Innovation opportunities in irrigation technology for using virtual water in 21st Century South Africa: Reflections from the past to the present

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Abstract

In 21st century South Africa, new and old technological innovations in agriculture can be employed to protect existing and future water supplies that are increasingly becoming vulnerable to encroaching global warming trends. The purpose of this article is to identify irrigation technology, the impact on irrigative farming of a polluted water environment through mining and other baneful industrial activities in the Republic. It also aims to discuss innovation opportunities in irrigation technology for using virtual water – a concept commonly associated with the Middle East. South Africa possesses arguably the most sophisticated engineering technology in irrigation in southern Africa. In this article, reflections on irrigation from the past to the present will be complemented by a historical focus of the context in which this farming enterprise evolved. A brief historical synopsis of irrigation shows that this activity which became more technologically advanced in the colonial and post-independence eras was also practiced in the pre-colonial period for food security and as an insurance against drought. Irrigation was practised in South Africa before and after the colonisation of the Cape by the Dutch in 1652. Irrigation technology in the seventeenth century tended to lack the sophistication and modernisation of the contemporary world. Innovative improvements became imperative as the state increasingly became more involved in agriculture from the 1920s and 1930s largely as part of a process leading to the evolution of settler irrigation policy which was premised on capital accumulation and the deprivation of Africans of land ownership rights. This policy orientation clearly changed from the advent of independence to the 21st century in favour of a policy that aimed at economically empowering the Black smallholder sector farmers without necessarily neglecting the large-scale commercial producers. Irrigation farming is not a novel phenomenon to the region. Since the turn of the new millennium, technological innovation has been prioritised because South Africa is situated in a predominantly hot arid zone of the sub-region. Total evaporation creates endemic water shortages. It is therefore imperative that water resources are well managed in a country which thrives largely on mining, industrial and agricultural pursuits. Due to South Africa's geophysical location in one of the world's arid terrains, irrigation has been identified as an essential corollary to dry land farming and other economic endeavours. Nevertheless, in spite of advances that have been made in centre-pivot manufacturing, South Africa has generally tended to ignore cheaper irrigation methodologies such as the drip, terracing and flood systems which seem more suitable and appropriate in arid conditions. It has also ignored the fact that using large volumes of both riparian and imported water from Lesotho to irrigate a crop like maize in the Eastern Free State Province, for example, is not only unviable but it is also unsustainable.

A major rethink of how food supply can be boosted on the basis of irrigated agriculture, utilising more advanced and peculiarly suitable technology in hot and arid or water deficient areas is vital. This is more so because industrial demand for water – a large quantity of which is expensively procured or transferred from Lesotho through the Vaal River system - is in direct competition with the demand for water to produce surplus food under irrigation. Most industrial and farming activities in Gauteng, Free State and Mpumalanga provinces, to name a few, are dependent on this water which is under threat of depletion. Given South Africa's arid conditions, the adoption of the virtual water concept, following the Saudi Arabian experience, would be a possible conservationist measure. This article also argues that because water is limited, mining and air pollution which eventually ends up in the water should be controlled to ensure safe drinking and irrigation water.

Keywords: Environmental history; Irrigation technology; Innovation; Environmental pollution; Air and water pollution; Acid Mine Drainage (AMD); Climate change; Global warming; arid environments; South Africa.

Introduction

This article assesses opportunities and the possible irrigation technological innovations that South Africa in the SADC region can adopt in the face of fast approaching aridity. It also focuses on the prospects for utilising and implementing the virtual water concept, including reflecting on how the past of irrigation development can be used to inform the present. The major justification for this case study of South Africa is aridity as this may proffer some lessons for other arid zones. South Africa is the 30th most arid country in the world, with Limpopo being one of the most desiccated provinces.[1]

South Africa thrives on irrigation and dry land farming, including mining and other industrial activities. Water for irrigation has been a crucial developmental resource for the country before independence and in the post-apartheid era. The key question the research undertakes to investigate is whether irrigation technological innovation in South Africa in the new millennium is influenced by aridity. Additionally, the article attempts to assess whether the adoption of such technology is driven by the need to supplement humidity or moisture levels through the use of appropriate water conservationist methods in such arid conditions. This is important for a country that requires increased water use for irrigation farming, industry, domestic, mining and power generation. Between 1990 and 2010, the demand for water for such usage varied from 2.3% to 50.9%.[2]

For a period transcending a decade since the 1990s, the marked decrease in precipitation in South Africa has required the application of agro-techniques that are commensurate with changing environmental conditions. The Free State Province, for instance, has been characterised by varying precipitation levels, with the Western Free State receiving low annual rainfall; the Central Free State, moderate rainfall; and the Eastern Free State, higher rainfall.[3] Diminishing water supplies in South Africa are a direct consequence of repeated drought spells. Whilst it is clear that temperature and climatic patterns have been changing, corresponding advancement in irrigation methods has largely not taken place. In light of this seeming neglect of appropriately designed technology, it is suggested that a new policy direction in farming should include measures to build irrigation systems that can sustain food productivity in the event of worsening climatic conditions.

Irrigation has a long history throughout the world. Irrigation and water history in general, have clearly become significant areas of study. Globally, scientists in a variety of fields have started concentrating on water and its scarcity in arid terrains as a subject. In a nutshell, water history refers to an interdisciplinary study which aims to foster historical understanding of

1 SABC 3 News, 05:30 Bulletin, 24 November 2009.

2 GDT de Villiers, PMU Schmitz & HJ Booysen, "South Africa's Water Resources and the Lesotho Highlands Water Scheme: A Partial Solution to the Country's Water Problems", *Water Resources Development*, 12(1), 1996, p. 68.

3 A Barnard & MF Smith, "The Effect of Rainfall and Temperature on the Preharvest Sprouting Tolerance of Winter Wheat in the Dryland Production Areas of the Free State Province", *Field Crops Research*, 112, 2009, pp. 158-164.

the relationship between water and humankind as it links scholarship in humanities and social sciences with the natural and applied sciences.[4] It also provides a forum for research in water management. As water has influenced the development of human communities throughout the world, the study of water contributes to an understanding of economic, political, social and environmental history, the history of science, medicine, technology, environmental sciences and geography.[5] In other words, as a result of the ubiquitous nature of water, the discipline of water history includes within its study elements of technology history, history of science, as well as a number of other fields of study. Water history is thus more than mere environmental history.

Although several works on water and irrigation history predate colonialism, it is the 1990s that generated increasing global awareness to the fact that it would become a finite natural resource in the not-too-distant future in spite of it being seemingly plentiful. Scholars such as Tempelhoff, Turton and Ohlsson have amply demonstrated the precariousness of the situation for South Africa and many water-stressed parts of the world.[6] Historically, the state has focused on controlling the natural water system to address the lack of water for agricultural usage and industrial development.[7] The development of modern irrigation techniques in South Africa was, among other things, intended to mitigate against aridity and to reduce dependency on the state.[8] For Nyandoro, McNider and Mollinga, irrigation can be practised in both dry and wet environmental conditions as it is essential in complementing dry land agricultural production.[9] Tempelhoff argues that irrigation technology

4 JWN Tempelhoff et al, "Where has the Water Come From?" *Water History*, 1, 2009, pp. 1-18.

5 JWN Tempelhoff et al, "Where has the Water Come From?" *Water History*, 1, 2009.

6 JWN Tempelhoff, "Historical Perspectives on Pre-colonial Irrigation in Southern Africa", *African Historical Review*, 40(1), July 2008, pp. 121-160; AR Turton, *Water Scarcity and Social Adaptive Capacity: Towards an Understanding of the Social Dynamics of Managing Water Scarcity in Developing Countries* (London, SOAS, 1999); AR Turton & L Ohlsson, *Water Scarcity and Social Stability: Towards a Deeper Understanding of Key Concepts Needed to Manage Water Scarcity in Developing Countries* (London, SOAS, 1999); AR Turton, *Water and State Sovereignty: The Hydropolitical Challenge for States in Arid Regions* (SOAS, 1999).

