

**Age and origin of groundwater resources in the Ararat Valley, Armenia: a baseline study applying hydrogeochemistry and environmental tracers**

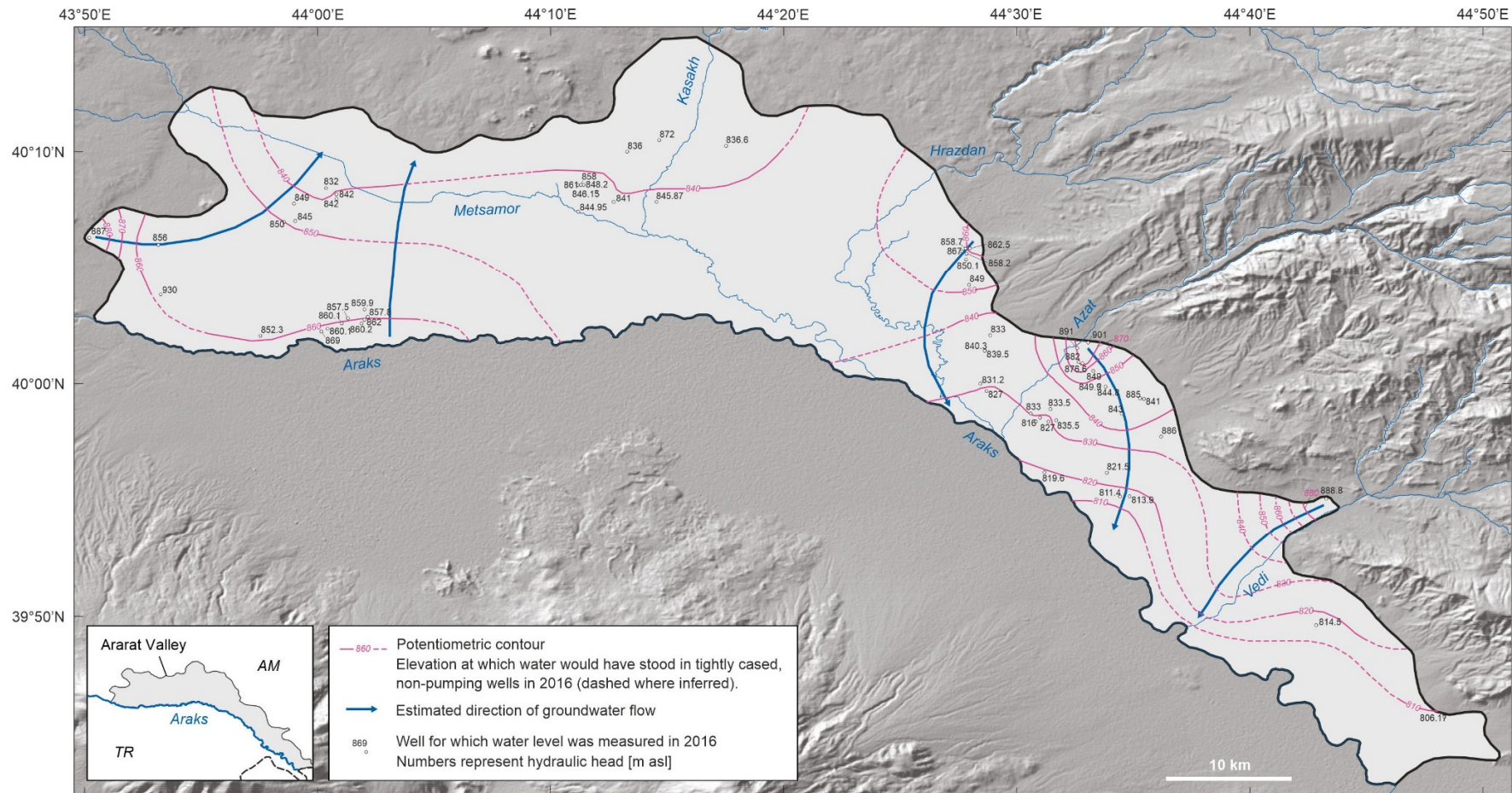
Michael Schubert, Nils Michelsen, Axel Schmidt, Laura Eichenauer, Kay Knoeller, Alexander Arakelyan, Lilith Harutyunyan, Christoph Schüth

