Des Midgley Memorial Lecture

Can we Solve Tomorrow's Problems with Yesterday's Experiences and Today's Science?

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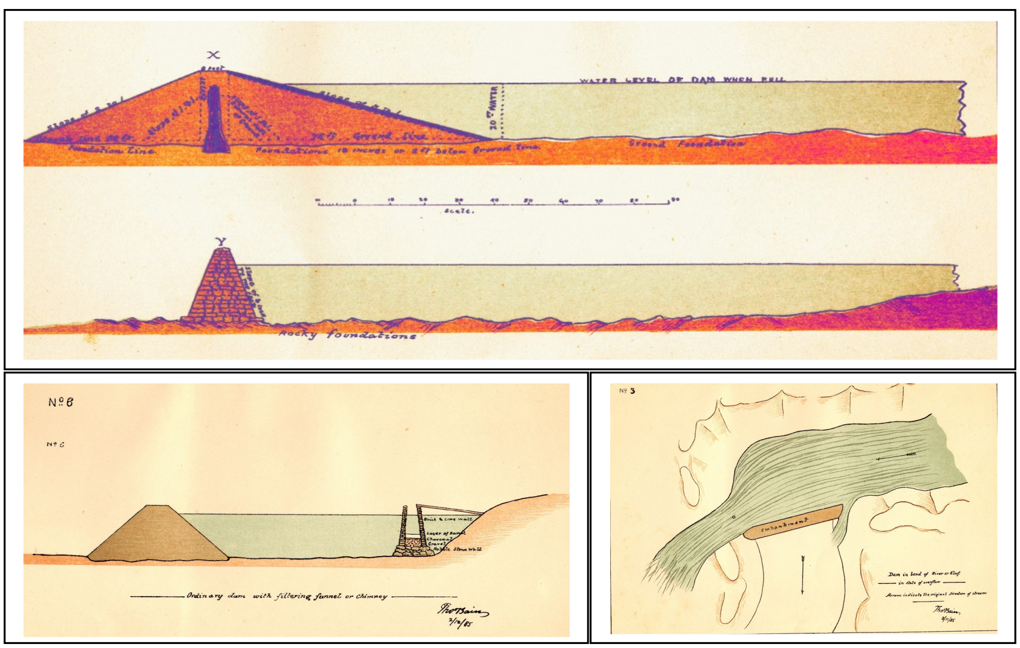
South Africa is at a threshold. In order to understand the ramifications of this simple fact, one needs to unpack the drivers at work. I intend to do this by joining dots – the stock in trade of the strategic planner and analyst – in an attempt to answer the key question we should all be asking: can we solve tomorrow's problems using yesterday's experiences and today's science? I believe we cannot do this, and that is the essence of my lecture here today.

What do I mean by this? Surely, I hear you all ask, we have always solved tomorrow's problems using yesterday's experiences and today's science? Is science, engineering and technology not cumulative? To this I answer simply, yes; but then I immediately caveat that by saying we *could* do so in the past, simply because we had not yet crossed the threshold I mentioned in my opening sentence. So the real answer is yes, we *could* do that in the past; but no, we cannot continue to *assume* that we can do that in the future, with a high assurance of success.

Why is this so?