7 W Nomquphua, E Brauneb & S Mitchellc, "The Changing Water Resources Monitoring Environment in South Africa", *South African Journal of Science*, 103, 2007, pp. 306-310.

8 M Nyandoro, *Development and Differentiation: The Case of TILCOR/ARDA Irrigation Activities in Sanyati (Zimbabwe), 1939 to 2000*, Saarbrucken: VDM Verlag Dr Muller, December 2008, pp. 1-460.

9 M Nyandoro, *Development and Differentiation: The Case of TILCOR/ARDA Irrigation Activities in Sanyati (Zimbabwe), 1939 to 2000* (Saarbrucken, VDM Verlag Dr Muller, December 2008); R McNider, et al., "Irrigation Assisted Rain-fed Agriculture: A Sustainable Adaptation Strategy"; R McNider, et al., *Southeastern Irrigation* (Orlando, SECC/WMO), (available at: http://www.wamis.org/agm/meetings/ictusa08/S3-McNider.pdf), as accessed on 31 January 2011, pp. 1-70; PP Mollinga et al., "Strategies for Rainfed and Irrigated Agriculture: Tungabhadra Basin, India and Tagus Basin, Spain and Portugal", *STRIVER Task Report*, 9(2), September 2008, pp. 1-55.

has developed from the small irrigation furrow of the "subsistence" farmer in pre-colonial times to the sophisticated irrigation technology adopted by South Africa in the new millennium.[10] It is important to note that Tempelhoff, Turton and other water scholars categorically refute Mulwafu's assertion that in the decade preceding the new millennium, the study of water and other natural resources was often disregarded as a critical determinant of historical events.[11] A similar argument to Mulwafu's that can also be contested is Beinart's position that water and the environment were not perceived as resources that transformed human experiences.[12] Indeed, numerous studies, including those by Abderrahman, Dennis, Nell and Phillips[13], have acknowledged the historical and interdisciplinary or transboundary nature of water and that water is a key element whose utilisation has shaped human civilisations since time immemorial. The conversion to virtual water[14] in Saudi Arabia, as indicated by Allan and Turton among others, is to some extent evidence of the agro-economic and industrial importance of water whether or not it exists within a country's borders.

In South Africa, irrigation agriculture is a chief means of food production and this calls for wide ranging scientific improvement. Limited irrigation technological innovation has been adopted beyond the centre-pivot system. This has virtually hampered irrigation farming activity, notwithstanding irrigation's potential to feed the country's population, the majority of whom live in arid and semi-arid parts of the Republic. Rethinking irrigation and agricultural production to enhance food supply is therefore essential especially in water deficit areas. This is more so given the stiff competition for water between industry and agriculture. United Nations (UN) projections indicate, for example, that this seemingly infinite supply of water is likely to

10 JWN Tempelhoff, "Historical Perspectives on Pre-colonial Irrigation in Southern Africa", *African Historical Review*, 40(1), July 2008.

11 WO Mulwafu, "Does Water have a History? Water Use and Management in Malawi", JWN Tempelhoff (ed.), *African Water Histories: Transdisciplinary Discourses* (Vanderbijlpark, Corals Publishers, 2005), p. 1.

12 W Beinart, "African History and Environmental History", *African Affairs*, 99(395), 2000, pp. 269-302.

13 WA Abderrahman et al., "Impacts of Irrigation on Shallow Groundwater in Eastern Province, Saudi Arabia", *Water Resources Development*, 16(3), 2000, pp. 369–390; WA Abderrahman et al., "Computerized and Dynamic Model for Irrigation Water Management of Large Irrigation Schemes in Saudi Arabia", *Water Resources Development*, 17(2), 2001, pp. 261–270; HJ Dennis & WT Nell, "Precision Irrigation in South Africa", Bloemfontein: Centre for Agricultural Management, Faculty of Natural and Agricultural Sciences, University of the Free State, (available at: http://natagri.ufs.ac.za/dl/userfiles/Documents/00001/1341_eng.pdf), as accessed on 31 January 2011, pp. 1-17; DJH Phillips et al., "The TWO Analysis - Introducing a Methodology for the Transboundary Waters Opportunity Analysis", *Stockholm International Water Institute (SIWI) Report*, 23, 2008, pp. 1-36.

14 Virtual water (also known as embedded water, embodied water or hidden water) refers, in the context of trade, to the water used in the production of a good or service.

dry up by 2015 due to excessive evaporation, drought conditions created by global warming, and as a result of suboptimal usage of the water by various stakeholders. Such a bleak situation will obviously destabilise industrial and economic growth in South Africa.

For South Africa, just like Saudi Arabia - a country situated in one of the driest parts of the Middle East - a conversion to virtual water would provide relief and reduce the strain being imposed on limited water supplies by irrigating unprofitable crops. Because of the challenges imposed by an arid topography in South Africa, the article will therefore examine how such conditions can be counteracted, as far as surplus food production is concerned, by building up sufficient irrigation and pollution combating technological capacity to deal with agro-development in an environment of cumbersome aquatic provision and possibilities.

Arid South Africa: A concise topographical and spatial reflection

South Africa possesses diverse geophysical and climatic situations. With a surface area of 1 219 912 sq km it has a population estimated in 2008 to be approximately 49 million.[15] It receives summer rainfall, but parts of the country experience winter rains brought by the humid sea-winds from the Indian Ocean. Rainfall and its seasonal distribution varies between 400 and 1200 mm annually. This is a consequence, among other things, of the east-west distribution of rainfall in the Republic and extreme variations in relief. In a nutshell, South Africa's major environmental concerns arise from a lack of important arterial rivers or lakes; hence it requires extensive water conservation and control measures. In addition, the growth in water usage due to agro-industrial and other activities is outstripping supply. Other problems include pollution of rivers from agricultural runoff and urban discharge, air pollution resulting in acid rain, soil erosion and desertification.[16] Aridity and the environmental consequences of industrialising such as mine and air pollution which ends up in the water are adversely affecting irrigation farming. For example, irrigation projects along the Vaal River barrage of South Africa suffer from unstable water supply. Most farms along the barrage rely on what

15 Anon, "South Africa People: 'The Rainbow Nation', (available at: http://www.expatcapetown.com/south-africa-people.html), as accessed on 31 January 2011.

16 SE Nicholson, "The nature of rainfall variability over Africa on time scales of decades to millennia", *Global and Planetary Change*, 26, 2000, pp. 137-158.

has been termed grey water. Grey water in irrigation is secondary water. This is used water. It is not pristine or pure water. Such water is not conducive to normal crop or plant growth.

In many ways, industrial waste poses a danger to agriculture and the environment. Most of the Gauteng Province, which is the industrial hub of South Africa; parts of the Free State and other areas are characterised by excessive gaseous and chemical emissions into the atmosphere due to intensive industrial activity. Eskom, a coal or thermal-electricity generating plant in Vereeniging (Gauteng Province) and the Sasol chemical and petroleum manufacturing plant using coal situated in the small Free State Province town of Sasolburg, are some of the biggest polluters of the air in the area.[17] Sasol, for instance, emits sulphur and other gases into the air. This is exacerbated by the synthetic environment created by the Eskom power station in the Vaal Triangle area around the Gauteng Province towns of Vereeniging and Vanderbijlpark.[18] These, just like similar industrial plants in South Africa, are responsible for the amount of acid rain that falls in the country during the rainy season. In particular, air pollution which eventually ends up in the water, contaminates reservoirs, notably dams, riverine systems, wells and open tanks.[19] As a consequence, such sources cannot be used for irrigation farming especially of edible crops or fruits. Clearly, air pollution has a bearing on acid rain due to the residue of polluting industries. This rain is not good for agriculture - an activity that is also hindered by Acid Mine Drainage (AMD).

