The Water Wheel publishes the following articles, written by three well-known and prominent researchers in the South African water field, to conclude the fascinating debate on climate change - Ed.

Climate Change – A Cause For Concern

by Professor Bruce Hewitson, Climate System Analysis Group, University of Cape Town

Mention climate change in any group of people and one is bound to stir up some derisive comments. It would seem that many people hold strong opinions – and the facts are often, apparently, of secondary importance. The reality is that, on one level, climate change is a complex subject requiring careful consideration, and this article can only begin to touch the surface of the subject.

On the global scale there is much that can be stated with confidence about climate change; for example, that human activity has undeniably changed the global atmosphere (as evident in, for example, atmospheric CO_2 concentrations). However, when it comes to statements about regional scale change and impacts, the purported threat rouses strong reactions. Yet, if climate change is real, and if we ignore the issue, at a minimum we do a disservice to society and the future generations who are the inheritors of our inaction. At worst, our irresponsibility results in very real suffering and hardship when the consequences of climate change exceed the limitations of the societal infrastructure and activities.

ATTITUDES

Perhaps the most dangerous attitude we could adopt is to over simplify matters. Far too often one encounters generalized, sweeping assertions that are justified with the briefest of evidence. Such assertions can never be responded to in a few simple statements and this demonstrates the power of rhetoric to confound and mislead, where a closer examination would perhaps indicate a contrary conclusion. Rather, assertions about what will, or will not be, require careful consideration. For example, a statement might be made that the climate of a region is not changing, and in support the evidence offered is perhaps that the mean annual precipitation (MAP) for a recording station shows no trend. However, this completely ignores pertinent questions such as: is the period analyzed appropriate, is MAP actually what is relevant, is the station representative of the region, or whether the data is appropriately quality controlled for any number of spurious artifacts[1], etc. For example, dry spell duration and rainfall intensity could both increase significantly, yet MAP could remain unaffected. Such

Pictures of the contrast over the Western Cape between 2002 and 2003, showing the effect of drought.

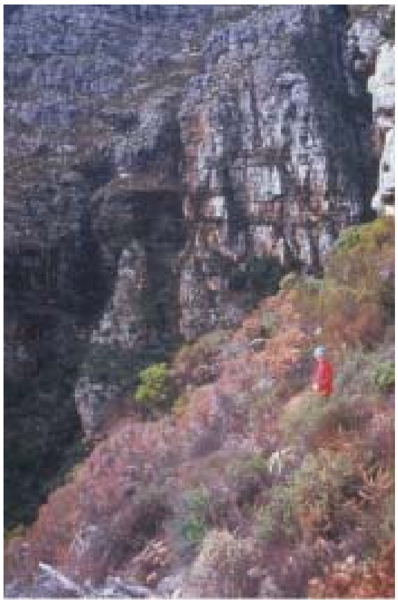
changes would obviously have a significant impact on society and remain completely unidentified in the MAP. Similarly, if calculating the trend of a time series over the last 100 years in order to assess possible change, one needs to be cautious of simple linear trends considering, for example, that a) the human induced signal is only detectable against natural variability in the latter half of the 20th century, b) the change signal is likely exponential and would be under-estimated by a linear trend, or c) simple linear trends are highly sensitive to outliers in the data.

Thus, because of the tremendous importance of the question of climate change to all aspects of society, it is imperative that we examine the issue carefully. Of special importance are the relevant aspects of climate change for any given sector; what are the interdependencies of the coupled human-environment system? For example, for an agricultural crop such as maize, changes in dry spell duration and water availability, coupled with increases in temperature, would together affect soil moisture, crop stress, and vulnerability to crop diseases with significant impacts on productivity. Such combinatory impacts could potentially make a given activity in one region non-viable with further consequences for the economy, employment, and quality of life for many. This example serves to emphasize the extreme importance of careful assessment. Crucially, it must be recognized that as society builds an infrastructure and undertakes activities designed for a given climate, any change in the climate makes the infrastructure sub-optimal, potentially to the point of failure.

