Supplementary material for:
Comprehensive space-time hydrometeorological simulations for estimating very rare floods at multiple sites in a large river basin

Daniel Viviroli, Anna E. Sikorska-Senoner, Guillaume Evin, Maria Staudinger, Martina Kauzlaric, Jérémy Chardon, Anne-Catherine Favre, Benoit Hingray, Gilles Nicolet, Damien Raynaud, Jan Seibert, Rolf Weingartner, Calvin Whealton

Correspondence to: Daniel Viviroli (daniel.viviroli@geo.uzh.ch)

Contents:

Supplementary Table 1. List of precipitation (P) and temperature (T) stations used in the daily (1930–2014) and hourly (1990–2014) data sets.

Site and station code	*Elevation [m a.s.l.]*	*P daily*	*P hourly*	*T daily*	*T hourly*
Aadorf / Tänikon (TAE)	539		■		■
Aarberg (ABE)	493	■			
Acquarossa / Comprovasco (COM)	575		■		■
Adelboden (ABO)	1 326	■	■		■
Affoltern im Emmental (AIE)	755	■			
Aigle (AIG)	381		■		■
Airolo (AIR)	1 139	■			
Altdorf (ALT)	438	■	■	■	■
Andermatt (ANT)	1 438	■		■	
Bad Ragaz (RAG)	496			■	
Balsthal (BAT)	525	■			
Basel / Binningen (BAS)	316		■	■	■
Baulmes (BAU)	642	■			
Bauma (BAM)	667	■			
Bellelay (BEY)	923	■			
Belp (BEP)	515	■			
Bern / Zollikofen (BER)	552	■	■	■	■
Beromünster (BMU)	642	■			
Beznau (BEZ)	325		■		■
Beznau (BZN)	327	■			
Biel (BIL)	433	■			
Boltigen (BOT)	855	■			
Braunwald (BRW)	1 299	■			
Brienz (BRZ)	567	■			
Buchs / Aarau (BUS)	386		■		■
Bülach (BUE)	402	■			
Bullet / La Frétaz (FRE)	1 205		■		■
Burgdorf (BUD)	525	■			
Chasseral (CHA)	1 599		■		■
Château-d'Oex (CHD)	1 029	■		■	
Chaumont (CHM)	1 136	■		■	
Chur (CHU)	556		■		■
Cimetta (CIM)	1 661		■		■
Col du Grand St-Bernard (GSB)	2 472		■		■
Cossonay (COS)	590	■			
Courtelary (COY)	695	■			
Couvet (COU)	728	■			
Davos (DAV)	1594		■		■
Dietikon (DIT)	385	■			
Disentis / Sedrun (DIS)	1 197		■		■
Ebnat-Kappel (EBK)	623	■			
Echallens (ECH)	603	■			
Eigenthal (EIT)	1 114	■			
Einsiedeln (EIN)	910	■		■	
Elm (ELM)	958	■		■	
Engelberg (ENG)	1 035	■	■	■	■
Entlebuch (ENT)	768	■			
Eptingen (EPT)	565	■			
Evolène / Villa (EVO)	1 825		■		■
Fahy (FAH)	596		■		■
Flühli, LU (FLU)	939	■			
Fribourg / Posieux (GRA)	646	■		■	
Frick (FRI)	345	■			
Frutigen (FRU)	756	■			
Genève-Cointrin (GVE)	412		■	■	■
Glarus (GLA)	516	■	■	■	■
Göschenen (GOS)	950	■			
Gösgen (GOE)	380		■		■
Grimsel Hospiz (GRH)	1 980	■	■	■	■
Grosshöchstetten (GHS)	755	■			
Grüningen (GIN)	520	■			
Gryon (GRY)	1 146	■			
Gsteig, Gstaad (GSG)	1 196	■			
Guglera (GUG)	877	■			
Gütsch ob Andermatt (GUE)	2 283		■		■

