Derivation of simple hydrogeological models created on the basis of hydrogeological maps, parallel flow

Simple calculations of groundwater flow in EXCEL, testing of key parameters

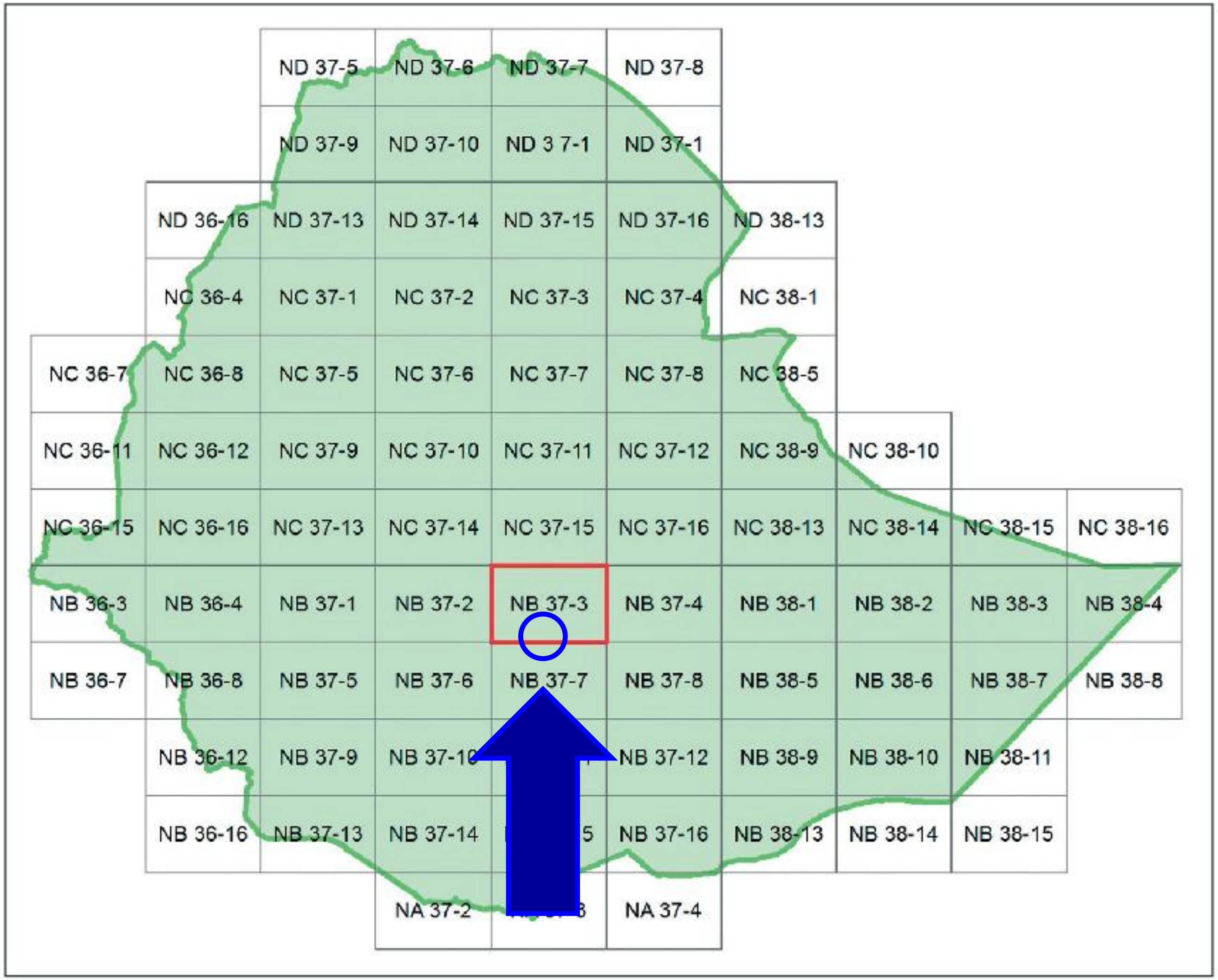
Ondrej Nol

Content:

1. ***Case problem – introduction to the hydrogeological problem;***
2. ***Dupuit aassumptions and derivation of governing equation; Determination of boundary conditions and resulted equations;***
3. ***Derivation key input data from explanatory notes: hydraulic heads, hydraulic gradient, hydraulic conductivity, aquifer base, aquifer thickness and aquifer width.***

Content:

4. Estimations of groundwater volume flowing through the aquifer for given hydraulic conductivity, water saturation and aquifer geometry, Calibration;
5. Comparisons of groundwater flow derived from different approaches;
6. Discussions, uncertainity;
7. Evaluation of quality.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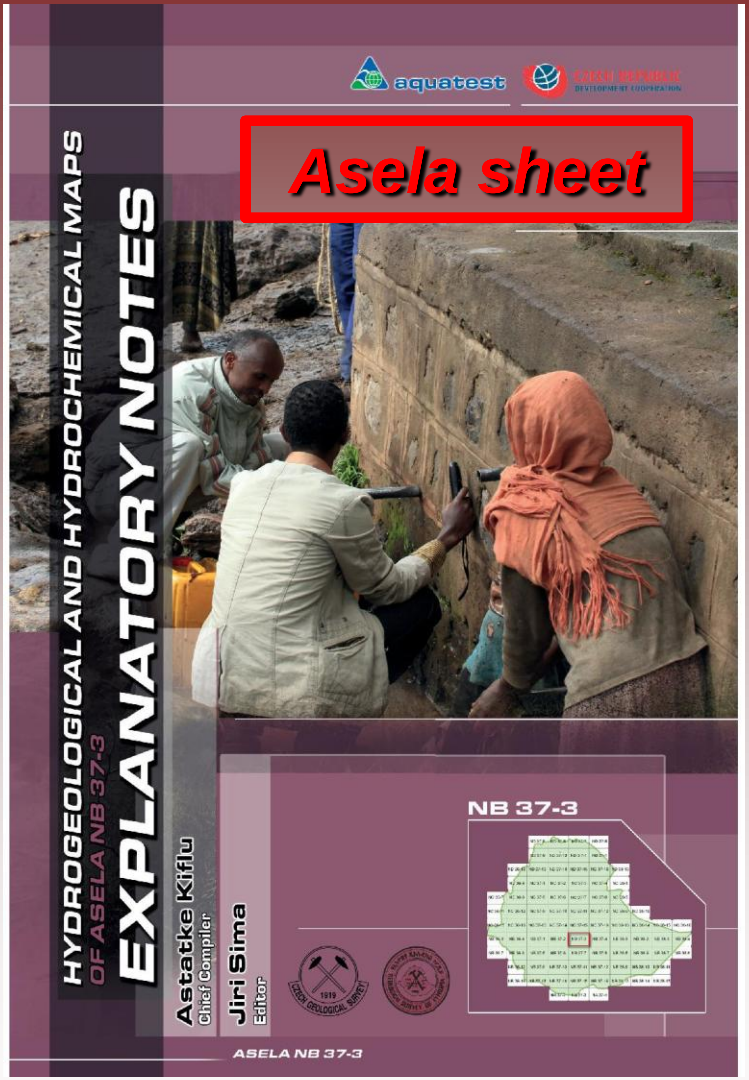

Addis Ababa 14.10.2013

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Maps:
Hydrogeological Map of Asela NB 37-3 – full size and A3 size
Hydrochemical Map of Asela NB 37-3 – full size and A3 size

Annexes

bounded by the Nazret sheet to the north, the Hosaina sheet to the west, the Ginnir sheet to the east and the Dodola sheet to the south.

The area is accessible by the road connecting Addis Ababa – Dukem – Ziway – Arsi Negele – Shashemene – Dodola – Bale Robe or by the road connecting Addis Ababa – Adama – Asela – Dodola – Bale Robe, which is half asphalted and half graveled. At Shashemene, the gravel road which branches to east and passes through Dodola, Arsi Robe, Goba and Dello Mena links the study area to the Borena administrative zone and renders it fairly accessible. There are also seasonal roads that connect different districts of Asela, West Arsi and Bale zones. A few sparsely disseminated trails and negotiable tracks of the Bale Zone readily provide access to the intended sites. The northeastern part of the area, consisting of the volca the river valleys is totally inaccessible. The main accessible roa Fig. 1.2.

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1.2 Population, Settlements and Heal

The study area is administrated mostly by the Asela, West Arsi and Bale zones of the Oromia regional state. The population of the study area and its surrounding is unevenly distributed. This unevenness is primarily the result of the differences in the suitability of environmental conditions for settlement and also the result of socio-economic factors.