Electronic supplementary material – Hydrogeology Journal

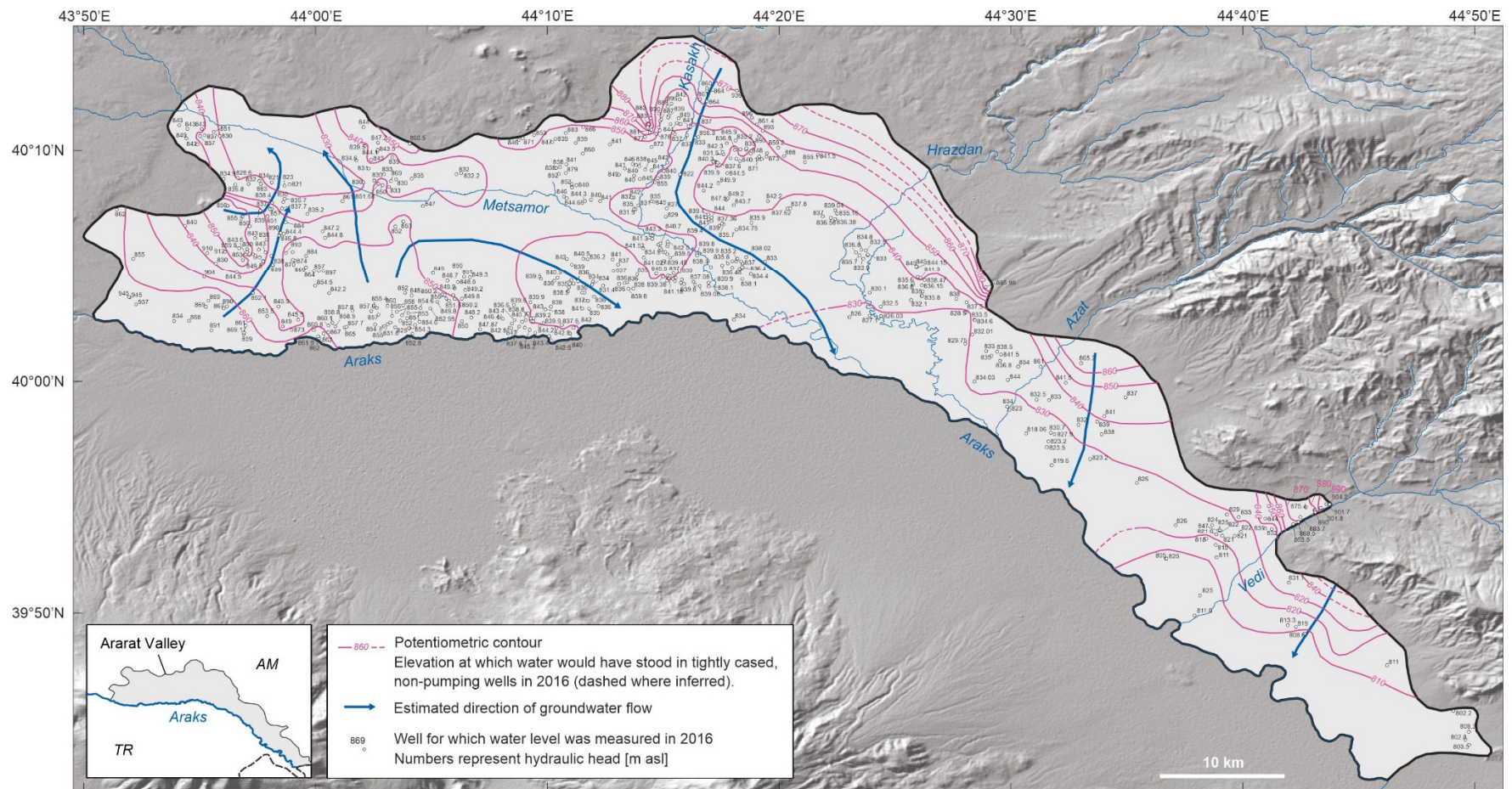
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Figs. S1 – S7