Site and station code	*Elevation [m a.s.l.]*	*P daily*	*P hourly*	*T daily*	*T hourly*
Guttannen (GTT)	1 055	■			
Güttingen (GUT)	440		■		■
Herbetswil (HTW)	544	■			
Herzogenbuchsee (HEB)	467	■			
Interlaken (INT)	577	■	■	■	■
Isenthal (IST)	778	■			
Jaun (JAU)	1 030	■			
Jungfraujoch (JUN)	3 580			■	■
Kaiserstuhl (KAI)	361	■			
Kandersteg (KAS)	1 178	■			
Kiental (KIE)	930	■			
Küsnacht, ZH (KUE)	412	■			
La Brévine (BRL)	1 050	■			
La Chaux-de-Fonds (CDF)	1 018	■	■	■	■
La Cure (CUE)	1 185	■			
La Dôle (DOL)	1 669		■		■
La Valsainte (VST)	1 042	■			
Lachen / Galgenen (LAC)	468	■			
Lägern (LAE)	845				■
Langenbruck (LAB)	731	■			
Langnau im Emmental (LAG)	745	■		■	
L'Auberson (AUB)	1 096	■			
Laufenburg (LFB)	330	■			
Lausanne (LSN)	601	■			
Lauterbrunnen (LTB)	815	■			
Le Moléson (MLS)	1 974		■		■
Leibstadt (LEI)	341		■		■
Les Brenets (BNE)	907	■			
Les Ponts-de-Martel (PDM)	1 052	■			
Leukerbad (LEU)	1 286	■			
Locarno / Monti (OTL)	366		■		■
Longirod (LON)	900	■			
Lugano (LUG)	273		■		■
Lungern (LUN)	740	■			
Luthern (LUT)	767	■			
Luzern (LUZ)	454	■	■	■	■
Magadino / Cadenazzo (MAG)	203		■		■
Marsens (MAS)	714	■			
Meiringen (MER)	588	■		■	
Mervelier (MEV)	540	■			
Montana (MVE)	1 427	■	■	■	■
Mosen (MOA)	453	■			
Moudon-Origine (MDO)	561	■			
Mühleberg (MUB)	479		■		■
Muri, AG (MUR)	577	■			
Napf (NAP)	1 403		■		■
Neuchâtel (NEU)	485	■	■	■	■
Nyon / Changins (CGI)	455		■		■
Oberiberg (OBI)	1 075	■			
Payerne (PAY)	490		■		■
Payerne-Ville (PAV)	448	■			
Pilatus (PIL)	2 106		■		■
Piotta (PIO)	990		■		■
Piz Corvatsch (COV)	3 302		■		■
Plaffeien (PLF)	1 042		■		■
Poschiavo / Robbia (ROB)	1 078		■		■
Pully (PUY)	455		■		■
Romont (ROM)	692	■			
Rünenberg (RUE)	611		■		■
Samedan (SAM)	1 708		■		■
San Bernardino (SBE)	1 638		■		■
Säntis (SAE)	2 502		■	■	■
Sargans (SAR)	590	■			
Sarnen (SRN)	475	■			
Sattel-Aegeri (SAG)	790	■			
Schaffhausen (SHA)	438		■	■	■
Schwarzenegg (SCE)	920	■			
Scuol (SCU)	1 303		■		■

Site and station code	*Elevation [m a.s.l.]*	*P daily*	*P hourly*	*T daily*	*T hourly*
Sedrun (SED)	1 400	■			
Sevelen (SEV)	457	■			
Sion (SIO)	482		■	■	■
St. Gallen (STG)	775		■		■
St. Urban (STU)	491	■			
Stabio (SBO)	353		■		■
Starkenbach (STB)	897	■			
Thun (THU)	570	■			
Ulrichen (ULR)	1 345		■		■
Unterkulm (UNK)	454	■			
Uster (UST)	440	■			
Vaduz (VAD)	457		■		■
Valeyres-sous-Rances (VAR)	512	■			
Visp (VIS)	639		■		■
Wädenswil (WAE)	485		■		■
Wasen im Emmental (WIE)	770	■			
Weesen (WEE)	425	■			
Weissfluhjoch (WFJ)	2 691		■		■
Weisstannen (WET)	1 010	■			
Wimmis (WIS)	669	■			
Wittnau (WIT)	463	■			
Wynau (WYN)	422		■		■
Yverdon-les-Bains (YVN)	433	■			
Zermatt (ZER)	1 638		■		■
Zürich / Affoltern (REH)	443		■		■
Zürich / Fluntern (SMA)	555	■	■	■	■
Zürich / Kloten (KLO)	426		■		■
Zweisimmen (ZWE)	1 015	■			

Supplementary Table 2. List of streamflow records used.

