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KENYA GROUNDWATER GOVERNANCE

CASE STUDY

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PREFACE

Groundwater comprises 97 percent of the world's readily accessible freshwater and provides the rural, urban, industrial and irrigation water supply needs of 2 billion people around the world. As the more easily accessed surface water resources are already being used, pressure on groundwater is growing. In the last few decades, this pressure has been evident through rapidly increasing pumping of groundwater, accelerated by the availability of cheap drilling and pumping technologies and, in some countries, energy subsidies that distort decisions about exploiting groundwater. This accelerated growth in groundwater exploitation—unplanned, unmanaged, and largely invisible—has been dubbed by prominent hydrogeologists "the silent revolution." It is a paradox that such a vast and highly valuable resource—which is likely to become even more important as climate change increasingly affects surface water sources—has been so neglected by governments and the development community at a time when interest and support for the water sector as a whole is at an all-time high.

This case study is a background paper for the World Bank economic and sector analysis (ESW) —entitled "Too Big To Fail: The Paradox of Groundwater Governance"—that aims to understand and address the paradox at the heart of the groundwater governance challenge in order to elevate the need for investing in and promoting proactive reforms toward its management. The ESW examines the impediments to better governance of groundwater, and explores opportunities for using groundwater to help developing countries adapt to climate change. Its recommendations will guide the Bank in its investments on groundwater and provide the Bank's contributions to the GEF-funded global project—"Groundwater Governance: A Framework for Country Action."

Five countries—India, Kenya, Morocco, South Africa, and Tanzania—were selected as case studies to understand the practical issues that arise in establishing robust national governance frameworks for groundwater and in implementing these frameworks at the aquifer level. This report describes the results from the Kenyan groundwater governance case study.

This case study focused on both the national and local levels. At the national level, it analyzed the country's policy, legal, and institutional arrangements to identify the demand and supply management and incentive structures that have been established for groundwater management. At the local level, it assessed the operations, successes, and constraints facing local institutions in the governance of four aquifers. The Tiwi and Baricho aquifers are small, strategic coastal aquifers that are essential for water supply to Kenya's south coast; the Merti aquifer is a large fossil aquifer that provides one of the few reliable water sources in the semi-arid northeast of Kenya; and the Nairobi aquifer system is of major economic importance to Kenya providing supplementary or emergency water for domestic and industrial use in Nairobi complementing the primary surface water supply sources.

This case study found that, with about 17 percent of renewable groundwater resources being used, there is considerable potential for groundwater to support Kenya's development. Kenya has an excellent, modern water governance framework. The issues lie in its implementation. There are overlaps in perceived responsibilities between the Ministry and the implementing agencies (WRMA, water boards and water service providers), particularly with respect to data handling and sharing. The WRMA does not have the trained staff, or the technical or financial resources, or the right structure to manage aquifers. Consequently, it is not able to enforce legal provisions for controlling abstractions, pollution and borehole drilling. Finally, there is a poor level of understanding amongst both water sector staff and the public about the specific characteristics of groundwater that affect its management and the connectivity between surface water and groundwater.

The report provides a comprehensive strategy to develop effective groundwater management and a pilot groundwater management plan. Kenya's draft Policy for the Protection of Groundwater provides most of the requirements for improving groundwater governance, including participation and empowerment of groundwater users, decentralization of management to local level, integration of surface and groundwater management, improving monitoring and data collection, identifying sites for MAR, mapping strategic aquifers and conjunctive use opportunities, and identifying groundwater conservation areas. Consequently the most important action is to accept, adopt and implement this policy. But there is also a need to take action, and the report proposes that a pilot groundwater management plan be drawn up for an aquifer such as the Tiwi aquifer to generate agreement on the actions needed to protect this important resource before it experiences significant problems. The opportunities provided by the ongoing and planned preparations of future water supply source masterplans for both the Nairobi area and the Coast region should be seized to direct attention on and address the groundwater management and governance challenges as part of integrated water resources management.

ACRONYMS AND ABBREVIATIONS

ASALs	Arid and semi-arid lands
AWSB	Athi Water Services Board
BCM	Billion cubic meters
bgl	below ground level
BGS	British Geological Survey
CAACs	Catchment Area Advisory Committees
CCN	City Council of Nairobi
CMS	Catchment management strategy
CSA	Case study aquifer
CSOs	Civil society organizations
CTL	Central Testing Laboratory, Ministry of Water and Irrigation
CWSB	Coast Water Services Board
EIA	Environmental impact assessment
EMCA	Environmental Management and Coordination Act
ENSO	El Niño/Southern Oscillation
FAO	Food and Agricultural Organisation (UN)
GCA	Groundwater Conservation Area
GDE	Groundwater-dependent ecosystems
GOD	Groundwater confinement, overlying strata, depth to groundwater
GoK	Government of Kenya
GWO	Groundwater officer (WRMA)
IAH	International Association of Hydrogeologists
IGRAC	International Groundwater Assessment Centre
IHP	International Hydrological Programme
ILEC	International Lake Environment Committee Foundation
IPCC	Intergovernmental Panel on Climate Change
ITC	International Institute of Aerospace Survey & Earth Sciences, Enschede, The Netherlands
IWRA	International Water Resources Association
IWRM	Integrated water resources management
IWRM & WE	IWRM & water efficiency plan
JICA	Japan International Cooperation Agency
KARA	Kenya Alliance of Residents Associations
KCC	Kwale County Council
KEBS	Kenya Bureau of Standards
KEPSA	Kenya Private Sector Alliance
KEWASNET	Kenya Water and Sanitation Civil Society Network

KEWI	Kenya Water Institute
KFS	Kenya Forestry Service
KISCOL	Kwale International Sugar Company Limited
KLDA	Karen Lang'ata District Association
KSFR	Kenya Society for Fluoride Research
KShs.	Kenya shillings
KWASCO	Kwale Water and Sewerage Company Limited
KWIA	Kenya Water Industry Association
KWS	Kenya Wildlife Service
MAR	Managed aquifer recharge
MALWASCO	Malindi Water and Sewerage Company Limited
MCM	Million cubic meters
MDGs	Millennium Development Goals
MEMR	Ministry of Environment and Mineral Resources
MLD	megaliters per day
MoA	Ministry of Agriculture
MoH	Ministry of Health (Medical Services; & Public Health & Sanitation)
MoL	Ministry of Lands
MoLH	Ministry of Lands and Housing
MoNMD	Ministry of Nairobi Metropolitan Development
MoRDA	Ministry of Regional Development Authorities
MoWI	Ministry of Water and Irrigation
MCTA	Mombasa and Coast Tourist Association
NAS	Nairobi Aquifer System
NCCRS	National Climate Change Response Strategy
NCWSC	Nairobi City Water & Sewerage Company Limited
NESC	National Economic and Social Council
NWCPC	National Water Conservation and Pipeline Corporation
NWMP	National Water Master Plan
NWRMS	National Water Resources Management Strategy
NWSB	Northern Water Services Board
PA	Pastoralist Association
PPPG	Proposal for a Policy for the Protection of Groundwater
PPP	Public-Private participation
RBOs	River basin organizations
RO	Regional office (WRMA)
SAT	Soil aquifer treatment
SCHA	South Coast Hotelkeepers Association
SCMP	Subcatchment management plan
SCRA	South Coast Residents Association

SEI	Stockholm Environmental Institute
SKM	Sinclair Knight Merz
SRO	Sub-regional office (WRMA)
TDS	Total dissolved solids
TI	Transparency International
TPZ	Total Protection Zone
UN	United Nations
UNEP	UN Environment Programme
UNESCO	UN Educational, Scientific, and Cultural Organisation
UNFCC	UN Framework Convention on Climate Change
UNHCR	UN High Commissioner for Refugees
UNICEF	UN Children's Fund
USEPA	U. S. Environmental Protection Agency
USGS	U.S. Geological Survey
WAP	Water allocation plan
WASREB	Water Services Regulatory Board
WRMA	Water Resources Management Authority
WRMR	Water resources management rules
WRUA	Water Resources Users Association
WSB	Water Service Board
WSP	Water service provider

NOTES: **UNLESS OTHERWISE NOTED, ALL CURRENCY IS IN U.S. DOLLARS; ALL WEIGHTS ARE IN METRIC TONS**

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[1] During the Project Concept Note review, the proposed title for this World Bank Economic and Sector Work was "Improving groundwater governance: The Political economy of groundwater policy and institutional reforms".

[2] It is based on a larger report prepared by Professor Albert Mumma, Professor Edward Kairu and Mr. Mike Lane and commissioned for the World Bank economic and sector analysis under the direction of Rafik Hirji (team leader).

May 2007 CAAC Operationalization Workshop (in Kisumu), in which many of the issues the CAACs continue to express today were first aired. The process of forming the Mbagathi WRUA (in which one of the authors has been closely involved) was of considerable value in shaping parts of this report, and to this end thanks are owed to the Interim Committee under Cilla White and to Anthony Kiamba, the WRMA Athi SRO.

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DISCLAIMER

EXECUTIVE SUMMARY

This report presents a case study on groundwater governance in Kenya, conducted under the aegis of a World Bank economic and sector analysis project entitled “Too Big to Fail: The Paradox of Groundwater Governance.[3]” The objectives of the study were to (a) describe groundwater resource and socioeconomic settings for four selected aquifers; (b) describe governance arrangements for groundwater management in Kenya; and (c) identify the relevance of these arrangements for planning and implementing climate change mitigation measures.

Kenya is a water-scarce state (534 m^3/capita/yr in 2009), with a resource endowment of 21 billion cubic meters a year. Groundwater is of considerable importance, more so than it might seem given that it only constitutes about 5 percent of the nation’s renewable water resources. In the 2009 Census, 43 percent of rural and 24 percent of urban households stated that they relied on a spring, well, or borehole as their main source of water. Its intrinsic advantages—its ubiquity, the speed with which it can be developed, the relatively low capital cost of development, its drought resilience, and its ability to meet water needs “on demand”—make it a critical component in rural water supply and for small (and sometimes large) towns, as well as domestic water, irrigation, industry, and commercial uses. However, despite its importance, the value of groundwater is not appreciated, nor is its vulnerability understood.

[3] During the Project Concept Note review, the proposed title for this Economic and Sector Work was “Improving groundwater governance: The Political economy of groundwater policy and institutional reforms”.

Kenya case study aquifers

The four case study aquifers (CSAs) vary greatly in size (from a few km^2 to 140,000 km^2), agro-climatic zone (semi-arid to semi-humid), and land use (extensive pastoralism to intensive urbanization). Each has unique hydrogeological and socioeconomic characteristics, and each faces different management challenges. CSA characteristics are summarized below.

Case study aquifer characteristics

Parameter	Merti	Nairobi (NAS)	Tiwi	Baricho
Aquifer type	(Semi)-consolidated sedimentary	Inter-montane valley fill	Major alluvial	Major alluvial
Lithology	Clays, sands, sandstones, limestones	Lavas & lake sediments	Clays & sands	Alluvial sand & gravel
Dominant flow regime	Inter-granular	Inter-granular / fissure	Inter-granular	Inter-granular
Scale	Regional/ Transboundary	Regional	Local	Local
Surface area, km^2	60,900 fresh water	6,500	~30	~2
Recharge, MCM/yr	3.3 (modern)	109	21	≈83
Abstraction, MCM/yr	5.3	58	4.8	22
Pollution vulnerability	0.1 Negligible - low	0.1 Negligible - low	0.3 Low - moderate	0.6 High
Saltwater vulnerability	N/A	N/A	0.5 Moderate	0.1 Negligible
Depletion vulnerability	Moderate/local	Serious/extensive	Low	Low
Dominant water use (in approximate order of volumetric use)	• refugee camps • livestock • domestic • public W/S	• domestic • commercial • industrial • irrigation • public W/S	• public W/S	• public W/S
WRMA Type	Strategic / Special	Strategic	Major	Major
WRMA Status	Satisfactory / Alert	Alarm	Alert	Satisfactory

Notes: MCM is millions of cubic meters; WRMA is the Water Resources Management Authority

These aquifers—and aquifers elsewhere in Kenya—are not “managed” in any true sense; new water allocations are not based on a formal assessment process or a water allocation plan. Indeed, the poor level of compliance by water users in respect to water permits and the payment of water use charges make water allocation an uncertain exercise at best. The groundwater conservation area (GCA) meant to protect the Nairobi aquifer system (NAS) has completely failed to achieve this objective. The complete lack of rational land use planning has meant that attempts to restrict abstraction have been severely constrained by indifference, commercial interests, and a building boom.

The land-groundwater interface

Groundwater exists because a suitable body of geological material is available for recharge and storage. For that storage to be maintained, there must be a recharge zone. Some types of land use may pollute recharge water and thus aquifers. These can be point sources, such as an industry discharging waste that mixes with recharge water; a pit latrine leaching nutrient and bacteria into the aquifer; or diffuse sources, such as fertilizers (nitrates, phosphates) or pesticides (toxins).

A second element involves land use planning. Planners in Kenya do not understand that land use plans not only change aquifer recharge and discharge characteristics, but also influence aquifer use patterns. The classic Kenya case is the NAS, where planning permission is given for development in areas with insufficient or unavailable municipal water supplies, leaving groundwater as the only available water resource.

Governance aspects of groundwater management in Kenya

In Kenya all water resources are vested in the state; water use is subject to approval and a water permit, typically defining water use, the volumes authorized for abstraction, and the duration of the permit. Notwithstanding the express provisions of the law, in practice groundwater management is strongly influenced by the common law perception of groundwater as a private resource belonging to the owner of the land. It therefore is perceived and treated as a typical common pool resource, and the majority of water users exploit it for short-term gain and ignore the long-term consequences of unregulated use.

Kenya does not have policies, laws, and institutions dedicated specifically to the management of its groundwater. Rather, groundwater management is subsumed under broader policy, legal, and institutional frameworks dealing with the management of water resources, or more broadly, natural resources, and with land use and physical planning. Existing policy, legal, and institutional frameworks are deficient from the perspective of groundwater management. An overhaul is required to bring them in line with the requirements of frameworks for sound groundwater management. Deficiencies have been identified in key areas.

Groundwater management decision making is sector-based and on the whole *ad hoc*; there is no mechanism for coordination and for fostering cross-sector linkages. Consequently, the management of groundwater resources has continued to be carried on in isolation from the management of land and other land-based resources, with the inevitable consequence that the implications of management decisions in critical areas such as physical planning, land use planning, and agricultural activities have often been overlooked. At the same time, groundwater decision making remains overly centralized, with limited real involvement of stakeholder units, such as catchment area advisory committees (CAACs) and water resources user associations (WRUAs).

Key groundwater conservation provisions in the law have not been acted upon and given effect. Provisions exist for groundwater conservation plans that establish a framework for taking special measures for the protection of groundwater—in cases where there is a risk of over abstraction, for instance. In the context of GCAs, it is possible to designate recharge protection zones and aquifer protection zones to protect the aquifer from water pollution, for instance from the discharge of wastewater. But since the entry into force of the 2002 Water Act, no GCAs have been designated.

Furthermore, many groundwater abstractors do not have permits, and many of those that do have permits do not pay water charges for abstracted groundwater. This is exacerbated by the absence of a framework for systematically implementing and enforcing the requirement for payment of user charges. Given the dependence of the implementing agency, WRMA, on water use charges for the execution of its mandate, this has denied it much-needed financial resources.

Overall, groundwater management is weak and ineffective, and is characterized by a lack of strategic focus and limited resources. The study has concluded that this is due to a perception that groundwater is an inexhaustible resource. This perception is caused by poor knowledge of groundwater resources, general weakness in institutional capacity, limited technical capacity that is not appropriately deployed, poor funding, and weak political commitment at the senior policy-making level. The result is that overabstraction and poor management has continued. The study also has concluded that addressing the problems affecting groundwater does not require additional or new legislation, except in respect of an overarching policy for climate change.

What is required to redress the situation is action on key recommendations and policy objectives that have been made in policy statements over the years. Key among these is the development of a functioning mechanism for coordination of actions relating to groundwater across diverse sectors that affect the sustainable management of groundwater resources, including land, environment, and water resources. It will also be necessary to give priority to groundwater management in the activities and programs of groundwater management institutions. This requires providing the resources—human, technical, and administrative—necessary to discharge their mandates effectively.

Groundwater management to mitigate climate change impacts

It is inadequately appreciated in Kenya that better management and use of groundwater resources is a “no-risk” measure for climate change adaptation—a measure that will contribute to socioeconomic growth even if no climate change occurs. However, there is also a limited understanding of how groundwater management offers potentially substantial gains in adapting to climate change and in meeting the Millennium Development Goals.

Kenya has yet to fully exploit the advantages of conjunctive use in the management of water resources, although this is beginning to change in the face of the repeated and destructive flood-drought cycles experienced in recent decades. Conjunctive use schemes seek to optimize both surface and groundwater – and other forms of water such as recycled wastewater – to “spread the load,” and in so doing develop resilience to extreme weather events. In addition to conjunctive use, both supply-side and demand-management measures will be needed. Pragmatic groundwater management and an improved understanding of our groundwater resources is an essential part of the former, while more efficient water use is a key facet of the latter.

Managed aquifer recharge is another example of a technical approach that already has improved drought resilience to communities in semi-arid Eastern Kenya. Managed aquifer recharge in the broadest sense includes both the enhancement of natural recharge and the planned use of aquifer storage. Although the level of understanding of Kenya's aquifers is generally poor, the experience of sand dams and their enhancement of bank storage in eastern Kenya is a launch point for rolling out this simple and practical approach to other parts of the nation. Pre-feasibility studies have described a range of possible schemes and some of these should be considered for pilot projects.

Study findings

This study has found that the present approach to groundwater management in Kenya not only does not serve the public interest in the short term, but is also likely to jeopardize the value of groundwater in the medium to long term. There is a very limited understanding of the land surface-groundwater linkage among professionals in the relevant sectors, and as a consequence there is no strategic awareness of the need to protect groundwater resources. Public understanding of groundwater and its importance is dismally poor, and attempts at education have been minimal at best. Technical capacity needs to be enhanced, and support and funding for the WRMA needs to be increased. Water sector reform processes have failed to solve the data management bottleneck, with the Ministry for Water retaining data that the WRMA needs for day-to-day groundwater management processes, to the detriment of water management in general and groundwater management in particular.

That some of Kenya's aquifers are in urgent need of "management" and "protection" is irrefutable; the legal and institutional instruments to create conditions for pragmatic aquifer management already exist, although some cross-sectoral streamlining would improve management processes. The only real impediments to developing a national groundwater management strategy and implementing local aquifer management plans are limited political understanding and support for such measures, and a lack of funding by the parent Ministry for the responsible agency, the WRMA, to do so.

The absence of a strategic framework is an impediment to rational groundwater management. To this end, a strategic planning framework has been drafted for consideration by the ministry. A framework for developing a groundwater management plan for the South Coast has also been drafted.

1. INTRODUCTION

1.1. Groundwater: a common resource pool

The world faces enormous challenges in meeting human and ecological needs for water. Population growth, urbanization, and rising standards of living across the globe put water resources under increasing stress, while at the same time catchment degradation and poor waste management reduce freshwater availability. Further uncertainty is imposed by climate change.

Global annual precipitation is 577,000 km^3/yr; 79 percent of this rain falls on the oceans, 2 percent on lakes, and 19 percent on land. The vast proportion of what falls on land is lost to evaporation or runoff, leaving only 2,200 km^3 (2 percent) to percolate into the groundwater store (Shiklomanov 2002). However, when aquifer storage is taken into account, groundwater still makes up 97 percent of global freshwater (excluding ice), and is the most intensively exploited natural material in the world. Increasing demand for water, allied to technical developments in drilling and pumping technology, has driven groundwater development.

The use of groundwater has spurred agricultural growth across the world. The top three groundwater-abstracting states are India, the United States, and China, which between them account for over 50 percent of global groundwater abstraction (442 km^3/yr of an estimated 840 km^3/yr) (World Bank 2010a; Margat 2008). The value of India's agricultural output rose from \$28.3 to \$49.9 billion from 1970/73 to 1990/93; at the start of this period, groundwater contributed only 4.4 percent of this value, while by the mid-1990s it contributed 14.5 percent (Letitre 2009). In 1951, India had an estimated 4 million groundwater abstraction points; by 1997, the number had risen to nearly 17 million (Llamas and Martinez-Santos 2004). By the end of the first decade of the present century, India accounted for 230 km^3/yr, over 25 percent of global groundwater use (World Bank 2010a).

The initiative to develop groundwater on this scale, particularly for agricultural purposes, was largely taken by water users, not governments. It has been mostly unregulated, with government funding in groundwater resources management far out of proportion to its benefits and far smaller than equivalent or proportional funding for surface water development and management. Indeed, the growth of intensive groundwater abstraction has, in most cases, been largely unnoticed by governments. This evolution has been called the "silent revolution" (Llamas and Martinez-Santos 2004, 2005), and has been of immense benefit to rural populations in arid and semi-arid countries. However, the silent revolution has also had its costs (Table 1).