CLIMATE CHANGE FOUNDATIONS

To understand climate change one must begin with the recognition that the climate is a response to the energy balance of the coupled global system. Change the distribution or level of energy and the climate system responds. One of the key determinants of this global energy balance is the chemistry of the atmosphere, commonly referred to by the misnomer of "*greenhouse effect*". This is the process by which a number of gasses (not just CO_2) affect the global radiative energy balance. In this respect it is absolutely clear that human activity has changed the atmospheric chemistry; accordingly the climate system is responding. The key question is whether the magnitude of the climate system response is, or will be, of any relevant consequence to society.

What is a "relevant consequence"? This is a question often ignored by many sectors and requires thinking beyond the simple attributes of averages in space and time. In many cases the sensitivity of a sector is not understood. For example, the spatial extent of malaria is highly sensitive to minimum temperature. As shown later, this attribute of the climate is changing significantly over southern Africa – imagine the cascade of consequences of malaria becoming prevalent in Gauteng! Thus, a starting point in considering the relevance of climate change to a given sector of interest (e.g. water) is to first understand the sensitivity of that sector to climate, and especially what the existing infrastructure can accommodate (e.g. peak storm water flows in an urban setting).



Courtesy: Prof Peter Linder

A picture of dead vegetation from a drought year on Table Mountain. It shows the death of many individual shrubs in this normally moist vegetation. These shrubs normally survive until fire arrives to burn them and trigger seed release and germination, so drought death is highly unusual ecologically, as it can rapidly lead to extinction. Such events are being noticed on broader and broader scales by naturalists.

Every sector of society needs to address this question. In Africa the water resource management sector particularly needs to understand sensitivity and response to change in the climate. However, prior to investing in such activities it is appropriate to separate and briefly consider the different elements that underlie the climate change debate.

COMMON ISSUES

- The first issue is that of detection. According to basic physics it is undeniable that humans are changing the climate – but can

[1] Data quality is the subject of data homogenisation; a difficult task where subtle errors in the data may have notable effects on the analysis, and may often go unidentified in cursory data quality control.

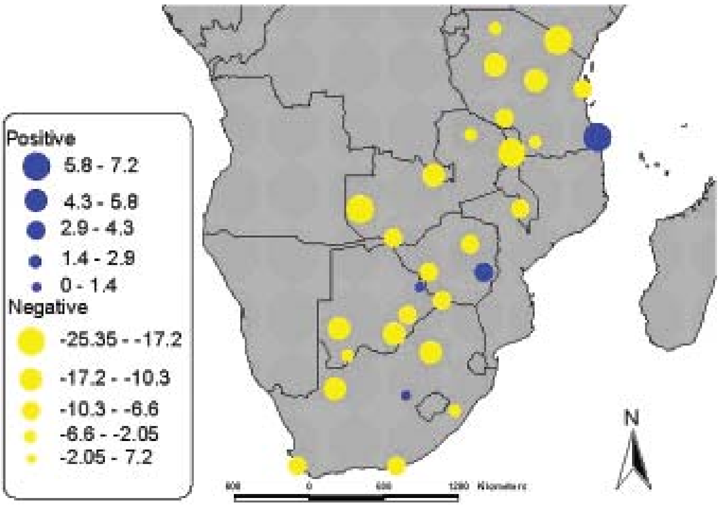


Figure 1

50-year change in the number of days where daily minimum temperature dropped below the 10th percentile. Yellow indicates a decrease, and the pattern is remarkably spatially cohesive. These trends are from the early results of the ETCCDMI[4] workshop held in June, 2004, Cape Town.

one detect historical change on time scales of relevance? This requires separating change from natural variability, which in turn requires consideration of appropriate time scales. For example, the atmospheric composition and climate system dynamics 400 000 years ago may be of scientific interest, but is of little value to managing societal infrastructure and natural resources. Of concern here is the period since the industrial revolution.

Again, on basic physical principles, it is apparent that change[2] as a consequence of human activities will likely be an accelerating attribute. The human contribution to altering the climate system has been one of ever increasing magnitude and can be measured by a broad range of attributes, such as atmospheric CO_2 concentrations. Consequently, in addition to the fundamental questions of data quality as mentioned earlier, detection studies need to consider non-linear change, or at the least understand that linear techniques[3] are likely to underestimate the change. Undertaking detection is a complicated task; one good example is the range of activities of the ETCCDMI[4] which, using sophisticated techniques and careful data preparation, have assessed changes over a number of global regions. Figure 1 shows one example of the significant change in daily minimum temperatures across the sub-continent. In another more national example (Figure 2), it is clear that at sub-annual scales there have been strong changes over the last 50 years.