River and site name [a]	*ID*	*Catchment area [km²]*	*Site elevation [m a.s.l.]*	*Mean elevation [m a.s.l.]*	*Glaciation [%]*	*Years daily* [b]	*Years hourly*	*First year observed*	*Operator* [c]
Aabach at Lenzburg	AabLen	175	394	565	0.0	37	37	1979	AG
Aabach at Schmerikon	AabSch	38.2	415	803	0.0	26	26	1990	SG
Aare at Bern, Schönau	AarBer	2 969	502	1 610	9.1	99	42	1917	FOEN
Aare at Brienzwiler	AarBri	554	570	2 150	21.0	42	42	1905	FOEN
Aare at Brugg *	AarBru	11 750	332	1 010	2	106 +	42	1909	FOEN
Aare at Brügg, Ägerten *	AarAeg	8 317	428	1 150	2.9	112 +	42	1904	FOEN
Aare at Hagneck *	AarHag	5 128	437	1 380	4.5	40	40	1976	FOEN
Aare at Murgenthal *	AarMur	10 143	399	1 070	2.4	100 +	42	1916	FOEN
Aare at Thun *	AarThu	2 490	548	1 760	9.5	110	42	1906	FOEN
Aare at Untersiggenthal, Stilli *	AarUnt	17 625	326	1 050	2.1	81 +	42	1935	FOEN
Arbogne at Avenches	ArbAve	69.7	435	597	0.0	32	32	1984	VD
Areuse at Boudry	AreBou	377	444	1 060	0.0	34	34	1982	FOEN
Arnon at Grandson	ArnGra	83	434	942	0.0	23	23	1993	VD
Bibere at Kerzers	BibKer	50.1	443	540	0.0	53	34	1955	FOEN
Broye at Payerne	BroPay	392	441	710	0.0	96	42	1920	FOEN
Bünz at Othmarsingen	BueOth	111	390	533	0.0	59	42	1957	AG
Chandon at Avenches	ChaAve	38.6	432	571	0.0	32	32	1984	VD
Chise at Freimettigen	ChiFre	44.9	645	835	0.0	31	31	1985	BE
Dünnern at Olten	DueOlt	196	400	750	0.0	39	39	1977	FOEN
Emme at Burgdorf	EmmBur	673	550	990	0.0	37	37	1979	FOEN
Emme at Wiler *	EmmWil	939	458	860	0.0	95	42	1921	FOEN
Engelberger Aa at Buochs	EBABuo	227	443	1 620	4.3	100	42	1916	FOEN
Furtbach at Würenlos	FurWue	39.1	410	482	0.0	39	39	1977	ZH
Galtera at Tafers	GalTaf	38.7	631	788	0.0	16	16	2000	FR
Giessbach at Brienz	GieBri	23.9	899	1 951	0.0	19	19	1997	BE
Grosstalbach at Isenthal	GroIse	43.9	767	1 820	9.3	60	42	1956	FOEN
Gürbe at Belp	GueBel	117	511	837	0.0	94	42	1922	FOEN
Jona at Rüti	JonRue	57.8	450	669	0.0	22	22	1994	ZH
