ADDIS ABABA UNIVERSITY

INSTITUTE OF TECHNOLOGY

DEPARTMENT OF CIVIL ANDENVIRONMENTAL ENGINEERING

STREAM OF HYDRAULIC ENGINEERING (PG)

FINAL PROJECT ON

Effective groundwater resource management for Addis Ababa city

Prepared by

MISIKIR TADELE GSR/3944/05

Advisor name

Dr. DANEAL F.

December, 2015

Addis Ababa University

Addis Ababa Institute of Technology

School of Civil and Environmental Engineering

EFFECTIVE GROUNDWATER RESOURCE MANAGEMENT FOR ADDIS ABABA CITY

By

MISIKIR TADELE

A Project submitted to school of Civil and Environmental Engineering

Addis Ababa University, Addis Ababa Institute of Technology, for partial fulfillment of requirement of Masters of Science Degree in Civil Engineering

(Hydraulics Engineering)

APPROVED BY BOARD OF EXAMINERS

Dr. DANEAL FIKREMARIAM		
Advisor	Signature	Date
Mr. WONDMYIBZA TSEGAYE		
Internal Examiner	Signature	Date
Dr. ESAYAS GEBREYOHANS		
Chairman, Department Committee	Signature	Date

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

EFFECTIVE GROUNDWATER RESOURCE MANAGEMENT FOR ADDIS ABABA CITY

BY

MISIKIR TADELE G/HANA

A Project submitted to School of Civil and Environmental Engineering Addis Ababa University, Addis Ababa Institute of Technology, for partial fulfillment of requirement of Masters of Science Degree in Civil Engineering

(Hydraulic Engineering)

Advisor

Daneal Fikremariam (Dr.)

DECEMBER, 2015

ADDIS ABEBA, ETHIOPIA

ADDIS ABABA UNIVERSITY

ADDIS ABABA INSTITUTE OF TECHNOLOGY

SCHOOL OF CIVIL AND ENVIRONMENTAL ENGINEERING

PLAGIARISM DECLARATION

First, I declare that this project is my original work and that all sources of materials used for this project have been properly acknowledged.

MISIKIR TADELE G/HANA

____

DECEMBER / 2015

Acknowledgements

At first I want to thank Ethiopian Road Authority (ERA) for giving me the opportunity to have this program.

Also I want to thank Addis Ababa University (AAU), Water Works Design and Supervision Enterprise (WWDSE), Addis Ababa water and Sewerage authority (AAWSA) and Legedadi Deep Wells Water Supply project Staff for their unconditional support by giving data that is needed to do this Project.

Finally I owe special gratitude to all my family members and friends for always being there for me.

Thank you all.

Abstract

These days' young and old people are seen carrying plastic container (jerrycans) in the streets of northern and eastern part of Addis Ababa to collect drinking water. Not only residents in Addis Ababa are suffering from acute shortage of water, but also civil servants in some of various state offices are in trouble of getting tap water. The residents of Kechene, Shiromeda, Piassa, AddisuGebeya, SidistKillo and uptoKotebe in the city are often hardest hit by the disruption, and get water supply just once a week and sometimes once in two weeks.

Due to imbalance between demand andavailability, management approaches are facing various ethical dilemmas. For aneffective, efficient and sustainable groundwater resources development and management,the planners and decision makers have future challenges to assess the inextricable logicallinkages between water policies and ethical consideration. Groundwater being a hiddenresource is often developed without proper understanding of its occurrence in time and space. Thus groundwater management on scientific lines is the key for sustainability of this vital resource.

The issue of groundwater management is multidimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, reuse/recycling, its existing depletion, pollution, and its protection from depletion and degradation. And using Independent local management Approach with policy adjustment, different regulatory provisions, demand side measures, and making quality measure and supply management as the framework of groundwater management found in the result section, groundwater can effectively managed.

Table ofContents

List of Tables

List of Figures

List of Appendix

List of Abbreviations

AAIT	Addis Ababa Institute of Technology
AAU	Addis Ababa University
AAWSA	Addis Ababa Water Supply and Sewerage Authority
BCM^3	Billion Cubic Meters
CSA	Central Statistics Agency
DWL	Dynamic Water Level
EGS	Ethiopia Geological Survey
ENGDA	Ethiopian National Groundwater Data Base
EPA	Environmental Protection Agency
ERA	Ethiopian Road Authority
GWMATE	Groundwater Management Team
MDG	Millennium Development Goal
MoWR	Ministry of Water Resources
NFS	National ForestSystem
NGIS	National Groundwater Information System
NGO	Non-governmental Organization
NRM	Natural Resource Management
PASDEP	Plan of Action for Sustainable development to End Poverty
SCADA	Supervisory Control and Data Collection
UNEP	United Nation Environmental Program.
UNESCO	United Nation Educational, Scientific, & Cultural Organization
USDA	United States Department of Agriculture.
UTM	Universal Transverse Mercator coordinate system
VAT	Value Added Tax
WWDSE	Water Works Design and Supervision Enterprise

1. Introduction

1.1 Study area

Addis Ababa was established as the capital city of Ethiopia in 1886 and has grown to become the largest urban and commercial center in the country. During its early years, the principal sources of water were the numerous springs located at the foot of the Entoto mountain range and hand dug wells located in the lower areas. The larger springs were tapped and fed into a number of small tanks for local distribution.

The city provides its water supply from both surface water and groundwater sources. There are three main surface water dams as sources for the surface water supply. These are Gefersa, Legedadi and Dire. The groundwater source is from Akaki groundwater (Akaki well field) and from spring and wells within and near Addis Ababa. There are two conventional water treatment facilities, namely Legedadi water treatment plant and Gefersa water treatment plant to supply the city treated water from the aforementioned sources. The location of water supply sources in the Addis Ababa, Gefersa dam is situated 18-kms west of Addis Ababa; Legedadi dam is situated 25-kms east of Addis Ababa; and Akaki well field is situated southeast of Akaki and about 22- kms south of Addis Ababa.

The city has three main subsystems namely: Legedadi, Gefersa, and Akaki subsystem. Legedadi subsystem includes supplies from Legedadi water treatment plant to service reservoirs of Kotebe terminal, Karalo, Ankorcha, Jan Meda, Gebrial Palace, TeferiMekonnen, Entoto, Belay Zeleke, Police Hospital, Army Hospital and KasaGebre; and to pumping stations at Ureal and Mexico Square.

Gefersa subsystem includes supplies from Gefersa water treatment plant to service reservoirs of Rufael, St. Paul, and RasHailu. Akaki subsystem includes the supply of water from Akaki well field to CT, GW1, GW2, GW3, Bole Bulbula service reservoir and Lebu service reservoir. The three subsystems have additional groundfiwater well sources apart from their principal sources.