The uncertainty over the future of intensive groundwater use is aggravated by the lack of knowledge about groundwater and the common perception that, because it is a common pool resource (Ostrom 1990), it faces unique and possibly insuperable management challenges. This is fuelled by the widespread perception that groundwater is a "private" resource—land owners consider that they have an absolute right to the water beneath their land, irrespective of what laws may say (GWMATE 2009). This encourages the unsustainable use of groundwater, to the ultimate cost of all. However, despite the costs listed above, groundwater has enormous potential to mitigate the looming global water crisis, given appropriate management and a better understanding of its costs, benefits, and limitations on the part of water users, regulators, the private sector, and the political cadre. Appropriate groundwater use will also do much to mitigate the impacts of climate change, and underlies the cross-sectoral nature of groundwater resources management.

Table 1. Benefits and costs of the "silent revolution"

Benefits	Costs
Increased food production and income	Depleted groundwater storage in many aquifers
Reduced water shortages	Increased abstraction costs
Reduced risk of crop failure	Salinization of groundwater, increased pollution
Increased are of land in productive use	Destruction of ground-water dependent ecosystems
Increased domestic water supply	Land subsidence
Increased employment….etc	Water use conflict…etc
….improved resilience against drought	….. increased uncertainity for the future

Source Llamas and Martinez-Santos 2004, 2005

Shah et al. (2007) identified six key attributes of groundwater. These were given in the context of groundwater for irrigation, but the same attributes apply equally to other groundwater uses, especially small-scale water supply:

- Groundwater is very nearly ubiquitous,
- Groundwater abstraction systems can be developed quickly,
- Although operating costs are typically higher, the capital costs of groundwater systems compared to conveyance of surface water are much lower,
- Groundwater systems offer great drought-resilience, especially in large storage aquifers,
- Groundwater systems provide water on demand,
- Groundwater systems face smaller transmission and storage losses than surface water systems.

Groundwater offers numerous socioeconomic advantages to both developed and developing nations. However, its development and use require management, and that is the core theme of this study.

1.2. Case study background

The World Bank Group commissioned this case study as part of its economic and sector analysis (ESW) project entitled “Too Big to Fail: The Paradox of Groundwater Governance.[4]” The objectives of this study are:

- Describe the groundwater resource settings for select aquifers, including their characteristics, groundwater use patterns and drivers, user profiles, and socioeconomic factors influencing groundwater use.
- Describe the governance arrangements for managing groundwater in Kenya.
- Identify the relevance of these arrangements in defining strategies for coping with impacts of climate change.

The Kenya case study analysis has been carried out at both strategic, policy and planning, and local institutional levels. Four aquifer systems were examined in detail in order to illustrate issues relating to the objectives.

1.3. Groundwater Governance

In this study, groundwater governance refers to those political, social, economic, and administrative systems that are explicitly aimed at developing and managing water resources and water services at different levels of society that rely solely or largely on groundwater resources. This definition includes all mechanisms relating to financing, knowledge and technical capacity, and the rights and responsibilities of sector players (including water users).

“Bad governance” includes any of the following activities, attitudes, or approaches to groundwater resources management:

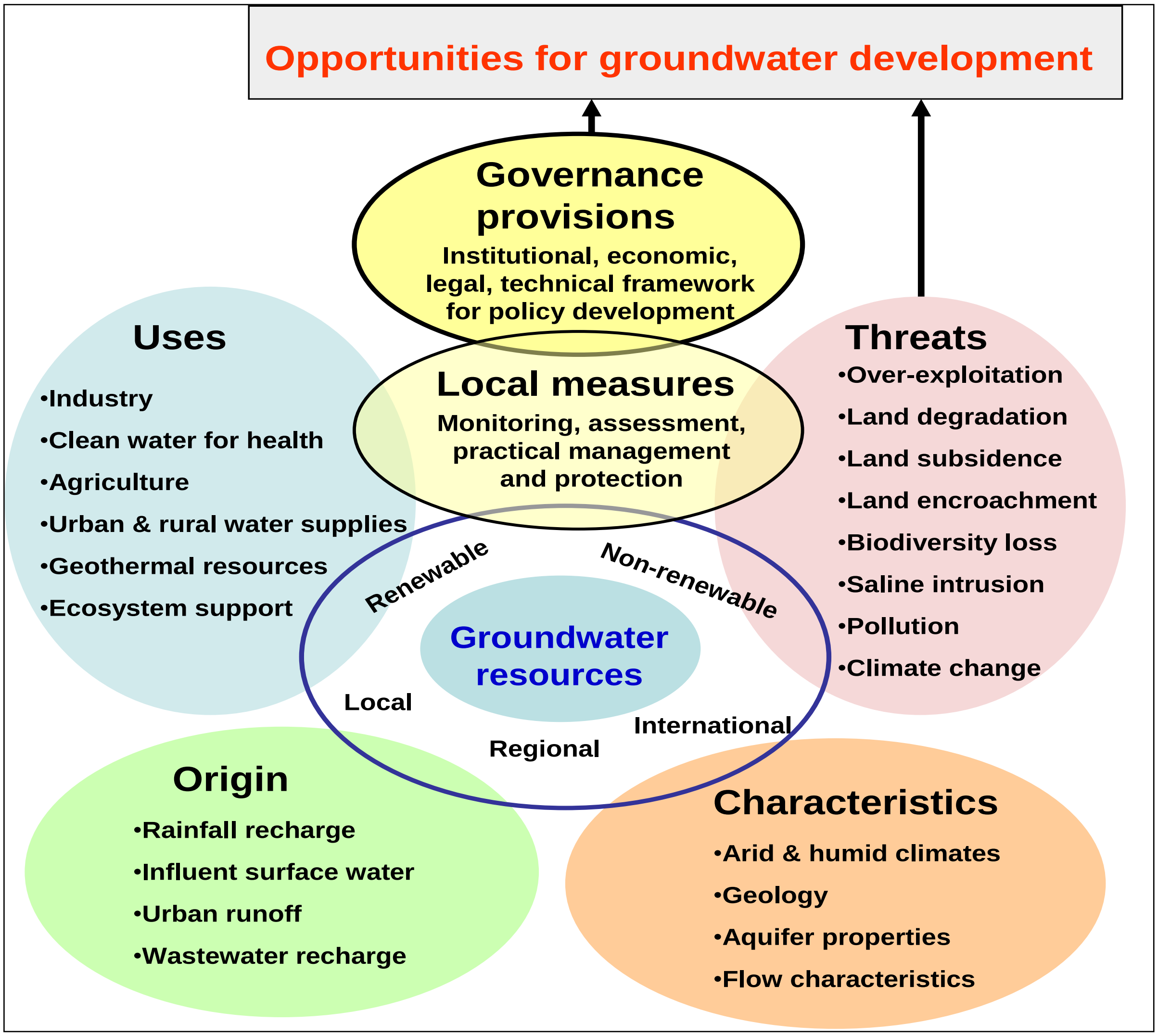
- Inadequate policies, strategies, and legislation relating to groundwater resources and their management, or the ineffective application of those policies, strategies, or laws.
- Inadequate technical and financial capacity to support groundwater resources management.
- Lack of professional integrity, transparency, and accountability.
- Failure to enforce laws relating to allocation and groundwater use.
- Ignoring stakeholders’ rights to equitable access to groundwater resources.
- Poorly managed groundwater projects.
- Inherent corruption in groundwater management processes, including the “quiet corruption”— low-level, small-scale corruption at the service provider/ water user interface (World Bank 2010b).

[4] During the Project Concept Note review, the proposed title for this this Economic and Sector Work was “Improving groundwater governance: The Political economy of groundwater policy and institutional reforms”.

1.4. Linkages in groundwater development

Groundwater is widely considered to be a seriously undervalued resource (World Bank 2009). The complexity of groundwater as a resource and the linkages between groundwater resources, threats to it, governance, and management arrangements are encapsulated in Figure 1 below.

Figure 1. Linkages in groundwater development



Source: World Bank 2009.

2. KENYA: WATER RESOURCES AVAILABILITY AND USE

2.1. Water resources

Water resources in Kenya are irregularly distributed in both space and time, a situation exacerbated by considerable climate variability (Table 2). Cycles of drought and flood (El Niño/La Niña) wreak havoc with physical infrastructure, human life, and development (World Bank 2004); 80 percent of the country is arid or semi-arid, yet hosts 34 percent of the human population and 50 percent of its livestock (UN-Water 2005). These natural conditions are vulnerable to climate change.

Table 2. Water resources availability by catchment

Basin	Area (Km²)	Rain (mm/yr)	Runoff (mm/yr)	Surface water (10^6 m³/yr)	Ground water (10^6 m³/yr)
Victoria	46,229	1,245	149	11,672	116
Rift Valley	130,452	535	6	2,784	126
Athi	66,837	585	19	1,152	87
Tana	126,026	535	36	3,744	147
Ewaso Ngiro	210,226	255	4	339	142
Total				**19,691**	**618**

Source: IWRMS&WE Plan MoWI 2009c

Table 3. Water resources availability values from different sources (10^9 m³/yr)

Source	Surface water		Groundwater	
	Annual resource (BCM)	"Safe yeild" (BCM/yr)	Annual resource (BCM)	"Safe yeild" (BCM/yr)
MoWD / JICA (1992)	24.6		0.65	
UNESCO (2004)	17.2		3.0	
MoWI (2007)	19.6	7.4	2.1	1.04
MoWI (2009c) as Table 2 above	19.7	7.4	0.62 (Table 2)	1.04

Note: "Safe yield" is not defined; the whole concept of "safe" or "sustainable" groundwater yield is contentious at best
Sources: Bredehoeft 1997: Alley et al. 1999: Kendy 2003: Morris et al. 2003: Konikow and Kendy 2004: Llamas 2004

The most useful definition of “safe” or “sustainable yield” is from Evans (2002): the groundwater extraction regime, measured over a specified planning time frame that allows acceptable levels of impact and protects the higher value uses that have a dependency on the water.

In 2009 it was estimated that of the 1.04 BCM/yr considered “safe” groundwater yield, only 0.18 BCM/yr (17.3 percent) was used (0.18 BCM is 0.18 km^3). Catchment degradation and inadequate investment in water development have led to reductions in per capita volume of water in storage, and this trend must be reversed if Kenya is to achieve Vision 2030 (NESC 2007). Water insecurity/vulnerability is one of the biggest impediments to poverty eradication and development, and will only be exacerbated by climate change.

2.2. Water in Kenya’s economy

While Kenya is water insecure and vulnerable, water is at the same time critical to the economy. Kenya is a largely agricultural economy, contributing 27 percent of GDP, employing an estimated 80 percent of the workforce, and providing 57 percent of exports (MoA 2009; MoWI 2009b). According to the Minister for Water, in August 2010 the area under irrigation was 120,000 ha, out of a potential area of 539,000 ha (Hansard 2010b).

The City of Nairobi meets its demand from both surface water (Ruiru, Sasumua, and Ndaka’ini dams) and groundwater (Kikuyu Springs and thousands of boreholes). Nairobi generates approximately 50 percent of Kenya’s GDP (KIPPRA 2008). The city has at times been held hostage to restricted water supply. Because of this, many domestic, commercial, and industrial water users rely on their own boreholes as a coping strategy in the face of inadequate municipal supply. Abstraction across the metropolitan area is estimated to be 160 MLD, or 58 MCM/yr (WRMA 2010a).

Similarly, the investment legacy has meant that water supplies to the major population centers of the coast have often been under stress. All the significant water sources that provide water to the port, industry, tourism, commerce, and residential population on the coast are groundwater (Lamu sand dune aquifer, Baricho aquifer, Mzima Springs, Marere Springs and Tiwi aquifer), which puts this vital component of Kenya’s economy at the mercy of climate change.

2.3. Groundwater and its use

It is estimated that of the 1.04 BCM of renewable groundwater available to Kenya annually, only 0.18 BCM (about 500 MLD) is utilized. As the IWRMS & WE Plan (MoWI 2009c) states, “Although groundwater exploitation has considerable potential for boosting water supplies in Kenya, its use is limited by poor water quality, overexploitation, saline intrusion along the coastal areas, and inadequate knowledge of the occurrence of the resource.”

Other population centers across Kenya are even more reliant on groundwater than is Nairobi. Public water supply in the coastal strip is almost entirely dependent on groundwater (as described above). Many domestic, commercial, and industrial water users rely on groundwater to meet their needs in the South Coast, Mombasa, and the North Coast (Kilifi and Malindi). Numerous towns in Kenya rely largely or exclusively on groundwater for public and private water supply; examples include Naivasha, Nakuru, Wajir, Mandera, and Lodwar.

Rural centers overwhelmingly rely on groundwater resources, even (perhaps surprisingly) in the humid highlands. Much of North Eastern Province relies on groundwater for human and livestock needs (the Merti aquifer; Daua Parma alluvium; and aquifers in the Jurassic limestones of Mandera District). Boreholes equipped with hand pumps meet water needs in villages across the nation. Village borehole water supplies are the norm in Western and, to a lesser extent, Nyanza provinces, and past rural water supply projects in Turkana, Samburu, and the Ukambani districts have led to considerable reliance on groundwater in those areas.

Water sources for smallholder (86,500 ha) and public irrigation schemes (18,900 ha) are typically sourced from surface waters, but a significant proportion of water used by private schemes (78,500 ha) comes from boreholes, particularly around Lake Naivasha and in the northwest Mt. Kenya area. MoWI (2009c) states that only 5 percent of water used in irrigation is groundwater in localized areas in north-eastern Kenya. This may be an underestimate, given the reliance on groundwater by private sector irrigators in the Central, Rift Valley, and Eastern provinces. The irrigation master plan acknowledges that future growth will include private sector-driven groundwater-based irrigation because of the high capital cost of surface water storage. It calculates that 0.2 BCM/yr of groundwater could be allocated to irrigation.

Groundwater is extensively used by industry, especially in Nairobi, Nakuru, and Thika. Volumes used are not known, but an estimate made in 2009 suggested that 27 MLD (9.8 MCM/yr) is pumped daily from boreholes in the Nairobi-Athi River industrial area alone (WRMA 2010a).

Ecological uses of groundwater are numerous, but poorly understood in Kenya. The draft National Wetlands Policy (GoK 2008) is silent on groundwater-dependent ecosystems (GDEs), but explicitly acknowledges the importance of wetlands in both the recharge and discharge of groundwater. GDEs are most easily classified according to their geomorphological setting (GWMATE 2006). Examples in Kenya using this classification are: a) natural outflow from deep groundwater flow systems as discrete springs (e.g. Mzima, Njoro Kubwa); b) wetlands through discharge from shallow aquifers in depressions (e.g. Lari Swamp, Limuru); c) baseflow from extensive aquifers provide dry-weather flow in the upper reaches of river systems; d) brackish coastal lagoons fed by natural discharge; e) terrestrial ecosystems without open water that host phreatophytes extracting moisture directly from the water table (e.g. the Kibwezi “groundwater forest”); and f) upland surface-water fed marshes forming natural recharge zones (e.g. Ondiri Swamp, Kikuyu).

2.4. Transboundary aquifers

Kenya shares over 50 percent of its water resources with other states, which greatly complicates water management. This is more significant for surface waters than groundwater, but even so, there are five significant transboundary aquifer groups: the Rift Valley aquifers, the Elgon aquifer, the Merti aquifer, the Kilimanjaro aquifer, and the Coastal sedimentary aquifers.

Although the National Water Policy recognizes that Kenya has shared water resources, no specific proposals for the management of shared groundwater resources are included in the policy objectives. In 2009, the Ministry formulated a draft policy paper on shared water resources (MoWI 2009d) that did not give particular prominence to shared groundwater resources.

Currently, there are efforts to develop cooperative frameworks for the Mara River Basin between Kenya and Tanzania (including the establishment of a transboundary water resources users association) and for the Sio-Malaba-Malakisi River Basin between Kenya and Uganda. In both these cases, the catchment area has been defined on the basis of surface water catchment areas, and not on the basis of groundwater basins. There are no arrangements under way to develop a cooperative framework for the management of shared groundwater resources, such as the Merti, which is shared with Somalia.

3. THE GOVERNANCE FRAMEWORK

3.1. Policies and legislation

3.1.1 National Policy on Water Resources Management and Development

Sessional Paper No. 1 of 1999, *National Policy on Water Resource Management, and Development* (GoK 1999a), is the principal policy framework for Kenya's water sector reform process. The National Water Policy sets out four policy objectives: 1) to preserve, conserve and protect available water resources and allocate it in a sustainable, rational, and economic way; 2) to supply good quality water in sufficient quantities to meet the various water needs, including poverty alleviation, while ensuring safe wastewater disposal and environmental protection; 3) to establish an efficient and effective institutional framework to achieve a systematic development and management of the water sector; and 4) to develop a sound and sustainable system for effective water resources management, water supply, and sanitation development.

The policy's implementation measures have implications for groundwater management as it relates to: a) identifying the availability and vulnerability of groundwater resources; b) developing the institutional, capacity, and financing arrangements for groundwater management; c) supporting integrated water resources management; and d) considerations for groundwater quality management. Table 4 gives a summary of the main groundwater management issues addressed in the policy paper and observations concerning their implementation or enforcement.

Table 4. Key issues from the National Policy on Water Resources Management

Policy issues	Observation
Groundwater resources are vulnerable to human and land use activities, and intensifying human activities are a threat to the country's water resources. The policy identifies the need for identification and establishment of groundwater conservation zones.	No groundwater conservation area (GCA) has been developed, apart from that around Nairobi that predates this policy statement. There has been an effort to develop a groundwater conservation zone around Lake Naivasha, which has yet to be gazetted
A range of problems are identified on the institutional framework: over centralized decision-making processes, inappropriate monitoring networks and database, discontinuous assessments, uncoordinated source development, non-operative water rights, and the absence of special courts to arbitrate on water use conflicts.	This remains the position to date, notwithstanding the enactment of the 2002 Water Act. What this highlights is that the problem is not an absence of policy, but rather of the will to implement the solutions.
Information flow is characterized by data gaps due to weak monitoring systems and an inadequate user database. This has to be addressed at all levels.	No such database has been established as yet for groundwater data. The WRMA is embarking on a survey of groundwater abstraction in Nairobi.
Water revenue has been inadequate due to limited revenue base, ineffective revenue collection mechanisms, and low water tariffs.	Although the act and rules introduce water use charges on raw water abstraction, the collection of this charge from groundwater had been inadequate to date.
On groundwater management capacity, the government will encourage private sector-led drilling initiatives through competitive tendering procedures.	There are a large number of private drilling contractors who drill boreholes, often haphazardly, and their regulation has become a major issue.
On IWRM, the policy proposes that a National Standing Committee to deal with cross-sectoral issues will be established with representatives from all main water and related sector actors	No such committee has been set up. The different sectors (land, water and forests) still develop their own policies, which lack the necessary linkages.

3.1.2 Water Act 2002

The Water Act of 2002 further underwrites the water sector reform and creates the mechanisms for planning, including the establishment of the Water Resources Management Authority (WRMA 2005). It regulates the ownership and control of water and makes provision for the conservation of surface and groundwater and the supply of services in relation to water and sewerage. Box 1 provides a number of the groundwater-related priorities in the Water Act.

Box 1. Groundwater-related topics in the Water Act

- Every water resource is vested in the State, but subject to any rights of user granted by or under this Act or any other written law (sect. 3).
- The Minister shall have control over every water resource in accordance with provisions of this Act (sect. 4) and shall be assisted by a Director of Water (sect. 6).
- The WRMA is established as a body corporate to manage water resources in Kenya; develop principles, guidelines, and procedures for its allocation; monitor the national water strategy adopted under section 11; and carry out other functions outlined in section 8. The Authority shall establish regional offices (sect. 10).
- The Minister shall prescribe a system for the classification of waters (sect. 12) and determine the water reserve for each classified water resource.
- The Authority may designate catchment areas and shall formulate a strategy for each area. Each area shall have an advisory committee. Protected catchment areas may be declared by the Authority.
- The national water services strategy adopted under section 49 shall provide for national monitoring and information systems on water services (sect. 50). The Minister may constitute Water Services Boards under section 51. These Boards shall provide water services or delegate functions to water service providers.
- Other provisions of Part IV concern rights and duties of holders of licenses to provide water and some other matters relating to water supply.

Source: Kenya, Water Act 2002

3.1.3 National Water Resources Management Strategy

The act provides that the Minister shall formulate a national water resources management strategy (NWRMS) in accordance with which Kenya's water resources shall be managed, protected, used, developed, conserved, and controlled. The strategy shall further provide for: a) determining the reserve; b) classifying water resources; and c) identifying areas to be designated protected areas and groundwater conservation areas.

The NWRS is under the WRMA and includes the following activities with respect groundwater:

- Define and describe groundwater bodies in Kenya (✓)
- Define and quantify the Reserve for each groundwater body (×)
- Identify groundwater bodies which are at risk of over abstraction or water quality deterioration (✓)
- Produce a hydro geological map of Kenya (×)
- Produce a groundwater vulnerability map of Kenya, in detail as and where required (×)
- Identify groundwater bodies that have been subject to significant pollution (×)
- Develop a classification scheme for Kenya's groundwater resources (✓)
- Develop a monitoring network for groundwater quantity and quality (✓ and ×)
- Develop an overview of the status of groundwater quantity and quality in Kenya (×).

