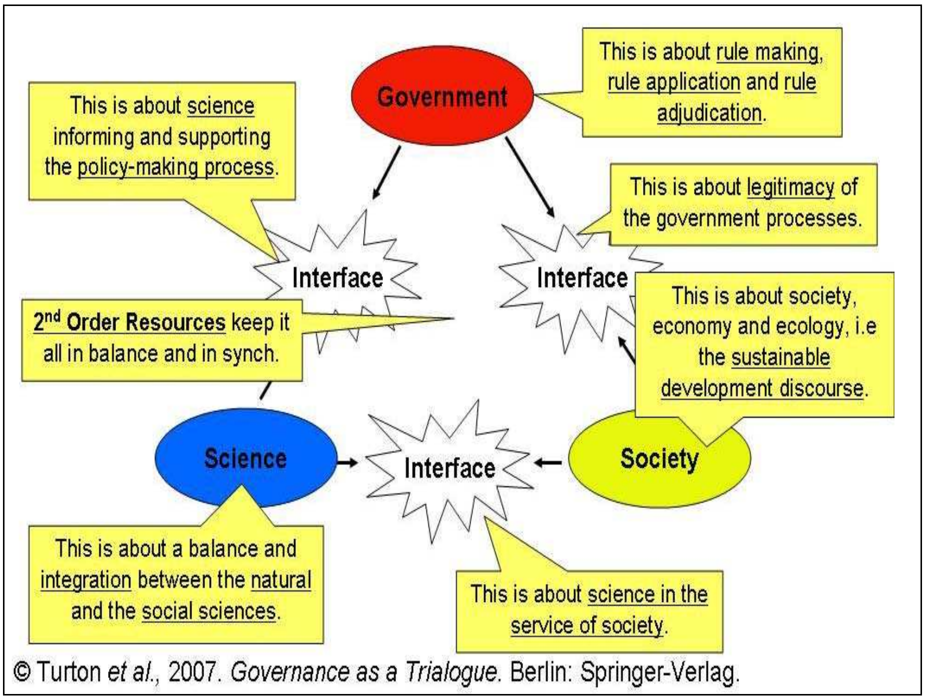


Figure 6. The Trialogue Model illustrates the relationship between three actor-clusters being mediated *via* interfaces (Turton *et al.,* 2007). It is clear that Science needs to engage in different ways with Government and Society if it is to have an impact.

I believe that it is the Trialogue approach, which will empower the CSIR to navigate the uncharted territory of these new waters. In this process, I see three critical challenges internal to the CSIR that will need to be managed if we are to succeed in playing our role in the mitigation of the looming water crisis suggested above:

- **Internal Challenge No. 1. Communicating Science**. The way that we as scientists engage in the communication of our so-called academic consumables will change. Gone are the days when we generated technical solutions and tossed them over the fence hoping that they would hit a passing problem (to quote Pete Ashton). The feedback loops inherent to the Trialogue approach means that we will have to listen as much as speak, and become more responsive to the needs of our stakeholders. No more should we speak of clients and increasingly we must think of these as partners. We must also start to hold ourselves accountable to the citizens of this country, because it is their tax money that will be converted by the CSIR into useful Technical Ingenuity. Our communication will therefore have to be bold, honest and done *via* channels not familiar to most scientists – the mass media. That simply scares most scientists and they recoil in horror at the very thought of it.

- **Internal Challenge No. 2. Public Funding**. Sustained access to public funding is *the* new challenge. It is clear that the mixed funding model is failing (Walwyn & Scholes, 2006)(Figure 1) and that we have unintended consequences arising from this failure (Oberholster & Ashton, 2008; Van Vuuren, 2008). It is also clear that we cannot allow this to happen, because that failure will eventually lead to the total erosion of the national SET capacity and the country will be the poorer. It is significant that it is public funding that has allowed for the massive breakthrough that occurred when the Water Research Commission (WRC) decided to fund the ground-breaking studies that revealed the existence of radionuclide and heavy metal contamination in streams downstream of gold mining activities (Coetzee *et al.,* 2006; Wade *et al.,* 2002; Turton, in prep). It is also significant that the WRC was willing to fund a study into human health arising from environmental risks in groundwater (Toens *et al.,* 1999) and is currently considering funding the first ever high confidence study of human health risks arising from chronic exposure to populations living adjacent to gold mining operations (CSIR, 2008). It is for this reason that we need more access to public funding, because it is the public nature of that funding that places the science generated back into the public domain. Private funding removes that science from the public domain, by placing contractual restrictions on both its scope and dissemination. Without this funding we simply cannot do Science in the Service of Society, because it exposes the CSIR as a national asset to the risk of being hijacked by private interests, which have no wish to open up these complex legacy issues, for various reasons. This is the unique contribution that the CSIR can make to deepen our democracy, by empowering society to engage with government and industry over issues that affect their daily lives. Very few scientists that I know have ever thought that they are engaged in this important task of deepening our democracy, but in essence that is what we are doing already. If you read the fine print, it is what we *should* be doing, because it is actually implicit in the second portion of our Parliamentary mandate.