Acid Mine Drainage(AMD): Mining pollution of water

The province of Gauteng boasts of some of the biggest gold, diamond and coal mines in the Republic, including redundant or disused mines. The country faces very serious challenges from AMD. AMD is caused by water which is not pumped out when mines close or shut down. Consequently, heavy metal layers result, that is, steel in rock formation. When water fills

17 Anon, "Industry news: Sasol, Eskom top South Africa's pollution list", *Global Carbon Exchange*, (available at: http://www.globalcarbonexchange.com/sasol-eskom-top-safrica-s-pollution-list.html), as accessed on 31 January 2010. See also Incite Sustainability, *Carbon Disclosure Project*, South Africa JSE 100, 2009, pp. 1-72.

18 Anon, "Industry news: Sasol, Eskom top South Africa's pollution list", *Global Carbon Exchange*, (available at: http://www.globalcarbonexchange.com/sasol-eskom-top-safrica-s-pollution-list.html), as accessed on 31 January 2010.

19 H Thompson, *Policies, Legislation and Organizations Related to Water in South Africa, with Special Reference to the Olifants River Basin*, Working Paper 18 (South Africa Working Paper No. 7). Colombo: International Water Management Institute (IWMI), 2001.

up again this leads to acid rain or toxic water and heavy metals. This is the case, for example, in the Wonderfontein Spruit, Modderfontein Spruit and the largely mined-out West Rand (See Image 1) in South Africa, where it is impossible to use the water for irrigation or any other purpose afterwards.[20]

Image 1: Scraggy Remnants - The stark reality of the damage to the environment on South Africa's largely mined-out West Rand

Source: M Wait, "Environmental Protection: Opportunity or Curse - Holistic solution needed to acid mine drainage problem", Creamer Media's Online Mining Weekly Magazine, 2011, (available at: http://www.miningweekly.com/article/holistic-solution-needed-to-acid-mine-drainage-problem-2011-01-12, as accessed on 31 January 2011). Photograph: Duane Daws.

AMD has a bearing on mining activities. The emission of dolomitic aquifers below the surface to get mining activities going poses one of the greatest threats to the environment. Environmentalists have termed AMD the single most significant threat to South Africa's environment. The AMD problems being experienced at the East Rand operations of provisionally liquidated and Johannesburg Stock Exchange (JSE)-suspended Pamodzi Gold are a good

20 For more detail on how AMD has affected mines on the Wonderfontein Spruit and the Modderfontein Spruit see ES van Eeden, M Liefferink & E Tempelhoff, "Environmental ethics and crime in the water affairs of the Wonderfontein Spruit Catchment, Gauteng, South Africa", *TD: The Journal for Transdisciplinary Research in Southern Africa*, 4(1), July 2008, 31-58; ES van Eeden, "An historical assessment of NGO efficiency in progressing towards a sustainable environmental heritage focus, with as case study the Wonderfontein Spruit catchment, Gauteng", *New Contree*, 53, May 2007, pp. 55-78; RA Adler, M Claassen, L Godfrey & A Turton, "Water, mining and waste: an historical and economic perspective on conflict management in South Africa", *The economics of Peace and Security Journal*, 2(2), 2007, pp. 33-34. Information on how South Africa's very articulate civil society has reacted to the problems of AMD, water quality and water delivery to the people can be gleaned from CR Dakalo, "Various Rietspruit Forum meeting minutes", Sebokeng: Sebokeng Water Care Works, 2009-2011.

example of this threat.[21] The Water for Growth and Development Framework (WGDF), launched by the Department of Water and Environmental Affairs in early 2009, argues that ground- and surface-water pollution, as a result of AMD from abandoned mines, poses a threat and an obstacle to securing water for growth and development.[22] In concurring with the WGDF, DWA has illuminatingly reported that, in the central and western basins of the Witwatersrand mine systems, this threat is "present and immediate," and requires urgent intervention.[23] Media reports in South Africa suggest an awakening of both government and the mining industry to the scale of the AMD problem and the need to alleviate its environmental effects. For Turton, AMD is a limiting factor, which, if left unresolved, will severely impact on agriculture and future economic development.[24] Thus, existing mining technologies need to be transformed so that water for agricultural usage, which is already scarce due to aridity, is not incessantly contaminated.

Aridity and water scarcity

South Africa, just like many other parts of the globe situated in arid and semi-arid conditions, faces intractable aquatic environmental challenges. One of the country's biggest tests is by far linked to water scarcity and the efficient utilisation of this resource due to the escalation of global warming and its attendant environmental problems. Water problems have been reported, inter alia, in the Eastern Cape, Free State, Western Cape and Limpopo provinces as shown in Table 1. The Table reflects current and potential irrigation development in different South African provinces:[25]

21 B Naidoo, "Acid mine drainage single most significant threat to South Africa's environment", in Creamer Media's Mining Weekly.com, 2009, (available at: http://www.miningweekly.com/article/acid-mine-drainage-single-most-significant-threat-to-sas-environment-2009-05-08, as accessed on 30 December 2009).

22 WGDF cited in B Naidoo, "Acid mine drainage single most significant threat to South Africa's environment", in Creamer Media's Mining Weekly.com, 2009, (available at: http://www.miningweekly.com/article/acid-mine-drainage-single-most-significant-threat-to-sas-environment-2009-05-08), as accessed on 30 December 2009.

23 DWA, B Naidoo, "Acid mine drainage single most significant threat to South Africa's environment", in Creamer Media's Mining Weekly.com, 2009, (available at: http://www.miningweekly.com/article/acid-mine-drainage-single-most-significant-threat-to-sas-environment-2009-05-08), as accessed on 30 December 2009.

24 AR Turton cited in B Naidoo, "Acid mine drainage single most significant threat to South Africa's environment", in Creamer Media's Mining Weekly.com, 2009, (available at: http://www.miningweekly.com/article/acid-mine-drainage-single-most-significant-threat-to-sas-environment-2009-05-08), as accessed on 30 December 2009; WRC, "AMD: Local solutions for local challenges", *The Water Wheel*, September/October 2010, pp. 28-30.

25 SABC 3 News, 19:00 Bulletin, Saturday 2 January 2010.

Table 1: Areas currently under irrigation and land suitable for potential irrigation development in the different provinces (1996)[26]

Province	Land								Water available for further development ha
	Very suitable		Suitable		Risky		Total		
	Current ha	Potential ha	Current ha	Potential ha	Current ha	Potential ha	Current ha	Potential ha	
Eastern Cape	34 568	14 524	94 995	19 370	25 367	14 735	154 930	48 629	52 000
Free State	39 104	14 496	41 131	12 580	18 745	2 146	98 980	29 222	10 000
Gauteng	16 925	4 100	6 895	1 600	2 864	0	26 684	5 700	0
KwaZulu-Natal	66 625	52 552	71 762	31 955	31 855	15 056	170 244	99 563	77 000
Mpumalanga	129 225	31 250	25 426	4 070	2 769	490	157 420	35 810	7 000
Northern Cape	80 965	8 707	71 356	5 250	9 553	1 340	161 874	15 297	20 000
Limpopo	61 752	6 100	46 898	3 550	26 496	1 420	135 146	11 070	2 000
North West	83 660	700	16 306	1 800	3 352	100	103 318	2 600	0
Western Cape	100 861	6 840	128 038	14 578	52 637	14 401	281 536	35 459	10 000
Total	613 687	138 909	502 807	94 753	173 638	49 688	1 290 132	283 350	178 000

Source: Water Research Commission (1996).

Note: Based on the Report of the Commission on a Food and Feeding Strategy for South Africa (1990).

