THE IMPACTS OF MINING LEGACY IN A WATER-SCARCE SOUTH AFRICA:

AN ENVIRONMENTAL SECURITY PERSPECTIVE

by
Thomas M. Hanlon

RESEARCH PAPER
Submitted to
THE DEPARTMENT OF GEOSCIENCES

In partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE
GEOGRAPHY PROGRAM

June 1, 2010

Directed by
Dr. Aaron T. Wolf

Disclaimer

Funded by the Institute of National Security Studies at the United States Air Force Academy, this case study analyzes an environmental security issue regarding contamination of strategic water supplies resulting in South Africa as a result from mining byproduct. This project is written from the angle of a United States foreign affairs venture as this country seeks to define its global leadership role in a future beset with chronic water scarcity and increasingly complex environmental security issues abroad, mainly in the developing world where extreme poverty is pervasive and the institutional capacity is very low. Particular attention is given to the general environmental security role of US Africa Command. Any recommendations or positions asserted herein reflect only those of the author and not necessarily those of the US military or faculty of Oregon State University.

Abstract

Key Terms: South Africa, AFRICOM, Water Crisis, Acid Mine Drainage, Minerals, Gold Mining, Coal Mining, Resilience, Social-ecological systems, Thresholds, Water Security, Environmental Security

---

Given the growing human security implications resulting from the high rates of change in social-ecological systems, the general question motivating this research is: **how can the traditional security establishment respond to rising non-traditional threats?** This question comes from the ongoing debate of whether military resources should be used in some way to prevent conditions of social instability by assisting in stabilizing environmental decline? The Establishment of United States Africa Command (AFRICOM) in 2008 underscored the change of direction in US policy towards the African continent that began earlier in the decade. The command's unique interagency structure departs from the Napoleonic battle-staff structure typical of other regional commands organized for strategic military campaigns. This paradigm shift signifies the greater security paradigm shift of the contemporary post Cold War era where deteriorating *conditions* such as poverty, energy crisis, disease, and environmental degradation are now recognized as the modern enemies of humanity. This notion fuels the ongoing debate about AFRICOM's mission on the continent. Given the growing linkages of environmental degradation to socioeconomic decay and conflict, how could AFRICOM play a hand in non-traditional missions of improving environmental security in Africa where these linkages are most evident? This question is further reduced to a specific case study where an ongoing environmental crisis is occurring in South Africa – the geographic southern tip of the continent but economic center of gravity. The growing water crisis clashes with a century of mining legacy that places water security at grave risk in that nation as well as future prospects for growth and stability. The specific questions analyzed in this project are: **How does mining byproduct (acid mine drainage) impact water security in this nation of increasing water scarcity? Does the institution have the capacity to absorb the change that this environmental disturbance can potentially bring? How could AFRICOM improve the environmental security in this particular scenario?** Data was collected through field visits to problem areas and numerous engagements with stakeholders and interested academic parties to assess the threat to the "triple bottom line". Guided by *resilience theory*, it steps out of the water sector in a whole-systems approach to understand how other converging institutional stresses such as crime, massive skills exodus, and HIV/AIDS are severely increasing the complexity of the nation and draining precious energy away from the institution needed to repel the water crisis. AFRICOM can make a positive contribution to this imminent environmental security crisis through technology sharing, capacity building, and increased partnerships among the many various actors in its area of activity. Most importantly, it can do this transparently in accordance with both the Secretary of Defense's and Commander's intent.

The Impacts of Mining Legacy in a Water-Scarce South Africa:

An environmental security perspective

Abstract **pg 3**

Acknowledgements **pg 6**

Section I Introduction: **pg 7**

1.1 The Centrality of Water………………………………………………………………………………………………… pg 7

1.2 Research Questions…… pg 8

1.3 Case Study Background: Water, Mining, and the Paradox of Economic Development……………… pg 8

1.4 Justification: Why South Africa for this Case Study?... pg 13

1.5 Project Goals and Methods……………………………………………………………………………………………… pg 13

Section II Theory: Resilience, Thermodynamics, and Tectonic Stress **pg 15**

2.1 Environmental Security and “Water Wars”……………………………………………………………………… pg 15

2.2 Resilience……… pg 17

2.2.1 Adaptive Cycles……………………………………………………………………………………………… pg 17

2.2.2 Thresholds……………………………………………………………………………………………………… pg 20

2.3 Thermodynamics and Society……………………………………………………………………………………… pg 22

2.4 “Tectonic Stress”……………………………………………………………………………………………………… pg 24

Section III The Mining Legacy: **pg 25**

3.1 A Historical Brief: Socioeconomic and Demographic Outcomes……………………………………… pg 25

3.1.1: Colonialism and Geopolitics…………………………………………………………………………… pg 25

3.1.2: The Demographic Shift of the Native Population……………………………………………… pg 25

3.1.3: Seeds of Apartheid………………………………………………………………………………………… pg 26

3.2 The Environmental Legacy……………………………………………………………………………………… pg 26

3.2.1: AMD in the Famed Goldfields of the Witwatersrand……………………………………… pg 26

3.2.2: Decant in the West Rand……………………………………………………………………………… pg 29

3.2.3: Imminent Decant in the East and Central Basin………………………………………………… pg 33

3.2.4: AMD in the Highveld Coal Seams…………………………………………………………………… pg 35

3.2.5: Corporate Accountability and Loose Regulation………………………………………………… pg 36

3.2.6: AMD Reclamation and the Irony of Cheap Water……………………………………………… pg 37

3.2.7: Section Summary……………………………………………………………………………………………… pg 38

Section IV Complexity, Converging Stressors, and Resilience to the South African Institution pg 38

4.1 Water Security……. pg 39

4.1.1 Water Quantity: The Challenge of Developing in a High and Dry Place……………………. pg 39

4.1.1.1 The Arid Climate…………………………………………………………………………………. pg 39

4.1.1.2 Colonial Geography and the "Hard Path" of Water Security……………………. pg 41

4.1.2 Water Quality: The Revenge Effects.…………………………………………………………………. pg 44

4.1.2.1 Dilution Capacity…………………………………………………………………………………. pg 45

4.1.2.2 Industrial Waste and Algal Blooms…………………………………………………………. pg 45

4.1.2.3 Municipal Sanitation and Pathogens………………………………………………………. pg 47

4.1.2.4 Transboundary Effects…………………………………………………………………………. pg 47

4.1.3 Climate Change…………………………………………………………………………………………………. pg 48

4.2 Energy Security………. pg 48

4.2.1 Load Shedding…………………………………………………………………………………………………. pg 48

4.2.2 South African Coal: The Give and Take of Energy……………………………………………………. pg 49

4.3 Socioeconomic Security: Governance, Demographics, Stress, and Economic Shock…………………… pg 51

4.3.1 Post Mandela Era and Black Economic Empowerment: Is Affirmative Action Working? pg 51

4.3.2 Civil Unrest: Tectonic Foreshocks?... pg 52

4.3.2 Income Disparity……………………………………………………………………………………………….. pg 53

4.3.3 Impacts of Crime……………………………………………………………………………………………….. pg 54

4.3.4 Flight of Ingenuity……………………………………………………………………………………………... pg 55

4.3.5 HIV / AIDS……………………………………………………………………………………………………….. pg 56

4.3.6 Section Summary………………………………………………………………………………………………. pg 57

Section V: United States Foreign Policy on Environmental Security: Policy Options pg 58

5.1 Environmental Security in the National Security Strategy: A Priority?…………………………………. pg 58

5.2 Policy Recommendations: United States Africa Command on Environmental Security………………… pg 59

Section VI. Conclusion pg 65

Bibliography pg 68

Endnotes pg 71

*** * * Acknowledgements * * ***

These past two years at Oregon State University have been a unique and privileged experience in the midst of an active duty Army career that has taken me on a journey across the world and back again; from the neck-deep swamps of Florida and Georgia to the Sinai Desert; through the ethnically divided mahalas of Kosovo to the war-rubbled streets of Ramadi, Iraq and to the rugged Hindu Kush mountains of the Kunar Province in Afghanistan. As a fan of geography, I have kept my eyes open on the people and the landscape each step of the journey trying to take it all in. Peace and conflict have always been separated by only the finest of lines in the dynamic world I have seen. While this experience offered great challenge, it also offered reprieve.

First and foremost, I owe my deepest gratitude to my wife Liz who has been with me from the beginning; holding the fort while I'm gone (and when I'm not), sharing and supporting the decisions along the way, pulling the weight in raising our two children, Kat and Will… and through it all, demonstrating an uncommon and extraordinary level of patience in me.

I'm very thankful to the United States Army for this academic opportunity – specifically Colonel Laurel Hummel and the Geography faculty at the United States Military Academy at West Point who faithfully endorsed my application to serve at that historical symbol of our country perched along the Hudson. I look forward to getting back in uniform and joining that team and instructing the next generation in "The Long Gray Line".

I was especially privileged to be mentored by my advisor Dr Aaron Wolf during this academic endeavor. A world renowned water and conflict resolution expert, he was instrumental in helping me find my way and staying on my heading. Dr Dan Henk from the United States Air Force Air University, Dr Kent Butts from the Strategic Studies Institute at the Army War College each provided initial guidance that proved to be extremely helpful. Steve Hearne from the Army Environmental Policy Institute in Washington, D.C. along with Jim Smith from the Institute of National Security Studies at the United States Air Force Academy were crucial in backing my funding for my research in South Africa. I am also thankful for two of my professors, Dr Bryan Tilt and Dr Larry Becker for serving on my committee.

The most memorable experience during this endeavor bar none was the opportunity to stay with Dr. Anthony Turton and his lovely wife Ansie. Dr Turton, a proud 12^{th} generation South African, is intimately connected to the rich history of his country. A most colorful character, he is a combat veteran from the conflict in Angola and continues to serve his country in their struggle to achieve water security. Aside from sharing sanctuary and wholesome food for several weeks, he shared many of his experiences with an unforgettable passion – truly a life experience for me to see his country through the soul of someone so connected to its history and its future. I felt like family throughout my stay. Dr Turton led me to the proverbial well of this research and I am deeply grateful. I met many wonderful people in South Africa who were willing and helpful; Mariette Liefferink, an outspoken environmental and human rights advocate nicknamed the "Erin Brokovich" of South Africa, Adam Welz, a free-lance journalist, Stephan DuToit, a game reserve manager, Dr. Terence McCarthy, a Geochemist at University of Witwatersrand, and numerous others there who helped me along. What a beautiful and intriguing part of this world – I hope to return one day soon!

And finally, I am indebted to my father and to my peers Chevelle and Jeff who provided critical comments to early draft work in this process. Thank you all!

-- Major Tom

* * * * *

I. Introduction

1.1. The Centrality of Water

> *"Among the many things that I learnt as president was the centrality of water in the social, political and economic affairs of the country, the continent and the world."*
> *-- Nelson Mandela, World Summit on Sustainable Development, Johannesburg 2002*

Fundamental to a society functioning, prospering, and enduring is its ability to harness and sustain the flux of freshwater resources available to that society. No level of human advancement can exceed the central role of water for there can be no substitute for this vital resource. Remnants of ancient and sophisticated hydraulic infrastructure from fallen empires still evident today are testimony to society's quest for water over the ages. Aqueducts still standing in southern Europe attest to Roman hydraulic engineering feats, transferring water from distant basins to nourish its imperial cities and surrounding agricultural fields. Dams, weirs, canals and reservoirs were all critical to the development of the Mayans of Mesoamerica, the Babylonians of Mesopotamia, the Khmer kingdoms of southeast Asia and myriad others whom no longer exist (Tainter 1988), (Diamond 2005), (Stone 2009). Many researchers link the collapse of these once powerful and enduring societies to some varying form of hydraulic stress and the inability of their respective institutions to absorb the change (ibid). Water scarcity alone however does not bring an advanced society to its demise or dissolution. This occurs only when multiple stressors converge simultaneously to tip the balance beyond the threshold where the result is an entirely different regime altogether, a tenet of resilience theory (Holling 1973, Homer-Dixon 2006).

Societies at every scale are part of complex adaptive systems that include the human component and all biophysical components within the system. As conditions inevitably change, the system will adapt its functions accordingly. The human - environment systems for which we are all part are referred to as social-ecological systems (SES). When a SES exceeds its capacity to absorb change as all complex adaptive systems eventually do, it undergoes a potentially irreversible regime shift or chaotic reorganization. What follows is either a transformative renewal of the system or an alternative state of conditions - conditions that, by comparison, are undesirable and may persist indefinitely which present security challenges.

As earth-systems have changed more in the last century than the previous 19 centuries combined, we should expect more SESs to succumb to radical change as they exceed their resilience and cross thresholds (Dodds 2005). In this century, climatic and demographic stresses are projected to have vastly uneven impacts worldwide. A wide swath of nations from Africa through India to northern China are approaching chronic water scarcity in the next two decades – a level defined by severe economic constraints to the respective society (FAO 2010).[1] This will create the potential for social instability when expectations of populations demanding basic services exceed the capabilities of their governments to deliver (Turton 2009a). From the perspective of United States foreign policy, this requires a more comprehensive understanding of the complexity and fragility within the societies of these affected areas in order to properly posture within the "3 D's" of foreign policy: *diplomacy, development,* and *defense.*[2]

1.2. Research Questions

Given the growing human security implications resulting from the high rates of change in social-ecological systems, the general question motivating this research is: **how can the traditional security establishment respond to rising non-traditional threats?** This question comes from the ongoing debate of whether military resources should be used in some way to prevent conditions of social instability by assisting in stabilizing environmental decline? The recent establishment of the United States Department of Defense's (DOD) newest regional command, Africa Command (AFRICOM), stimulates this debate given the especially precarious state of development throughout the continent.

This research proceeded as a special case study focusing on a specific environmental security threat occurring within AFRICOM's unique regional area of activity. To clarify, multiple working definitions for the broad concept of environmental security have been proposed by various institutions. Applied in this research is the one that is simplest and shortest: *"… the freedom from social instability due to degraded environmental conditions"* (Glenn 1998).[3] Here, water security is examined as a special case study in South Africa with the focus on byproduct from mining activity as a compelling environmental "tipping point" toward destabilizing a potentially delicate balance of State security in Africa's most developed country. A detailed understanding of a specific problem and its greater security implications is critical. This research proceeded under the following questions: **How does mining impact water security in a water-scarce South Africa? Is the institutional capacity within South Africa sufficiently resilient to absorb this type of environmental disturbance?** Finally, possibilities for AFRICOM expanding beyond traditional expeditionary roles in its region are considered in the wrap-up question: **How can AFRICOM be used to increase environmental security in this case study scenario?**

1.3. Case Study Background: Water, Mining, and the Paradox of Economic Development

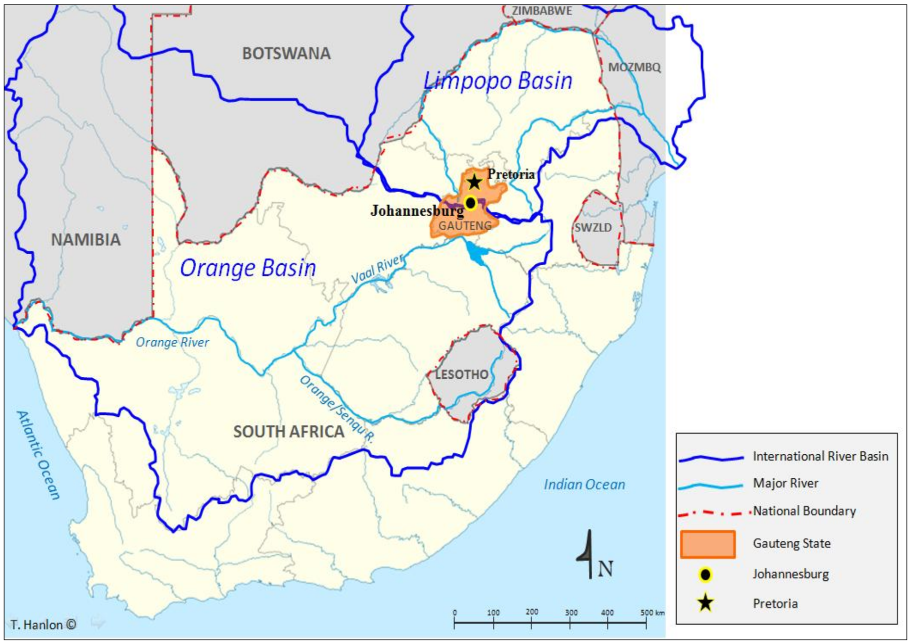
Largely due to its extraordinary mineral wealth, South Africa stands alone as the most developed state on a continent lagging far behind the rest of the world in development. Though endowed with the greatest diversity of minerals in the world, it is the famed prolific gold mines of the Witwatersrand Goldfields in the Johannesburg region, which historically comprised the majority of the minerals sector in its integral role of South Africa's path to economic development (COM 2010). Paradoxically, gold mining's environmental legacy along with the resurgence of coal mining threatens the future development of a country where mineral extraction, water security, and energy security clash. The legacy of over 100 years of virtually unregulated mining have created what several scientists in South Africa are calling "*the* most significant environmental threat to ever face this country" – the human-triggered geochemical process known as acid mine drainage (AMD) (McCarthy 2009b). AMD, an especially virulent and costly type of pollution, threatens strategic supplies of water in the economic heartland of a country built upon its mines.

South Africa is a frontline nation in the global water crisis. Currently considered "water-stressed," it is projected to become "water-scarce" by 2025, although several critical river basins have already reached this threshold metrically demarcated at $1000m^3$ per capita annually (UNEP 2008).[1] As an arid nation, South Africa relies heavily on the large "heroic" engineering projects of the 20^{th} century to secure strategic water supplies to support industrial demands (Heyns 2002). Per river kilometer, it is among the most densely dammed nations on earth and employs multiple inter-basin water transfer schemes to artificially shift bulk water supplies toward the greater demand (WCD 2000). The Lesotho Highlands Water Project, which diverts critical water supplies to the parched and burgeoning Johannesburg, is the largest hydraulic infrastructural project in Africa (IRN 2009). At a larger timescale these so-called "hard path" or supply-side mechanisms can only be considered stop-gap in an arid society where socioeconomic, demographic, and regional pressures have grown considerably over time, pushing the limits on the water supply.[4] Based on now ageing data from 1998, 98 percent of the national resource is appropriated with some sub-basins over-allocating up to 150 percent, thus severely limiting room for future economic growth (Turton 2008d). Future opportunities for conventional heroic projects of diverting and storing surface water supplies have been geographically exhausted in the country in terms of economic viability as costs vs. benefit margins shrink to zero. Creating "new water" will require more innovative ways to secure supply, notably groundwater but will also require increasing reliance on "soft path" solutions – ones that favor greater efficiencies in demand (Turton 2009a). As important as water *quantity* is water *quality*. Securing new water will require more water reclamation from mining byproduct and other industrial activity (ibid).

AMD is a byproduct of mining operations where the presence of iron sulfides exists in the ore. This is especially common in gold and coal settings where pyrite typically co-occurs. When sulfur-bearing minerals come into contact with water and air the result is sulfuric acid with a pH of 2.5 to 4.0, the equivalent of vinegar or lemon juice (Hobbes 2009a). AMD contamination is devastating to stakeholders and aquatic ecosystems. AMD contamination renders water resources highly acidic and heavily polluted with toxic metals such as arsenic, mercury, nickel, iron, manganese, aluminum, and uranium. Where uranium is present, the toxic water carries unstable radionuclides. Additionally, AMD is laden with high dissolved salt load, which increases salinity in the water often beyond consumable levels (McCarthy 2009c, Coetzee 2004).

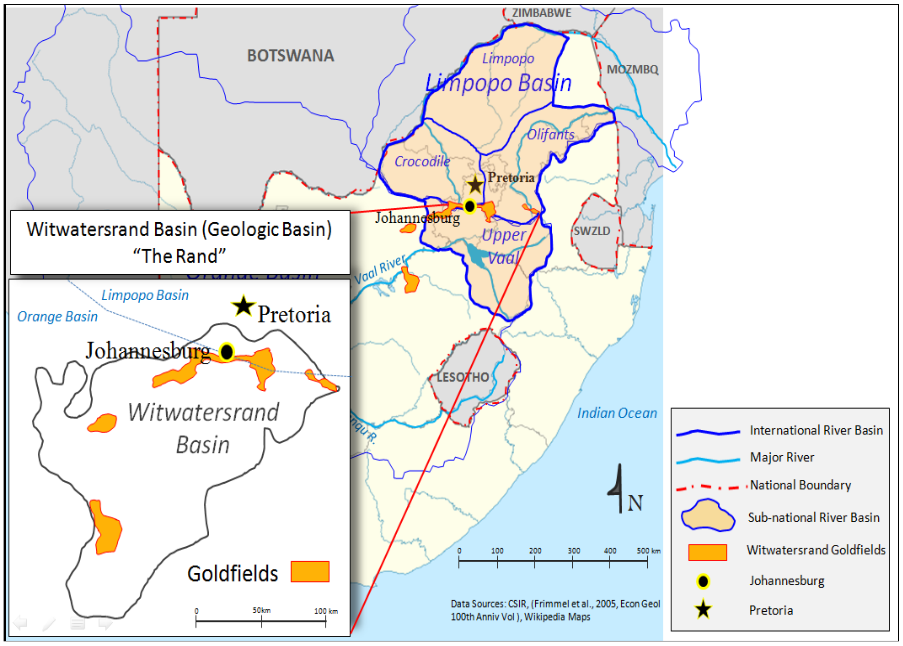
Left unchecked, by 2014 the potential for AMD contamination in the Witwatersrand Basin, the economic heartland of the country, will reach an estimated daily decant rate of 350 Megaliters (Ml) per day into the watershed, an equivalent of approximately 140 Olympic-sized swimming pools (DME 2009b). 350Ml is 10 percent of the entire daily consumption of water in the Witwatersrand provided by Rand Water (Turton 2009b), the parastatal water utility provider to Johannesburg. AMD contamination, though a constant presence throughout the active phase of mining, **is most problematic when mines reach their closure**. The defunct mine voids refill with oxygenated water triggering the acidification process. Liability is elusive. Reclamation is costly, in many cases perpetual, and in certain settings will eventually exceed the economic value of the culpable mining operation - the hidden costs outweigh the benefits (Adler 2007). Therefore, the costs are externalized to the tax payers (Turton 2009a).