Among the major environmental factors that influence population distribution in the area are the terrain characteristics (relief), the presence or absence of perennial water points, and the suitability of the land for farming and cattle breeding. The non-environmental factors that contribute to the variation of population distribution are the development of communication networks and a basic social infrastructure such as schools, health facilities, drinking water, etc.

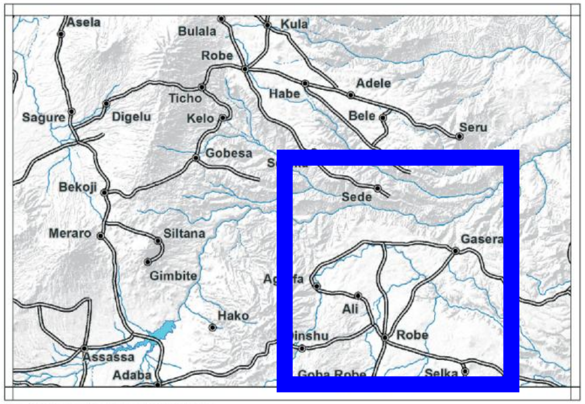
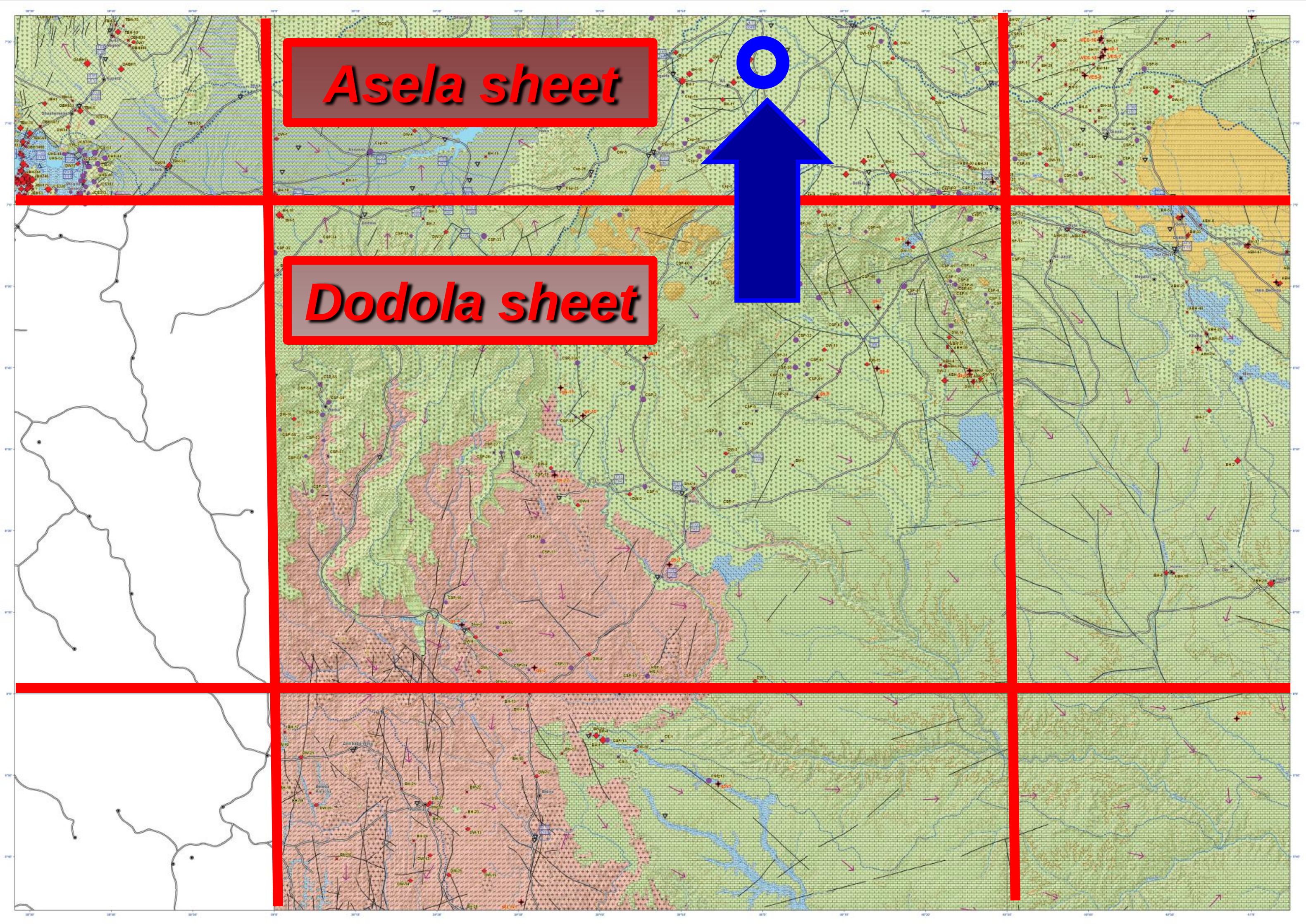
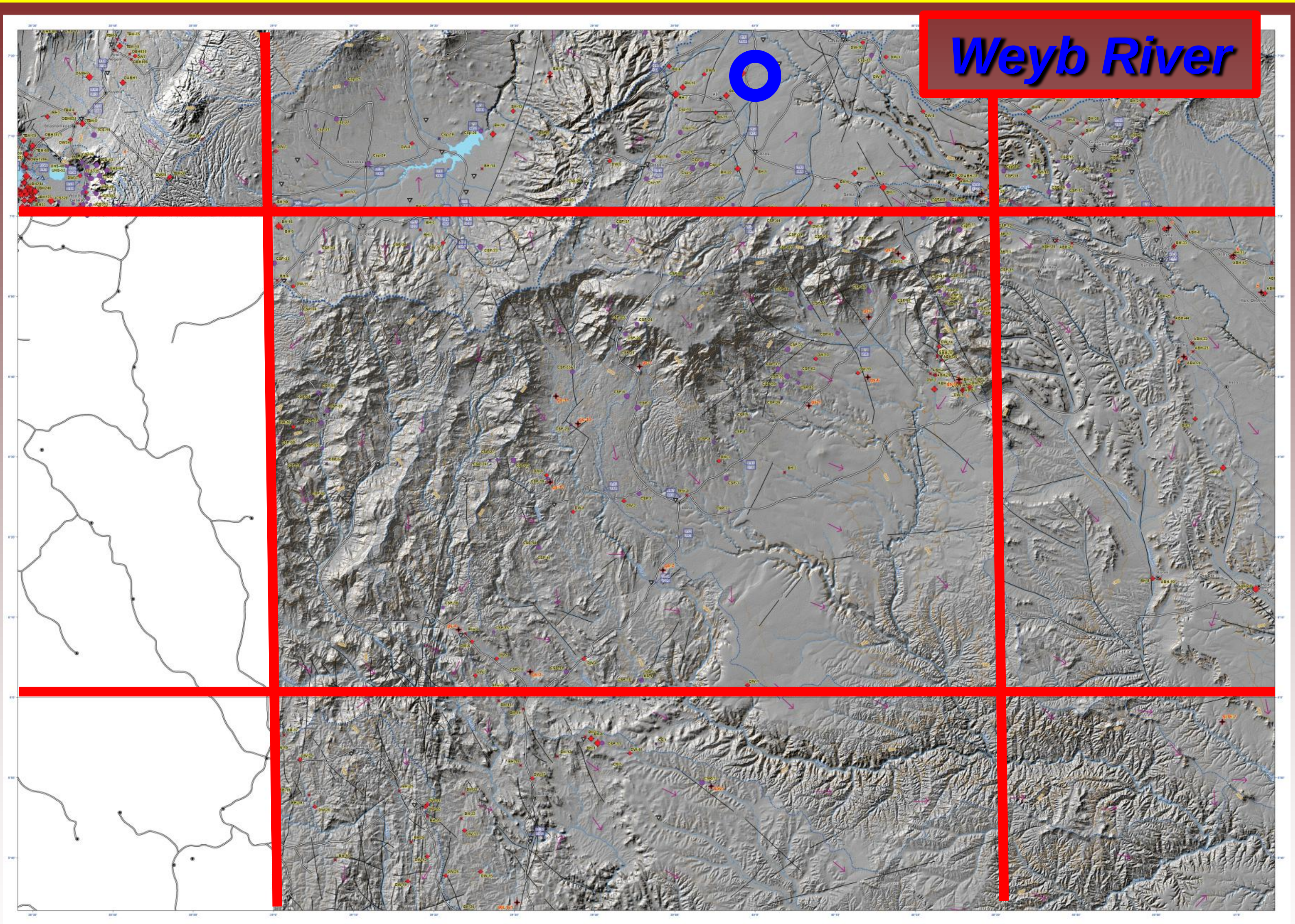