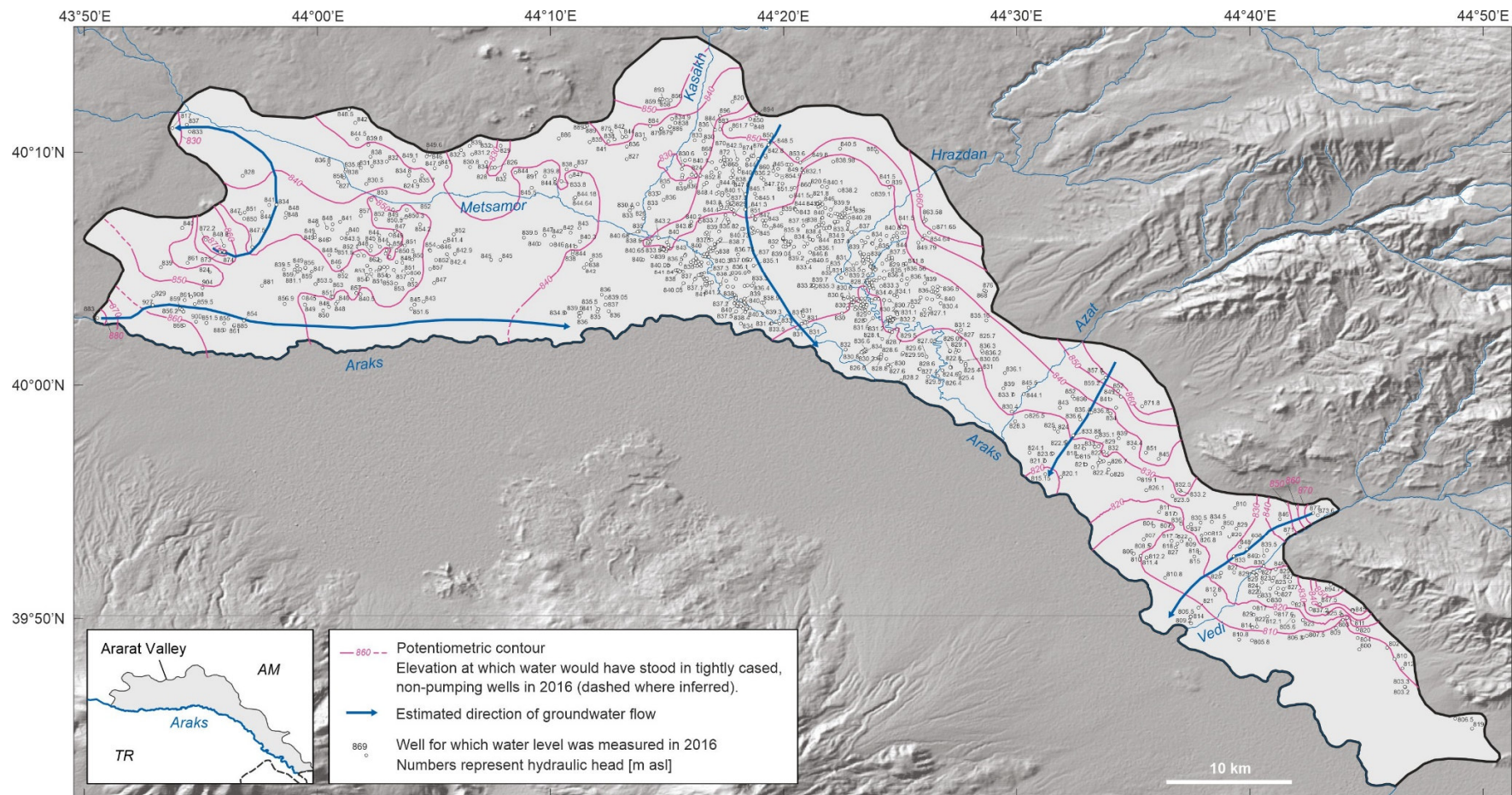
Table S1



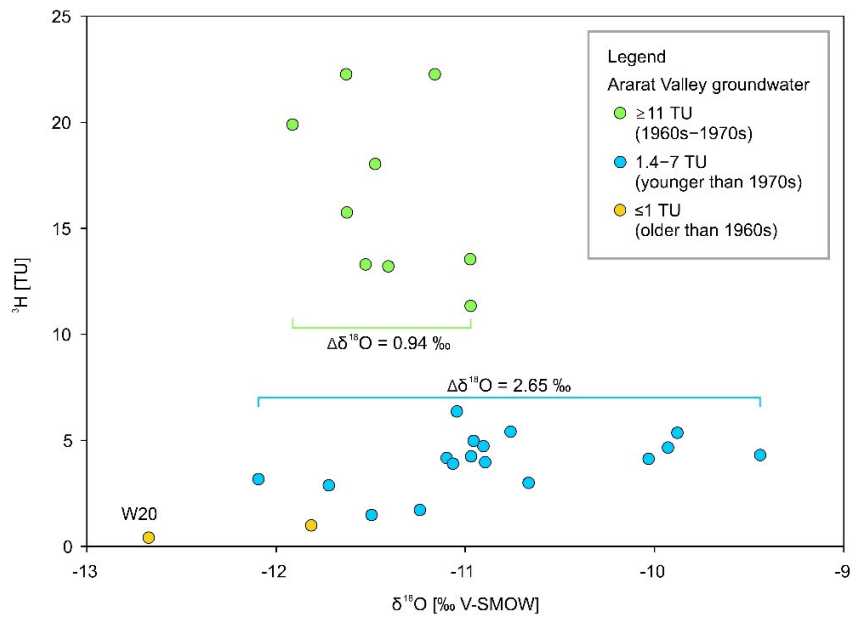
**Fig. S1** Groundwater contour map for Hydrogeologic Unit 2 (Valder et al. 2018, modified). Note that the groundwater flow direction in the west is away from the