- Following detection is the question of attribution – can detected change be attributed to human activities? Beginning in the IPCC[5] Third Assessment Report[6], and subsequently replicated by a number of researchers, it has been convincingly demonstrated that the climate record of the 20th century cannot be explained without including the effect of human activities. Moreover it has been recognized that most of the increase in global temperature in the last 50 years is attributable to human activities. Regional attribution is still difficult due to the complex mix of the regional response to the global energy balance and other local forcings. However, this does not negate the clear detection of change at the regional scale that has been found in most regions of the world, and that the detected change is consistent with our understanding of the physics and dynamics of the climate system.

- Given the detection of change, and the attribution of human contributions (at least at the global scale), the subsequent very real questions raised are: a) can one prevent change, and b) what response is appropriate? To the former the answer is clear; we are 100% committed to a continuation and acceleration of climate change for at least the next 50-100 years. One may quibble over the magnitude of the change, but the commitment is clear – society is wedded to energy use from fossil fuels, population and energy demand are growing, and significantly, the residency times

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[2] It is important to distinguish global change from global warming – the latter is not automatic for any given region.
[3] For example, a linear regression fit to a time series that has an exponential growth will under-estimate the rate of change.
[4] The Expert Team on Climate Change Detection, Monitoring and Indices – an international team of scientists facilitating detection studies. See http://www.clivar.org/organization/etccd.
[5] Intergovernmental Panel on Climate Change
[6] Available from http://www.ipcc.ch. See especially the summary for policy makers from Working Group 1.

in the atmosphere of the relevant gasses contributing to the change are of the order of decades. Furthermore, the climate system's response to greenhouse gas forcing is a delayed response, and change will thus continue even if the atmospheric chemistry were stabilized.

The second question of 'what response is appropriate?' brings us full circle in our discussion. The appropriate response is to be responsible. If climate change is real (and the basic physics says it is), recognizing the accelerating nature of such change, and acknowledging that societal structures are not often designed for change, we need to urgently assess the vulnerability of South Africa. This cannot be answered with simple generalizations, but requires care – with potentially dire consequences if ignored.

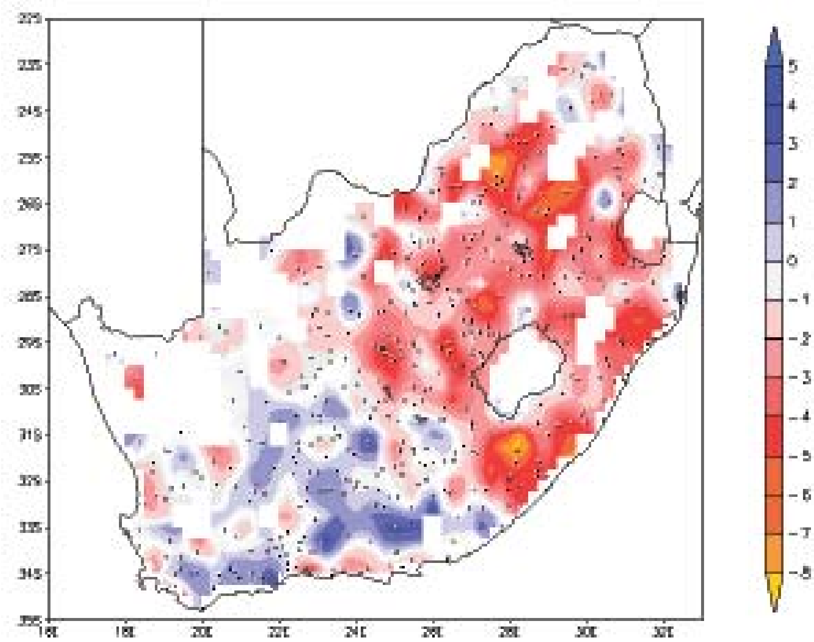

Figure 2

50-year change in the average number of April raindays (blue = increase), indicating that marked, spatially cohesive changes have and are occurring on sub-annual time frames. Trends are calculated with a robust regression technique for 482 stations (indicated by black dots) from the Lynch (2002) data set. The trend values on each station have been spatially interpolated with Cressman interpolation. All stations have been quality controlled and have fewer than 1% missing days.

