PAPER 10

OPPORTUNITY IN CRISIS: AN INTERDISCIPLINARY, 'LEARN BY DOING' APPROACH TO RESOURCE MANAGEMENT OF THE CAPE FLATS AQUIFER

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ABSTRACT

Cape Town faces "Day Zero," the date when the city could run out of water. The proximate cause is a three-year drought, considered to be a roughly 1-in-400-year hydrological event. By end of February 2018, the Theewaterskloof dam fell to ~11%, highlighting the importance of obtaining water from diverse sources in adequate storage volumes for assurance of supply, especially in variable and less predictable climate. Development of the Cape Flats Aquifer as an emergency and long-term source was initiated in 2017. This combination of short- and long-term horizons necessitated adopting a 'No Regrets' and 'Build Back Better' approach, inherent in Disaster Risk Response and Reduction best practice.

The integration of remote sensing mapping, GIS modelling, and geological (process) understanding informed the aquifer geometry and properties (product). This aquifer geometry and properties was innovatively combined with of land- and air-borne geophysics, parallel exploration and production drilling with a borehole testing programme running in conjunction with iterative numerical modelling to inform wellfield and reticulation design. Further, long term aquifer management options to ensure sustainability and inhibit saline intrusion using Managed Aquifer Recharge was developed. This 'Learn by Doing' approach was necessary to realise results in a very short space of time.

Understanding the hydrogeological constraints and opportunities that existing infrastructure presents for long term aquifer management underpins decisions regarding aquifer protection and management in a complex social, cultural and environmental context. Taking water supplies into a socially sustainable future requires making the links between existing social capital and physical infrastructure, finding ways to address social habitat and aspirational issues in the project context. Wanting to do so means to accept that (re)weaving the urban landscape, vitalising communities and building best practice in Aquifer Protection, Monitoring, Modelling and Management is as important a part of scheme design, implementation and commissioning as the science and the engineering. This concept is growing into an opportunity to create safe urban parkland overlying, and protecting the water quality in, the aquifer; from the suburbs in the east, west and north across the Cape Flats towards False Bay.

1. INTRODUCTION

The severity of the current drought faced by the City of Cape Town (CoCT) (South Africa) highlights the importance of adequate storage and diversified water supply in order to ensure growing water demands are met in a variable and less predictable climate. Groundwater in and of itself provides an additional water source to supplement supply, often with high storage capacity and water quality, even in dry seasonal periods when rainfall is scarce and surface water is fast depleted (Van Camp et al., 2010). Conjunctive use of surface and groundwater may enhance the resilience of water supply systems by managing storage to maximise available resources at any season.

The Cape Flats Aquifer (CFA) has been part of the CoCT's water augmentation strategy. Apart from being a source, the aquifer provides an additional resource: storage. The CFA is located within the urban sprawl (i.e. beneath the city), making it convenient (from an infrastructure point of view) to link with the urban elements of the hydrological cycle. Thus, the aquifer is useful as a water source and as 'natural storage infrastructure' to capture urban discharge (i.e. stormwater and treated effluent), which would otherwise be discharged into the sea and 'lost' (from an anthropogenic perspective).

Managed Aquifer Recharge (MAR) of the CFA is included in the Master Plan for the emergency development of the Cape Flats Aquifer, and is informed by the Cape Flats Aquifer Management Strategy (DWS, 2016). The proposal for MAR of the CFA encompasses both short and long-term strategies informed by two disaster risk reduction (DRR) principles: 1) No regrets and 2) Build Back Better. MAR makes provision for the sustainability of the short-term strategy for disaster response (development of emergency boreholes, treatment and reticulation) and the long-term strategy for disaster risk reduction (diversification of source supply to the City of Cape Town and conjunctive water resource management).