Some of these activities have already been achieved, while others have not (indicated by ✓or × above). The NWRMS was published in January 2007, and the groundwater allocation thresholds document with both aquifer classifications and aquifer status in October 2007.

3.1.4 Proposal for a Policy for the Protection of Groundwater (PPPG)

In 2006, the WRMA formulated a policy paper specifically on groundwater governance (WRMA 2006). The paper discusses a framework for the sustainable development of Kenya's groundwater resources providing a common framework to: a) conserve groundwater resources by balancing sustainable use and national development; and b) protect groundwater quality by minimizing the risks posed by pollution (S. 1.4).

The paper proposes an approach that spells out statutory responsibilities for protecting and conserving groundwater resources. This includes specific measures to: a) ensure that all risks to groundwater resources are handled within a common framework; b) provide a common national basis for decisions affecting groundwater resources; and c) encourage a common approach to groundwater protection by all relevant statutory bodies.

The study addresses many of the shortcomings of the National Water Policy from the perspective of groundwater management. However, it remains a proposal that has not been officially adopted by the government as representing the country's policy on groundwater management.

3.2. Related policies and plans

3.2.1 National Land Policy

Kenya does not have a national land use policy at present, but a National Land Policy was adopted by the government in 2009 (GoK 2009). Section 3.4 deals with land management issues, and states that problems of rapid urbanization, inadequate land use planning, unsustainable production, poor environmental management, and inappropriate ecosystem protection and management are commonplace and require policy responses. These same problems have been identified in the national water policy as bedevilling the sustainable management of water resources, including groundwater resources.

The policy calls for putting in place the necessary mechanisms for effective coordination across sectors. However, no concrete steps have been taken to put in place such coordinating mechanisms, and therefore the policy statements remain aspirations. The key issue is that notwithstanding the recognition of the need for coordinated management, land-based resources are still managed on a sector-specific basis. This undermines the sustainable management of groundwater resources.

3.2.2 Policy on Environment and Development

Another important policy paper in the context of groundwater management is the environmental management policy (GoK 1999c). Whereas specific mention is made of the protection of water catchments and wetlands as objectives, no mention is made of groundwater conservation. Groundwater resources are not addressed even in the context of the discussion on rangeland resources, whose effective utilization is often dependent on groundwater resources. Neither is groundwater mentioned in the discussion on land degradation, drought, and desertification.

3.2.3 Policy on Climate Change

At present there are no overarching policies or laws explicitly for the management of climate change. The National Climate Change Response Strategy (GoK 2010) proposes that the EMCA is reviewed in light of the need for response to climate change. The Kenya climate change response strategy for water resources will be discussed in Chapter 4

3.2.4 Irrigation Master Plan

The Irrigation Master Plan identifies activities that, if implemented, would increase the area under irrigation and drainage from 140,000 ha to 300,000 ha. It proposes enhancement of groundwater recharge and increase of groundwater use for irrigation to 0.2 BCM/yr. Significantly, the plan makes no reference to the potential for depletion of groundwater resources resulting from more intense abstraction to meet the demands of increased irrigation.

3.3. Groundwater management instruments

The Water Act gives the WRMA specific mandates to develop instruments for groundwater management. These are also related to the policies and plans of other sectors (see above) and the related legislation such as the Physical Planning Act (1996) and the Environmental Management and Coordination Act (1999).

3.3.1 Catchment areas and catchment management strategies

The WRMA has a mandate to formulate a catchment management strategy for the management, use, development, conservation, protection and control of water resources within each catchment area. Among other issues, the strategy shall: a) contain water allocation plans that set out principles for allocating water; and b) provide mechanisms and facilities for enabling the public and communities to participate in managing the water resources within each catchment area. So legislation provides for the formulation of water resources management plans, which are referred to as catchment management strategies (CMS) and sub catchment management plans (SCMPs). There is no different treatment accorded to groundwater, though at the same time there is no specific mention of groundwater management planning. There is therefore a risk that groundwater resources would not be optimally managed in accordance with the CMS or SCMP, since the key focus is surface water resources.

3.3.2 Groundwater development and allocation

For the regulation of groundwater development, the Water Act states that the WRMA will determine in the allocation plan for a given aquifer the spacing of boreholes or wells to be equipped with motorized plant. The WRMA would be guided by: a) existing borehole or well spacing; b) individual aquifer characteristics, including water quality; c) existing aquifer use; and d) existing bodies of surface water.

3.3.3 Groundwater conservation areas (GCAs)

The WRMA is mandated to enforce special measures for the conservation of groundwater where necessary in the public interest. The WRMA can, following public consultations, declare an area as a GCA; impose such requirements and regulate or prohibit such conduct or activities that it may deem necessary for the protection of the GCA area and its groundwater. The only gazetted GCA in the country is Nairobi.

GCAs are linked to land use planning and therefore related to other legislation like the Physical Planning Act and Environmental Management and Coordination Act. The analysis shows that both acts make no specific mention of the conservation of groundwater resources as a relevant consideration in formulating physical developments plans and environmental planning.

This is a particularly acute problem with respect to the NAS, which is subject to intense exploitation. To date, the only physical plan that has been prepared is for the Karen Langata area of Nairobi. Though gazetted, it is not officially recognized by the City Council of Nairobi and therefore has not been enforced (MoLH 2006).

Box 2. Summary of Policies and Legislation

As this review of policies and laws shows, the Water Act and the Water Resources Management provides guidelines together with other sectoral laws, such as the Physical Planning Act, include specific groundwater provisions. Notwithstanding that the common law has dealt with groundwater as a private resource. On the contrary, the Water Act has dealt with it as a public resource vested in the state and subject to control by the minister, as is the case with surface water. Legislation specifically regulates the construction of wells and boreholes. There are rules regulating wastewater discharges insofar as it affects groundwater and groundwater pollution.

These provisions form a sound basis for managing groundwater resources. However, the key weakness is that GCAs have not been designated anywhere in the country (except for NAS, which dates from before the enactment of the Water Act). There are, however, significant weaknesses in the implementation and enforcement of the legal provisions and guidelines. In a number of cases, the guidelines duplicate each other, particularly those made under the Water Act and the ones made under the Environmental Management and Coordination Act. The implementing agencies lack the institutional capacity to discharge their statutory mandate adequately. Furthermore, the priority given to groundwater, in contrast to that given to surface water, has been low. At the same time, there are limited inter-sectoral coordination mechanisms. This limits opportunities for cooperation, coordination and information sharing between the various implementing agencies.

In summary, Kenya's policy framework recognizes groundwater as an important land-based resource. However, the treatment of groundwater in policy statements is cursory. Groundwater is dealt with under the general umbrella of water resources, and its significance is muted. No specific policy statements are made that would facilitate the sustainable use and management of groundwater resources. These shortcomings are reflected in the priority given to groundwater in the actual management of land-based resources, where surface water has a far higher profile.

3.4. Regulation and controls

There are still few regulations in place that effectively control groundwater management, allocation, and protection. One of the obstacles to this is the effect of the common law on groundwater, which states that a private landowner effectively owns the resource and can abstract it and put it to his own use without having to take account of the wider social requirements. This underscores the perception that groundwater is a private resource. This common law position has been qualified by the statutory provisions dealing with groundwater management. This is illustrated below with a few typical examples of regulatory controls for groundwater.

3.4.1 Water rights and water permits

Under the Water Act, water rights may only be acquired through a permit. Section 27 makes it an offense to construct or use works to abstract water without a permit. Section 26 makes three exceptions to the permit requirement, one of which relates specifically to the use of groundwater.

Statutory law deals with groundwater in a way that is markedly different from surface water, notwithstanding that the ownership of both groundwater and surface water is vested in the state. Unlike the guidelines and regulation for surface water use, the use of groundwater does not ordinarily require a permit. A permit is required where: a) the works are situated within 100 meters of surface water, and b) the works are situated within a GCA.

3.4.2 Regulating the construction of wells and boreholes

The construction of wells and boreholes are regulated under the Water Act, which contains rules governing the abstraction of groundwater that apply even in areas that fall outside GCAs. The regulatory guidelines stipulate a number of conditions for the person/drilling contractor constructing a well/borehole. Through these requirements, the WRMA would be in a position to regulate the abstraction and use of groundwater. The weakness of this system, however, is that it is dependent on landowners coming forward with the information regarding their intention to abstract groundwater. Since boreholes are located within the boundaries of private property, there is a good chance that the WRMA and neighboring landholders may not know that a borehole has been drilled. The WRMA's ability to enforce these rules through its own inspection, monitoring efforts and collaboration with neighboring landholders in providing information therefore becomes critical for enforcing regulation.

3.4.3 Wastewater licensing

The Water Resources Management Rules (WRMR) include a set of provisions for waste water to (a) control the pollution of water; (b) impose a requirement for an effluent discharge permit; and (c) stipulate that effluent may only be discharged into a water resource if it meets prescribed standards. However, for these rules to provide the protection required it would be necessary to identify strategic and vulnerable aquifers and groundwater abstraction points and focus the implementation and enforcement on such aquifers for maximum effect. At present, these rules have not been applied to any of the CSAs.

Artificial recharge can also potentially threaten the quality of groundwater. Regulation 78 of the WRMR (GoK 2007) deals with artificial groundwater recharge and states that no person shall undertake to construct works for the purpose of conducting artificial groundwater recharge of an aquifer in a GCA unless the person has been authorized by the WRMA to do so. This enables the WRMA to regulate the practice of artificial recharge.

3.4.4 Controls on development in recharge/discharge zones and pollution

The protection of recharge and discharge zones of groundwater from pollution could also be achieved under the powers given to water service boards (WSBs) to make regulations that protect any water against degradation (whether on the surface or underground). The regulations would define the area within which the licensee deems it necessary to exercise control. Within that area, it would prohibit or regulate any act prescribed by such regulations and provides penalties.

Although these regulations are appropriate for protecting groundwater from pollution, no WSPs have gazetted any regulations to protect groundwater from which they abstract water for public water supply. This is the case even in vulnerable aquifers such as Tiwi and Baricho, which are critical public water supply sources for the coastal strip (see chapter 4).

3.4.5 Strengths and weaknesses of current regulation

Kenya has a comprehensive legal framework for the management of groundwater resources. The laws recognize groundwater as a water resource that is distinct from surface water resources. There are provisions for requiring authorizations and permits to be obtained for the abstraction and use of groundwater. The law recognizes the value of groundwater and imposes a charge for its abstraction and use. There are also provisions for groundwater conservation and protection.

However, enforcement has been weak, and many of the provisions have not been implemented. By way of example, GCAs have not been declared since the Water Act 2002 came into effect and many groundwater abstractors do not have permits and do not pay water charges for abstracted groundwater. Weak implementation is due to a perception that groundwater is an inexhaustible resource. This perception is rooted in a poor knowledge of groundwater resources, weak institutional capacity, poor funding, and weak political commitment at the senior policy-making level. As a result, over abstraction and poor management have continued. The statement made in the National Water Policy thus remains substantially true in regard to groundwater management today. It states that groundwater is characterized by "over-centralized decision-making processes, an inappropriate and run-down monitoring network, inadequate database, discontinuous assessment programs, uncoordinated source development, non-operative water rights, the absence of special courts to arbitrate on water use conflicts, and a generally weak institutional set up."

3.5. Institutional and organizational arrangements

Key agencies in the water sector

The reform of the water sector under the Water Act (2002) has resulted in the establishment of dedicated agencies (13 new, 2 existing) with clearly defined roles and responsibilities. The Ministry of Water and Irrigation (MoWI) is responsible for the development of legislation, policy formulation, sector coordination and guidance, and monitoring and evaluation. The agencies and their key roles are summarized in Table 5.

Table 5. Roles and responsibilities of water sector institutions

Institution	Roles and responsibilities
Water Resources Management Authority (WRMA)	• Water resources planning, management and protection • Planning, allocation, apportionment, assessment, and monitoring of water resources • Issuance of water permits • Water rights and enforcement of permit conditions • Regulation of conservation and abstraction structures • Catchment and water quality management • Regulation and control of water use • Coordination of IWRM Plan
Catchment Area Advisory Committees (CAACs)	• Advising WRMA on water resources issues at catchment level
Water Resource Users Associations (WRUAs)	• Involvement in decision making to identify and register water user • Collaboration in water allocation and catchments management • Assisting in water monitoring and information gathering • Conflict resolution & cooperative management of water resources
Water Services Regulatory Board (WSRB)	• Regulation and monitoring of Water Services Boards • Issuance of licenses to Water Services Boards • Setting standards for provision of water services • Developing guidelines for water tariffs
Water Services Boards (WSBs) (8 in total)	• Responsible for efficient/economical provision of water services • Developing water facilities • Applying regulations on water services and tariffs • Procuring and leasing water and sewerage facilities • Contracting Water Service Providers (WSPs).
Water Service Providers (WSPs)	• Provision of water and sewerage services
Water Services Trust Fund (WSTF)	• Financing provision of water and sanitation to disadvantaged groups
The Water Appeals Board (WAB)	• Arbitration of water-related disputes and conflicts.
National Water Conservation and Pipeline Corporation (NWCPC)	• Construction of dams and drilling of boreholes
Kenya Water Institute (KEWI)	• Training and research
National Irrigation Board (NIB)	• Development of Irrigation Infrastructure

3.5.1 The extent to which groundwater is integrated with surface water

In line with national policy to endorse the conjunctive use of groundwater and surface water, the institutions (Table 5) manage surface water and groundwater alike, with no particular distinction made for groundwater. At both WRMA and the MoWI, groundwater staff are designated, with roles built into the organizational structure of these institutions. However, these two functions are not integrated, but operate in parallel. So when a surface water abstraction application is made, the implications for groundwater recharge are not factored into the decision making.

The effect of not having a dedicated groundwater management institution has been to further marginalize groundwater management, since greater priority is given to surface water—in terms of both human and financial resources—than to groundwater.

3.5.2 Decentralized groundwater management

Under the Water Act, the WRMA has defined six catchment areas: Lake Victoria South, Lake Victoria North, and the catchment areas of the Athi, Rift Valley, Tana and Ewaso Ngiro North (Figure 2). The WRMA is required to formulate a catchment management strategy for each catchment; appoint a CAAC for each catchment area; and devise mechanisms for the establishment and operation of WRUAs that would facilitate conflict resolution and cooperative management of water resources in each catchment area.

These basins were set up during 2005 and have been operational for a period of six years. Each catchment area is headed by a regional manager. For the purposes of groundwater management, WRMA has deployed to each regional office one hydrogeologist, with the exception of Athi region (within which the Nairobi aquifer is located), where there are three.

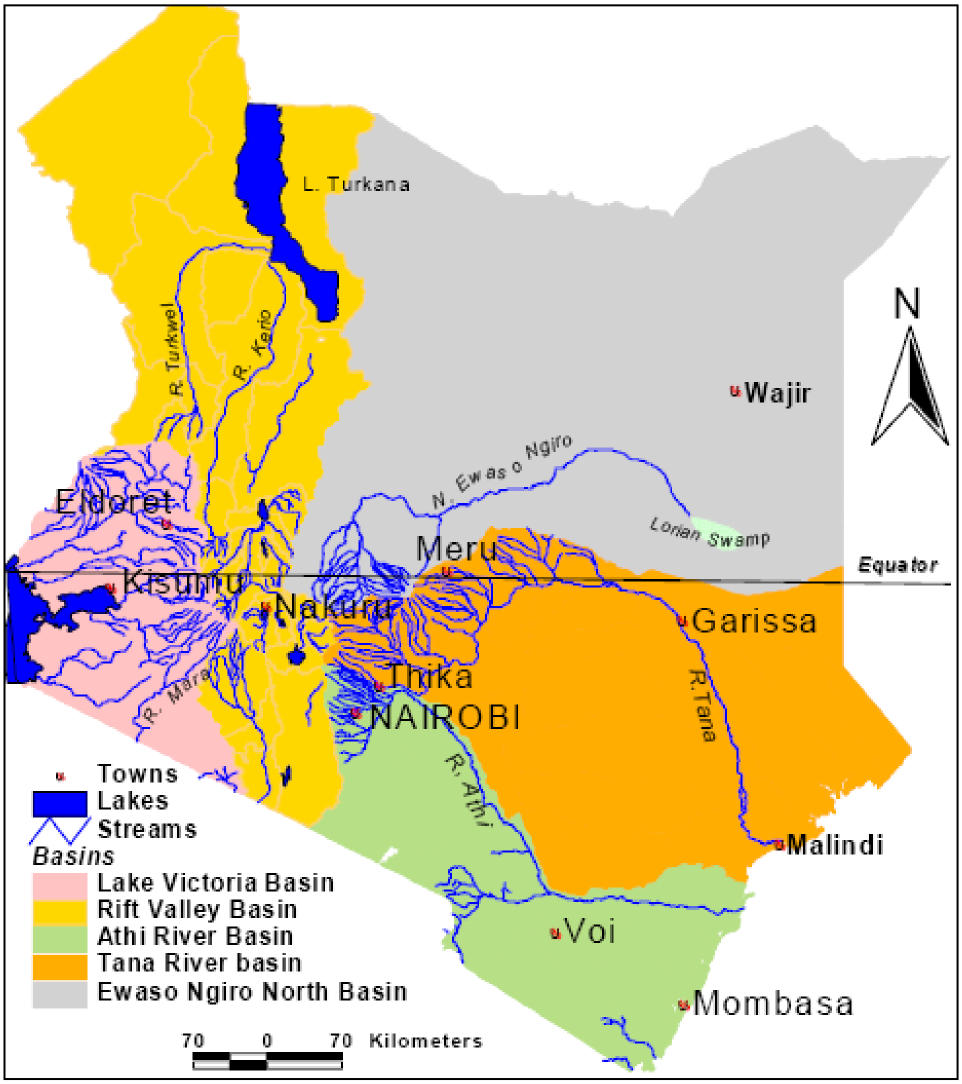
In defining the catchment and sub catchment areas, there has been no consideration of how the groundwater resources might affect the definition of catchment or sub catchment areas. Consequently, certain groundwater resources underlie two catchments and many more sub catchments. These overlaps have not been t taken into account the institutional arrangements for management of surface and groundwater. The institutional models tend to be based on surface water systems alone.

The WRMA is in place at the regional (RO) and sub regional (SRO) office levels, but is not as effective as it might be due to institutional, human resource, technical capacity, and finance limitations. Its groundwater manpower in particular is severely limited; in only one case does an aquifer have any groundwater staff dedicated to it.

3.5.3 Catchment Area Advisory Committees (CAACs)

CAACs were established to advise WRMA regional managers on water resources management issues in the catchment. The CAAC has a statutory membership of fifteen persons drawn from stakeholders—including the government, the private sector, and civil society—with an interest in water resources management. Non-governmental organizations also could be represented. However, in making appointments to CAAC, no special consideration is given for appointment of stakeholders with expertise and/special interest in groundwater management. This shortcoming ought to be addressed, particularly in those catchment areas where water development is heavily reliant on aquifers.

Figure 2. Locations of catchment areas



A common complaint emanating from CAACs is that, being advisory in nature, they have limited influence on decision making. WRMA ROs are not obliged to heed advice tendered by their CAACs, and are not accountable to the CAACs for their actions. This could be remedied by paying greater attention to enhancing coordination mechanisms, including developing linkages with the existing District and Provincial Environment Committees, as well as the District and Provincial Physical Planning Liaison Committees.

In summary, the capacities of the CAACs have not been fully used and, because they have no powers, they are not always able to influence decision making in WRMA. Consequently, their effectiveness in respect to CSA or other aquifer management has been limited.

3.5.4 Stakeholderparticipation/WRUA's

The 2002 Water Act provides for the establishment and operation of water resources user associations (WRUAs). It envisages that where the water resource in question is a groundwater resource, the WRUA would be formed in regard to the management of that particular groundwater resource. No distinction is drawn between groundwater and surface water resources.

WRUAs are not traditional organizations. They are associations set up specifically to bring together users of a given water resource. They could certainly be based on traditional arrangements, but as water resources are allocated by means of abstraction permits rather than on traditional rights of access, WRUAs tend not to focus on traditional use rights. Table 6 shows the registration status of WRUAs by region as of mid-2010.

A number of WRUAs have been effective in resolving water use conflicts. However, WRUAs are voluntary associations and therefore are not uniformly spread across the country. Groundwater management WRUAs are rare. Only two groundwater-specific WRUAs are under formation in the Tiwi and Gongoni areas (Athi catchment), and three exist in the Tana catchment (Lamu, Hindi and Mpeketoni/Lake Kenyatta). Overall WRMA has not made use of the full potential of WRUAs to manage water resources—and equally, water users and other stakeholders have not grasped the opportunities offered by WRUAs. However, this may change, as the example provided by WRUAs in the Lake Naivasha basin shows (Box 3).