Araks River (*blue arrows*), indicating losing stream conditions. Further downstream, the Araks River is a gaining stream.



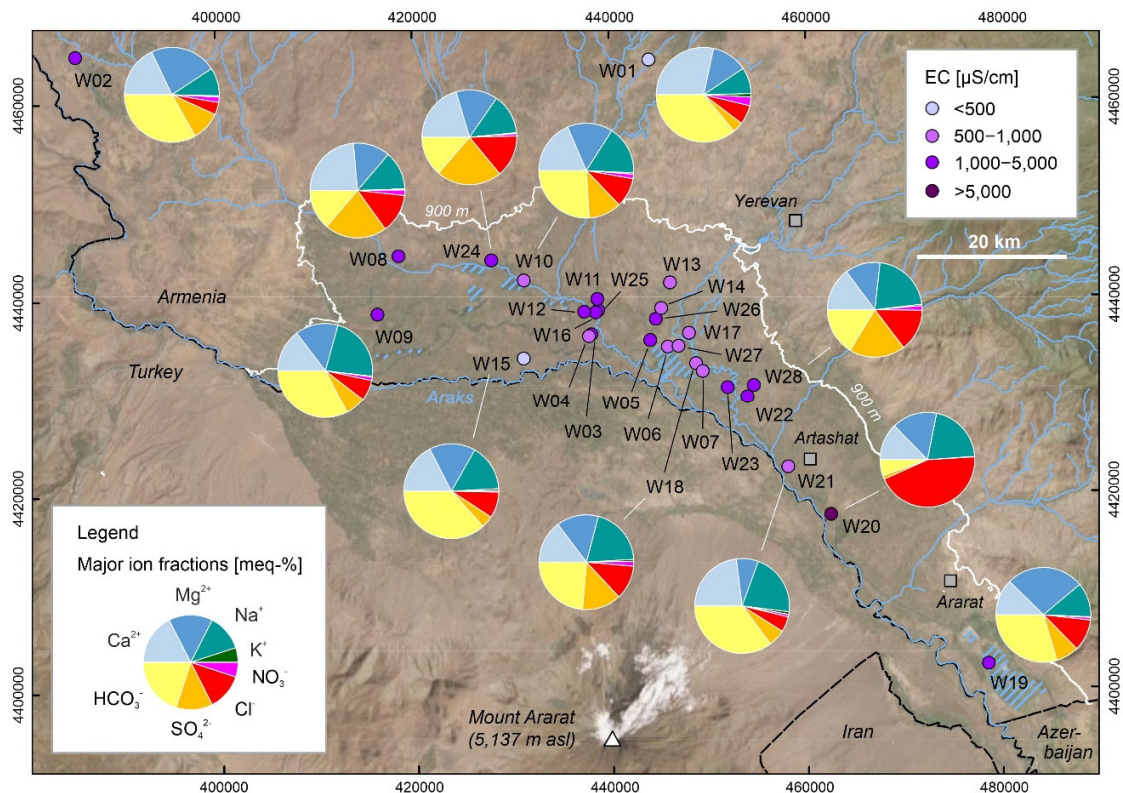
**Fig. S2** Groundwater contour map for Hydrogeologic Unit 4 (Valder et al. 2018, modified).