Frequent droughts, possibly due to climate change as well as mismanagement, are exacerbating water scarcity, not only in South Africa, but also in many parts of the southern African region. Water for irrigation, as well as water for industrial and domestic consumption has become an area of serious contestation[27] compounded by the reality that many economies in the arid regions have only half the water they need, prompting fears of an imminent water war. Such fears are speculative because, in spite of the fact that the Middle East is inadequately endowed with freshwater and that the region ran out of water resources to meet its strategic needs (for domestic and industrial use as well as for food production) in 1970, no military conflict erupted over water.[28] In South Africa no water war has occurred either. It can be noted that sentiments around a water war are therefore alarmist because in spite of warnings by some world leaders, however, there has been no recorded clash over

26 GR Backeberg, "Water Usage and Irrigation Policy", Chapter 9 in L Nieuwoudt & J Groenewald (eds.), *The Challenge of Change: Agriculture, Land and the South African Economy*, Pietermaritzburg: University of Natal Press, 2003, p. 152.

27 M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010, pp. 1-24.

28 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002, pp. 255-272; T Allan, "Watersheds and Problemsheds: Explaining the absence of armed conflict over water in the Middle East", *MERIA Journal*, 2(1), March 1998; AR Turton, "Water wars in Southern Africa: Challenging Conventional Wisdom", H Solomon & AR Turton (eds.), *Water Wars: Enduring Myth or Impending Reality* (Durban, Accord, 2000).

water.[29] If anything, notwithstanding depleted water resources and mounting water demand in view of increasing population growth, international tensions and relations over water have markedly subsided since 1970.[30] A possible explanation for the decline in tension is that in the decades after this date water has been made ever more available on the international market in the form of "virtual water."[31] Although in the main the global political economy of water use and trade has had fundamental positive effects on the way water is perceived in the Middle East, it is disconcerting to note that the impact of the global system has been perverse in that the availability of virtual water (a theory described on pp. 20-22 of this article) has dramatically slowed the pace of reforms intended to improve water efficiency.[32] In the South African irrigation field, justifications for adaptation or change to virtual water can be viewed against the backdrop of conspicuous trends and developments in this sector since the 1990s.

Overview of irrigation trends and developments since the 1990s

State-run irrigation in the 1990s cannot be understood without a historical background of its development since the 1920s. Irrigation in the early stages of the Union of South Africa started without much state direction on the most appropriate technological interventions and methods required. A smaller section of the total land area was utilised for irrigation. For instance, of the 13 million acres of cultivated farmland in 1921 only 572 003 acres were irrigated.[33] The development of irrigation facilities was undertaken by the Irrigation Department of the Union Department of Agriculture which carried out scientific investigations into the needs and possibilities of irrigation in South Africa. This happened without much attention being given to the

29 For detail on this see T Allan, " 'Virtual water': a long term solution for water short Middle Eastern economies?", Paper presented at the British Association Festival of Science, Roger Stevens Lecture Theatre, University of Leeds, 9 September 1997, p. 1-20.

30 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002. For some statistics on South Africa's population see Anon, "South Africa People: 'The Rainbow Nation', (available at: http://www.expatcapetown.com/south-africa-people.html), as accessed on 31 January 2011.

31 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002. See also T Allan, *'Virtual Water': A long term solution for water short Middle Eastern Economies?,* (London, SOAS, 1997).

32 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002; AY Hoekstra & PQ Hung, "Globalisation of water resources: international virtual water flows in relation to crop trade", *Global Environmental Change*, 15, 2005, pp. 45-56.

33 CD Forde, "Irrigation in South Africa", *The Geographical Journal*, 65(4), 1925, pp. 342-349.

question whether the irrigation technology designed in the 1920s and 1930s suited the needs of the 21st century. This did not mean irrigation was not important. It was recognised in both state and public circles that agriculture needed to be complemented by irrigation.

The dependence of agriculture on irrigation is exemplified by the fact that for many parts of South Africa such as the Karroo and the south-west of the Free State Province, agriculture is practically impossible without irrigation due to low rainfall.[34] At the state level, irrigation development in South Africa cannot be separated from the policy orientation of the colonial and Apartheid governments. Shillington has described the broader picture of irrigation agricultural schemes as enterprises that were linked to settler accumulation and the dispossession of Africans of their land.[35] He argues that in order for irrigation to facilitate the transformation of rural society it requires large capital outlays and direct state intervention. Government intervention in irrigation was evident during the economic crisis of the 1930s. It was a way of securing the whites on the land and at the same time curtailing a potentially massive rural-to-urban migration by this group of farmers. The Vaalharts Scheme was launched in the 1930s after the completion of the storage dam. From the 1930s to the 1940s, plots that varied in size from 17 ha to 25 ha were allocated to settlers for irrigation, but on a probationary basis. Evictions of people which were frequently undertaken since the colonisation of South Africa were still being carried out in the 1970s in pursuit of the rationalisation of the area under irrigation. The Vaalharts model of irrigation development was replicated for smallholder farmers in the Bohuputswane Scheme and "homeland" areas in order to give credibility to state development policies during Apartheid.[36] However, whilst earlier irrigation schemes such as the Vaalharts relied on flood irrigation (which sometimes caused waterlogging); the emphasis on the use of centre-pivots throughout the 1980s and the 1990s

34 CD Forde, "Irrigation in South Africa", *The Geographical Journal*, 65(4), 1925.

35 K Shillington, "Irrigation, Agriculture and the State: The Harts Valley in Historical Perspective", W Beinart, P Delius & S Trapido (eds.), *Putting a Plough to the Ground: Accumulation and Dispossession in Rural South Africa 1850-1930* (Johannesburg, Ravan Press, 1986), p. 3; A Vaughan, "Irrigation Development – Current Realities, New Policies, and Future Possibilities for Positive Impacts on Rural Poverty: A Contribution to the Poverty and Inequality Study", Institute for Social and Economic Research, 12 November 1997, (available at: http://docs.google.com/viewer?a=v&q=cache:2rpunM4DSD4J:www.info.gov.za/otherdocs/1998/poverty/irrigation.pdf+A+HISTORICAL+FOCUS+of+irrigation+in+south+africa&hl=en&gl=gh&pid=bl&srcid=ADGEESjXHeQLmKHodK94uYJYQW1PQUaj_bTnhb0S0DnGOxJ19J96vqz94tJoEjoK-FqjvOL4rfJCJlp7CSLJxADYUZkFxvHpN5SRT-95fRSKluyIFZbJX1oZyT6OCfC-EYQDxXpEruTS&sig=AHIEtbSR7k13L1bZQtWtGaYDaw1O91sq4g), as accessed on 05 July 2011.

36 K Shillington, "Irrigation, Agriculture and the State: The Harts Valley in Historical Perspective"; W Beinart, P Delius & S Trapido (eds.), *Putting a Plough to the Ground: Accumulation and Dispossession in Rural South Africa 1850-1930* (Johannesburg, Ravan Press, 1986).

was intended to be a step towards modernising agricultural technology in the twentieth century. The 1990s can be seen as marking a real watershed in efforts to improve and manage irrigation systems more efficiently which partly explains the existence of concerted research on the subject as illustrated in this paper. This brief agricultural history proves that from the 1920s to the 1980s there was irrigation technological innovation, but evidence from the 1990s onwards shows that technology needed to be upgraded in line with prevailing climatic and environmental needs and dictates of the 21st century. Clearly, for South Africa to achieve sustainable growth in the new millennium it needed to be an innovator rather than an adopter of technology.

Innovative present day irrigation knowledge and technology

The move towards efficient, conservationist-oriented and sustainable technology

Contemporary irrigation knowledge and technology should not ignore the geophysical disparities of the Republic and the dissimilarities of land and water potential in the country. Whilst there is a general shortage of water, this factor alone cannot be used to assume agrarian homogeneity as privileged and non-privileged appropriation of water exists between large-scale commercial farmers and the small-scale irrigators as revealed by the example of farming along the Wilge, Axle and Liebenbergsvlei Rivers in the Free State Province.[37] For South Africa, water scarcity and the prevalence of drought should influence the adoption of irrigation technological innovation in direct response to conditions of aridity and the need to produce food crops throughout the year because pure rain-fed agriculture in most areas is inefficient.[38] Ideally, irrigation should be encouraged even where water is plentiful and, for the entire world, conservation should be given top priority by using efficient methods as opposed to the use in South Africa of wasteful

37 M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010.

38 R McNider, et al., "Irrigation Assisted Rain-fed Agriculture: A Sustainable Adaptation Strategy", R McNider, et al., *Southeastern Irrigation* (Orlando, SECC/WMO), (available at: http://www.wamis.org/agm/meetings/ictusa08/S3-McNider.pdf), as accessed on 31 January 2011.

methods such as centre-pivots (which can have a 450m radius - See Image 2)[39] and others that consume larger amounts of water compared to drip methods.