Due to the shortage of the water source and unbalance system between demand and supply another groundwater supply have been introduced to the city of Addis ababa and it is Legedadi Deep well Water supply project, which is located at the suburb of Addis Ababa city in Oromia Regional State, at a distance of approximately 30 km from the city center. Legedadi well field lies within the UTM coordinates of (1010420, 1003420) East and (493155, 504155) North and the average elevation is about 2494.88 m a.s.l. The transmission line extends from Legedadi collecting tank, near the well field to Ayat Square area. The distribution line extends to YekaAbado, YekaAyat,BoleAyat, Bole summit and Bole Arabsa condominium sites.

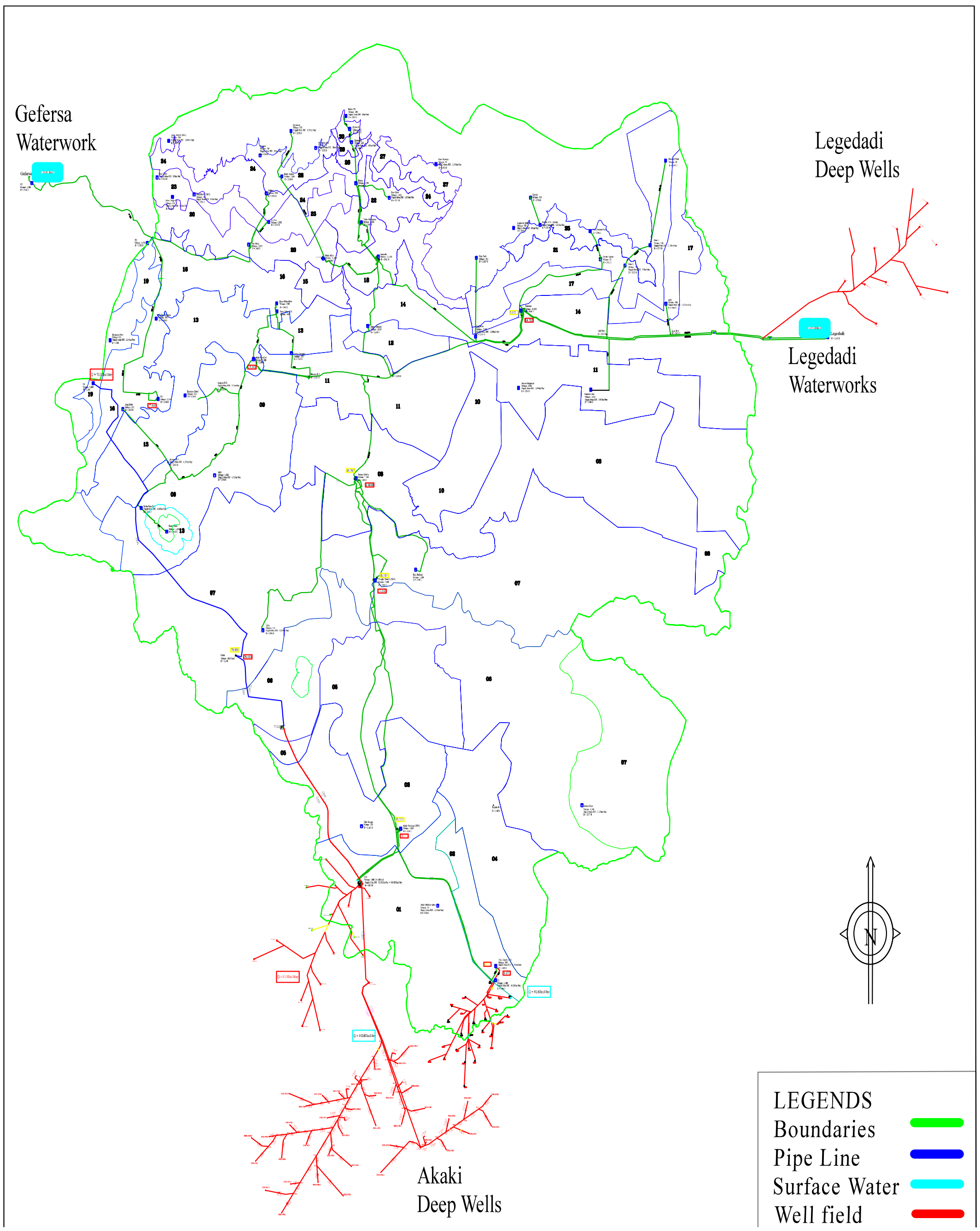


Fig 1. Addis Ababa Water supply sources

1.2 Statement of the problem

Increased Demand for Groundwater

Increased demand for groundwater will be especially strong where surface wateris unavailable due to, for example, poorer quality or higher cost. Intensive andincreased groundwater withdrawals may require drilling into deeper aquifers withthe risks of lower water tables, decline in well yield, greater lift costs and, in isolatedcases, saline intrusion or land subsidence.

Groundwater Contamination from Pollutants

Growing local populations and urban concentration increase the risk of contaminationof groundwater, including:

- Threat of chemical contamination from urban wastewater (via sanitary-sewerleaks), industrial chemicals (spillage, ground disposal) and solid waste disposal(landfills); road de-icing chemicals and dust suppressants; fertilizers and pesticides;leaking underground storage tanks; and leachate from operating and decommissionedlandfills, among others.
- Threat of microbial contamination from surface sources since upper-aquifer andshallow groundwater supplies in urban areas are particularly vulnerable to suchcontamination.
- As urban boundaries expand, potable water may still be supplied through privatewells, and homes and businesses may remain on septic systems. The intensity ofuse would thus amplify any issues pertaining to groundwater quality.

1.3 Objective of the project

1.3.1 General objective

The general objective of this project is to suggeston how to effectively manage groundwater resource for Addis Ababa city.

1.3.2 Specific objective

The specific objectives of the project are

1. Suggesting ideas, which support the sustainability of the city water supply sources.
2. Providing possible framework for the groundwater management.

2. Literature review

2.1 Introduction

Today, many of the concerns about groundwater resources on or adjacent to public land involve questions about depletion of groundwater storage, reductions in stream flow, potential loss of groundwater-dependent ecosystems, land subsidence, salt water intrusion, and changes in groundwater quality. The effects of many human activities on groundwater resources and on the broader environment need to be clearly understood in order to properly manage these systems. Throughout this technical guide, we emphasize that development, disruption, or contamination of groundwater resources has consequences for hydrological systems and related environmental systems.

This technical guide begins by reviewing the legislative and policy framework, and the issues related to groundwater inventory, monitoring, contamination, and development. Individual sections then focus on key concepts, principles and methods for managing groundwater resources.