AMD is a major challenge in mining operations throughout the world. Multiple superfund sites within the United States are the legacy of AMD byproduct. The estimated AMD reclamation costs in Pennsylvania's Monongahela and Allegheny River basins alone exceeds USD 15 Billion leaving over 3,000 miles of western Pennsylvania waterways badly contaminated (Sams III 2000). However, given South Africa's particular geography and delicate politics, there is little if any buffer for the state to isolate this environmental problem. Future development and human security could be substantially threatened from cascading effects generated by this process. South Africa is an especially complex country where significant water and energy challenges exist while pressures from various simultaneous converging stressors are constraining its governing institutions.

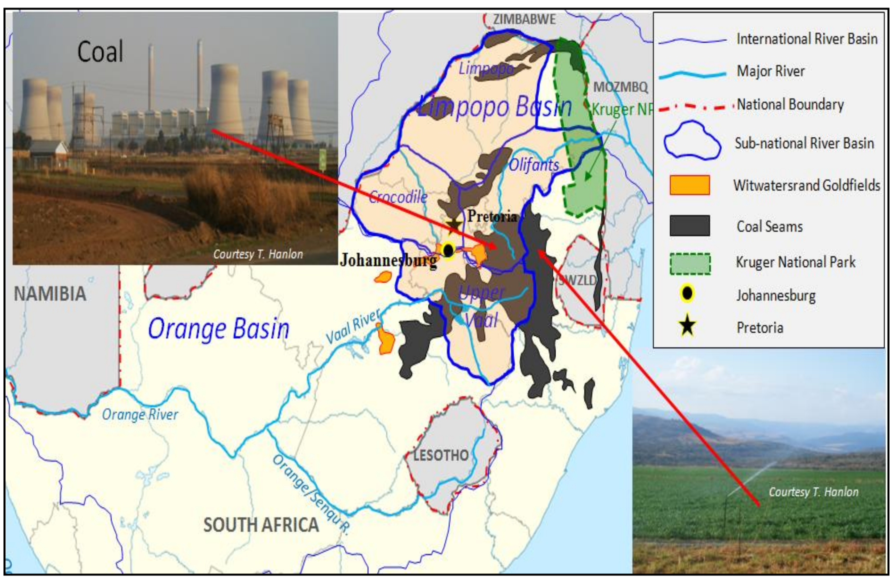


Map 1. South Africa is the upstream riparian to three international strategic basins, the Limpopo and Orange Basins. The Gauteng Province (shaded in orange) is the economic hub of the country with Johannesburg and Pretoria contained within this small geographic area. It is situated geographically on the basin divide. Data Sources: CSIR, DWAF, DME, Wikimaps for blank map.

Map 2. Consequently, the majority of economic activity occurs within four sub-basins or tributaries, the Limpopo, Crocodile, Olifants, and Upper Vaal. The Vaal Dam is the primary source of water for Johannesburg's 10 million people.



Map 3. The Witwatersrand Goldfields are the most prolific goldfields in the world. Johannesburg is situated on this gold reef.



Map 4. South Africa is the ranked 3rd in the world for coal exports. The coal seams are exploited east of Johannesburg in the Mpumalanga Province, the powerhouse of the country. This is also where the country's most productive agricultural zones are.

1.4. Justification: Why South Africa for this Case Study?

South Africa is of special significance for several reasons: First, it is a regional anchor or pivot state. It is the number one foreign capital exporter to Africa exceeding the United Kingdom, United States, France, and China (Tayob 2010). It generates one quarter of the GDP for all of Africa, provides over 60 percent of the power supply to southern Africa, and serves as a linchpin toward economic development in the southern African sub-region – a subregion that just enjoyed its first conflict-free decade in modern history after protracted civil wars in Angola and Mozambique arrested any hopes for development in those afflicted states (DIRC 2010). The onset of peace in the region facilitated various rates of growth throughout the region, though Zimbabwe's collapsed economy under dictator Robert Mugabe's regime remains the exception (IMF 2010). A slowdown in South Africa would have regional effects and undermine global efforts of developing this beleaguered region achieve the Millennium Development Goals (Ohlsson 1995).

Second, South Africa is an important connection to the greater global trade network. It hosts the largest reserves of much of the worlds strategic and economic minerals (Anderson 1998). Like the emerging economies of Brazil, Russia, India, and China, or "BRIC" as this group is commonly referred in the global economy, South Africa is also considered a major emerging economy though its rate of development is significantly slower than BRIC nations (IMF 2010).

Finally, the nation symbolizes the tenets of democracy. The "Rainbow Nation" as former President Nelson Mandela nicknamed it for its extraordinary diversity, is still a fledgling democracy. Since the globally celebrated abolishment of the Apartheid era in 1994, the nation was reformed into virtually a brand new country with a new flag, a new constitution, and new opportunity. Yet, tension, mistrust, and uncertainty remain about the common future. As converging stresses are building beneath the surface of the social and political institutions of South Africa, these institutions become *increasingly complex* and conversely *less resilient* to shocks, a central concept to be discussed in the next section. This should be of concern to security observers and foreign policy makers charged with properly posturing for the contemporary threats of the 21st century.

1.4. Project Goals and Methods

Within the context of institutional *resilience*, this research emphasized mining product as a potential "tipping point" to maintaining water security and consequently destabilizing. Far-fetched? Considered separately, mining byproduct would likely seem inconsequential to anything larger than local scales. However, taken wholly through a "systems approach" where multiple geographical, political, and social causal linkages are considered, the significance at greater scales becomes manifest.

The goal of this research was two-fold. The first goal was to illuminate the linkage of an environmental security issue to the potential of significantly disrupting State security and consequently regional development by considering multiple influencing factors. Second, it was to frame the issue from the perspective of United States foreign policy matters of environmental security and offer plausible recommendations of its newest regional command, United States Africa Command, to improve security while improving foreign relations.

To answer the general question, this research project reduced the question into a case study of an acute environmental security issue lending to the more specific questions. Answering the case study question regarding the impact of mining byproduct to water security in South Africa required extensive understanding of the overall state of water security relative to the country as well as the specific process of mining byproduct generation. This project included a three week visit to Johannesburg, South Africa to collect data from various resources. Several problem areas were visited on Johannesburg's "West Rand" and "Far West Rand" of the Witwatersrand Goldfields where AMD directly enters the watershed and impacts the environment and socio-economic livelihoods. Environmental water quality data was gathered from the records of a game reserve downstream of the West Rand decant and compared against acceptable environmental levels published by South Africa's various government agencies. Semi-structured and open-ended interviews were conducted with affected stakeholders and interested parties including mining house representatives, affected stakeholders, professional university and government affiliated academics, environmental and reclamation engineers, the United States Minerals Attaché to South Africa, the United States Defense Attaché to South Africa, and a NGO environmental advocacy.[5] Three public-participation events hosted by mining houses addressing socio-economic challenges were attended. The various forms of data were compiled and analyzed using GIS techniques to form a qualitative spatial analysis of how the gold and coal footprints overlap with the important watersheds determined by economic activity, agriculture, and population.[6]

To estimate institutional capacity, this research adapted a "systems" approach from a theoretical framework model from Homer-Dixon (2006), which he refers to as five "tectonic stresses" that converge simultaneously against a system or institution to cause "synchronous failure" of the system. These five stresses include: (1) environmental degradation, (2) climate change, (3) energy stress, (4) environmental demographic stress, and (5) economic shock. As these stresses converge simultaneously, the *resilience* to the system, e.g. a society, may be pushed catastrophically beyond a threshold. This framework is couched in the theoretical construct of *resilience theory*. While Homer-Dixon applied this framework at the global scale citing the effects of globalization, this research proceeded at the *state* scale using South Africa as a special case study. Each category is analyzed by considering the top issues in each category and documenting its state-of-affairs using supporting statistical data from various online data sources including the CIA World Fact Book, the United Nations Development Program, the World Bank, the International Panel on Climate Change, Department of Water Affairs and Forestry, The Chamber of Mines and various other reliable sources. Media journal reports used are corroborated with statistical data from these various agencies. The list of institutional issues addressed to answer this question is not a comprehensive list but is selected due to its heavy strain on the institution.

These concepts of resilience along with thermodynamics are discussed more in Section II on the theory behind this research. Section III discusses the importance of gold mining in the history of South Africa and divulges its environmental legacy of acid mine drainage. It also describes the problem of coal development relative to AMD. Section IV builds argument to the question of institutional capacity by relating other institutional challenges and analyzes South Africa's water and energy crisis under the theoretical construct of *resilience*. As this project is ultimately a foreign affairs endeavor, Section V will shift focus towards the final question regarding United States policy on matters of environmental security abroad and as such used for policy recommendations before concluding this work in Section VI.

II. Environmental Security Discourse and Theory: Resilience, Thermodynamics, and Tectonic Stresses

2.1. Environmental Security Discourse and "Water Wars"

> *"We know that the 'enemies' in the world today are actually conditions—poverty, infectious disease, political turmoil and corruption, environmental and energy challenges."*
> *-- Former Central Command Commander, General (Ret) Anthony Zinni testimony before Senate Committee on Foreign Affairs 2007 (Atwood 2008)*

After the Berlin Wall fell and the Cold War era abruptly ended, optimism for a more secure world was quickly diffused by a surge of sub-national conflicts erupting across the globe from the Balkans to Central Asia and Africa. The sudden shock to the global balance of power cascaded down through national to sub-national scales producing chaotic social and political effects in multiple afflicted regions (Dilloway 1999). Conventional security threats of the 20th century gave way to the emerging contemporary threats of the 21st century. New threats to human security expanded to include those that arise from non-state actors reliant on terrorism as well as other less conventional threats such as rampant poverty, pandemics, and degraded environmental conditions. The increased recognition of the close relationship between socio-economic decay and environmental degradation prompted the rise of the modern environmental security discourse. This linkage is not difficult to conceive as all societies are part of complex social-ecological systems (SES).

Within the environmental security discourse, much focus has been given to the relationship of natural resources and armed conflict due to increasing natural resource scarcity and potential rent-seeking by those in power (Homer-Dixon 1999). With population pressure, climate change, and abject poverty fueling the worsening global water crisis, the notion of "water wars" became quite popular in the news media as well as political arenas. Former Secretary General of the United Nations Kofi Annan among others echoed the claim that "the wars of the 21st century will be fought over *water*, not *oil*". Such sensational conjecture however has since been largely debunked by empirical research demonstrating virtually no historical evidence exists to support such claims. In fact, the research shows that the opposite is far more probable; disputes over water resources are likely to produce *cooperation* as opposed to *conflict*, even amongst adversaries (Wolf 2003).[7] This debate however detracts from the more realistic issue of water's intrinsic role in human and environmental security.

Central to the socio-economic development of any society past and present is its ability to harness and sustain the "available" freshwater resources. Here, "available" refers to the physical hydrological relationship of water to that society whether it is *on* the ground, *in* the ground, in the atmosphere, in the biomass, and even that which is beyond its official political domain to include neighboring societies (or countries) and even saline marine environments. As importantly, "availability" is defined by, and limited by, a society's *human ingenuity*: the ability to produce adequate social, technical, and financial capital, and use them toward sound water management strategies. Together, it can be considered the *total potential*. Compromised water security arrests development and produces adverse cascading effects that can include poverty, disease, migration, and political turmoil – all of which create a suitable environment for mass movements and armed conflict (Homer-Dixon 1999). In this way, water scarcity magnifies existing tensions as an accelerant, specifically over resource allocation and conservation.

2.2. Resilience Theory:

> *"Things that are complex are not useful. Things that are useful are simple"*
> *-- Mikhail Kalashnikov, inventor of the AK-47, the most widely circulated and used assault rifle in the world. The AK-47 is reputed for its simplicity and reliability in adverse conditions. It is resilient.*

"Resilience" refers to the capacity of a system to absorb disturbance and reorganize while undergoing change so as to still retain essentially the same structure, function, feedbacks, and identity (Walker 2004). Put more simply, it is the flexibility of *something* under applied stress to maintain or return to its original integrity during and after stress. From romantic relationships to economic systems to forest ecosystems there are no shortages of examples of systems under stress. Consequently, it is the forest and the discipline of ecology under the work of C. S. Holling in the 1970s from which this theory originates in its utility in understanding *complex adaptive systems*, that is, systems that constantly adapt their associated functions in a changing environment(Walker 2006). Humans have an inextricable link to their natural environment. Our social-ecological systems (SES) are complex adaptive systems. An SES encompasses humans and the ecosystem along with the relative ecosystem services provided to the human component. In a globalized world with ever-tighter network connections, an SES can be scaled at a tribal village or community, a river basin, a state or any political jurisdiction, and all the way in scale to now include the entire Earth system. Holling's theories have since been imported into the social sciences to better understand the intricacies and resilience of our various social systems. The two key concepts within resilience theory are adaptive cycles and thresholds described below.

2.2.1. Adaptive Cycles

On a larger scale of spatio-temporal cyclicity, collapse and renewal of complex adaptive systems are part of a revolving four-phase cycle of regime shifts. This cycle of growth, steady-state preservation, collapse, renewal, and back to growth is referred to as the *adaptive cycle* and is the first of two key concepts within *resilience theory*. All complex adaptive systems complete this cycle generally in this order (ibid).

The beginning phase of the cycle is called the Growth Phase, represented by "r". Here, there are abundant resources or opportunities for early exploiters. As a system grows, it matures. Resource stakes are claimed and become scarce. This is the Conservation Phase or Steady State Phase denoted by "K" (kappa for carrying capacity). During K, connectivity increases between entities in the system. As it does so, this increases complexity and conversely decreases resilience to shocks as more pathways allow for cascading effects or chain reactions. The system becomes increasingly rigid during this longest phase of the cycle and requires increasing energy or capital inputs to maintain itself. In a State system, this phase is easily recognized by an increasing amount of subsidies, a form of capital (Walker 2006). Ultimately breakdown or collapse results as its resilience reaches a threshold (Gunderson 2002). This is the Release Phase denoted by "Ω" (omega). A "*creative destruction"* occurs during this phase after a dominant regime can no longer sustain itself giving way to renewal and opportunity in some alternate type of state.[8] However, the subsequent transition or renewal of a system (or society) into an alternate state could result in what may be considered undesirable by comparison (Kinzig 2006). In *a "deep collapse"*, a system collapses so catastrophically that the potential for a positive renewal is delayed indefinitely (Gunderson 2002). The final phase is Reorganization Phase denoted by "α" (alpha) where entities start re-assembling into a new system. Figure 2a, b, and c below provide a visual conceptual model of this theory along with a narrative summary of the cycle phases using examples.

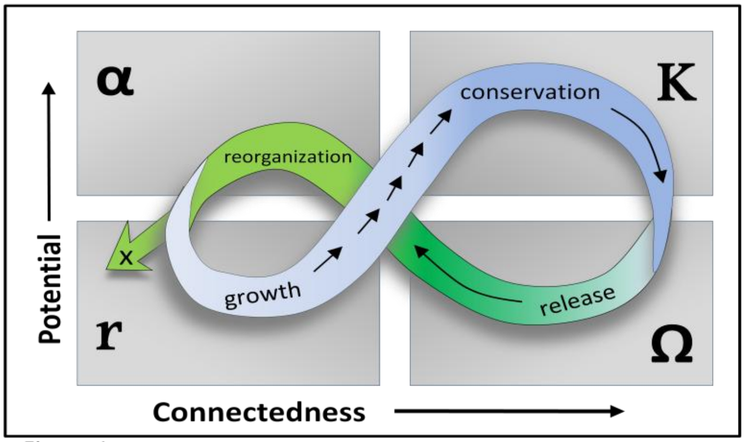


Figure 1a

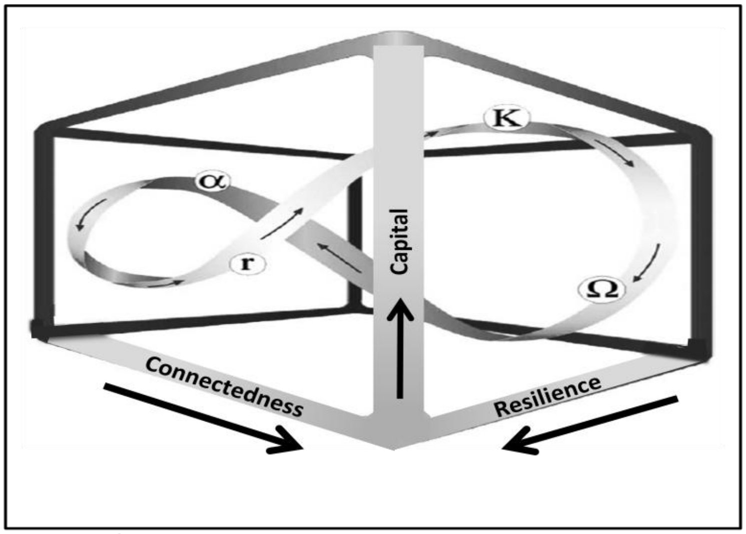


Figure 1b

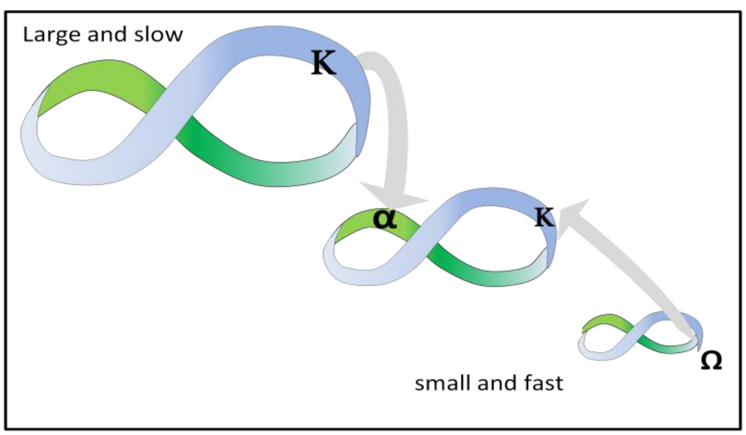


Figure 1c

Adaptive Cycle of Complex Systems:

Figure 2a represents the 4-phase cycle of a complex adaptive system referred to in the literature as the "adaptive cycle". It is depicted roughly as a figure-8 or infinity symbol though several variations of the diagram exist. Essentially, all complex systems cycle through through the phases of growth (r), conservation (K), release (Ω) and reorganization (α). The *growth phase* (r) is characterized by exploitation of newly created opportunities and sudden availability of resources.

Ecology example: new plant growth after a forest fire is able to flourish in sunlight previously inaccessible

Market example: new businesses establish after a larger dominant competitor bankrupts.

This transitory phase eventually matures into the *conservation phase* (K), a period where slower growing species or entities now dominate the system. Resources are locked up by the dominant species, or company, or social group. Energy into the system at this phase goes into conserving existing structure. A system cannot sustain itself forever under the increasing complexity from ever-greater connectedness and capital. It requires ever-increasing energy and will eventually fall into the *release phase* (Ω). This is also known as *creative destruction*. This is the fire in the forest, the market failure, or a war. The fourth phase is *reorganization* (α). After the release, some entities may return but not necessarily with the same function. From here, the cycle may begin anew at r or transition to something entirely different (x). It may suffer deep collapse.

Figure 2b represents the same diagram with a third axis to account for resilience. Through the conservation phase (K), resilience decreases. The confines of the 3D box are the theoretical confines for this system to alter its shape (stretching or steepening etc.)

Figure 2c represents the hierarchical scales of adaptive cycles. An event at the smaller scale can cascade upward and affect a vulnerable stage in a larger, slower scale.
(Gunderson and Holling, 2002)

2.2.2. Thresholds

As the limits of our systems are put under increasing pressure and ultimately fail, we strive to understand their *thresholds*. A threshold can occur in a complex system that undergoes numerous changes or disturbances of which accumulate over time. Often cause and effects from disturbances are not proportional. A response or effect could be far larger in proportion to its cause. This is described as *non-linear* behavior (Walker 2006). At some point, the behavior of the whole system suddenly shifts to a radically different state, thus a *critical threshold*, often unseen and unexpected, has been crossed and the effects can jump scales through connective pathways connecting scales.

The first World War is traced back to two fatal gunshots fired in Sarajevo on June 28, 1914. The heir to Austro-Hungarian throne Archduke Franz Ferdinand of Austria and his wife Sofie were assassinated by a squad of six Bosnian Serb revolutionaries. Their objectives were political; they wanted territory under Austro-Hungarian control to be annexed to Greater Serbia. However, the single event set off a sequence of cascading effects that ultimately brought most of the Western world to war. The event cascaded up in scale through a connective pathway. That pathway was a secret international treaty signed 22 years prior between the French and Russians that established agreements to form a coalition to counter a mobilization from within the Triple Alliance of Germany, Austria-Hungary, and Italy. When that day came, Europe would rapidly spiral into a war that would leave 16 million people dead by its end (Albertini 1953). This is a classic example of a non-linear response to a disturbance.

The classic example of a threshold effect in an ecosystem is a freshwater pond that undergoes a sudden algal bloom.[9] It can exist in a steady state of a balanced carbon dioxide and oxygen exchange indefinitely. The pond can be disturbed by adding nutrients such as phosphorous. The pond may or may not visually reveal a response as it adapts to the change but its resilience to phosphorous is diminished as it approaches a saturation point. Adding more phosphorous inputs to the pond until its capacity to absorb the nutrients is exceeded and the pond will erupt into a runaway algal bloom from hyper-productivity and consequently asphyxiate all of the resident fish in rapid order. A critical nutrient threshold was reached perhaps in conjunction with another multiplier disturbing a key function somewhere in the oxygen cycle and the pond suddenly endured a regime shift, one that was not beneficial by comparison (Walker 2006). Similarly, this event occurs in a backyard swimming pool if the pH is not methodically maintained. The green algae-clogged pool must be chemically shocked to be fit for swimming again. Unfortunately, most SESs cannot be deliberately shocked back to a previous regime although vast financial resources are spent on trying to reverse ecological regime shifts.[10] The "ball-and-basin" diagram Figure 2 below is a conceptual model useful in understanding thresholds. The most important concept in this model is that as a system (represented as a ball) approaches a threshold (a peak), the magnitude of the shock needed to shift the regime becomes proportionately smaller. In the algal bloom pond example above, it is the last molecule of phosphorous.

