Use of ^{222}Rn and δ^{18}O-δ^{2}H isotopes in detecting origin of water and in quantifying groundwater inflow rates in an alarmingly growing Lake

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43rd Congress of the International Association of Hydrogeologists, Montpelier, 25-29 Sept 16

Presentation outline

1. Introduction
2. The problem
3. Methodology
   - ^{222}Rn approach
   - $\delta^{18}O$-$\delta^{2}H$ approach
4. Results-Discussion
5. Summary

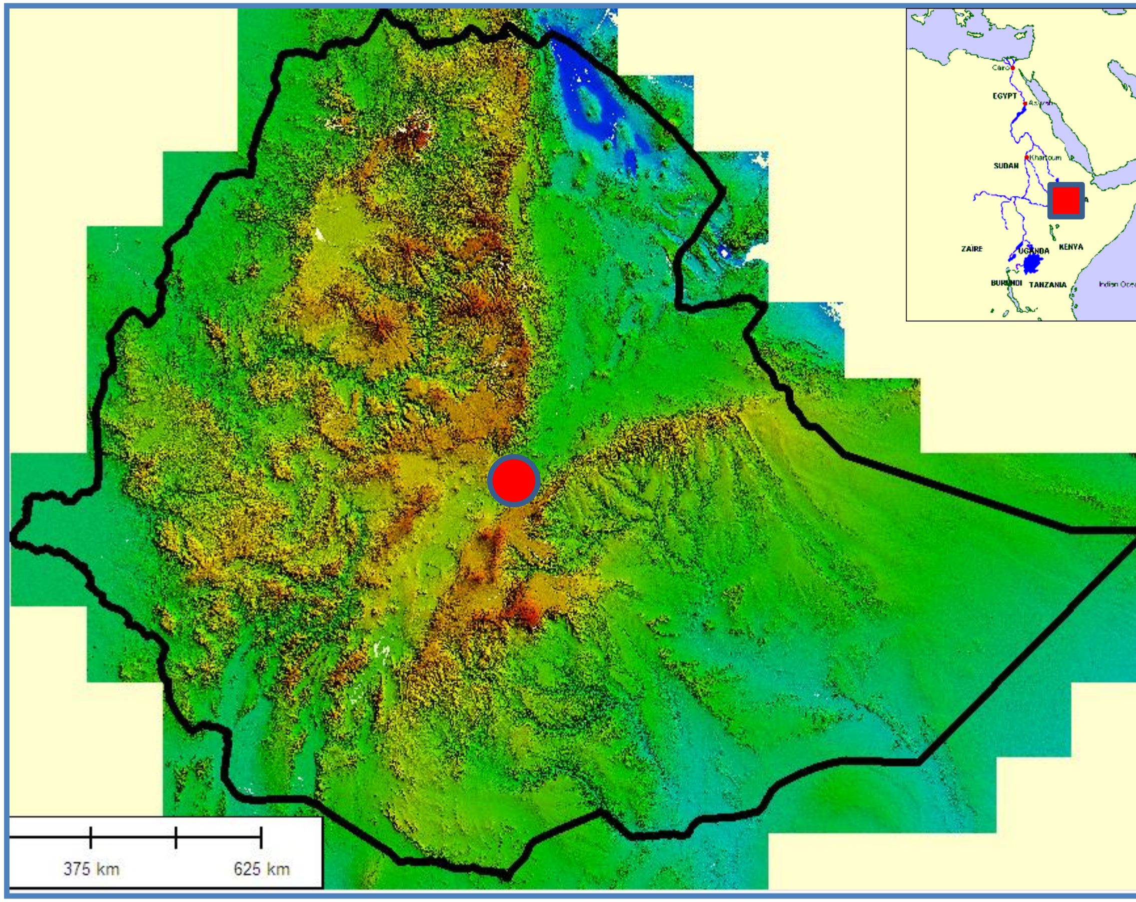
Introduction

Expanding irrigation since 1954

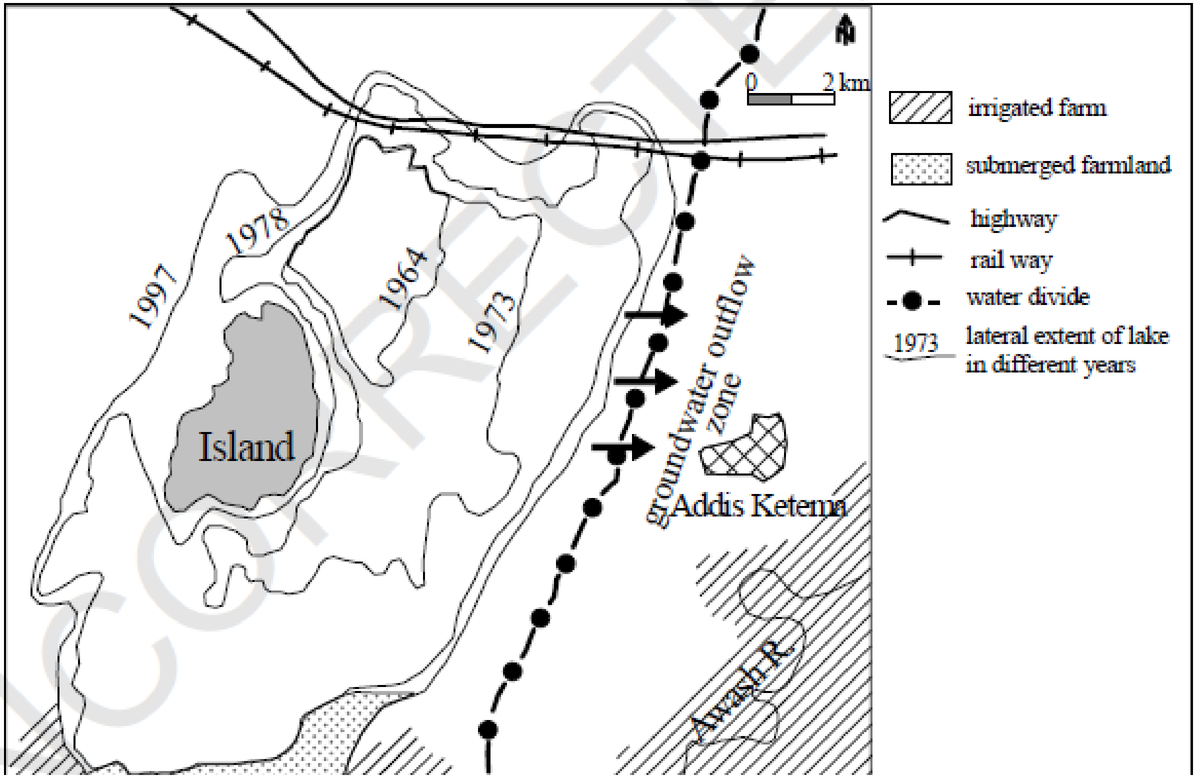
Active seismicity

Active ground deformation and ground-fissuring

Axial part of rifting



The problem- a rapidly expanding lake



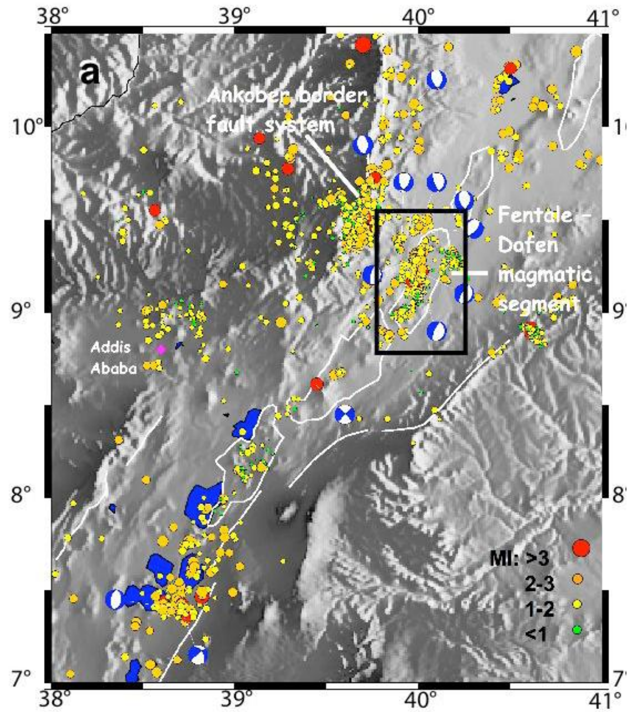
	1968 (Pitwell, 1968)	2014 (current)
Salinity	50 g/L	3.5 g/L
Area	2.5 km^2	56 km^2