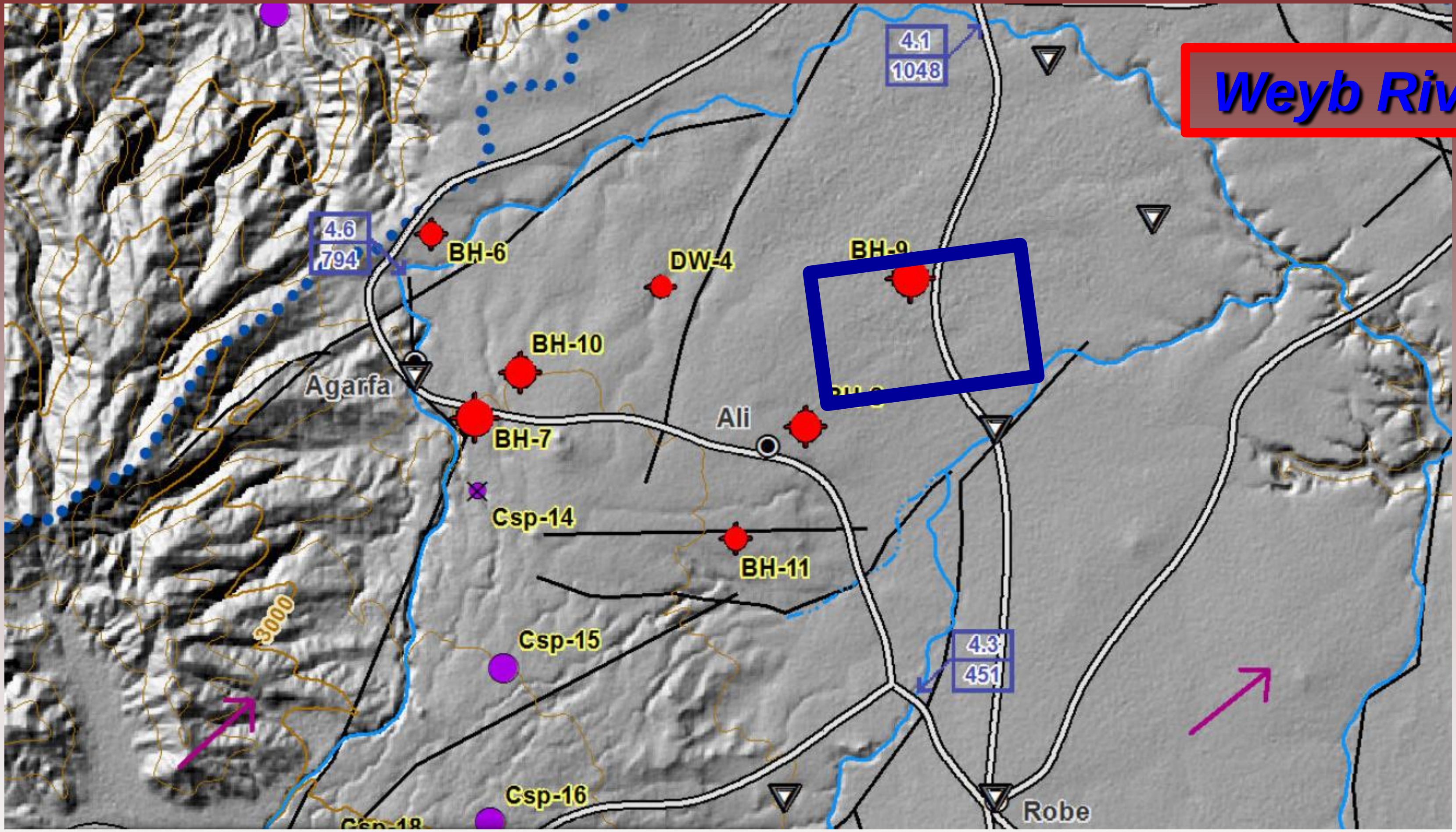
Fig. 1.2 The main roads and settlements



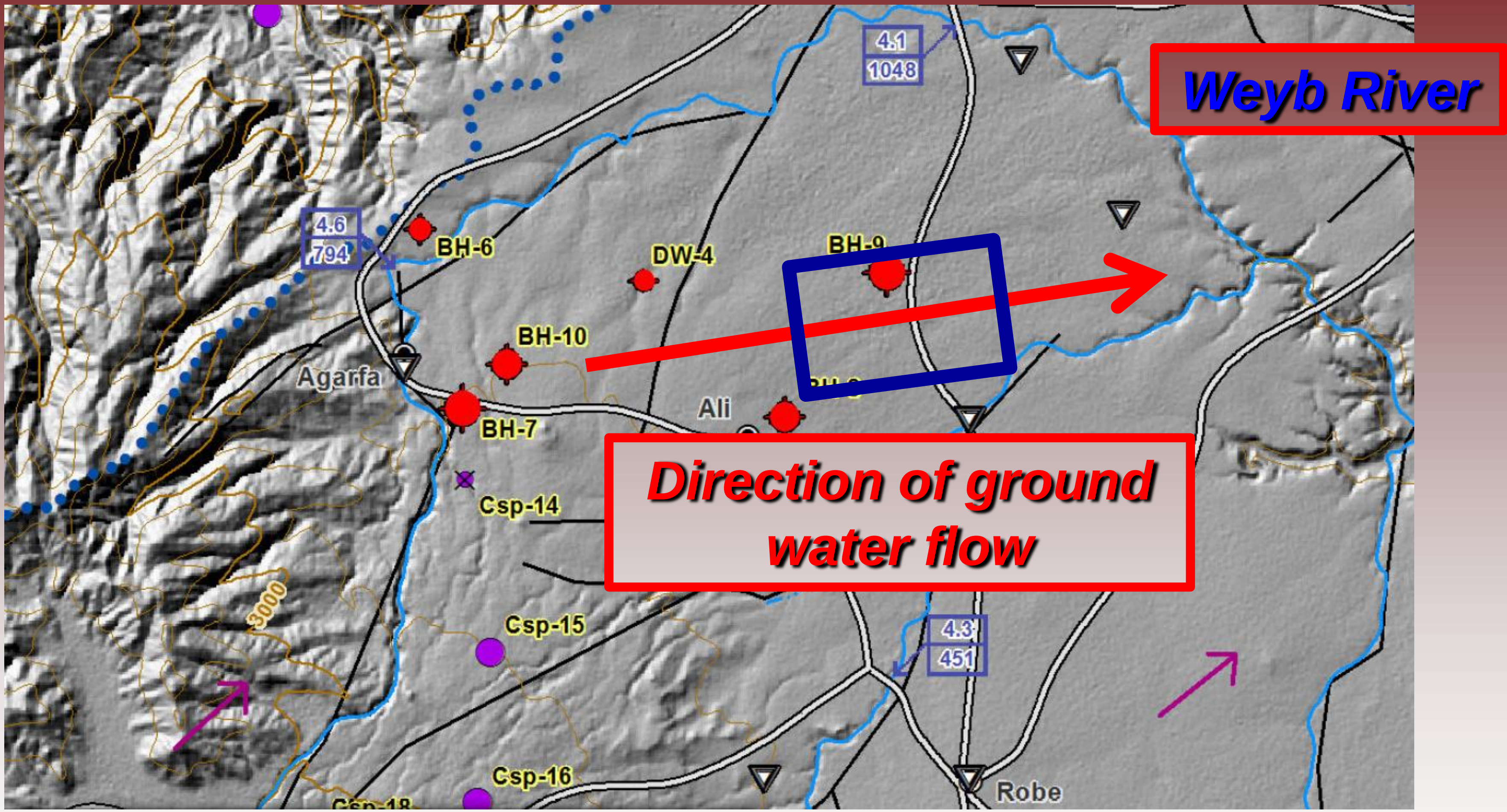
Asela sheet
Dodola sheet


Weyb River

Weyb River



4.1
1048
4.6
794
BH-6
DW-4
BH-9
BH-10
Agarfa
BH-7
Ali
Csp-14
BH-11
3000
Csp-15
4.3
451
Csp-16
Robe



Weyb River
4.1
1048
4.6
794
BH-6
DW-4
BH-9
BH-10
Agarfa
BH-7
Ali
Direction of ground water flow
Csp-14
3000
Csp-15
4.3
451
Csp-16
Robe

Precipitation infiltrate in the highlands into aquifers developed in outcropping volcanic and sedimentary rocks. The groundwater flow direction in the whole area coincides with the topography following the surface water flow direction. Infiltrated groundwater forms shallow local groundwater flow which drained by local perennial and/or intermittent rivers of the plateau area. Some of the groundwater infiltrates to deeper aquifers developed by deeper located volcanic as well as by sedimentary rocks. This deep groundwater flows to the northwest to the Rift Valley and to the southeast to the adjacent lowlands.