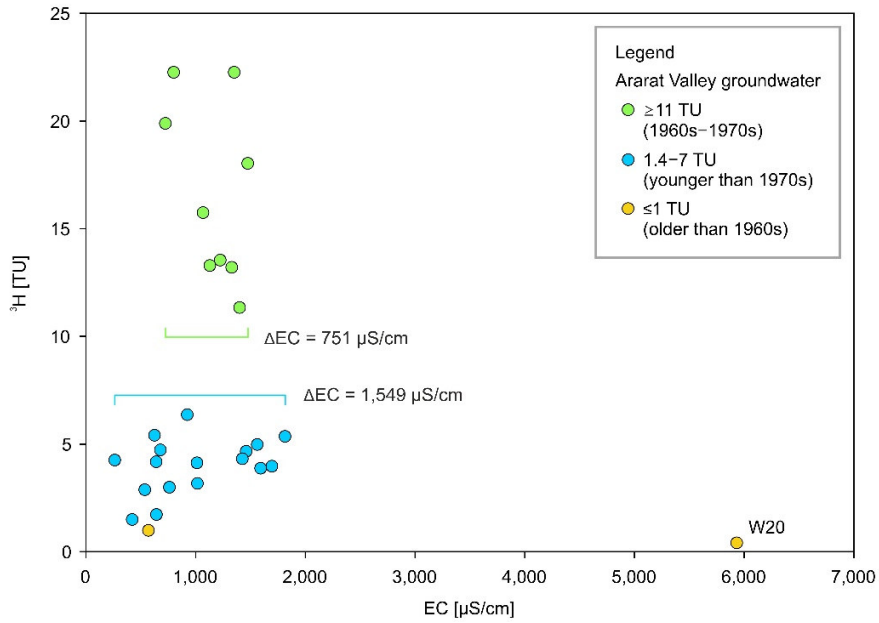
**Fig. S3** Groundwater contour map for Hydrogeologic Unit 6 (Valder et al. 2018, modified).



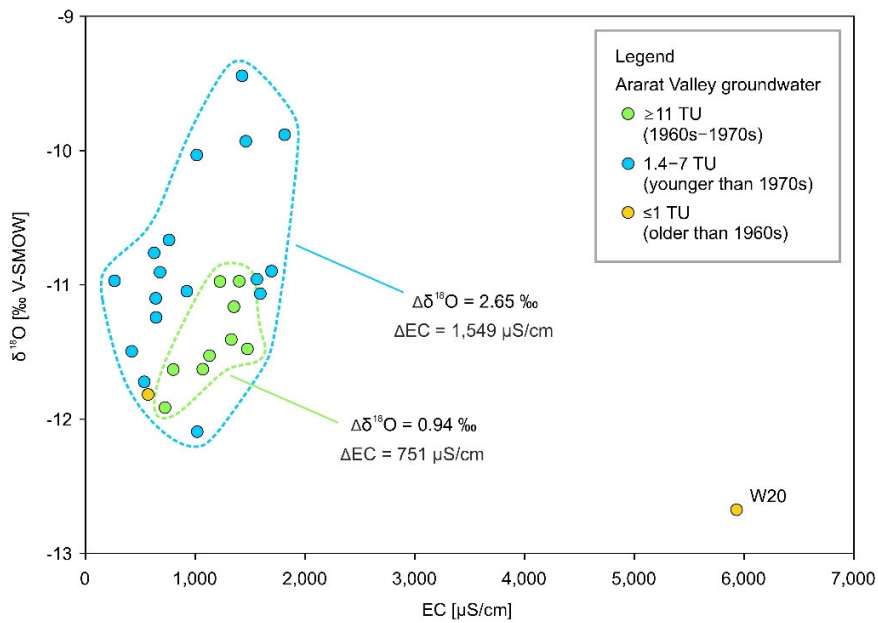
**Fig. S4** Scatter plot  $^3\text{H}$  vs.  $\delta^{18}\text{O}$ . Note the relatively large  $\delta^{18}\text{O}$  scatter in the age cluster “younger than 1970s” (blue symbols; 2.65 ‰), compared to the cluster “1960s–1970s” (green symbols; 0.94 ‰).



**Fig. S5** Map showing the spatial EC variability (purple symbols) and major ion compositions for selected wells (pie charts). Note the unique hydrochemical character of sample W20, with an EC of 5,930  $\mu\text{S}/\text{cm}$  and a pronounced  $\text{Cl}^-$  dominance among the anions (red pie slice).



**Fig. S6** Scatter plot  $^3H$  vs. EC. Note the relatively large EC scatter in the age cluster “younger than 1970s” (blue symbols; 1,549  $\mu S/cm$ ), compared to the cluster “1960s-1970s” (green symbols; 751  $\mu S/cm$ ).