2.2 Purpose and Objectives

This technical guide provides guidance for implementing the U.S. Department of Agriculture (USDA) Forest Service national groundwater policy. It describes hydrological, geological, and ecological concepts, as well as the managerial responsibilities that must be considered to ensure the wise and sustainable use of groundwater resources on National Forestsland (NFS), which are largely forest and woodland areas owned collectively by the American people through the federal government and managed by the United States Forest Service, part of the United States Department of Agriculture.

2.3 Management Considerations and Protection Strategies

The Forest Service groundwater policy is specifically designed to protect groundwater-dependent ecosystems so that, wherever possible, the ecological processes and biodiversity of their dependent ecosystems are maintained, or restored, for the benefit of present and future generations. The general level of understanding of the role of groundwater in maintaining ecosystems throughout the public lands is very low. Groundwater resource managers and investigators tend to underestimate ecosystem vulnerability to groundwater development, pollution, and land-use change. Planners must recognize ecosystem dependence on groundwater and related processes. Perhaps such recognition can be best achieved by incorporating groundwater resource inventory, monitoring, and protection into management plans.

The initial step in protecting groundwater-dependent ecosystems is developing an inventory of those systems on NFS lands. Identify and describe their locations, ecological values, and degrees of dependence on groundwater.

Land management plans should then be reviewed and revised as necessary to incorporate groundwater-level, groundwater extraction-rate, groundwater recharge-rate targets or other management rules that minimize localized impacts on dependent ecosystems. The degree of protection will vary according to the characteristics and dynamics of each groundwater system and the significance of the groundwater-dependent ecosystems. Protection may range from minimal where the aquifer is deep and has little connection to the surface, to significant where the connection is strong and the conservation value of dependent ecosystems is high. More localized measures for protecting groundwater-dependent ecosystems may include the following steps:

- Establishing buffer zones around dependent ecosystems, within which groundwater extraction is excluded or limited.
- Establishing maximum limits to which water levels can be drawn down at a specified distance from a dependent ecosystem.
- Establishing a minimum distance from a connected river, creek or other dependent ecosystem from which a well could be sited.
- Protecting groundwater quality in areas that provide recharge to dependent ecosystems by limiting the types of activities that can take place there.

Monitoring

Groundwater monitoring is critical for appropriate water-resource management. The hydrological connections between groundwater and surface water mandate that monitoring programs for all water resources be closely linked. By acknowledging this close hydrological connection, groundwater monitoring can provide critical support to surface water and groundwater management programs.

Monitoring of groundwater quality is defined as an integrated activity for obtaining and evaluating information on the physical, chemical, and biological characteristics of groundwater in relation to human health, aquifer conditions, and designated groundwater and surface water uses. With accurate information, the current state of groundwater resources on NFS lands can be better assessed, water-resource protection programs can be run more effectively, and long-term trends in groundwater quality and the success of land management programs can be evaluated.

Monitoring programs have the following general objectives:

- Assess background groundwater-quality and quantity conditions.
- Comply with statutory and regulatory mandates.
- Determine changes (or lack of change) in groundwater quality and quantity over time to define existing and emerging problems, to guide monitoring and management priorities, and to evaluate effectiveness of land and water management practices and programs.
- Improve understanding of the natural and human-induced factors affecting groundwater quality and quantity.

Groundwater Development and Sustainability

A groundwater system consists of a mass of water flowing through the pores or cracks below the Earth's surface. This mass of water is in motion. Water is constantly added to the system by recharge from precipitation, and water is constantly leaving the system as discharge to surface water and as evapotranspiration. Each groundwater system is unique in that the source and amount of water flowing through the system is dependent on external factors such as rate of precipitation, location of streams and other surface water bodies, and rate of evapotranspiration. The one common factor for all groundwater systems, however, is that the total amount of water entering, leaving, and being stored in the system must be conserved. An accounting of all the inflows, outflows, and changes in storage is called a water budget (Alley and others 1999).

Human activities, such as groundwater withdrawals and irrigation, change the natural flow patterns, and these changes must be accounted for in the calculation of the water budget. Because any water that is used must come from somewhere, human activities affect the amount and rate of movement of water in the system, entering the system, and leaving the system.

2.4 Conclusion

i. In cities, groundwater resources are very useful and important in sustaining people's lives. However, the intensiveuse of groundwater has depleted this resource and also caused problems such as land subsidence. On the otherhand, as seen in Japanese cities, strict control of groundwater pumping resulted in the increase of groundwaterlevel and has now created "enough groundwater" problems. Merely placing restrictions on the abstraction ofgroundwater does not contribute to the “sustainable” use of groundwater where it is used without causing criticaldepletion of the resources.

ii. In many cities with seasonal fluctuations in water availability, the overall condition of water resources is verygrave. As a stable source of water as well as a way to rationalize water use, reclaimed water can be promoted asa promising option and an alternative to groundwater. Especially in the cities where industrial groundwater useis dominant, such as Bangkok, Bandung, and Ho Chi Minh City, the “reclaimed water use” industrial sector hassignificant potential to reduce groundwater stress. Moreover, reclaimed water use also contributes to pollutioncontrol.

iii. In terms of groundwater quantity control, many cities have already introduced basic measures. However, theimplementation stage varies according to factors such as the adequacy of regulatory schemes for the majorgroundwater users, availability of other water sources that could be substituted for groundwater use, and incentivemechanisms designed to shift groundwater use to other water resources. Groundwater quality management shouldbe strengthened with adequate monitoring put in place.

iv. In many countries, surface water is a potential alternative water resource to groundwater. However, discussion onthe availability of both water resources is not conducted from the aspect of their quantity and quality.

v. Although there is a certain mount of data on groundwater levels in many cities, scientific facts such as the existenceof groundwater, groundwater use, and groundwater quality are either insufficient or poorly stored. This hinderseffective planning and implementation.

3. Research methods, materials and procedures

3.1 Method of data collection

Based on the project objectives, the method, how the project is carried out, was by collecting the secondary data or information from societies and from respective organization such as Addis Ababa Water Sewerage Authority (AAWSA), who has a great responsibility to supply water for the city and Water Works Design and Supervision Enterprise (WWDSE).

Also Secondary data collected through Literature studies and document analysis. Several printed books used; in addition to that, Internet was the major instrument to access government documents.

3.2 Procedures of assessment

3.2.1 Data requirements for the project

Groundwater data, whether from borehole drilling, geophysical surveying, or largerscale pumping tests, are expensive to obtain. It is therefore surprising to find that thesedata, once obtained, are commonly not preserved in an efficient or accessible format.

The data required for effective groundwater management fall under the followinggeneral headings:

- Geological data (includes elements such as borehole logs, sediment grain size and compositional analyses, geophysical survey results, and mapping products);
- Climate data;
- Groundwater quality data; and
- Groundwater withdrawal data

Geological Data

Geological information to support an understanding of groundwater flow can beextracted from various geological mapping programs undertaken by provincialgeological surveys, the Geological Survey of Addis Ababa, or studies undertaken byuniversity researchers and consultants.