The context of the CFA is multifaceted, covering a large spatial extent with high spatial heterogeneity in the character and dynamics of the aquifer below ground and the urban/social landscapes above ground. Improved understanding of the aquifer itself (in terms of spatial extent; interaction with surface water; three-dimensional geometry, storage capacity, water quality) has been central to conceptualizing and designing MAR and abstraction schemes, involving multiple sources of data covering a range of temporal and spatial scales. Above ground, aside from the complexity of demographics and built environment, the CFA involves a spectrum of users (agricultural, residential, municipal, industrial) and local, provincial and national mandates (i.e. some water outside of City control such as groundwater). Keeping focus on the "safe and just space" framework (Raworth, 2012), integrating *sustainable* resource management (below ground) and *equitable* social development (above ground) underpins the direction of aquifer management of the CFA.

1.1 The working vision

"*The importance of visioning and the development of options through scenarios offer important management tools that are well-recognised in complexity theory for accommodating change*" – Pollard and du Toit (2008).

A conceptual depiction of the pathways and stores of freshwater flows within the CFA (Figure 1) comprises the urban reticulation and sewer system, surface waterways (such as rivers, canals) and their connections to the CFA and the ocean. Fresh water is 'lost' out of the system into the sea via surface or subsurface discharge into False Bay. Improving our management of water (Figure 2) involves the reduction of losses, storage and quality assurance of the resource for continued use. As a means of 'closing loops', we propose to divert water from waste water treatment works (WWTW) and stormwater ponds, that would otherwise flow to sea, into the aquifer for storage. Aquifer recharge will involve both active and passive systems, requiring the improvement of WWTW effluent quality for direct injection and the re-establishment of wetland ecosystems for passive infiltration respectively. The benefits of this approach, particularly the latter, include the improvement of surface and ground water quality, the re-establishment of wetland ecosystems (and their associated eco-services) and the immense opportunity for creation of green infrastructure, urban greening and enriching the urban/social landscape of the Cape Flats.

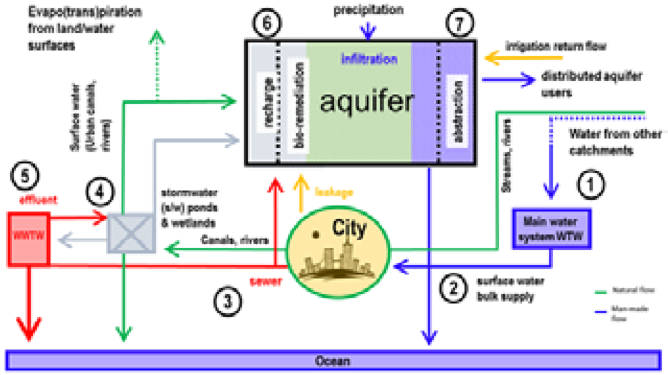

Figure 1: **Before ADAPT "Our water system as it is now": Water from other catchments is stored in dams (Steenbras, Theewaterskloof etc), comes into the system, is treated at WTP (1) such as Fourie and enters the bulk water supply system (2). Water enters the reticulation system, moves through households and into the sewer system (3), is treated by WWTW (4) and is released into surface water rivers and canals (green line). Concurrently, storm water run-off from the city flows into stormwater ponds and existing wetlands (4). Water from both rivers and these storm water ponds naturally infiltrates into the aquifer or flows into the sea. Licensed boreholes abstract from the borehole (7).**