**Fig. S7** Scatter plot  $\delta^{18}O$  vs. EC. Note the larger scatter in the age cluster “younger than 1970s” (blue symbols), compared to the cluster “1960s-1970s” (green symbols), with respect to both parameters.

**Table S1** General information on sampled wells and results of isotopic and hydrochemical analyses

ID	Latitude [deg min sec]	Longitude [deg min sec]	Elevation (GoogleEarth) [m asl]	Well depth [m]	Screen depth [m]	Hydrogeological Unit	Artesian (yes/no)
W01	40° 19' 28.5"	44° 20' 29.6"	1211	100	57-75, 85-93	2	no
W02	40° 19' 32.7"	43° 39' 18.8"	1264	125	95-115	6	no
W03	40° 04' 25.0"	44° 16' 23.4"	836	140	115-140	6	yes
W04	40° 04' 18.6"	44° 16' 13.1"	837	186	105-175	6	yes
W05	40° 04' 06.1"	44° 20' 37.7"	832	180	-	6	yes
W06	40° 03' 45.0"	44° 21' 53.1"	831	130	-	6	yes
W07	40° 02' 49.7"	44° 24' 23.9"	828	150	-	6	yes
W08	40° 08' 42.2"	44° 02' 32.2"	869	90	54-70	6	no
W09	40° 05' 29.5"	44° 01' 02.3"	872	120	85-110	6	no
W10	40° 07' 22.1"	44° 11' 32.4"	845	145	95-130	6	yes
W11	40° 06' 21.3"	44° 16' 49.1"	840	130	78-125	6	no
W12	40° 05' 39.0"	44° 15' 52.6"	839	160	95-125	6	yes
W13	40° 07' 15.8"	44° 22' 02.0"	841	97	48-58, 80-90	6	no
W14	40° 05' 51.7"	44° 21' 24.3"	831	93	65-87	6	yes
W15	40° 03' 04.8"	44° 11' 31.9"	843	80	60-75	4	no
W16	40° 05' 37.3"	44° 16' 42.1"	839	80	60-75	4	yes
W17	40° 04' 30.1"	44° 23' 24.4"	831	195	-	6	yes
W18	40° 02' 50.1"	44° 23' 54.7"	828	80	65-75	4	yes
W19	39° 46' 17.5"	44° 44' 56.9"	805	148	115-140	6	yes
W20	39° 54' 29.8"	44° 33' 37.6"	819	170	143-165	6	yes
W21	39° 57' 06.6"	44° 30' 32.8"	825	120	62-100	6	yes
W22	40° 00' 59.6"	44° 27' 36.8"	830	110	85-100	6	yes
W23	40° 01' 30.6"	44° 26' 11.2"	825	190	125-185	6	yes
W24	40° 08' 28.0"	44° 09' 12.2"	849	90	45-70, 75-80	6	no
W25	40° 05' 43.9"	44° 16' 53.4"	839	90	65-85	6	yes
W26	40° 05' 16.1"	44° 21' 01.5"	832	180	35-55	6	yes
W27	40° 03' 47.2"	44° 22' 38.8"	830	95	-	6	yes
W28	40° 01' 37.8"	44° 28' 03.4"	834	134	50-115	6	yes