REALISTIC ACTION

While there is much more that may be said on the previous topic, what may be suggested for the water sector? Limited by the constraints of this article, some suggestions may be proposed as being of value regardless of one's opinion on climate change:

- Assess the *characteristics of relevance* in the climate system for the water sector: which climate characteristics are important? For example, is it rainfall totals, interannual variability, seasonal timing, dry spell duration, extreme events, the histogram of daily rainfall magnitudes, return periods of rare events, etc?

- What *multiplicative attributes* may be important? For example: is temperature a complicating factor, is interannual variability important, does changing societal demand for a resource exacerbate potential climate change? Are there thresholds, which if exceeded by the climate system, will have an amplified consequence?

- Undertake scenario based *sensitivity assessments*. For those variables identified above, explore what the consequences to the water sector would be for a perturbation of, say, a 20% decrease in summer rain with a 10% increase in dry spell duration and a 2°C increase in minimum temperature.

- Examine the past record for evidence of changes in these attributes – *change detection*. This requires careful quality controlled data, assessing the spatial representivity of the data, and understanding the limitations and possible misleading characteristics of the chosen analysis method.

- Consider the *projections of future change*. There are a number of approaches to this, from the simple (e.g. Hewitson, 2003), to more sophisticated downscaling and probabilistic approaches. We must realize that these are accompanied by some measure of uncertainty, but nonetheless are probable developments of the climate system based on the best understanding of the climate system physics and dynamics.

- Consider *adaptation possibilities*. Are there strategies that can be adopted that would minimize the impact of climate change?

Are there "no-regrets" policies that could be implemented that are beneficial regardless of the climate change?

- *Keep up to date* with developments, explore the literature, listen to both sides of the debate, and understand the strengths and limitations of the science. Many readily accessible publications facilitate this[7].

In conclusion, what may be said with confidence? Humans are affecting the global climate system, regional changes can be detected and are manifest on widely different scales of time and space, and these changes are consistent with the physics of greenhouse gas forcing. Climate change will continue, and very probably accelerate. Society is structured for a given climate and all change places stress on these structures.

As noted by the recent report "Poverty and Climate Change" (African Development Bank, et al., 2003), prepared by 10 development and environmental agencies; "climate change poses a serious risk to poverty reduction and threatens to undo decades of development efforts." This is an issue that is possibly the single largest long-term threat to development in Africa. There is much more to be said on the subject, convincing evidence to be presented, and issues to be explored that are not covered here. This article seeks to raise awareness of the reality of climate change, and that there is very real cause for concern.

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[7] For example, Tiempo (http://www.cru.uea.ac.uk/tiempo/) offers up-to-date and accessible articles on new developments and understanding about climate change and the developing nations.

Is Climate Change Really of no Concern?

A Call for a More Holistic Vision

by Professor Rob Hart*, Programme Director – Ecology and Conservation Biology, School of Botany and Zoology, University of KwaZulu-Natal; and Peter Ashton, Principal Scientist & Divisional Fellow, CSIR-Environmentek, Pretoria**

Will Alexander's View point article in the January/February 2004 *Water Wheel* suggests that climate change is of no environmental concern. Flying in the face of contemporary opinion it is a brave call. But we believe it is erroneous. It simplifies, even trivializes, an issue that affects humanity at large, and demands debate. We are in no position to challenge the validity of his analysis showing that rainfall has increased roughly 10% in the past 70 years. But we vigorously contest his subsequent conclusion that climate change therefore poses no environmental threat. Accepting that rainfall is indeed higher, the punch line of Will's article – that higher temperature (the necessary driver or corollary of this higher rainfall) poses no threat to the environment is at variance with an awesome amount of scientifically accredited evidence. His conclusion (unsubstantiated inference, in fact) is fundamentally flawed in two respects. First, it totally disregards the indubitable effects that temperature plays on the environment as a whole, and on the ecology and physiology of its constituent biota. Second, 'water quantity' is equated to the 'environment' as a whole. We elaborate some our concerns in these regards below.