At a broader scale, information from water well records can also be used to supportthe conceptualization of the regional geological setting.

Fig 2. Installing a Groundwater-Monitoring well.

Well Data

Label	Ground elevation (from Well field Surveying)	DWL	Pump elevation	Well Elevation	Discharge (l/s)	Pump Head (m)	Calculated Water Power (kW)
PMP-LLA3	2461.00	14.3	2361	2,446.70	51.24	95.38	47.84
PMP-LLA-4	2461.00	14.3	2381	2,446.70	101.64	107.30	106.76
PMP-LLA5	2492.50	37.3	2392.5	2,455.20	51.84	102.37	51.95
PMP-LLA6	2496.50	111.1	2346.5	2,385.40	40.95	156.96	62.91
PMP-LLA-PW1	2463.00	27.8	2363	2435.2	80.92	111.63	88.42
PMP-LLA-PW3	2503.50	32.8	2403.5	2470.7	101.49	91.58	90.98
PMP-LLA-PW4	2485.00	26.4	2385	2,458.60	89.88	83.08	73.09
PMP-LLA-PW5	2482.00	86.7	2362	2,395.30	41.37	144.08	58.34
PMP-LLAA-PW6	2513.00	80	2393	2433	90.81	125.63	111.68
PMP-LLA-PW7	2500.00	70.7	2370	2,429.30	81.87	120.57	96.63

Table 1: - Legedadi borehole Data

Rainfall data

The optimized recharge rate by model calibration is 42 mm (6% of the mean annual rainfall), while the chloride mass balance shows that the recharge is in the order of 30-40 mm year-1 (4.5-6% of the mean annual rainfall in the area). Considering the standard deviation in the chloride concentration of the groundwater samples, the recharge estimated by chloride mass balance method is in the same range as the recharge determined by the model calibration.

Previously, the groundwater recharge in the area has been estimated by different studies (Hussien 2000, Yehdego, 2003 and Teklay, 2006). The studies of Hussien (2000) and Yehdego (2003) estimated the recharge by applying a water balance method as 9% of the average annual rainfall. By applying the same method, Teklay (2006) estimates the recharge as 5.3% of the annual rainfall. The reported recharge values vary widely. This report estimates the groundwater recharge in the area in the range of 4.5 to 6% of the annual rainfall.

Aquifer characteristics

Quantitative description of aquifers is vital in order to address several hydrological andhydrogeological problems. Fluid transmissivity, hydraulic conductivity and aquifer depth arefundamental properties describing subsurface hydrology. The most effective way of estimatinghydraulic properties of an aquifer is the pumping tests that are carried out on certain boreholes sites.

As the aquifer parameters arereported in WWDSE (2006), a highly variable and wide range of transmissivity and hydraulic conductivity characterizes the area. The hydraulic conductivity ranges from 0.02 to81 m day-1. In some of the wells the hydraulic conductivity is extremely high and in others it is verylow which is indicative of the heterogeneous condition of the subsurface geologic system. Thevariability in the hydraulic properties mainly results from the intense fracturing and heterogeneity dueto the existence of dolerite dykes. The hydraulic conductivity is not uniform over the catchment.

Well Id	Elevation (m)	Transmissivity (m2 day-1)	Aquifer thickness (m)	Hydraulic conductivity (m day-1)
PMP-LLA3	2461.00	1138	14	81.3
PMP-LLA-4	2461.00	2630	53	49.7
PMP-LLA5	2492.50	967	30	74.4
PMP-LLA6	2496.50	138	30	4.6
PMP-LLA-PW1	2463.00	92	30	3.1
PMP-LLA-PW3	2503.50	1	45	0.02
PMP-LLA-PW4	2485.00	2260	30	74
PMP-LLA-PW5	2482.00	500	34	14.7
PMP-LLAA-PW6	2513.00	24	9	2.82
PMP-LLA-PW7	2500.00	51	16	3.2

Table 2. Transmissivity and hydraulic conductivity

Groundwater abstraction

Groundwater pumping is frequently the least measured water balance component (Ruud et al., 2004). The groundwater abstraction in Legedadi well field is poorly documented and the recorded data shows many gaps. The operating periods of the boreholes are also not well known, thus it is difficult to get the accurate abstraction rate from the well field. By examining and analyzing the available abstraction records, 7156 m^3 of average daily groundwater abstraction from the well field is estimated and this value is implemented in the steady-state model through the well package.

3.2.2 Approaches to groundwater management

The issue of groundwater management is multidimensional, related to reliable assessment of available water, its supply and scope for augmentation, distribution, reuse/recycling, its existing depletion, pollution, and its protection from depletion and degradation.

However, like surface water resource management, not much concerted efforts have been made for management of the hidden complex under groundwater resources.

The four generally acceptable approaches towards groundwater management are the following:

- Independent Local Management Approach: when there is significant aquifer with a limited extension amount of ground water resource.
- Surface water-Groundwater relation approach: are critical approach to avoid problems and is done when river basin underlain by extensive shallow aquifer.
- Groundwater flow systems dominate approach: still little surface water an

extensive deep aquifer system in arid region.

- Limited interactionwith the overlying river basin approach: when there is minor aquifer with shallow depth and low potential.

The management options of groundwater in urban areas are generally based on the patterns of groundwater use, and the responsibility remains largely with municipal supply utilities, as well as with individuals. However, large-scale, publicly funded tube-well development tend to be supply driven; legal and regulatory provisions at national level cannot be policed adequately; and, enhancement of indirect recharge may work for shallow groundwater circulation, but recovery of deeper systems requires sophisticated injection and alternative sources of high-quality water*.

From among these characteristics, two broad types of management approaches for groundwater emerge: (I) approaches encompassing tools such as power pricing, subsidies for efficient technologies, economic policies that discourage water intensive crops, etc. and (II) approaches dealing with specific aquifers on the basis of command and control management through a resource regulator. Whichever approach is adopted, the development and management of these resources must be based on an adequate knowledge of a clear aggregate status or situation of groundwater aquifer system and its replenishment. In the context of the impact of climate variability and spatial variability in drought, two major gaps in groundwater management emerge, with significant implications for sustainable development (i) inability to cope with the acceleration of degradation of groundwater systems by over-abstraction, and effective resource depletion through quality changes (pollution, salinity), and (ii) failure to resolve competition for groundwater and aquifer services between sectorial uses and environmental externalities**.

3.2.2.1 Policy adjustments

Cooperation between Oromia and Addis Ababa

An encouraging development is the cooperation between Addis Ababa and Oromia Regional State with respectto land use planning and regional development. Cooperation between Oromia Regional State and the AddisAbaba Administration needs to be furtherelaborated, since the aquifer is shared between the two regions.