The problem- Inundation

The problem-inundation

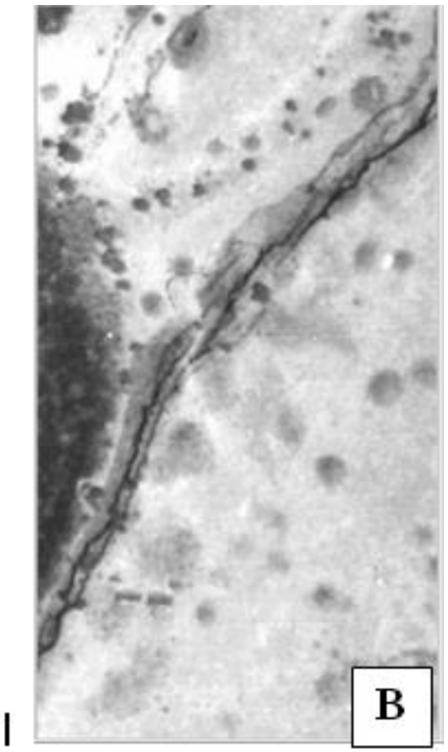
The problem- downstream salinization

The problem- multiple interacting processes



Kier et al., 2005

Seismicity

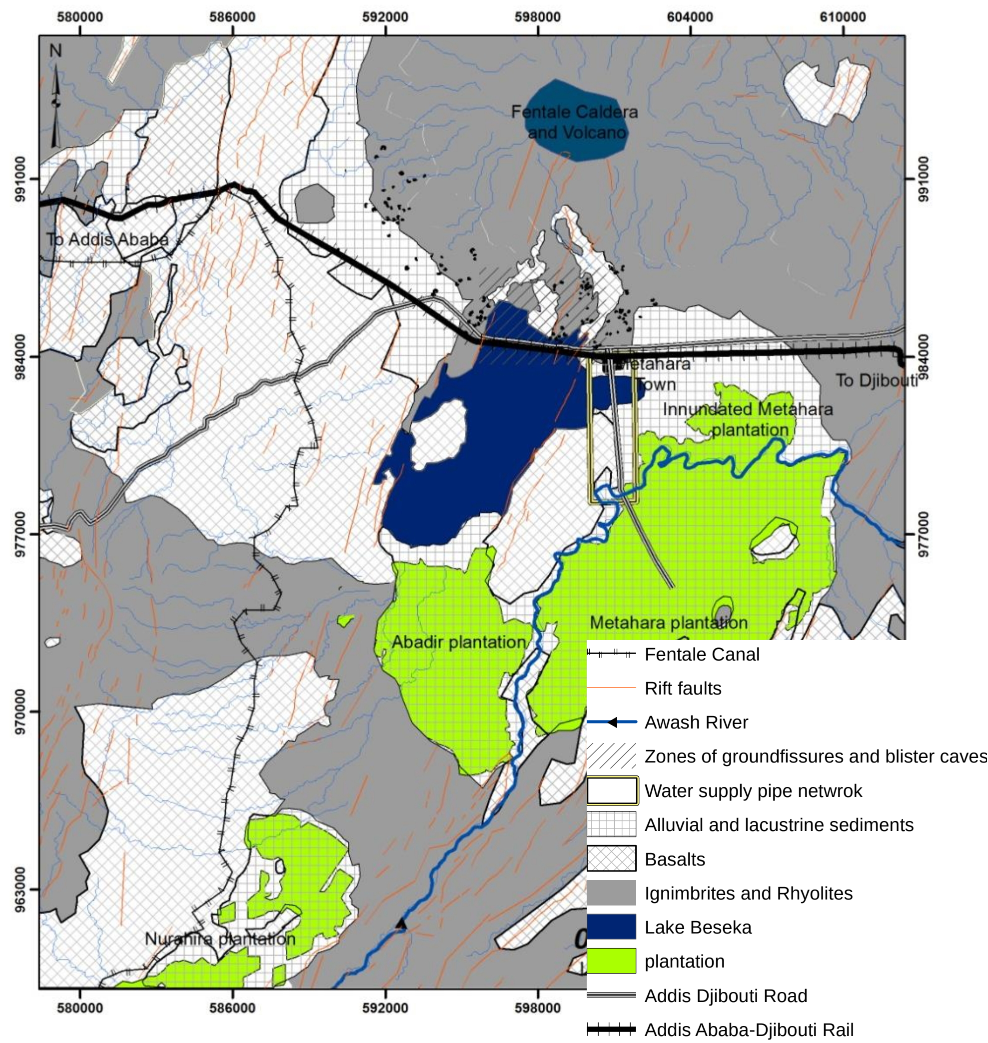


Abebe et al., 2003

Blister caves

Williams et al., 2003 Ground fissuring

The problem- multiple interacting processes



The problem- multiple interacting processes

1. Groundwater mounding in relation to irrigation expansion [MWIE, 2007]
   - Conventional hydrology/hydrogeology

2. Deformation of the Lake bathymetry [Goerner et al., 2009]
   - Altimetry

3. Increase in spring discharge to the Lake [Goerner et al., 2009]
   - Satellite based temperature changes

4. Neo-fractures (ground fissures) induced deep groundwater inflow [Belay, 2009; Ayenew, 1998; Abiye 2006]
   - Modeling and water level monitoring

5. Irrigation excess water [Abiye 2006]
   - Pragmatic- coincidence between water level rise and irrg expansion