Kander at Hondrich	KanHon	520	650	1 900	7.9	36	36	1980	FOEN
Kleine Emme at Emmen	KEmEmm	478	431	1 050	0.0	80	42	1936	FOEN
Limmat at Baden *	LimBad	2 396	351	1 130	1.1	65	42	1951	FOEN
Limmat at Zürich, Unterhard *	LimZue	2176	400	1190	1.2	110	42	1906	FOEN
Linth at Weesen	LinWee	1061	419	1 580	2.5	109	42	1907	FOEN
Lorze at Frauenthal *	LorFra	259	390	690	0.0	102	42	1913	FOEN
Lorze at Zug	LorZug	100	417	818	0.0	34	34	1982	FOEN
Lütschine at Gsteig	LueGst	379	585	2 050	17.4	108	42	1908	FOEN
Mentue at Yvonand	MenYvo	105	449	679	0.0	45	42	1971	FOEN
Muota at Ingenbohl	MuoIng	316	438	1360	0.1	100	42	1916	FOEN
Murg at Murgenthal	MurMur	207	419	637	0.0	36	36	1980	FOEN
Nozon at Pré Chaillet	NozPrC	45.2	440	882	0.0	23	23	1993	VD
Önz at Heimenhusen	OenHei	84.1	440	583	0.0	29	29	1987	BE
Orbe at Orbe	OrbOrb	333	439	1 130	0.0	110	42	1906	FOEN
Ösch at Kriegstetten	OesKri	60.3	450	532	0.0	20	20	1996	SO
Petite Glâne at Villars-le-Grand	PGlVlG	84.6	433	560	0.0	32	32	1984	VD
Reppisch at Dietikon	RepDie	69.1	380	594	0.0	31	31	1985	ZH
Reuss at Luzern *	ReuLuz	2 251	432	1 500	4.2	93	42	1922	FOEN
Reuss at Mellingen *	ReuMel	3382	345	1 240	2.8	81	42	1934	FOEN
Reuss at Seedorf	ReuSee	832	438	2 010	9.5	112	42	1904	FOEN
Saane at Laupen *	SaaLau	1861	480	1 140	0.2	71	42	1944	FOEN
Sarine at Broc	SarBro	637	682	1 520	0.6	94	42	1922	FOEN
Sarine at Fribourg *	SarFri	1 269	532	1 240	0.3	105	42	1911	FOEN
Sarner Aa at Sarnen	SaASar	267	469	1 280	0.0	109	42	1907	FOEN
Sense at Thörishaus	SenLau	351	553	1 071	0.0	89	42	1911	FOEN
Seyon at Valangin	SeyVal	112	630	970	0.0	37	37	1979	FOEN
Sihl at Zürich	SihZue	336	412	1 060	0.0	91	42	1925	FOEN
Simme at Latterbach	SimLat	564	665	1 598	2.2	32	32	1984	FOEN
Sionge at Vuippens	SioVui	45.3	681	862	0.0	41	41	1975	FOEN
Steinenbach at Kaltbrunn	SteKal	19.1	451	1 112	0.0	36	30	1968	FOEN
Suhre at Unterentfelden	SuhUnt	197	407	581	0.0	37	37	1979	AG
Surb at Döttingen	SurDoe	67.2	335	511	0.0	36	36	1980	AG