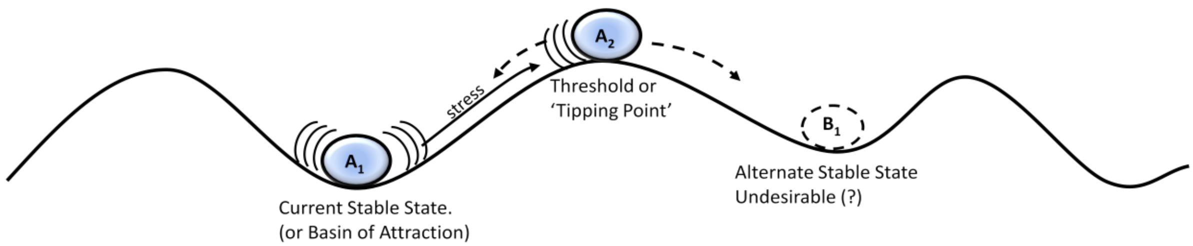


Figure 2. Theoretical "ball–in-the-basin" diagram. Adapted from Peterson et al (1998). The ball (A_1, A_2) represents a current given system. The basins represent stable states or basins of attraction, the bottom of which represents equilibrium. The slope steepness and relative depth of the basins represent the degree of resilience a system can tolerate in that state. The asymmetry of a basin represents the variance of vulnerability in a state. Highpoints represent thresholds which are unstable (A_2). From here the system will return to the stable state or fall towards an equilibrium of an alternate stable state. This is the most basic conceptual model of resilience theory and does not depict the possibility of irreversibility.

Adapted from (Peterson 1998)

A notable criticism of resilience theory is the difficulty in hypothesis testing and predicting the occurrence of a threshold event. Ecologists can observe disturbance and measure responses and cascading effects on variables although effects of disturbance at various scales are difficult to estimate due to the complexity of pathways in the connective networks of overlapping systems. Defining the extent of a study area is also problematic (Sole 2006). Often, studies aimed at pinpointing thresholds in a complex adaptive system is a retroactive process – conducting the research on a system that already shifted stable states in order to investigate for a critical threshold. Furthermore, resilience and thresholds are often complicated by the slow-creeping of such stressors such as climate change when the rate of change is slow enough to mask itself. For these reasons, a common criticism of resilience suggests that this theory has no application in policy because it cannot be used to predict, prevent, or manipulate a complex social adaptive system (Groffman 2006). While this is true, it is mostly irrelevant as resilience is meant primarily to increase understanding of these complex systems that we live within. This project avoids unfounded alarmist predictions but rather builds a case to increase understanding of water security through theory and illuminate the need for special precaution and handling of policy.

2.3. Thermodynamics and Society:

Among the more pivotal breakthroughs in science over the last millennium was the development of the Laws of Thermodynamics – the fundamental understanding of the flows of energy through a system. Energy cannot be created nor destroyed. It takes energy to harness energy. Within a closed system of energy flow, all sources of energy undergo *entropy* – that is, the quality of the energy degrades as it disperses in the system. In other words heat diffuses, but it does not go away. These are the raw simplifications of the most important concepts in thermodynamics. No systems outside of a laboratory are truly closed but the same concepts apply accept there is energy flux in an opened system.

These principles are increasingly critical today as civil engineers the world over grapple with them every day in the quest for energy efficiency. Societies around the world are appreciating that "easy energy" is a thing of the past as they are increasingly squeezed by the high energy demands of achieving or sustaining growth and development. Oil mining companies resort to smaller reserves as the giant reservoirs dwindle and they are returning to old fields with new technology to tap into residual stocks previously abandoned when profit returns diminished (Homer-Dixon 2006). Essentially as energy sources become scarcer, we are accepting a lower *energy return on investment* or EROI as it is commonly referred by engineers. Simply put, we are getting less *out* for every unit of energy put *in* or in the language of economics – we reach the point of *diminishing returns*. When this ratio shrinks to 1:1, it has become a zero-sum venture. As returns diminish towards 1:1, we can expect ever-higher prices capable of arresting economic development. Governments can subsidize them up to a point to buffer its population but this drains the public coffers and limits the ability to render other basic services such as water or physical security. Ultimately, this will require tax increases which transfer the burden back to the consumer and stifles economic development. Understanding these concepts is important in relating back to adaptive cycles, particularly the journey through the long Conservation (K) Phase of the cycle that systems or societies strives to prolong indefinitely. Increasing subsidies in society is symptomatic of a system struggling to maintain itself (Walker 2006). It is expending capital to maintain the status quo such as in financial bail-outs. Often subsidies are doled out by the State to a recipient to *not* do something in an effort to maintain the acceptable steady-state.

When we think about energy, we naturally think about oil, coal, wind, solar, hydro, and biofuel resources and we tend not to think about energy as capital or in its fundamental physical force as the capacity of a system to do “work”. Every physical motion by man or beast or machine requires some caloric output. Caloric storage is gained from nourishment of a food resource which grew from its capture of solar energy (Homer-Dixon 2006). A flowing river is doing work when it transports sediments or toxins, a critical ecosystem service provided by the river. Through the hydrologic cycle powered by solar energy, the water is transported to altitude where it condenses and falls as rain and subsequently drains down-gradient under the power of gravity (ibid). Withdrawals from any part of this hydrological process whether it’s the felling of transpiring trees or consumption of water ultimately degrades the total system from available energy to do some form of work. This concept is largely missing from how we think about water and how we think about energy but the reality is it is difficult to decouple these two intertwined flows. It is problematic for society to deal with these two critical needs in two separate bubbles (Turton 2009a).

When fertile land is cleared for building or taken out of production from water pollution, we are making withdrawals against the overall energy budget. Agricultural land taken out of production is a withdrawal because it is sacrificed calories, calories that could have been available to do work such as supply the farmer or the laborer the physical energy required to produce. It is *potential energy* that will never be mobilized. The crops must now be imported, a result of the comparative advantage of the global economic model. In this regard, financial capital is a substitute for energy since physical labor and money are interchangeable. When a government provides a service to one sector, it is essentially appropriating some if its finite “energy” toward that sector leaving less energy to dedicate towards another. We know this about energy, but as a society we do not think about it in this fundamental way.[11]

Recent research explains the demise of the Roman Empire through the lens of thermodynamics (Tainter 1988, Homer-Dixon 2006). Over the centuries, the fascination with Rome’s collapse resulted in many theories: incompetent leadership, social decadence, relentless Germanic invasions and myriad others. While many theories hold evidence and may perhaps carry at least some element of truth, it is more likely that they are cascading effects resulting from an empire in thermodynamic crisis (ibid). As the institutional complexity waxed during stress, the resilience waned. Failure to maintain water security in the Maya, Babylonia, and Khmer can be considered as a type of energy failure. If there is not sufficient water for irrigation, crops fail. Deforestation leads to soil failure and the calories required to sustain work throughout the empire are unachieved.[12] The required potential energy to maintain the

Conservation (K) Phase can no longer be mobilized. Competition for scarce resources increases facilitating mass migrations, demographic stress, social mass movements, and heightened tensions often culminating in total social and political chaos –hence, the Release Phase (Ω).

2.4. Tectonic Stresses:

Synchronous failure is the simultaneous or sequential collapse of political, social, and economic order within a society as a result of converging stressors that combine to *multiply* their effects. Such a deep collapse could be highly destructive rather than constructive – that is, the potential for constructive renewal is limited in such circumstances (Walker 2006). Homer-Dixon (2006) uses the term "tectonic stress" as a metaphor to an impending social earthquake on a scale that could harm millions or even billions of people through a systematic catastrophic breakdown of national and global order. In plate tectonics, immense geological stresses build beneath the surface along fault zones. They remain virtually undetectable even by modern technology. Eventually the pressure releases suddenly and violently with an earthquake. Given the magnitude of the earthquake and/or the fragility of the overlying human landscape, the results can be catastrophic as they were in Port Au Prince, Haiti in January 2010. Though the event may be preceded by a series of foreshocks, the eventual release of pressure is still largely unpredictable by geophysicists. In much the same way, Homer-Dixon describes metaphorically five "tectonic stresses" building beneath the surface of society on a global scale. They are (1) *environmental stress* from increasing degradation of land, water, forest, and fishery resources; (2) *climate stress* from the unprecedented rate of climate change underway (3) *demographic stresses* within the society from social or political disparities; (4) *energy stress* from the growing scarcity of available high quality energy resources; and (5) *economic stress* from greater global economic instability and widening income gaps between the rich and the poor (Homer-Dixon 2006). These five stresses synchronizing together push the "ball" out of the "basin" where it can fall towards an alternate basin. This research proceeds under an adaptation of this framework at the national scale isolating South Africa as a special case study, a nation that epitomizes each of these tectonic stresses.

And what of acid mine drainage? As this paper will show, the convergence of seemingly disparate factors makes this environmental problem a viable potential threshold effect or tipping point. A State failing to sustain water security is a matter of national security with implications that reach regional and global scales. It will likely define South Africa's future. Water security hangs in the balance. Could AMD tip the balance beyond a *threshold*?

III. The Mining Legacy

3.1. A Historical Brief: Socioeconomic and Demographic Outcomes of the Mines

3.1.1. Colonialism and Geopolitics

The discovery of diamonds in 1867 and later gold in 1886 in South Africa forever changed the geopolitical landscape of that nation.[13] Before the mineral discoveries, Great Britain's interest in the region was wholly maritime: securing the geostrategic Cape Route for her commerce to port and pass safely to and from her primary foreign interest in colonial India. When the potential mineral wealth of the South African interior became manifest after the discoveries, the Crown then turned her interest inland as the historic Witwatersrand Gold Rush began. What would follow was a rich but often turbulent history forged in blood and oppression (Thompson 2001).

3.1.2. Demographic Re-ordering of the Native Population

Though very much a part of the fabric of South Africa, the gold mines have long been a contentious subject in the nation and even the world as a matter of human rights. The price of this important sector in the economy transcends far above that of ordinary operation costs. In 1908, the British colonial system imposed a "hut tax" on every native black South African household to exploit the large native population for labor requirements desperately needed for development. The hut tax, payable in cash, labor, stock or grain marked a turning point for the much larger native black population by legally obligating them into the colonial cash-based economy. This, in effect, geographically separated the head of household away from the home to go work for meager wages to pay the hut tax. The rapidly developing gold mining industry in Johannesburg was a logical destination for the diaspora of working-aged males seeking labor from across the nine indigenous tribes of South Africa (Pakenham 1991). To this day, labor and family are commonly geographically isolated within the country.

3.1.3. Seeds of Apartheid

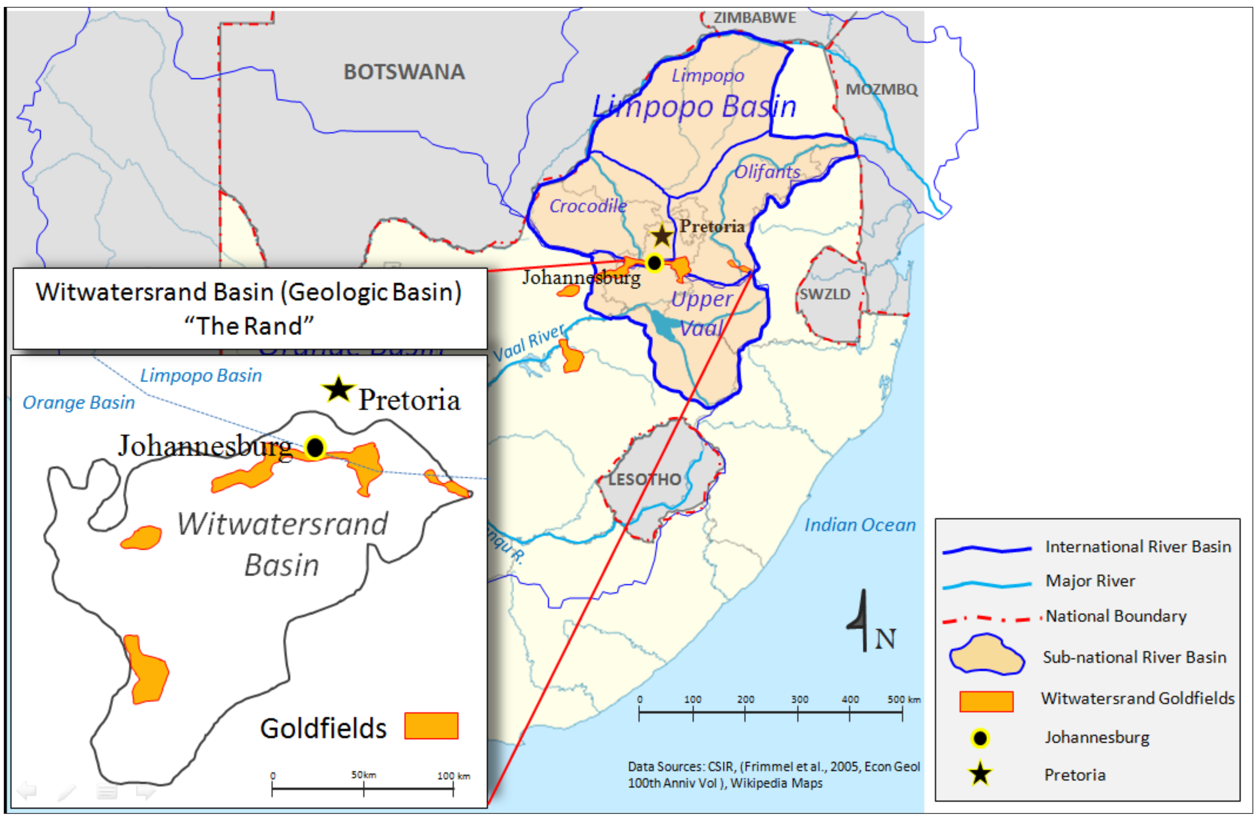
In the years following the hut tax and subsequent labor migrations, violent clashes and unrest were frequent in the mining labor sector between white and black labor classes. In 1922, working conditions and the competition for labor between classes escalated to armed militant conflict. The policies that followed were highly discriminatory toward the blacks. The official policies of segregation would ultimately form the cornerstones of Apartheid – the legacy of which still define persistent class tensions today. For the remainder of the 20th century, black labor was restricted to unskilled labor tasks. Labor conditions were considered hardly different than that of slave labor (Thompson 2001). High losses of life, degraded health, deplorable working conditions and insufficient wages led to multiple labor strikes by the Miners Union and frequent violent clashes with state police. Although labor conditions have improved somewhat since the previous era, they are still flashpoints for these occurrences in the present day.[14]

3.2. The Environmental Legacy

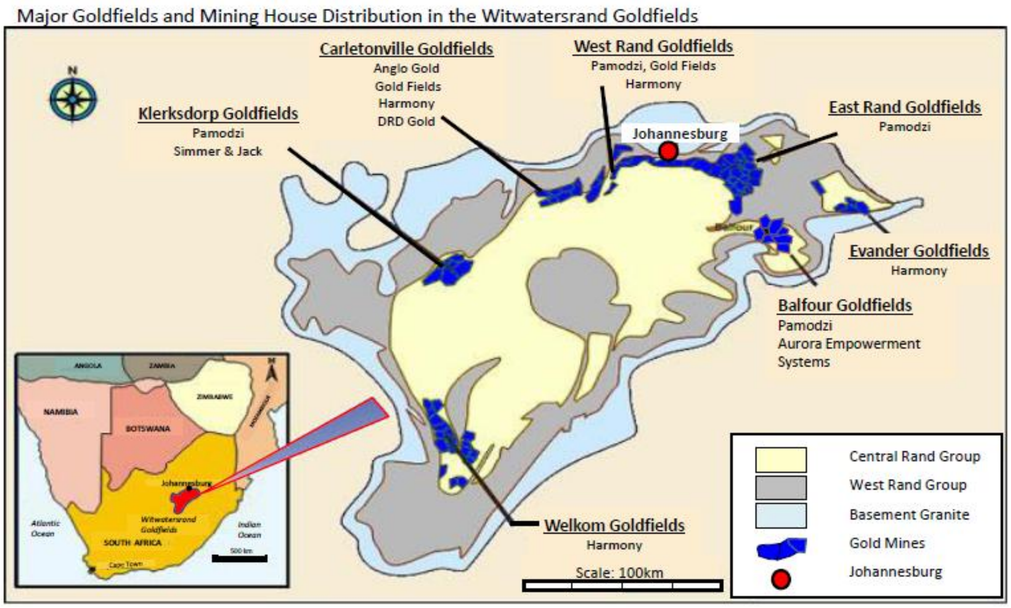
3.2.1 Acid Mine Drainage in the Famed Goldfields of the Witwatersrand

Beyond the unpopular socio-political issues with the mines from the Apartheid era, the mining industry now leaves behind a new legacy – environmental devastation (Turton 2009a). Though minerals are critical to economic development and State security, the terms “mining” and “sustainable development” are often incompatible. Extracting strategic and economic minerals from the earth involves large-scale mechanized processes to remove earthen material, often employs highly caustic chemical processes to separate minerals from the ore, and through an unintended geochemical process, produces the highly toxic byproduct of acid mine drainage (AMD). Mining pollution around Johannesburg generate the most costly environmental damage and socio-economic impacts in the country (Coetzee 2004).

Johannesburg, the hub of gold mining in South Africa and the rest of the world, sprawls across a gentle topographical upland known as the Witwatersrand - Afrikaans for “Ridge of White Waters” and most commonly referred simply as the “Rand”. Over the past century, the famed Witwatersrand goldfields proved to be the most prolific gold-bearing reef in the world yielding 40 percent of all the gold ever mined on Earth. Over USD 750B in revenue have been generated from this 300km arc of goldfields where large multinational mining houses abound (McCarthy 2005). The Witwatersrand is no longer aptly named, for the waters which once percolated up from numerous springs in the dolomite outcroppings no longer flow freely. Extensive mining workings over the past century dramatically altered the groundwater hydrology in and around the city through the mechanical dewatering of large and deep mining voids (Turton 2009a). The predominant topographical relief in the city comes in the form of numerous large mine tailings impoundments; the earthen refuse piled high around the mines (see photos below). From a downtown Johannesburg skyscraper, when air quality allows, one could marvel at the numerous tailings impoundments or "slimes dams" that rise around the periphery of the city. They are the most visible consequence of mines in this country.[15]



Map 3. Witwatersrand Basin



Map 5. Map of the major goldfield complexes in the Witwatersrand. Goldfields are depicted in blue in a 300km arc spanning the Witwatersrand. Map modified for clarity. Original: http://content.edgar-onlin.com

Photos of tailings impoundment landscape around Johannesburg. Robinson Lake (upper left) is a natural lake in the vicinity of a decanting AMD site in the Western Basin. It has a pH level of 2.5. The environmental norm is 7.3. It has a Uranium concentration of 16mg/l, over 40,000 times the background Uranium concentration for water. This lead to the National Nuclear Regulator declaring this lake a hazardous radiation area. The radiation signs were recently installed at this tailings site (lower right) due to public pressure. These images were taken in the West Rand. *Photos courtesy T. Hanlon*

Uranium is often spatially correlated with the presence of gold as a result of their hydro-geologic origins. Gold mining tailings throughout the Witwatersrand contain the radioactive element (Coetzee 2004). Uranium mining often occurs concurrently or after gold mine closure. Newer technology allows for tailings impoundments to be re-exploited for salvaged minerals previously discarded in the tailings. Of historical note, the highly enriched uranium used in the Manhattan Project originates from the Witwatersrand basin (Du Toit 2009). The fine dust from the many large tailings dams of Johannesburg disperses in the frequent winds of the sub-arid climate. Mining houses install sediment-retaining fences on the tailings impoundments and continuously spray water on the fine sediment to suppress the toxic dust. However, these efforts are largely ineffective as the fine dust accumulations can be seen throughout the townships. The townships are immediately adjacent to the tailings dams with resident properties abutting the tailings dams are most exposed to the toxic dust. Awareness of the radioactive threat is low amongst the residence as children commonly climb and play on the tailings piles (Liefferink 2009),(Turton 2009a).

3.2.2. Decanting in the West Rand

While AMD occurs throughout the lifecycle of gold mining, most problems arise after cessation. Many of the once lucrative gold mines of the Witwatersrand are reaching the end of their productive eras (Coetzee 2004). Mentioned in the Introduction, when the mines close, dewatering is discontinued allowing groundwater to ingress back into the cavernous mine voids. In 2002, a concoction of ferrous rust-tinted, highly acidic water began decanting onto the surface from the lowest lying mine shaft in one of the now defunct gold mines in the West Rand on the western periphery of Johannesburg. The mine shaft essentially became a spring of poison spewing high volumes of the AMD continuously into the watershed ranging from 15 to 35Ml per day – about 12 Olympic-sized swimming pools per day (Coetzee 2004). Immediately downstream of this decant site is the Krugersdorp Game Reserve, agricultural fields, expanding residential development, and the Cradle of Humankind World Heritage Site – a limestone cavern complex known to contain the oldest hominid fossils.[16]

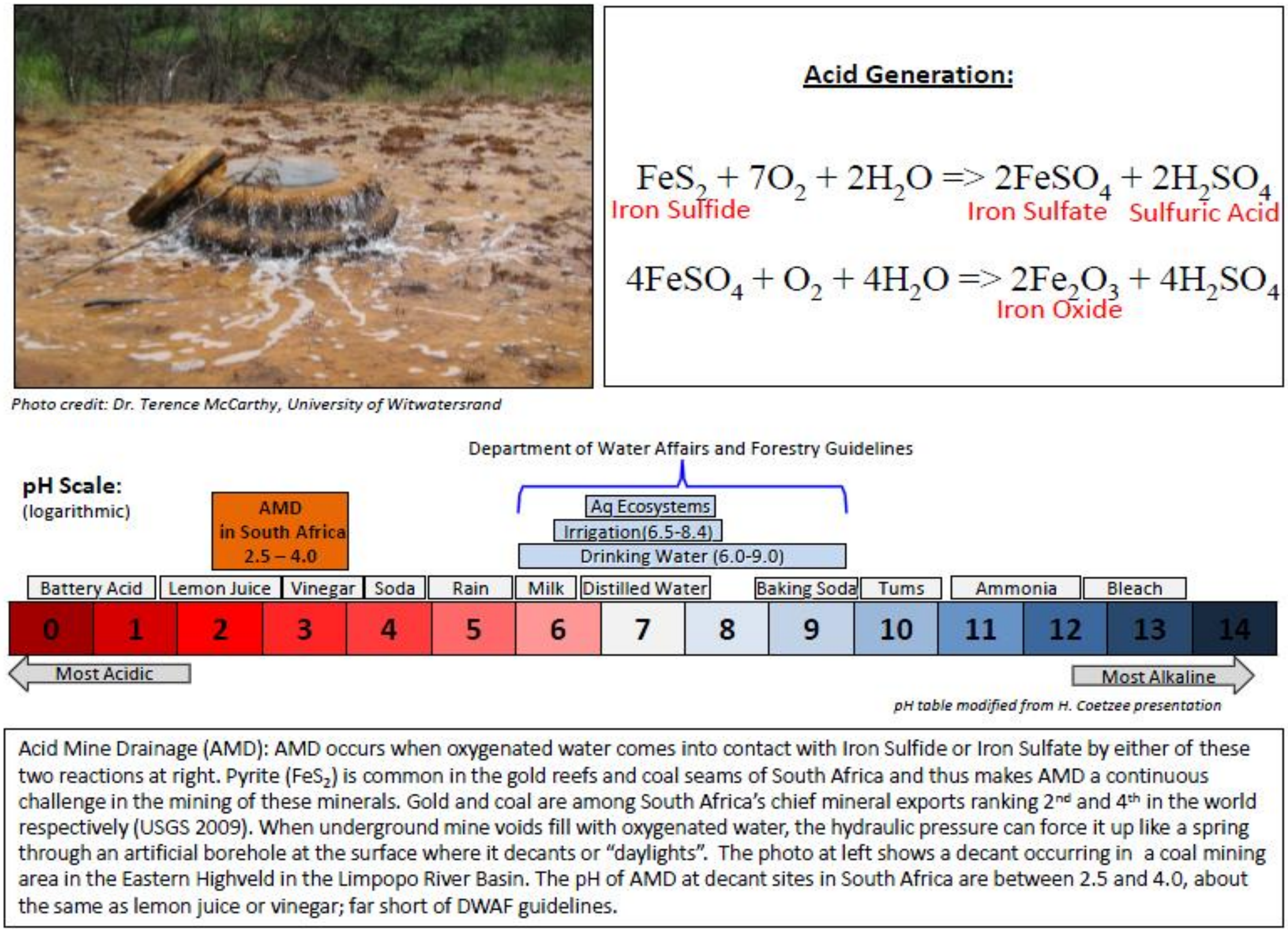


Figure 3. pH scale.