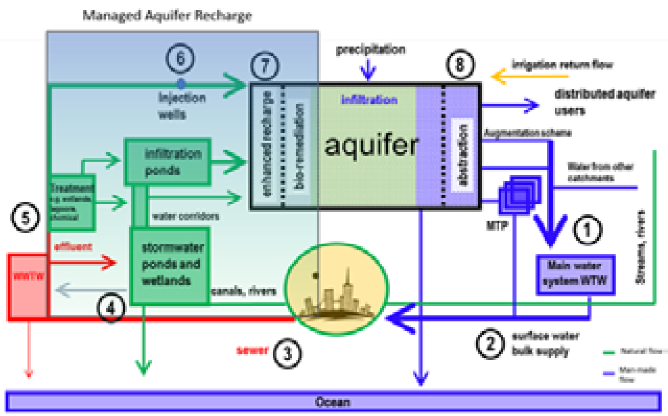

Figure 2: **After ADAPT "Proposed optimized system": By augmenting bulk water supply through groundwater abstraction and managed aquifer recharge implementation we can optimize our water supply by: reduction of surface water losses to the ocean through aquifer recharge utilising WWTW outflow and storm water pond infiltration. By further treatment of waste water treatment to comply with international standards (4), creating artificial wetlands, water corridors and infiltration ponds throughout the city (5) we can add an extra step in our system: enhanced recharge (7). Enhanced recharge can take the form of active recharge (injection wells) (6) or passive recharge (through water corridors, wetlands and SUstainable Drainage Systems - SuDS) (5).**

2. MONITOR, MODEL AND MANAGE: THE ITERATIVE AND INTERDISCIPLINARY PROCESS OF IMPROVED CONTEXTUAL UNDERSTANDING – 'LEARN BY DOING'

For the context of the CFA, a purely 'groundwater' perspective (encompassing hydrogeology, geology, hydrology, biochemistry, engineering) will be insufficient to address the challenges posed by the complex systems within the 'urban' context and thus requires the integration of political/social and ecological sciences, within the arenas of community and art. Thus, the CFA required a two-phase approach: establishing the physical parameters of the aquifer itself, and defining the ecological and social landscapes, which we link together through their shared and overlapping space. Further we consider that the kind of changes that are happening, and need to happen, to support the implementation of such a project requires transformation at local, provincial and national scales in a way that supports meeting the SDG targets (e.g. Waddel *et al.*, 2015).

A 'learn by doing' or 'learning loops' approach serves as "a shorthand for the logic driving that change" (Waddel *et al.*, 2018) at both the short-term response and long term transformation. Relevant elements in this project are -

3. AQUIFER CHARACTERISATION: COLLATION OF CURRENT KNOWLEDGE AND INFORMATION

3.1. Extent and boundary conditions

Geographically enabled data (using GIS to integrate terrain and remotely sensed digital elevation models) has gone through several iterations to spatially discretise the aquifer proper (Figure 3). The geomorphological edge of the Cape Flats is defined by the change in slope angle. An edge corresponding to the 2° gradient contour was selected as roughly coincident with the Pliocene palaeo-strandline on the eastern and western sides. The dune geomorphology of the southern Cape Flats is well represented by the areas with slope >2°, rising above the flatter regions, and showing a locally rugged topography of linear, parabolic or barchanoid surface shapes.

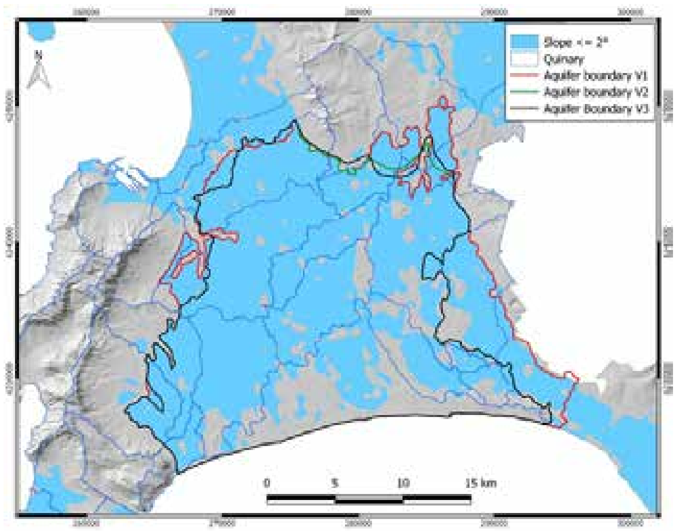

Figure 3: **Aquifer boundary development. Version 1 (red polyline) was based on separating the Cape Flats (slope<2°) from regions of higher slope (slope >2°) using a smoothed surface model. Version 2 (green polyline) was refined based on the location of basement geology outcrops, while Version 3 (black polyline) further incorporated surface sub-catchments at the quinary scale.**