Table 6. WRUA registration status by region, 2010

Region	WRUA Establishment					
	Potential	Target	Archieved	Success (%)	WRUA registered by AG	WRUA registered by Social services
Lake Victoria N	100	-	32		24	8
Lake Victoria S	-	80	36	43	29	7
Rift Valley	-	51	47	92	30	47
Athi	60	50	57	114	15	0
Tana	840	60	63	105	46	21
Ewaso Ngiro N	-	45	38	84	18	20
Total:	**>1000**	**286**	**273**	**438**	**162**	**103**

Source: WRMA

3.5.5 Human resources

WRMA inherited the majority of its staff from MoWI, many of whom joined WRMA on secondment. The staff composition at WRMA headquarters and in the regional and sub regional offices is set out in Table 7 below.

Box 3. WRUAs in basin management: the Lake Naivasha case

In the early part of the present decade, water users in the Lake Naivasha Basin had become increasingly aware of the unsustainable level of abstraction from the hydrological system, a situation that was nearly impossible to quantify due to poor and inaccurate hydrological records; lack of accurate information on actual abstraction; weak water permit data; and poor compliance with and weak enforcement of water laws. Commercial water users led the way in commissioning a water allocation plan, and by 2005 were working with the WRMA to develop this and improve the transparency and accountability of water uses in the basin. Water user interests were to be taken on-board through the development of Water Resources Users Associations (WRUAs).

The Lake Naivasha Water Resources Users Association (LANAWRUA) is a blanket WRUA that includes the 12 WRUAs in the Naivasha Basin (the upper sub-basins of the Malewa, Gilgil, and Wanjohi and others; and the Lakeside zone). Since its inception, the WRUAs have:

- Conducted abstraction surveys (both surface and groundwater) and water permit compliance surveys (both)
- Monitored and checked flowmeter status (both)
- Sensitized water users on water use regulations and their obligations (both)
- Provided direct feedback to the WRMA on applications for water permits (both)
- Provided a forum through which water conflicts can be resolved.

Partly as a result of the WRUAs, new rules have been developed that propose both catchment and groundwater protection (The Lake Naivasha Catchment Area Protection and Groundwater Conservation Area Rules), and under which the Lake Naivasha Catchment Area Water Allocation Plan was gazetted in 2011.

At present, the powers of the WRUAs are limited to what is allowed under existing legislation. Under the proposed rules, they are expected to be key in education, checking water use compliance, and in promoting water use efficiency. They will be appointed agents of the WRMA "for the purposes, inter alia, of assisting the Authority in gathering information about water resources within its area of operation; monitoring the use of water; inspecting compliance to these rules; and enforcing compliance with the conditions of water use permits."

These rules have yet to be passed into law, and it remains to be seen how effectively they will work in practice; however, this is the first time a GCA has been proposed under water legislation since before independence, and may show the way forward for participatory groundwater resources management in Kenya.

Table 7. WRMA staff complement, 2010

Regions	Staff, Permanent (No.)	Staff, Casuals (No.)	Groundwater staff	
			Region	Sub region
WRMA HQ	40	–	1	
Lake Victoria North Catchment Area	56	6	1	0
Lake Victoria South Catchment Area	45	7	1	0
Rift Valley Catchment Area	73	3	1	0
Athi Catchment Area	70	10	1	2
Tana Catchment Area	82	5	1	0
Ewaso Ngiro North Catchment Area	55	6	1	0
Total:	**421**	**37**	**1 + 6**	**2**

Source: MoWI 2009c.

Whereas available information suggests that the number of groundwater staff (geologists, drilling inspectors and superintendents, groundwater inspectors, and groundwater assistants) working in the ministry are approximately 100, only nine hydrogeologists are deployed by WRMA as groundwater (management) officers. Each regional office has one groundwater officer, apart from Nairobi SRO (within which the Nairobi aquifer is located), which has two groundwater officers. Given the vastness of the areas to be covered by its staff, the capacity of WRMA to effectively manage groundwater abstractions is limited. Additionally, there is limited groundwater management capacity in the private sector, which employs a number of hydrogeologists as consultants. Occasionally, on specific assignments, these consultants are engaged in undertaking studies and other assignments on groundwater issues on behalf of WRMA.

3.5.6 Private sector participation

The private sector plays a key role in borehole drilling. Other private sector stakeholders include: qualified water resource professionals such as geologists/hydrogeologists, engineers, and so on. They are regulated under Part XIII of the Water Act's guidelines that require these qualified water professionals and contractors be licensed by the ministry. The ministry is required to introduce codes of practice for compliance by the professionals and the contractors, but to date this has not been done.

The ministry therefore acts as the regulator of the professionals and contractors. A number of commentators have expressed the view that WRMA, which issues permits and monitors the activities of the professionals and contractors, should regulate the professionals. Experience has shown that the ministry has often used its role as the regulator to diminish WRMA's authority and ability to impose its requirements on these contractors. Consequently, the WRMA has often been unable to carry out its regulatory mandate. For instance, if a contractor drills a borehole without an authorization, WRMA can only report the matter to the ministry, where the likelihood of punitive action is small. Indeed, there is no recorded instance since the commencement of the 2002 Water Act in which the ministry has taken disciplinary action against a drilling contractor for drilling a borehole without an authorization. Furthermore, the proposed codes of practice to ensure compliance by water sector professionals and drilling contractors with good practice have not been gazetted.

3.6. Monitoring

3.6.1 Water level monitoring

Until recent years, the regular monitoring of groundwater resources was not carried out or was only carried out on a somewhat ad hoc basis. WRMA has now instituted a monitoring program that targets most of the important Kenyan aquifers. The principal disadvantage of the monitoring network currently in place is that the majority of boreholes used are production boreholes and require water levels to return to static levels prior to the measurements.

Eleven dedicated monitoring boreholes are in the process of being constructed in a variety of aquifers across Kenya (Table 8). These monitoring boreholes will be equipped with digital loggers, which will provide more reliable data than hitherto—and allow flexibility in determining how frequently data are collected.

WRMA attempts to manually collect water-level and quality trends quarterly, which is a reasonable compromise for a developing nation. However, for intensively utilized aquifers such as the NAS, water-level measurements are collected monthly; 20 monitored boreholes are spread unevenly across the NAS, and equate to one well per 273 km^2. Water levels are collected weekly to monthly in the Dadaab Merti by CARE Kenya (CDC 2009). These boreholes have been monitored since 1992, and constitute the longest continuous groundwater level data set in the country. Limited water-level monitoring is about to commence at both Tiwi and Baricho.

Table 8. Dedicated monitoring borehole network

Region	Monitoring BH location	Depth	Aquifer	Class	Status
Lake Victoria N	Bungoma Town	100 m	Kavirondan (Bungoma)	MAJOR	Alarm
Rift Valley	Bahati Kabatini, Nakuru	160 m	Nakuru Town	STRATEGIC	Alert
	Rongai Town, Nakuru District	180 m	Rongai	SPECIAL	None
Athi	Kenya High School, Nairobi	300 m	Nairobi	STRATEGIC	Alarm
	Mbagathi Ridge, Nairobi	310 m	Nairobi	STRATEGIC	Alarm
	Kenya Polytechnic, Nairobi	300 m	Nairobi	STRATEGIC	Alarm
	Mombasa	18 m	Coral limestones & sands	MAJOR	Alarm
	Tiwi	100 m	Coral limestones & sands	MAJOR	Alert
Tana	Kenol, Mukuyu	200 m	Nairobi	STRATEGIC	Alarm
Ewaso Ngiro N	Dagahaley Refugee Camp	150 m	Merti	SPECIAL	Alert
	Merti Town	70 m	Colluvial (alluvial)	POOR	Satisfactory

Source: *pers. comm*. World Bank August 21, 2010, WRMA 2007.

3.6.2. Water quality monitoring

Water quality data are also collected for a selection of groundwater sources. For the coastal aquifers, this is limited to pH, color, EC_{25}, TDS, chloride, salinity, total alkalinity, total hardness, magnesium, and calcium. Nitrate and total phosphorus should be added to the parameters analyzed (as indirect indicators of pollution). At Baricho, monitoring should include iron and manganese, and include periodic testing for pesticide metabolites and a selection of trace metals.

Water from the Dadaab Merti is tested annually by CARE Kenya (CDC 2009), but is restricted to the basic suite of analyses conducted by the Ministry of Water and Irrigation's Central Testing Laboratory (CTL).

Despite past recommendations (CDC 2009; UNICEF KCO 2004), repeat tests for selected heavy metals have not been carried out. Groundwater in the Nairobi aquifers are tested at intervals and samples from boreholes used by the Nairobi City Water and Sewerage Company Limited (NCWSC) are tested more frequently for parameters of interest to health (including fluoride).

3.6.3 Data and information sharing

In Kenya, water resources and allocation data of all kinds are theoretically available for purchase, at costs described in the Rules (GoK 2007). However, in reality these data are often difficult or impossible to obtain; some are held by the MoWI, some by the WRMA, and some by the WSBs/WSPs. There is no centralized repository of data, nor is there anywhere a detailed listing of which agency has what data (and at what cost). This means that water allocation decisions may be based on incomplete data or no data.

It matters little which agency or agencies are responsible for archiving, maintaining, and selling groundwater data. It matters rather more how much such data costs, but provided stakeholders are made to understand that data collection and archiving has costs, and that the level set for data purchase can be justified objectively, charges should be made for data.

The current situation is a state of near chaos, and it is imperative that the MoWI acts to organize the proper archiving, maintenance, and selling of groundwater data. Laws make this the principal responsibility of the WRMA—also the agency that has a most definite need for groundwater data for its archiving and must have ready access to it. The ministry—which is responsible for the "development of legislation, policy formulation, sector coordination and guidance, and monitoring and evaluation" (MoWI 2007a)—certainly needs groundwater data to perform its role, but not necessarily in its raw form.

3.7. Financing

The WRMA may determine charges to be imposed for the use of water from a water resource and may retain some or all of the revenue from water use charges payable under a permit to be applied in meeting the costs of performing its functions. Such charges include charges for abstraction of groundwater, although WRMA does not segregate the charges it collects from groundwater and surface water. WRMA may review water use charges, taking account of (a) the inflation rate; (b) the cost of managing the water resources and water catchment areas; (c) the use of water charges as a tool for water demand management; and (d) the use of water as a social and economic good.

The rules are designed on the basis of self-assessment, where the water user should make a fair assessment of the quantity of water used with respect to each permit. Where the user does not make a fair assessment, WRMA makes the assessment of the quantity of water used. Water use charges may be paid directly to WRMA or to an appointed revenue collection agent. Failure to pay water use charges is a breach of the conditions of a permit and may be a basis for revocation of the permit. This system of self-assessment is difficult to enforce because the locations are often not known, and groundwater users are unlikely to come forward of their own volition and make payment. Consequently, the WRMA has experienced a serious shortfall in financial resources ever since it was established. Its development budget for 2009/2010 is tabulated below (Table 9).

Table 9. WRMA Development budget, 2009/10

Region	Development Budget (Million K. Shs)
WRMA HQ	450,714
Lake Victoria North Catchment Area	25,000
Lake Victoria South Catchment Area	24,969
Rift Valley Catchment Area	35,858
Athi Catchment Area	31,004
Tana Catchment Area	36,463
Ewaso Ngiro North Catchment Area	35,000
Total:	**639,008**

Of this, WRMA was able to collect less than KShs. 400 million from water use fees. It received no allocation from the Treasury, and so has had to live with a budget deficit of 37 percent. This compares with the actual and projected MoWI budgets shown in Table 10.

Table 10. MoWI budgets, 2004-13 (KShs. Billion)

Year	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013
Type	Actual	Actual	Actual	Actual	Actual	Actual	Printed	Estimate	Projection	Projection
Recurrent	2,090	2325	2,239	2,669	3,574	4,171	5,689	9,450	5,419	7,078
Development	4,854	4,669	5,016	6,201	4,950	9,041	24,084	41,968	51,242	41,643
Total	**6,944**	**6,944**	**7,255**	**8,870**	**8,524**	**13,212**	**29,773**	**51,418**	**56,661**	**48,721**

Sources: 2003/4 – 2006/07 IEA 2008 : 2007/08 – 2012/13 GoK 2010

There is little information on the apportionment of finances between groundwater and surface water, since expenditures are not normally categorized between them. This potentially can exacerbate the low priority given to groundwater as opposed to surface water in the activities of WRMA. WRMA has been able identify expenditures on groundwater management since its inception (Table 11). Its shows that in 2009/10 actual expenditures on groundwater management was less than 10 percent of the budgeted amount.

Table 11. Analysis of expenditure on groundwater activities (KShs. Billion)

Financial year	2009/10	2008/09	2007/08	2006/07	2005/06
Annual Budget	55,000,000	100,260,000	0	0	0
Actual expenditure	3,918,558	26,821,242*	0	3,588,340	0
Variance	**51,081,442**	**73,438,758**	**0**	**-3,588,340**	**0**

Notes: * Funds used for purchase of six sets of geophysics equipment for use in the six regional offices.
Source: WRMA

4. GROUNDWATER MANAGEMENT AND CLIMATE CHANGE

4.1. Climate change impacts on groundwater in Kenya

Few water sector professionals doubt that climate change will affect Kenya—indeed, there is ample evidence that it already has (GoK 2010). The NCCRS has outlined the ways in which the water sector (in the broadest, cross-sectoral sense) should address adaptation and mitigation, though more detailed implementation plans will be required following the necessary policy and legal changes required to put the strategy into effect (Section 2.5 above). SRES A1B is the middle-of-the-road emissions scenario developed by the IPCC.[5] Its implications are tabulated below.

Table 12. East African regional temperature, precipitation and extremes for SRES A1B

Season	Temperature response (%)					Precipitation response (%)					Extreme seasons (%)		
	Min	25	50	75	Max	Min	25	50	75	Max	Warm	Wet	Dry
DJF	2.0	2.6	3.1	3.4	4.2	-3	6	13	16	33	100	25	1
MAM	1.7	2.7	3.2	3.5	4.5	-9	2	6	9	20	100	15	4
JJA	1.6	2.7	3.4	3.6	4.7	-18	-2	4	7	16	100	-	-
SON	1.9	2.6	3.1	3.6	4.3	-10	3	7	13	38	100	21	3
Annual	**1.8**	**2.5**	**3.2**	**3.4**	**4.3**	**-3**	**2**	**7**	**11**	**25**	**100**	**30**	**1**

Notes: East African region averages of temperature and precipitation projections from a set of 21 global climate models based on the SRES A1B scenario. Values given are the likelihood of change from a baseline of 1989–99 in the period 2080–99; values are shown only when at least 14 of the 21 simulations are in agreement.
Source: Based on Table 11.1, Christensen et al. (2007).

The table shows that in Kenya temperatures are virtually certain to rise and precipitation may increase. Overall, wet seasons are likely to be wetter than at present; the likelihood that dry seasons will be more intense is less than for wet seasons. Runoff is projected to increase (Bates et al. 2008), which will lead to more erosion. More intense rainfall in ASALs is likely to lead to higher volumetric recharge, as recharge typically only occurs after soil field capacity is met. Increasing water scarcity (temporal and spatial) may increase the risk of corruption (TI 2008). Sea level rise will threaten coastal aquifer systems (halocline transgression), though it is possible that the Kenya Coast may not be affected severely (Han et al. 2010).

[5] "The A1 storyline and scenario family describes a future world of very rapid economic growth, global population that peaks in mid-century and declines thereafter, and the rapid introduction of new and more efficient technologies. Major underlying themes are convergence among regions, capacity building, and increased cultural and social interactions, with a substantial reduction in regional differences in per capita income. The A1 scenario family develops into three groups that describe alternative directions of technological change in the energy system. The three A1 groups are distinguished by their technological emphasis: fossil intensive (A1FI), non-fossil energy sources (A1T), or a balance across all sources (A1B) (balanced is defined as not relying too heavily on one particular energy source, on the assumption that similar improvement rates apply to all energy supply and end use technologies" (IPCC 2000).

Groundwater systems react in different ways to climate change; shallow aquifers with short residence times will react more quickly to changes in recharge, while deeper aquifers (particularly those with large storage) will react more slowly—they are better buffered against climate change (BeBuffered.com 2010; Bates et al. 2008).

Given the relatively poor level of understanding of Kenyan aquifers, it is difficult to determine the degree to which they are sensitive to climate change. For the CSAs, a qualitative description of the vulnerability to degradation is given in Chapter 5.

In order to guide the decision-making process and determine aquifer protection priorities, it is clearly important to determine which aquifers are likely to be the most vulnerable. SKM (2009) describe a vulnerability assessment framework that can be applied in both data-rich and data-poor environments and at any scale. This is a risk-based assessment approach, and calls for a five-step process:

- Establish the context
- Identify the relevant climate change hazards for each applicable climate change scenario
- Assess the vulnerability of the groundwater system as it is
- Determine what adaptation measures could be implemented, repeat the consequences and likelihoods exercise from this “adapted” viewpoint
- Test the risks by identifying adaptation options for each scenario.

The actual adaptation phase starts with a list of priority measures that can be implemented—projects, works, education, and so on. The process should be monitored and periodic reviews carried out. Reviews repeated over time should result in better identification of effective adaptation measures, and will also inform research into reducing the uncertainties of risk assessment. An aquifer should be selected for a pilot assessment project to prove the approach in Kenya.

Ultimately, aquifer vulnerability to climate change assessments should be carried out for all strategic and major aquifers, possibly as part of the CMS process and definitely whenever a sub catchment Management Plan (SCMP) is drawn up for a sub catchment in which groundwater plays (or may be expected to play) a role in the socio-economy.

At the national or regional level, the ministry should consider carrying out drought and flood vulnerability mapping (Eriyagama et al. 2010). WRMA should also consider developing drought security maps for climate-vulnerable parts of the nation (see MacDonald et al. 2001 on water security mapping in Ethiopia).

Groundwater offers good opportunities for adapting to climate change by (a) making use of groundwater resources in dry periods in anticipation of wet season recharge, taking advantage of the natural buffering capacity of aquifers; (b) managing aquifer recharge; (c) promoting recharge as part of spate irrigation projects; (d) making better planned use of conjunctive groundwater and surface water (Table 13); (e) promoting ancillary management measures such as enhancing natural vegetation in degraded catchments to restore recharge rates to pre-degradation levels; (f) bunding fields or pasture, which will pond rainwater, encourage infiltration, and enhance soil moisture, thus improving crop yields or grass quality; and (g) re-using water (of all types) to take some of the pressure off water resources in general and complete the "3R" trio (water recharge, reuse, and retention (BeBuffered.com 2010). Broader, catchment-wide measures also contribute to climate change adaptation and mitigation.

Table 13. Adaptation measures for water resources (UNFCC 2007)

Reactive adaptation	Anticipatory adaptation
Protection of groundwater resources	Better use of recycled water
Improved management and maintenance of existing systems	Conservation of water catchment areas
Protection of water catchment areas	Improved water (resources) management
Improved water supply	Water policy reform + pricing + irrigation policies
Groundwater and rainwater harvesting/desalinization	Development of flood control/drought response tools

Source: UNFCC 2007

4.2. Adaptation: managed aquifer recharge

Managed aquifer recharge (MAR) systems are "engineered systems where surface water is put on or in the ground for infiltration and subsequent movement to augment groundwater resources" (Bouwer 2002). There are numerous ways in which this can be achieved, and the appropriate method is almost always aquifer-specific (WRMA 2009a; NWCPC 2006). This measure is of limited utility in aquifers where the travel path and time from natural recharge zone to the zone of use is very long, unless direct recharge methods (such as borehole injection) are carried out in the zone of use. MAR has a number of potential applications, including (a) storing water for future use; (b) stabilizing or recovering groundwater levels in overexploited aquifers; (c) reducing losses by evaporation; (d) managing halocline invasion or land subsidence; and (e) making use of waste or storm water through soil-aquifer treatment (SAT) (Foster et al. 2004).

Small-scale MAR—at the household or village level—offers considerable potential for mitigating drought. The SASOL Foundation has constructed in excess of 500 sand dams in Kitui District. These illustrate MAR at its simplest and most elegant. With low maintenance costs and a lifetime of ~50 years, the potential of sand dams for improving livelihoods is proven and the technology entirely domestic. Sand dams are especially suited to crystalline basement rocks, which cover much of Kenya, and are a sound climate change adaptation strategy, as the Kitui example shows. They are in no way "managed" as part of a formal water development program, and have now acquired a momentum of their own and are managed at the local level by water users for water users.