- **Internal Challenge No. 3. Building Trust**. Trust is vital in a country, which is still engaged in nation-building, but has not yet adequately dealt with the legacy of a century of violence, abuse of power and non-accountability. Trust is earned and in this regard the CSIR has a unique potential to act as honest broker when contested situations arise needing a robust scientific solution (Mmemezi, 2008; Smillie, 2008). I think here of the need to mitigate the impact of Acid Mine Drainage (AMD), from both the coal and gold sectors, which has the capacity, if left unmanaged, of destroying the last remaining water resource on which the economic aspirations of a 'nation' depend (Oelofse, 2008b). Likewise with the human health implications of cyanobacteria and microcystins and uncontrolled endocrine disruption arising from our loss of dilution, all of which will require a concerted effort to re-build the trust we need – the Social Ingenuity that has to be mobilized – if we are to find sustainable technical solutions to these vexing problems.

These are our internal challenges. The journey has already begun and even as I speak the CSIR is engaging with a specific Government Department about the possibility of developing a *National Water Quality Science, Technology and Policy Support Program*. Likewise we are engaging with other government departments in an effort to go back to the program-style of managing parts of the CSIR. We are also engaging with major players in the energy sector that rely on coal as primary feedstock, because just as they are faced with the challenge of developing new energy, the CSIR is faced with the challenge of developing technologies that will create new water, some from acid mine drainage caused by their operations. Significantly, the Natural Resource and Environment (NRE) unit at the CSIR has already made a decision to develop acid mine drainage and associated human health into a Flagship Program, based on recent recommendations made by the Research Advisory Panel (RAP). This new dispensation for SET will therefore be based on the Trialogue in which we engage more proactively, but always with integrity, because after all, good science is never afraid of robust public scrutiny and debate.

We can now answer the question posed in the opening statements of my presentation. The simple answer is that our parliamentary mandate says we must do two things: develop the SET-base for the national economy; and apply our minds to issues of national importance. We will do that using the Trialogue approach, a process that is already underway.

Three Strategic Water Quality Challenges

Now to deal with the title of this presentation – the identification of three strategic water quality challenges that decision-makers need to now about (Turton, 2008b).

As a result of the fact that we have lost our dilution capacity, we are now faced with an increasing water quality problem. This will be addressed through the *National Water Quality Science, Technology and Policy Support Program* currently under development, in terms of which there will be three highly specific focal points. These are all based on three strategic challenges that decision-makers in both government and the private sector are being confronted with on a daily basis (Turton, 2008b). These are the following:

Strategic Challenge No. 1: National Quest for Sustainability. South Africa is one of the few countries in the world that has legislated for sustainability in their national Constitution. We therefore need to turn these noble words into actual deeds supported by robust science. To this end the CSIR has already invested heavily in what is known as Sustainability Science. We need to now turn that theory (Burns *et al.,* 2006; Burns & Weaver, 2008) into concrete science, technology and policy. In that process our available scientific knowledge tells us that there are two major issues that are about to burst into the board rooms of large corporations and into the corridors of government power in Pretoria and Cape Town. These two issues are:

- **Acid Mine Drainage**. Our entire national energy strategy is largely based on coal as a feedstock. That dependence is complex and will not be easily changed (Oelofse, 2008b), so we have to focus our attention in the quest to develop sustainable solutions to AMD, both coal and gold-based. This is a highly complex issue and can only be overcome by leveraging all of our SET assets in a concerted and focussed National Strategic Program with all major players in both the energy sector (coal-based AMD) and mining sector (gold-based AMD) as fully-fledged partners. To do this we must move away from the current posture of being on a quest to hold corporations legally liable for legacy issues, because that drives them into defensive positions from which cooperation is not possible. In this regard we are already learning from the German experience after unification where similar challenges arose. We need to build robust partnerships, both nationally and globally, to achieve this objective. We also need to solve technical problems that result in "new water" that is generated in a way that is both environmentally and economically sustainable. The SET component of this challenge will need to be robust, probably exceeding the combined capacity of all our existing research institutions, meaning that cooperation and partnerships are an absolute necessity. In this regard, the principle being applied is that the level of ingenuity needed to solve a problem, exceeds the level of ingenuity that created the problem in the first place. This means that by definition, no one institution will be able to solve this perplexing problem alone. Partnerships, and only partnerships working in a highly coordinated manner, will be capable of achieving this strategic objective. Leadership for this process will be a major challenge, given the complexities of the issue, the degree of transdisciplinarity needed to find viable solutions and the level of political and commercial sensitivities involved. The decision to appoint and mandate an appropriate person for this leadership role will thus be pivotal to the prognosis for any future success.