3.2. 3D aquifer geometry

The CFA has been studied at various times and for differing purposes over the last several decades. Available data has been collated and curated into a single dataset. Integration of existing borehole data with the CFA geomorphology informed initial estimates of aquifer geometry and identified knowledge gaps, which was used to plan additional exploratory drilling and geophysical surveys. These have provided additional data with greater spatial distribution and resolution. Geological modelling has collated all available sources of data resulting in a better quantification of the aquifer 3D geometry and understanding of available storage capacity, serving as the framework for the development of a numerical model of the system (Figure 4).

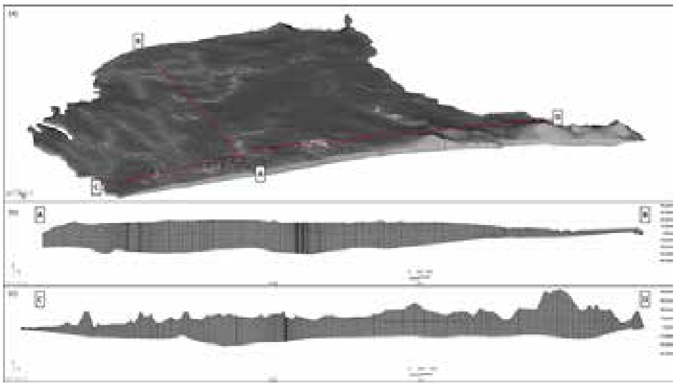

Figure 4: 3D triangular finite element mesh of CFA (a) with two cross-sections (b) and (c) illustrating potential aquifer thickness.

3.3 Aquifer hydraulic parameters

On-going drilling of boreholes across the CFA has provided an extensive and spatially distributed dataset of aquifer parameters. By linking these to the updated understanding of the aquifers' 3D geometry and geology, allows for greater understanding of the 3D hydraulics of the system. By understanding which geological formations allow for greater flow rates, and by knowing where these are, flow paths and rates can be predicted with greater confidence (Figure 5).

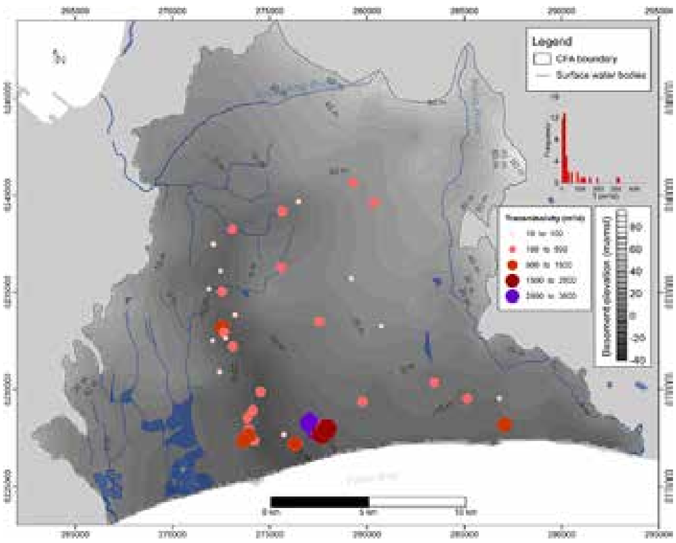

Figure 5: Spatial distribution of transmissivity determined from ongoing pump-test analysis at boreholes drilled during the current project.

3.4 Preferential groundwater flow paths

Airborneelectromagnetic and magnetic mapping has allowed for the identification of structures in the aquifer such as dykes and other geological features of interest. For example, further insight has been gained into the preferential groundwater discharge zones into False Bay (Figure 6). A more accurate quantification of the mass balance of the aquifer, and thus better management, is achievable through further exploration of these processes.