More imaginative use of groundwater will reap dividends for Kenya as the effects of climate change become more serious. The implementation of MAR at the local level brings with it a need to decentralize aquifer management, and the acknowledgment that local management—at the water user level—is the most appropriate approach. This is perhaps the strongest argument in favor of greater liberalization of the groundwater sector

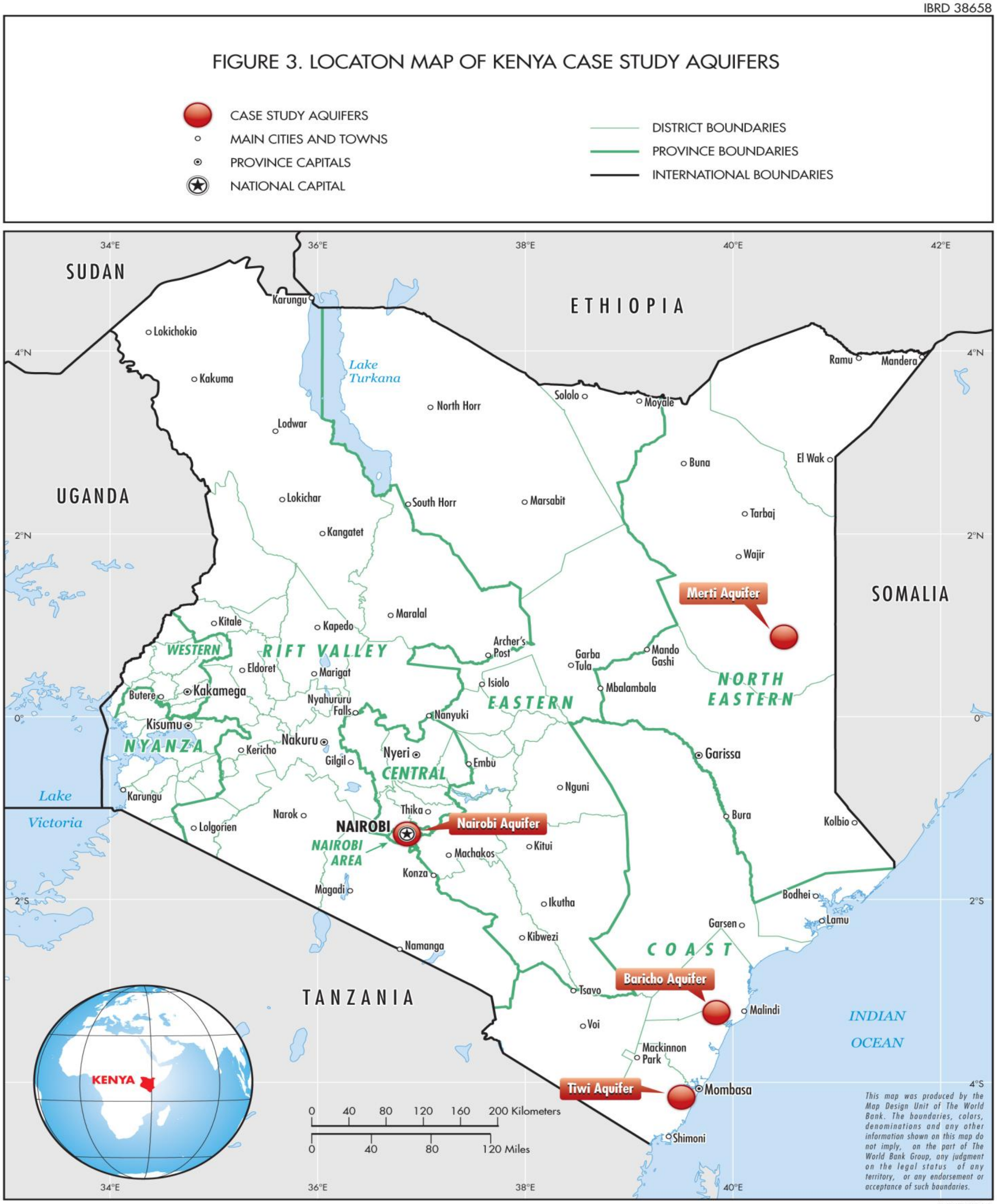
Improved formal management of groundwater as part of climate change and conjunctive use strategies is as yet inadequately explored in Kenya, partly because many of our aquifers are relatively poor in terms of the efficiency of their water production and the cost of abstraction. However, if periodic drought becomes commonplace, even the less efficient aquifers will become vital components in small-town water management strategies. Again, the creation of increased groundwater storage in anticipation of wet season recharge will be an important part of such strategies.

5. CASE STUDY AQUIFERS

5.1. Overview

The four case study aquifers have been selected to represent different sizes, agro-climatic zones, and land use (Figure 3). Each has unique hydrogeological and socioeconomic characteristics and faces different management challenges (Table 14). The table provides the WRMA classification on the type and status of the aquifers (see section 3.1.3). The CSAs are described in more detail in the following paragraphs, including a summary table of: a) the resource setting, and b) the risks and responsibilities.

Figure 3. Location map of the case study aquifers (CSAs)



Source: World Bank 2011 IBRD 38658

Table 14. Case study aquifers' characteristics

Parameter	Merti	Nairobi (NAS)	Tiwi	Baricho
Aquifer type	(Semi)-consolidated sedimentary	Inter-montane valley fill	Major alluvial	Major alluvial
Lithology	Clays, sands, sandstones, limestones	Lavas & lake sediments	Clays & sands	Alluvial sand & gravel
Dominant flow regime	Inter-granular	Inter-granular / fissure	Inter-granular	Inter-granular
Scale	Regional/Transboundary	Regional	Local	Local
Surface area, km^2	60,900 freshwater	6,500	~30	~2
Recharge, MCM/yr	3.3 (modern)	109	21	≈83
Abstraction, MCM/yr	5.3	58	4.8	22
Pollution vulnerability	0.1 Negligible–low	0.1 Negligible–low	0.3 Low–moderate	0.6 High
Saltwater vulnerability	N/A	N/A	0.5 Moderate	0.1 Negligible
Depletion vulnerability	Moderate/local	Serious/extensive	Low	Low
Dominant water use (in approximate order of volumetric use)	• refugee camps • livestock • domestic • public W/S	• domestic • commercial • industrial • irrigation • public W/S	• public W/S	• public W/S
WRMA Type	Strategic / Special	Strategic	Major	Major
WRMA Status	Satisfactory / Alert	Alarm	Alert	Satisfactory

Notes: MCM is millions of cubic meters
Source: WRMA 2007.

5.2. Merti Aquifer

Merti is the largest aquifer in Kenya. It underlies the Lagh Dera, the ephemeral drainage system that forms the eastward continuation of the Ewaso Ngiro North River, and parts of two WRMA regions, Tana and Ewaso Ngiro North. It covers an area of 61,000 km^2 within Kenya (this classification is based on water quality, with electrical conductivities of less than 8,000 µS/cm: the saline or fine *facies* of the aquifer cover a further 139,000 km^2, in which electrical conductivities are higher than 8,000 µS/cm) (UNICEF KCO 2004). It is a transboundary aquifer, flowing into southern Somalia. It is confined through almost all of its range, with water depths of 90 to 120 m bgl.

Merti dates to the Pliocene age and comprises semi-cemented to cemented sands, intercalated clays, and (in the east) intercalated limestone beds. Its effective thickness is uncertain, but the thickest reported was 80 m (C-11715, Dertu). However, evaluation of four hydrocarbon exploration boreholes suggests a possible aquifer thickness of 130 to 280 m (Aquasearch Ltd 2002). Transmissivity ranges from 0.2 m^2/d (fine *facies*) to 840 m^2/d (coarse *facies*), with a median of 275 m^2/d (n = 20). Derived hydraulic conductivity values range from 0.007 m^2/d to 0.013 m^2/d (fine *facies*) to 0.1 to 12 m/d (coarse *facies*). Storage coefficient ranges from 4.3×10^{-5} to 6.7×10^{-4} (n = 6). The hydraulic gradient ranges from 0.001 in the western part of the aquifer, falling to 0.0001 to 0.005 toward the border with Somalia.

5.2.1 Development, history and abstraction

The Merti aquifer is a strategic resource, providing water for rural centers (Habaswein and Dadaab being the largest) and for the refugee camps in the Dadaab area, which currently host approximately 272,000 refugees (pers. comm., M. Owen, 17 May 2010). Discovered in the Second World War, little was done to develop the Merti aquifer until the 1970s, when 50 boreholes for livestock water supply were drilled (UNICEF KCO 2004). The second development phase occurred in the early 1990s with the establishment of three refugee camps. A fourth refugee camp is to be constructed north of Ifoe, with an expected maximum camp population of 80,000 refugees (Owen 2010). Historic and projected 2010 abstractions are in Table 15.

Table 15. Abstraction from the Merti aquifer over time (m^3/yr)

Year	Source	Refugee	Non-refugee	Total
1970	Swarzenski et al. 1977	0	28,900	28,900
1973	Swarzenski et al. 1977	0	69,500	69.500
1992	Lane 1995	250,000	Not stated	> 250,000
1994	Lane 1995	641,000	Not stated	> 641,000
1997	CARE internal reports	885,750	Not stated	> 885,750
2002	UNICEF KCO 2004	997,000	1,526,000	2,523,000
2008	CDC 2009	1,770,000	Not stated	> 2,523,000
2009	Owen 2010	2,120,000	2,420,000	4,550,000
2010	Owen 2010 projected	2,740,000	2,540,000	5,280,000

Source: Various. See column 2.

Non-refugee camp water users are more important in socioeconomic and developmental terms, even if their abstraction is lower than that for the refugee camps; the 1999 domestic population was approximately 93,000. Water supply boreholes serve small rural communities and Location Centers, meeting both livestock and human water demand.

5.2.2 Recharge

Of the four case study aquifers, Merti is unique in that abstraction comes from fossil water. Based on radiocarbon dates, groundwater age is about 30,000 years in the Dadaab area (UNICEF KCO 2004). Modern recharge is estimated to be limited (~3.3 MCM/yr), with major recharge events (~30 MCM) occurring at intervals of thousands to tens of thousands of years.

5.2.3 Vulnerability to pollution

The Merti aquifer is not vulnerable to pollution, as it is largely or wholly confined. Trace metals may occur at slightly excessive concentrations; if verified, their presence is very likely to be natural.

5.2.4 Vulnerability to depletion

Most of the aquifer is under insignificant depletion stress, although there is very limited data available. Some evidence exists to show that long-term abstraction at Habaswein may have led to some salinization of groundwater at that location, and the same may be the case at other boreholes from the mid-1970s. At Dadaab, depletion has occurred and continues, albeit at a slow rate (~0.1 m/yr), and water quality has deteriorated over time (electrical conductivities have approximately doubled since the early 1970s).

5.2.5 Transboundary management

There is no formal transboundary management strategy in place. Since the Merti is a nonrenewable groundwater resource under current conditions,[6] a long-term plan for its use needs to be developed. This should recognize that while ultimately the resource will become exhausted—the most conservative (Lane 1995) estimate suggests about 600 years—its use should balance current development priorities with inter-generational equity. Decisions on this use need to be jointly developed and agreed by both Kenya and Somalia.

5.2.6 Groundwater dependent ecosystems

The Lorian Swamp, a formerly perennial feature southeast of Habaswein, overlying the Merti Aquifer, is the most historically significant ecosystem. When first described, it covered an area of 150 km^2 (Haywood 1913). In 1960, it covered 39 km^2 (Bestow 1963), but today it is strictly seasonal and only exists after significant flooding in the Ewaso Ngiro River. Swarzenski et al. (1977) state that there was permanent swamp vegetation into the early 1950s, and that flow into the swamp occurred when flow at Archer's Post exceeded 35 to 40 MCM/month. It probably once played a role in maintaining recharge to the Merti Aquifer in this area, or at least maintaining recharge to near-surface aquifers in the Habaswein-Sabena zone.

5.2.7 Management

[6] Nonrenewable groundwater is a "groundwater resource available for extraction, of necessity over a finite period, from the reserves of an aquifer which has a very low current rate of average annual renewal but a large storage capacity" (UNESCO 2006).

There are two regional GWOs based in the Ewaso Ngiro North (Nanyuki) and Tana (Embu) regions. Neither regional office is closer than 250 km from the nearest part of the aquifer; Dadaab, the area of most intensive abstraction, is over 320 km from both ROs.

In the Merti Aquifer, there are both WRUAs, which have formed around community-owned boreholes for water supply management purposes, and pastoralist associations (PAs),which are broader, community-interest organizations that necessarily include issues relating to water and related conflict resolution, and which also manage water supplies (FAO 2006: Oxfam 2002). However, neither of these association types are involved in groundwater resources management.

In the Merti, limited impacts on the aquifer (which are mostly restricted to the refugee camp area) mean that there has not been the degradation or depletion that would drive sector players together to manage it. This will change in the long term, and will bring with it a need for both regional management (at the aquifer scale) and local-level management (essentially abstraction management).

The major single water users—the UNHCR and refugee camp NGOs—are known and abstraction is also known with reasonable accuracy. However, water charges are not paid, apparently because of an agreement between the UNHCR and the government. This is inconsistent in terms of international agreements, since the UN was the progenitor of the Dublin Principles (WMO 1992) and the organizing host of the Earth Summit in Rio de Janeiro (UNCED 1992 and Agenda 21).

Table 16. Resource settings, Merti aquifer

Hydrogeological condition Source		Value	Remarks
Definition of groundwater body	Well-defined in *x*, *y* and *z* planes	-	*X* and *y* planes good: *z* less certain
	Transmissivity (*T*) (m^2/d)	3–840	Median 275 (n = 20)
	Hydraulic conductivity (*k*) (m/d)	0.1–12	Derived from *T* and *D* data
	Storage coefficient / specific yield (S / S_y)	4.3^{-5} - 6.7^{-4}	(n = 6)
	Surface area (km^2)	60,900	EC_{25} less than 8,000 µS/cm
	Rainfall (mm/yr)	260–320	Relatively sparse data, but arid
	Recharge (MCM/yr)	3.3 annually	Periodic recharge (millennial scales)
	Abstraction (2010) (MCM/yr)	5.3	Projected, assumes new camp constructed
	Natural discharge	Unknown	Assumed to be oceanic front, Kismayu area
	Soil type / thickness	Variable	Thin, typically sandy; clays at depth
	Natural land cover	Natural	Significant conversion in the refugee camps
Resource renewability		Fossil water: recharge insignificant (millennial intervals)	
Surface water interaction		None (or extremely limited)	
Susceptibility to irreversible degradation		• Very susceptible to localized over abstraction • Water quality deterioration with abstraction: Moderate	
Vulnerability to pollution		Negligible to low (GOD: 0.1)	
Socio-economic condition			
Groundwater users		Refugee > Livestock > Domestic > Other	
Analysis of groundwater use		Fair, but not quantitative	
Analysis of pollution drivers		None	

5.2.8 Other issues

Water quality across the Merti is highly variable, being freshest along the aquifer center-line (the Lagh Dera), becoming progressively more mineralized to the north and south. Waters are typically calcium bicarbonate type, though with intense abstraction they tend toward sodium chloride dominance. The fine *facies*—the peripheral aquifer—is sodium chloride dominated, brackish to saline. One identifying characteristic of Merti groundwater is that it is warm (36 to 40^{o}C). Very few tests for trace constituents have been conducted; however, slightly elevated concentrations of arsenic, boron, cadmium, nickel, lead, and mercury have been reported (Lane 1995: UNICEF KCO 2004). These data are isolated and have not been confirmed through repeat analyses, which have not tested for these substances.

Table 17. Rights and responsibilities, Merti aquifer

1. Groundwater governance metrices	Score	Remarks
• Inventory of groundwater users, uses, and use status	1	A range of data exist, but not in a form that allows easy water balance calculation, determination of what uses dominate, or the degradation status of the aquifer.
• Clear right to access groundwater established	0	Legal instruments exist, but public understanding is poor. Right is based on fixed-quantity, fixed time period, but does not consider the water balance in water allocation
• Mechanisms for local stakeholder involvement in GW planning and management	1	Mechanisms exist via the WRUA framework, but practical involvement has yet to be realized; some direct involvement through pastoral associations
• Existence of WRUAs and their effectiveness in representing GW users		
• Effective legislation for supporting WRUAs	2	Legislation exists, uptake so far poor
• Level of authority accorded to representative groups	0	None as yet
• Opportunities for women and minority involvement in GW planning and management	0	Government has requirements on levels of representation by women & minorities; ineffective in practice (no GW WRUAs)
2. Role of private sector in Groundwater exploration/development		
• Hydrogeologists	1	In response to market forces
• Drilling contractors	1	In response to market forces
• Developers	0	No or little commercial development drive
• Government / development partners	3	Principal drivers are for water supply improvement by government / development partners, and by pastoral associations.
3. Public education on aquifer status		
• Education re. degradation (overabstraction)	1	Limited understanding in the groundwater sector, none outside it, or by the public; no education
• Education re degradation—pollution	0	None
• Education re natural contaminants in groundwater	0	None
• Education re vulnerability of recharge zones	0	None

Note: 0 = nonexistent, 1= incipient, 2 = fair, and 3 = excellent.

5.3. The Nairobi Aquifer System

In economic and scale of abstraction terms, the Nairobi Aquifer System (NAS) is the most significant of the four case study aquifers. It is under increasing pressure as a result of economic growth combined with the inability of water service providers to develop water supply infrastructure in tandem with demand growth. Different parts of the system are subjected to different levels of stress, with a number of notable "hotspots" where abstraction intensity has led to significant water level decline, water quality change, and low-level conflict between water users, with some dissatisfaction expressed by civil society at what is seen to be unregulated groundwater development. The WRMA considers the NAS to be a "strategic" aquifer in an "alarm" state (Table 14). A map showing the Nairobi aquifer system is shown in Figure 1.

The NAS covers an area of ~6,500 km^2, and underlies much of the Nairobi metropolitan area. Its origins date to the Plio-Pleistocene age. It is a complex multilayered volcanic / volcanoclastic aquifer system, recharged along the eastern edge of the Rift Valley with groundwater moving toward the east. It is unconfined in the recharge zone, becoming confined with the eastward progression. The principal aquifer unit, the Upper Athi Series, is entirely confined, and typically found at depths of 120 to 300 m bgl.

Transmissivity values range from 0.1 to 160 m^2/d, with hydraulic conductivities ranging from 0.01 to 1.3 m/d. Storage coefficient values range from 1.2 x 10^{-4} to 4.2 x 10^{-1}.

5.3.1 Development, history and abstraction

Abstraction growth over time is difficult to determine, though a number of estimates and calculations have been made (Table 18).

Table 18. Abstraction from the NAS overtime

Year	Source	Area covered	Abstraction (MCM/yr)
1980	TAMS 1980	Nairobi (684 km^2)	11.8
1992	MoWD / JICA 1992	Nairobi (684 km^2)	13.8
1997	BCEOM 1998	Central aquifer (2,000 km^2)	32.9
2009	WRMA 2010a	Aquifer (5,460 km^2)	57.6

Source: WRMA (2010a)

WRMA (2010a) compared authorized vs. actual abstraction in five "hotspot" zones and projected abstraction across the aquifer by area (Table 19).

The population of the aquifer area is difficult to determine with any accuracy, but estimates for the Nairobi metropolitan area give indicative values for 1999, 2007, and 2012 of 3.33, 4.73, and 5.62 million respectively (MoNMD 2008). The metropolitan area is approximately similar to the aquifer area, except that it includes the basement areas of Tala, Kangundo, and Lukenya.

Table 19. Abstraction from the NAS by area, 2009

Area	Authorized abstraction (m^3/day)	Actual Abstraction (m^3/day and MCM/yr)		No. BHs	Area (Km^2)
		Daily	Annual		
Kikuyu-Limuru-Kiambu	26,697	59,616	21.8	1,296	1,457
Thika-Juja-Ruiru	21,351	12,025	4.4	325	1,129
Westlands-City-Centre-suburbs	41,988	15,200	5.5	950	181
Karen-Langata	19,160	18,216	6.6	552	80
Ongata Rongai-Kiserian-Ngong	11,799	8,003	3.0	510	502
Industrial Area-Athi River	15,068	26,876	9.8	553	357
Kajiado East-Kaputiei-Stony Athi-Koma Rock	15,852	17,668	6.5	670	1,498
TOTALS	**151,915**	**157,604**	**57.6**	**4,856**	**5,204**

Source: WRMA (2010a)

5.3.2 Recharge

Mean annual recharge is estimated to be 109 MCM/yr, which assumes a relatively high recharge rate of 9.2 percent (WRMA 2010a). This is possibly high, given the strictly localized nature of recharge to the NAS. Irungu (1997) estimated recharge to humid volcanic aquifers to be 8 percent. Recharge occurs only in the western and northwestern parts of the aquifer. The range of ages of waters in the NAS are not known; however, given the lengths of flow paths (~15,000 to 30,000 m), aggregate aquifer thickness (several hundreds of meters) and hydraulic gradients (~0.02 – 0.04), ages must be of the order of hundreds of years in the aquifer underlying the city itself (World Bank 1998).

Groundwater is used for public and community water supply; for commercial, industrial, and irrigation uses; and overwhelmingly for domestic use. An estimated 4,856 boreholes have been constructed in the NAS.

5.3.3 Vulnerability to pollution

As the NAS aquifer is largely confined, it is not significantly vulnerable to pollution. It has a GOD vulnerability index of 0.1 (negligible/low); however, as little research has been directed toward the recharge areas in the (north) west, this generalization should be treated with caution.

5.3.4 Vulnerability to depletion

NAS is the most heavily exploited aquifer in Kenya, and concerns have been growing about the sustainability of the current levels of abstraction. Initial efforts to manage abstraction from the NAS commenced in colonial times, with the establishment of the Nairobi Groundwater Conservation Area (Gevaerts 1964; defined in GoK 1972). However, the Nairobi GCA has failed to control abstraction; borehole numbers have grown from 10 in 1940, to 2,000 in 2002 (GWMATE 2005c), to an estimated 4,000 by 2009 in the central 2,140 km^2 of the NAS alone (WRMA 2010b).