Under a government directive, the responsible party, a gold and uranium mining company, established a reclamation facility for this continuous decant of AMD. The facility captures, holds, and treats the decanting AMD and neutralizes the acidic pH with sodium bentonite clays and subsequently returns the neutralized water to its downstream flow. Bentonite contains properties that absorb toxic metals in solution while also raising the pH level back to levels tolerable to the environment. This must be done in perpetuity. However, there are multiple serious deficiencies with this procedure. First, the bentonite is not cost efficient. Bentonite deposits do not occur in close spatial proximity and therefore, the heavy clays must be shipped in bulk large distances.[17] Second, the high dissolved salt loads (sulfates) are not adequately reduced and continue downstream into the receiving environment(Du Toit 2009). Third, remediation does not capture all decanting point sources in a given area nor can it completely attenuate what it does capture (ibid). Rates of groundwater recharge fluctuate based on rainfall events. This often causes the decant rates to exceed the capacity of the remediation facility allowing the unbuffered AMD to enter the receiving watershed. Environmental reports from the downstream Krugersdorp Game

Reserve reflect varying high levels of the toxic constituents. Consequently, birthing rates of the various game on the reserve have dropped precipitously in recent years suggesting the possible compromised health of the animals (ibid). Finally, and perhaps most significantly, the remediation is only conducted *at the surface*. The groundwater remains highly acidic and untreated. It is not well understood how a century of deep subsurface mine working will alter the groundwater dynamics in the basin (ibid). It is currently believed that this subsurface plume of AMD will drain through subsurface pathways via mine workings, fractured geologic substrata, and porous dolomite layers towards one of Johannesburg's strategic groundwater aquifers rendering it highly toxic. Current monitoring of the underground AMD plume projects this convergence to occur in December of 2011 (Hobbes 2009b). Numerous other decants have sprung up through various boreholes in the area. The Witwatersrand is a virtual "Swiss-cheese" of mine workings. There are over 600 abandoned mine apertures in the West Rand alone(Coetzee 2004).

AMD remediation at a West Rand decant site near Krugersdorp Game Reserve. AMD "daylighting" is channeled from decant point into a sump where it begins treatment process (Top left, Top right). With the pH levels buffered, the treated water continues into the receiving watershed. (Lower left) The photo shows Hippo Pond at Krugersdorp Game Reserve. The tailing dams can be seen over the trees at horizon. Two ornery hippos are seen in the pond. (Lower right) The treated water flowing out of an impoundment below the hippo pond. The water is heavily laden with iron oxide and is highly sulfuric.

West Rand AMD Decant. Photos courtesy T. Hanlon

(Top left) 12 inch diameter pipes like this one are discarded alongside the road near a remediation facility in the West Rand. The pipes require frequent replacement due to the iron oxide precipitating out of solution and adhering to the pipe walls. (Top right) The iron oxide crust in this pipe section is approximately 4 inches thick. (Right) Iron oxide crust formed over reed grass in a wetland.

Reclamation challenges at West Rand Decant. Photos courtesy T. Hanlon

100 kilometers west of Johannesburg are the industrial mining towns of Carletonville and Klerksdorp in an area referred to as the Far West Rand of the Witwatersrand basin. The large rural open areas in between the scattered mining operations are used for agriculture. In recent years, several ill-health trends have become manifest in the Far West Rand and are consistent with illnesses associated with radioactivity -recall the correlation of uranium to gold (Turton 2009a, Liefferink 2009, Coetzee 2004). A recent environmental impact assessment conducted lead by National Nuclear Regulator (NNR) reveals radioactive uranium in the environment at levels of great risk to humans (ibid).

One respondent in this research, a farmer living in this region outside of Carletonville approximately five kilometers downstream of a gold mine owns dogs, cattle, pigs, and other stock. Each of his animals has produced stillborn offspring in recent years. Both his dogs and his pigs produced litters of grotesquely malformed stillborn pups born without skeletal structure. These kinds of odd deformities have been seen in the human malformed "jelly fish babies" born in the South Pacific islands after extensive nuclear testing conducted in those areas (Welz 2009). Coincidentally, the respondent's wife passed away seven years prior from pancreatic cancer at the age of 45 though official causality was never linked to water pollution. This farmer's corroded plumbing works leaks of acidic ferromagnesian water which him to purchase all consumable water from a bottled water company though this is not economically or logistically viable for livestock (Respondent1 2009).

Socioeconomic Effects: (Left) The plumbing works throughout the house of a Clarksville farmer living downstream of gold mine in the Far West Rand are badly corroded from acid and leak iron oxide water. The farm depends on well water. The family relies on bottled water (right) to cook and drink although the livestock must consume the well water. Photos courtesy T. Hanlon

Farmers to include this respondent do not receive compensatory settlement from the mining house due to lack of credible evidence, lack of capital to procure lawyers, and lack of lawyers willing to challenge the mining houses (Liefferink 2009). There have been multiple reports of pancreatic cancer in the region in recent years. Oncologists at a hospital in Pretoria have noted unusually high pancreatic cancer in their patient inventories (Welz 2009, Turton 2009a, Liefferink 2009). However, much of the evidence is largely anecdotal as research is commonly stifled by an industry with deep political networks (ibid). Many scientific researchers choose not to challenge this industry with science that could generate controversy and jeopardize the industry – and ultimately the employment security of the researcher. In an especially sensitive socio-political environment where employment security is at risk, this conservative approach prevails (Turton 2009a).

3.2.3. Imminent Decants in the Central and East Basins

The remaining groundwater basins in Johannesburg, the east and central groundwater basins, are continuing to ingress with AMD and are predicted to decant in 2012 and 2014 respectively. The total decant potential for the entire Witwatersrand Basin is 350 Ml per day or about 140 Olympic sized pools everyday. These decant events are inevitable as more mines are decommissioned. The rising AMD in the mine void threatens the large fractured rock aquifer perched atop the mine void. This aquifer is considered strategic water as it has been virtually unexploited.

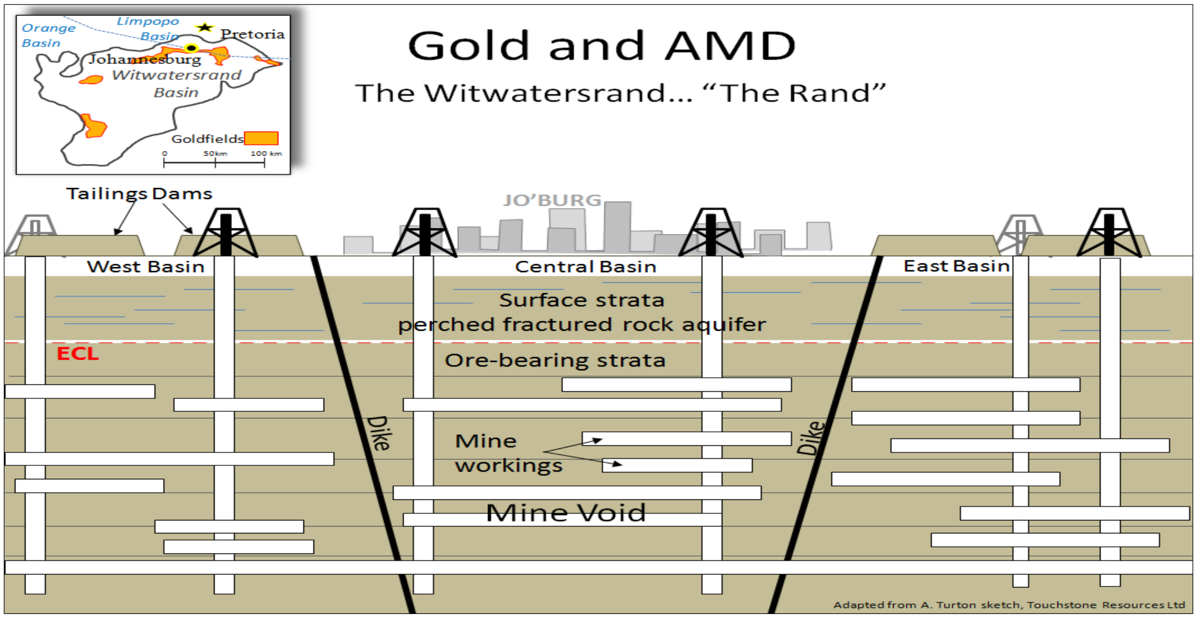


Figure 4a. Schematic of Witwatersrand mine void, a labyrinth of mine workings constructed over 120 years. The groundwater has been pumped out of the workings. The surface strata still contains uncontaminated freshwater and presents a strategic source of future water supplies in the water scarce region. Figure 4b below shows the rising AMD ingressing into the three separate groundwater basins. Redrawn from Turton sketch (2010), Touchstone Resources Ltd.

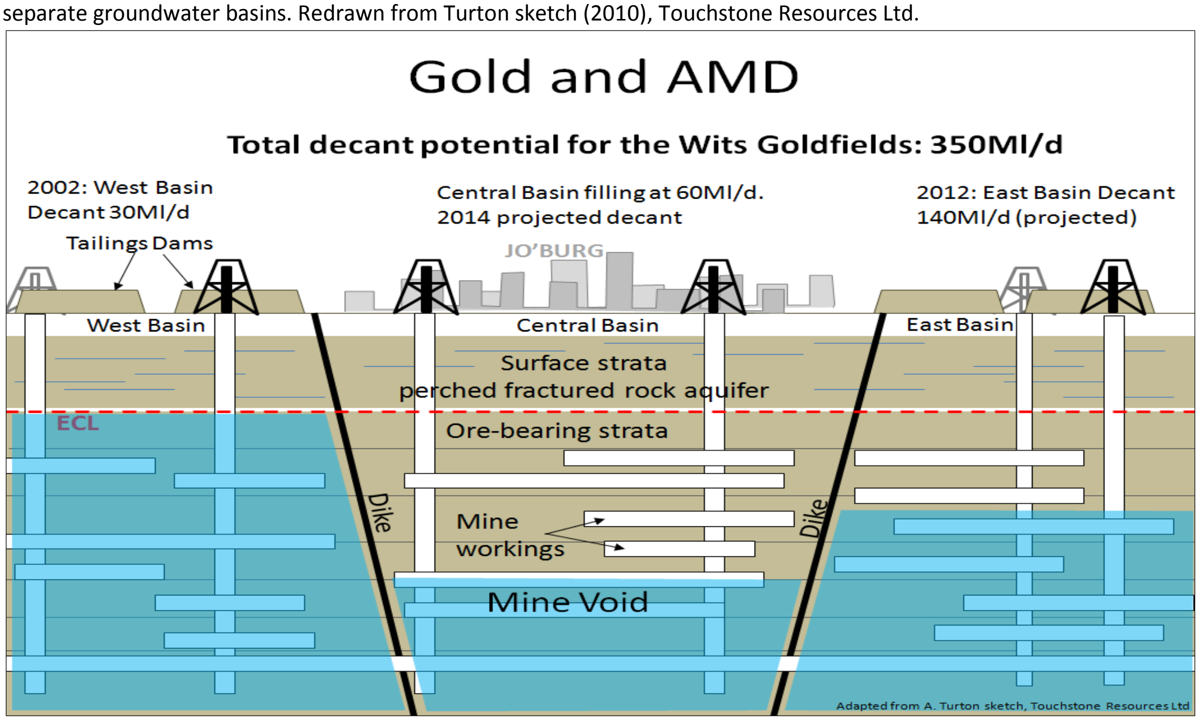
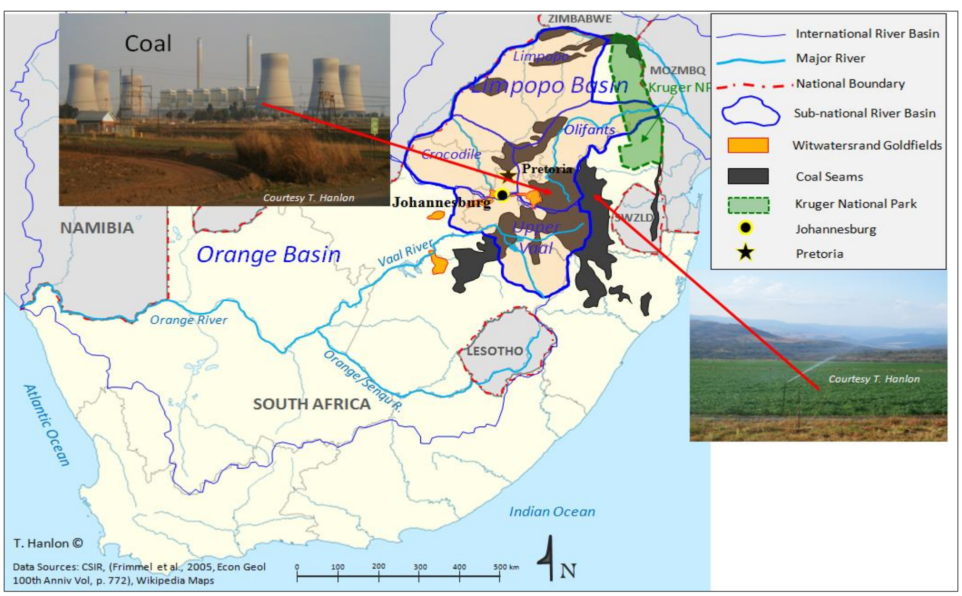


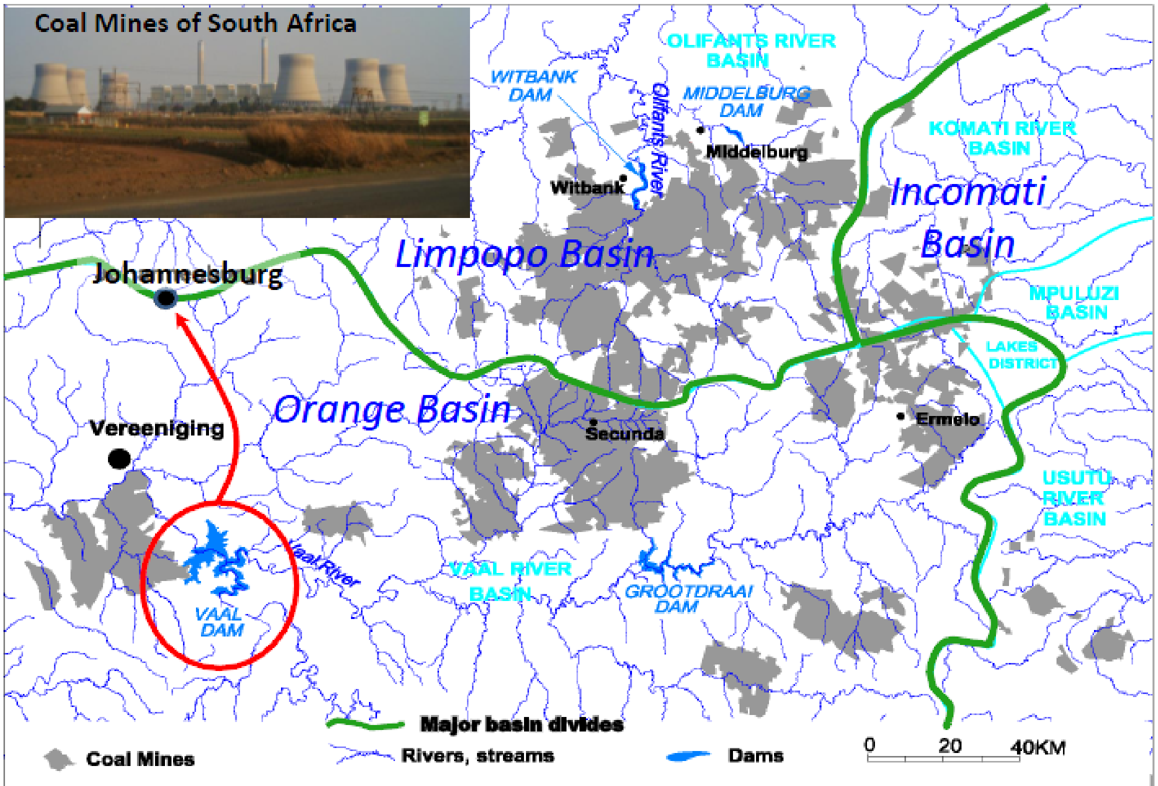
Figure 4b.

3.2.4. Acid Mine Drainage in the Highveld Coal Seams

Like gold mining, coal mining produces high volumes of acid mine drainage byproduct through the same process due to the geologic commonality of pyrite. In coal however, radioactive contamination does not occur due to the absence of uranium in this setting. Low pH, high dissolved salt load, and toxic metals are the primary problem in this region (McCarthy 2009a). South Africa's coal seams lie in a geographic region in the eastern margin of the country referred as the Highveld, centered approximately 100 kilometers east of Johannesburg. The Highveld spans across the northeastern states of Limpopo and Mpumalanga. This is one of the poorest parts of the country and the region where the most water quality problems occur (discussed more in Section IV). The effects of AMD coal mining on the water resources are thought to exceed even the impacts of gold mining due to the extraction process and geographical extent of coal mining activity in the Highveld (McCarthy 2009c). The areas in gray on the map below show the extensive coal mining activity in the east. The majority of coal mining straddles the Limpopo and the Orange basin divides, two of the most strategic and highly vulnerable watersheds in the country and similarly the southern African region.[18] These watersheds are depicted on the map below by green boundaries. They are both heavily polluted. Given the current energy crisis, high unemployment rates, and vast coal reserves, it is unlikely coal mining will abate anytime in the foreseeable future(McCarthy 2009c).



Map 4. The Coal Footprint shown in dark gray color. Most economically exploitable mines are east of Johannesburg in Mpumalanga Province.



Map of coal-mining areas of South Africa. Of note, the strategic Vaal Dam (circled in red) is Johannesburg's primary source of water. It is primarily supplied by the massive interbasin transfer from the Lesotho Highlands Water Project (LHWP) 250km to the south. Data from many monitoring stations along the Vaal already show higher levels of salinity than are acceptable to Receiving Water Quality Objectives (RWQO) set forth by the Department of Water Affairs and Forestry (DWAF) (McCarthy 2009).

Map 6. Photo inset courtesy T. Hanlon

3.2.4. Corporate Accountability and Loose Regulation

Reputations of both labor conditions and environmental stewardship vary widely amongst the mining houses. Several mining houses are reputed to adhere as closely as possible to the Best Practice Guidelines published by the Department of Water Affairs and Forestry. The Environmental Projects Director from the AngloGold Corporation stated however that a mining corporation can easily elude such policies as enforcement is virtually non-existent. Compliance of a particular mining house is mostly left to the devices and ethics of the individual mining house. "Corporate accountability is a tremendous problem and the government is too weak to address it" (Rex 2009).

3.2.5. AMD Reclamation and the Irony of Cheap Water

Current reclamation efforts of AMD are ill-suited to substantially reduce the effects of AMD. Several methods exist. Passive water treatment, the least expensive method, employs a biological remedy by diverting the mining effluent through a series of constructed wetlands to naturally filter the toxic byproduct by the work of bacteria. Active water treatment includes chemical processes to buffer the AMD such as the method described in the West Rand decant. Geotechnical engineering projects also help to control the ingress and egress of water in mine voids. Lowest cost methods are employed to meet the perceived requirements of liability in the constitutionally-mandated “polluter pays principle” legal setting of South Africa.[19] Best-outcome technological options exist to further mitigate the environmental effects of AMD but are substantially more costly and essentially economically unviable to the mining house polluter. Such options include reverse-osmosis treatment and ion exchange technology(Doyle 2009). Ion exchange technology in concept separates all of the constituents of AMD. This creates the potential of some cost-recovery by the separating and reusing the toxic constituents into useable roles in fertilizer products and other usages.

The primary barrier to technological solutions however is cost and the fundamental problem is the price of safe water is simply valued too cheaply than what it should realistically be worth. The end product, safe water, does not cost enough to warrant expensive treatment. The cost of a m^3 of potable water is still one third of what it would cost to properly treat it technically (Turton 2009a). The plan of action endorsed by the government up until just prior to print time of this report was to transfer the cost of remediation from the mining house to the consumer. The Western Utility Corporation (WUC) in collaboration with the parastatal Rand Water service provider would treat the AMD to a consumable quality dictated by the Department of Water and Environmental Affairs (DWEA) and recover the cost *from the consumer* by way of increased water pricing. Essentially, this absolves the mining houses of their liability. However, at print time, increased public animosity by this seemingly unconstitutional principle derailed this course of action (for the time being) in favor of an alternative resolution yet to be finalized (ibid). However, time is of the essence in finding solutions as the subsurface plume of AMD continues to approach strategic aquifers underlying Johannesburg.

3.2.6. Section Summary

This section explained the environmental impacts of mining in South Africa. Qualitatively, it answered the first case study question: "How does mining impact water security in a water-scarce South Africa?" The externalities of AMD were explained in two settings, gold mining of the Witwatersrand and coal mining of the Highveld. The geography of the problem is especially significant as these mining areas fall within the watersheds that contain over one third of the economic output of the country. These watersheds are at high risk of irreversible degradation that could severely disrupt socio-ecological systems at larger scales. Technologic solutions exist to buffer AMD more effectively than existing biological and chemical methods, however, in the current model of water management, the economic model keeps that technology out of reach to most mining and reclamation operations.