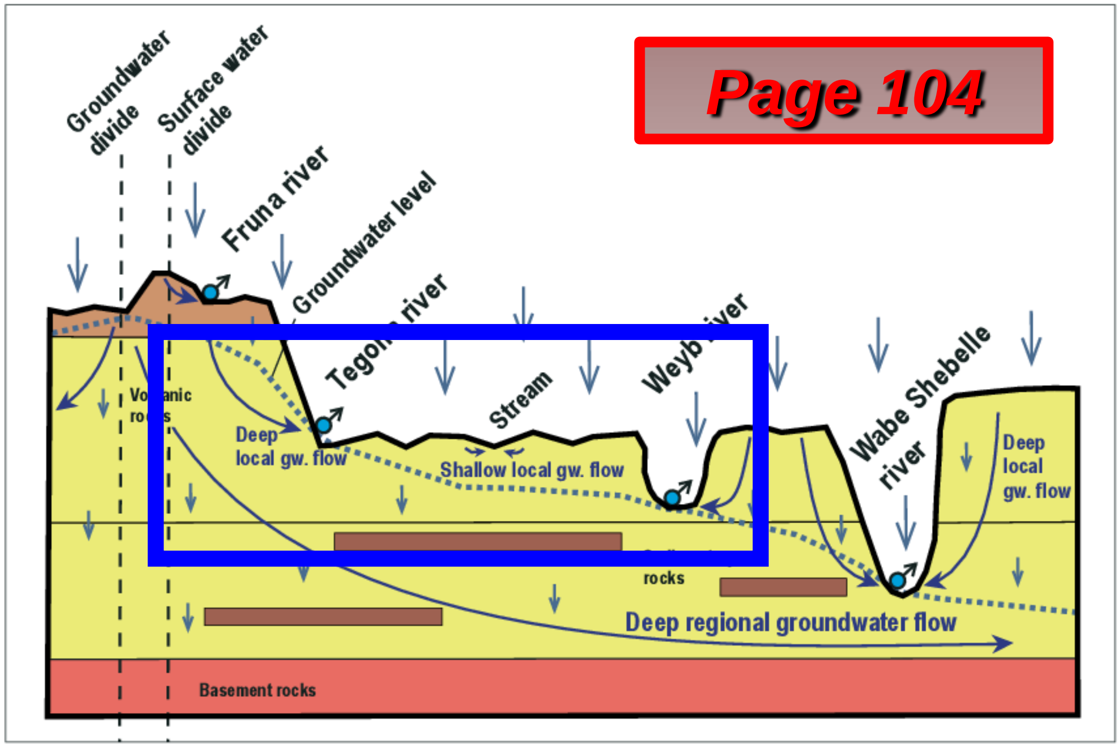


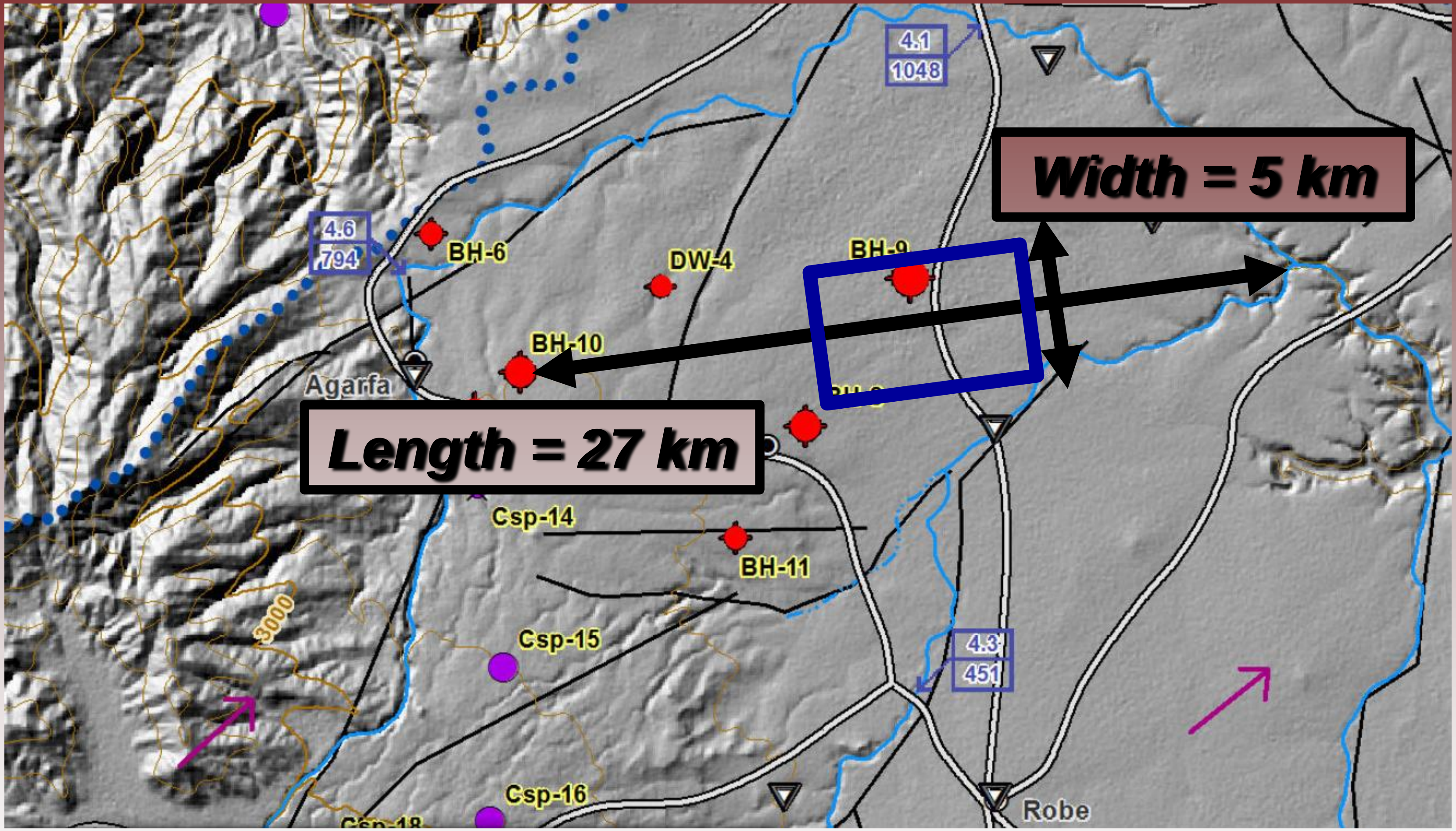
Fig. 4.8 Conceptual hydrogeological model of the Asela highland area