Image 2: An irrigation pivot near Frankfort, on the banks of the Wilge River in the Eastern Free State[40]

Source: Photograph: Johann Tempelhoff 30 April 2009.

A historical review of agricultural practices in South Africa reveals an urgent need for cheaper and improved irrigation techniques that help conserve limited water supplies in arid zones.[41] For example, large-scale farmers in the Free State Province utilise either illegally or lawfully the Axle-Liebenbergsvlei

39 A Qassim, F Dunin & M Bethune, "Water balance of centre pivot irrigated pasture in northern Victoria, Australia", *Agricultural water management*, 95, 2008, pp. 566-574. Centre pivots are typically less than 500m in radius. The most common or standard size centre pivot has a 400m radius. Centre pivot irrigation is also known as central pivot irrigation or circle irrigation.

40 M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010.

41 PJ O'Farrell et al, "Human response and adaptation to drought in the arid zone: Lessons from southern Africa", *South African Journal of Science*, 105, 2009, p. 36.

water transfer scheme for irrigation.[42] They use expensive and environmentally damaging sprinkler and centre-pivot technology despite the persistence of profound water shortages in arid South Africa. As a result of the growing demand for water supplies primarily by domestic and industrial consumers in Gauteng Province, the National Department of Water Affairs now renamed the Department of Water and Environmental Affairs (DWA) has been concerned with consumption patterns.[43] In the main, the unlawful abstraction of water for irrigation purposes in the region has been identified as a potential over-consumption hotspot.[44] Thus, the DWA, on the basis of the National Water Act (NWA) of 1998[45] on which post-apartheid water reforms were premised is attempting to regulate water use in the Free State's Liebenbergsvlei region and thereby curb the surreptitious exploitation of water for intensive irrigation farming.

Regulation of this resource is essential because water is a major catalyst for economic development. Because South Africa is located in a highly water constrained zone of the SADC region, it is urgent for the country to focus on relevant irrigation technological innovation. This urgency is made more poignant by predictions about water scarcity[46] which have been made by the United Nations and other hydro-related organisations such as the

42 Empirical research in the Liebenbergsvlei River has revealed that the action of some irrigation farmers is tantamount to theft or stealing of water. For detail on this see GMOA, Correspondence 1, 2009.08.11 and GMOA, Interview 7, 2009. 05.21 in M Ginster, C Gouws, CM Gouws, H Mäki, R Mathipa, S Motloung, M Nyandoro, & JWN Tempelhoff, "The problem of irrigation from Lesotho Highlands water in the Axle and Liebenbergsvlei river catchment, Eastern Free State", *Report 1/2009, Version 2.10*, CuDyWat, NWU, Vanderbijlpark, 2009.08.26; M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010. N.B. Notes of interviews by the Liebenbergsvleiriver (LBVR) research team are numbered to protect the identity of respondents. The codes of researchers' files in the electronic project archive are referenced in alphabetical order as follows: Martin Ginster (GMOA), Claudia Gouws (GCOA), Ina Gouws (GIOA), Harri Mäki (MHOA), Mark Nyandoro (NMOA), Ruth Mathipa (MROA), Sysman Motloung (MSOA) and Johann Tempelhoff (TJOA).

43 M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010, p. 2.

44 M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010.

45 Government Notice, *National Water Act*, No. 1091 of 26 August 1998 in *Government Gazette of the Republic of South Africa*, 19182, 1998.

46 AR Turton, *Water Scarcity and Social Adaptive Capacity: Towards an Understanding of the Social Dynamics of Managing Water Scarcity in Developing Countries* (London, SOAS, 1999); AR Turton, "What Water Problem? A Multi-Dimensional Perspective on Critical Water Issues in the Upper Vaal Catchment", Paper presented at the North-West University (NWU) Vaal Triangle Campus Symposium, 20 November 2009 & *MEWREW Occasional Paper*, 18, (available at: http://www.soas.ac.uk/Geography/WaterIssues/OccasionalPapers/home.html), as accessed on 27 November 2009; D Seckler, R Barker and U Amarasinghe, "Water Scarcity in the Twenty-first Century", *Water Resources Development*, 15(1/2), 1999, pp. 29-42.

International Water Management Institute (IWMI). The scarcity is a result of increased demand and creepy environmental factors such as global warming.[47] World water indexes for 2015, 2020, 2050 and 2070 paint an ominous picture of the country's water situation, and these are likely to worsen with the envisaged increase in climate variability after the 2050s. The 2006 United Nations Human Development Report also reveals a dismal picture of global water scarcity and the increasing pressure on agricultural water supplies.[48] Water resources are fast dwindling. It is not a misnomer to assert that South Africa is highly water constrained in light of, not only the volumes, but also the quality of water the country needs for agricultural (irrigation), industrial and domestic consumptive needs (See Table 2 for expected total demand of water for these sectors between 1990 and 2010):

Table 2: Expected total use and percentage of total demand[49]

Demand sector	**1990 (million m^3/yr)**	**(%)**	**2000 (million m^3/yr)**	**(%)**	**2010 (million m^3/yr)**	**(%)**
Direct use Municipal and domestic	2281	12.0	3220	14.4	4477	17.3
Industrial	1448	7.6	2043	9.1	2961	11.4
Mining	511	2.7	582	2.6	649	2.5
Power generation	444	2.3	779	3.5	900	3.5
Irrigation	9695	50.9	10974	48.9	11885	45.9
Stock-watering	288	1.5	316	1.4	358	1.4
Nature conservation	182	1.0	187	0.8	191	0.7
Indirect use Forestry runoff reduction	1427	7.5	1570	7.0	1700	6.6
Ecological use Estuaries and lakes	2767	14.5	2767	12.3	2767	10.7
Total	19043	100.0	2243	100.0	25888	100.0

47 AR Turton, "The Construction of Knowledge and the Climate Change Debate: A Perspective from the Developing South", Paper presented at the ISODARCO Summer School entitled "Global Climate Change and Impact on Natural Resources" held at Candriai, Italy 20 - 29 June 2001; DJ Merrey, *Expanding the Frontiers of Irrigation Management Research: Results of Research and Development at the International Irrigation Management Institute, 1984 to 1995* (Colombo, International Irrigation Management Institute, 1997); DJ Merrey & CJ Perry, "New Directions in Water Research: IWMI at the Threshold of the Twenty-first Century", *Water Resources Development*, 15(1/2), 1999, pp. 5-16; United Nations (UN), "A Place for Water Markets: Performance and Challenges", *Applied Economic Perspectives and Policy*, 31(1), April 2009, pp. 50-67; UN, "Water: A Shared Responsibility – The United Nations World Water Development Report 2 (WWDR 2)", *Development in Practice*, 17(2), April 2007, pp. 309-311.

48 UN, "A Place for Water Markets: Performance and Challenges", *Applied Economic Perspectives and Policy*, 31(1), April 2009.

49 GDT de Villiers, PMU Schmitz & HJ Booysen, "South Africa's Water Resources and the Lesotho Highlands Water Scheme: A Partial Solution to the Country's Water Problems", *Water Resources Development*, 12(1), 1996, p. 68.