IV. Complexity, Converging Stressors, and Resilience in South Africa

Gold mining is diminishing in the Witwatersrand. Coal mining is flourishing in the Highveld. Both present enormous institutional challenges to a nation already burden by other great challenges. To fully appreciate the potential impacts of AMD, one must consider the institutional capacity available to absorb this problem in the face of increasing water scarcity. The term "institution" is used to describe no particular entity but instead the general body of knowledge and capability within the state's domain. The following analysis seeks to answer the second case study question: "Is the institutional capacity within South Africa sufficiently resilient to absorb this type of environmental disturbance?**"** The argument builds off of the five factors or "tectonic stressors" emphasized by Homer-Dixon (2006): *environmental, climate, energy, demographic* and *economic stressors* are considered as they pertain to South Africa. For this analysis, these stressors are consolidated as *water security, energy security,* and *socioeconomic security,* with related issues subcategorized under these headings. Considering the problem of AMD in the Witwatersrand and in the coal fields of the Highveld against these converging tectonic stressors occurring below the surface of the institution, the high demand for institutional capacity and resilience within the state and its agencies becomes manifest as does the vulnerability of its overall State security. Within the scope of this paper, the complexity of the State can only begin to be appreciated. Recall from the adaptive cycle when a society becomes increasingly complex conversely becomes increasingly less resilient to shocks. Based on the following analysis, it can be argued that South Africa is entering the downward slope of the conservation (K) phase of the adaptive cycle.

4.1. Water Security

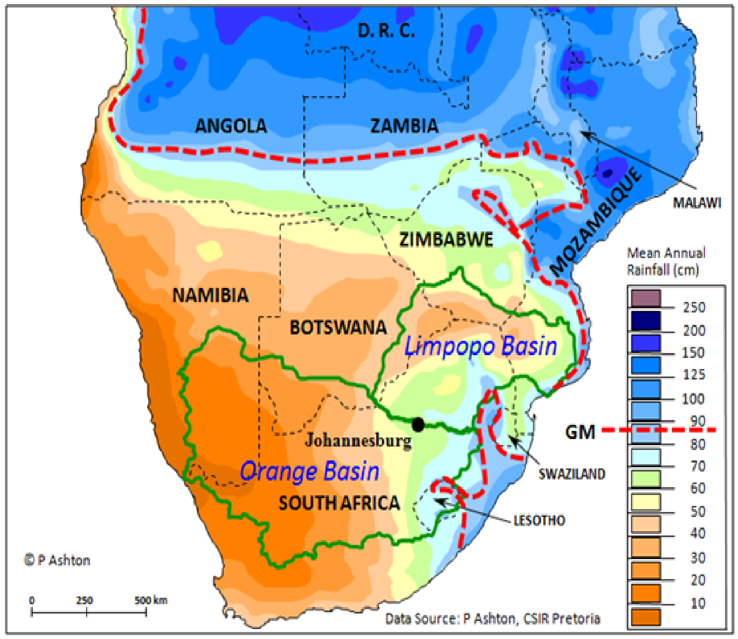
Already, the issue of environmental stress is given considerable attention in the previous section detailing AMD. Here, the greater challenges of water security in South Africa are addressed. The challenges of water provision in South Africa are extraordinary and clearly water security as a whole is the top environmental issue in the country. Water professionals are concerned with water's *quantity, quality* and *timing*. Each of these three facets falls under enormous pressure in South Africa. This analysis focuses primarily on *quantity* and *quality*. Timing challenges are inherent with its bimodal climate consisting of two distinct seasons, wet and dry, and will not be elaborated any further.

4.1.1. Water Quantity: The Challenges of Developing in a High and Dry Place

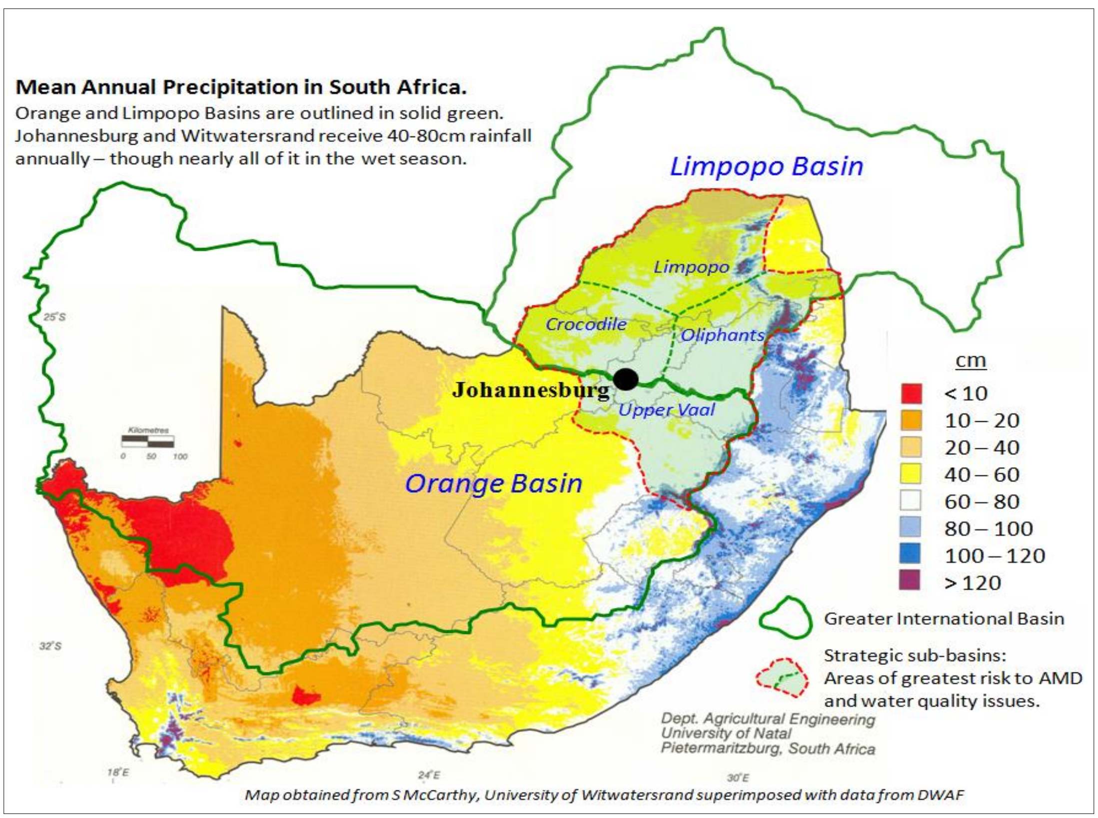
4.1.1.1. Arid Climate

South Africa is mostly an arid and sub-arid nation containing the southern extent of the Kalahari Desert and its savannah margins. The average annual rainfall in Johannesburg where the vast majority of population and economic output occurs is 50 to 70cm per year, nearly all of which occurs in the austral summer wet season. The region has the lowest conversion of mean annual precipitation (MAP) to mean annual runoff (MAR) of any inhabited region on Earth. Only 15 to 20 percent of the limited rain that falls actually makes it to a stream compared to 35 percent in the eastern United States and 45 percent in Europe. The rest evaporates into the extremely "thirsty" atmosphere or absorbs into dry sandy substrate (Turton 2008b). Given this naturally occurring climatic constraint, this low baseline *dilution capacity* already imposes a handicap to development. Dilution capacity refers to the ability of the in-stream flow of the river network to dilute the effects of effluent (toxins and sediment) from mining activity, industry, agriculture, and municipality (ibid). Any additional natural or man-induced decrease of in-stream-flow further reduces the dilution capacity of the river networks.

Mean Annual Precipitation in Southern Africa:
The red isohuet denotes the global mean (GM) at 86cm. Johannesburg and Witwatersrand receive 60-70cm rainfall annually – though nearly all of it falls in the wet season. The Eastern Highveld receives the highest precipitation in the country – approximately the same as the GM. The Orange and Limpopo Basins are outlined in green and fall nearly entirely on the drier side of the GM



Map 7. Southern African Climate. Courtesy P. Ashton. Clarity added

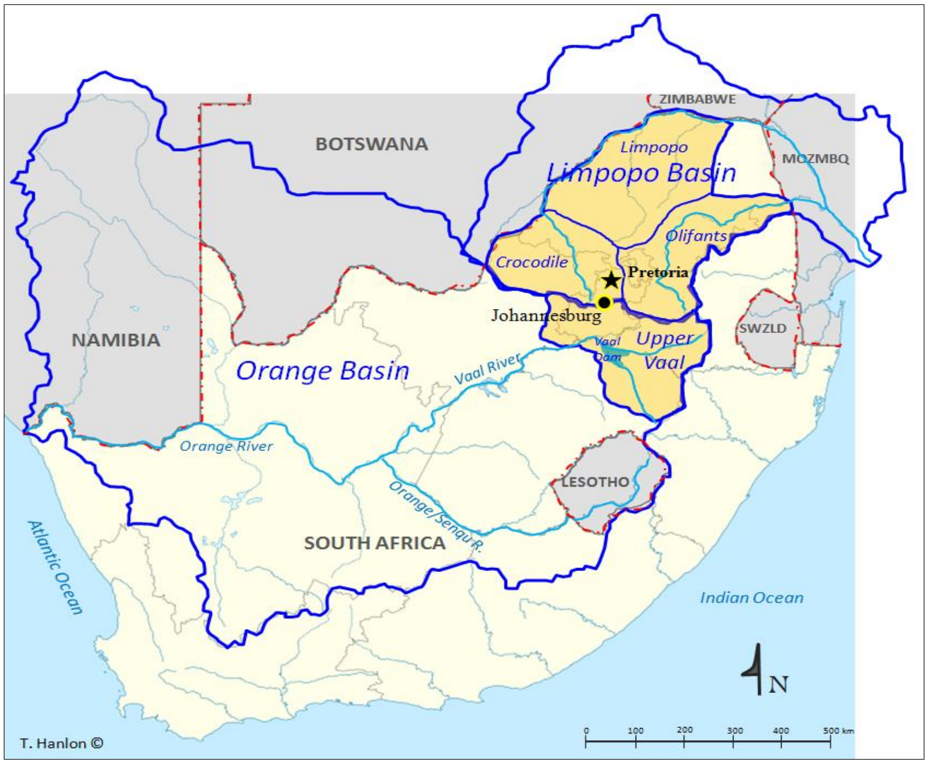


Map 8. Climate of South Africa. The international "basins at risk" are outlined in green. The sub-national strategic watersheds are outlined in red dotted line. Most acid mine drainage issues occurs within these four tributaries. Consequently, most South African economic activity occurs within them.

4.1.1.2. Colonial Geography and the "Hard Path" to Water Security

Complicating the water security is the peculiar industrial geography of South Africa and the greater southern African region. Most of the population lives "uphill" of assured water resources. Johannesburg, a city of 10 million and therefore a "megacity" is the largest city in the world to be situated away from a coastline or river. It is the most modern city in Africa and accounts for over 10 percent of the GDP on the entire continent (WB 2010). The regional occurrence of cities upland and away from a nourishing water source is a challenge mostly unique to southern Africa. This anomalous urban development pattern exemplifies the legacy of the colonial era as once remote mining camps adjacent to extraction sites eventually burgeoned into the large cities of the modern era, Johannesburg being the most remarkable example.[20] This challenge requires the mechanical and costly re-engineering of the surface hydrology or what was referred in Section I as "heroic engineering" (Heyns 2002). Mineral wealth accumulated over the past 125 years created the requisite financial capital for a country to overcome the development constraints typical of an arid nation through the heroic engineering of scarce freshwater resources.

Johannesburg and the Witwatersrand goldfields sprawl across the divide between two international water basins; the Orange River, which drains west toward its mouth on the Atlantic in Namibia and the Limpopo River which drains east to the Indian Ocean toward its mouth in Mozambique. It is significant to note that each of these international river basins are classified among the top 15 basins internationally to be "most at risk" for conflict due to the assessed weak institutional capacity to absorb significant disturbance within each of these two vulnerable basins (Wolf 2003). Both basins are critical to development in the southern African region due to the high economic activity taking place within them, much of which depends on water and much of which contaminates the water. Therefore, a sub-national water crisis in these basins could transcend national boundaries thus regionalizing the problem through the politics of water (Vaz 2000, Ohlsson 1995). The bulk of economic activity falls primarily within four strategic watersheds that geographically comprise roughly 15 percent of the total area of both river basins. The Upper Vaal is a sub-basin of the Orange River. The Crocodile, Olifants, and Limpopo water management areas are sub-basin management areas of the Limpopo River (DWAF 2009) (see map 9 below). Consequently, these are the areas exposed to the highest AMD contaminations.

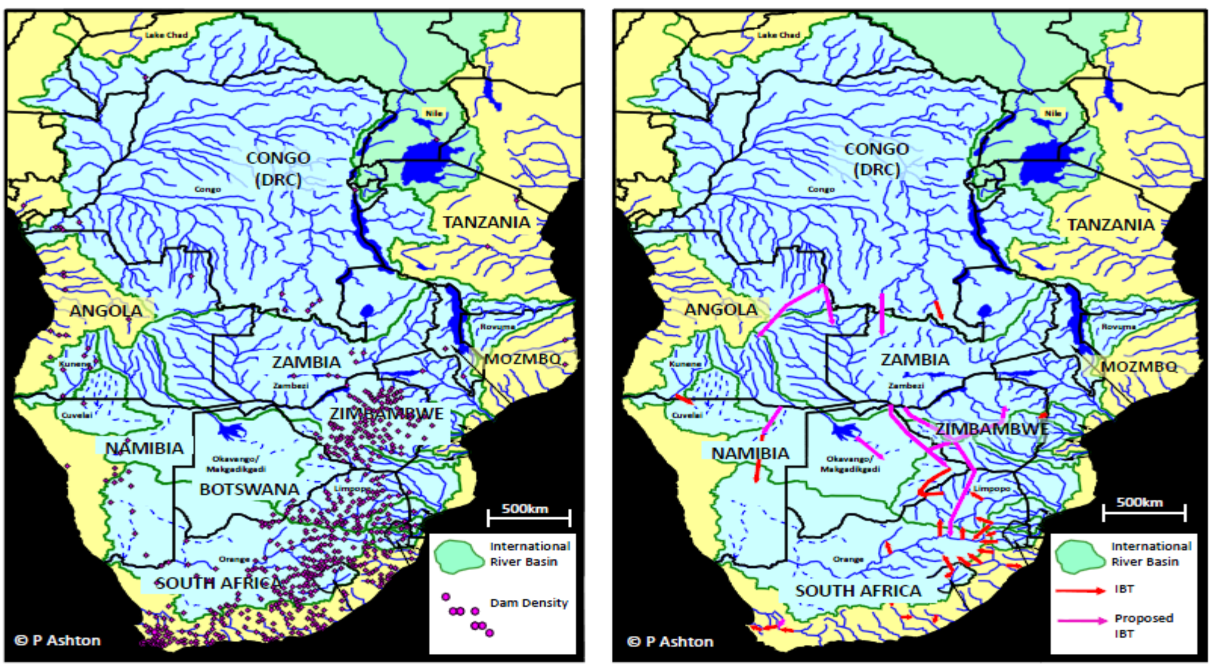


Map 9. Data source: Base map from Wikimaps. River data fromDepartment of Water Affairs and Forestry.

The British realized early in the 20th century that Johannesburg could not sustain the rapid growth given its geographical distance from an assured freshwater resource. Ironically, the megacity sits atop four sizeable aquifers but the labyrinth of mine workings dewaters much of the subterranean environment in order to operate the mines (McCarthy 2009b). British engineers conceived plans of a major hydraulic engineering scheme that would divert water from the mountainous Lesotho Highlands in the Kingdom of Lesotho, a small landlocked underdeveloped enclave within South Africa, into the Vaal River where it could be captured and stored in the Vaal Dam within proximity to Johannesburg. The massive project, called the Lesotho Highlands Water Project (LHWP) came to fruition in 1986 and its first major phase was recently completed in 2004. A second phase is underway and is projected to be completed within 20 years. It is the largest hydraulic project in Africa (IRN 2009).

Today, South Africa is among the top 10 countries on earth for highest dam density per kilometer of river, many of which were created during the era of dams in the mid 20th century before the long term impacts on ecosystem services were well understood (WCD 2000). South Africa also employs more basin transfer schemes than most other nations pumping water up and over basin divides toward the higher demand, thus further increasing its infrastructural complexity. The extensive engineering schemes have essentially run dry as there are no more economically viable future dam sites to exploit beyond the ongoing second phase of the LHWP (Turton 2008d).

Strategic reservoirs in South Africa are suboptimal. They are typically large, wide, and shallow as opposed to being ideally narrow and deep. The larger exposed surface area equates to a massive loss of water through evaporation – up to 40 percent of Johannesburg's primary strategic storage, the Vaal Dam, is lost annually to evaporation (Turton 2009a). One proposed transfer scheme for future water supply calls for the 1,500 kilometer transfer of bulk water from the water-surplus Congo River Basin to the water-deficit Vaal River Basin to sustain Johannesburg. This regional transfer scheme would likely have extensive impacts to ecological integrity creating new pathways for opportunistic species and pathogens to exploit linking two vastly different biological zones. Though the Minister of Water Affairs supports this concept, no formal plans to finance this massive scheme have solidified (ibid).



Map 10a and 10b: "Heroic engineering" of South Africa. 6a (left) shows the dam density of South Africa and Zimbabwe relative to its regional neighbors. 6b (right) shows existing and proposed inter-basin transfer schemes (IBTs). Note that proposed IBTs are significantly longer in distance than existing ones. Source: P. Ashton, Council of Scientific and Industrial Research (CSIR), Pretoria.

The hard path solutions from the 20th century are in effect short-run fixes. In most cases, they are not sustainable as the ecosystems and their associated services are severely degraded over time (Postel 2003). Remediating unforeseen damage is costly. Not remediating is also costly as ecosystem services are lost (ibid). This is lost energy from the system as it is no longer available for work. Furthermore, the hard path fixes make the institution more complex. A Congo River Basin transfer for example would be a massive undertaking and would increase the scale of complexity by at least an order of magnitude. Complexity decreases institutional resilience by making the institution more rigid. A rigid institution will splinter after a critical threshold is crossed. For example, if the Congo River Basin proposal were to come to fruition, a new supply of water will have been artificially supplied to the system and thus extend the conservation (K) phase of the adaptive cycle making it more complex and less resilient. A fall from this height in the cycle could be more precipitous, and more potential for a deep collapse. In the growth imperative economy, the new resource supply will be quickly appropriated as users become dependent upon its assurance. If the assurance of this flow became inhibited by some variable such as persistent drought for example, this growth dependent on this resource will essentially die on the proverbial vine. That could equate to massive disenfranchised citizens who demand service delivery that the state cannot deliver. When expectations of the society exceed the capabilities of the government, conflict can be the outcome, especially in a country with a historical propensity to resort to mass violence (Turton 2008c).

4.1.2. Water Quality: The Revenge Effects

As has been observed in most developed societies, technological manipulation of the environment often produces unanticipated consequences that manifest in time years later. DDT used against malarial mosquitoes and Agent Orange used to defoliate rain forest canopy each produced serious health problems to those exposed many years later. These are just two of many classic examples of the unforeseen "revenge effect" (Tenner 1997). The following water quality issues are revenge effects from 20^{th} century aggressive water management schemes used to develop the semiarid nation.

Ouroboros Effect: The Revenge Effects of Unintended Consequences
"The origin of the Ouroboros symbol (serpent devouring its own tail) can be traced to ancient Egypt and China, Norse mythology, Medieval Europe, and into modern times. It has been interpreted in a variety of ways, but here represents the cyclic and interactive nature of events. More specifically, it reflects how some of our best attempts to solve problems comes back to bite us!" http://faculty.css.edu/dswenson (multiple examples on website compiled by D. Swenson, PhD)

Figure 5. Ouroboros Effect

4.1.2.1. Dilution Capacity

"The solution to pollution is dilution" was a common mantra of civil engineers and industry alike that reverberated in the previous era in the United States when there was still a large industrial footprint. Much of the industrial byproduct spewed directly into rivers exploiting their function as free open sewer systems. This is still common practice throughout the world where industry thrives. Though this policy is quite flawed and no longer tolerable in most developed societies, there is at least some measure of truth to this principle. That is, a toxin of some finite amount will have less potency in a larger volume of water than a smaller volume as it can achieve greater dispersion. Given the extremely low level of dilution capacity of South Africa's rivers discussed previously as well as the abundance of dams that slow and stagnate flows, any toxic effluent will have a more significant impact under these conditions (Turton 2008b).

Recently, ecologists have researched to establish the "critical thresholds" of riparian habitat in order to establish a minimum in-stream flow for which the basic functions of that ecosystem (along with its ecosystem services) can still persist (Postel 2003). This is extremely important for the stakeholder parceling of off-stream water appropriations. However, these established minimum flow levels do not account for an infusion of toxins of a given quantity or potency and the higher flow that would be required to dilute them to a safer level. The dilution and transport of toxins by a river is an especially critical ecosystem service but one that has been severely degraded by human land and water use in South Africa. Recall that water not there is energy not there for the work required to transport. Reducing the flow reduces resilience of the watershed to shocks. Maintaining a minimum in-stream flow at the so-called Environmental Critical Level (ECL) may seem most efficient in the competing use for water but does not allow for flexibility of the watershed to sustain shocks from quality (toxic effluent) or quantity (prolonged drought).

4.1.2.2. Industrial Waste and Algal Blooms

In recent years, rivers downstream of mining and industry have suffered chronic eutrophication, particularly in the Limpopo River basin in the northeastern provinces of Mpumalanga and Limpopo as well as Northwest Free State(McCarthy 2009c). Biodiversity is exceptionally high in this region. World renowned Kruger National Park, the top tourist attraction in the country is located in this margin and is under increasing pressure from decreasing water quality. Several water bodies in this region have turned bright green due to algal blooms, most of which contain the accumulation of mycrocystins.

Microcystins are an especially virulent form of cyanobacteria that are highly toxic to the aquatic life exposed to them. Large die offs of crocodiles, fish, and other aquatic vertebrates have been observed where these toxins have accumulated as this bacteria attacks their internal organs (ibid).