Well, the answer to that is not so simple, but the easiest way to begin to unravel this complex puzzle is to start off with a few key elements of my argument. The first of these is the simple fact that South Africa is a fundamentally water-constrained economy. The ratio of runoff to rainfall is amongst the lowest of any populated region of the world (O'Keeffe *et al.,* 1992). I have an interest in history and had the privilege of being lead author on the very first attempt to write up the hydropolitical history of South Africa's international river basins (Turton *et al.,* 2004). It is in the context of my inquisitiveness about where we come from, and what has taken us to get to where we are today, that I have made some interesting observations. One of these is that we have always been a water-constrained country. The oldest book that I have found on water scarcity in South Africa – the very foundation of our rich history of water resource infrastructure development – is a book that was written in 1875 by a man called Brown. I regard him as the father of South African hydrological thought and awareness. His book was given the heady title of the *Hydrology of South Africa; or Details of the Former Hydrographic Conditions of the Cape of Good Hope, and causes of its Present Aridity, with Suggestions of Appropriate Remedies for this Aridity.* This is interesting for a number of reasons. Firstly, he was referring to the geographical place at the southern tip of Africa, rather than the country we now know as the Republic of South Africa. Secondly, he was framing his entire discussion in terms of aridity. Even more interestingly, he was "blaming" this aridity on human beings – in this case the Khoikhoi and the San – in a manner that was fashionable at the time due to the writings of Charles Darwin and his 1859 classic *The Origin of Species by Means of Natural Selection,* significantly subtitled *The Preservation of Favoured Races in the Struggle for Life*. In some circles this is referred to as Cultural Darwinism, in which cultural values are infused into Darwin's Theory of Natural Selection. This is evident, interestingly enough, in the whole sorry saga of the Piltdown Man, "discovered" in 1912, but now known to be a hoax and often referred to as a classic example of the vulnerabilities arising from Cultural Darwinism. I digress only to illustrate the unintended consequences of pursuits in which science is driven by strong political agendas. Two years after the first book was published, Brown (1877) produced his second, this time showing his preferred solution to the problem in the title *Water Supply of South Africa and the Facilitation for the Storage of It.* You see, Brown is not only the father of hydrological thought and awareness – he is also the first person to write about the need for dams and hydraulic infrastructure, to bring a high assurance of supply, in a place that is profoundly hydrologically insecure. Interestingly enough, a famous South African explorer, now credited with having described a large number of the flora and fauna of this country – a civil engineer called Thomas Baines – also laid the foundation for the development of water resources as a means of bringing economic growth and development into arid areas of this country (Baines, 1886). Hand-drawn maps and sketches of diversion weirs and irrigation canals along the Orange River date back to November 1885 (see Turton *et al.,* 2004: 121 - 124). In fact, one diagram closely resembles the design of Maguga and Mohale Dam's with their rock face and clay core (see Turton *et al.,* 2004: 123).



Various drawings by Thomas Baines around 1885 (Turton *et al.,* 2004).

It is interesting to examine Baines' drawings. At one level they show a remarkable sophistication and insight, in many ways reflecting contemporary engineering concepts. At another level they reflect the need to leave some streamflow in the river channel after diversion (lower right image), so this could be considered an early example of a rudimentary awareness of what we currently call Instream Flow Requirements (IFR) or the "Ecological Reserve".

So South Africa has always been arid – at least since it was permanently settled by Europeans after 1652 – with current historians describing how the Khoikhoi occupied the "better" of the arid lands as pastoralists, with the San being relegated to the most hostile of them all as hunter-gatherers (Welsh, 2000). The word "Kalahari" is derived from "kgalahadi" meaning "great thirst" (Turton, 2006a). The early commentators on aridity (Brown and Baines) both advocated the construction of dams as a means of solving this problem. So this is the start of our quest to understand why we cannot solve tomorrow's problems using yesterday's experiences and today's science.

As we built dams we started to engineer a stable foundation on which we could subsequently develop a modern economy. In this regard a number of key elements are historically relevant. The first of these is the technology of large dam construction. Baines' designs were based either on an earth embankment, or on masonry as a key element of the wall construction. These have structural limitations and it was really the engineering breakthrough that occurred when steel was refined to such a level that it could be inserted into concrete (a substance known to the Romans) in such a way as to build massive structures capable of "taming" wild rivers.

The first of these so-called wild rivers was the Colorado in the USA. Long coveted for its potential since the first navigation of this system in 1869 by a one-armed veteran of the American Civil War, Major John Wesley Powell, and his intrepid band of seven men (Dolnick, 2001; Ghiglieri & Bradley, 2003; Stegner, 1982), the Colorado River was always seen as being too "wild" to "tame" (Reisner, 1993). Too wild that is, until the refinement of steel to the point that it could be made consistently enough to guarantee specific properties at a high enough level of certainty to be seriously considered for the design of large dams and thus capable of "taming" such rivers. The first of these large dams that "tamed the Colorado" was the Hoover Dam (Reisner, 1993), also known as Lake Mead. Started in 1931 and completed in 1936, some sixty years after Powell's incredible expedition to map the river, the Hoover Dam changed the way we view the world and thus had a major impact on what we today understand as the developmental relevance of hydrology. The sheer size of the impoundment is impressive, having a volume of 35.2 km^3, with a wall standing an imposing 221.4 metres high, 200 metres wide at the base and an elegant 15 metres at the crest. Yet, as impressive as these numbers are, the relevance of the Hoover Dam does not lie in these figures. The true significance of this massive dam lies in three discreet historical facts, mostly invisible to the casual observer.