6. Change is stage of Awash River [Tesema, 1998]

Methodology

^{222}Rn uses

- Detecting site of groundwater inflow

- Quantifying water balance

Cook et al., 2003

$\delta^{18}O$-$\delta^{2}H$

- Detecting groundwater outflow directions

Krabbenhoft et al., 1990

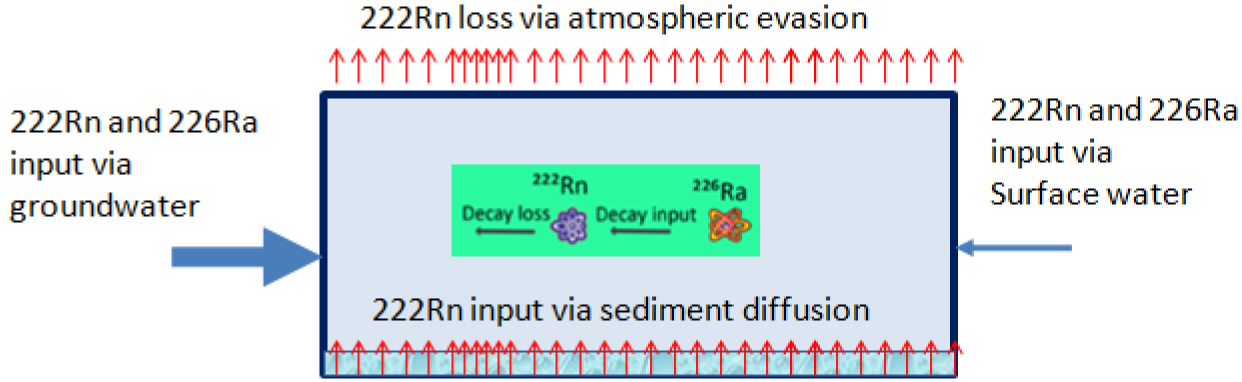
- Detecting composition and thereby source of contributing water to lakes

Dincer, 1968; Yi et al., 2008

- Quantifying water balance

- Proven tool

Methodology- Radon Inventory



222Rn: Quantifying groundwater inflow to Lake- assuming radon steady

$$G + S + PA_L = Q + EA_L$$

$$C_G G + C_S S + FA_b = QC_L + kAC_L + \lambda V C_L$$

$$G = \frac{(S + PA_L + kA_L + \lambda V)C_L - FA_b - SC_S}{C_G - C_L}$$

$$FA_b = kAC_L + \lambda V C_L$$

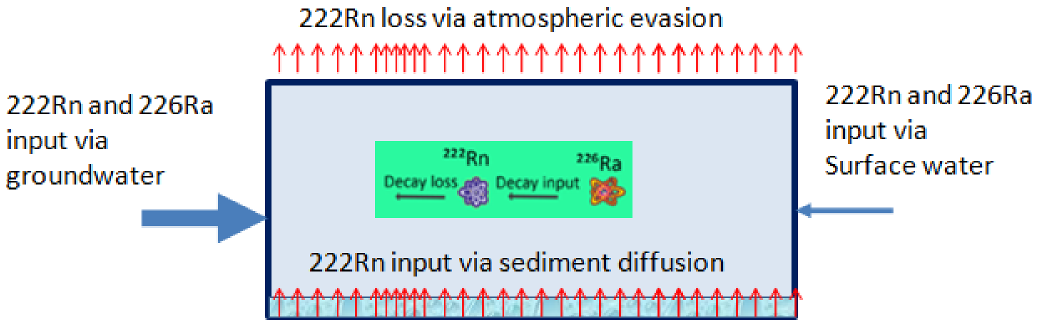
Assumptions

-Radon and hydrology steady state

- Radon production inside the Lake, negligible

- Lowest radon in the lake correspond to diffusive flux (F)