It is clear from Table 2 that the largest demand for water comes from the irrigation sector which by 2010 was utilising more than 50% of total water supply.[50] It should be noted, however, that before the 1990s most engineering advances in large-scale commercial irrigation farming saw huge investment in centre-pivot methods. If available forecasts are anything to go by, South Africa which is a water stressed country should reconsider the viability of alternative irrigation methods that are either cost-cutting or cost-saving, if not conservationist oriented. It is imperative to focus on investment in appropriate technology in order to achieve a meaningful reduction in the quantity of water used for irrigation by existing farmers in the Republic.[51]

Irrigation technology should certainly take into account the regional climatic and geophysical diversity of South African society. As revealed by DWA and studies by Ginster, the centre-pivot system is not necessarily ideal for South Africa as it is characterised by many shortcomings and deleterious effects on the environment.[52] Compared to flood irrigation, centre-pivot irrigation technology is, to a great extent, more sophisticated and requires a higher level of managerial skill if a farmer is to benefit from the new system.[53] Another centre-pivot constraint includes application rates that exceed the infiltration capacity of most soils.[54] However, despite these disadvantages, power-driven centre-pivot sprinklers use less water more efficiently and the land does not become waterlogged.[55] If appropriate irrigation technology can be designed to forestall or eradicate these limitations, then South Africa can be assured of sustainable food production to feed a rapidly increasing population which is estimated to reach over 49 million by 2015. Conserving and efficiently using irrigation water is critical for sustainable agricultural

50 GDT de Villiers, PMU Schmitz & HJ Booysen, "South Africa's Water Resources and the Lesotho Highlands Water Scheme: A Partial Solution to the Country's Water Problems", *Water Resources Development*, 12(1), 1996, pp. 65-77.

51 Department of Water Affairs and Forestry (DWAF), *Water for Growth and Development*, *Version 7* (Pretoria: 2008). DWAF is now the new Department of Water and Environmental Affairs (DWA).

52 DWAF, *Water for Growth and Development, Version 7* (Pretoria, 2008); M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010.

53 H Jordaan & B Grové, "Factors Affecting Maize Producers Adoption of Forward Pricing in Price Risk Management: The Case of Vaalharts", *Agrekon*, 46(4), December 2007, p. 559.

54 OE Magwenzi & SV Nkambule, "Suitability of Centre Pivot Irrigation for Sugarcane Production in Swaziland", *Proc S Afr Sug Technol Ass 77*, 2003, pp. 352-363.

55 K Shillington, "Irrigation, Agriculture and the State: The Harts Valley in Historical Perspective", W Beinart, P Delius & S Trapido (eds.), *Putting a Plough to the Ground: Accumulation and Dispossession in Rural South Africa 1850-1930* (Johannesburg, Ravan Press, 1986), p. 331.

development in arid and semi-arid environments.[56] Even the massive body of water being conveyed from Lesotho[57] to supplement South Africa's irrigation, manufacturing, mining and potable needs, is projected to dry up by 2015 because of anticipated climatic changes which are threatening to destabilise the country's economically productive regions and other regions in the world. Indeed, in order to enhance food productivity, South Africa should harness proactive irrigation technologies that are sustainable given the country's arid background.

Not all South African provinces are renowned for irrigation agriculture. The Eastern Free State, Swartland and the Southern Cape (Western Cape Province) are the wheat and grain basket of the Republic, with some fruit irrigation farms along the Liebenbergsvleiriver (LBVR).[58] Other provinces are not major grain producers but are renowned for fruits, for example Limpopo. Such provinces' dependence on agriculture means that a steady supply of water has to be maintained.

The economy of South Africa is as dependent on global water as it is on the renewable waters of the region, and, with increasing aridity, it will be much more in need of global water in future.[59] The country would convert a lot of land into production if it invested in and adopted appropriate irrigation technology. Installing requisite newer and more efficient water and irrigation technologies is very expensive because it requires huge capital expenditure. South Africa, however, seems to have the financial resources to embark on massive improvements to the existing irrigation infrastructure. Given proper planning and sound management, it is capable of massive injection of funds for irrigation expansion as there is a need to overhaul the existing water or irrigation technologies in the country.

56 RG Pablo et al, "Evaluation of Corn Grain Yield and Water Use Efficiency Using Subsurface Drip Irrigation", *Journal of Sustainable Agriculture*, 30(1), 2007, pp. 153-172.

57 Commercial agriculture in the dry interior of South Africa is heavily dependent on irrigation water from the Katse Dam in Lesotho; GDT de Villiers, PMU Schmitz & HJ Booysen, "South Africa's Water Resources and the Lesotho Highlands Water Scheme: A Partial Solution to the Country's Water Problems", *Water Resources Development*, 12(1), 1996.

58 JS Wright, "The Impact of Katse Dam Water on Water Quality in the Ash, Liebenbergsvlei and Wilge Rivers and the Vaal Dam", MSc dissertation in Environmental Management, Faculty of Science, University of Johannesburg, September 2006, p. 30.

59 RM Saleth & A Dinar, "Institutional changes in global water sector: trends, patterns, and implications", *Water Policy*, 2, 2000, pp. 175-199 & T Allan, " 'Virtual water': a long term solution for water short Middle Eastern economies?", Paper presented at the British Association Festival of Science, Roger Stevens Lecture Theatre, University of Leeds, 9 September 1997. Global renewable water resources include surface water and groundwater flowing from and between neighbouring countries or rivers that form the border between countries. Global water resources are that unused water accounted for as a resource in upstream and is again counted as a resource in downstream countries.

Between the nineteenth and the mid-twentieth centuries, irrigation engineers endeavoured to achieve irrigation technological innovation which, lamentably, has not been paralleled by similar efforts in the new millennium, particularly in enhancing food production in the more arid parts of South Africa, such as in the Northern Cape which thrives on fruit growing and tourism. Save for the limited computerisation of farming and the rather partial shift to micro or drip irrigation in isolated parts of the Republic, a lot needs to be done to counteract or offset conditions of aridity. It is true that in South Africa, economic growth and development is fundamentally constrained by water resource availability as the country has a low average annual precipitation of 480 mm.[60] Consequently, low-cost drip irrigation under conditions of water shortage is widely regarded as the most promising irrigation system.[61]

The demand for food and the increasing prospect that South Africa could run out of water by 2015, exposes the insufficiency of the "irrigation technological revolution" and the state's predominantly silent national policy on irrigation in the present era. Irrigation, which is the largest single water user in South Africa, therefore, provides a lot of hope to alleviate poverty by enormously boosting the country's food and grain reserves. On the whole, water is central to meeting the United Nations Millennium Development Goals (UNMDGs).[62] For instance, this resource can be harnessed to meet some developmental challenges, including reducing hunger and poverty especially in Africa, Latin America and Asia.

Indeed, UN poverty alleviation goals in the developing world will remain a pipe dream if the arid regions, not only of South Africa, but also of similarly affected areas are not brought to a level of irrigation technological advancement to produce sufficient food reserves in the face of fast encroaching aridity conditions.[63] However, it should be pointed out that this idyllic model has not been achieved anywhere in the world, but an attempt towards it should be

60 AR Turton et al, "Editorial: Setting the Scene - Hydropolitics and the Development of the South African Economy", *Water Resources Development*, 24(3), 2008, pp. 323–327.

61 L Karlberg et al, "Exploring potentials and constraints of low-cost drip irrigation with saline water in sub-Saharan Africa", *Physics & Chemistry of the Earth* - Parts A/B/C, 29(15/18), 2004, pp. 1035-1042.

62 One of the main targets of the MDGs adopted in 2000 was to cut in half the number of people suffering from hunger between 1990 and 2015. However, crop yield growth has slowed down in much of the world because of declining investments in agricultural research, irrigation, and rural infrastructure and increasing water scarcity. New challenges to food security are posed by accelerated climatic change. For detail on this see L Murari, "Implications of climate change in sustained agricultural productivity in South Asia", *Regional Environmental Change*, 16, 2010, p. 16.