Site ID	Site name (owner), locality/ wereda, zone	Grid or map reference - UTM Northing/ Easting	Elevation [m a.s.l]	Date visited (G.C)	Drilling company/drilling completion date	Depth of borehole/ screen interval below ground surface [m]	Depth to water struck below ground surface [m]/ date struck	Depth to static water level below ground surface [m]	Measuring point (MP) height above(+)/below(-) ground surface [m]	Depth to water level during visit below MP/below ground surface [m]	Yield [l/s]	Drawdown [m]	Specific capacity [l/s.m]	Transmissivity [m^2/d]	Case diameter [inch]	Type of pump/power source	Pumping hours/day	Aquifer	Use	Topographic setting	Borehole status	Temp. [°C]	Field chemistry: Field EC [µS/cm]	Field chemistry: Field pH
BH-9	Sheneka, Sheneka kebele, Agarfa	0806813 N	2410	3.11.2009	OWWCE	102		23.31			5.5	22.53	0.24	89.3	6	Submersible		Confined single	Public supply	Flat	In use	23	107.3	7.96
	Bale	0607438 E			1996 E.C																			
BH-10	Elane-Goda, Agarfa	0803486 N	2484	3.12.2009	OWWCE	148				58.85	3.1				6	Submersible	8		Public supply	Flat	In use	20.7	32.6	9.11
	Bale	0593841 E			1991 E.C																			
BH-11	Abi-Nasa, Elabidu, Agarfa	0797698 N	2505	3.12.2009	NCA	42				12.5	0.2				6	Hand pump			Public supply	Flat	In use	20.7	96.4	7.27
	Bale	0601383 E			1989 E.C																			
BH-12	Berbersa/ Lajo, Adaba	0806654 N	2335	16.3.2009	OWWCE	35		23			0.3				6	Hand pump	6		Public supply	Flat	In use	23.6	177.1	6.92
	Bale	0563441 E			1992 E.C																			
BH-13	Garadela, Garadelo-Misra, Adaba	0797991 N	2404	16.3.2009	OWWCE	35				23	0.4				6	Hand pump	7	Unconfined single	Public supply	Flat	In use	22.2	97.5	7.53
	Bale	0554958 E			1995 E.C																			
BH-14	Hunte, Madeda kebele, Adaba	0784685 N	2358	17.3.2009	OWWCE	60		12		5.5					6	Submersible	6.5		Mixed	Depression	In use	21.6	81	7.28
	West Arsi	0547848 E			1972 E.C																			
BH-15	Hako, Hako-Kara, Adaba	0791754 N	2479	17.3.2009	OWWCE	98-98.6				Artesian					6	Submersible		Confined single	Public supply	Depression	Not functional	21.5	79.9	7.56
	West Arsi	0559089 E			1998 E.C																			
BH-16	Melka Wakena Power Station, Gededo/Ebsay, Adaba	0792681 N	2328	17.3.2009	OWWCE	88				9.3	1.04				12	Submersible	13.5		Mixed	Depression	In use	23.3	122.3	7.2
	West Arsi	0550336 E			1999 E.C																			

Annex No. 1 Borehole inventory (Part 2)

Annex No. 1 Borehole inventory (Part 2)

Site ID	Site name (owner), locality/ wereda, zone	Grid or map reference - UTM Northing/ Easting	Elevation [m a.s.l]	Date visited (G.C)	Drilling company/drilling completion date	Depth of borehole/ screen interval below ground surface [m]	Depth to water struck below ground surface [m]/ date struck	Depth to static water level below ground surface [m]	Measuring point (MP) height above(+)/below(-) ground surface [m]	Depth to water level during visit below MP/below ground surface [m]	Yield [l/s]	Drawdown [m]	Specific capacity [l/s.m]	Transmissivity [m^2/d]	Case diameter [inch]	Type of pump/power source	Pumping hours/day
BH-9	Sheneka, Sheneka kebele, Agarfa	0806813 N	2410	3.11.2009	OWWCE	102		23.31			5.5	22.53	0.24	89.3	6	Submer-sible	
	Bale	0607438 E			1996 E.C												
BH-10	Elane-Goda, Agarfa	0803486 N	2484	3.12.2009	OWWCE	148				58.85	3.1				6	Submer-sible	8
	Bale	0593841 E			1991 E.C												
BH-11	Abi-Nasa, Elabidu, Agarfa	0797698 N	2505	3.12.2009	NCA	42				12.5	0.2				6	Hand pump	
	Bale	0601383 E			1989 E.C												
BH-12	Berbersa/ Lajo, Adaba	0806654 N	2335	16.3.2009	OWWCE	35		23			0.3				6	Hand pump	6
	Bale	0563441 E			1992 E.C												
BH-13	Garadela, Garadelo-Mi-sra, Adaba	0797991 N	2404	16.3.2009	OWWCE	35				23	0.4				6	Hand pump	7
BH-14	Adaba					60		12		5.5					6	Submer-sible	6.5
	West Arsi	0547848 E			1972 E.C												
BH-15	Hako, Hako--Kara, Adaba	0791754 N	2479	17.3.2009	OWWCE	98-98.6				Artesian					6	Submer-sible	
	West Arsi	0559089 E			1998 E.C												

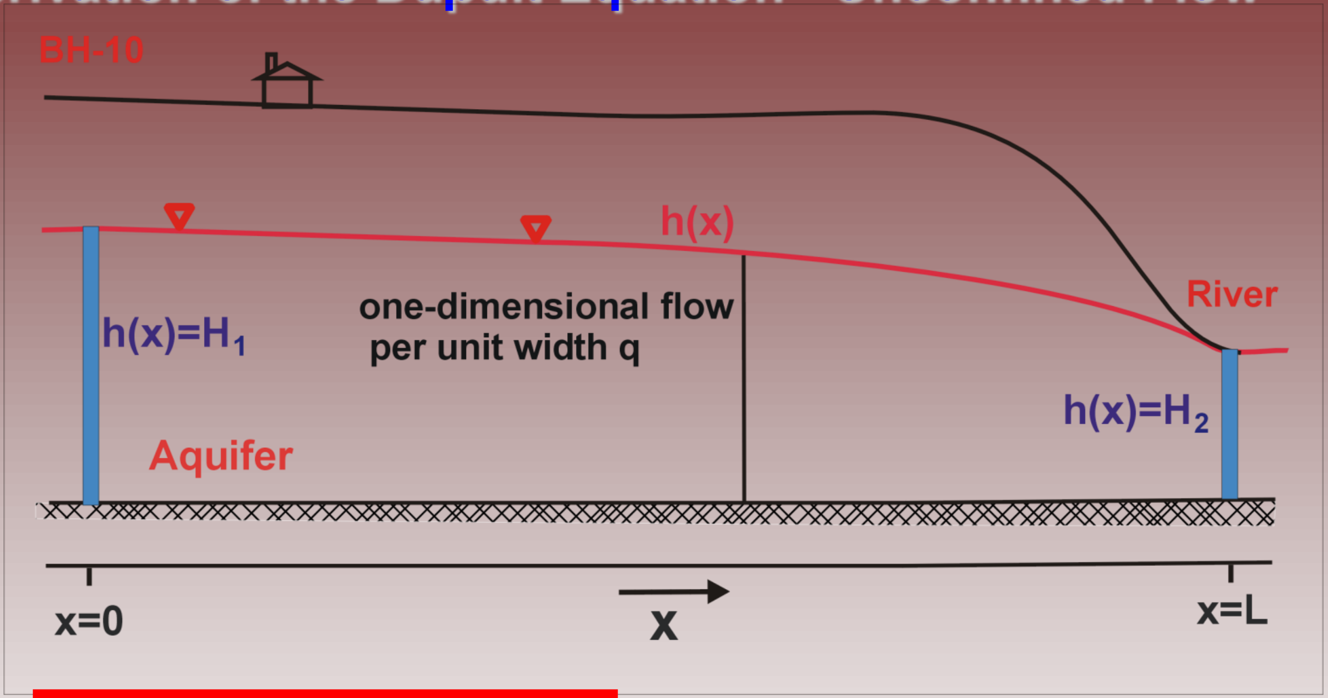

4.1
1048
Width = 5 km
4.6
794
BH-6
DW-4
BH-9
BH-10
Agarfa
Length = 27 km
Csp-14
BH-11
3000
Csp-15
4.3
451
Csp-16
Robe

Dupuit Assumptions:

For unconfined ground water flow Dupuit developed a theory that allows for a simple solution based of the following assumptions:

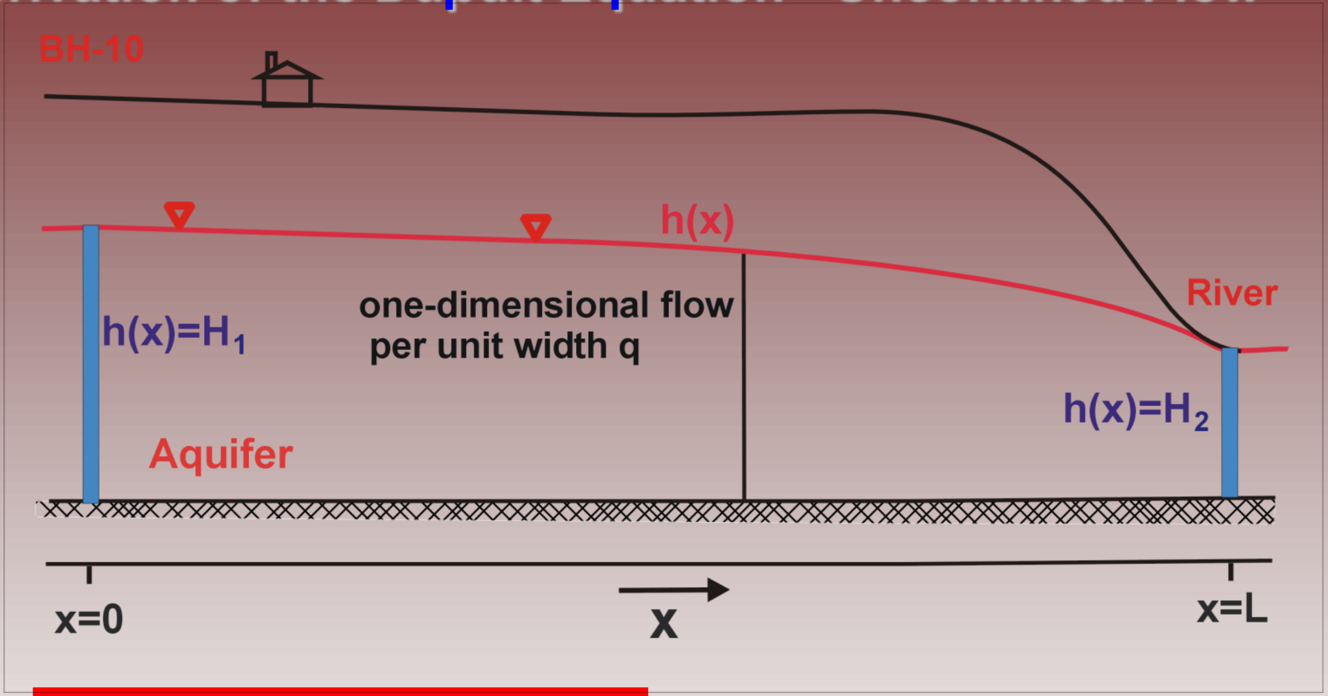
1) *The water table or free surface is only slightly inclined*
2) *Streamlines may be considered horizontal and equipotential lines, vertical*
3) *Slopes of the free surface and hydraulic gradient are equal*