The Karen Lang'ata District Association (KLDA), a residents association in the western part of the city, and the Kenya Alliance of Residents Associations (KARA), an umbrella residents association organization, have both expressed concern about the high density of boreholes and apparently uncontrolled drilling over the past decade. Numerous private complaints have also been received by the WRMA in recent years. An attempt by the WRMA to introduce a six-month suspension of borehole authorizations in the metropolitan area, pending the completion of a water allocation plan study (WRMA 2008), was not supported by the parent ministry. The WRMA commissioned a preliminary water allocation plan study (WAP), which was released in January 2010 (WRMA 2010a).

According to the WAP, "it is strongly recommended that sound groundwater management be practiced and strictly adhered to." It also noted that the Athi WSB's plans to increase its use of groundwater to meet water demand are not in line with the urgent need to reduce groundwater abstraction. The strategy made broad recommendations to (a) ban commercial irrigation abstraction in specified hotspot zones; (b) bring about a change in mindset about groundwater at both the user and policy level; (c) increase investment in groundwater research and information; (d) improve information sharing between the WRMA and WSBs/WSPs; (e) ensure that regulations to protect against overexploitation and pollution are enforced; (f) ensure that programs are in place to adequately monitor resource status; and (g) build hydrogeology capacity for the WRMA staff in the NAS and the country in general.

5.3.5 Aquifer management and technical capacity

There is inadequate capacity in the WRMA offices responsible for the NAS. Between them—two geologists are deployed to Nairobi SRO, none in Kiambu SROs—groundwater staff must manage about 4,000 groundwater permits. Furthermore, logistical support is inadequate. Planning departments in the NAS area do not have any technical groundwater capacity, nor does the NCWSC.

5.3.6 Groundwater-dependent ecosystems

There are certainly GDEs—e.g. the Ondiri Swamp—in the NAS, and the draft WAP presents a long list of GDEs for this aquifer. It is estimated that baseflow accounts for between 34 and 44 percent of stream flow across the NAS (WRMA 2010a).

The natural discharge from the NAS occurs as baseflow, but there are also a number of springs that discharge from the western side of the Athi River in the Munyu area (Grabowsky and Poort BV 1997). At Baricho, the natural discharge from underflow east of the waterworks contributes to baseflow, as well as possibly contributing to the recharge of the underlying Kambe Limestones.

5.3.7 Management

The Nairobi aquifer system is the best staffed of the CSAs, with two GWOs deployed at Nairobi SRO. Neither of the other SROs within the NAS has a GWO deployed (Kiambu and Tana Region's Murang'a SRO).

The NAS is unique among the CSAs due to its largely urban character. The common pool nature of the resource and ownership perceptions means that there is little interest in groundwater conservation, and widespread ignorance of the impacts the aquifer has already sustained means that those bodies that might be able to contribute to participatory management focus more on surface water resources that have been visibly affected. Thus the Mbagathi River WRUA (to the west of the city) was established to stem degradation of the Mbagathi River. While its membership is aware that groundwater management is an issue, it is not of a sufficiently high profile to be considered a major WRUA priority. The Athi CAAC has been involved in reviewing applications for groundwater permits, and in several cases has recommended rejecting some of these.

The NAS is the aquifer most in need of pragmatic management, but its urban nature, the practical value of groundwater to commercial developers, and the lack of a rational groundwater allocation process all conspire against participatory management. This will have to change if the best use is to be made of this resource. First, an aquifer use policy needs to be developed to guide further groundwater use.

In the NAS it is estimated that approximately 15 percent of all water users abstract water in accordance with the law; that is, they possess water permits and pay water charges (WRMA 2010b). It is expected that this situation will improve in the wake of a borehole inventory study that is currently being conducted.

5.3.8 Other Issues

Much of the groundwater in the NAS is naturally high in dissolved fluoride, often exceeding the Kenya standard of 1.5 mg/l (KEBS 2007). This is particularly so in the deeper aquifers, water from which may exceed 10 mg/l of fluoride. Of 16 public water supply boreholes operated by the NCWSC for which chemical data are available, 12 exceeded the national standard (partial sample of 27 NCWSC boreholes; KEBS 2010). EC25 ranges from 250 µS/cm in the northwestern part of the aquifer (the recharge zone) to over 1,000 µS/cm in the Embakasi area (Coertsiers et al. 2008; Aquasearch Ltd 2001; MoLRRWD/BCEOM 1998). In their natural state, waters are typically of sodium-bicarbonate type; time series data show that the chemistry of some groundwater has changed, with calcium concentrations falling and chloride and fluoride concentrations increasing.

Table 20. Resource settings, Nairobi aquifer system

Hydrogeological condition Source		Value	Remarks
Definition of groundwater body	Well-defined in *x*, *y* and *z* planes	-	General geometry understood, but not in detail
	Transmissivity (*T*) (m^2/d)	0.1–160	Large range (n = 83, median = 3.4 m^2/d)
	Hydraulic conductivity (*k*) (m/d)	0.01–1.3	Large range but few data
	Storage coefficient / specific yield (S / S_y)	1.2^{-4}–4.2^{-1}	Large range (n = 82, median = 1.0^{-2})
	Surface area (km^2)	5,462	WRMA 2010a
	Rainfall (mm/yr)	917 mean	WRMA 2010a
	Recharge (MCM/yr)	109	WRMA 2010a
	Abstraction (2010) (MCM/yr)	58	WRMA 2010a
	Natural discharge	Uncertain	Assumed as baseflow to Athi: no data
	Soil type / thickness	Variable	Reasonable to good understanding
	Natural land cover	Variable	Land largely converted
Resource renewability		Areally restricted, travel times 10–100+ years	
Surface water interaction		Significant: baseflow 35 to 45 percent of total flow	
Susceptibility to irreversible degradation		• Depletion susceptibility: High • Water quality deterioration with abstraction: Moderate	
Vulnerability to pollution		Negligible to low (GOD: 0.1)	
Socio-economic condition			
Groundwater users		Domestic > Commercial > Industrial > Irrigation > PWS > Other	
Analysis of groundwater use		Fair, but not quantitative	
Analysis of pollution drivers		Incipient	

Table 21. Rights and responsibilities, Nairobi Aquifer System

1. Groundwater governance metrices	Score	Remarks
Inventory of groundwater users, uses, and use status	1	A range of data exist, but not in a form that allows easy water balance calculation, determination of what uses dominate, or the degradation status of the aquifer
Clear right to access groundwater established	0	Legal instruments exist, but public understanding is poor. Right is based on fixed-quantity, fixed time period, but does not consider the water balance in water allocation
Mechanisms for local stakeholder involvement in GW planning and management	0	Mechanisms exist via the WRUA framework, but practical involvement has yet to be realized;* CSO concerns regarding GW degradation are infrequently responded to**
Existence of WRUAs and their effectiveness in representing GW users	1	A few WRUAs in the aquifer area but none are directly involved with GW resources
Effective legislation for supporting WRUAs	2	Laws exist, uptake so far poor
Level of authority accorded to representative groups	0	None as yet
Opportunities for women and minority involvement in GW planning and management	1	Government has requirements on levels of representation by women & minorities; ineffective in practice (no GW WRUAs)
2. Role of private sector in Groundwater exploration/development		
Hydrogeologists	2	Key, but respond to market forces
Drilling contractors	2	Key, but respond to market forces
Developers	3	Main driving force behind GW development
Government / development partners	2	Key, but respond to market forces
3. Public education on aquifer status		
Education re. degradation (overabstraction)	1	One effort was made to sensitize the KWIA (hydrogeologists/ drillers/suppliers) on the impacts of over abstraction; this was not successful
Education re degradation—pollution	0	None
Education re natural contaminants in groundwater	1	Some emerging awareness of the risks associated with drinking naturally fluoridated water—NCWSC, SFR
Education re vulnerability of recharge zones	0	Emerging awareness within the water sector, but no public education effort made

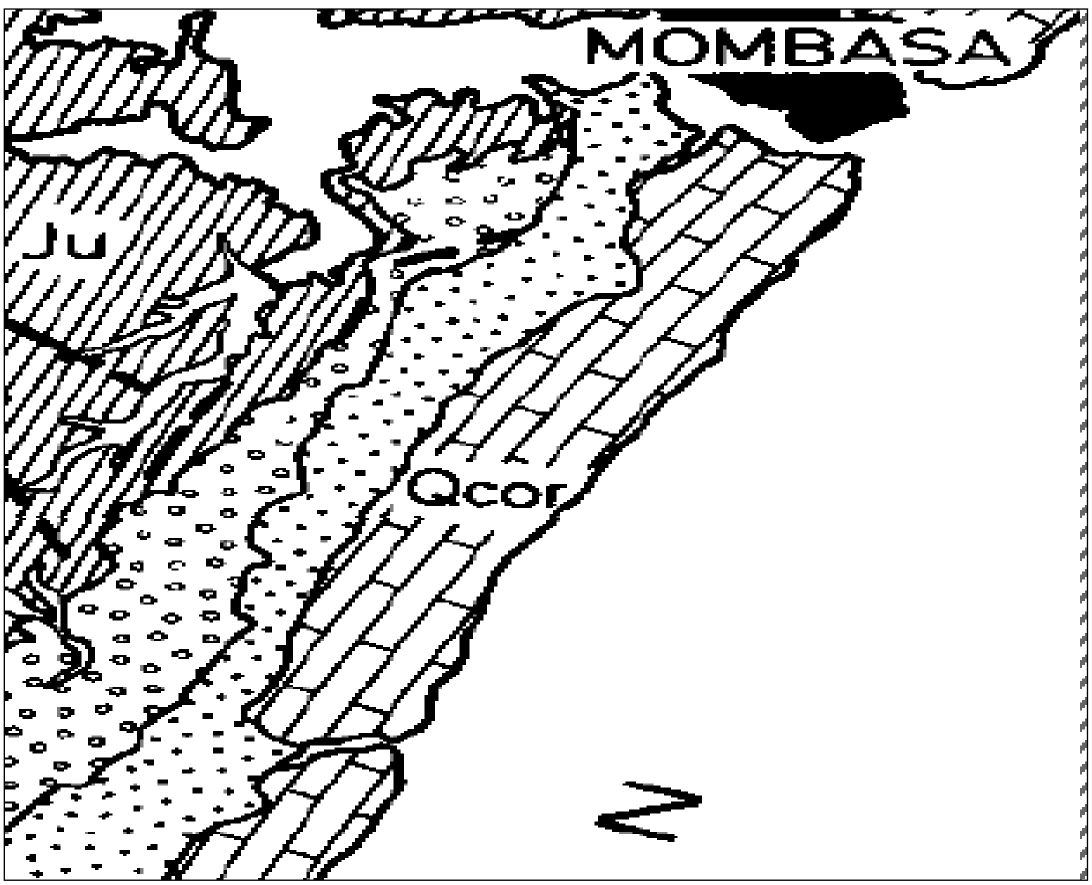
Note: 0 = nonexistent, 1= incipient, 2 = fair, and 3 = excellent. * The Lake Naivasha WRUA (LANAWRUA) is actively involved in reviewing applications for water permits, but their views are not always taken into account by THE WRMA (see Text Box, Section 8.5 of main report).** Resident associations and individuals question the WRMA about groundwater permits or the viability of a new borehole in an area of high borehole density, but responses are rare.

5.4. The Tiwi aquifer

The Tiwi Aquifer is a small but strategically important groundwater source on the South Mombasa Coast. It underlies an area of 147 km^2 between the Mwachema River to the south and a point between Matuga and Ngombeni in the north; its eastern boundary is the contact with the Pleistocene coral limestone, and its western boundary is approximately 2,000 meters west of the Likoni-Ukunda road (Adams 1986). It comprises back-reef deposits (lagoon sands) of Pleistocene age, not more than 70 m thick (also called the "Kilindini Sands"). Technically this aquifer might be considered a recent coast limestone aquifer; however, as its character is alluvial (very fine to coarse sands), we consider it a major alluvial formation

The Tiwi Aquifer is semi-confined or confined, with rest water level 25 to 30 m bgl and struck levels typically a meter or so deeper than this. Individual boreholes are capable of very high yields, though there is a tendency to pull fine sands into wellbores, partly because of improper slot-size selection. Transmissivity values range from 120 to 600 m^2/d, and storage coefficients from 9.3×10^{-3} to 8.0×10^{-2}. Derived values of k range from 13 to 36 m/d.

Figure 4. The Tiwi aquifer



Source: Diani (after Horkel et al 1984)

5.4.1 Development, history and abstraction

The Tiwi Aquifer has been developed for public water supply purposes since the mid-1970s, and is currently one of the two major water sources in the South Coast (the other being the Marere Springs south of Kwale Town).

A total of 13 boreholes have a potential installed capacity of 13,000 m^3/d (4.8 MCM/yr), which supplies Ukunda, Likoni, and Matuga. An additional seven boreholes are planned for construction under the Water and Sanitation Service Improvement Project (WaSSIP; CWSB 2010). Three existing boreholes are to be rehabilitated; the new boreholes are to be replacement boreholes, so will add little to mean daily abstraction. There are no significant Tiwi Aquifer users apart from the Coast WSB.

5.4.2 Recharge

The aquifer is recharged from the west and possibly also from seasonal swamps and lakes directly overlying the aquifer; recharge is both autogenic and allogenic. Adams (1986) calculated mean annual recharge to be approximately 9.9 MCM (27,000 m^3/d), though mean annual flux calculations are much higher than this (90 MLD or 33 MCM/yr). He recommended that a working recharge value of 57.5 MLD or 21 MCM/yr be used when planning the long-term development of this resource.

5.4.3 Vulnerability to pollution

The Tiwi Aquifer is currently not threatened; land uses are predominately agricultural, and abstraction is currently far less than mean annual recharge. However, two potential threats to this aquifer have been identified; sand harvesting, and unsewered urban development. Unregulated sand harvesting may remove enough of the overlying unsaturated material to increase the risk of pollution by direct recharge of dirty water. Any urban development that relies on site sanitation systems (pit latrines or septic tanks) will also constitute a risk to this aquifer.

Wellhead protection is generally poor (see below), and there are no wellhead protection zones other than the compounds in which the boreholes are located, which are probably sufficient as a Total Protection Zone (TPZ), but probably not as a 50-day ToT protection zone (ARGOSS 2002).

Electrical conductivity values currently range from 420 to 750 µS/cm, similar to when the boreholes were first constructed (493 to 1,000 µS/cm). Little current drawdown data are available, but what there is suggests that dynamic water levels are at or around sea level (drawdown ranges from 1.6 to 20 m).

The risk of salinization as a result of lateral or vertical movement of the halocline, certainly exists. However, there are no data to suggest this is taking place (although deeper boreholes were found to produce more saline water at depth). The Ghyben-Herzberg principle describes the relationship between freshwater and saltwater in a coastal aquifer, and suggests that the risk of vertical halocline movement is limited, and the risk of lateral halocline transgression is no more than moderate.

At a practical level, the wellhead protection at individual boreholes in the Tiwi well field is poor in cases. Although Tiwi borehole compounds are manned and fenced, leaving a borehole open like this is poor practice. Boreholes should be capped with steel, perforated to accommodate the rising main, the power cable, and a dipper tube.

5.4.4 Vulnerability to depletion

Under the current abstraction regime, the Tiwi Aquifer faces no vulnerability risk; this may change if the South Coast develops as envisaged in Vision 2030.

5.4.5 Groundwater-dependent ecosystems

Throughout the Tiwi area there are numerous small wetlands that flood entirely during and after wet seasons. These areas are very likely to contribute recharge to the Tiwi Aquifer itself, and if so perform an important ecological function by not only providing habitat for aquatic life, but also partly purifying surface water as it recharges.

5.4.6 Management

Both the Tiwi and Baricho Aquifers are managed from Athi Region's Mombasa SRO, which has no GWO deployed (the GWO at Mombasa was re-deployed to Nairobi SRO). The Tiwi Aquifer and the Baricho aquifer are located 10 km, 110 km from Mombasa respectively. There is also a Regional GWO at Machakos RO, which is over 300 straight-line km from the coast CSAs. The CWSB has recently recruited a hydrogeologist, who should contribute to the better management of the two Coast CSAs.

The Tiwi Aquifer does have some scope for participatory management, with the key stakeholders being the CWSB/KWASCO, Kwale County Council, and the NESC (in the context of the South Coast Resort City and V2030). As it is currently not degraded, and as it is likely that in the medium to long-term greater abstraction from it is likely, a strong case can be made for the initiation of a planning and groundwater management process immediately. However, for any meaningful participatory management to take place, the regulatory and support environment needs to change. This is discussed elsewhere in this report.

None of the CSAs are recognized as discrete entities that are specifically "managed;" consequently, there is no information dissemination protocol developed for any of them. In the cases of Tiwi and Baricho, there is very limited liaison between the CWSB and the WRMA, and WRMA is in possession of very limited data regarding these resources.

Abstraction data can be estimated for the Tiwi and Baricho aquifers. They are used exclusively for public water supply through the CWSB. At Tiwi and Baricho, the details should be easy enough to compile; however, as there are no water permits issued for either of these aquifers, and as no water use charges are paid, the WRMA does not have any details other than approximate abstraction data.

Table 22. Resource settings, Tiwi aquifer

Hydrogeological condition Source		Value	Remarks
Definition of groundwater body	Well-defined in *x*, *y* and *z* planes	-	General geometry understood (*x*, *y* & *z*)
	Transmissivity (*T*) (m^2/d)	120– 600	Log mean 167–323 m^2/d
	Hydraulic conductivity (*k*) (m/d)	13–36	
	Storage coefficient / specific yield (S/S_y)	9.3^{-3}–8.0^{-2}	(n = 3)
	Surface area (km^2)	~30	Total catchment area 147 km^2.
	Rainfall (mm/yr)	1,109 mean	
	Recharge (MCM/yr)	21	
	Abstraction (2010) (MCM/yr)	4.8	Maximum abstraction capacity, not actual annual abstraction
	Natural discharge	Uncertain	Assumed discharge across oceanic front, Waa-Mwachema
	Soil type / thickness	Variable	Good understanding
	Natural land cover	Variable	Land partly converted
Resource renewability		Bi-annual (direct and lateral recharge)	
Surface water interaction		Moderate to strong	
Susceptibility to irreversible degradation		• Depletion susceptibility: none at present • Water quality deterioration with abstraction: halocline invasion risk 0.5 or moderate (SEA-GIndex)	
Vulnerability to pollution		Low to moderate (GOD: 0.3)	
Socio-economic condition			
Groundwater users		PWS	
Analysis of groundwater use		Good	
Analysis of pollution drivers		Fair—sand harvesting and wastewater (unregulated development)	

Table 23. Rights and responsibilities, Tiwi aquifer

1. Groundwater governance metrices	Score	Remarks
• Inventory of groundwater users, uses, and use status	3	Data exist and the aquifer is monitored; as it is entirely used for PWS, use and status are relatively easy to determine
• Clear right to access groundwater established	0	Legislative instruments exist, but public understanding is poor. No water permits, no water use charges paid
• Mechanisms for local stakeholder involvement in GW planning and management	0	Mechanisms exist via the WRUA framework, but practical involvement has yet to be realized. Local CSO is uncertain about the definition of the "Tiwi Aquifer," as compared with the "Msambweni aquifer" or the "Tiomin aquifer"
• Existence of WRUAs and their effectiveness in representing GW users	0	No WRUA
• Effective legislation for supporting WRUAs	2	Laws exists; no uptake in aquifer area
• Level of authority accorded to representative groups	0	None
• Opportunities for women and minority involvement in GW planning and management	1	Government has requirements on levels of representation by women & minorities; ineffective in practice (no GW WRUAs)
2. Role of private sector in Groundwater exploration/development		
• Hydrogeologists	1	Key, but respond to market forces
• Drilling contractors	1	Key, but respond to market forces
• Developers	0	None (directly)
• Government / development partners	1	Key, but respond to market forces
3. Public education on aquifer status		
• Education re. degradation (overabstraction)	0	None
• Education re degradation—pollution	0	None
• Education re natural contaminants in groundwater	0	Emerging awareness within the water sector, but no public education effort made
• Education re vulnerability of recharge zones	0	None

Note: 0 = nonexistent, 1= incipient, 2 = fair, and 3 = excellent.