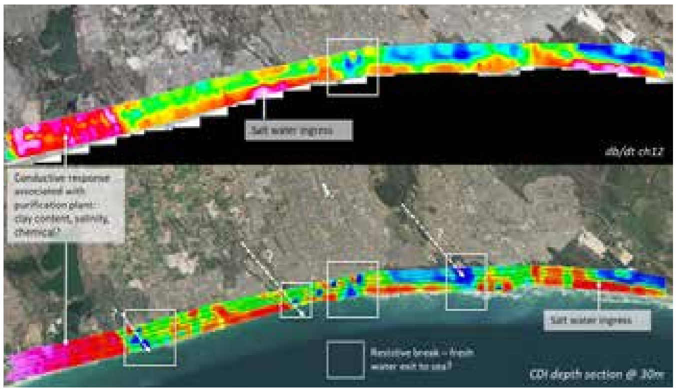

Figure 6: The Baden Powell profiles, channel plots and depth images provide a useful means for the mapping of salt-water ingress (conductive) as well as highlighting breaks associated with outlets of potential fresh water aquifers.

3.5 Numerical groundwater flow modelling

The numerical model of the CFA is being developed as a decision support tool to assist in planning and management of the groundwater abstraction and recharge scheme. A regional flow model is in continuous development for well-field and aquifer management purposes, taking into account the most recent data. The model provides an up-to-date representation of existing hydrogeological data and is used to assess the impact of proposed abstraction and managed recharge schemes on selected indicators (i.e. water levels and flow rates).

Given the complexity of the aquifer system, the ever changing and updating nature of data and decisions inherent to an emergency response project, the 'in development' numerical model has been used as a dynamic 'thinking tool' to collate information, conceptual models and test ideas - which feed directly back into the data collection, drilling and planning process (Figure 7). The inherent uncertainty from model results at this stage of development must be recognised when utilizing model results to support decision making, especially as the urgency in project implementation does not allow for long term prior in-depth study of the system. Notwithstanding, as is, the model already is a collation of available data and knowledge of the system and provides insight into aquifer response to proposed changes, as well as guiding data collection to reduce uncertainty in results.

In the long-term, model results will assist in managing the spatio-temporal dynamics of groundwater storage for management of the groundwater abstraction and recharge scheme as part of the long-term scheme within the greater context of the Western Cape Water Supply System.

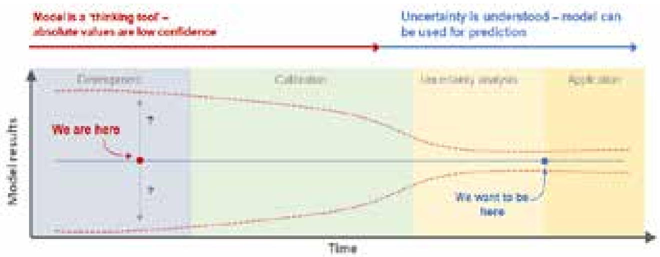

Figure 7: Illustration of model development and application process and associated confidence.

3.6 New and integration of infrastructure

A traditional civil engineering approach sees the mapping, detailing of purpose and constraints being completed before the design process. However, for this project it has been necessary to initiate innovative designs, guided only by the purpose and best estimates of design constraints viz. position and yield of production boreholes, and preliminary measure of spatially variable hydrochemistry. The purpose has been clear – to inject new water into the CoCT reticulation system as once borehole equipment is installed, wellfields are producing water and water quality confirmed. The necessity of exploration and production drilling occurring in parallel resulted in designs being iterated as geohydrological results become available, realising increased confidence and best possible planning for implementation. This meant that the exact positions and yields of each production borehole only become available during the implementation phase of the project.

*"Real Time"*design of infrastructure requires management of change in a complex system involving different disciplines, with current bureaucratic processes not supporting the implementation of such emergency schemes. The situation become more complexed when needing to work with the fluid 'in principle' land exchange agreements; especially as multiple stages of the scheme are running in parallel and with changing parameters. Whereas *"Real Time Implementation"* in the CFA saw the need for good security timing during construction for protection of the new infrastructure, with security cages fully enclosing borehole and control to guard against vandalism (Figure 8).