- *P.S.Datta, Groundwater Ethics for its sustainability, Current Science, September 2005.*

** *P.S.Datta, Groundwater Ethics for its sustainability, Current Science, September, 2005.*

Linking land use plans and groundwater management

In the land use plan primeland is allocated for agriculture and horticulture, whereas land that is less suitable is allocated to industry,housing, quarrying and others. The development of new heavy industry is planned in the South East of Sendafa, away from the borehole area.

Policy for private sector roles

When groundwater has taken off through private sector investment and services, it requires both a facilitating environment and a regulatory regime. There needs toa clear vision on how to engage the private sector in groundwater development and management in the AddisAbaba region, including:

- Clarity on regulatory procedures
- Opportunities to develop private sector role and capacity in drilling, well operation, monitoring compliance and communication.

Support for regulation

The reverse side to enlarged private sector involvement is better regulation. Currently regulation is weak andhas no priority, as is clear to the meager manpower dedicated to it, the logistical means and the politicalsupport for enforcement. If groundwater use is to intensify and extent to agro-economic use, regulatoryactivities need to be better resourced both in Addis Ababa and in Oromia. This should start by enforcing theregulations that are there by making theminimum required resources to do soavailable.

3.2.2.2 Regulatory provision

Enhancing monitoring capacity

Legedadi Deep wells water supply project control room and pump house are together so that it can be managed and monitored easily.

a) Outside pump house

b) Inside pump house

Fig.3 Monitoring capacity of the wells using SCADA software in pump house

Well development guidelines

It is proposed to develop national well drilling guidelines and the Ministry of Water Resources has made a start of this. The urgency of these guidelines is particularly high in the Addis Ababa region where intense exploratory and exploitation drilling is taking place. In the drilling of the test wells a large variation in quality and techniques is observed. The well drilling guidelines would help to set quality standards in well development and to protect the well drilling sector against unfounded complaints. The well drilling guidelinesshould make use of standardized well designs.

Strengthen regulatory body

Groundwater regulation should be strengthened. Licensing is now done by Addis Ababa EPA and Oromia Water Resources Bureau ****, but the effort is piecemeal and incomplete. There is a large backlog particularly in the AddisAbaba city limits with many wells unregistered. Any effort in groundwater regulation should start with reconstructing an up-to-date database of production wells.

There have been cases of the EPA being overruled moreover by the major stakeholders when it objected on the developmentof some new AAWSA wells. Rather than overruling it is better than adding an objection clause to the currentregulation. All in all regulatory enhancement should be practical with licensing and after licensing requirementsbeing at par with the capacities of the regulatory bodies and the well owners.

3.2.2.3 Stakeholder involvement

Clarify institutional roles

There are a large number of organizations who activities have a bearing on the sustainable use of groundwater from regulation, abstraction, recharge and quality point of view. It is encouraging that groundwater hasalready moved into the realm of land use planning – opening the scope to manage groundwater beyond thewater domain, yet there is no organization that masterminds the management or development of groundwater.

At federal level the main stakeholders are the Ministry of Water Resources, the Federal EnvironmentalProtection Agency, the Ministry of Mines and Energy - in particular the Ethiopian Geological Survey, theMinistry of Agriculture (as it concerns land use), the Ministry of Urban Planning and Ministry of Health and inthe private sector the Drillers's Association. At regional level the stakeholders are the Oromia Water Resources Bureau, the Addis Ababa Water Supply and Sanitation Authority, the Addis Ababa Environmental Protection Agency, the Oromia Land and Environmental Protection Bureau, Housing Bureaus and Regional Urban Bureaus apart from private sector service providers and users. The activities of all organization have a bearing ongroundwater use

**** *These are both suitable short and medium term arrangements of convenience – in the long run a dedicated licensing office under the regional government maybe more appropriate – as in OWRB there is a conflict of interest as the OWRB alsocommissions well drilling and AA-EPA mandate is on overall environmental management.*

and management. Roles should be clarified – between federal/regional organizations andbetween regional organizations – as well as the mechanism to coordinate the different interests. The same should be done for the Addis Ababa area.

Several of the organizations mentioned above undertake activities that have a bearing on sustainablegroundwater management.

Linking knowledge and research parties

The complaint from participators' and policy makers' the knowledge institutes is that (a) groundwaterdevelopment and management gets very scant attention and (b) the attention is often far from practical. Thereis a need to reengage – by having trainee ships, guest lecturers, and discussion on the curriculum and engaginguniversity staff and students in studies. This is possible with the universities and vocational training centers inthe region. A mechanism that can be utilized in this respect is the University Water Sector Partnership that aimsto bridge this gap and coordinate activities in this respect.

Private sector roles

Private sector roles in groundwater development need to expanded and intensified – among others with thehelp of the Drillers Association that is being developed. Incentive structures should be created for private welldeveloper to expand their business – both through contract arrangements and through financial incentives. Atpresent focus has been on strengthening public sector for strengthening private sector capacity should create instance through procurement of drilling rigs but more incentives. This can be done by a number ofactivities:

- License companies for drilling in shallow to very deep aquifers
- Carry out regular audits of work done by drillers and consultants, and link extension of permits to performance
- Design guidelines and schedules, standards and norms for borehole drilling project implementation
- Include borehole-sitting specifications in standard contracts as well provision for failed drillings
- Closer monitoring of NGOs and enforce implementation procedures according to standard documents
- Introduce engineer's estimates for drilling and sitting
- Review taxation framework for the sector and introduce incentives such a the waiving of import duties and VAT and special loans – as is being considered now

for public enterprises

- Facilitate access to credit for drillers and consultants
- Set up training programs (collaborate with private sector) and courses
- Improve compliance and enforcement of water laws, permits and licensing conditions for drillers and consultants.

3.2.2.4 Quality measures

Water quality protection through zoning

The importance of protecting the quality of the vital groundwater resources in view of rapid urbanization andindustrial development in the Addis Ababa region is imperative for long-term sustainable development.

An elaborate study ***** undertaken with the help of UNEP and UNESCO has mapped the risk of groundwatercontamination in the area and is still valid. This should be the basis of zoning regulation that would regulate thesitting of potentially polluters – petrol stations, industries, waste disposal plants and the investment in sanitationmeasures. In addition protection zones based on pollutant travel time around critical assets – in particular largewell fields – should be enforced. Maps should be produced that make the zoning visible in a single overview.

Water quality monitoring and risk assessment

Monitoring of groundwater quality should start to be able to assess the degree of contamination. At presentgroundwater quality monitoring is being done fragmentarily. This should also be tied to drinking waterprovision for the city and the surrounding towns and become a routine activity on given production andobservation wells.

***** *TamiruAlemayehu, DagnachewLegess, TenalemAyenew, YirgaTadesse, Solomon Waltenigus and Nuri Mohammed (2005), Hydrogeology, water quality and the degree if gorundwater vulnerability to pollution in Addis Ababa, Ethiopia. UNEP, UNESCO.*

a) Outside chlorination house

b) Inside chlorination house

Fig. 4 Chlorination house

Well head protection

Legedadi Deep wells Water supply project it is well protected with security and fence.