Methodology- Radon Inventory assumptions



Assumptions made based on literature [Cook et al, Schmidt et al, Kluge et al., Peterson et al., Duliaova et al…]

-Radon and hydrology steady state

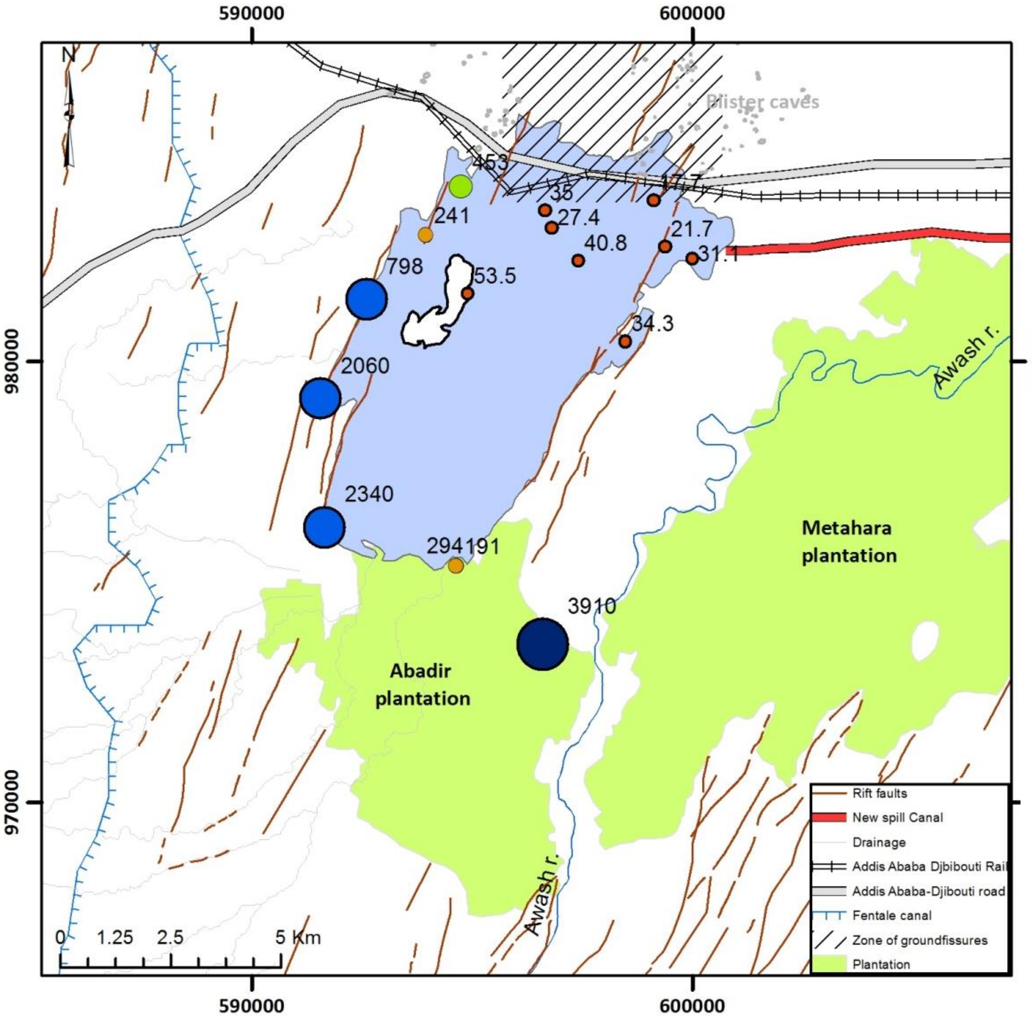
- Radon production inside the Lake, negligible

- Lowest radon in the lake correspond to diffusive flux (F)

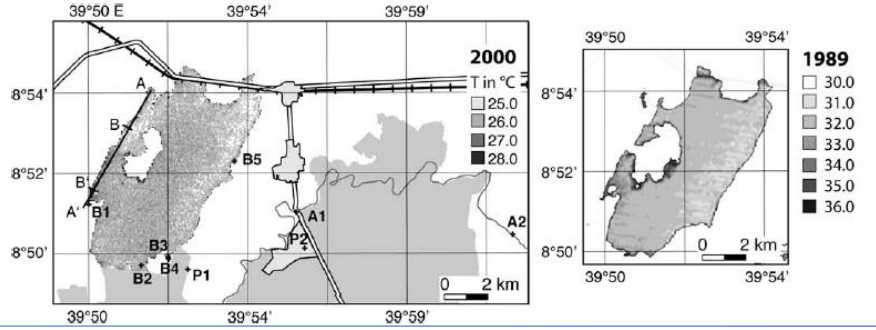
Methodology- Radon Inventory inputs

Variable	Unit	Required input parameters
G	m^3/day	Groundwater inflow rate
S	m^3/day	Surface water inflow from channelized and overland flows
P	m/day	Depth of precipitation on the lake
Q	m/day	Aggregate water loss to surface and groundwater outflows
A_L	m^2	Lake Area, m^2
E	m/day	Depth of evaporation from lake surface
A_b	m^2	Area of Lake bottom surface contributing radon flux via diffusive pathways from sediments
V	m^3	Lake volume
Λ	day^{-1}	Radon decay constant
K	$mday^{-1}$	Gas exchange velocity (wind speed and temperature turbulent degassing rate)
F	Bq/m^2/day	Diffusive radon flux from lake bottom sediments, $FA_b = kAC_L + \lambda VC_L$
C_L	Bq/L	Mean Radon activity in the Lake
C_G	Bq/L	Mean radon activity in inflowing groundwater obtained from measurement in a borehole
C_S	Bq/L	Mean radon activity in inflowing runoff