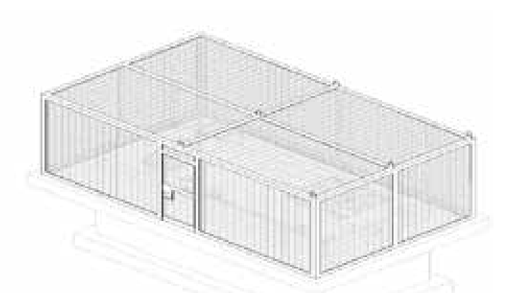

Figure 8: Design of security cage over boreholes and control equipment.

The design philosophy of infrastructure delivery under the emergency and constrained conditions was based on flexibility of optional delivery of "First Water" as soon as physically possible in the engineering world. Figure 9 schematically illustrates the three (3) options to deliver additional water:

- Alternative A: Injection of potable water in the bulk network of CoCT
- Alternative B: Blending of ground water with potable water as a first interim measure, while procuring and constructing required advanced treatment;
- Alternative C: Provision of draw off point for the collection of (lightly) treated ground water with related infrastructure in parallel to infrastructure for off take consumers.

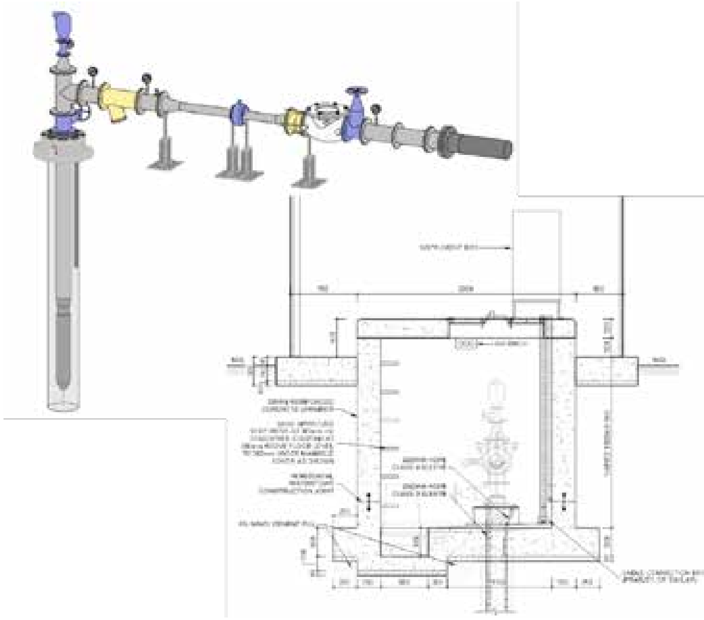

Figure 10: Modular innovation of borehole (top left) and chamber designs (bottom right).

The requirements of "First Water" saw the need for innovative modular borehole designs, pump station and water treatment processes formed part in order to ensure quick delivery of water (see Figure 10 showing a 3D modular borehole and chamber design).

4. MAPPING THE MULTIFACETED URBAN, ECOLOGICAL AND SOCIAL LANDSCAPES

To achieve a more robust understanding of the issues to address and risks to manage *above ground* data and input are required from all disciplines. This involves the integration of urban planning (reticulation/supply systems, available land and landuse, upgrading of sanitation systems in informal areas); architecture (design of green corridors, localised infiltration areas); engineering (storm-water network design), ecology (water treatment via wetlands, incorporating ecology into urban spaces) and social and political sciences (community participation and engagement, design of community green spaces and water corridors) and artists (visualization and communication of vision and challenges).