Hardbeesport Dam is strategic water supply situated downstream on the outskirts of Johannesburg. It supplies water to the Johannesburg and Pretoria conurbation and is an especially popular tourist destination owing to its resorts, scenic beauty and many boating and recreational activities (DWAF 2009). However, algal blooms containing the microcystins have severely impeded both the tourist economy and its more important function of supplying water. The algae clogs the hydraulic infrastructure by clogging filters, reducing pipe and canal capacity and drives up the cost of service delivery to the household consumer. In some cases, the water is so severely polluted it is even unfit for industrial use(McCarthy 2009a). Currently, there are no known solutions to remediate against microcystins. They are especially persistent as they remain in the sediments of water bodies. Current levels of the persistent microcystins are over 100 times greater than ever occurred in the United States. Only China compares with a higher degree of microcystin contamination due to grave water quality issues(Turton 2008b). AMD from coal mining facilitates these algal blooms as does industrial and agricultural effluent (McCarthy 2009a). Microcystins will be an increasingly serious impediment to water security as coal mining in this region is projected to increase (ibid).

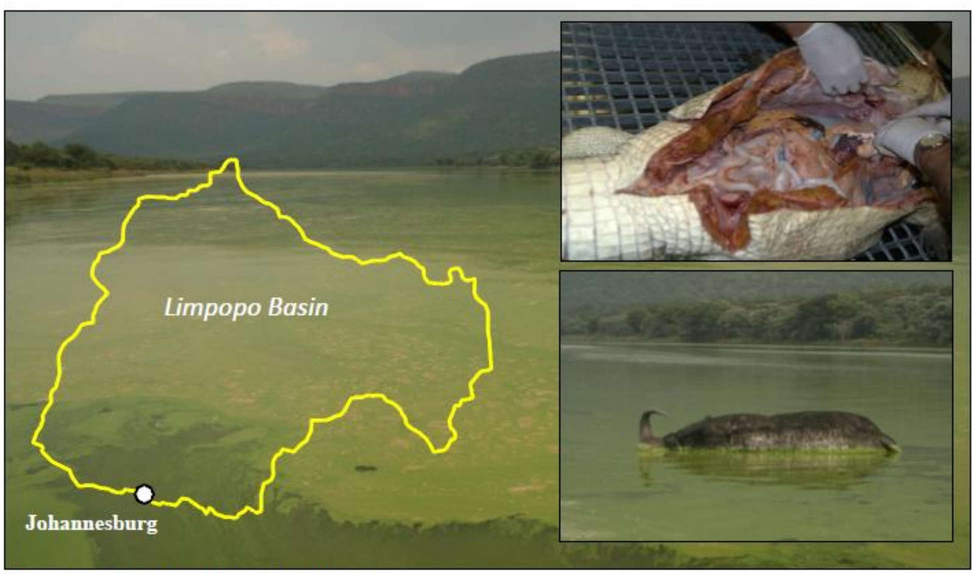


Photo credits: S McCarthy, University of Witwatersrand

Algal bloom in a reservoir in the Limpopo River Basin. The cyanobacteria can be extremely toxic. The microcystis formed here are always toxic. Autopsies on animal carcasses reveal hardening of vital organs. Microcystis blooms are increasingly common in the Limpopo basin (McCarthy 2009).

4.1.2.3. Municipal Sanitation and Pathogens

Municipal sanitation in the Johannesburg conurbation is in virtual crisis(Turton 2009a). Currently, this is a publicly operated service. Those charged with running these facilities often lack the skills and leadership necessary to do so safely and satisfactorily. Technical water experts have become a scarce commodity in the country in recent years. Those that are there typically are not working in the public sector and they are especially not working in sanitation jobs like sewage treatment facilities. This job is poorly incentivized and the least desired. As such, the lowest qualified technicians are charged with operating these facilities. The result is often a dysfunctional facility that may remain "offline" or degraded for long periods of time due to maintenance problems and the inability to rectify them in rapid order (ibid). Dysfunctional sewage treatment enables the proliferation of water-borne pathogens and chemicals. This has become a significant problem in the northeast provinces where cholera, tuberculosis, and diarrhea have become a major problem in the many poor communities where the water crisis is already very much present (Turton 2009a). This adds further strain to a health care system already burdened to capacity by the HIV / AIDS epidemic.

4.1.2.4. Transboundary Impacts of Upstream Water Quality Issues

While coal mining byproduct directly impacts strategic water resources in South Africa, it has further reaching effects internationally. The coal mining footprint straddles three transboundary river basins: the Limpopo, Orange, and Incomati River basins. Of special concern is South Africa's downstream developing neighbor Mozambique where the Limpopo and Incomati Rivers drain to their mouths in that undeveloped country. These rivers traverse eastward from their severely polluted tributaries in the Highveld uplands down through the fertile agricultural coastal lowlands of Mozambique toward their mouths on either side of Maputo, the nation's capital and largest city of the country. Mozambique, one of the poorest nations on earth, has not been party to international river basin treaties which otherwise could afford them some legal protection against polluted water and rights to benefit sharing with its upstream polluters(Turton 2008a). Mozambique is still emerging from a tumultuous past. Shortly after fighting for and winning independence in 1975 from Portugal, its colonial occupier, a protracted civil war followed spanning three decades halting any possibilities for development. Since the cessation of war in the 1990s, Mozambique has seen modest but steady growth (IMF 2010). Continued growth will rely on assurance of safe water supplies at the mercy of South Africa and its other upstream riparian neighbors.

4.1.3: Climate Change

Exacerbating all of the current water challenges facing South Africa are the predictions forecasted by the International Panel on Climate Change (IPCC). The most current modeling scenarios predict as much as a 30 percent decrease in MAP in the Orange and Limpopo River Basins and a significant increase in temperature by as much as 3 to 5°C by 2090 (IPCC 2007). This makes this region somewhat of a "ground zero" for climate change impacts as these are among the most severe changes predicted in any world region.[22] Should this forecast come to fruition, the climate in these already vulnerable basins would shift from semi-arid Mediterranean climate to a purely desert climate more susceptible to extreme climatic events such as prolonged drought. Increased temperatures may also bring malaria deeper into the country which for now only exists along the subtropical border margin with Mozambique.

4.2. Energy Security

4.2.1. Load Shedding

In 1998, the Department of Minerals and Energy warned of the approaching energy crisis calling for immediate energy reform of the grid and massive private investment. Unfortunately, the government did not heed the warnings and investment never came. By 2007, Eskom, the government-controlled energy provider to the country could no longer meet the energy demands of the entire grid. The company started rationing its energy by implementing rolling blackouts or load shedding to avoid a total collapse of the grid. Mines and industry would go dark for days at a time as would business enterprises of all sorts. Economic activity in Africa's most economically productive nation would become significantly constrained by the lack of electrical power (Bearak 2008). Load shedding is predicted to occur until 2013 when new power plants are completed.

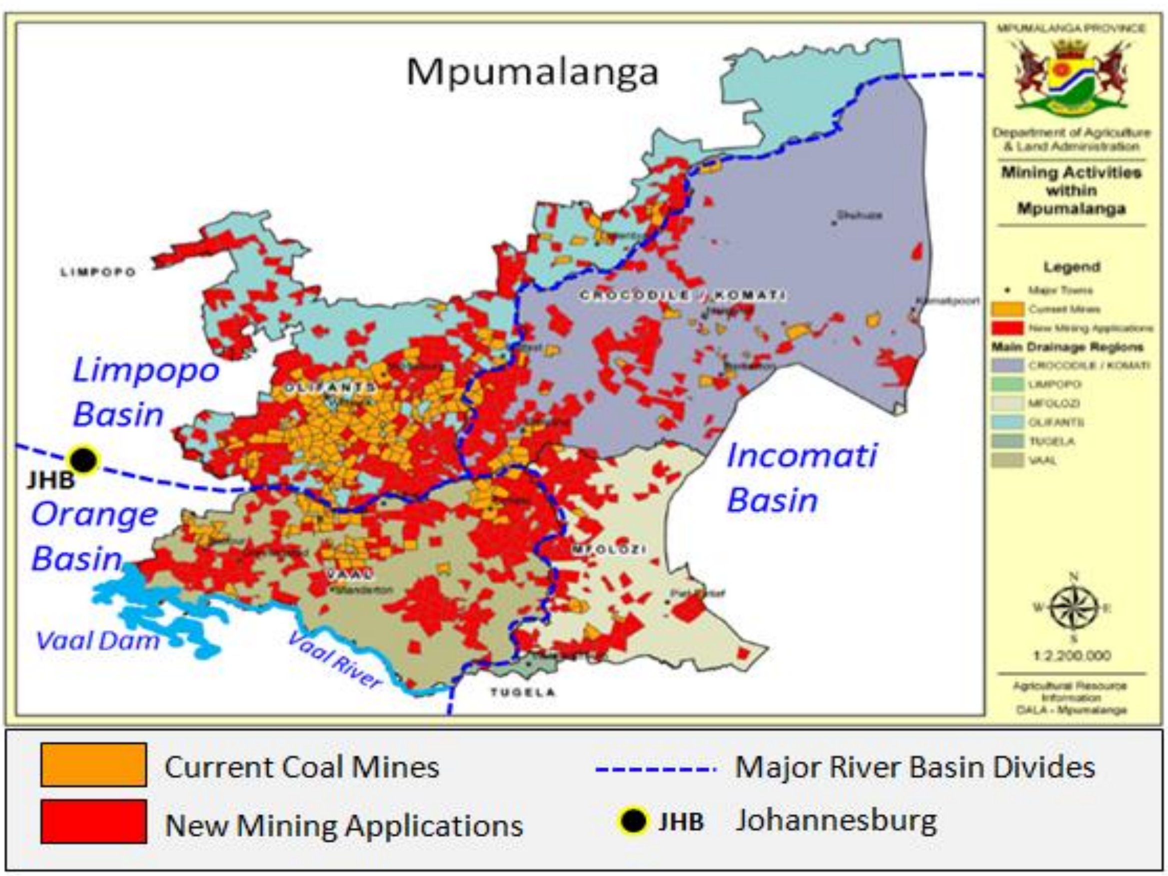
The energy sector faltered for several reasons. First, the energy infrastructure is greatly outdated and disjointed in its organizational structure. In 2007, there were over 400 subsidiaries of Eskom spread across the country, many of which were dysfunctional in both human resources and dated hardware(Bearak 2008). Efficiencies have since been made freeing up more potential energy. Second, as a factor of the democratic transition from Apartheid in 1994, nearly 30 million more South Africans now had access to the grid after many spent the oppressive Apartheid era in the dark. The grid simply could not absorb this massive influx of new users and was ill-prepared for this reality (ibid). Third, in recent decades, South Africa diversified its economy reducing the percentage (but not the size) of the mining sector in the GDP to just 10 percent compared to 50 percent of the mid 20th century. Manufacturing and industry rose to 30 percent of the economy (CIA 2009). The increase in industry greatly increased the need for ever-more energy to support the developments. While the economy diversified, the energy sector did not. Fossil fuels cornered the market as they have for years. Finally, the government did not mobilize its available resources after the warning from nearly a decade prior that the grid would fail in the near future (Bearak 2008).

4.2.2. South African Coal: The Give and Take of Energy

Coal is the primary source of energy in the country as it is cheap and abundant. The coal footprint is centered in the Mpumalanga province in the northeastern margin of South Africa. The northeastern coalfields are the powerhouse of the entire country supplying 75 percent of the entire electrical power budget of South Africa (DME 2009a). Abundant smoke stacks from industrial coal burning break up the pastoral horizon in this region. The irony of coal in South Africa is its geographic occurrence in the most agriculturally productive part of the country. Agriculture comprises five percent of the economy, a comparatively small portion of the GDP but accounts for 10 percent of total employment (CIA 2009). A predominantly arid and semiarid state, most of the country's soils are too marginal to support significant agricultural production. The northeastern region however does support quality larger scale agricultural production as the soils are far more conducive for production in the subtropical margin in the northeast where annual rainfall is significantly higher than the extreme arid west. Industrial coal mining in the northeast consequently compromises the productivity of these limited agricultural zones due to AMD byproduct (McCarthy 2009c). Essentially, the energy "investment" that coal offers conversely results in the "withdrawal" of less obvious but very real energy sources offered by the agricultural productivity.

South Africa ranks third in the world for coal exports (COM 2010). The Olifants basin in the Mpumalanga Province, a sub-basin of the Limpopo is worth over USD 3.7B in coal exports. This equates to employment for tens of thousands in that region alone. The World Bank recently agreed to funding a coal mining plant in the Limpopo basin for USD 3.5B, despite President Barack Obama's statement of non-support for fossil fuel projects due to climate change concerns (Dugger 2010). According to the development minister of South Africa, not receiving the loan would have been more consequential. The project would have gone forward with far more expensive financing (ibid). The World Bank did however mandate one quarter of the loan to be invested towards renewable energy in accordance with its climate policy. Of note, the loan provided by the World Bank is the first loan by that institution to South Africa since the bank participated in Western sanctions against the country initiated during the Apartheid era (ibid).

With the current energy crisis, the development of coal mining in the Limpopo basin has no apparent end in sight. The map below generated by the province of Mpumalanga's Department of Agriculture and Land Administration shows the active coal footprint (orange polygons) in this northeastern province as well as the vast future potential of coal mining indicated by the current applications for extraction (red polygons). The map represents jobs but also serves as an ominous forecast for the several affected watersheds.



Map 11. Map showing the Mpumalanga Province where the majority of coal mining occurs. The orange areas are current coal mining activities while red areas are areas where coal industry has applied for future extraction. The Vaal, Olifants, and Crocodile basins in this map are tributary basins to the Orange, Limpopo, and Incomati respectively. (Source: Mpumalanga Province Department of Agriculture and Land Administration (courtesy T McCarthy at Witwatersrand University))

4.3. Socioeconomic Security: Governance, Demographics, Economic Shocks

The third category in this analysis applies to the broader range of other institutional stressors that exert enormous strain on the government. These stressors come from governance, multiple demographic pressures, and economic stress. At first glance, these stressors seem unrelated to the environmental issue at hand: acid mine drainage. However, using this systems approach, the evidence for decreasing institutional resilience becomes manifest. In this state, it is highly vulnerable to many types of shocks to include ones that come from the environment. Signals or foreshocks can be seen in increasing non-linear responses.

4.3.1. Post Mandela Era and Black Economic Empowerment: Is Affirmative Action Working?

When Nelson Mandela was democratically elected to the highest office of South Africa, a new nation was born. A new flag was raised and a new constitution drafted. The oppressive era of Apartheid officially ended and nearly overnight, over 30 million black South Africans now had freedoms previously unattainable for five generations. The vast majority of the population marginalized for five generations and extremely underinvested in by society would now access senior political and commercial positions previously unobtainable. This ongoing transition comes at time when the nation's critical aging hydraulic and energy infrastructure is reaching the end of its expected durability of approximately 50 years and requires modernized replacement and massive overhaul (Turton 2008b). Regardless of these daunting challenges, the leadership of Mandela generated a sense of national identity and hope that propagated through the "Rainbow Nation" and around the world about the prospects of moving forward beyond Apartheid and overcoming the frictions of rapid reform (Turton 2009a).

Large shoes are hard to fill. Mandela was succeeded by Thabo Mbeki in 1999, who remained in office until 2008. Widespread support for Mbeki paled in comparison to his predecessor (Turton 2009a). His legitimacy grew suspect when he vehemently declared the HIV / AIDS crisis as a Western pharmaceutical scam targeting Africa for exploitation. As such, Mbeki denied the access to anti-retroviral medicines and mother-to-child virus prophylaxis provided by global funds to hundreds of thousands of infected South Africans triggering decries of human rights violations. One report estimates over 330,000 lives and nearly 4 million person-years lost between 2000-2005 as a result of this unpopular policy (Chigwedere 2008). However, the more significant mark of President Mbeki's lasting legacy was his installment of the

Black Economic Empowerment affirmative action plan commonly referred as BEE. In concept, BEE was designed to more rapidly matriculate the black population into positions of power throughout all sectors, a noble and overdue goal. In practice, however, BEE has proven to be extremely divisive.

Ironically, one of BEE's most outspoken critics is political economist Moeletsi Mbeki, deputy chairman to South African International Affairs and brother of the now former president Thabo Mbeki. Moeletsi Mbeki argues BEE's policies as they are practiced are designed to keep and effectively suppress a large labor class from the benefits of empowerment. Only a small percentage of the majority black population, the upper middle class political elite have been empowered by this policy while most are in fact no better off financially than prior to its installment (Mbeki 2006). In the long term, the South African transformation powered by BEE is creating a larger urban underclass. Meanwhile the minority white population who are employed often find professional progression tenuous and live in fear of retrenchment.[21] The problems encountered by BEE are driven by a type of capitalism that is unique to South Africa; it is a capitalism with all power consolidated in its so-called Minerals and Energy Complex or MEC. Just as before the historic transformation, South Africa's powerbase comes from the MEC (Mbeki 2006). The MEC encompasses the sectors associated with extraction and finishing activities of minerals and metals as well as the generation of electrical power; a coal-dominated enterprise. Recent fiscal policies have allowed South Africa's other manufacturing sectors outside the MEC to succumb to the cheaper competition from China, which in turn has given the MEC all the more clout while driving unemployment up to an official 26 percent though broader definition estimates put it closer to 40 percent in the Black population (GPRG 2010). Additionally, the MEC's subscription to globalization practices allows for the international recruitment of lower cost labor which further keeps more South African's unemployed (Mbeki 2006).

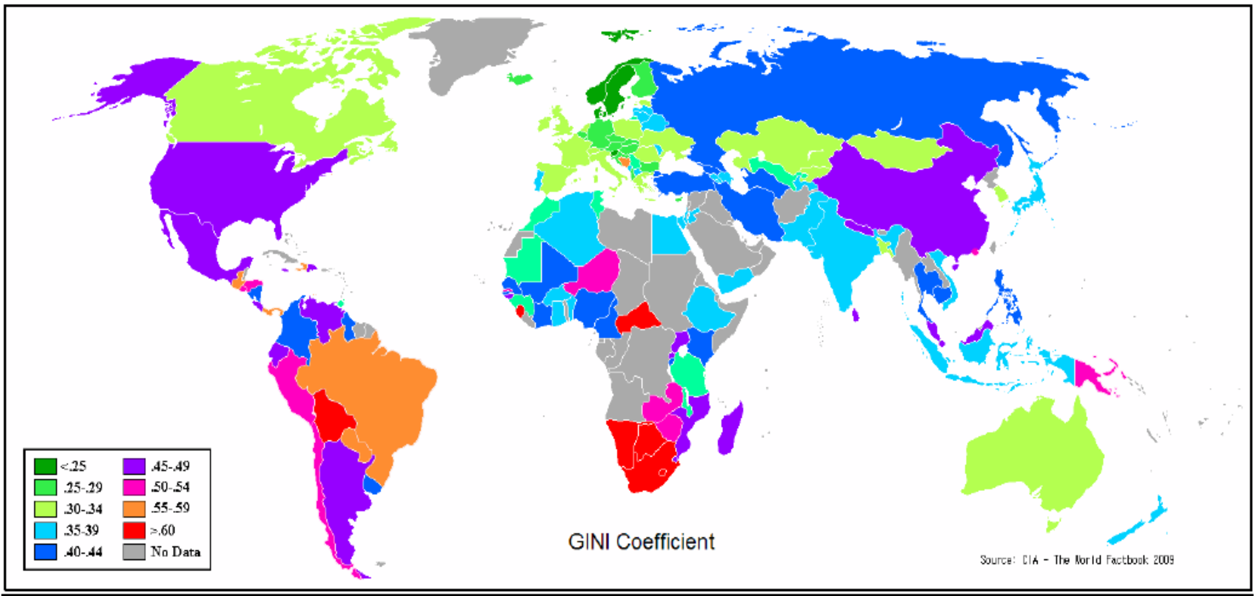
4.3.2. Civil Unrest: Tectonic Foreshocks?

Under current Zimbabwean dictator Robert Mugabe's regime, the neighboring country's economic prosperity collapsed into total economic ruin with a staggering 95 percent of the population now unemployed (CIA 2009). This triggered the outflow of some 6 million illegal immigrants into South Africa since 2000. Many argue that President Mbeki's passive policies toward Zimbabwe helped facilitate the collapse (Mbeki 2006). In 2008, violent riots erupted in Johannesburg targeting illegal immigrants from Zimbabwe leaving 64 dead, some of which were killed brutally by the mob in broad daylight by "necklacing," a brutal style execution previously used against accused collaborators during the Armed Struggle of the Apartheid era (Gordin 2008). A victim's arms and torso are forced inside of a rubber tire doused in gasoline and then set ablaze. The riots, motivated by xenophobia, are an indicator of the increasing scarcity of opportunities and resources that the government can no longer provide. When asked by the media why after eight years of steady immigration did the mob turn to brutal violence, Mbeki's response was simple: "The shanty towns are tinderboxes of poverty. All that has to happen is for one person to knock a car or cry 'thief' and everything can quickly go up in flames. These places are huge pressure cookers of poverty, HIV / AIDS… you name it!"(Mbeki 2008). This disproportionate response by the rioters is an example of non-linear behavior mentioned in Section II.

Riots in South Africa occur frequently, many of which receive little press attention (Welz 2009). They are largely motivated by disenfranchised populations protesting the lack of government services. In August of 2009, during the field phase of this research, members of South Africa's Defense Forces marched in front of Parliament in protest of the poor pay and benefits rendered to the nation's Defense Forces. The protests turned violent. The police extinguished the riots using full riot gear and non-lethal munitions. News images showed rioters overturning police cars and setting them ablaze on Parliamentary property. "When the level of expectation by society exceeds the capacity of government to deliver, then violence can be an outcome" (Turton 2009a). Furthermore, South Africa is a nation forged from extreme internal violence. The frequent violence dating back two centuries was never far from home and therefore families and communities could seldom avoid the social effects of violent conflict. Scorched earth policies, brutal concentration camps, targeting of non-combatants, and oppressive policies have left imprints on each of South Africa's diverse groups (ibid). Events such as the recent riots, especially those that resort to violence or sheer brutality could be foreshocks of the tectonic stresses building beneath the institution. In a nation with a historic propensity to violence and under multiple stressors to its institutions, one should expect to observe more instances of non-linear type of responses.

4.3.2. Income Disparity

The income disparity in South Africa is among the highest of anywhere in the world, ranking in the 10 lowest countries of available data (CIA 2009). The contrast of the two-tiered economy is glaring, as if two countries exist within the same border. Affluent gated communities juxtaposed against squatter settlements constructed of improvised materials are common sight. Most of the country's 49 million live well below the poverty line in conditions that are more representative of the rest of Sub-Saharan Africa. By GDP , South Africa ranks 32 out of 190, a top 20 percent ranking. GDP however is not representative of the "haves" and "have-nots". It ranks 129 out of 182 countries (with data) on the more comprehensive United Nations Human Development Index (HDI), among the lower half of the medium-developed countries. The GINI Coefficient of income disparity is represented in the map below (CIA 2009).