63 For an elaborate discussion on water and poverty reduction see United Nations Development Programme (UNDP), *Water: A Key to Meeting the Millennium Development Goals* (New York, United Nations, 2004); UNDP, *Water Governance for Poverty Reduction* (New York, UNDP, 2004).

made. This theoretical model has not been achieved partly because of the wide geophysical differences found in the country and partly because of aridity. Arid conditions will probably be exacerbated by the phenomenon of global warming. In these circumstances, harnessing innovation opportunities in irrigation technology for using virtual water seems to be the ultimate answer for 21st Century South Africa.

Virtual water and wheat trade

In addressing global warming challenges South Africa could take a leaf from the experiences of Saudi Arabia with virtual water. A full discussion of Saudi Arabia is beyond the scope of this article. However, the learning curve for South Africa which by far is incommensurable with Saudi-Arabia in terms of demographics, historical trajectories and resources, including what virtual water and its relationship with technology entails, requires an understanding of what virtual water is. Since the 1990s, in response to climate change and water scarcity, South Africa has generated serious debate on water utilisation, management and sustainability. In southern Africa, from 1995 to 1999 South Africa had a net import of virtual water related to crop trade. For instance, in this period it had a gross virtual water export of 2558.3 compared to a net virtual water import of 4369.3 all of which were measured in 10^6 m^3 yr^1.[64] Bearing this in mind, the focus for South Africa is to build the country's capacity to become a net exporter of a relatively large amount of virtual water for its benefit and for the benefit of other water constrained economies. In the twenty-first century, the country is grappling with the idea of selling water as a commodity that can be listed on the stock exchange. This, in essence, amounts to privatisation of water.[65] Privatisation of water is linked to virtual water, which is a measure used to discern how much water is required to produce crops and indeed other goods and services locally - an extremely important concept in the Middle East.

The term "virtual water" is a concept that was formulated by Tony Allan. It refers to the volume of water needed to produce a commodity or service. For example, it typically takes 1 000 tons of water to produce one ton of wheat.

64 AY Hoekstra & PQ Hung, "Globalisation of water resources: international virtual water flows in relation to crop trade", *Global Environmental Change*, 15, 2005.

65 For a continental human rights-based perspective of privatisation of water and governance see O Olowu, "Privatisation and water governance in Africa: Implications of a rights-based approach", *TD: The Journal for Transdisciplinary Research in Southern Africa*, 4(1), July 2008, 59-93.

This represents the virtual water value of wheat. As such, it is easier and less ecologically destructive to import one ton of wheat than to pipe in 1 000 tons of water. In other words, water in the global trading system is known as "virtual water." It is the water embedded in key water-intensive commodities such as wheat. The international wheat trade, for example, is a very effective and highly subsidised global trading system which operates to the advantage of water and food deficit countries. Virtual water is also present in hydroelectric power and constitutes the volume of water needed to produce a given unit of hydroelectricity.[66]

All this supports the argument that, instead of using valuable local water to produce a crop like wheat under irrigation in arid regions like South Africa, it is economically sound to import wheat or virtual water.[67] The virtual water concept applies to all material items that can be produced using water. The idea is to attach a distinctive value to every commodity in the world. This is the virtual price of water. It should be pointed out that historically virtual water was developed precisely for the Middle East to comprehend how best to use available water resources, but if properly evaluated and monitored the same concept can be useful for the South Africa situation.

In agriculture, it is important to ascertain how much water is required to produce, for example, a kilogram of wheat or any other crop and, in the manufacturing sector, how much water is needed to procure a litre of tea, coffee or a bottle of beer. Indeed, economies that can import grain avoid having to mobilise scarce freshwater from their own resource base to produce

66 Elaborate descriptions of virtual water can be gleaned from T Allan, *'Virtual Water': A long term solution for water short Middle Eastern Economies?* (London, SOAS, 1997), pp. 1-20; AR Turton, A Strategic Decision-Makers Guide to Virtual Water, African Water Issues Research Unit (AWIRU) and the Center for International Political Studies (CIPS), University of Pretoria, (available at: http://www.plinklet.nl/bibliographies/water/files/4643.pdf), as accessed on 14 December 2009; AR Turton, "The Hydropolitics of Southern Africa: The Case of the Zambezi River Basin as an Area of Potential Co-operation Based on Allan's Concept of Virtual Water", Unpublished MA Dissertation, Pretoria: Department of Political Science, University of South Africa (UNISA), 1998, pp. 7-8; AR Turton, "Precipitation, People, Pipelines and Power in Southern Africa: Towards a 'Virtual Water'-based Political Ecology Discourse", P Stott & S Sullivan (eds.), *Political Ecology: Science, Myth and Power* (London, Oxford University Press), 2000(a), p. 145.

67 A Earle and AR Turton, "The virtual water trade amongst countries of the SADC", AY Hoekstra (ed.), *Virtual Water Trade: Proceedings of the International Expert Meeting on Virtual Water Trade - Value of Water Research Report*, Series No. 12, IHE Delft: February 2003, pp. 183-200; AR Turton, A Strategic Decision-Makers Guide to Virtual Water, African Water Issues Research Unit (AWIRU) and the Center for International Political Studies (CIPS), University of Pretoria, (available at: http://www.plinklet.nl/bibliographies/water/files/4643.pdf), as accessed on 14 December 2009.

wheat themselves.[68] For instance, by the year 2000, the Middle East and North Africa were importing 50 million tons of grain annually, satisfying the largest demand for water in the region which represented 80% of total food production.[69] It is hoped that the remaining 20% of water demand for drinking, domestic and industrial use will be met through low-cost desalinated sea water.[70]

Determining water use by its virtual value, thus, takes into cognisance the fact that this precious resource is not only seasonal but finite. In South Africa, the fluctuating seasons characterised by rain and at other times lack of rain are exacerbated by the phenomenon of global warming. Under conditions of global warming, it is difficult for people to cope with these fluctuations. On this basis, a more informed perspective that looks at water as a flux can therefore be developed. All this calls for the application of proven irrigation techniques which include, but are not exclusively based on virtual water.

Possible solutions: New and proven irrigation techniques

New irrigation techniques in agriculture are an essential solution in the new millennium. In the twenty-first century, there has been a general shift in South Africa towards sophisticated systems of irrigation by farms producing for the export market. Such farms are optimalised in distributing water. On many farms in Upington, for example, irrigation has been computerised. This is, however, very expensive especially if the farm is producing crops which are not profitable. Studies carried out in the Eastern Free State have shown that some farmers are irrigating maize and wheat to achieve food security along

68 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002, pp. 255-272. In South Africa, the importation of maize and wheat from abroad can be avoided if farmers are properly capacitated to feed the nation; MSOA, Interview: J Nel (49), Reitz, 2009.04.28 and NMOA, Interview: J Nel (49), Reitz, 2009.04.28 in M Ginster, C Gouws, CM Gouws, H Mäki, R Mathipa, S Motloung, M Nyandoro, & JWN Tempelhoff, "The problem of irrigation from Lesotho Highlands water in the Axle and Liebenbergsvlei river catchment, Eastern Free State", *Report 1/2009, Version 2.10*, (CuDyWat, NWU, Vanderbijlpark), 26 August 2009; M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010.

69 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002.

70 JA Allan, "Hydro-Peace in the Middle East: Why no Water Wars? A Case Study of the Jordan River Basin", *SAIS Review*, 22(2), July 2002.

the Liebenbergsvlei River. This is, however, counterproductive.[71] It seems they merely push up production to achieve individual profit and national or general food security.[72] However, as the LBVR study has proven, it is a waste of valuable water. The result is lack of sustainability. In the main, though, the farmers themselves are monitoring the situation better than the government.