Derivation of the Dupuit Equation - Unconfined Flow



$$\frac{d(q(x))}{dx} = 0$$

Derivation of the Dupuit Equation - Unconfined Flow



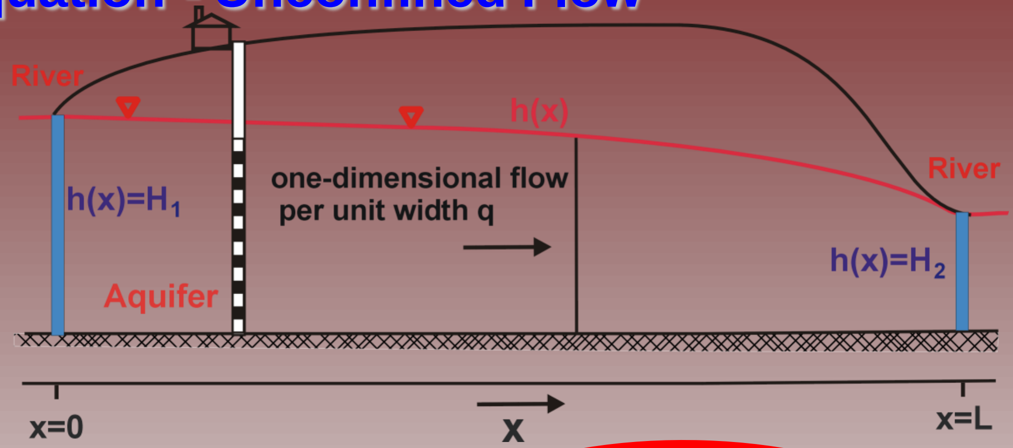
$$q = -k\frac{dh}{dx}h(x)$$

$$\int q\,dx = \int -\,kh(x)\,dh$$

$$qx = -k\frac{h(x)^2}{2} + c$$

Derivation of the Dupuit Equation - Unconfined Flow

$$qx = -k\frac{h(x)^2}{2} + c$$

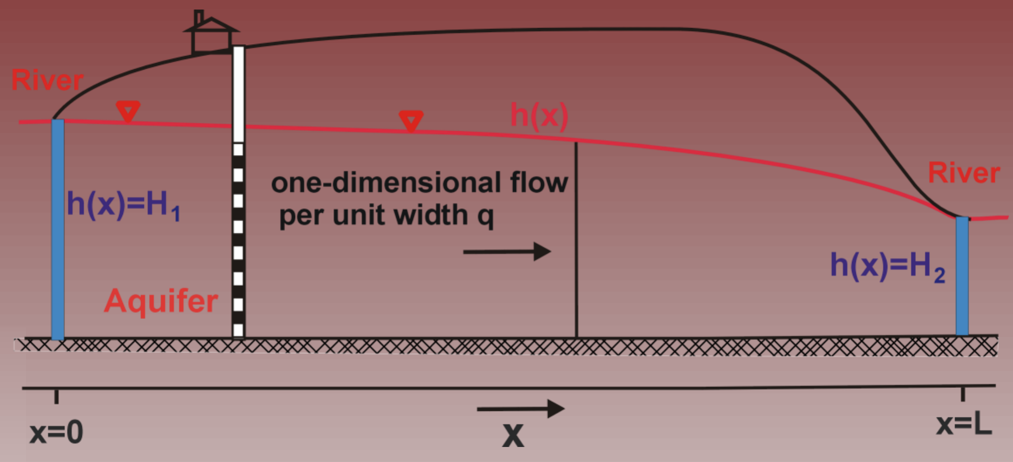


h(0)=H_1 $$q0 = 0 = -k\frac{H_1^2}{2} + c$$

h(L)=H_2 $$qL = -k\frac{H_2^2}{2} + c$$

$$qL = k\frac{H_1^2}{2} - k\frac{H_2^2}{2}$$

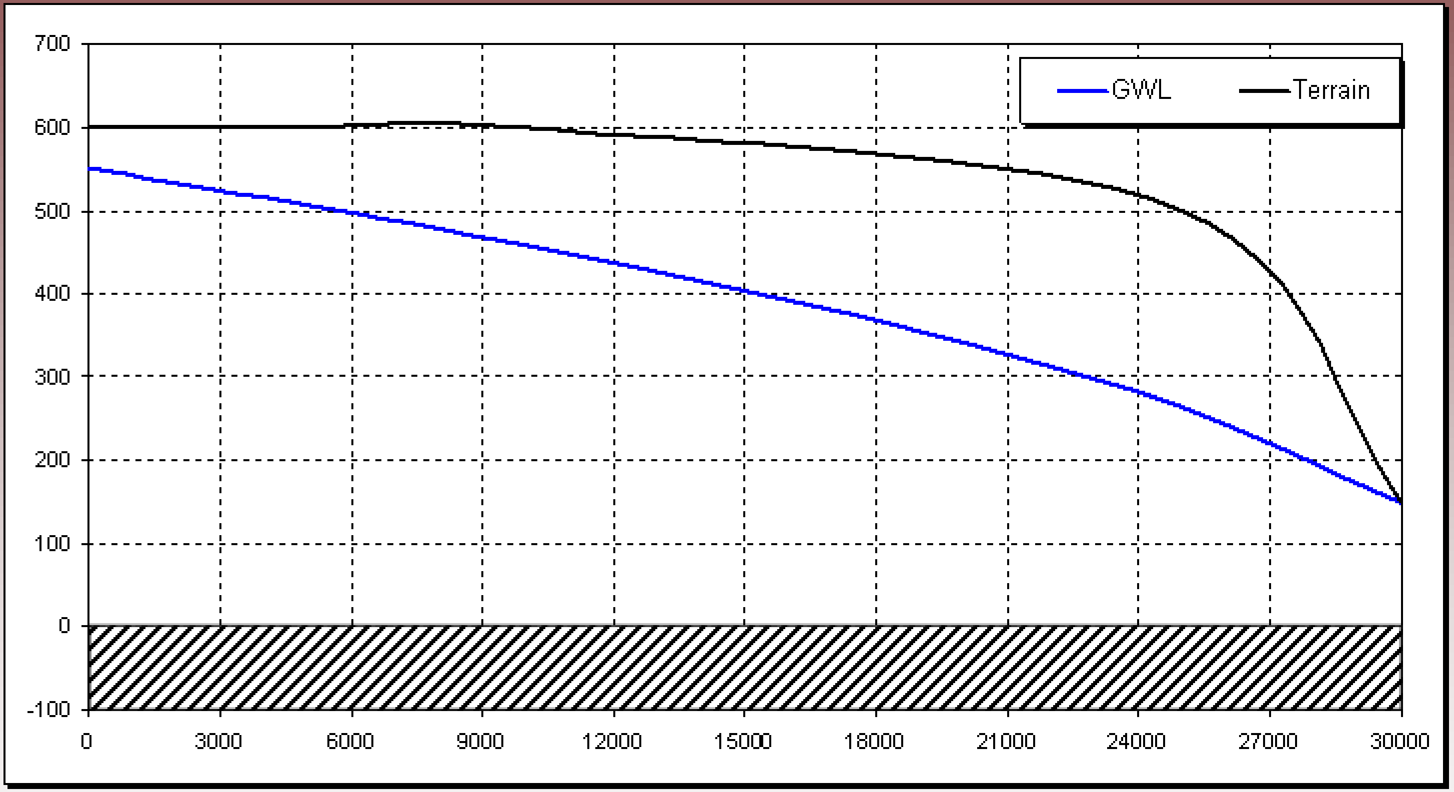
$$q = k\frac{H_1^2 - H_2^2}{2L}$$



For given one-dimensional flow yields:

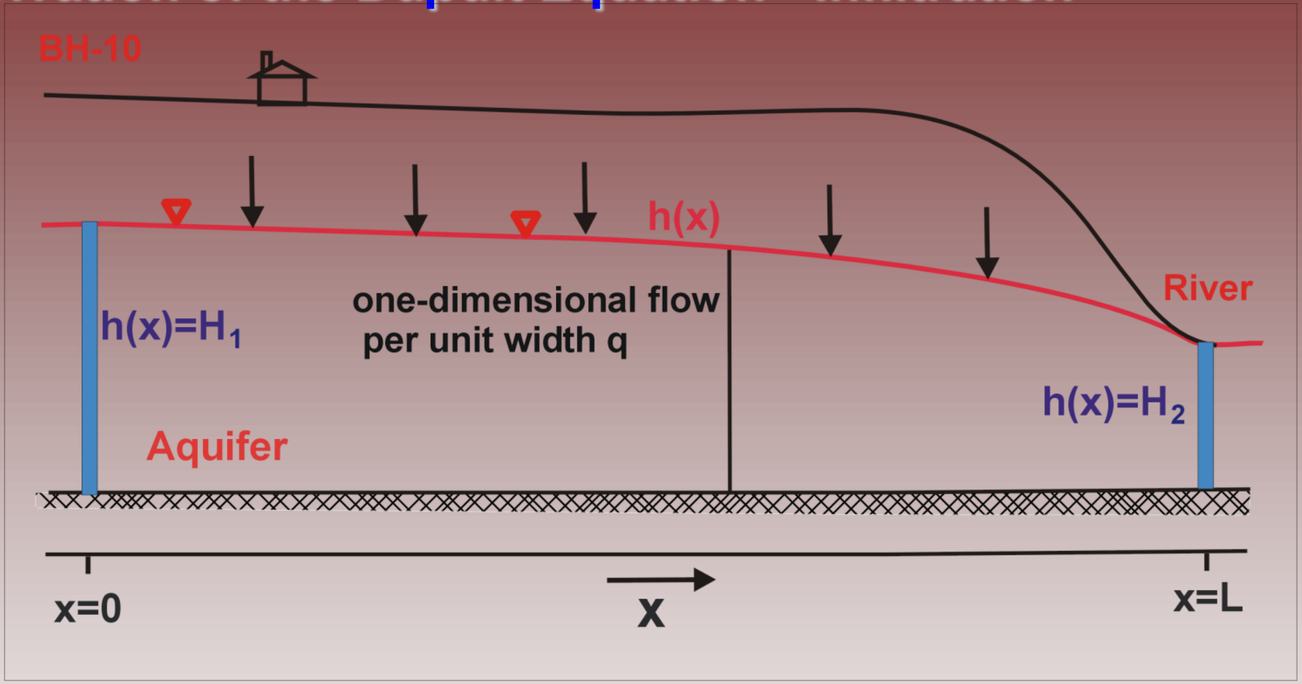
$$h(x) = \sqrt{H_2^2 + \frac{2xq}{k}}$$

However, this example does not consider recharge to the aquifer.



Inflow hydral. Head H1 is known, no infiltration

Derivation of the Dupuit Equation - Infiltration



$$\frac{d(q(x))}{dx} + e = 0$$

$$q = -k \frac{dh}{dx} h(x)$$

Derivation of the Dupuit Equation - Infiltration

$$-k\frac{dh}{dx}h(x)+e*x+c_1=0$$

$$-k\frac{h(x)^2}{2}+\frac{1}{2}e*x^2+x*c_1+c_2=0$$

h(0)=H$_1$

$$0=-k\frac{H_1^2}{2}+c_2$$

$$c_2=k\frac{H_1^2}{2}$$

h(L)=H$_2$

$$-k\frac{H_2^2}{2}+\frac{1}{2}e*L^2+L*c_1+k\frac{H_1^2}{2}=0 \qquad c_1=k\frac{H_2^2}{2L}-k\frac{H_1^2}{2L}-\frac{1}{2}e*L$$

$$-k\frac{h(x)^2}{2}+\frac{1}{2}e*x^2+x*\left(k\frac{H_2^2}{2L}-k\frac{H_1^2}{2L}-\frac{1}{2}e*L\right)+k\frac{H_1^2}{2}=0$$

$$h(x)^2=\frac{e}{k}*x^2+x*\left(\frac{H_2^2}{L}-\frac{H_1^2}{L}-\frac{1}{k}e*L\right)+H_1^2$$