The first of these is the timing of its construction, coinciding as it did with the Great Depression. Starting with the stock-market crash on what is now known as Black Tuesday (29 October 1929), this became a cataclysmic event that shaped world history (Mundell, 2000; Rothbard, 1963). That was a bleak time for mankind, leading to massive poverty, driving politics to either the extreme left or right, creating the enabling environment in which dictators like Adolph Hitler, Benito Mussolini and Joseph Stalin could rise to infamy, setting the scene for the horrors of what was to come as the world went to war with itself in an orgy of violence in an unprecedented global theatre that took killing to an industrial scale of sophistication, the pinnacle of which was the splitting of the atom. In the short-term however, the construction of the dam provided jobs when they were scarce, and hope where there was generally very little of that precious commodity. This element was captured in what became known as the New Deal, a policy developed by President Franklin D. Roosevelt, between 1933 and 1938. Based on what were called the "Three R's" – relief, recovery and reform – the New Deal rationale became the foundation for what subsequently came to be known as the "hydraulic mission" of society (Reisner, 1993; Swyngedouw, 1999; Waterbury, 1979). The hydraulic mission is defined as, "the overarching rationale that underpins the state's desire to establish conditions that are conducive to socio-economic and political stability … [by mobilizing water resources, becoming] … a form of ideology … infusing itself into the dominant or sanctioned discourse, serving to legitimize (and thereby sanction) this discourse" (Turton & Meissner, 2002: 38).

A mural in the US Department of Interior produced by William Gropper in 1939 during the New Deal era entitled "Construction of a Dam" reflects the American Hydraulic Mission (image courtesy of Wikipedia Commons).

The second lies in the results of the construction, best illustrated during the Battle of Britain. War is about resource mobilization and ultimately about industrial capacity, underscored by the resilience of a given economy to withstand the shocks created by mass violence. The popular understanding of the Battle of Britain saw the Luftwaffe attempt to gain the air superiority needed to pave the way for the subsequent ground invasion of Britain. The hydrological understanding of the same event is that it was about the capacity to replicate aircraft at a rate greater than losses in battle. Stated differently, the outcome was defined by the capacity of one side to produce aluminium at a rate faster than the other. To produce aluminium you need two things – bauxite and energy – lots of energy in fact. The scales of energy that were flowing out of the newly installed turbines in the recently completed Hoover Dam. So in the final analysis the hydraulic advantage associated with damming the Colorado River, translated into the capacity of the Allies to produce aluminium at a rate faster than the Axis powers, and it was this critical advantage that enabled the invasion of Britain to be halted, thereby stabilizing the advances made against the Allies, effectively buying time to change the global balance of power. The first time the Axis did not win a battle against an adversary was the Battle of Britain, but the first victory against the Axis forces was the Battle of Al Alamein (Mills & Williams, 2006). Central to both of these pivotal events was the industrial capacity of the USA, powered by the energy flowing out of the Hoover Dam, to simply outperform the industrial capacity of the Axis powers. Have you ever stopped to wonder what the significance of the Dam Buster raids were in the overall scheme of things? Yes. That series of raids was based on the same core logic that converts hydraulic flows into industrial advantage. There is a direct link between those raids and hydrology if you think hard and long enough!

The third lies in its name, honouring the Secretary of Commerce Herbert Hoover, who played a vital role in the decision to build the dam after a commission was established in 1922 to investigate the costs and benefits of such a massive project. The significance of this aspect is that it was the Secretary of Commerce that was honoured, because the dam brought with it economic prospects that were welcomed during the bleak years of the Great Depression and the build-up to the Second World War. So the name of the dam shows us the link to the economy, and it is here that we find the need to jump across the Atlantic Ocean to the place we call home – South Africa.