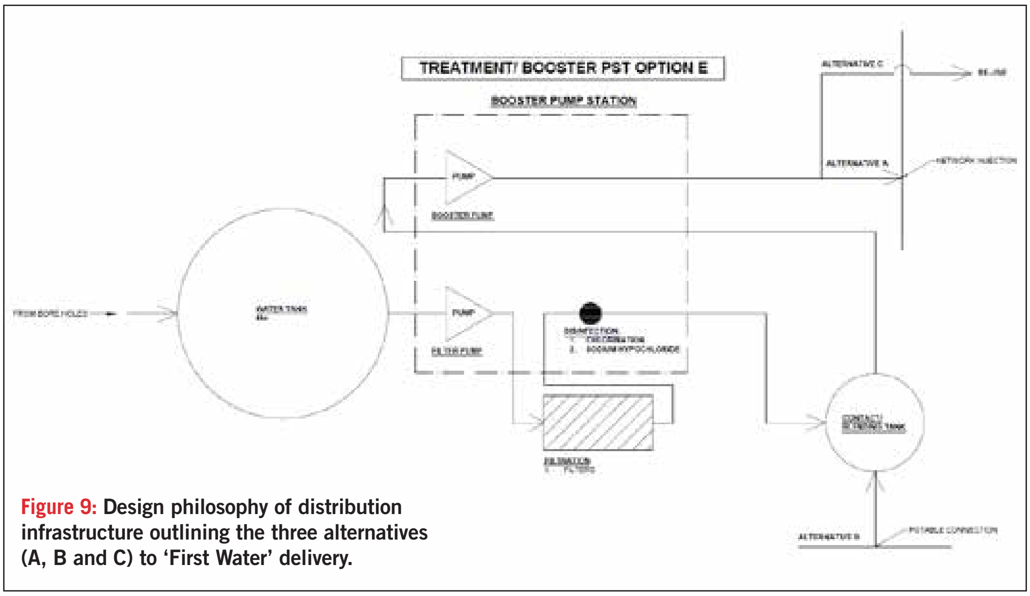

Figure 9: Design philosophy of distribution infrastructure outlining the three alternatives (A, B and C) to 'First Water' delivery.

4.1 Achieving the "safe and just space"

An important intervention is to protect and remediate the catchment of the aquifer. Aquifer Protection Zones (APZs), a buffer zone and the planning district authority has been delineated within which activities with an impact on the aquifer are controlled and/or restricted (Figure 10). The APZs are used to give effect to Policy 26 of the SDP 2012 ". . .*[to] reduce* *the impact of urban development on river systems, wetlands, aquifers, aquifer recharge and discharge areas".* The intention is that bylaws will be defined for future land development, as well as regulating activities in the APZ. In addressing an *equitable* social development, these APZ's also aim to support the bill of rights where all those living in South Africa have the right to an environment"a) *that is not harmful to their health or wellbeing, b) [that is protected] through measures that (i) prevent pollution and ecological degradation; (ii) promote conservation; and (iii) [secure ecological sustainable development] while promoting justifiable economic and social development"*

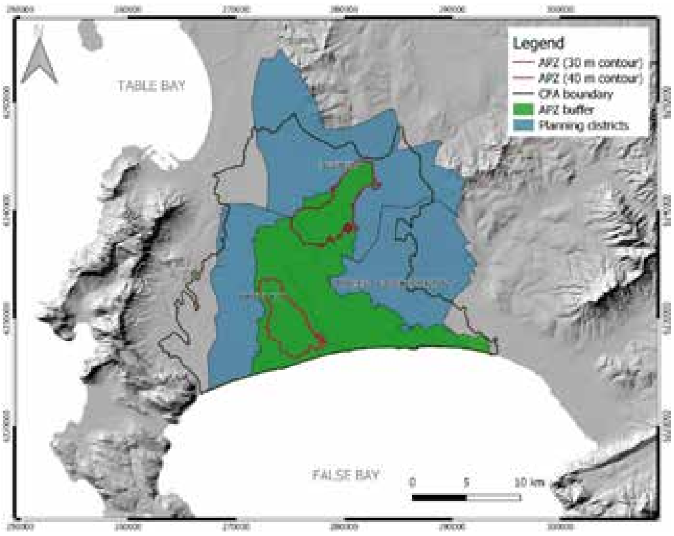

Figure 10: Core aquifer protection zones (APZ) delineated from the 30 m and 40 m contour of the aquifer thickness, illustrate the most productive parts of the CFA. APZ buffer zones integrate the quinary water catchment divides and the aquifer thickness 30 m contour to delineate the areas believed to be key catchment area for the most productive parts of the aquifer. The city planning districts (Cape Flats, Mitchells Plain/Khayelitsha and Tygerberg) form the authorities with the greatest responsibility to implement aquifer catchment management.