Color code Fig. 1

**Table S1** General information on sampled wells and results of isotopic and hydrochemical analyses (continued)

ID	Sampling date	T [°C]	pH [-]	O <sub>2</sub> [mg/L]	EC [μS/cm]	<sup>35</sup> S [mBq/L]	<sup>3</sup> H [TU]	<sup>3</sup> H error [TU]	Estimated age	δ <sup>18</sup> O [‰ V-SMOW]	δ <sup>2</sup> H [‰ V-SMOW]
W01	Dec 2019	9.5	6.68	11.12	263	-	4.3	0.4	younger than 1970s	-10.97	-71.9
W02	Dec 2019	14.4	7.05	8.50	1015	-	3.2	0.4	younger than 1970s	-12.09	-82.1
W03	Dec 2019	13.8	6.61	7.17	1399	-	11.3	0.9	1960s-1970s	-10.97	-75.7
W04	Dec 2019	15.2	7.55	5.49	534	-	2.9	0.4	younger than 1970s	-11.72	-79.1
W05	Dec 2019	13.1	6.67	7.85	1473	-	18.0	1.3	1960s-1970s	-11.48	-77.6
W06	Dec 2019	13.4	6.69	8.98	798	-	22.3	1.6	1960s-1970s	-11.63	-78.1
W07	Dec 2019	13.1	6.98	9.01	623	-	5.4	0.5	younger than 1970s	-10.76	-70.4
W08	Dec 2019	15.3	7.42	8.24	1591	-	3.9	0.4	younger than 1970s	-11.07	-75.6
W09	Dec 2019	15.4	7.31	7.17	1011	-	4.1	0.4	younger than 1970s	-10.03	-67.6
W10	Dec 2019	14.2	7.36	7.18	922	-	6.4	0.6	younger than 1970s	-11.05	-74.3
W11	Dec 2019	12.8	7.07	5.47	1350	-	22.3	1.6	1960s-1970s	-11.16	-76.0
W12	Dec 2019	13.3	6.92	7.70	1127	-	13.3	1.0	1960s-1970s	-11.53	-77.7
W13	Dec 2019	13.9	6.56	8.44	638	-	4.2	0.4	younger than 1970s	-11.10	-72.0
W14	Dec 2019	14.4	6.90	8.52	722	-	19.9	1.5	1960s-1970s	-11.91	-79.1
W15	Dec 2019	14.2	7.89	6.14	419	-	1.5	0.3	younger than 1970s	-11.50	-78.3
W16	Dec 2019	13.3	7.00	7.21	1326	-	13.2	1.0	1960s-1970s	-11.41	-78.4
W17	Dec 2019	12.2	7.03	9.20	677	-	4.7	0.5	younger than 1970s	-10.90	-72.3
W18	Dec 2019	14.7	7.14	8.40	759	-	3.0	0.4	younger than 1970s	-10.67	-71.5
W19	Dec 2019	16.7	7.17	1.62	1693	-	4.0	0.4	younger than 1970s	-10.90	-74.6
W20	Dec 2019	21.3	6.67	1.97	5930	-	0.4	0.3	older than 1960s	-12.67	-87.2
W21	Dec 2019	15.8	7.58	5.63	568	-	1.0	0.3	older than 1960s	-11.81	-78.1
W22	Dec 2019	14.3	7.14	7.22	1812	-	5.4	0.5	younger than 1970s	-9.88	-67.6
W23	Dec 2019	14.8	7.33	7.66	1424	-	4.3	0.5	younger than 1970s	-9.44	-64.7
W24	Oct 2019	-	6.30	-	1559	b.d.l.	5.0	0.5	younger than 1970s	-10.96	-74.8
W25	Oct 2019	-	6.90	-	1223	b.d.l.	13.6	1.0	1960s-1970s	-10.97	-76.0
W26	Oct 2019	-	7.00	-	1066	b.d.l.	15.8	1.2	1960s-1970s	-11.63	-78.5
W27	Oct 2019	-	7.10	-	641	b.d.l.	1.7	0.3	younger than 1970s	-11.24	-73.5
W28	Oct 2019	-	6.80	-	1459	b.d.l.	4.7	0.5	younger than 1970s	-9.93	-66.1