Derivation of the Dupuit Equation - Infiltration

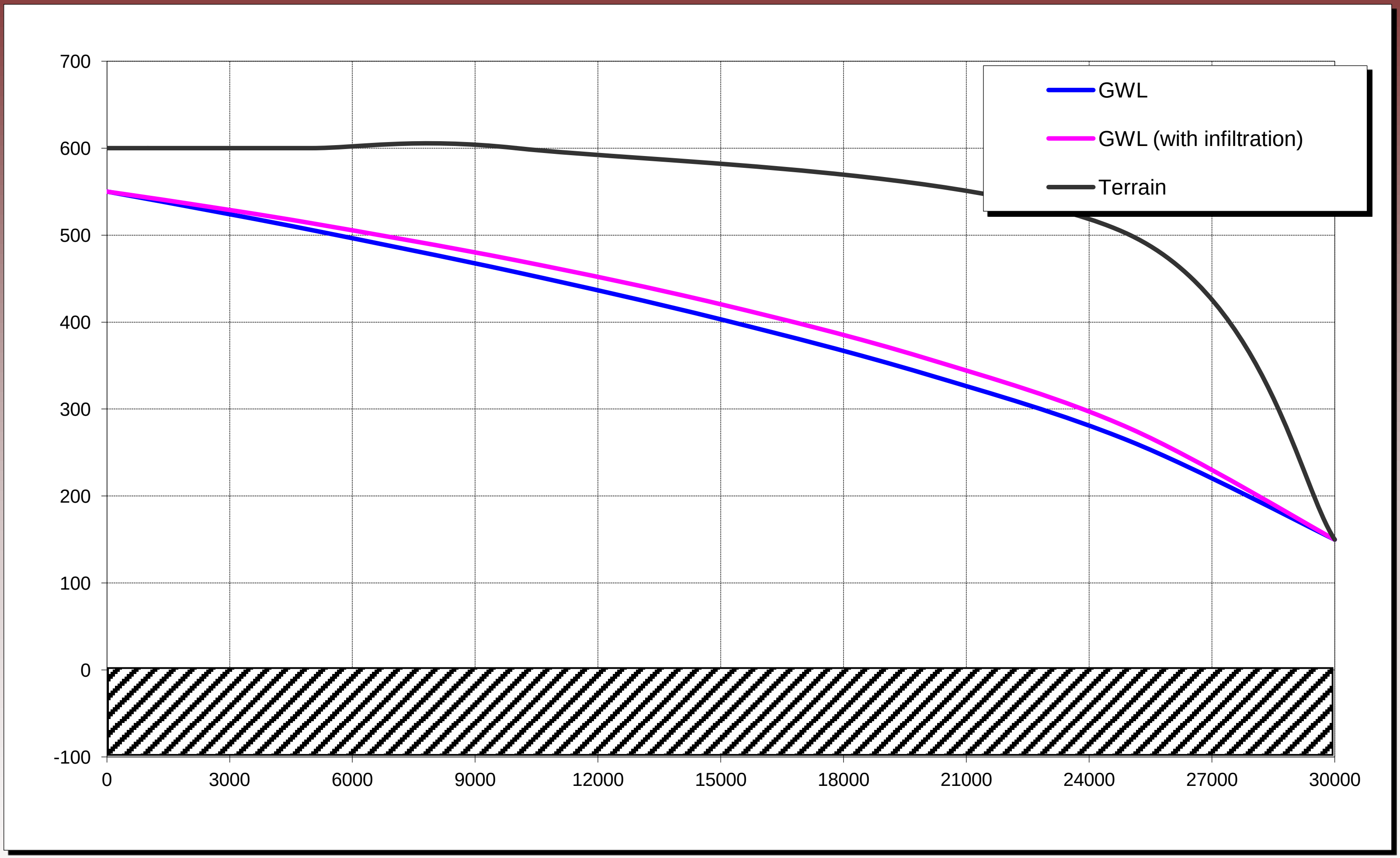
$$-k\frac{dh}{dx}h(x)+e*x+c_1=0$$

$$c_1=k\frac{H_2^2}{2L}-k\frac{H_1^2}{2L}-\frac{1}{2}e*L$$

$$q(x)=-e*x-c_1$$

$$c_1=-q-\frac{1}{2}e*L$$

$$q(x)=-e*x+q+\frac{1}{2}e*L$$



700
600
500
400
300
200
100
0
-100
0
3000
6000
9000
12000
15000
18000
21000
24000
27000
30000
GWL
GWL (with infiltration)
Terrain

The area of active aquifers that store and transmit water was calculated based on the hydrogeological map. The active aquifers (Tab. 6.1) of porous, karst and fissured permeability in the sheet cover an area of 18,225 km².

Tab. 6.1 Aquifers in the area

Aquifers	Area [km²]
Porous	103
Fissured and karst in sedimentary and volcanic rocks	18,121
Total	18,225

The runoff chara … d
hydrogeological cha …

Page 122

The surface river … g
stations within the … a
about water resourc … t
of groundwater resources of the whole area because they do not show the total drainage of the map sheet. Data from other river gauging stations within the Genale-Dawa, Wabe Shebelle and the Rift Valley Lakes basin (Katar basins) were considered in the assessment of surface and baseflow values. The surface flow as well as baseflow assessment is highly affected by short and incomplete data series and the intermittent character of some rivers in some years. Data can be also highly influenced by the effect of bank groundwater storage, difficulties in flow measurements of wide and unstable river channels and unknown groundwater flow beneath gauging stations. ***For further calculations, the value of specific surface runoff of 8.0 l/s.km² and specific baseflow of 2.6 l/s.km² for areas consisting volcanic rocks and is used also for sedimentary rocks of the Asela area***. The assessed water resources of the Asela area are shown in Tab. 6.2.

Tab. 6.2 Assessment of water resources of the Asela area

	Input	Area [km²]	Resources total	Remark
Precipitation	1,050 mm	18,300	19,215 Mm³/year	
Total water resources – map	8 l/s.km²	18,300	4,620 Mm³/year	24 % rainfall
Renewable groundwater resources active aquifers	2.6 l/s.km²	18,225	1,501 Mm³/year	8 % rainfall
Static groundwater resources karst and fissured aquifers	5 % porosity 100 m thickness	18,122	90,610 Mm³	
Static groundwater resources porous aquifers	15 % porosity 30 m thickness	103	463.5 Mm³	

6.2.1 Surface Water Resources Development

Despite of the fact that river gauge measurements show relatively moderate, but logical, evapotranspiration when nearly 25 % of precipitation is drained as total runoff from the area. There

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Tab. 5.7 Suitability of water for use in industry

Industry or use	Solids (TDS) [mg/l]	pH	Chlorides as Cl [mg/l]	Sulfates as SO_4 [mg/l]	Number of samples in the range
Brewing	500–1,500	6.5–7.0	60–100		0
Carbonated beverages	< 850		< 250	< 250	134
Confectionary	50–100	> 7.0			20
Dairy	< 500		< 30	< 60	113
Food canning and freezing	< 850	> 7.0			123
Food equipment washing	< 850		< 250		134
Food processing general	< 850				134
Ice manufacture	170–1,300				84
Laundering		6.0–6.5			3
Paper and pulp fine	< 200				62
Paper groundwood	< 500		< 75		118
Paper bleached cardboard	< 300		< 200		77
Paper unbleached cardboard	< 500		< 200		118
Paper soda and sulfate pulps	< 250		< 75		71
Rayon and acetate fiber pulp production	<100				30
Rayon manufacture		7.8–8.3			43
Sugar	< 100		< 20	< 20	30
Tanning		6.0–8.0			119
Textile			< 100	< 100	136

Remark: Sugar requirements for TDS are in general low

Tab. 5.8 Concentration limits for incrustation (Part 1)

Component	Concentration [mg/l]	Number of sample in the range
Bicarbonates (HCO_3^-)	> 400	129
Sulfates (SO_4^{2-})	> 100	137
Silicon (Si)	> 40	65

Annex No. 2 Chemical analyses data in mg/l (Part 1)
(TDS calculated from analytical results, EC in µS/cm at 25°C)

ID	Lab. No.	Na	K	Ca	Mg	SiO_2	CO_3	HCO_3	Cl	SO_4	F	NO_3	EC	pH	TDS
BH-1	6613	40	4	27	25	54	NA	295	28	22	0.39	9.3	553	8.08	450.69
BH-2	6619	40	4.1	45	30	38	NA	336	27	17	0.47	13.3	620	8.11	512.87
BH-3	6620	33	3.6	51	30	42	NA	342	27	21	0.47	18.6	643	7.95	526.67
BH-4	6621	50	3.7	46	26	39	NA	332	39	34	0.46	10.2	661	8.14	541.36
BH-5	6622	22	1.6	69	22	44	NA	281	47	29	0.31	18.2	619	7.96	490.11
BH-6	6628	20	0.6	58	16	46	NA	318	5	9	0.52	5.8	487	7.99	432.92
BH-7	6629	40	0.5	3	3	20	6	55	8	8	0.38	0.4	196	8.53	124.28
BH-8	6632	60	5.2	23	6	46	NA	159	45	32	1.33	11.5	475	8.08	343.03
BH-9	6633	60	8.1	27	13	43	NA	220	41	45	0.64	2.7	546	8.1	417.44
BH-10	6634	70	0.4	1.2	1	18	9	79	7	12	0.54	1.4	167	8.88	181.54
BH-11	6636	20	1.4	55	13	45	NA	268	17	22	39	15.9	503	7.9	451.3
BH-12	6641	41	2.6	94	18	44	NA	300	77	88	0.52	33.2	886	7.68	654.32
BH-13	6642	30	1.9	44	16	52	NA	287	14	9	1.46	7.1	495	7.97	410.46
BH-14	6643	21	2	43	9	29	NA	258	5	9	0.55	2.7	409	7.86	350.25
BH-15	6644	30	2	39	8	32	NA	194	16	8	0.41	22.2	406	8.03	319.61
BH-16	6645	30	1.7	56	24	50	NA	326	20	13	0.69	18.6	593	7.94	489.99
BH-17	6654	47	8.3	44	10	74	NA	291	13	21	1.07	2.7	522	7.89	438.07
BH-18	6656	12.5	4.6	43	10.5	65	NA	220	4	8	0.51	10.2	361	8.15	313.31
BH-19	6657	31	7.5	22	5.5	59	NA	205	2	5	0.74	0.4	312	7.73	279.14
BH-20	6658	19	3.4	59	15	65	NA	335	7	11	0.91	8	541	8.02	458.31
BH-21	6659	23	4.3	56	13	67	NA	307	7	10	0.8	7.1	513	7.61	428.2
BH-22	6669	850	40	30	100	86	NA	2333	363	462	0.7	0.4	4640	7.3	4179.1
BH-23	7560	55	4.3	63	200	68	NA	406	45	11	1.3	54.5	898	7.8	840.1
BH-24	7561	16	1.8	65	18	53	NA	296	32	15	0.58	19	583	8	463.38

Annex No. 2 Chemical analyses data in mg/l (Part 1)