4.2 Social capital

Different groups have different immediate concerns, many of which are inter-related but not necessarily focussed solely on access and use of water. Through concept mapping (Figure 11) we seek to increase social capital by integrating the APZ into areas/zones/corridors where people can interact and connect with each other. Our initial concept is to highlight the potential areas that meet the needs of the APZ's environmentally, and socially. These linking spaces (linking the surface to sub-surface) are not considered fixed but serve as a point from which to start the conversation with the relevant communities on who the protection and improvement of the CFA groundwater is dependent. Given the required investment of physical infrastructure for aquifer integration into the City's water supply, opportunities exist to enhance this urban space, through re-thinking the current urban landscape. Some of the conceptual ideas involve increasing the number of open, green spaces and integrating them into existing and future social spaces (e.g. multi-use green space where sports, social and cultural activities may occur in the same space). Such projects are long term goals, requiring multi-level stakeholder engagement and support, but through the utilisation of the learn-by-doing approach we can identify these, and integrate them into implementation of the long-term vision of sustainable management of the CFA.

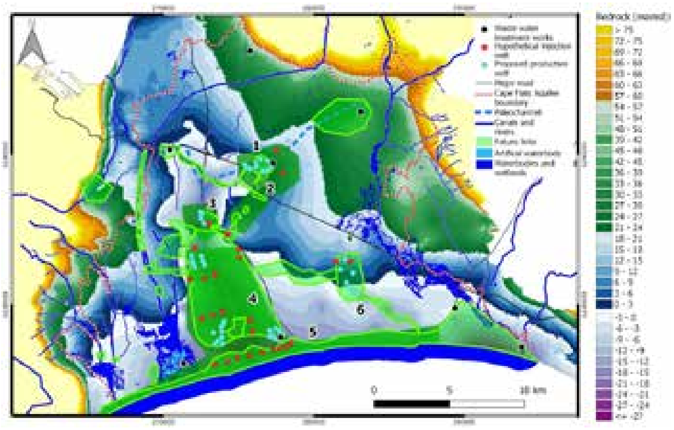

Figure 11: Illustration of future links and (re)weaving the urban landscape. The integration of social, cultural, environmental and water elements, we can take water supplies into a socially sustainable future. Using future links (green polygons) as opportunities for innovative infrastructure solutions we propose the linking of 6 zones in the CFA. 1 - Heart of the matter; 2 - Necessary umbilical link; 3 - Industry meets art; 4 - Feeding the city; 5 - Drive to the future; 6 - Khayelitsha gateway.

5. CONCLUSIONS AND RECOMMENDATIONS

The development of the CFA wellfield proved that the success depends on working relationships, local experience and common sense to overcome the discomfort of working outside traditional roles. The challenge of needing to take decisions within constraints of limited time and available information requires ingenuity and design flexibility to balance project confidence with availability of data constrained by the emergency timelines.

The integration of the CFA into the water supply system for the city, through the latest techniques of conjunctive surface water and managed aquifer recharge, can provide the capacity and flexibility needed for Cape Town to deal with the challenges of ensuring water supply in a climate of uncertainty. Extensive use of geographically resolved data has enabled the focus of immediate relief by taking advantage of the 'excess' capacity of the aquifer in the short term. Adopting a 'learn by doing' approach, the collation of data and knowledge into an interactive model has provided insight into aquifer response to short term water relief measures. The long-term integration of groundwater into the Western Cape Water Supply requires further insight and understanding of the uncertainties, as well as the further incorporation of data across all disciplines and sectors of society associated with groundwater both directly and indirectly.

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