When examining the South African Hydraulic Mission, we are taken by the early references to aridity noted by Brown (1875; 1877). We then see that Baines (1886) draws practical plans for the diversion of water along the Orange River to be used to develop an otherwise harsh region, which on its own has very little prospect for economic development. Our story through time and space then takes us to a series of hydrologically-significant events in our own back yard.

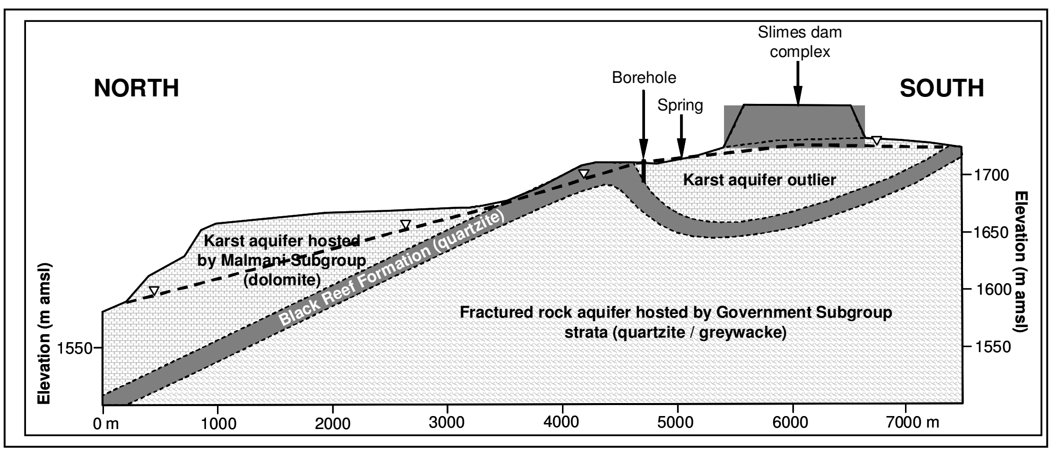
After the discovery of gold along what became known as the Witwatersrand in 1886, the pieces were in place on a global chess board in which the stakes were economic power and global dominance. The main players were the British Empire, at the very peak of its global power, and the small sovereign state known as the Transvaal (South African Republic), inhabited by the Boers, seen through the eyes of the British tinged with the bias of Cultural Darwinism that portrayed the latter as being lazy, corrupt and incompetent (Welsh, 2000). Coveting this wealth that simply could not be allowed to fall into the hands of the degenerate Boers (so the British thought), the first attempt was made to unseat the government by a third-party. Known as the Jamieson Raid, this ended in catastrophe, failing to meet its military objective and leaving many dead bodies (Longford, 1982), some of which are buried very close to where I live in Krugersdorp, alongside the Cradle of Humankind. While some authors speak of him as being a "colourful character" (Seymour Fort, 1908), Jamieson has also been described as a common thief and vagabond, for the role he played in the theft of gold from Lobengula and the subsequent massacre of the Matabele in what is called the First Matabele War (Welsh, 2000). This gives some insight into the motives and methods of the British Government as they lusted after gold and power (Porch, 2000), but it also bears reference to the first use of the contemporary concept of a "third-force", so often referred to in South Africa during the Armed Struggle (Turton, 2006a). The second attempt was the Anglo-Boer War, designed to bring the wealthiest goldfields in the then known world under the control of Britain (Turton *et al.,* 2006). Using the most barbaric of methods, including a scorched earth policy that was aimed at subjugating non-combatants, and the first use of concentration camps in which more people died, mostly women and children, than on the field of battle on both sides (Fawcett, 1901; Hasian, 2007; Hobhouse, 1901; Krebs, 1992; Raath, 1999; Spies, 1977; Van Rensburg, 1980), the Anglo-Boer War created an outcome that was to favour modern hydrology in a way few have yet set out to analyse.