Fig. 5 Control Panel (Well-Head) protection with fence and security Guard

3.2.2.5 Demand side measures

Reduce unaccounted for water

Though water availability has not reached the critical levels it has in several other fast growing third world citieswater sources is precious and needs to be saved. In Addis Ababa city the figure for so-called unaccounted forwater are in the order of 30-40%. Clearly such figures are at variance with the high costs of exploring anddeveloping water resources in the larger Addis Ababa area: particularly as the city depends on sources outsidethe municipal borders it is difficult to accepts such large losses.

There are two categories of unaccounted for water – the water that is supplied but does not show up in thefinancial records and the water that is lost due to leakage. From a water resource management point of view itis very important to control the second category of loss. This goes beyond water saving. Leaks are also a majorreason for the contamination of the water supply systems – with sewage entering into the pipe network. This isa major issue in Addis Ababa with the older parts of the network not well mapped and waterlines passingthrough areas with high water tables and nearly 'floating' latrines.

Water conservation campaigns

Water conservation is also an important issue in (future) agricultural use. Particularly as deep aquifers withlarge recharge times will be developed at substantial cost judicious use is important. This should be encouragedby at least full real cost pricing for agricultural consumption.

Looking at tariff structures

Tariff structures particularly for large consumers should reflect and should encourage efficient water use – notnecessarily through paying for water consumed but also by bonus or mauls system for efficient respectivelywasteful water use. The current trend of including environmental cost to create sustainable environmentsshould be encouraged – as recently was done by adding the charges for solid waste collection to the water bill making it also more straightforward to collect such costs.

The value of water is apparent from the difference in land prices in area with and without reliable surface. The water service provider and regulator should also capture this difference in prices.

3.2.2.6 Supply management

Conjunctive use

Several supply side measures are to be undertaken to ensure the sustainable management of the groundwaterresource. Conjunctive use is an important one. In case of the Addis Ababa area the operation of surface waterreservoirs and groundwater abstractions should be synchronized. This has two dimensions:

- The surface water storage is more vulnerable to dry spells. By maintaining a balance in water supplyfrom both surface water and groundwater, the provision of water to Addis Ababa and other fastgrowing cities in the region is secured during cycles of dry years too.
- There is also a need to consider the sharing of water from both (newly developed) surface water and groundwater sources between the Addis Ababa Special Region and the Oromia Regional State.

Enhanced aquifer recharge

In the catchment of Addis Ababa there is scope for enhanced recharge – particularly when linking recharge toimproved watershed management programs, road planning and land use planning.

Also the urban surface entire in the region increases the removal of storm water – and subsequent retentionand reuse becomes more important. Storm water can be collected and spread over recharge zones – providedwater quality allows.

Managing waste and storm water

Water use in the Addis Ababa area depends on both surface and groundwater and it is important that waterfrom both sources is managed in a conjunctive manner. This concerns the water supply to Addis Ababa – wheregroundwater can act as a safety valve in drought years – compensating for low surface water supplies.

There is also a case to link wastewater and storm water into conjunctive management. Both sources can be anopportunity as source of recharge and storage but also a threat i.e. as a source of contamination. The planningof the sewer and wastewater disposal system should take this into account. The following areas are of help:

- Most sewerage water in Addis Ababa is untreated. By anaerobic or aerobic treatment waste water canbe made reusable for recharge or linkage to surface storage bodies
- Related to this using natural wetland areas and lakes around Addis Ababa should be investigated fortheir contribution to improved water quality (the kidney function) and creating other high valueamenity (recreation, attractive housing)

Develop of new groundwater sources

The development of new groundwater resources should be accelerated – following the ongoing assessment.

Several promising well field location have been explored and phase II of this Legedadi deep wells water supply project is on going.

3.2.3 Strategies of groundwater management

Understanding the importance of groundwater resources and the growing demand for it makes it impertinent to search for effective strategies for managing the groundwater. For an effective supply side management, it is essential to have full knowledge of hydrogeological controls that govern the yield and behavior of groundwater levels under abstraction stress, the interaction of surface and groundwater in respect of river base flow and changes in flow and recharge dates due to their exploitation. Groundwater management policies therefore will need to address a multitude of issues including

- Management of supplies to improve water availability in time and space
- Management of demands including efficiency of water use, sectorial interaction with economic activities etc.

- Balancing competing demands and preservation of the integrity of water dependent eco system.

In demand side management socio economic dimension plays an important role involving managing the users of water and land. Mere regulatory interventions like water rights and permits and economic tools of water pricing etc. cannot be successful unless the different user groups are fully involved. For effective management of groundwater resources there is a need to create awareness among the different water user groups and workout area specific plans for sustainable development. Thus groundwater management not only requires proper assessment of available resources and understanding of interconnection between surface and groundwater system, but also actions required for proper resource allocation and prevention of the adverse effects of uncontrolled development of groundwater resources******.

Sustainable development and management of groundwater requires the following strategies:

- **Scientific Development of Groundwater**

  Scientific development of groundwater involves a proper understanding of the local groundwater availability, its behavior and demand centric development with scientific planning. The need for scientific development of groundwater under different hydrogeological conditions involves the following elements such as, development of deep aquifers, development of groundwater in non- developed areas, development of Flood plain aquifers, development of groundwater in Water logged areas, development of groundwater in Canal Commands:
- **Artificial Recharge of Groundwater**

  Another effective strategy is augmentation of available groundwater resources through rainwater harvesting and artificial recharge. It is estimated that annually about 36.4 BCM of surplus surface runoff can be recharged to augment the ground water.
- **Regulation of groundwater Development**

  One of the important strategies for sustainable management of groundwater is regulation of groundwater development in critical areas. Over development of groundwater resources is increasingly being recognized as a major problem. The

****** *Dr. Salem Romani, Ground water Management:A key for sustainability, CESS papers, 2005.*

tendency towards over development of groundwater resources is rooted in the rapid spread of energized pumping technologies, resource characteristics, demographic shifts and government policies. There is very little efforts to check the over exploitation and regulation of groundwater resource. However it is not easy to implement the legislations with out people's support and awareness creation.

4. Result and Discussion

From the method and materials I collected, this chapter is designed to analyze the findings and discuss the overall results of the project which is that when ever there is a need to manage a groundwater resource we need to apply the conjunctive use of groundwater resource with surface water resource, with more attention given to management results.

4.1 Groundwater budget

The input term to the groundwater considered for thisproject is direct recharge from rainfall.Whereas the output terms considered are well withdrawals, groundwater drains to the river and head dependent groundwater flow out of the aquifer system.