Research by Backeberg of the Water Research Commission (WRC) and Reinders of the Agricultural Research Council (ARC) further reveals the effort South Africa has been putting into new irrigation techniques since the turn of the new millennium in order to revolutionise farming.[73] In light of the aridity and decline in water availability for irrigation, South Africa has adopted new techniques to use irrigation water more efficiently and in a sustainable way. The country is no longer heavily relying on the centre-pivots as was the case previously. It is moving away from centre-pivots and canal irrigation technology in preference for other techniques such as drip irrigation that help save water in conditions of aridity. The surface and sub-surface drip irrigation system is certainly the most efficient method in terms of crops produced per volume of water used. Higher capital investments and higher levels of management competencies for successful operation are, however, required for drip irrigation. This method can experience problems if poor quality water (wastewater and mine contaminated water) is used and if poor maintenance management practices are followed.

The movement towards more efficient techniques has been particularly brisk after 2000. On-going trends in the modernisation of irrigation technology in South Africa should be applauded. For instance, since the 1990s gradual shifts have taken place away from less efficient flood or surface irrigation to more efficient micro and drip irrigation methods in light of water scarcity in South Africa.[74] The most important methods adopted by 1990 were flood irrigation on 32,8% of the total area, sprinkler irrigation on 54,4% of the area

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71 TJOA, Interview: F Joubert (43), (GIS expert on Liebenbergsvlei River water), Schoeman & Vennote, consulting engineers to the DWA, Brits, 2009.05.12 in M Ginster, C Gouws, CM Gouws, H Maki, R Mathipa, S Motloung, M Nyandoro & JWN Tempelhoff, "Views on unlawful water abstractions along the Liebenbergsvlei River, South Africa," *TD: The Journal for Transdisciplinary Research in Southern Africa*, 6(1), July 2010, p. 7.

72 For more detail on food security see D Love, S Twomlow & W Mupangwa, "Implementing the millennium development food security goals - Challenges of the southern African context", P*hysics and Chemistry of the Earth*, Parts A/B/C; 31(15/16), January 2006, pp. 731-737.

73 GR Backeberg and FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 3.

74 RM Armitage, WL Nieuwoudt & GR Backeberg, "Establishing tradable water rights: Case studies of two irrigation districts in South Africa", *Water SA*, 25(3), July 1999, pp. 301-310.

and micro/drip irrigation on 11,8% of the area.[75] However, in a subsequent WRC survey conducted in 1999, it was found that the relative importance of these methods of irrigation had changed, with flood irrigation constituting 28,5%, non-mechanised and mechanised sprinkler irrigation at 53% and micro irrigation (including drip irrigation) rose to 18,5%.[76] By 2008 these figures had changed further to 14,4%, 54,9% and 21,8% respectively.[77] Thus, in an 18-year period (from 1990 to 2008), the area under micro and drip irrigation had therefore more than doubled from 152 235 ha to 365 342 ha.[78] According to technical efficiency standards, on-field application efficiency can be increased by as much as 30% when changing from flood or surface irrigation to micro or drip irrigation. For Reinders, the technical efficiency levels that are realistically achievable range from 55-65% for flood irrigation, 70-85% for sprinkler irrigation and 85-95% for micro irrigation. [79]This illustrates an increasing trend in the adoption of the latter method. According to Backeberg and Reinders, inefficient water use in commercial irrigated agriculture is therefore a baneful phenomenon which should be addressed as a matter of priority.[80]

75 GR Backeberg, TJ Bembridge, ATP Groenewald, JA Hammes, PS Pullen, RA & H Thompson, *Policy Proposals for Irrigated Agriculture in South Africa* (Discussion document, WRC Report No. KV96/96, Pretoria, 1996), p. 29.

76 RJ Stirzaker, "When to turn the water off: scheduling micro-irrigation with a wetting front detector", *Irrigation Science*, 22, 2003, pp. 177-185 & GR Backeberg, "Water usage and irrigation policy", L Nieuwoudt & J Groenewald (eds.), *The Challenge of Change: Agriculture, Land and the South African Economy* (Pietermaritzburg, University of Natal Press, 2003), p. 151.

77 I van der Stoep, FJ du Plessis & A Pott, *Interim Report on Preparatory Workshops and Final Questionnaire*, Deliverable 2, *WRC Project,* No. K5/1778/4 on Awareness Creation, Implementation Plans and Guidelines for Management of Sustainable On-Farm and On-Scheme Water Measurement, Pretoria: WRC, 2008, 6-7; GR Backeberg & FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 3.

78 GR Backeberg and FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 3.

79 FB Reinders, "Irrigation Systems", Agring, 10, Silverton, Pretoria, 1992; GR Backeberg & FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 3. In dry areas water harvesting and supplemental *irrigation* can be used for improved water productivity. On water harvesting see O Theib & H Ahmed, "Water harvesting and supplemental *irrigation* for improved water productivity of dry farming systems in West Asia and North Africa", *Agricultural Water Management*, 80(1/3), 2006, pp. 57-73.

80 GR Backeberg & FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 1.

Conclusion

Giving priority to more modern irrigation techniques as well as addressing the threats posed by water, mining and air pollution in the arid world is thus of strategic significance in a water-constrained country with a strong agricultural, industrial and mining economy like South Africa. The emphasis is on eliminating all forms of pollution or effluence and developing new technologies that are consistent with worsening aridity in the wake of clear global climate change.[81] In other words, there is an urgent need to save or conserve a limited resource such as water by upgrading to better irrigation technology over the next 10 to 20 years.[82] Since the philosophy of drip irrigation in most cases is to supply water "little and often", - a conservationist ethos – it is vital to note that "when to turn the water on" is not the crucial question, but knowing when to turn the water off is more important.[83] It can be noted that the NWA of 1998 does not make provision for water conservation (WC) and demand management (DM). WC and DM "relate(s) to the efficient and effective use of water and the minimization of loss and wastage of water."[84] Such a focus will help grow the entire South African economy and attempts to find alternative technological breakthroughs are directly linked to this rationale.

The acute lack of water, including the lack of appropriate technology in an arid environment, is definitely a limiting factor to future economic growth in the country if not in the whole SADC region. In this regard, the government, industry and other stakeholders should initiate new irrigation technology as a strategic-level dry area security issue. Wastewater problems should also be addressed. Indeed, there could be limited policy options for a water-stressed state such as South Africa, but for the country it is imperative to quickly get into a post-apartheid development mode and conceptualise a new approach to irrigation knowledge, which includes virtual water innovations in line with

81 DJH Phillips et al., "The TWO Analysis - Introducing a Methodology for the Transboundary Waters Opportunity Analysis", *Stockholm International Water Institute (SIWI) Report*, 23, 2008, pp. 1-36; AR Turton, Environmental Security: A Southern African Perspective on Transboundary Water Resource Management in *Environmental Change and Security Project Report*, 9, 2003.

82 RJ Stirzaker, PA Hutchinson, ML Mosena, "A new way for small farm irrigators to save water" in Proceedings of the sixth International micro-irrigation congress, Cape Town: South African National Association of Irrigation and Drainage, 23-26 October 2000, pp. 1-10; GR Backeberg & FB Reinders, "Institutional Reform and Modernisation of Irrigation Systems in South Africa", Paper presented at the 5th Asian Regional Conference of ICID held in New Delhi, India, 9-11 December 2009, p. 1.

83 RJ Stirzaker, "When to turn the water off: scheduling micro-irrigation with a wetting front detector", *Irrigation Science*, 22, 2003.

84 DWAF, *National Water Resource Strategy, First Edition* (Pretoria, 2004), pp. 78-80.

what Saudi Arabia is doing. Government hesitancy should be eliminated and once appropriate and affordable technology is designed, vast expanses of South Africa can be opened up for dry-land irrigation in a country where water is perceived as the factor of production in short supply.[85] On this basis, therefore, innovation opportunities in irrigation technology and the prospects for utilising and implementing the virtual water concept, including reflecting on how the past of irrigation development can be used to inform the present assist in addressing the full gamut of water-related complexities in South Africa.

85 A Earle & AR Turton, "The virtual water trade amongst countries of the SADC", AY Hoekstra (ed.), *Virtual Water Trade*, February 2003, pp. 183-200.