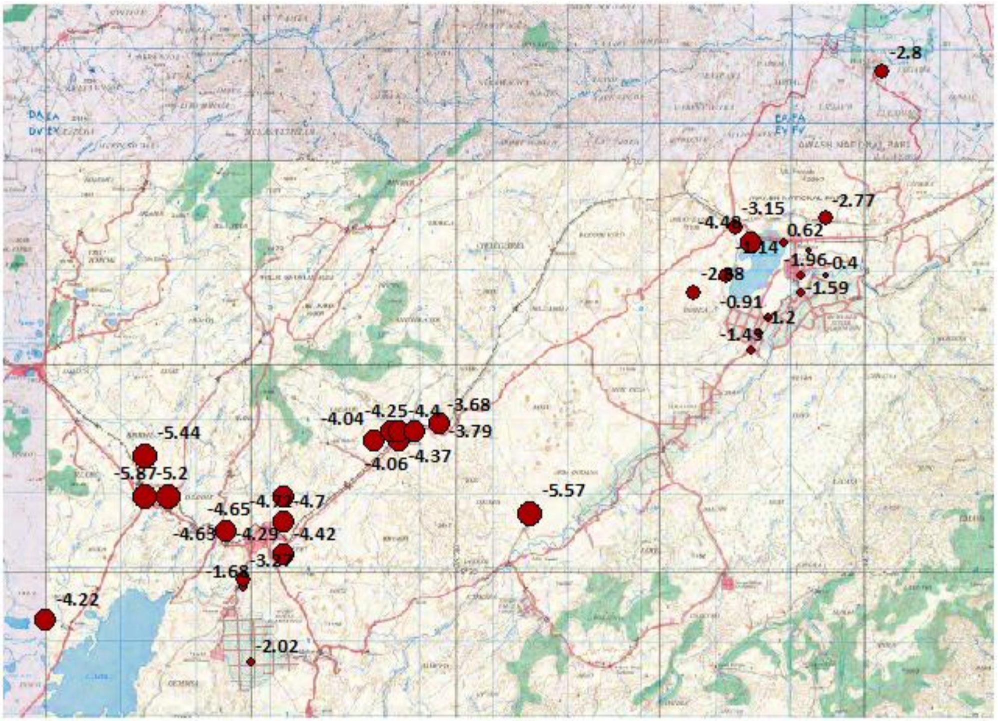
Results- 21 sites measured using Durrige RAD Aqua

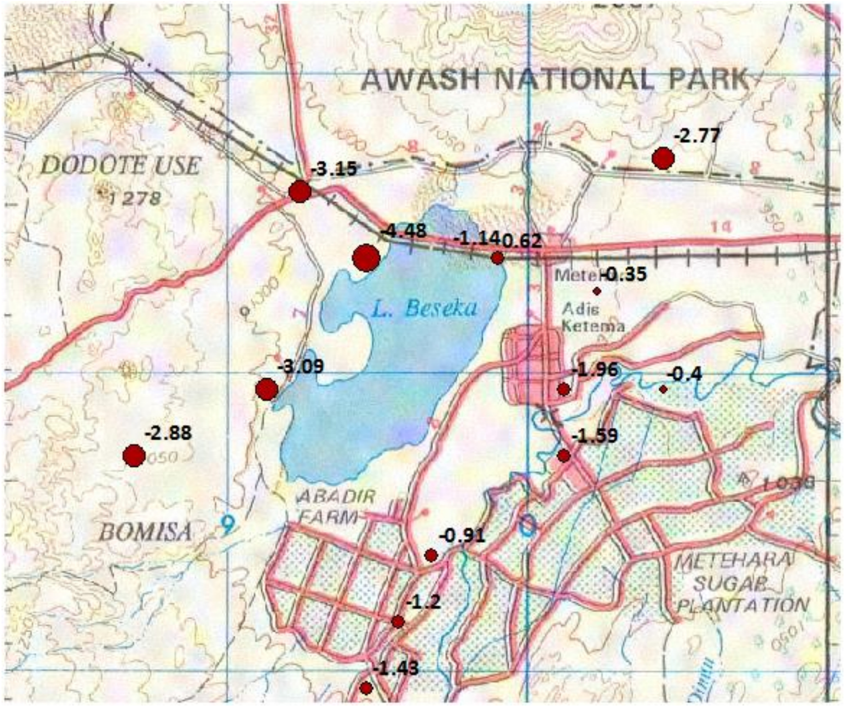


Major groundwater inflow takes place from South East and South- mirroring the temperature anomaly map of Goerner et al., 2009