Recharge

Recharge is very difficult to estimate reliably and in many cases more than one recharge estimation method is required. There are as many methods available for quantifying groundwater recharge, as there are different sources and processes of recharge. Each of the methods has its own limitations in terms of applicability and reliability. The estimated recharge value may vary depending on errors associated to the method and the standard deviation of the chloride content measurements both in the groundwater and the rainwater.

Model simulated groundwater budget

The groundwater budget can be quantified on the basis of the calibrated model output. The groundwater flow budgets calculated by the model for the non-pumping and pumping scenarios are indicated in table 3 and table 4 respectively.

Flow term	IN (m3 day^{-1})	OUT (m3 day^{-1})
Recharge	11982	
River		7236
Head dependent flow through the western boundary		4746
Well withdrawals		
Total	11982	11982

Table 3. Model simulated groundwater budget of the area for the non- pumping scenario

Flow term	IN (m3 day^{-1})	OUT (m3 day^{-1})
Recharge	11982	
River		810
Head dependent flow through the western boundary		4015
Well withdrawals		7156
Total	11982	11982

Table 4. Model simulated groundwater budget of the area for pumping scenario

There are several indicators that the overall result of Effective groundwater resource management for Addis Ababa city;

- The deviation of the simulated heads from the observed heads is within the pre-established calibration target.
- The simulated groundwater level drawdown due to pumping in the wellfield area is in agreement with the observed groundwater levels.
- The model calculated inflow and outflow terms are balancing.
- Groundwater flow direction simulated by the model is reasonable and in agreement with the flow direction defined in the conceptual model.

Nevertheless, there are a number of limitations and uncertainties in the steady-state groundwater flow model developed here.

4.2 Limitations of existing approaches

Though there exists various strategies for sustainable management of groundwater resources, it often fails to create any positive impact on the sustainable use due to number of reasons. Due to absence of any pricing mechanism and strict regulation, indiscriminate groundwater exploitation, its wasteful utilization and land disposal of wastes continued.

Research on groundwater use in socio- economic context being relatively small, the highly technical knowledge of the aquifer systems is of relatively little use for practical management purpose. Most of the hydro-geological and groundwater development research has been fragmented, technocratic and relates to groundwater flow and remediation. For practical management practices, it is impertinent to examine people’s indigenous adaptive strategies, climate change response etc. However in the present scenario less attention has been paid to these areas.

5. Conclusion

Therefore effective management ofgroundwater can be done using Independent Local Management Approach since the source of the water supply is only groundwater and managing policies that ensure long-term sustainable groundwater use in Addis Ababa will have to be robust, not only with respect to the emerging issues, but also in the face of possible changes inpublic attitudes that may accompany future developments. Establishing wellhead protection zones to protect water quality has a high levelof uncertainty, and risk reduction often involves either land-use restrictionsor the outright purchase of property, both of which have substantialeconomic consequences. Application of the precautionary principal underthese circumstances could result in very costly requirements that may, in fact,be impractical.

And considering lessons from other countries on groundwater quality management, not only the continuously strengtheningof current management measures, but also the creation of innovative pollution control measures for new types ofcontamination are required in order to promote sustainable and proactive groundwater use for Addis Ababa city in the future.

Also according to the overall groundwater resource assessment carried out by integrating geological, hydrological data and steady-state flow modeling it is concluded that water balance components that play important role in the groundwater table fluctuation of the well field are recharge and groundwater abstraction from wells. The steady-state numerical model is suitable as a tool to improve our understanding of the groundwater flow system in response to recharge and abstractions and to estimate aquifer properties in the area without data.

Primary and secondary porosity and permeability of the main water bearing geologic unit (limestone) plays a most important role in controlling the natural groundwater occurrence and movement in the Legedadi catchment. Due to the inter-layering of the limestone unit with less permeable shale and dolerite rocks, the groundwater in the area occurs under confined to semi-confined conditions. In response to the geological heterogeneity, broad ranges of aquifer parameters (transmissivity and hydraulic conductivity) are reported from the results of pumping test analysis. As major part of the project, a steady-state groundwater flow model was developed with and with non-pumping scenarios to assess the groundwater resource of Legedadi sub-basin.

6. Recommendation

Finally it is advised to consider the following points in relation to groundwater resources management in the well field.

- Protection of groundwater supplies from depletion: Sustainability requires that withdrawals can be maintained indefinitely without creating significant long term declines in regional water levels.
- Protection of groundwater quality from contamination: Sustainability requires that groundwater quality be not compromised by significant degradation of its chemical or biological character.
- Protection of ecosystem health: Sustainability requires that withdrawals do not significantly impinge on the amount and timing of groundwater contributions to surface waters that support ecosystems.
- Achievement of economic and social well-being: Sustainability requires that allocation of groundwater maximize its potential contribution to social wellbeing (interpreted to reflect both economic and non-economic values).
- Application of good governance: Sustainability requires that decisions about groundwater are made transparently, through fully informed public participation and with full account taken of ecosystem needs, intergenerational equity, and the precautionary principle.
- Future groundwater resource development plans in the well field should take into account the balance between the groundwater recharge and the intended abstraction rates to ensure the sustainability of the resource in the catchment.
- It is advisable to redistribute the pumping wells from the narrow right lower bank of the catchment to the upper catchment to reduce the groundwater stress resulting from localized pumping.
- The drawdown in the well field should not become so high that the groundwater levels in the well field is becoming lower than the level at the outlet.

The transmissivity to which the model is highly sensitive requires better future characterization. The cell size applied in the discretization of the problem domain (250 by 250m) is not small enough to adequately represent the drawdown in the wells. Thus the model can be further developed by integrating additional data and by applying finer grids in the pumping areas. To improve the uncertainties on the model boundaries, regional scale steady–state groundwater flow modeling is recommended so that the steady-state solution of the regional model is applied to set the boundary condition for the model at the local scale.

This project is not the end of groundwater management in the area rather it is a good starting work for detailed management in the future. With additional data, further refinement of the process with models is possible, which is expected to improve the accuracy of the management. Further extensive field-based observations combined with down hole geophysical well logging and hydraulic testing techniques, detailed delineation of fractures and other secondary porosity is required to compile the hydrogeologic framework for each geological sequence. Prior to detail groundwater management, detail structural mapping is required which will have a great importance in aquifer characterization and definition of boundary conditions.

References

- Alley, W.M.; Reilly, T.E.; Franke, O.L. 1999. Sustainability of groundwater resources. Circular 1186. Geological Survey. P 79.Washington D.C., USA.

- Anderson, T., Cauchi, T., Mozina, M., and Smyth, B. 2014. Approaches to Achieve Sustainable Use and Management of Groundwater Resources in the Murray–Darling Basin Using Rules and Resource Condition Limits, Literature Review Report Prepared for Murray–Darling Basin Authority. Australia.