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TEMPERATURE

Temperature plays a ubiquitous role in ecology. It is a prime determinant of habitat suitability for living organisms, and serves as the singularly most important abiotic dimension of ecological niche for virtually all ectothermal biota (i.e. virtually all living organisms – biodiversity at large). While their warm-bloodedness may 'spare' birds and mammals from such effects, their food supplies are generally not spared. Beyond its extraordinarily far-reaching consequences to aquatic ecosystems and, in turn, to human life, temperature also has an enormous array of consequences outside the aquatic environment that ultimately will impact also on the aquatic environment. Changes in land use patterns, cropping patterns, crop types, water use patterns, fertilizer application patterns, etc. will all, gradually or abruptly, bring about changes in water quantity and/or water quality. Temperature's effects are direct and/or indirect, subtle and obvious. Whole volumes are dedicated to the comprehensive elaboration of the impacts of environmental warming at both global and regional levels, and document its multiplicity of effects. Agricultural crops, agricultural pests and human disease vectors may be foremost in the public mind. Maize, wheat, sugar and cotton lands will shift and change; our famous southern Cape vineyards are likely to shrink; fungal rusts, weevils and worms, along with parasite-vectoring mosquitoes are likely to expand or otherwise change their distribution ranges – either in space and/or time. But these are only the visible tips of the proverbial iceberg. Temperature affects the density of water, the solubility of solids and gases, and the rates of biochemical processes, all factors that are major determinants particularly of aquatic ecosystem function and structure.

A rise in water temperature of one or two degrees Celsius (°C) may seem unimportant in ensuring a reliable and sufficient supply of wholesome water. But this seemingly small rise has profound implications for all manner of biological and ecological processes. There is a veritable arsenal of information documenting these effects.

As a prominent water resource engineer, Will Alexander cannot be unaware of thermal stratification events in standing waters, and the eutrophication threats to our national water resource base. Yet his conclusion disregards any consideration of the impact of warming on these crucial issues. That increases in air temperature will unquestionably impact on the heat content of surface waters, intensify stratification, and thereby *inter alia* increase the competitive ability of blue-green 'algae' to endure the now stronger and longer summer stagnation period. That longer (and quite probably denser) summer blooms of the least favourable autotrophs, those nasty blue-green 'algae' that are in reality photosynthetic prokaryote bacteria, and not eukaryote protists – are an almost inevitable outcome, along with a host of indirect effects cascading through the lacustrine ecosystem. Prominent examples include reduced zooplankton grazing, depressed rates of secondary productivity, greater sediment sequestration of phosphorus, increased internal phosphorus loading, and yet greater competitive advantage for nitrogen fixing 'nasty' cyanophytes in particular. And so on.

MICROBES

For credible practical reasons, ecologists have tended to focus on macroscopic organisms, whereas the "real" ecosystem web-masters, particularly in aquatic systems, are microbes. Temperature impacts on the rates at which almost every bacterial (and other biochemical) transformation process proceeds. With Q_{10} values mostly between 3 and 7 over the temperature range of 15-35°C, bacteria will at least triple their reaction rate for every 10°C rise in temperature. A mere 2°C rise in temperature translates into an increase in biochemical transformation rate of somewhere between 30 and 70%. Meanwhile, the rate-temperature functions are such that rate acceleration increases disproportionately with rising temperature. So, with climate warming, decomposition processes, in particular, will literally "take off". (That we may not have already documented such effects in South Africa is most probably because of the very limited funding levels allocated to date to basic, and long-term ecological research in the country). Similar effects would be seen in terms of nitrification and denitrification, sulphur reduction, carbon dioxide and methane production. Higher water temperatures favour cyanobacteria and bacteria over diatoms, green, brown and red algae. The consequences for eutrophication processes and symptoms in general would be profound.