GINI Coefficient: an indicator used to measure income disparity.
A value of 0 means everyone in the country makes the same amount. A value of 1 means one person makes all the money. South Africa GINI value is >.60, the highest category of countries with data. (CIA World Fact Book)

Map 12. South African income disparity compared to the rest of the world (CIA WFB).

4.3.3. Impacts of Crime

> *"As long as I've lived, I've never known the feeling of security whether it was national security during the Cold War or fragile State security throughout the Apartheid era. Job security is never certain in this accelerated affirmative action environment and now crime is so out of control, I have no sense of personal physical security."*
>
> -- Anthony Turton PhD, University of Free State, former RSA Secret Service intelligence officer, Director of Touchstone Resources Ltd

High crime rates are symptomatic of a society that cannot provide adequate employment and a government failing to provide services such as adequate physical security. Violent crime is especially problematic in South Africa. Violent crime rates increased in the 1990s placing the nation consistently among the highest per capita violent crime hotspots in the world (UNODC 2008). It is considered to be the most dangerous country not at war (BBCNews 2002). It has been dubbed the "rape capital of the world", consistently leading the world in rape crimes. The increased crime forces the government to increase financial resources towards physical security which then drains energy from the total energy budget that could otherwise be directed elsewhere. The crime fighting budget is USD 3.5 billion, 11 percent of the total government expenditure (ibid).

Violent crime tears at the social fabric of the nation. Secure gated communities have become the norm for middle-class while non-gated neighborhoods rely on fortifying their individual homes with walls or razor wire fences and electric gates. This has the effect of internal compartmentalizing thus severing communication within neighborhoods making community or national identity harder to achieve. Another deleterious effect of crime is it serves as a "push" factor in emigration. South Africans have emigrated for a number of reasons in recent years. Crime is one of the primary concerns for many outbound expats (Turton 2009a, Johnson 2009). Typically, those who leave have skills and seek a safer life elsewhere. Lost skills are essentially lost energy from the society. It takes years to accumulate skills and considerable financial resources. In this way, crime facilitates a large outflow of energy in the form of human capital.

4.3.4. Flight of Ingenuity

> *"As upset as I am about my son leaving this county, I am equally upset that my daughter remains here"*
> -- response by a South African during a conversation on emigration (name withheld)

Like the rest of Sub-Sahara, South Africa itself suffers from the "brain drain" of its educated population. While some whites chose to leave after the regime shift in 1994, most remained during the Mandela era to experience the exciting prospect of a unified country with equal opportunity and less violence. However, the growing disenchantment with BEE policies and truncated opportunity for professional progression combined with increasing physical security concerns from rampant crime have facilitated the steady stream of emigration of White South Africans to Europe, North America, and Australia. Since the transformation, approximately 20 percent of the White population of South Africa expatriated while increasing amounts of Blacks, Coloureds, and Indians are also expressing their desires to leave (Johnson 2009). The country is experience an exodus on par with countries plagued by war or natural disaster (ibid). The loss of technical ingenuity is extremely detrimental to the water-stressed state in high demand of technical expertise. Recall that over time, societies or any complex adaptive systems become increasingly complex over time. The increasing complexity for society to sustain itself requires a level of technical ingenuity proportional to the amount of complexity. As this research has shown, South Africa's water security meshed with the energy crisis meshed with poverty and politics vastly increases complexity. Yet, the available science, engineering, and technology (SET) skills have declined substantially since prior to the transformation in 1994 (Turton 2008b).

Replacing the lost technical ingenuity with new ingenuity from the young black population is deficient. Funding to the Council of Scientific and Industrial Research (CSIR), the nation's primary research and development agency declined by nearly one half from 1989 to 2008. This is representative of all six agencies of South Africa's National Science Council. The amount of Black engineers trained has grown only marginally while the loss of older white engineers retiring or emigrating continues steadily. Furthermore, the engineers in the country are less available for public employment as most have aligned under private enterprise. Access to their skills is considerably more expensive to the government. This supply deficit of engineers combined with the growing demand for the need of their skills in the face of growing water and energy shortages creates a widening "ingenuity gap" whereas throughout the 20th century, the state maintained equilibrium in supply and demand (Turton 2008b, Homer-Dixon 1999)

4.3.5. HIV/AIDS: Water and Institutional Energy

Finally, there is perhaps no greater stress against South Africa's governing institution than the HIV/AIDS pandemic. South Africa's HIV prevalence rate is 18 percent, consistent with the southern Africa region (UNAIDS 2010). This pandemic is almost entirely confined to the Black population. Since the recognition of HIV/AIDS in the early 1980s, no one predicted the rate of prevalence and scale of crisis this would become today (Ashton 2002). The World Bank recognizes it as an absolute crisis for human development. As such, it is an extraordinary financial burden for the South African government heavily reliant on global fund donor aid, especially from the generous President's Emergency Plan for AIDS Relief (PEPFAR) initiated by former US president George W. Bush in 2003. Because the disease mostly affects young children and working-aged adults, it will continue to have deleterious effects on the economy for the foreseeable future. Its prevalence rate in both urban and rural communities impacts every sector of society and the economy. It will continue to drain enormous energy from the government in the form of lost financial and human capital.

It would first seem that there is no linkage of HIV to the water crisis aside from the enormous consumption of financial energy drained from the government. However, there are less obvious but significant links of HIV to water with long-term implications for water resource management. Where water quality is of heightened concern and water-borne pathogens are more common such as in the Limpopo and Mpumalanga provinces, a weakened immune system from HIV/AIDS is less resistant to the pathogens (Ashton 2002). This increases the risk of mortality which severs families and increases dysfunction in communities. While HIV/AIDS has truncated the population growth rate which in effect keeps water demand from rising, the effects on the economy and social dysfunction negates this one morbidly positive effect. Degraded socio-economic conditions in communities will require more subsidies (energy) from the government to render services to include water service delivery and sanitation (ibid).

4.3.6 Section Summary:

This section highlighted the multiple converging stressors placing enormous pressure on South African water management and the entire institution writ large. Like many places in the world, South Africa symbolizes a complex adaptive system that employed increasingly complex technological solutions to maintain the status quo during the 20th century. With a possible basin transfer from the Congo on the horizon, this conservation or steady-state phase may be extended deeper into the 21st century. Early sections in this paper illuminated some of the revenge effects of short term solutions – AMD, microcystins, pathogens, and insufficient dilution capacity to mitigate them. So though we cannot accurately predict how an alternate state will look, we can be reasonably assured that it will be severely constrained by a scarce water supply with potentially irreversibly damaged aquatic systems no longer able to render comparable ecosystem services. This leaves little room for a functioning society. Given its importance to the Southern African Development Community (SADC), a dysfunctional South Africa would likely produce deleterious effects throughout SADC and greatly hinder international efforts of achieving the Millennium Development Goals (MDG) in Africa, the greatest hurdle to this global effort.

V. Environmental Security in United States Foreign Policy

5.1 Environmental Security in the National Security Agenda

The focus now shifts towards United States policy towards environmental affairs abroad. The linkages of environmental degradation to collective socio-economic decay have become more evident to wider audiences in recent years. As such, the U.S. Government increased its vigil on the subject of environmental security since its emergence during the Clinton administration when it was elevated to a national security priority published in the 1998 National Security Strategy (Clinton 1998). National priority toward this security issue subsequently waned during the George W. Bush administration but it is once again gaining precedence under the Obama administration (Bush 2002, Dabelko 2009). Though it would seem as part of the revolving process of cyclical partisan turnover in Washington, it is more likely the result of increased academic understanding on complex social-ecological issues as well as increasing international and domestic pressure on associated matters, most notably climate change and the energy crisis. Still, national environmental security policies remain largely undefined. This is especially so for regional issues that would seem to bear no direct internal threat to the United States. However, in a globalized world becoming increasingly smaller, it is difficult to discern what is internal and what is external. If the socio-economic gap between the global South and the global North were to continue to widen, the current path of resource extraction from the South would eventually cause a systematic failure in global networks as resources dwindle and human populations deteriorate socioeconomically – a global scale manifestation of the release phase in the adaptive cycle.

The global water crisis could likely be the greatest challenge to humanity in the 21st century. While climate change debate continues to filibuster in political arenas and draws more press, the water crisis is generally recognized by all societies. With or without major climate changes, the water crisis will intensify due to current consumption patterns, pollution, population growth and momentum, urbanization, poverty, and weak institutions. Nowhere is the crisis more acute and widespread than in most all of Africa. Consequently, water is a common thread in many of the global issues including food security, disease, and poverty. Discussed in Section II, much attention has gone to the popular misconception of a future plagued by “water wars” – an extrapolation from the so-called “oil wars” of the current era. However, this attention is undue and unproductive. Therefore, it would be far more productive to direct focus on the vital role of water to sustaining a functional society. For when water security can no longer be assured, violent conflict or cultivated fanatical networks are only part of the many dysfunctions that could arise in a social system that begins to unravel and collapse. Consider the following statistics:

- *29 countries worldwide are currently under severe water stress, by 2025, 25 countries in Africa alone will be under severe water stress or water scarcity*
- *1.2 billion people do not have access to freshwater*
- *2 billion people do not have access to some reasonably hygienic form of sanitation*
- *2 million die every year from waterborne disease, over half of which are children under five (Gleick 2009, UNEP 2008)*

Note that far more people perish annually to water-related issues than in violent conflict. These conditions are largely distributed through the least developed regions. Africa remains especially problematical and is proving the most elusive region in the world in achieving progress toward the Millennium Development Goals of halving the population without access to safe water by 2015 (Gleick 2009).

5.2 Policy Recommendations Africa Command and the Environmental Security Mission

Given the enormity and gravity of the water crisis, the role of United States foreign policy towards water must be more clearly defined in order to meet this monumental challenge. It should involve a more collective inter-agency fusion of effort and it will have to be more focused geo-strategically to produce the greatest effects and still produce the *most* results for US interests. Congressional appropriations toward this end are critical as is the careful dispensing of limited funds. Concerted US commitment to this crisis presents opportunities to the US that transcend that of water to include increasing diplomatic clout, economic opportunities, and global leadership in an era where that leadership has come into question. The fusion of effort must build upon coordinated efforts from the “3 D’s”: Defense, Diplomacy, and Development implemented primarily by Department of Defense, State Department, and USAID respectively. However, other national elements of power shared by other agencies can bring significant assistance to the water crisis with coordinated employment of their assets. The scope of this policy recommendation stays in the vein of the working debate regarding the role of the Department of Defense (DOD) with specific consideration to its newest regional command AFRICOM.

Given the strong linkage of environmental degradation to rising security concerns, the DOD should assume a supporting role where the risks are highest, particularly in Africa. The recent establishment of

United States Africa Command (AFRICOM) makes that more realizable than at any time in the past. It is postured to actively oversee or assist program implementation under its auspices and take a key role in bringing several national elements of power together into a region previously considered an afterthought to the DOD.

Many Africans and internationals remain skeptical of the US agenda behind the establishment of AFRICOM believing its formation to be part of a geopolitical power play to: one, leverage the War on Terrorism to project interests and two, to counter the enormous footprint of China on the continent (Pike 2007). AFRICOM confronts such claims. Rather than operating in secrecy, it makes it a priority to speak directly to the international public through web forums administered by its Public Affairs officers. AFRICOM is a unique regional command which strives to operate as an interagency supporting entity in order to meet the specific challenges in its region rather than operate as a traditional battle-staff command structured to orchestrate large military campaigns (ibid). The establishment of the command symbolizes a major committed US initiative toward Africa as part of larger US paradigm shift toward Africa that began with the PEPFAR program in 2003 and other initiatives.

After its first year of official establishment, the debate continues as to how this command should participate in development tasks or posture against more contemporary threats such as environmental security. It is argued that the DOD should not participate in environmental security issues and be reserved strictly for traditional roles in contingency operations, natural disasters, humanitarian crises as they arise. However, based on the assertion that security is a precondition to development, this research suggests that while traditional expeditionary roles will remain the command's priority mission-essential tasks, it would be in the nation's interest for the command to assume less traditional supporting tasks as well, particularly on a continent posing the greatest challenges to development. This could be accomplished unobtrusively with an appropriately small footprint, as per the intent already specified by the Secretary of Defense as well as the command.

On the central matter of water, AFRICOM is ill-equipped to make direct impacts as there are scarce high payoff military-to-military opportunities in this regard. However, as the regional extension of the most powerful agency in the world, AFRICOM can generate some positive effects to the water crisis. To start, recognizing water's central role to *intrastate* security, the command should upgrade the issue of water throughout the continent to a higher risk profile. Currently, it is "nowhere near the top five security interests" for the command in South Africa (Langdorf 2009). Doing so would enable for more meaningful collaboration with other government, non-government, and international agencies, as well as commercial enterprises that are more resourced for environmental issues. Intrastate security issues are far more historically prevalent than interstate conflict in Africa (Tayob 2010). Therefore, the myth of interstate "water wars" should be discarded although the motivation of water security should be retained.

Modern tenets of integrated water resource management (IWRM) call for the decentralized management of the resource within the State. Resilience theory would also support that modularizing within a system protects the whole system from shocks (Walker 2006). AFRICOM is not resourced to work in a decentralized approach per say but can assist in the *centralized* planning of a *decentralized* system.

With resources always a constraint, AFRICOM would first have to establish its *strategic priorities*. There are 53 Africa nations in the African Union (AU). The command cannot interact with them all, especially with environmental security matters and therefore must prioritize the focal *centers of gravity* (COG) by region for which any benefits of improvement could radiate through the regional community in indirect ways. The COG would ideally be the strongest governments with the strongest economies and democratic principles but more realistically would be the ones with the greater regional influence. According to Moeletsi Mbeki, Deputy Chairman of the South African Institute of International Affairs, this is typically found in the larger African nations of South Africa, Angola, Nigeria, Ethiopia, and DRC (Tayob 2010). Regionalizing is already the command's intent to meet challenges on the continent. With COGs identified, environmental security risks that pose the greatest risk to those COGs should be greatest in priority since their internal effects could have more widespread impacts. Johannesburg and its surrounding gold and coal mining area presents the quintessential example. South Africa is to the continent what the US is to the world. Both comprise approximately 5 percent of the total population but make up one quarter of the total GDP to their respective scales (Tayob 2010). Most importantly, ***South Africa is the number one foreign capital exporter to Africa***, overtaking France, the UK, and even the US while China's investment is climbing rapidly (ibid). This underscores South Africa's criticality on the continent.

Possibilities for water security assistance AFRICOM could facilitate include:

- **Capacity Building:**

  Science Engineering and Technology (SET): Discussed previously, the growing water scarcity and complexity in South Africa is compounded by the flight of ingenuity from South Africa. For this society to persevere, it must reverse and stabilize this invaluable exodus of human energy. This will require a much larger international initiative. AFRICOM's role would be through access to the US Army Corps of Engineers (USACE) - leveraging an existing capability within DOD. USACE has a long history of water development in the US and therefore a strong base of institutional knowledge. The long duration allowed for significant evolution of the organization in this field as longer lag environmental effects from projects have become increasingly exposed. USACE personnel could be used on a limited expeditionary basis to assist in capacity building where institutional knowledge is scarce. Africa as a whole loses much of its educated talent abroad every year. A small contingent of USACE personnel could be deployed to capacity-build where there is high potential to strengthen institutions. This would be a two-way learning opportunity that could work in tandem with an Environmental Affairs component with a focus on sustainable methods and maintaining the value of desired ecosystem services into the future. South Africa is primed for this. Its institutional framework is already established and the new constitutional laws have codified progressive integrated water management strategies. There is a critical shortage of technical experts, especially those available to the government. USACE members could augment a program at one or more of the national science institutions such as the Council of Scientific and Industrial Research (CSIR) to help train new staff of South African state-ran engineering firms: South Africa Institute of Civil Engineers (SAICE) or the Water Institute of South Africa (WISA). An expansion of this could include sending South African students to the United States to attend technical apprenticeship programs such as the ones ran by the Bonneville Dam facility, a major USACE project on the Columbia River. This would increase technical expertise necessary to close the current ingenuity gap discussed in Section IV. This is especially important as much of the hydraulic infrastructure is aged and requires modernization.

- **Technology Sharing:**

  Geospatial intelligence sharing: Further provision of imagery/overhead assets available to US intelligence agencies could be shared. Sharing of remote sensing data would require selective declassification to assist in assessing land use changes and environmental responses to water quality issues such as vectors and radioactivity which can be detected from air and space remote sensing platforms. This would require collaboration amongst the various intelligence agencies such as the National Security Agency, the Central Intelligence Agency and Department of Defense subordinates. AFRICOM could be the clearinghouse for this type of geospatial data when sharing with African counterparts. Early warning drought and famine monitoring is already employed by remote sensing.

- **Project Scope Expansion:**

  AFRICOM already prioritizes environmental projects through the existing environmental affairs office. Many of the projects are valuable but narrow in scope, geared toward environmental improvement of military installations throughout the continent. This venture could be expanded into a broader scope of sustainable development projects that would involve a deployable cadre of USACE personnel to erect or improve hydraulic infrastructure that nests with the local values for managing water resources, similar to USACE missions in Iraq and Afghanistan. While USACE typically does not fall under the control of regional commands when deployed, AFRICOM's security needs would justify mobilization of USACE for water security projects. Increasing the scope of projects would require increased resources to the environmental desk. Project proposals should attempt to recruit African university higher education students whenever possible.

- **Increase Strategic Partnerships with Private Enterprise, NGOs/Non-profits, and Development Banks Committed to Development and Security:**

  Interagency operation is a focus of this unique regional command. This requires the full breadth of understanding of the enablers and their capabilities working on the continent toward water-specific issues. Additionally, it requires the means of sourcing domestic agencies such as the Environmental Protection Agency or Department of Agriculture to mobilize skills that are in demand in the region. This would especially useful where specific environmental security threats deserve specific attention. AFRICOM shares responsibility with national intelligence agencies to perceive near and long term security threats in its area of activity. As such, it should have the clout to assemble a customized task force of experts to respond to specific threats. In recognizing security threats, it should also pass recommendations to sister agencies. For example, the acid mine drainage issues and other water resource challenges exacerbated by the flight of ingenuity in South Africa highlights the urgency to generate local SET capacity. AFRICOM should recommend to Department of State to increase Fulbright Scholarship opportunities to prospective South African SET students to augment the country's domestic outputs of SET graduates and help shut the "ingenuity gap." In this case, AFRICOM initiates important resources and remains transparent.

In 2007 and 2008 USACE participated in a multi-agency Water Resources Management workshop in the Zambezi basin to promote capacity building and sound sustainable development in the multinational basin. The project included familiar NGOs including The Nature Conservancy, the World Wildlife Fund, and Conservation International and drew funding from multiple development banks (Cain 2008). Partnerships such as this have high potential to facilitate development and improve *resilience*. The rise of NGOs and Non-profits in recent decades with their significant resources makes these non-state actors important enablers. AFRICOM could help orchestrate such partnerships and provide supporting logistical assets such as rotary or fixed wing aircraft to reach remote regions with personnel and heavy equipment.

With the multitude of actors on the continent communications between actors and African institutions is problematic. AFRICOM could serve as a clearinghouse to synchronize efforts and communication to avoid redundancy, confusion, and wasted resources.

Each of the above recommendations is directed towards greater improvements to water resource management. However, given that water and energy crises are intertwined, the scope of efforts to bolster environmental security should not be limited to just a water-centric effort. Efforts to improve or influence any sector of energy consumption will almost by default yield improvements to the water crisis. This includes all energy constraints imposed on the society. For example, the HIV/AIDS pandemic is a major energy sink. It greatly strains the health care system, which siphons off government capital while depleting trained and experience human resources who succumb to the virus.

VI. Conclusion:

This research built argument toward the general question: **How can the traditional security establishment respond to rising non-traditional threats?** This question was reduced to a special case study on an environmental security issue taking place in what is arguably the center of gravity in the command's area of activity – the Johannesburg region. The legacy of development centered on its mines presents an enormous institutional challenge in the face of imminent water scarcity. The specific questions in the case study asked were: **how does mining, specifically acid mine drainage, impact water security in a country of increasingly scarce water supply? Is there sufficient institutional capacity to absorb this degree of environmental disturbance?** Finally, addressing United States policies toward this matter, **how should AFRICOM approach this issue?**

Section II provided the theoretical framework and systems approach used for this research. Resilience theory explains the adaptive cycle of growth, steady-state, collapse, and renewal and helps in understanding the concept of *thresholds events.* Applying this theory, we can come to understand the vulnerability of our social-ecological systems, particularly when they are under stress from converging factors or "tectonic stressors". Though the theory is limited by not being able to precisely predict thresholds, we can appreciate that they can be crossed with relatively small event in a complex adaptive system. Increasing institutional stress from environmental (water), energy, and multiple socioeconomic factors significantly increases the complexity and demand for overall energy resources to sustain the system – thereby eventually pushing the system into thermodynamic crisis(Homer-Dixon 2006). As this crisis pushes institutional resilience closer to its threshold, the smaller the tipping event is required to force a regime shift (Walker 2006).

The first specific case study question was analyzed in Section III. The impacts of acid mine drainage to water security were answered by visiting the affected areas and speaking directly with affected stakeholders, academics, and environmental engineers to gain clarity and scope of the AMD problem. A qualitative spatial analysis was done to show how the geography exacerbates this problem as the gold and coal mining extents are situated in water-scarce areas of poor water quality, high population, and consequently the highest economic activity historically on the entire continent. Complexity will increase manifold in the next few years as the mine void beneath Johannesburg continues to fill unabated with an AMD of a pH level of about 2.5. This water is projected to reach a strategic aquifer in the next few years and decant onto the surface with hypersaline water, toxic metals, and potentially radioactive uranium creating more potentially irreversible environmental damage and increasing negative socio-economic effects. As more gold mines close in the Witwatersrand in the coming years as returns diminish, the severity will increase. Meanwhile, the coal sector east of Johannesburg in Mpumalanga Province will continue to expand in important watersheds. Its spatial situation upstream to the most productive arable land in the country will threaten domestic production for centuries and destroy farming livelihoods. Water reclamation technology exists but is not economically viable, especially after cessation of the mine.