5.4.7 Other Issues

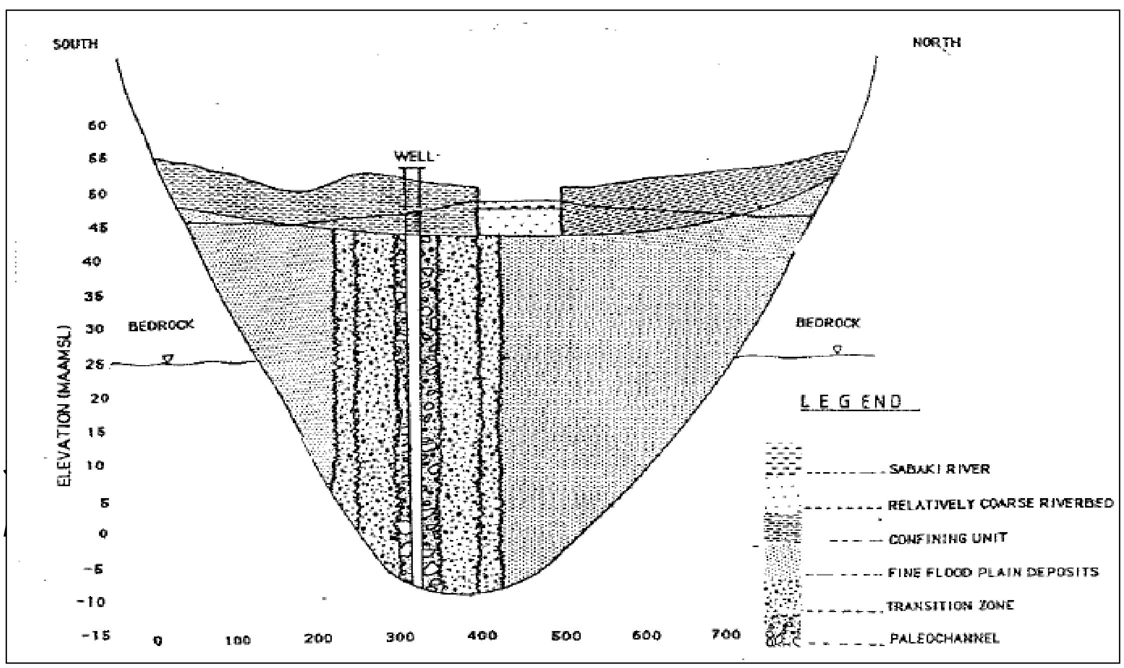
Given that Kenya's Vision 2030 envisages the development of a resort city on the South Coast (NESC 2007), pressures to change land use may increase the vulnerability of this aquifer to pollution, as well as possibly lead to greater abstraction.

5.5. The Baricho Aquifer

The Baricho Aquifer is the smallest of the aquifer systems examined in this case study, but WRMA considers it a strategic aquifer because of its great importance in public water supply to the Coastal Strip (extending from Malindi to the North Mombasa Mainland). The aquifer was formed astride the N-S trending Lango-Baya fault, which makes an unconformable contact between the Mazeras Sandstones and the Kambe Limestones. Pleistocene sea level fall led to down cutting; sea level rise then led to the infilling of the resultant river valley with coarse alluvium. In cross-section, the aquifer is shaped like an inverted triangle (Figure 5), incised into the underlying bedrock. This deeper unit is typically 40 m thick. Overlying this is up to 20 meters of sand, silt, and clay. In most boreholes, the entire sequence is saturated.

The aquifer is semi-confined to unconfined, with vertical hydraulic conductivities between 75 and 500 m/d (NWCPC 1995), inferring transmissivities of 3,750 to 25,000 m^2/d for a saturated thickness of 50 m. Modeled T values ranged from 3,000 to 10,000 m^2/d. Specific yield (S_y) ranges from 0.15 to 0.285, inferring storage of 7 to 13 million m^3. The part of the aquifer that has been exploited to date covers a small area (2 km^2). Water quality is good: EC_{25} ranges from 390 to 680 µS/cm, and water is moderately hard (Hem 1992).

Figure 5. Conceptual cross-section through the Baricho aquifer



Source: NWCPC 1995

5.5.1 Development, history and abstraction

First developed in the 1980s, the aquifer is strictly alluvial and very efficient; public water supply boreholes at Baricho Waterworks on the south bank of the Sabaki are 50–60 m deep, with water encountered 3 to 5 m bgl. At present, approximately 60 MLD is pumped from eight boreholes (22 MCM/yr); potential maximum capacity is 96 MLD (35 MCM/yr). In practical terms, the Baricho Aquifer provides surface water abstraction; infiltrating river water recharges the bankside and valley fill aquifer, which is then pumped into supply from large-diameter boreholes.

5.5.2 Recharge

Recharge is a function of surface water flow, although storage is considerable, providing a buffer against surface water drought. Recharge has not been calculated, as it is in part a function of abstraction (i.e. the more intensive the abstraction, the greater the drawdown and so the greater the volume of induced recharge). The net effect of large-scale abstraction is to reduce surface water flow downstream; simulations have shown that up to 228 MLD could be abstracted (83 MCM/yr) for short periods.

5.5.3 Vulnerability to pollution

The Baricho is potentially the most vulnerable of all the aquifers considered in this study, but its protection is favored by the fact that the area around the water works is sparsely populated and the land is owned by the government. The biggest threat to the aquifer is probably polluted surface water from the Sabaki River. No analyses have been made of trace contaminants, such as pesticides, so the susceptibility of this aquifer to contamination by these compounds is unknown. The aquifer has a GOD index of 0.6, which means its vulnerability is high.

5.5.4 Vulnerability to depletion

At the current levels of abstraction, the Baricho Aquifer is at no risk of depletion. Both the Tiwi and Baricho aquifers are managed from Athi Region's Mombasa SRO, which has no GWO deployed (the GWO at Mombasa was re-deployed to Nairobi SRO). There is also a regional GWO at Machakos RO, which is over 300 straight-line km from the coast CSAs. The CWSB has recently recruited a hydrogeologist, who should contribute to the better management of the two Coast CSAs.

None of the CSAs are recognized as discrete entities that are specifically "managed;" consequently, there is no information dissemination protocol developed for any of them. In the cases of the Baricho aquifer, there is very limited liaison between the CWSB and the WRMA, and WRMA is in possession of very limited data regarding these resources.

The Baricho aquifer is used exclusively for public water supply through the CWSB. The abstraction details should be easy enough to compile; however, as there are no water permits issued for the Baricho aquifer and water uses, and as no water use charges are paid, the WRMA does not have any details other than approximate abstraction data.

Table 24. Resources setting, Baricho aquifer

Hydrogeological condition Source		Value	Remarks
Definition of groundwater body	Well-defined in *x*, *y* and *z* planes	-	Good, well understood.
	Transmissivity (T) (m^2/d)	3,750–10,000	As modeled
	Hydraulic conductivity (k) (m/d)	75 – 500	Derived (D = 50 m).
	Storage coefficient / specific yield (S / S_y)	0.15–0.285	As modeled
	Surface area (km^2)	1.9	Aquifer area in use at present
	Rainfall (mm/yr)	550	Not relevant to Baricho aquifer management (value for 3AH, MoWI 2009a)
	Recharge (MCM/yr)	≈83	(Maximum modeled abstraction)
	Abstraction (2010) (MCM/yr)	22	Maximum abstraction capacity, not actual annual abstraction
	Natural discharge	Uncertain	Underflow and baseflow to Sabaki River
	Soil type / thickness	Understood	Silts and sand
	Natural land cover	Preserved	Largely natural
Resource renewability		Continuous direct recharge from Sabaki River	
Surface water interaction		Very strong	
Susceptibility to irreversible degradation		• Depletion susceptibility: none known at present • Water quality deterioration with abstraction: halocline invasion risk <0.1 or negligible (SEA-GIndex)	
Vulnerability to pollution		High (GOD: 0.6)	
Socio-economic condition			
Groundwater users		PWS	
Analysis of groundwater use		Good	
Analysis of pollution drivers		Poor	

5.5.5 Other issues

Flooding of some of the borehole headworks during the 1998/99 El Niño event led to the ingress of iron-reducing bacteria (*Gallionella*, *Crenothrix* or *Leptothrix spp.*), clogging screens which led eventually to reduced borehole efficiencies (increased drawdown per unit discharge). Boreholes were treated by superchlorination followed by surging. There are no data to show how successful these operations have been; alternative biofouling treatment methods have not yet been used, though some of these may be more appropriate. It is not known whether the aquifer itself is contaminated, though it has been known to occur in some hydrogeological environments (Walter 1997).

5.5.6 Management

Management issues for the Baricho Aquifer are comparable to those described for the Tiwi aquifer.

Table 25. Rights and responsibilities, Baricho aquifer

1. Groundwater governance metrices	Score	Remarks
• Inventory of groundwater users, uses, and use status	3	Data exist and the aquifer is monitored; as it is entirely used for PWS, use and status are relatively easy to determine
• Clear right to access groundwater established	0	Legal instruments exist, but public understanding is poor. No water permits, no water use charges paid
• Mechanisms for local stakeholder involvement in GW planning and management	0	Mechanisms exist via the WRUA framework, but practical involvement has yet to be realized
• Existence of WRUAs and their effectiveness in representing GW users	0	No WRUA
• Effective legislation for supporting WRUAs	2	Legislation exists, no uptake in aquifer area
• Level of authority accorded to representative groups	0	None
• Opportunities for women and minority involvement in GW planning and management	1	Government has requirements on levels of representation by women & minorities; ineffective in practice (no WRUA)
2. Role of private sector in Groundwater exploration/development		
• Hydrogeologists	0	Very limited for Baricho Aquifer
• Drilling contractors	1	In response to CWSB
• Developers	0	No direct role
• Government / development partners	0	Very limited for Baricho Aquifer
3. Public education on aquifer status		
• Education re. degradation (overabstraction)	0	None
• Education re degradation—pollution	0	None
• Education re natural contaminants in groundwater	0	None
• Education re vulnerability of recharge zones	0	Emerging awareness within the water sector, but no public education effort made

Note: 0 = nonexistent, 1= incipient, 2 = fair, and 3 = excellent.

5.6. Summary of risks and benefits of the CSAs

5.6.1 Risks and benefits

Table 26 summarizes the three typologies and their application to each of the CSAs and illustrates the broad range of risks and potential benefits in the four CSAs.

The Merti is a large fossil groundwater resource that is at risk of irreversible damage by abstraction—but only over a very long period of time (hundreds to thousands of years). An aquifer management plan should be developed to ensure that the most effective use is made of this resource, which is of critical value to North Eastern Province. It is not vulnerable to pollution from the land surface, and has considerable potential to contribute to meeting MDGs and in the development of the region through small-scale use (rural centers). It has minor natural water quality issues, which at present appear manageable. The scope for large-scale conjunctive use is limited, though this aquifer may ultimately be developed to supply towns—such as Wajir—in the region with water (MoWRM&D 2003). Its potential as a source of irrigation water is limited, because of a combination of poor soils and intrinsic groundwater quality. It is a transboundary resource that was hitherto of some importance to the downstream state (Somalia), though no joint strategies exist for its management at present.

The NAS is a socioeconomically important resource that is the most seriously stressed of the CSAs, principally because of localized overabstraction. Recharge occurs at its western edge, and groundwater beneath Nairobi is on the order of a hundred years old, so it is at some risk of irreversible degradation through abstraction, though at limited risk of pollution from the land surface. Given that it is currently under overabstraction stress, it offers little potential to meet MDGs or contribute to national development in any but a short time-frame; however, with suitably targeted artificial groundwater recharge, it offers some conjunctive use potential. Naturally high dissolved fluoride concentrations exceed national standards for this ion, which technically could limit its use.

The Tiwi Aquifer is a relatively small but important aquifer that is dedicated entirely too public water supply at present, supplying part of the South Coast with water. It is currently at limited risk of degradation from overabstraction or loss of storage, but is vulnerable to diffuse pollution from the land surface if sand harvesting or significant changes in unregulated land use occur. It is at greater risk from point-source pollution than either the Merti or the NAS, but less so than Baricho; however, it is at the greatest risk of halocline movement of any of the CSAs, although the risk is relatively small. With no natural water quality constraints, it has significant potential to meet greater water demand for urban water supply, but probably not for large-scale irrigated agriculture. Similarly, it has some potential to help meet rural MDGs and improve local livelihoods.

The Baricho Aquifer is a small, highly efficient aquifer of major importance as a source of water for the North Kenya Coast. It is under insignificant risk of degradation through overabstraction but is significantly vulnerable to pollution via recharging Sabaki River waters. Aquifer storage is at no risk of depletion under the current abstraction regime, and the aquifer offers considerable scope for meeting urban and rural water demand in the North Coast, so improving livelihoods and addressing MDGs. Although it is very vulnerable to point-source pollution, there is no evidence that this is a problem as yet; natural water quality is excellent.

Table 26. Typologies and threats to case study aquifers

Typology	Situation/process	Merti	Nairobi	Tiwi	Baricho
Risk of extensive quasi-irreversible aquifer degradation and subject to potential conflict among users	Intensive exploitation (leading to land subsidence, saline or polluted water intrusion)	+++	+++++	+	- - - - -
	Vulnerable to pollution from land surface (vulnerability, pollution)	- - - - -	- - - - -	+++	+++++
	Depletion of nonrenewable storage (in aquifers with low contemporary recharge)	+++++	++++	N/A	N/A
Potential water use conflict but not at risk of quasi-irreversible aquifer degradation	With growing large-scale abstraction (especially in aquifers with high T/S ratios)	N/A	N/A	- -	- - -
	Vulnerable to point-source pollution (vulnerability, pollution)	- - - - -	- - - -	+++	+++++
	Shared transboundary resource	+++++	- - - - -	- - - - -	- - - - -
Insufficient (or inadequate use of) scientific knowledge to guide dev. policy & process	Potential to improve rural welfare & livelihoods (not fulfilling MDG potential)	+++++	- - - - -	+++	+++++
	Natural quality problems (e.g. As, F)	++	++++	- - -	- - - - -
	Scope for large-scale planned conjunctive use (urban W/S or irrigated agriculture)	++	- - - - -	++++	++++

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- - - - - - - - - - - - - - - + ++ +++ ++++ +++++

No risk / hazard — Certain risk / hazard

5.6.2 Values

An attempt was made to determine the value of the groundwater in the four CSAs. Due to the lack of information about the aquifers, a simple method was used to indicate the relative value of the CSAs (Table 27) based on the following assumptions:

- The value of the Merti Aquifer abstraction is taken to be equivalent to water charges that would be paid by Category B, C, or D water users (greater than 20 m^3), assuming that 75 percent of abstraction falls into Categories B, C, or D and users would then pay KShs. 0.50/m^3.
- For the NAS, the revenue is calculated, using only the first tariff band (KShs. 18.71/m^3). This is compared with water charge revenue that the WRMA would expect to get if all water users in categories B, C, and D were paying the minimum water use charge[7] (KShs. 0.50/m^3), though in reality the actual earnings would be considerably higher than this minimum figure.
- For Tiwi and Baricho, we compare the tariffs used by the water companies and compare the value so calculated with the water use charge for public water supply (KShs. 0.50/m^3). As all use is high-volume abstraction, all water use is chargeable.

Table 27. Relative value of abstraction from CSAs

	Merti	Nairobi	Tiwi	Baricho
Volume (MLD)	14.5	158	13	60
Proportion charged (%)	75	81.6	100	100
Volume charged (MLD)	10.9	129	13	60
Water charge (KShs./m^3)	0.50	0.50	0.50	0.50
Value using water charge (KShs. Million/yr)	**2.0**	**23.5**	**2.4**	**11.0**
Tariff (KShs./m^3)	-	18.71	-	-
Volume charged (MLD)	-	158	13	60
Value using tariff (KShs. Million/yr)	-	**1,079**	-	-

It should be noted that these "values" (particularly those based on water charges) represent a minimum value. Irrigators place a far higher premium on their water supply; optimal net returns from water used by a range of irrigators in the Naivasha Basin ranged from \$0.054/m^3 for irrigated grass to \$4.4/m^3 for greenhouse flowers (KShs. 4.3 to 350/m^3) (Sayeed 2001). Groundwater abstraction in 2005 in this basin was estimated to exceed 43.5 MLD (~16 MCM/yr) (Rural Focus Ltd 2006), of which about 80 percent was used for irrigation. The "value" of groundwater for commercial irrigation users is thus very large.

Even ignoring the uncosted benefits (health, education, economic opportunity), it is clear that the CSAs have considerable economic value:

- In the Merti, the ability to access water is literally a matter of life or death; numerous small rural centers would largely fade away in the absence of groundwater, as happened at Wel Merer when its borehole failed in the 1980s and was re-established after a successful borehole was constructed

[7] 687 applicants for Category A water permits (10 m^3/d or less), out of a database of 3,737 applications, is 18.4 percent. Therefore, 81.6 percent of abstraction is assumed to be in Categories B, C, or D (WRMA 2007).

there in 2002 (Aquasearch Ltd 2002). Poor aquifer management—the approval of boreholes in valuable grazing lands, for example (Oxfam 2002)—can lead to grazing land use conflicts.

- The NAS is commercially far more valuable than the indicative economic values above would suggest. The highly profitable private sector commercial and residential building boom that the City of Nairobi has seen in the past eight or so years would largely fail were it to rely on mains water. Estate-type water supplies are often expensive, yet still cheaper than the purchase of bowser water. The actual cost of pumping water from a borehole and distributing it around an estate in western Nairobi was KShs. 104 per m^3 in early 2008 (*pers. comm.* Kisembe Estate Ltd).
- Both the Tiwi and Baricho aquifers are indispensable resources in their own right, supplying a significant proportion of drinking water to the Coastal strip.

5.6.3 Climate change impacts

Of the CSAs, the Merti is probably the most resistant to climate change; as little modern recharge occurs, changes in storage will reflect natural and anthropogenic discharge and not changes in climate. However, if significantly more frequent flooding of the former Lorian Swamp occurs, local recharge may lead to the invigoration of the shallow aquifer reported by Swarzenski et al. (1977) in the Habaswein-Sabena area.

The NAS may benefit from future increased natural recharge in the western uplands, but in the short term this will not be observed in the main abstraction areas because of the long flow path and travel time. The main driver of change in storage will be anthropogenic abstraction.

The two coastal CSAs are more directly linked to the surface environment and are more likely to show variation brought about by climate change. Tiwi will benefit from more recharge and so may be enhanced as a water supply source. Baricho will almost certainly benefit from higher discharge than at present, which will draw from almost the entire Athi Basin; again, this translates into greater abstraction potential.

While these direct outcomes appear positive, there will be negative effects, too; increased rainfall intensity will increase sediment load in rivers, which may ultimately affect the Baricho Aquifer by reducing the hydraulic conductivity of the river bed. Landslides will become a greater threat than they already are at present, putting at risk water monitoring, supply, and wastewater infrastructure (as well as roads, bridges etc).

6. Findings and recommended management actions

6.1. Evaluation of groundwater governance

Table 28 shows the evaluation of groundwater governance in the CSAs and on the national level and illustrates that Kenya does not score highly on groundwater governance.

Table 28. Evaluation of groundwater governance for CSAs and in national capacity

Capacity	Criterion	Context	Merti	Nairobi	Tiwi	Baricho	Inst. Capacity
				Provision			
Technical	Aquifer maps	ID GWR	1	1	0	3	2
	Hydrogeological maps	Aquifer classification	1	1	0	2	1
	Groundwater level network	Resource status	1	1	1	1	1
	Pollution hazard assessment	Quality risk	1	1	1	1	1
	Numerical models	Management	0	1	0	2	1
	Quality monitoring network	Pollution	1	1	2	2	1
	Permits / water rights	Large/small users	1	1	1	1	1
	Reversing GW abstraction	Closure/constraints	0	0	0	0	1
	Preventing GW abstraction	ALARM/ALERT aquifers	0	0	0	0	1
	Sanctioning illegal drilling	Penalties	0	0	0	0	0
Legal/ Institutional	Water use charges	Resource charge	1	1	1	1	1
	Land use controls	Controls on pollution	0	0	0	1	0
	Pollution charges	Incentive for pollution prevention	0	0	0	0	1
	Govt Agency as “GWR Guardian”	Cross-sectoral powers	1	1	1	1	1
	Community aquifer management	Mobilizing communities	1	1	0	0	1
Cross-sectional	Coordination with agriculture	Water savings / pollution control	0	0	0	0	0
	Urban/industrial planning	Conserve / protect GWR	0	0	0	1	0
	Compensation for GW protection	Land-use constraints	0	0	0	0	0
Operational	Public participation	Control exploitation / pollution	1	0	0	0	0
	GW management action plan	Measures and instruments	0	0	0	0	0

Notes: 0 = non-existent, 1= incipient, 2 = fair, and 3 = excellent. ID GWR = characterization of groundwater resources.

6.2. The need for a paradigm shift

Despite attempts to reform the water sector, together with the development of an Integrated Water Resources Management Strategy and Water Efficiency Plan (MoWI 2009c), both water sector professionals and the public still do not adequately understand the association between surface and groundwater. This must change, and in the first instance change must come from within the sector.

This means that mandate problems must be acknowledged, addressed, and fixed. Without doing so, any attempts at restoring a balance between the policy-making, regulating ministry on the one hand, and the implementing agencies on the other—WRMA for resources management, and WASREB, the WSBs and WSPs for water supply—will fail. This is of critical importance in respect to data provision and handling. The current lack of a transparent, accessible, coherent database makes water resources management of any type—and groundwater resources in particular—simply impossible.

Once internal problems have been rectified, similar "bridge-building" initiatives with other sector players—notably NEMA, Health and Sanitation, Agriculture, Lands and the natural resource managers (KFS and KWS)—must be initiated.