River and site name [a]	*ID*	*Catchment area [km²]*	*Site elevation [m a.s.l.]*	*Mean elevation [m a.s.l.]*	*Glaciation [%]*	*Years daily* [b]	*Years hourly*	*First year observed*	*Operator* [c]
Suze at Péry	SuzPer	176	588	1 029	0.0	39	39	1977	BE
Talent at Chavornay	TalCha	66.3	440	670	0.0	23	23	1993	VD
Wigger at Zofingen	WigZof	368	426	660	0.0	37	37	1979	FOEN
Worble at Ittigen	WorItt	60.5	522	679	0.0	28	28	1988	FOEN
Wyna at Suhr	WynSuh	120	392	617	0.0	36	36	1980	AG

[a] Sites used for validation of RS Minerve only are denoted with an asterisk (*), all other sites have been used for calibration of HBV.

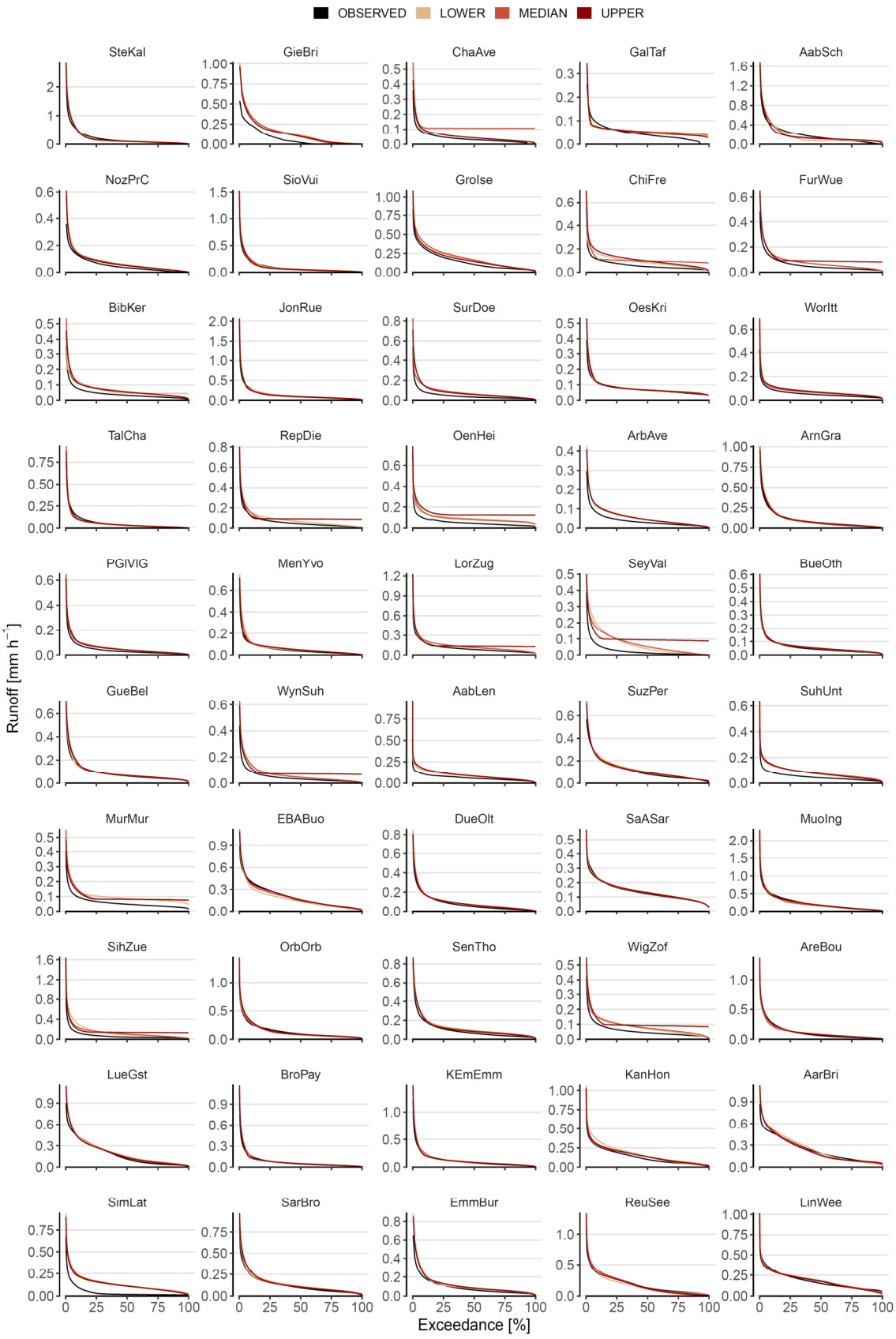
[b] Records for the Aare River downstream of Lake Biel are inhomogeneous due to impacts of the second Jura Water Correction (Bundesamt für Umwelt, 2020), with an assumed break point at 1974 after completion of the correction. The corresponding sites are marked with a cross (+).