After analyzing the scope and severity of AMD in Section III, the research addressed the question of institutional capacity in Section IV. Using Homer-Dixon's (2006) theoretical model, the analysis considered multiple converging stresses which should have presented a reasonable qualitative estimate of the State's ability to absorb this degree of environmental disturbance. Of special concern is the State's capacity to maintain water security in the face of growing water scarcity – while under inordinate institutional stress. The current trajectory suggests that this is unlikely. It suggests short-term development policies of the previous era will be overcome by long-term environmental lag effects. The long-term realities or *revenge effects* will increasingly manifest in the coming years or decades until the current prolonged phase of the adaptive cycle, the conservation phase (K), succumbs into the back loop of uncertainty.

All complex systems eventually succumb to the back loop of the adaptive cycle where they will *release* their stored capital and eventually reorganize. Cycling through the back loop does not necessarily constitute collapse. Often, this is where opportunity for renewal emerges as the complex system goes through a potentially turbulent and chaotic reordering. In resilience theory, this is where "constructive destruction" occurs just as it does in a market crash (Walker 2004, Walker 2006, Homer-Dixon 2006). However, the nature of the transition from the previous phase could dictate how chaotic and consequently how reversible or renewable a system is. If the shock or disturbance is too great, this could facilitate a *deep collapse* – and the birth of a new system highly undesirable socially, politically, economically, and ecologically. Somalia and Haiti present examples of national-scale systems that are likely to remain dysfunctional in most aspects for the foreseeable future.

Although no one can accurately predict what type of alternate regime may arise from the cycling through the back loop of the adaptive cycle, we do have more reason to be concerned by a system that has been extended in the conservation phase of the front loop for a prolonged period of time. Why is this? As technological fixes are implemented to extend the “business as usual” progression, the system becomes decreasingly resilient by default.

Finally, in Section V the final question is addressed. The advent of AFRICOM in 2008 presents interesting debate about how the US can employ this regional command in a diplomatic manner on matters of environmental security. The intent of the Secretary of Defense for the command is to improve US relations and security while enabling African countries to develop in secure environments. Toward that end, policy recommendations are offered here. They are selected based on their potential to build resilience, not complexity into the system. AFRICOM, in a new post-Cold War security paradigm, can produce positive effects although is not likely to have major impacts. As an enabler to Africa-generated solutions, it can provide capacity building by way of the Corps of Engineers. It can share technology by consolidating geo-spatial data from various agencies and used to detect land use and disease vector spread. The command can raise the profile of its environmental desk and increase the scope of its environmental projects and not limit them strictly to military-to-military or installation improvement but also include more military-to-civilian projects targeted at improving environmental security in trouble spots near centers of gravity. Finally, it can pilot more projects with non-traditional partnerships such as the Water Resources Management workshop conducted for Zambezi Basin stakeholders.

This new command represents a post Cold War experiment. Many feel AFRICOM should remain in a traditional capacity reserved for contingency and capacity building in African militaries. However, given the rate of change in the world and evolution of security threats to humankind, it would seem negligent to resist adaptation to such profound changes. Refusing to adapt after all is how systems become complex.

Bibliography

Adler, R. A., Classen, M., Godfrey, Turton, A.R. (2007) Water, Mining, and Waste: an historical and economic perspective on conflict management in South Africa. *The Economics of Peace and Security Journal,* 2**,** 8.

Albertini, L. 1953. Origins of the War of 1914. London: Oxford University Press.

Anderson, E. W., Anderson, Liam D. 1998. Strategic Minerals: Resource Geopolitics and Geo-Economics. 180. West Sussex, U.K.: Wiley.

Ashton, P., Ramasar, V. 2002. Water and HIV/AIDS: Some strategic considertions in Southern Africa. In *Hydropolitics in the Developing World: A Southern African Perspective,* ed. A. Turton, Henwood, R. , 19. Pretoria: African Water Issues Research Unit (AWIRU).

Atwood, B., McPherson, P., Natsios, A. (2008) Arrested Development. *Foreign Affairs,* 87**,** 123-132.

BBCNews. 2002. Talking Point: Crime in South Africa. London.

Author. 2008. Power Failures Outrage South Africa. *New York Times* January 31, 2008.

Bush, G. 2002. National Security Strategy. ed. T. W. House. Washington, D.C.

Cain, M. 2008. Using Sustainability to Build Stability in Africa: Strategic Policy Issues for the Army. Arlington: Army Environmental Policy Institute.

Chigwedere, P., Seage, G. Gruskin, S., Lee, T., Esses, M. (2008) Estimating the Lost Benefits of Antiretroviral Drug Use in South Africa. *Journal of Acquired Immune Deficiency Syndrom,* 49**,** 6.

CIA. 2009. CIA World Factbook.

Clinton, W. 1998. A National Security Strategy for a New Century. ed. T. W. House. Washington, D.C.

Coetzee, H., Winde, F., Wade, P. 2004. An Assessment of Sources, Pathways, Mechanisms and Risks of Current and Potential Future Pollution of Water and Sediments in Gold-Mining Areas of the Wonderfonteinspruit Catchment. ed. WRC, 266. Pretoria.

COM. 2010. Chamber of Mines. In *Economics and Statistics: Historical Summary*. Johannesburg.

Dabelko, G. 2009. Report: Issue 13 2008-2009. ed. J. Dabelko. Washington, D.C.: Woodrow Wilson Center Environmental Change and Security Program.

Diamond, J. 2005. Collapse: How societies choose to fail or succeed. New York: Viking Press.

Dilloway, J. 1999. *From Cold War to Chaos*. West Port: Praeger.

DIRC. 2010. Department of International Relations and Cooperation, Republic of South Africa. Pretoria.

DME. 2009a. Department of Minerals and Energy. Johannesburg.

---. 2009b. Overview of acid mine drainage impacts in the West Rand Goldfield: presentation to Director General of Department of Water Affairs and Forestry. Pretoria: Department of Minerals and Energy.

Dodds, F., Pippard, D. 2005. Environmental Security: An Agenda for Change. 270. Sterling: Earthscan.

Doyle, R. (2009) Interview: Richard Doyle, Chemical Engineer.

Du Toit, S. 2009. Interview with Stephan Du Toit, M.S, Environmental Manager at Krugersdorp Game Reserve, West Rand. Krugersdorp.

Author. 2010. South Africa Energy Needs Collide with U.S. Policy. *New York Times* April 6, 2010.

DWAF. 2009. Department of Water Affairs and Forestry.

FAO. 2010. Food and Agriculture Organization. Rome.

Gleick, P. 2009. The World's Water 2008-2009: The Biennial Report on Freshwater Resources. ed. P. Gleick. Washington, D.C.: Pacific Institute for Studies in Development, Environment, and Security.

Author. 2008. Ethnic Cleansing: South Africa's Shame. *The Independent* May 25, 2008.

GPRG. 2010. Unemployment, race and poverty in South Africa. ed. C. f. t. S. o. A. E. Global Poverty Research Group. Oxford.

Groffman, P. M. (2006) Ecological Thresholds: The Key to Successful Environmental Management or an Important Concept with No Practical Application? *Ecosystems,* 9**,** 13.

Gunderson, L., Holling, C. . 2002. Panarchy: Understanding transformations in human and natural systems. Washington, D.C.: Island Press.

Heyns, P. 2002. Interbasin transfer of water between SADC countries: A development challenge for the future. In *Hydropolitics in the developing world: A southern African perspective,* ed. A. Turton, and Henwood, R., 19. Pretoria: Afrian Water Issues Research Unit (AWIRU).

Hobbes, P. 2009a. Acid Mine Drainage in South Africa. 2. Pretoria: Council for Scientific and Industrial Research (CSIR).

---. 2009b. Overview of acid mine drainage impacts in the West Rand Goldfield. In *Sustainable Development Through Mining*. Pretoria: Council for Scientific and Industrial Research (CSIR), Department of Minerals and Energy, Council for Geosciences, MINTEK.

Holling, C. S. (1973) Resilience and Stability of Ecological Systems. *Annual Review of Ecology and Systematics,* 12**,** 16.

Homer-Dixon, T. 1999. Environment, Scarcity, and Violence. Princeton, NJ: Princeton Press.

---. 2006. The Upside of Down: Catastrophe, Creativity, and the Renewal of Civilization. 449. Washington, D.C.: Island Press.

IMF. 2010. International Monetary Fund. In *Counry Information*.

IPCC. 2007. Climate Change 2007: Synthesis Report. Geneva: International Panel on Climate Change.

IRN. 2009. International Rivers Network. In *African Rivers*. Berkeley.

Johnson, S. 2009. Fleeing from South Africa. In *Newsweek*. New York.

Kinzig, A., Ryan, P., Etienne, M., Allison, H., Elmqvist, T., Walker, B. (2006) Resilience and Regime Shifts: Assessing Cascading Effects. *Ecology and Society,* 11**,** 20.

Langdorf, K. 2009. Interview with COL Kelly Langdorf, United States Defense Attache to South Africa. Pretoria.

Liefferink, M. 2009. Interview: Mariette Liefferink, CEO of NGO Federation for a Sustainable Environment. Johannesburg.

Mbeki, M. 2006. What is Tranformation: The white roots of BEE. In *What is Transformation: The white roots of BEE*. University of Witwatersrand.

---. 2008. Jon Snow talks to Moeletsi Mbek about the violence flaring in South Africa's townships.

McCarthy, T. 2009a. Interview with Terence McCarthy, PhD, Professor, Geochemistry and Mineralogy, University of Witwatersrand. Johannesburg.

---. 2009b. Interview: T. McCarthy, PhD, Geochemist, University of Witwaterrand. Johannesburg.

---. 2009c. Water Water Everywhere, nor any Drop to Drink: The long term impact of coal mining on the Highveldt. Johannesburh: University of Witwatersrand.

McCarthy, T. a. R., Bruce. 2005. The Story of Earth and Life: A Southern African Perspective on a 4.6 Billion Year Journey. Cape Town: Struik.

Ohlsson, L. 1995. Hydropolitics: Conflicts over Water as a Development Constraint. 230. London: Zed Books Limited.

Pakenham, T. 1991. The Scramble for Africa: The White Man's Conquest for the Dark Continent from 1876 - 1912. New York: HarperCollins.

Peterson, G., Allen, C., Holling, C. (1998) Ecological Resilience, Biodiversity, and Scale. *Ecosystems,* 1**,** 12.

Pike, D. 2007. Africa Command: Opportunity for Enhanced Engagement or the Militarization of U.S.-Africa Relations? In *House Committee on Foreign Affairs, Subcommittee on Africa and Global Health*. Washinton, D.C.

Postel, S. R., Brian. 2003. Rivers for Life: Managing Water for People and Nature. 253. Washington, D.C.: Island Press.

Respondent1 (2009) Interview: Farmer near Carltonville alledgedly affected by acid mine drainage from gold mining upstream.

Rex, H. 2009. Interview: Harry Rex, Manager of Environmental Management Division, AngloGold Ashanti Corporation. Carltonville.

Sams III, J., Beer, K. 2000. Effects of Coal-Mine Drainage on Stream Water Quality in the Allegheny and Monongahela River Basins - Sulfate Transport and Trends. In *Water Quality Assessment Program*. U.S. Dept of Interior, U.S. Geological Survey.

Sole, R., Bascompte, J. 2006. Complexity in Ecological Systems. In *Self-Organization in Complex Ecosystems,* ed. R. Sole, Bascompte, J. Princeton: Princeton University Press.

Stone, R. (2009) Divining Angkor. *National Geographic,* 216**,** 28.

Tainter, J. 1988. The Collapse of Complex Societies. New York: Cambridge University Press.

Author. 2010. Moeletsi Mbeki addresses AFRICOM: Speaking truth to power or self-effacing obsequiousness? *Pambazuka News* May 13, 2010.

Tenner, E. 1997. *Why Things Bite Back: Technology and the Revenge of Unintended Consequences*. New York: Random House.

Thompson, L. 2001. A History of South Africa. New Haven: Yale University Press.

Turton, A. (2008a) A South African Perspective on a Possible Benefit-Sharing Approach for Transboundary Waters in the SADC Region. *Water Alternatives,* 1**,** 20.

---. 2008b. Three Strategic Water Quality Challenges that Decision-Makers Need to Know

About and How the CSIR Should Respond. In *Science Real and Relevant*. Pretoria, RSA: CSIR (Note: CSIR did not endorse this keynote address).

---. 2008c. Three Strategic Water Quality Challenges that Parliamentarians Need to Know About. ed. N. R. a. Environment. Pretoria.

---. 2009a. Interview with Anthony Turton, PhD, Professor, University of Free State, Director of Touchstone Resources, Ltd. Johannesburg.

---. 2009b. South Africa's Own Inconvenient Truths. In *SA Society of Aquatic Scientists Conference*. Magaliesburg.

Turton, A. R., Ashton, Peter J. (2008d) Basin Closure and Issue of Scale: The Southern African Hyrdopolitical Complex. *International Journal of Water Resources Development,* 24**,** 305-318.

UNAIDS. 2010. Joint United Nations Programme on AIDS Country Data.

UNEP. 2008. Freshwater Stress and Scarcity in Africa by 2025. Nairobi.

UNODC. 2008. United Nations Office on Drugs and Crime. United Nations Office on Drugs and Crime periodic report.

Vaz, A., Pereira, A (2000) The Incomati and Limpopo International River Basins: A View from Downstream. *Water Policy***,** 13.

Walker, B., Holling, C., Carpenter, C., Kinzig, A. (2004) Resilience, adaptability, and transformability in social-ecological systems. *Ecology and Society,* 9.

Walker, B., Salt, D. 2006. Resilience Thinking. Washington, D.C.: Island Press.

WB. 2010. World Bank (Countries/Africa).

WCD. 2000. A New Framework for Decision Making: The Report of the World Commission on Dams. ed. W. C. o. Dams. London.

Welz, A. 2009. Interview: Adam Welz, freelance journalist specialing in environmental issues. Johannesburg.

Wolf, A. T., Yoffe, S. B., Giordano, M. (2003) International Waters: Identifying Basins at Risk. *Water Policy,* 5**,** 29-60.

Endnotes:

1. The Falkenmark Water Stress Index is a metric defining the physical parameters of water stress and water scarcity. A country under water stress is defined at level of water availability between $1700m^3$ and $1000m^3$ per capita annually. When this level drops below $1000m^3$, then the system enters conditions of water scarcity. When it drops below $500m^3$, the system has reached chronic scarcity and implies a critical constraint to life. While convenient to use for national aggragation, this system has many shortcomings. It does not account for the demand from a specific country nor does it infer water quality problems that would significantly alter the data. Furthermore, it does not dissagregate spatial or temporal or social variations at the sub-naitonal scale or sub-basin scale. Some have access while others do not within the population. (http://www.Africanwater.org/). For simplicity, this research uses this very simplified index.

2. The "3 Ds", Defense, Diplomacy, and Development are the three pillars of so-called "smart power" used by Secretary of State Hillary Clinton and other foreign policy officials and commentators. The Department of Defense, State, and USAID are the primary agencies.

3. In the Cold War era, "environmental security" referred more to strategic capture of natural resources to strengthen State security. This was a pre-World War II era German political philosophy called "Realpolitik". Realpolitik refers to political decisions that are based simply on power acquisition and disregards morality. E.g., the Reich recognized the vast plains of Eastern Europe as the bread basket of the world. Whoever controlled these plains essentially controlled the world (according to that philosophy). However, environmental security in its modern context essentially is the resurgence of the ages-old Malthusian debate first originated by Thomas Malthus in 1798 citing socio-economic problems with resource scarcity in his collection of essays.

4. The "Hard Path" and the "Soft Path" is used by Peter Gleick to describe the supply-side large engineering projects vs. demand-side management strategies and technological efficiencies. See: Gleick, P. 2003. Global Freshwater Resources: Soft Path Solutions for the 21st Century. Pacific Institute for Studies in Development, Environment, and Security. Oakland http://www.atmos.washington.edu/~earth/earth3/gleick.pdf

5. Stakeholders and other interested parties included included in this research were:
    - Three farmers in an affected basin west of Johannesburg near Carletonville
    - Krugersdorp Game Reserve wildlife manager working in the contaminated game reserve (name withheld). The KGR wildlife manager was gracious enough to escort me from the problem areas upstream of the reserve to various areas of the game reserve. He provided copious water quality records taken regularly at the reserve.
    - Mariette Liefferink, CEO of Human Rights and Environmental NGO Advocacy called Federation for a Sustainable Environment (http://www.fse.org.za/). Ms. Liefferink is

nicknamed the "Erin Brokovich" of South Africa as a result of her rigorous campaign for human rights and accountability in areas contaminated with radioactive mine waste.

- Professional academics included scientific subject matter experts Dr Terence McCarthy, a Geochemical and Minerals professor from the University of Witwatersrand; Dr Anthony Turton, from the University of Free State and Director of Water and Energy company Touchstone Ltd; DThe Council for Scientific and Industrial Research (CSIR) and the Council for Geosciences. One mining house representative was interviewed. This was the environmental manager for AngloGold Ashanti Limited in Carletonville in the Far West Rand of the Witwatersrand Goldfields.
- Environmental reclamation engineers included those working for Rand Uranium at an AMD reclamation project at the decanting mine shaft in the West Rand of Johannesburg. Another prospective geochemical engineer, Richard Doyle specializing in ion exchange was interviewed.
- United States Defense Attaché to South Africa: Colonel Kelly Langdorf, US Embassy at Pretoria
- United States Minerals Attaché to South Africa: Paul White, US Embassy at Pretoria

Public participation workshop events attended were sponsored by Goldfields, Manganese Metal Company and the Krugersdorp Development Committee. These events were attended to gain public perception of the environment threats from the mines.

Coal mining AMD sites were not visited. Data from coal mining was obtained from Dr Terence McCarthy though much of the research orginates from Dr Paul Olberholster at the Council of Geosciences.

6. For the spatial analysis, I did not use a certified GIS program such as ArcMap. I simply used a blank raw map obtained from Wikipedia's raw maps available online and manually added layers to it from river basin data obtained from Department of Water Affairs and Forestry (DWAF) and economic geology data from Department of Minerals and Energy to formulate a geographic picture of the mining footprint relative to watersheds, economic hubs, agricultural areas, and population centers.

7. The Basins at Risk (BAR) project showed that violent conflicts that do emerge from water disputes are largely skewed in scale. Conflict occurs far more often at the smallest scales, e.g., farmer to farmer and extremely rare or practically non-existent at the international scale. (Wolf et al 2003).

8. Although adaptive cycles are more elaborated in ecology, the term "creative destruction" was coined by an Austrian economist Joseph Schumpter in 1950 when talking about the boom and bust cycles of capitalism… *"the perennial gale of creative destruction"* (Walker and Salt 2006).

9. The algal pond example is also used by Walker and Salt (2006).

10. The Everglades of south Florida is a National Park and United Nations World Heritage Site. Settlers who first viewed the biodiversity hotspot as a major obstacle to agricultural development devised hydraulic schemes to drain the Everglades of its life blood: its slow moving water. The U.S. Army Corps of Engineers constructed a series of levees to block the flow of water from Lake Okeechobee to the Everglades. The establishment of industrial agriculture in the region changed the entire phosphate cycle of a large part of the Everglades. Efforts to recover the Everglades to something close to their original state are ongoing, expensive, and especially intractable with the farming community within that social-ecological system.

11. The examples provided in this paragraph are inspired by the concepts provided by Homer-Dixon (2006) as well as conversations with Dr Anthony Turton, Director Touchstone Resources Ltd.

12. Much of the growing body of evidence that supports the theory that certain past civilizations collapsed comes from correlating droughts through tree ring data.

13. Gold was found in the Witwatersrand 15 years prior to the 1886 Gold Rush. However, its potential was largely kept secret. The 1886 discoveries revealed the vast potential of mineral wealth lying below the surface and prompted the Witwatersrand Gold Rush.

14. Miners employed at the Grootvlei gold mine operated by Aurora Empowerment Systems in the East Rand of Johannesburg have not been paid in three months leading up to the print time of this paper. Striking miners erupted into violent riots and clashes with state police in late March of 2010. The Grootvlei site is also accused of dumping untreated acid mine drainage directly into the watershed. One of the respondents in this research, Adam Welz, a South African freelance journalist is currently filming a documentary on the effects of AMD and received minor injuries while filming on location at the Grootvlei riots.

15. During the Armed Struggle when military force was used domestically, these artificial ridges were used by the South African Defense Forces to observe the townships and direct artillery strikes at targets within the townships (Turton, 2009a).

16. “Ms. Ples” is the name of the hominid skeleton found in the Sterkfontein caves near the decant site – though some paleoarchaeologists suspect it is a “Mr Ples”. Paleoarchaeologists believe she (or he) and other like her lived and evolved in this area because it is an elevated region which receives cooler temperature and therefore less disease vectors. She and her kind would have had abundant freshwater resources from the myriad springs in the dolomite outcrops. Mining in the contemporary era has dewatered the groundwater hydrology and virtually no water flows from the defunct springs (information obtained at the Sterkfontein caves).

17. All of the information in this paragraph regarding bentonite use was obtained from specialists during a visit to the Rand Uranium site where reclamation efforts are ongoing at the point of decant.

18. The Orange and Limpopo Basins are used throughout this paper to emphasize spatial relationships with the water quality issues. This is because these basins are assessed to be at risk (Wolf et al 2003). However, of most economic significance are the sub-basins. The Vaal River is a tributary to the Orange but is far more strategically important to South Africa's prosperity. The Crocodile and Olifant Tributaries of the Limpopo Basin also share the vast majority of the economic activity in the Limpopo Basin.

19. The new constitution of South Africa drafted after the historic transformation codifies progressive environmental stewardship. However, corporate accountability and government enforcement are highly insufficient. Many in South Africa believe the power base of the Minerals-Energy Complex (MEC) is simply too powerful in relation to the government (Turton, 2009a and multiple respondents).

20. Like Johannesburg,Windhoek, Gaborone, and Harare, the capitals of South Africa's neighbors Namibia, Botswana, and Zimbabwe are situated at the tops of watersheds as opposed to the traditional global trend of settling near a freshwater resource or coastal port. This unique settlement pattern is a colonial legacy.

21. In 2008, violent riots motivated by xenophobia targeted refugees from Zimbabwe and Mozambique. The cause for the xenophobia is believed to be driven by the scarcity of natural and economic resources as well as the belief of the perpetrators that the illegal immigrants are to blame for the rise in cholera in the receiving settlements.
22. These predictions follow the A1B SRES scenario characterized by a more integrated world with more widespread access to technology and balance of energy use systems.

23. During the conduct of this research interacting during open interviews, the topic of Black Economic Empowerment surfaced frequently amongst White respondents. Fear of retrenchment has profound impacts on their professional lives. In the academic community, this fear suppresses courageous research and publication. There are multiple articles available in online media on this topic.