- **Eutrophication**. South Africa, already highly water constrained, is now also faced with levels of eutrophication that are almost unprecedented globally. Left alone this will slowly poison our waters, rendering them useless for future economic development plans and driving up production costs for various industries, further undermining the South African economy. This also has major implications for a national population that already has a high level of people with compromised immune systems (Ashton & Ramasar, 2002). The science underpinning this was lost when the transition to the mixed funding model occurred (see Figure 1) (Van Vuuren, 2008). We need to rebuild that capacity as a matter of national priority and in this regard the recent decision by the WRC to revive the fight against eutrophication is to be welcomed and fully supported (Van Vuuren, 2008).

Strategic Challenge No. 2: National Quest for Human Health. South Africa has a number of health-related challenges (Hunter, 2003; Offringa *et al.,* 2007). One of the most notable is that associated with the scourge of HIV/AIDS that has left a substantial portion of our population with a compromised immune system (Ashton & Ramasar, 2002). Overlaid onto this is a developmental legacy that has exposed large portions of the human population to heavy metal and radionuclide contamination arising from more than a century of gold mining, much of which was largely unregulated (Adler *et al.,* 2007a; 2007b). This has many ramifications, which in my professional opinion, have not yet been unravelled in any concerted way. So, if we are to get serious about the science we do, we are going to have to show leadership in this regard (Turton, 2008b). This means focussing on the following known problem areas:

- **Microcystins.** South Africa has a microcystin load in our water storage impoundments that is amongst the highest in the world. The last serious science we did on this topic was in the decade before the start of the collapse noted in Figure 1. We need to rebuild that national capacity (Van Vuuren, 2008), specifically with respect to high confidence studies of human beings that might have been exposed to chronic doses of microcystin. That work will be costly, complex and politically sensitive, but we cannot allow these factors to cause us to waiver. No high confidence studies have been done and this is bordering on the criminally negligent if we do not address this issue as a matter of national priority. We need to know if microcystins are causing human health problems (Hunter, 2003; Humpage *et al.,* 2000; Ueno *et al.,* 1996), specifically in communities that are immune-compromised, and then design intervention strategies based on this new robust science.

- **Endocrine Disrupting Chemicals**. South Africa also has a growing problem with endocrine disrupting chemicals (EDCs), driven largely by our loss of dilution. This means that EDCs are being recycled without being removed. This leads to concentration and bioaccumulation, so our focus needs to be on understanding the fate and pathways in order to design appropriate interventions, both technological and policy-related.

- **Partially Metabolized Medication**. Given our high HIV/AIDS rate, South Africa has a growing anti retro-viral (ARV) load, which passes like any other medication, through the body in partly metabolized forms. This means that we are going to be seeing higher levels of ARV in our rivers, which by implication means that these complex chemical compounds will be entering the human population over time, either through the drinking water stream or *via* produce that has been irrigated with contaminated water. This specific South African issue is nested in a bigger technical problem known as Pharmaceuticals and Personal Care Products (PPCP's), which is a growing global concern, but is sufficiently unique to warrant strategic attention on its own. We need to develop the science to understand this better, because nowhere else in the world is there a coincidence of loss of dilution and high levels of ARV use as in this country. This is clearly a national priority that has major political implications. This science might even be a world first, but it is certainly a national strategic priority in which we will have to take the lead.

- **Radionuclide and Heavy Metal Contamination**. As a result of more than a century of largely unregulated gold mining, we now have a legacy of heavy metal and radionuclide contamination in rivers flowing out of most gold mining areas. We also have a high population density living in close daily contact with dust and sediment arising from mine tailings dams (large portions of SOWETO and the East and West Rand residential complexes are located on land that in most developed countries would be considered to be contaminated). South Africa has never done a high confidence study of off-mine populations to determine what the impact has been from chronic exposure to heavy metals and radionuclides (CSIR, 2008). This will be complex and costly, but we need such a study as a matter of national urgency.