Secondly, the WRMA must be given the tools it needs to properly manage the groundwater resources it is responsible for. At present, WRMA does not have the staff, technical, or financial resources to manage aquifers individually. Furthermore, the current structure of the agency does not lend itself to individual aquifer management, though this could be changed relatively easily. The Stakeholder Workshop organized under this assignment was universally of the view that any "aquifer management organization" should be maintained within the existing WRMA structure, for a variety of practical reasons.[8] This will require strengthening existing policies and WRMA's capacity.

Finally, a recognition must emerge that groundwater resources are not amenable to centralized regulation and management. Furthermore, without local participation by both groundwater users and other stakeholders, any management measures are likely to fail. Aquifers should be managed at the aquifer scale, with the caveat that transcatchment and transboundary aquifers need an overarching consultative framework.

This concluding section describes the development of a national groundwater management strategy and a pilot groundwater management plan. These are "no-regrets"[9] measures that should be implemented as part of ordinary IWRM, and not necessarily as explicit climate change adaptation measures—although they will help build climate change resilience. The proposed strategy would provide a starting point to discuss and develop the nature and role of aquifer management organizations, their position within the WRMA structure, and powers that might be vested in them.

[8] Alternative structures could be established, but would require new legislation, with the delays that this would entail. The delegation of some of WRMA's powers to an aquifer management organization could be made by the Minister for Water under §110 (2) (a), if the groundwater management role cannot be hosted within WRMA.
[9] According to the IPCC, "no regrets" measures are measures that would generate net social and/or economic benefits whether or not climate change occurs (Danilenko et al. 2010).

6.3. IWRM and conjunctive use

Focal points in setting up a groundwater management strategy are the IWRM approach and conjunctive use. Kenya has spent five years developing its Integrated Water Resources Management and Water Efficiency Plan (GoK 2009c), after a broad stakeholder consultation process, and it should be implemented as soon as is practicable. The NWRMS (GoK 2007a) recognizes that the "… IWRM& WE Plan as a national priority with obligations for participation and empowerment of stakeholders and decentralized management at the lowest appropriate level." Despite its undeniably high anticipated cost, the plan's overarching management approach to water management across all sectors will yield higher dividends in terms of the greater availability of water per person.

IWRM explicitly requires the integration of groundwater and surface water processes, and the IWRM & WE Plan does so. The principal activities in respect of groundwater in the plan are: (a) to improve monitoring and data collection networks; (b) to identify potential sites and aquifers for artificial groundwater recharge (MAR); (c) to map strategic aquifers and conjunctive water uses; (d) to prepare project designs for aquifer exploitation; (e) to harvest aquifers to increase supply from groundwater; and (f) to identify GCAs.

Conjunctive use is the planned use of both surface and groundwater to meet water demand. Conjunctive use does not necessarily mean that both waters are used simultaneously; indeed, the seasonal nature of surface water and the typically large storage capacities of groundwater systems often make it more logical to use surface water during flood periods and groundwater in dry periods. A properly managed conjunctive use scheme maximizes available water resources, minimizes costs, and minimizes water scarcity in a water supply system.

A number of Kenyan towns and cities (such as Nairobi, Nakuru, and Machakos) operate conjunctive use schemes, though sometimes as a coping strategy and not as a planned approach to meeting water demand. Current construction projects that will create planned conjunctive use schemes include the Kiserian Dam (5.3 MLD), which will supplement existing groundwater supplies to Kiserian, Ongata Rongai, and Ngong Town. The private commercial irrigation sector—for example, in the Naivasha and North West Mt. Kenya areas—often uses surface and groundwater conjunctively.

The key to effective conjunctive management of surface water and groundwater resources is more a question of appropriate capacity building, efficient organization, and better information sharing and communication. It also requires that groundwater and surface water are managed as a single entity, rather than as two, effectively separate, subsectors.

6.4. Groundwater management framework

6.4.1 Framework approach

No Kenyan aquifer is at present managed by a plan, formal or otherwise, and it is evident that some form of groundwater management process is needed for any of the CSAs, all of which face risks that can be mitigated by a groundwater planning process. This is also true for many of the other aquifers, of which Naivasha and Nakuru/Rongai are obvious examples. A framework for measured and logical groundwater resources management is shown in Figure 6.

This process must take place at the aquifer level, possibly through the subordinated management of aquifers by some form of aquifer management organization, and it stimulates the appropriate policy and regulatory framework to emerge. It would be hosted at the CMS or, more appropriately, at the SCMP level (particularly for smaller aquifers). The precise management vehicle would be developed in an aquifer management plan such as that proposed for the South Coast aquifers below.

Not all the groundwater management tools (policy/legislation, technical capacity, and financing frameworks) are currently in place in Kenya. More accurately, some sectoral realignment would be required for the appropriate management and technical conditions to be met. In addition to these measures, the water sector and other stakeholders must recognize that (a) groundwater should be protected; (b) groundwater quality should be conserved; (c) groundwater and surface water are parts of a single resource; (d) groundwater protection will not work without proper land use planning; and (e) water users must understand the need for groundwater protection.

Figure 6. A logical groundwater management framework

Current situation:

- Hydrogeology
- Socioeconomic conditions
- Operational

Desired situation:

- Strategic targets
- IWRMS & WE Plan
- MDGs and Vision 2030
- Resource sustainability

Instruments:

- Policy changes
- Regulatory provisions
- Stakeholder participation

Measures:

- Water quality
- Supply management
- Demand management

Management actions:

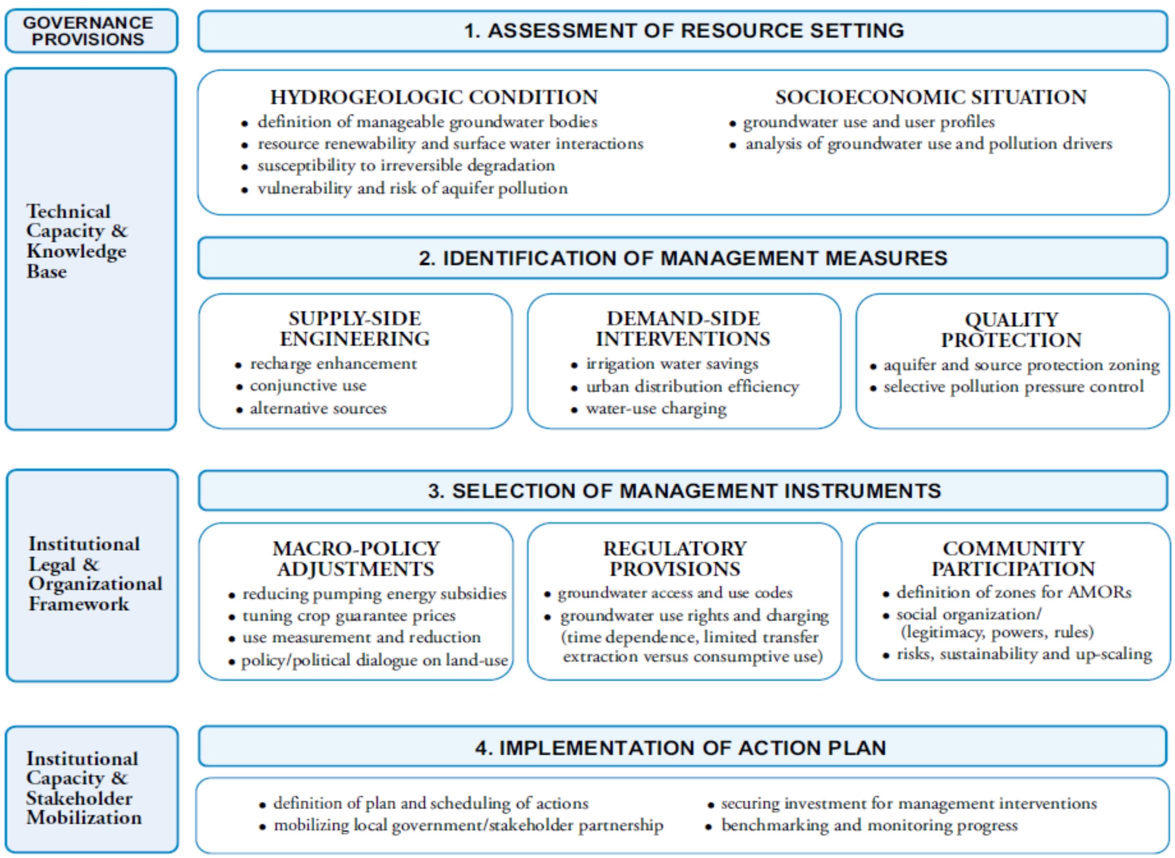
- GW management plans
- Planned conjunctive use
- CC adaptation

Once these basic precepts are recognized, then developing an aquifer management plan is relatively straightforward. The GWMATE strategic overview on groundwater governance (GWMATE 2009) presents a pragmatic and rational approach to aquifer management planning (Figure 7).

The framework can be applied at the national as well as local levels, though most of the management instruments are broadly similar. In the section below, a first attempt is made to apply the framework for Kenya, taking into account Kenyan conditions.

The framework embraces an approach that is truly multisectoral. It takes into account the views and interests of all the key stakeholders, including the public and water users. Ideally, it should be compiled by a workshop or in a similar environment. In developing a draft approach to a strategy (see below), we have taken into account the findings of this study as well as the dialogue and views expressed in the Kenya Groundwater Governance Workshop conducted on September 2, 2010. The framework reflects the interpretation of the consultant team and serves as a basis to be considered and amended in a future workshop or other appropriate forum.

Figure 7. Pragmatic approaches to aquifer management planning



Source: GWMATE SO1 2009.

6.4.2 Kenya national groundwater management strategy

Section 2 of this report considered the technical dimension of groundwater protection in Kenya. Section 3 assessed the governance framework currently in place in Kenya, and proposed measures to improve it in the light of increasing threats to groundwater. These sections inform our approach to the proposed groundwater management strategy in Figure 8.

Key stakeholders for further development of the framework are the MoWI (with WRMA, WASREB/WSBs/WSPs, NWCPC, KEWI); cross-sectoral linkages (MoH, MoA, MEMR, MoL, MoNMD, MoRDA, KFS, KWS); and linkages to UN organizations, multilateral/bilateral partners, and regional/national CSOs (KEPSA, KEWASNET, KSFR). The strategy would be overseen by the MoWI through its sector agencies, with the technical water resources management element overseen by WRMA and the water services side overseen by WASREB. The ministry would create the linkages between cross-sectoral stakeholders at the national/ministerial level, and subordinate MoWI agencies would carry this down the water management hierarchy to regional and local levels.

Figure 8. Proposed national management framework

GOVERNANCE PROVISIONS	1. ASSESSMENT OF RESOURCE SETTING		
Technical Capacity and Knowledge	**STATE OF HYDROGEOLOGICAL KNOWLEDGE** • Aquifer characterization: **incipient** • Land-use / groundwater interface: **incipient** • Pollution vulnerabilities: **non-existent** • Halocline transgression vulnerability: **incipient** • Over-abstraction vulnerability: **incipient**	**STATE OF SOCIO-ECONOMIC KNOWLEDGE** • Groundwater use and user profiles: **incipient** • Pollution drivers: **non-existent / incipient**	
	2. IDENTIFICATION OF MANAGEMENT MEASURES		
	SUPPLY-SIDE MEASURES • Conjunctive use • Managed aquifer recharge • Cross-catchment transfers • Alternative sources	**DEMAND MANAGEMENT MEASURES** • Recycle/reuse wastewater • Distribution management (NRW, UFW) • Water-use efficiency • Rainwater harvesting & use … and others	**QUALITY PROTECTION MEASURES** • Aquifer protection measures (TPZs; TOT zones) • "Polluter pays" controls on pollution • Assess GW vulnerability to CC • Public education and sensitisation
Institutional, Legal & Organisational Framework	**3. MANAGEMENT INSTRUMENTS**		

	MACRO-POLICY ADJUSTMENTS
	• Land-GW interface understood (politicians, planners & water users)
	• Policy for groundwater protection in place
	• Over-arching CC policy in place
	• Improved monitoring network in place
		REGULATIONS
		• Enforce Rules 2007 (permits, charges)
		• Develop a working & practical database
		• Develop WRUA, CAAC or aquifer management organisation management rules
		• Develop economic instruments : –
		  ○ Tradeable permits
		  ○ Pro-poor subsidies/support
		  ○ … and others
			STAKEHOLDER PARTICIPATION
			• Define aquifer "management areas"
			• Define boundaries of authority with respect to WRUA, CAAC or aquifer management organisation and WRMA
			• Define WRUA, CAAC or aquifer management organisation powers
			• Ensure financial sustainability
			• Define WRUA, CAAC or aquifer management organisation composition (gender, marginalised, poor)

Institutional Capacity & Stakeholder Mobilisation	**4. IMPLEMENTATION OF STRATEGIC PLAN**		
	Operational • Draw up implementation plan (duration, sector roles etc) • Mobilise National/Regional-level stakeholder partnerships = Devolve aquifer management planning to appropriate local level	**Support and monitoring** • Secure financing to support management interventions (intra- and cross-sectoral) • Establish monitoring, evaluation and reporting framework	

Once revisions have been made to the relevant institutions and the appropriate capacity vested in the WRMA and CAACs, a national groundwater strategy for Kenya should be developed as a matter of haste. It must incorporate and build upon the initiatives proposed by the NCCRS and IWRM & WE Plan, and must include a component on groundwater's vulnerability to climate change.

6.4.3 Pilot groundwater management plan for the South coast aquifers

Once the development of the national groundwater protection strategy is well advanced, a pilot South Coast Groundwater Management Plan should be initiated, customized to the issues in this region (Figure 9). This area was selected for a number of reasons:

- It hosts the Tiwi Aquifer, which is not accurately defined (geographic extent, flow model, etc). The Tiwi is a major aquifer that is considered by the WRMA to be in an “Alert” state (WRMA 2007).
- It is reasonably easy to define, comprising the Magarini Sands, the Pleistocene Kilindini sands and coral limestones, and alluvium. Its eastern boundary is the oceanic front and its western boundary is the contact with the much older low permeability Jurassic and Permo-Triassic rocks.
- Groundwater is a particularly important resource in the area; threats to it have been defined (sand harvesting; unregulated wastewater disposal; future growth in abstraction).
- It is under specific development pressures that may give rise to these threats (the proposed South Coast Resort City envisioned in V2010).
- Further socioeconomic development of this area would be better guided by a plan that protects groundwater than continuing with the current ad hoc, reactive approach.
- It has easily identified local stakeholders who already participate in the planning processes.

Figure 9. Preliminary management framework for the South Coast aquifers

GOVERNANCE PROVISIONS

Technical Capacity and Knowledge

1. ASSESSMENT OF RESOURCE SETTING

STATE OF HYDROGEOLOGICAL KNOWLEDGE
- Basic knowledge reasonable, Tiwi aquifer better defined than the rest
- Sedimentary aquifers (sediments; coral limestones)
- Preliminary hydraulic data available
- Principal risks to GW identified

STATE OF SOCIO-ECONOMIC KNOWLEDGE
- GW not represented in local development plan; Tiwi aquifer at least is under-utilised, others unknown
- Tourism & domestic growth drivers
- GW in strategic planning weak (S. Coast Resort City)
- Human resource & institutional constraints (poor enforcement of existing Rules)

2. IDENTIFICATION OF MANAGEMENT MEASURES

SUPPLY-SIDE MEASURES
- Recharge enhancement / MAR
- Conjunctive use management
- Rainwater harvesting
- Technology development

DEMAND MANAGEMENT MEASURES
- User awareness
- Water use efficiency planning
- Improved drilling capacity
- Rural electrification

QUALITY PROTECTION MEASURES
- GW protection zones
- Pollution mitigation strategy
- Risk assessment-based solutions
- Assess GW vulnerability to CC

Institutional, Legal & Organisational Framework

3. MANAGEMENT INSTRUMENTS

MACRO-POLICY ADJUSTMENTS
- Integrate GW in land-use planning
- Implement PPG
- Prioritise target areas
- WQ concerns

REGULATIONS
- Management plans for priority areas
- Implement new legal framework
- Expand monitoring network
- Implement CoPs

STAKEHOLDER PARTICIPATION
- Capacity building
- Firm up private sector roles
- Create linkages with other local institutions
- Develop shared information base

Institutional Capacity & Stakeholder Mobilisation

4. IMPLEMENTATION OF STRATEGIC PLAN (ROLL OUT TO WRMA REGIONS)

Operational
- WRMA/CACC formalise stakeholder engagement and cooperation at Sub-regional level
- Regulatory authorities (WRMA/CAAC and Lands) are empowered and capacities built
- Hydro censuses are conducted in all aquifers and water users are sensitised
- WRM Rules are enforced (water permits, wastewater discharge permits, water charges)
- Monitoring systems are expanded and rationalised (water levels, water quality, water charges)
- Aquifers are fully characterised, their vulnerabilities assessed
- Land use plans that include groundwater protection are developed
- Technical data are archived and shared as needed
- Information is made available to the public

Support and monitoring
- Secure financing to support management interventions (intra- and cross-sectoral)
- Establish monitoring, evaluation and reporting framework

Further elaboration of this framework should be done in close consultation with all stakeholders, including WRMA SRO Mombasa and Athi CAAC, CWSB/KWASCO, KCC, cross-sectoral partners (MoH, MoL, MEMR, MoA), local government, tourism, planning and national development (KWS, KFS), and local stakeholders (SCRA, MCTA, SCHA, Base Titanium, and KISCOL).

6.5. Concluding recommendations

The current status of groundwater management requires a broad array of linked measures to enhance its effectiveness. These measures relate to most of the topics discussed in the previous sections and include:

- Amending and streamlining sectoral and cross-sectoral policies
- Streamlining legislation and regulations
- Clarifying institutional mandates
- Aspects relating to rights and responsibilities
- Aspects relating to knowledge and capacity
- Information sharing
- Financial aspects
- Groundwater management strategy / local groundwater management plan.

Addressing the problems affecting groundwater does not require additional or new laws, except in respect of an overarching policy for climate change. It requires action on key recommendations and policy objectives that have been made in policy statements over the years and remain unattained.

Key among these is the development of groundwater management frameworks—for the national level, the catchment level, and/or specific aquifers (such as the CSAs)—to create a functioning mechanism for coordination of actions relating to groundwater across diverse sectors that affect the management of groundwater, including land, environment, and water resources.

Second, it will be necessary to give priority to groundwater management in the activities and programs of groundwater management institutions. This requires providing the resources—human, technical, and administrative—necessary to discharge their mandates effectively.

Third, action is needed to enforce the rules regarding the requirement for authorizations, permits, and water charges, and to improve compliance. Such action would need to target influential individuals and strategic public sector institutions, which have operated under a framework of impunity in regard to groundwater abstraction. Success depends therefore principally on political will and commitment, since the existing legal framework has the basic elements required to manage groundwater sustainably. If the political will is present, the institutions mandated to manage groundwater resources would be provided with the technical and managerial capacity they require to succeed.

6.5.1 Opportunities offered by the National Water Master Plan update

JICA has undertaken to support the updating of the 1992/98 National Water Master Plan, which offers opportunities to strengthen groundwater management. Some of the topics that have arisen from the workshop held on 2nd September 2, 2010 for inclusion in the NWMP are:

- Develop the National Groundwater Management Strategy
- Pilot the groundwater management plan for the South Coast area
- Draw up a list of priority aquifers for which hydrogeological mapping
- Include aquifers for which water allocation plans are urgently required
- Select an aquifer and develop and conduct a climate change vulnerability assessment
- Use the NWMP to educate and sensitize water users and the public of the vital role that WRMA has to play in IWRM, and include capacity-building processes for WRMA technical staff and the CAACs.

7. ANNEX 1: STAKEHOLDER CONSULTATIONS

Participant's name	Organization	Title	Duty Station
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Faith Wanyo	Catholic Diocese of Nakuru	Relations Officer	Nakuru
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Participant's name	Organization	Title	Duty Station
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Francis Gachuga	WRMA, Tana	RTM, Tana	Embu
Joseph Munyola	WRMA, Tana	RWGO	Embu

Source: Minutes of Stakeholder Workshop on the Kenya Groundwater Governance Case Study, Held September 2, 2010, Nairobi Kenya.

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9. BIBLIOGRAPHY

In the course of this project we reviewed a large number of reports, World Bank and UN publications and briefing papers, journal papers, and gray literature. Not all of these have been cited above. However, some particularly important general documents are essential reading for anyone interested in the subjects of groundwater management, conjunctive use, climate change, and their application and relevance to Kenya.

The GWMATE publications—accessible at the World Bank website <<www.worldbank.org/gwmate>> (some of which are directly referenced above) are a valuable source of information, and have been consulted as background reading for this study.

The various IPCC reports, over the past decade, catalogue the development of our understanding of climate change, science, and policy development, and are a useful source of background information, if somewhat voluminous.

The GWP, TEC, and TAC reports and briefing notes provide much valuable information on the evolution, development, and implementation of IWRM as an approach to water resources management.

Various national geological organizations offer useful background material, including some of explicit relevance to groundwater resource issues in Sub-Saharan Africa (BGS in particular, but also the USGS, BGR and the South African DWAF and Water Research Commission). Sector websites (IAH, IWMI, IGRAC etc) are also relevant.

In addition to these, the following provide useful context.

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