Results- d18O, d2H spatial pattern two gw types



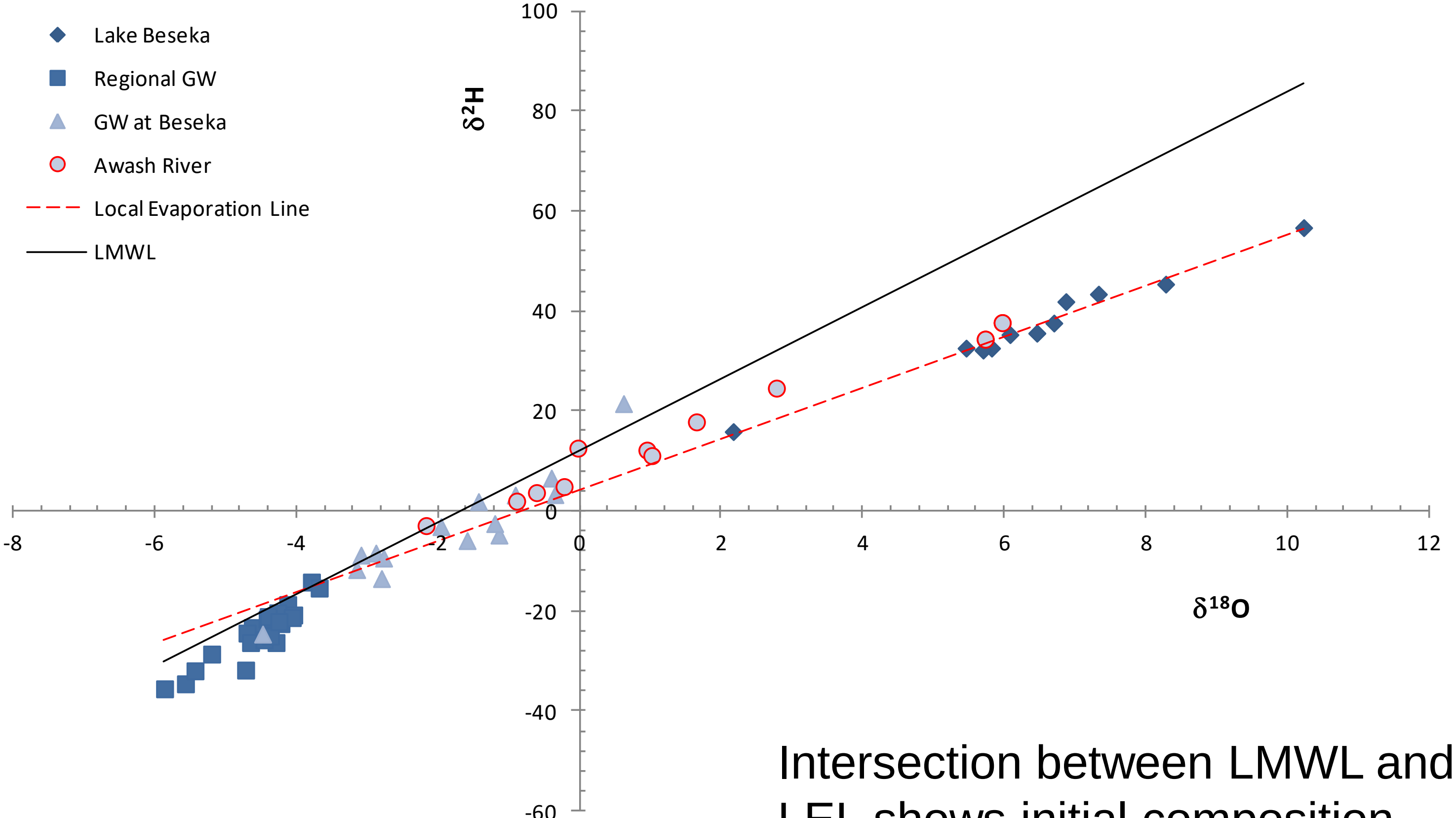


Two types of groundwaters

•d18O-d2H depleted deep, old waters [Craig 1977, Kebede et al, 2008; Brezler et al., 2011]

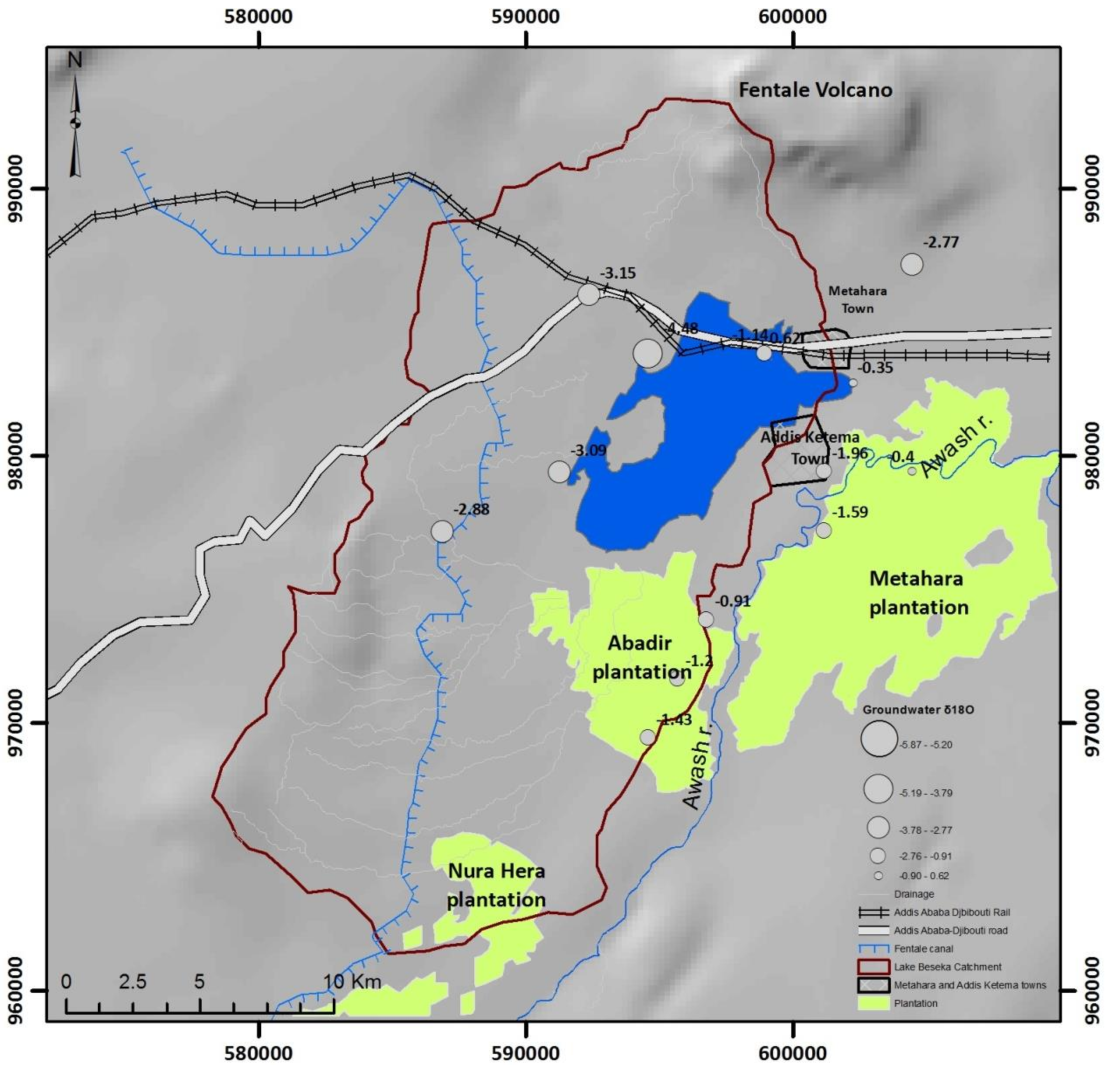
•d18O-d2H enriched shallow, young waters