[c] AG: Canton of Aargau; BE: Canton of Bern; FOEN: Federal Office for the Environment; FR: Canton of Fribourg; SG: Canton of St. Gallen; VD: Canton of Vaud; ZH: Canton of Zurich

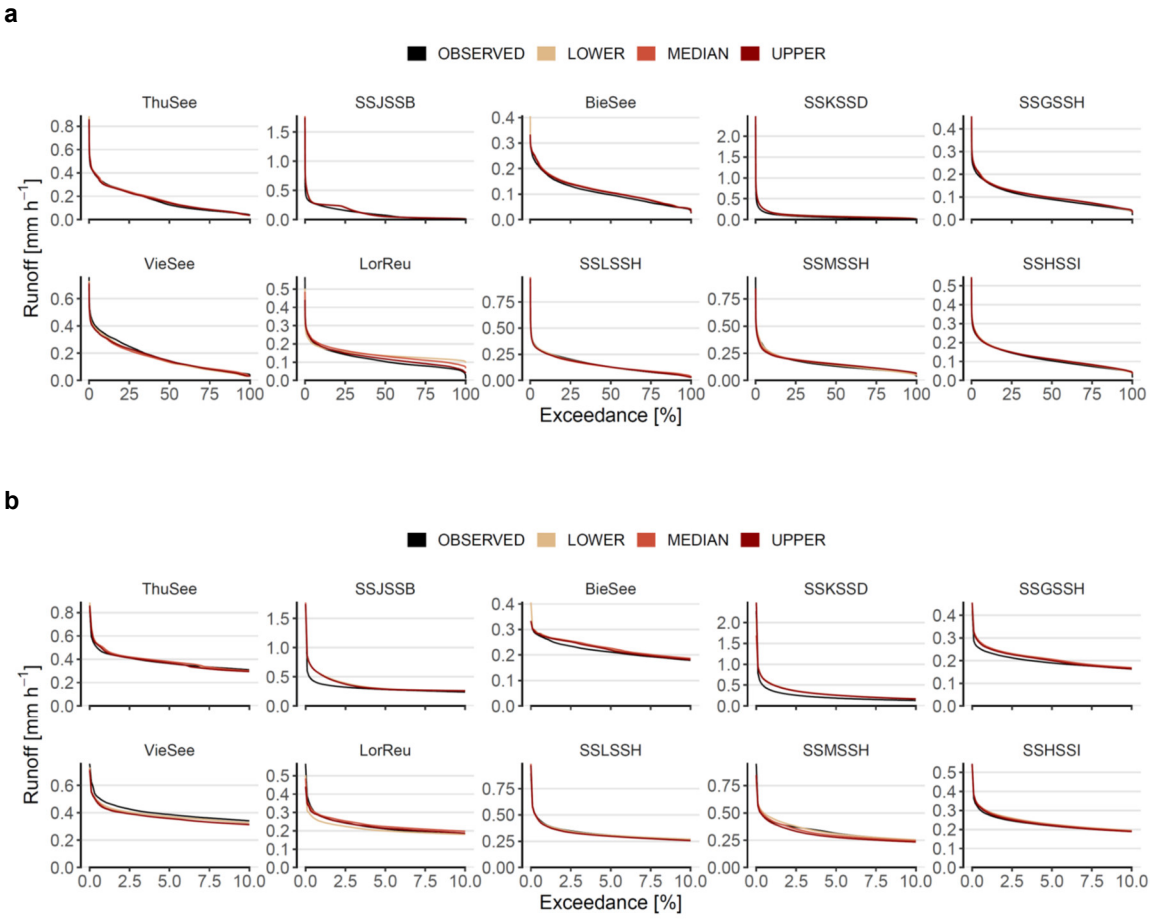
Supplementary Table 3. List of further sites simulated not already mentioned in Supplementary Table 2. Some sites simulated with RS Minerve are reasonably close to sites with streamflow measurements, and corresponding gauge sites are indicated in the last column.