Color code Fig. S5

Color code Fig. 2 – 5, S4, S6, S7



**Table S1** General information on sampled wells and results of isotopic and hydrochemical analyses (continued)

ID	Ca <sup>2+</sup> [mg/L]	Mg <sup>2+</sup> [mg/L]	Na <sup>+</sup> [mg/L]	K <sup>+</sup> [mg/L]	Sr <sup>2+</sup> [mg/L]	NH <sub>4</sub> <sup>+</sup> [mg/L]	Li <sup>+</sup> [mg/L]	Cl <sup>-</sup> [mg/L]	SO <sub>4</sub> <sup>2-</sup> [mg/L]	HCO <sub>3</sub> <sup>-</sup> [mg/L]	NO <sub>3</sub> <sup>-</sup> [mg/L]	NO <sub>2</sub> <sup>-</sup> [mg/L]	F <sup>-</sup> [mg/L]	Br <sup>-</sup> [mg/L]	CBE [%]
W01	30.2	8.0	10.9	2.4	0.20	0.04	0.04	12.3	9.4	117	9.9	0.005	0.30	0.47	1.61
W02	79.2	61.0	48.8	3.9	0.53	0.20	0.10	32.7	106.0	446	24.8	<0.065	0.69	0.42	1.65
W03	105.7	73.6	85.6	4.9	0.67	<0.20	0.14	157.2	286.4	285	22.3	<0.065	0.21	1.04	-0.77
W04	34.8	22.9	38.5	2.3	0.24	0.11	0.07	41.1	42.7	200	6.3	0.046	0.22	0.51	-0.63
W05	123.4	76.9	78.1	5.4	0.84	<0.20	0.14	156.1	312.6	307	20.6	0.055	0.33	1.11	-0.73
W06	70.3	31.2	46.4	4.5	0.47	<0.13	0.07	59.9	126.6	227	14.4	0.017	0.33	0.78	-0.33
W07	42.8	28.5	54.9	3.1	0.19	<0.13	0.06	51.8	63.9	200	12.6	0.006	0.58	1.34	5.13
W08	166.6	54.1	107.0	5.2	1.29	0.23	0.15	167.3	358.4	295	39.9	0.017	0.17	1.53	-0.23
W09	64.7	39.3	113.9	2.0	1.00	<0.20	0.10	55.5	74.0	438	16.5	0.007	0.68	0.38	4.28
W10	72.9	36.8	75.5	3.1	0.67	<0.20	0.08	70.4	105.1	311	18.3	0.004	0.19	0.39	2.47
W11	125.5	71.6	75.6	6.0	0.86	<0.20	0.14	136.0	312.1	293	22.9	0.037	0.29	0.96	0.39
W12	95.7	66.8	55.3	3.5	0.90	<0.20	0.15	101.8	240.7	262	19.2	0.089	0.28	0.88	1.19
W13	51.3	21.9	42.0	3.0	0.34	<0.13	0.08	59.6	71.7	176	12.7	0.025	0.44	0.52	0.11
W14	62.9	28.8	43.3	3.8	0.31	<0.13	0.08	52.7	102.1	224	13.6	0.005	0.49	0.59	-0.06
W15	28.5	15.5	29.7	2.0	0.14	<0.10	0.04	25.7	16.2	182	2.6	0.021	0.19	0.90	-0.42
W16	109.7	73.5	67.1	4.1	0.98	<0.20	0.13	129.5	299.8	272	22.4	<0.065	0.28	0.90	-0.48
W17	50.9	25.9	44.2	2.7	0.36	0.10	0.06	54.8	68.6	185	14.1	0.012	0.60	0.49	3.39
W18	45.0	26.6	70.0	4.0	0.32	0.11	0.08	63.0	97.5	221	15.8	0.007	0.66	0.55	-0.56
W19	98.8	127.7	107.0	3.9	1.31	<0.33	0.16	151.6	148.9	717	21.1	0.017	0.54	1.33	1.91
W20	314.7	230.7	587.8	6.1	8.60	0.99	<0.20	1933.6	77.1	407	3.5	0.043	0.10	6.05	-1.84
W21	53.9	10.6	57.6	4.0	0.33	0.11	0.05	21.5	32.8	251	6.3	0.035	0.27	0.95	5.77
W22	286.9	49.3	53.9	5.2	1.63	0.29	0.12	156.8	423.5	407	33.6	0.013	0.32	1.30	1.06
W23	93.3	48.2	140.2	6.2	0.87	0.16	0.09	138.0	282.9	298	28.3	0.012	0.75	0.89	-0.71
W24	135.5	57.4	104.5	4.1	0.62	0.14	0.05	168.3	355.5	277	18.6	<0.078	0.25	2.62	-2.50
W25	100.3	61.3	58.5	4.6	0.62	0.18	0.07	111.9	261.9	273	17.2	<0.065	0.35	2.30	-2.43
W26	90.6	52.2	49.0	3.0	0.63	0.45	0.06	85.1	216.1	272	15.3	0.142	0.22	2.30	-2.49
W27	39.0	27.1	42.0	1.7	<0.17	0.15	0.04	50.1	72.7	204	9.7	0.066	0.44	1.74	-3.03
W28	88.1	42.8	145.0	5.9	0.74	0.13	0.04	151.2	271.8	294	28.3	<0.065	0.68	2.24	-2.71

Abbreviations: b.d.l. below detection limit; CBE Charge Balance Error

## **ESM References**

Valder JF, Carter JM, Medler CJ, Thompson RF, Anderson MT (2018) Hydrogeologic framework and groundwater conditions of the Ararat Basin in Armenia, U.S. Geological Survey Scientific Investigations Report 2017–5163, 40 p., doi 10.3133/sir20175163