Results- LMWL intersection with LEL



Intersection between LMWL and LEL shows initial composition resembles the shallow irrigation groundwater in irrigation areas

Results- groundwater outflow



Groundwater outflow zone in the NE sector of the Lake detected from enriched d18O in the groundwaters

Results- radon balance

Current study	Belay, 2010	Goerner et al., 2009	MWIE, 2014	HALCROW, 1989	Tesemma, 1998
170	33	17	103*	1.5	37

* the value is for base year 2010

Annual groundwater inflow in MMC

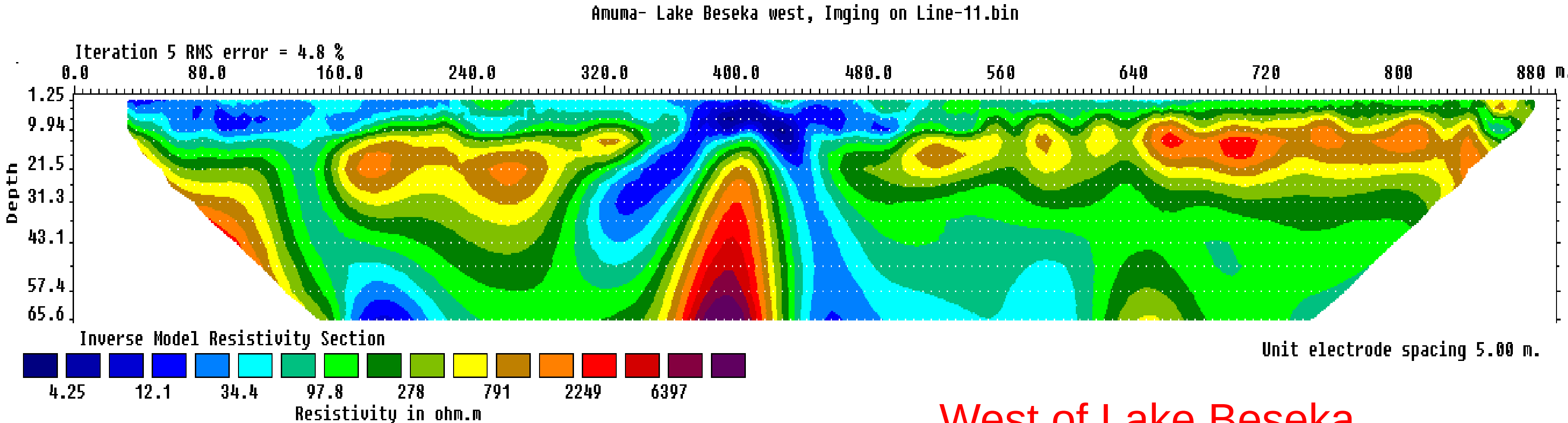
Current estimate = 170 MMC = 5.4 m3/s

Results- validation

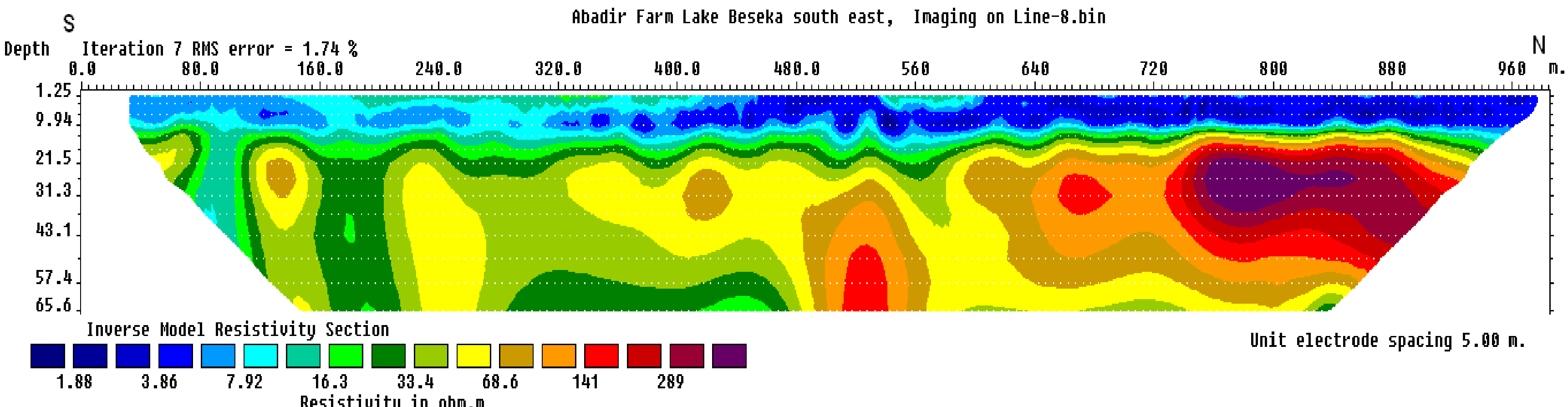
Farm	Start date	Farm size (ha)	Uptake (m^3/s)	Conveyance loss (m^3/s)	Distribution Loss (m^3/s)	Field level water application loss (m^3/s)	Net seepage loss (m^3/s)
Main-Metahara-	1965	8000	6.02	-	-	0.60	1.41
Abadir-Metahara	1968	3500	3.51	-	-	0.35	1.06
Nure Hera	1970	3740	2.55	-	-	-	1.02
Fentale	2007	4520	4.61	1.2	0.3	1.3	2.81