Strategic Challenge No. 3: National Quest for Climate Change Adaptation. Given that our water resources have already been fully allocated, and in many cases over-allocated, we have no more buffer capacity. This means that global climate change has very specific implications for us as a 'nation' to which we have not yet developed an adequate response (Hunter, 2003). Therefore we need to start by focussing on the following key areas of strategic importance:

- **Cyanobacteria.** While Al Gore's movie "An Inconvenient Truth" tells us to be afraid of sea level and temperature rise *in the future*, our own science is showing us that we are being threatened by toxic microcystins produced by cyanobacteria *at present* (Harding & Paxton, 2001; Oberholster & Ashton, 2008) **to which we have no known solution**. The future is already here and Al Gore's movie is merely causing us to take our eye off the ball, because there is tentative evidence that cyanobacteria population dynamics are influenced, at least in part, by changing ambient temperatures in our water bodies (Hunter, 2003). We therefore need to revive the National Eutrophication Program that collapsed at the end of the 1980's (Van Vuuren, 2008) (see Figure 1) in order to understand the exact linkages between climate change and cyanobacteria. Current indicators are that there is a link, but we need to drill down in greater detail to truly understand this with a higher degree of certainty.

- **Dilution Capacity.** Given that South Africa has lost its dilution capacity, we need to understand exactly what climate change will do to our national water resource that is so vital to our economic and social survival (Turton, 2008b). More specifically will future coal combustion, in the face of reduced precipitation, mean an increase in acid rain? What will this do to our agricultural production capacity? How will this change soil chemistry? What will the impact be on rivers and wetlands already under stress? Will this cause an increased mobilization of radionuclides and heavy metals? How will this impact on EDCs? Will this trigger additional eutrophication as iron and phosphate is mobilized from sediments? These are all complex questions that need a focussed and concerted scientific effort to answer reliably.

- **Ecosystem Thresholds.** Given that so much of our current effluent streams enter aquatic ecosystems often *through* terrestrial ecosystems, we need to understand their dynamics better, specifically with regard to their assimilative capacity as environmental sinks for heavy metals, radionuclides, EDCs, ARVs and the myriad of chemical pollutants we discharge daily. More specifically, we need to know if climate change will nudge any of these aquatic ecosystems across thresholds, pushing them into catastrophic collapse, such as that already in existence in the Hartebeespoort and Roodeplaat Dam systems.

What I have presented here is the embryo of what is hopefully going to become the *National Water Quality Science, Technology and Policy Support Program*, which will reverse the trend noted by Walwyn and Scholes (2006) (see Figure 1). This Program needs of necessity to be bold and ambitious. It must have ambitious targets such as producing 50 PhD graduates after ten years, 200 MSc graduates after the same time period, and a range of patents designed to overcome the problems presented above in a way that is both financially viable and ecologically sustainable. This means working closely with every university in the country, because they will be unable to produce this number of graduates alone, and only universities have the legal mandate to do this. In this Program the CSIR would become the “space” in which human capacity is nurtured in a highly structured manner, probably with many of the existing Principal and Chief Scientists being appointed as Extraordinary Professors in these partnership universities, simply to create the supervisory capacity needed for such a massive undertaking. This can only happen if the CSIR funding model is changed, because as it now stands, those Principal and Chief Scientists are the mainstay of cash generation and therefore institutional survival, rather than of the development of Technical Ingenuity in the national interest.

The CSIR funding model is thus a question of fundamental national significance, and the way we deal with it will be an example of Social Ingenuity creating the capacity to generate future Technical Ingenuity as defined by Homer-Dixon (2000).

If Kennedy could commit his nation to putting a man on the moon in a decade, why can we, as a ‘nation’, not commit ourselves to overcoming impediments to the quality of life that each South African citizen deserves? Why can we not decide to solve the problem of AMD in a decade, so that our mining can continue without the albatross of externalizing production costs around the necks of major mining houses?

I believe we *can* do these things. I believe we *should* do these things. I believe it is *noble* to do these things. But I believe we are *negligent* if we fail to do these things. This sums up what I think about these issues, specifically with respect to the way that the SET Leadership within NRE should be applying their collective minds to problems of national strategic importance.

I wish you luck as you grapple with these issues over the next few days, months and years. I close by saying that the new role of the CSIR will be to deepen our democracy by generating high quality science that is mostly uncontested, presented in a way that helps the public, government and corporations to engage in complex debates that will slowly transform South Africa from a non-accountable oligarchy into a fully accountable democracy in which every citizen can reach their full human potential, in a life based on dignity.

This is what I call Science in the Service of Society and that I believe is our new mission at the CSIR.

Thank you.

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