It is a historic matter of fact that the very first order of business at the cessation of hostilities after the Treaty of Vereeniging, signed on 31 May 1902, was the rapid development of the gold industry in order to pay war reparations (Welsh, 2000), a euphemism for the rampant plundering of wealth from South Africa and it's "repatriation" to Britain. I believe it is this fundamental reason that the gold mining industry is in crisis today. The nett outflow of natural capital, accompanied by the externalization of costs onto an increasingly unwilling society, arising from a century of accumulated impacts by a largely unregulated industry (Adler *et al.,* 2007), is now driving political activism as fears grow about the potential health risk associated with heavy metal and radionuclide contamination downstream of gold mines (Coetzee, 1995; Coetzee *et al.,* 2002; 2005; 2006; Hobbs & Cobbing, 2007; IWQS, 1999; Wade *et al.,* 2002; Winde, 2005). But how to grow an economy in a region that has one of the lowest conversions of Mean Annual Precipitation (MAP) to Mean Annual Runoff (MAR) in the world? The solution to this was to harness hydrology as a foundation of a phase of heroic engineering that led to the establishment of the Rand Water Board (Tempelhoff, 2003), tasked with the responsibility of developing a reliable water infrastructure on which the post-war extractive economy could be based (Turton *et al.,* 2006). As the Witwatersrand grew, it drove demand for water, so hydraulic infrastructure development started to fan out from the goldfields in concentric circles. Hydrology became vital for the economic growth and development of the Union of South Africa and thus an intimate component of the hydraulic mission of the state (Turton *et al.,* 2004). When gold was discovered in the Orange Free State, the same pattern of events occurred, this time without the need for a messy war to create the enabling conditions for subsequent wealth extraction from the bowels of the earth. It is in this light that the classic Ninham Shand (1956) Oxbow Scheme study must be evaluated. The sole purpose of that study was to determine the hydrological and engineering foundation needed to unlock the mineral wealth of what we today call the Freestate Goldfields, which was a smaller sub-set of what was seen at the time to be heroic engineering designed to capture water resources from as far afield as possible (Basson, 1995; Blanchon & Turton, 2005; Borchert, 1987; Borchert & Kemp, 1985; Davies & Day, 1998; Heyns, 2002; Scudder, 1989; 1990; 2005; Scudder *et al.,* 1993; Snaddon *et al.,* 1999; Trolldalen, 1992; Turton, 2000; 2004).

When the Sharpeville Massacre happened and the Armed Struggle was born in South Africa (Turton, 2006a), there was a massive loss in investor confidence, accompanied by a nett outflow of foreign capital, threatening to destroy the national economy. This trigger event can be considered the birth of the aggressive phase of the South African Hydraulic Mission, which was designed specifically to restore investor confidence (Turton *et al.,* 2004). It comes as no surprise therefore that we learnt from the United States. The Orange River Project (ORP) became South Africa's equivalent of the Hoover Dam, and Roosevelt's New Deal was transformed into elements of Verwoerd's Grand Apartheid, designed specifically to use hydraulic engineering to underpin economic development, in a region that was the recruiting ground of cadres for the Armed Struggle (Turton, 2006a). The Orange River Project gave us confidence and so we started in earnest to push rivers around (Conca, 2006), fiddling with nature by linking almost every significant river with each other (Davies & Day, 1998). Flushed with our newfound success, falsely interpreting the political stability that occurred between 1961 and 1975 as the result of stable economic growth driven by robust infrastructure, we naively believed that there was no limitation to the ingenuity of mankind. But there is (Homer-Dixon, 1995; 2000), and as Tenner (1996) has so eloquently shown, there is a downside to technology and "things bite back" when you push them around too much (Davies & Day, 1998).

In truth, the South African Hydraulic Mission enabled accelerated economic growth in the 1960's and 1970's, but at a great cost (Davies & Day, 1998). The rapid phase of dam-building harnessed most of the streamflow by the 1980's (Turton *et al.,* 2004). Rabie & Day (1992) suggest that the capture of around 60% of the streamflow is the absolute limit of economic viability. We have crossed that threshold with O'Keeffe *et al.,* (1992) noting that in the early 1990's we were already at 62%. Today we are confronted with basin closure in most of our significant systems (Turton & Ashton, in press), over allocation of the resource in some basins by as much as 150%, major pollution from so-called strategic industry and a highly skewed national plumbing system that reflects historic resource capture (Turton, 2000).