- Barraque, B. 1998. Groundwater management in Europe: regulatory, organisational and institutional change. In T. Hilding-Rydevik& I. Johansson, eds. How to cope with degrading groundwater quality in Europe. Stockholm, Sweden.

- Clarke, R., Lawrence, A. and Foster, S.S.D. 1996. Groundwater, A Threatened Resource, UNEP Environment Library 15, New York, USA.

- CSA. 2010. Addis Ababa city government urban development indicators by Finance and Economic development Bureau report.Addis Ababa, Ethiopia.

- Custodio, E. and Dijon, R. 1991. Groundwater Overexploitation in Developing Countries.UN InterregionalWorkshop Report. UN-INT/90/R43. New York, USA.

- Daniel P. Loucks and Eelco van Beek. 2005. Water Resources Systems Planning and Management,An Introduction to Methods, Model sand Applications.Paris, France.

- Driscoll, F.G. 1986. Groundwater and wells. St. Paul, MN: Johnson Division.P.1089.New York, USA.

- Foster, S., Chilton, J., Moench, M., Cardy, F. and Schiffler, M. 2000. Groundwater in Rural Development: Facingthe Challenges of Supply and Resource Sustainability. World Bank Technical Paper.P 463. Washington, D.C.,USA.

- Foster, S., Lawrence, A. and Morris, B. 1997. Groundwater in Urban Development: Assessing ManagementNeeds and Formulating Policy Strategies. World Bank Technical Paper. P 390. Washington, D.C., USA.

- https://en.wikipedia.org/wiki/Water_supply_and_sanitation_in_Ethiopia

- http://www.limpoporak.com/_system/DMSStorage/3471en/GWMATEBN01.pdf.

- Llamas, M.R. 1998. Groundwater Overexploitation. UNESCO Congress ‘Water in 21st Century: aLooming Crisis' 2: 1–20. Paris, France.

- S.K. Jain. 2003. Water Resources systems Planning and Management. India.

- Water works Design and Supervision Enterprise. 2014. Legedadi deep Wells water supply project Draft Report. Addis Ababa, Ethiopia.

Appendixes

Appendix 1

Secondary data collected from WWDSE

Existing Source of water

No.	Source	Flow (m^3/day)
1	Geffersa dam	30,000
2	Legedadi and Dire dam	165,000
3	Akaki Borehole, phase I	48,000
4	Other boreholes and springs	60,000
	Total	303,000

The total existing source of water is 303,000m3/d

On the table above, quantity of other boreholes and springs is not guaranteed; where as the remaining four are guaranteed.

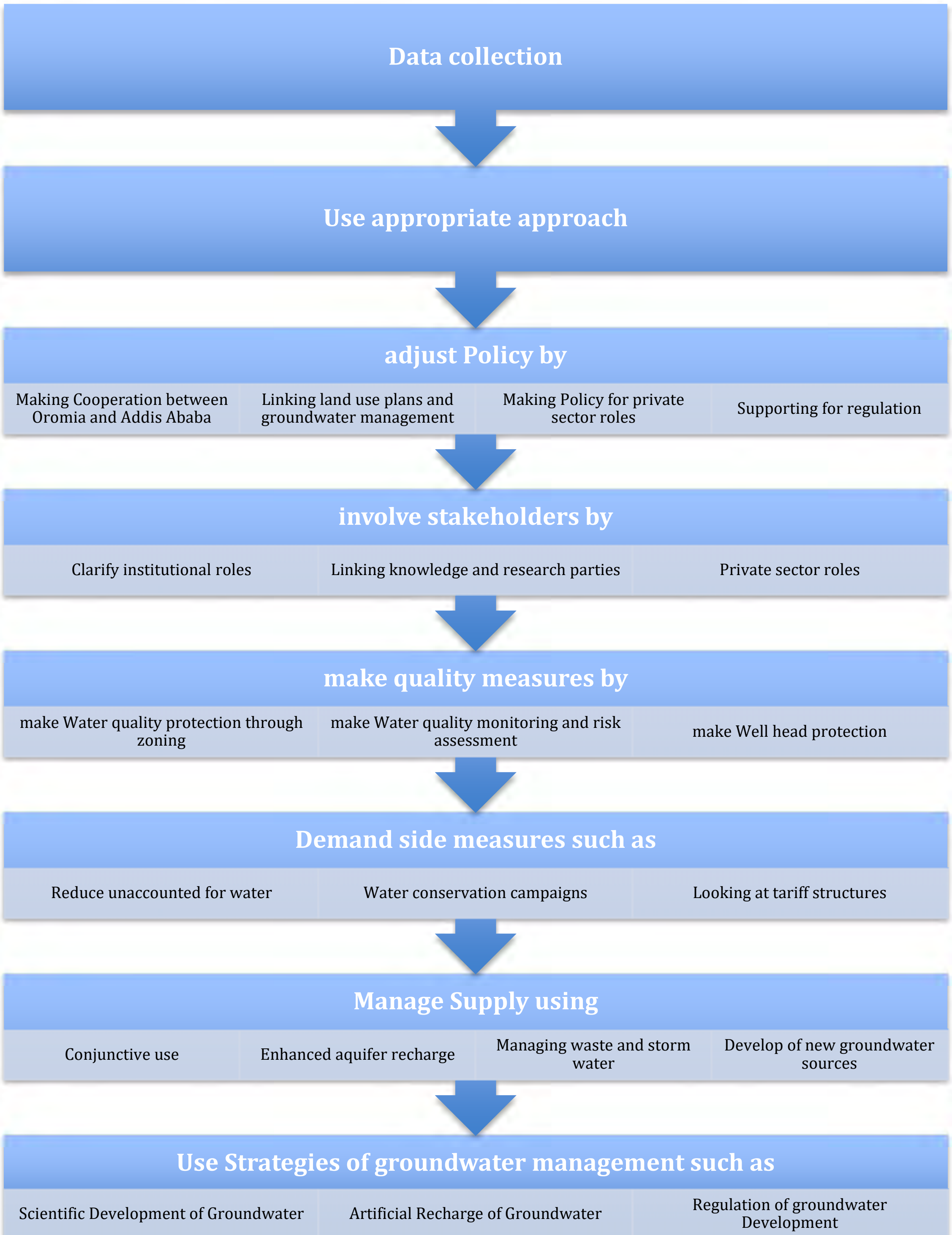
New Source of water under progress

No.	Source	Flow(m^3/day)
1	Akaki Phase II	83,000
2	Akaki Phase III, Part A	70,000
3	Akaki Phase III, Part B	70,000
4	Legedadi Deep Well	45,000
5	Dire Dam Retightening	30,000
	Total	298,000m3/d

The total source of water under construction is 298,000m3/d

Appendix 2

Effective groundwater resource management framework



Following the above framework groundwater can easily be managed and shortage of water found in Addis Ababa can easily be decreased.