Site name [a]	*ID*	*Catchment area [km²]*	*Nearest streamflow gauging station* [b]
Aare River at Aarau *	SSFSSG	10 899	-
Aare River at Aarburg *	SSESSF	10 560	AarMur
Aare River at Brugg *	SSGSSH	11 707	AarBru
Aare River at Golaten *	SSBSSC	5 070	AarHag
Aare River at Halen *	SSASSB	3 096	AarBer
Aare River at Solothurn *	SSCSSD	8 555	-
Aare River at Untersiggenhal *	SSHSSI	17 553	AarUnt
Aare River at Walliswil *	SSDSSE	9 728	-
Aare River outlet *	SSIOut	17 709	-
Aare River valley floor 1 (Lake Thun to Lake Biel)	YAAYY1	374	-
Aare River valley floor 2 (Lake Biel to Emme River)	YAAYY2	341	-
Aare River valley floor 3 (Emme River to Rhine River)	YAAYY3	674	-
Chise River, leftover area	ChiXXX	27.2	-
Emme River outlet *	SSKSSD	974	EmmWil
Emme River valley floor	YEMYYY	340	-
Glâne River	GlaXXX	193	-
Jogne River	JogBro	179	-
Lake Biel outlet *	BieSee	8 248	AarAeg
Lake Biel, smaller tributaries	XBIXXX	227	-
Lake Brienz, smaller tributaries from northwest	XBRXNW	59.0	-
Lake Brienz, smaller tributaries from southeast	XBRXSE	87.5	-
Lake Gruyère outlet *	LacGru	952	SaaFre
Lake Gruyère, smaller tributaries	XGRXXX	84.6	-
Lake Lucerne outlet *	VieSee	2 254	ReuLuz
Lake Lucerne, smaller tributaries from northeast	XVWXNE	147	-
Lake Lucerne, smaller tributaries from southwest	XVWXSW	291	-
Lake Murtensee, smaller tributaries	XMUXXX	46.6	-
Lake Neuchâtel, smaller tributaries from northwest	XNEXNW	250	-
Lake Neuchâtel, smaller tributaries from southeast	XNEXSE	314	-
Lake Thun outlet *	ThuSee	2 452	AarThu
Lake Thun, smaller tributaries from northeast	XTHXNE	125	-
Lake Thun, smaller tributaries from southwest	XTHXSW	101	-
Lake Zug, smaller tributaries	XZGXXX	92.9	-
Lake Zurich outlet *	ZueSee	1 825	LimZue - SihZue [c]
Lake Zurich, smaller tributaries from northeast	XZHXNE	46	-
Lake Zurich, smaller tributaries from northwest	XZHXNW	99.7	-
Lake Zurich, smaller tributaries from southeast	XZHXSE	207	-
Lake Zurich, smaller tributaries from southwest	XZHXSW	123	-
Limmat River outlet *	SSMSSH	2 404	LimBad
Limmat River valley floor	YLIYYY	130	-
Lorze River outlet *	LorReu	289	LorFra
Reuss River outlet *	SSLSSH	3 420	ReuMel
Reuss River valley floor	YREYYY	463	-
Rotache River	RtaXXX	37.6	-
Saane River outlet *	SSJSSB	1 826	SaaLau
Saane River valley floor	YSAYYY	274	-
Wägitaler Aa River	WagXXX	89.9	-
Zulg River	ZulXXX	88.6	-