You see, what we did not know at the time is that our heroic engineering was creating what we now call, in the emerging language of Sustainability Science, a Social-Ecological System (SES) (Funke *et al.,* 2007). By fundamentally altering the ecosystem that had evolved in response to the low conversion ratio of MAP to MAR over geological timescales, we brought certainty into an uncertain place. We conquered variability, but we started to become a slave to our own ingenuity, without knowing it (Homer-Dixon, 2000). We cleverly managed stochasticity and we felt deeply proud of that, but we never pondered for a moment on the future ramifications of this fundamentally altered hydrological regime. That hydrologist's silent victory over stochastics attracted people and capital, and so the economy grew, which is what we wanted, but it triggered a technology race that we can probably never win (Homer-Dixon, 1995; 2000), because "things bite back" (Tenner 1996).



A major challenge in contemporary South Africa is developing a new geohydrological capacity to accurately predict Acid Mine Drainage (AMD) and mine decant from gold mines in a post-closure phase. This profile of the hydrogeology of the current decant taking place at Harmony in Krugersdorp represents today's impact based on yesterday's science that allowed tailings dams to be located on karst aquifers (image courtesy of Oelofse *et al.,* 2007).

The more the demand for water grew on the Witwatersrand, the more we needed heroic engineering and so the ecological footprint got exponentially larger. This led in time to an exacerbation of the structural flaws in our national economy. Remember, the Anglo-Boer War meant war reparation and that drove the gold industry, in an uneven trade that saw a nett decline in South African natural capital, accompanied by an externalization of costs onto society. The Apartheid-era merely entrenched this further as an embattled state forged an unholy alliance with a strategic industry and allowed this largely unregulated plunder of our natural capital to carry on, with little concern for the impactions in the future (Adler *et al.,* 2007). To make matters worse, conventional wisdom at that time caused us to site tailings dams on dolomite (Oelofse *et al.,* 2007), seemingly to improve drainage (or maybe just to reduce costs a bit more so that profits could be truly maximized?), with no consideration for the long-term implications of this incredibly foolish engineering design. Suddenly, in the first decade of our new democracy, as Science was liberated and new funding became available, we discovered that heavy metals and radionuclides leach from these waste dumps, and move insidiously under the landscape in an unpredicted plume, finding their way into rivers and wetlands, potentially destroying farmer's livelihoods, entering food-chains and damaging human health (Coetzee, 1995; Coetzee *et al.,* 2002; 2005; 2006; Hobbs & Cobbing, 2007; IWQS, 1999; Wade *et al.,* 2002; Winde, 2005). This is the true cost of mining that was never brought onto any balance sheet. This is a legacy we have not even begun to comprehend in the hydrological and aquatic sciences. We are taking this seriously at the CSIR and are starting to do something about it (Claassen *et al.,* 2001; Geldenhuys *et al.,* 2003; Hattingh *et al.,* 2006; Leaner *et al.,* 2006; 2007a; 2007b; Maree, 1997; 2003; 2004; 2007; Maree *et al.,* 1998; 2004; 2005; 2006).

Today we sit with a complex legacy, which has nudged us across the threshold that I referred to in my opening statement (Coetzee & Winde, 2002; Coetzee *et al.,* 2006; Davies & Day, 1998; IWQS, 1999; Wade *et al.,* 2002). We have simply engineered ourselves into a situation where we are part of a massive Social-Ecological System that has now taken on a dynamic life of its own. The Witwatersrand area is now the largest single population of people in the southern hemisphere, possibly the entire planet, which does not lie on a river, lake or seafront (Turton *et al.,* 2006). We have created a monster that we now need to feed and can no longer control. Gauteng alone generates 10% of the total economic output of the entire African continent, is home to a staggering 25% of the South African population, all of which is 100% reliant on Inter-Basin Transfer of water (Basson *et al.,* 1997). That transfer is largely reliant on surplus energy from the national grid to lift water across the Drakensberg Mountains, but we now know that the concepts of "surplus" and "energy" and not necessarily synonymous in contemporary South Africa. To generate more energy we need to burn more coal and evaporate more water to drive larger turbines. On the water availability side, the National Water Resource Strategy (NWRS, 2004) has shown us that we are collectively in a national situation where we had allocated around 98% of our available resource, at a high assurance of supply in 2004, so we simply do not have much more to evaporate in boilers. Personally I do not believe that hydrologists can measure this as accurately as that, so in my mind we are as close to 100% allocation as we can become, knowing that we can perform mathematical wizardry to squeeze one more drop from somewhere in the system, but that is not real water. On the coal side, we are now seeing the long-term impacts of mining with a recent rise in Acid Rock Drainage in Mpumalanga, into the Olifants River Basin. Coal burning has major externalization costs that are not currently factored into the way we price our energy (Blignaut & King, 2002). Our work at the CSIR suggests that externalized costs of mining arising from Acid Rock Drainage might have a time duration of 500 years and reach a remedial amplitude that exceeds the value of the mineral mined in the first place (Adler *et al.,* 2007). If we are correct – and we hope that we are not – then this is serious indeed.