Seepage loss from Irrigation areas; 6.3 m3/s

Results- validation

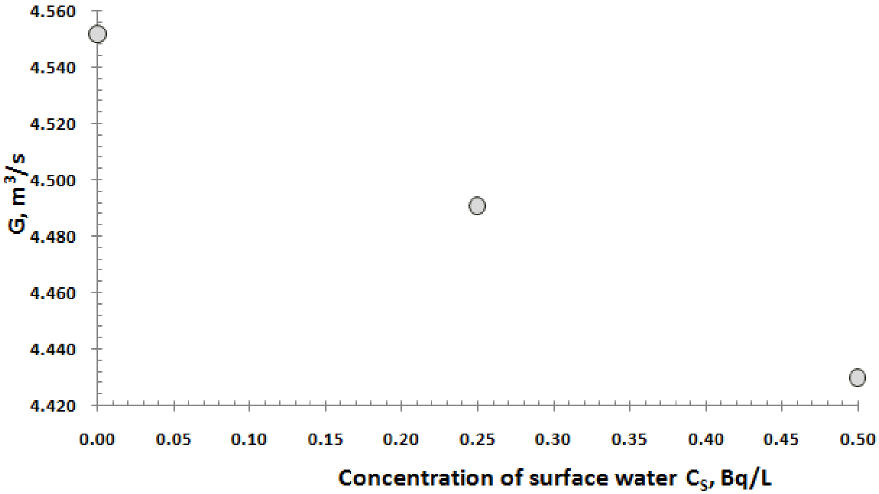


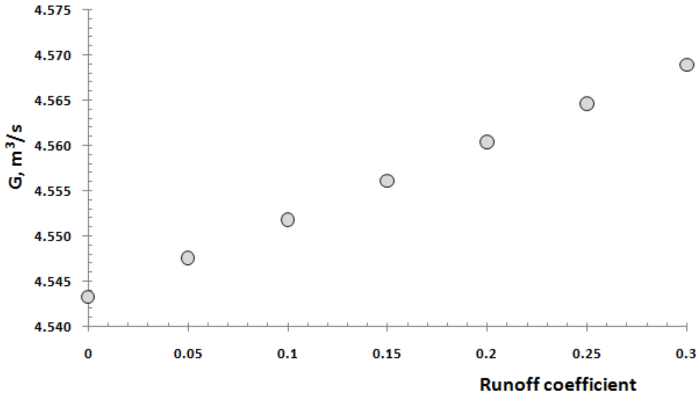
West of Lake Beseka

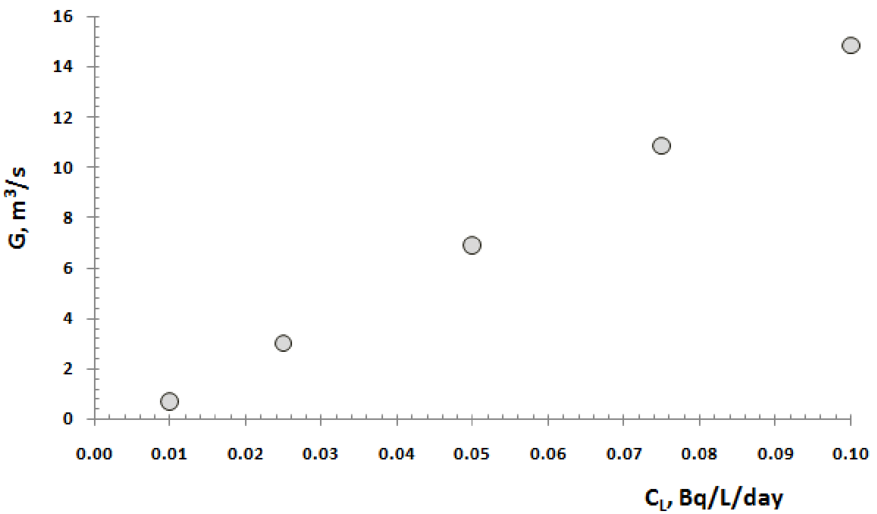


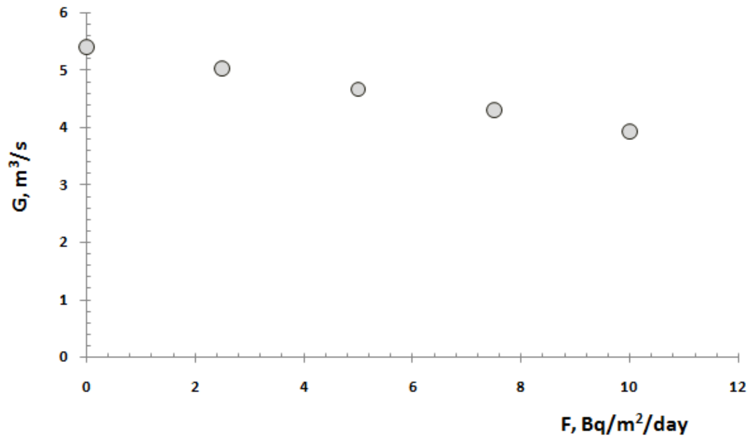
South of Lake Beseka; flow reversal?

Discussion- sensitivity









Estimated GI highly most sensitive to 222Rn in groundwater; 20% variation applied on all input parameters

Summary

1. Combined d18O-d2H and 222Rn constrain the origin of water and its amount

2. Rapid groundwater inflow may be aided by the fractures and the caves, but main source of water is the irrigation excece water getting its way to the lake through the sub surface

3. Lake Beseka poses far greater problem challenging the gain from irrigation investment

Thank you