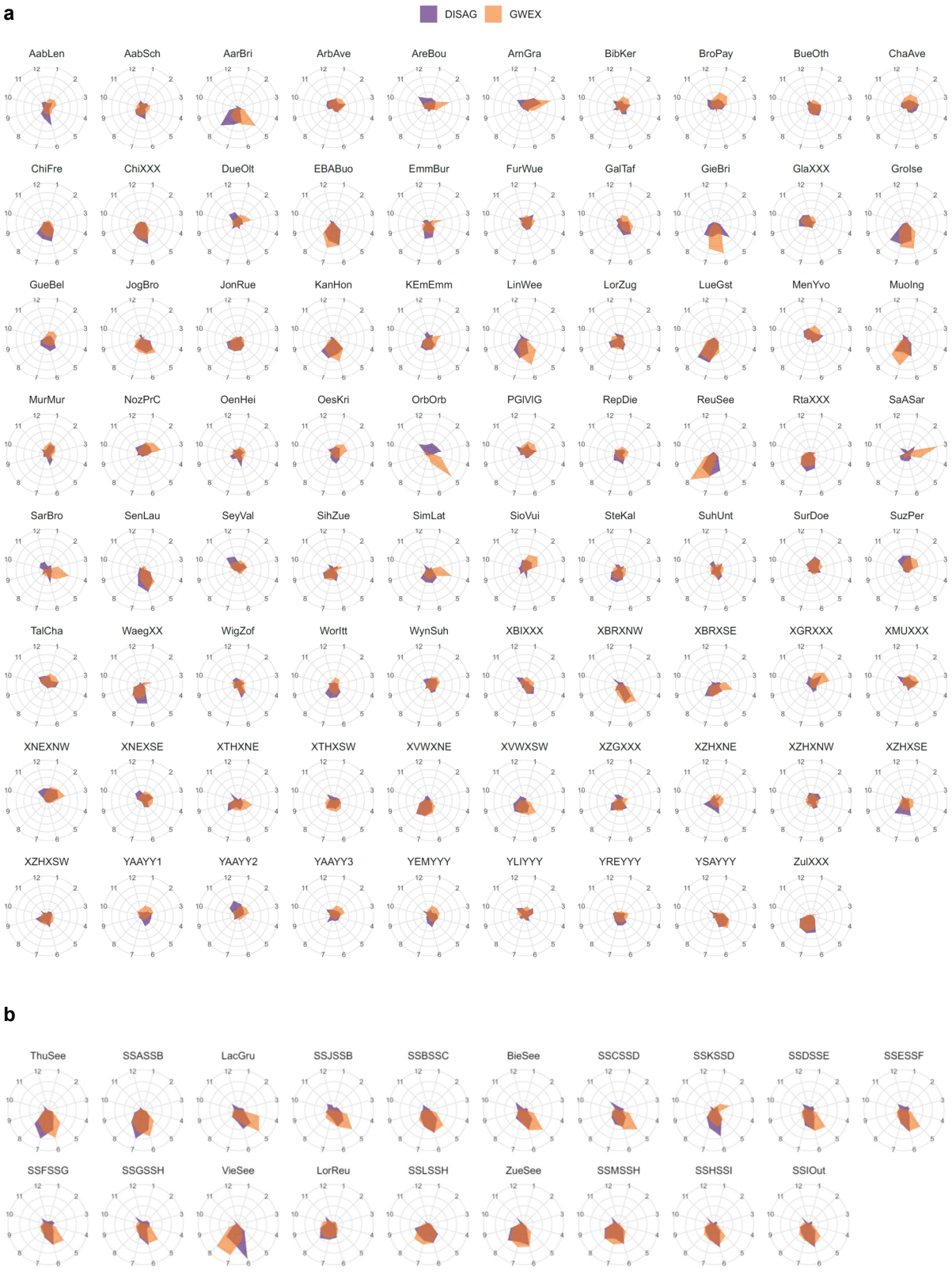
[a] Sites simulated with RS Minerve are denoted with an asterisk (*), all other sites have been simulated with HBV.
[b] See Supplementary Table 2.
[c] An approximation for the outlet for Lake Zurich is made by subtracting the values for Sihl at Zurich from these for Limmat at Zurich.



Supplementary Figure 1. Flow duration curves for 50 gauged sub-catchments simulated with HBV (lower, median and upper representative parameter sets; time period 1930–2014; ordered by increasing catchment area) in comparison to observations (varying time periods, see Supplementary Table 2).



Supplementary Figure 2. Panel a: Flow duration curves for 10 gauged output nodes of RS Minerve (lower, median and upper representative parameter sets; time period 1930–2014; ordered by location along the Aare River) in comparison to observations (varying time periods, see Supplementary Table 2). Panel b: Similar plots for highest 10% of flows.



Supplementary Figure 3. Seasonality of the largest annual 72-hour discharge events in simulations with disaggregated meteorology 1930–2014 (DISAG) and with GWEX scenarios. Panel a: 79 HBV sub-catchments; panel b: 19 RS Minerve output nodes.

Supplementary References

Bundesamt für Umwelt: Stationsbericht Hochwasserstatistik Aare – Untersiggenthal, Stilli, 2020.

Staudinger, M. and Viviroli, D. (Eds.): Extremhochwasser an der Aare: Detailbericht A Projekt EXAR. Hydrometeorologische Grundlagen, Zürich, 2020.