So this is where we are today. We have no more surplus water at a high assurance of supply. Aquatic ecosystems are in stress and some, like Hartebeespoort Dam, are simply at the very limit of our current scientific capacity to "manage". Our coal-based energy has resulted in externalized costs in the form of Acid Rock Drainage and Acid Rain. Our mining-based economy has resulted in externalized costs in the form of Acid Mine Drainage and decanting water containing potentially toxic loads of heavy metals and radionuclides. Our industry is globally uncompetitive due to the protectionist policies used by a pariah state to bolster the national economy, now producing effluent streams that are so costly to clean up, that in many cases the economic viability of the industry is at stake, if we expect a significant reduction in discharge. We have lost our dilution capacity in rivers and I have predicted that we are moving away from an Integrated Water Resource Management (IWRM) paradigm into a new Integrated Salts Management phase instead (Turton, 2006b). Then there is the issue of Global Climate Change, introducing another level of uncertainty.

So this is the challenge for hydrologists in the first decade of the 21st Century. The new South African brand of hydrology is about mobilizing a different form of technical ingenuity (Homer-Dixon, 2000), to deal with the unintended consequences (Davies & Day, 1998; Tenner, 1996) of the aggressive phase of the South African Hydraulic Mission (Turton *et al.,* 2004). That new hydrology is about the national Constitution, which mandates development that is sustainable, along with historic redress, within the hydrological constraints of a country that is located mostly in an area with a naturally low conversion of precipitation to runoff (O'Keeffe *et al.,* 1992). The new hydrology is about modelling salts loads and dilutions as much as it is about volumetric and temporal calculations. It is about finding new ways to understand groundwater movement away from mining areas, specifically where massive mine voids have affected flows through karstic systems. It is about creatively linking with the constitutional need to grow livelihoods, possibly by thinking anew about water trading and allocation. In this regard a refreshing new approach is Fractal Water Allocation, which some South African hydrologists have been dabbling with. But the new hydrology is also about shifting paradigms to grasp new realities. A significant paradigm shift is needed in moving away from the isolationist thinking of the past that saw South African hydrologists developing local software. Today we are integrated back into the world and there are great packages available off the shelf, enabling us to concentrate on the real problems, of which we have many (software development not being one).

But the biggest single challenge is to find a new relevance in the next phase of the South African Hydraulic Mission. That phase will be fundamentally different from the past, involving less heroic engineering, with more engagement in other fields. One field of engagement will be exploring the hydrological reality underpinning the Accelerated and Shared Growth Initiative for South Africa, known as ASGISA, which has been forged in total isolation of any understanding of resource realities in our country. That challenge is as much a political one as it is technical, because it is about engagement over thorny issues like the logic of citing large aluminium smelters, in a country that has no bauxite, little surplus energy and even less water, as key elements of strategic growth point initiatives. Hydrology has never been apolitical.

The cold reality is that we cannot solve tomorrow's problems with today's science based on yesterday's experiences, so the new hydrology will have to be pioneering – and have a social conscience – but it will also have to be a genuine partnership across scientific disciplines.

In conclusion then, I pay tribute to the South African hydrological profession, in the spirit of the Des Midgley Memorial Lecture. You are the silent and unsung heroes of our rich history of economic growth. You have been adaptable over time and have always risen to the occasion, so I have little doubt that you will again be up to the task. That new task is a noble one, because it is about enabling people, irrespective of colour, race or creed, to reach their full human potential in a democratic country with a fine constitution and the rule of law. We have a lot to be proud of. I thank you all for listening to me and I wish you well in your future endeavours.

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