SOLIDS AND GASES

Increased water temperatures would have significant implications for the solubility of solids and gases, and probably result in altered gas-water equilibria of certain key gases like oxygen, nitrogen, carbon dioxide, methane and hydrogen sulphide. Life cycles of aquatic invertebrates (and vertebrates) are closely linked to the timing, extent and duration of water temperature cycles. A one to two degree rise in water temperature would effectively raise the 'thermal latitudinal position' of numerous habitats, drawing them closer to the "thermal equator". Organisms that require colder temperatures would have some aspect(s) of their life cycle threatened or even curtailed. Emergence patterns of 'pest species' would alter, extending the duration of the 'pestilential potential' of Blackfly for example, and possibly also reducing their vulnerability to aquatic predators. Yet other species would hatch in greater numbers than usual and exhaust their normal food supplies earlier than anticipated.

AQUATIC PARASITES

At present, several areas of southern Africa effectively lack important aquatic parasites such as Bilharzia in man and Fascioliasis in stock. (And malaria can be added as a water-linked disease). Their absence is attributable to various factors that are directly or indirectly linked to temperature; climatic bio-regions that are simply too cold to sustain effective vector and/or parasite populations throughout the year; water that contains insufficient dissolved calcium or lies in a pH range that is unsuitable for shell formation in the snails, or inhibits the growth of suitable "snail fodder" plants. A rise in water temperature could (and likely would) change the spatial (and tem-poral) patterns of snail (and parasite) distribution and endemism.

Oxygen saturation (in milligrammes per litre) declines at higher water temperatures. Oxygen uptake and use by biochemical processes (e.g. nitrification and respiration) would increase the rate at which dissolved oxygen is consumed. Depending on the gas-water equilibria, and the (relatively slow) rate at which oxygen can diffuse into water, increased incidences and durations of 'oxygen deficits' can be expected to occur. The problems would be compounded where the water bodies concerned are also used as repositories for organic wastes such as treated domestic effluent.

WATER QUANTITY

Second: water quantity is neither synonymous with, nor equivalent to, "the environment" (aquatic or otherwise). By conducting a statistical analysis of rainfall and resulting river flows (water quantity), and then 'proving' that no significant change has occurred over time (or that any slight change that has occurred is, or may be, "beneficial" in terms of the same or more water being available), is to provide only part (a very small part) of the argument. Changes in the patterns of

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rainfall events (e.g. the same rainfall volume distributed between five rather than twenty storm events) generate quite dramatic differences in the rainfall intensity and the shape (height and duration) of rain-all-runoff hydrographs. Quite apart from the potential impacts on streamside-dwelling human populations, this would also have some 'interesting' effects on groundwater recharge patterns, as well as on evaporation/evapotranspiration patterns and the subsequent (surface water) stream flows. Simple annual or seasonal averages of total rainfall and total stream flow do not (and will not) reflect the "real picture" (or the importance of 'water quantity') from an aquatic ecology perspective, though they might be sufficient for individuals tasked with procuring adequate quantities of water for various off-channel uses. For example, whilst the quantity of water needed may be available, its *quality* would likely be questionable at best.

We hope that we have persuaded *Water Wheel* readers to accept that even small increases in temperature have manifold repercussions on ecosystems and the wider environment in general. Indeed, so seriously is this threat viewed globally that luminary ecologists are now spearheading a return to nuclear energy to prevent further greenhouse gas emissions. As horrifying as they were, former nuclear disasters like Chernobyl and Three Mile Island were at least spatially localized, and experiential knowledge now exists to avoid (but not preclude) future recurrences. Greenhouse gas emissions, on the other hand, exert truly global impacts. The failure of certain major nations (like the USA and Japan) to sign the Kyoto Protocol is now being viewed almost complacently by the rising "Green" nuclear champions, as it would have been too little, too late. To conclude that global warming poses no threat to the environment is to disregard the overwhelming weight of scientifically accredited evidence that can only be interpreted to the contrary. Scientific perspectives and understanding today require a much broader, more holistic, and commensurately realistic view of the World, fortunately embraced by many contemporary hydrologists and water engineers. Will Alexander's rainfall analysis provides important evidence consistent with regional climate warming, and we urge him to use his detailed information to join, rather than contest, this global challenge.