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Supplement of

Integrated assessment of global water scarcity over the 21st century under multiple climate change mitigation policies

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Figure S1 shows a schematic of the Global Water Availability Model (GWAM) structure

Figure S2 shows a detailed flowchart schematic of the GWAM model calculation algorithm.

Figure S3: Comparison of this study's global runoff volume to other data-based and model-based estimates; the bar denotes the highest and lowest simulated runoff

Figure S4: Comparison of this study's continental runoff volumes to other data-based and model-based estimates; the bar denotes the highest and lowest simulated runoff

Figure S5 shows the radiative forcing trajectories based on each of the four SRES emission scenarios (A1fi, A2, B2, and B1); blue and red dashed lines are GCAM equivalent simulations of the UCT and FFICT tax regimes to replicate SRES's emission pathways.

Figure S6 shows the the resulting carbon price, CO2 emission and concentration, and mean global temperature change associated with both the UCT and FFICT tax regimes and all four emission scenarios (A1fi, A2, B2, and B1); the A1fi scenario (black solid line) reflects the no-climate policy scenario (baseline)

Figure S7: Piechart distributions of global water demands (withdrawals) by sector for the baseline scenario (A1fi) in years 2005 & 2095, and for each of the climate change mitigation policies (2 tax regimes (UCT & FFICT) x 3 emission scenarios (A2, B2, and B1)

Figure S8 shows the total non-agricultural water demand (e.g., municipal, electricity generation, primary energy, manufacturing water demands) in years 2005, 2050, and 2095 under the baseline scenario. The increases in India and Eastern China are most pronounced

Figure S9 shows the total irrigation water demand in years 2005, 2050, and 2095under the baseline scenario. Regions such as Northern India, Northeastern China, and Southeastern Asia face dramatic increases in irrigation water demand in this scenario.

Figure S10 shows the total livestock water demand in years 2005, 2050, and 2095 under the baseline scenario. With higher population growth and greater demand for food (dairy and meat), places such India, China, Central Africa, and Brazil experience the largest increase in livestock water demand by the end of the 21st century under the baseline scenario. Note, livestock water demand is relatively minor in comparison with the total non-agricultural (Figure S5) and irrigation (Figure S6) water demands.

Figure S11 shows the total agricultural water demand (e.g., irrigation and livestock) in years 2005, 2050, and 2095 under the baseline scenario.

Figure S12 shows the total water demand (including both agricultural and non-agricultural sectors) in years 2005, 2050, and 2095 under the baseline scenario. The greatest increase in water demand is concentrated around Northern India and Eastern China.

Figure S13 shows the ensemble mean annual runoff in year 2005, 2050, and 2095; annual values are averaged over 2001-2010, 2046-2055, and 2091-2100, respectively; ensemble is based on four GCMs and the A1fi emission scenario. The latter two periods are ensemble mean annual runoff values based on using four GCMs to simulate GWAM in the future.

Figure S14 shows the the water scarcity index (WSI) in years 2005, 2050, and 2095 under the baseline scenario; a value close to one indicates extreme water stress condition while a value close to zero indicates abundant water resources as compared to demands.

Figure S15shows the change in (a) total water demands, (b) total water availability, and (c) water scarcity index between 2095 and 2005 under the baseline scenario.

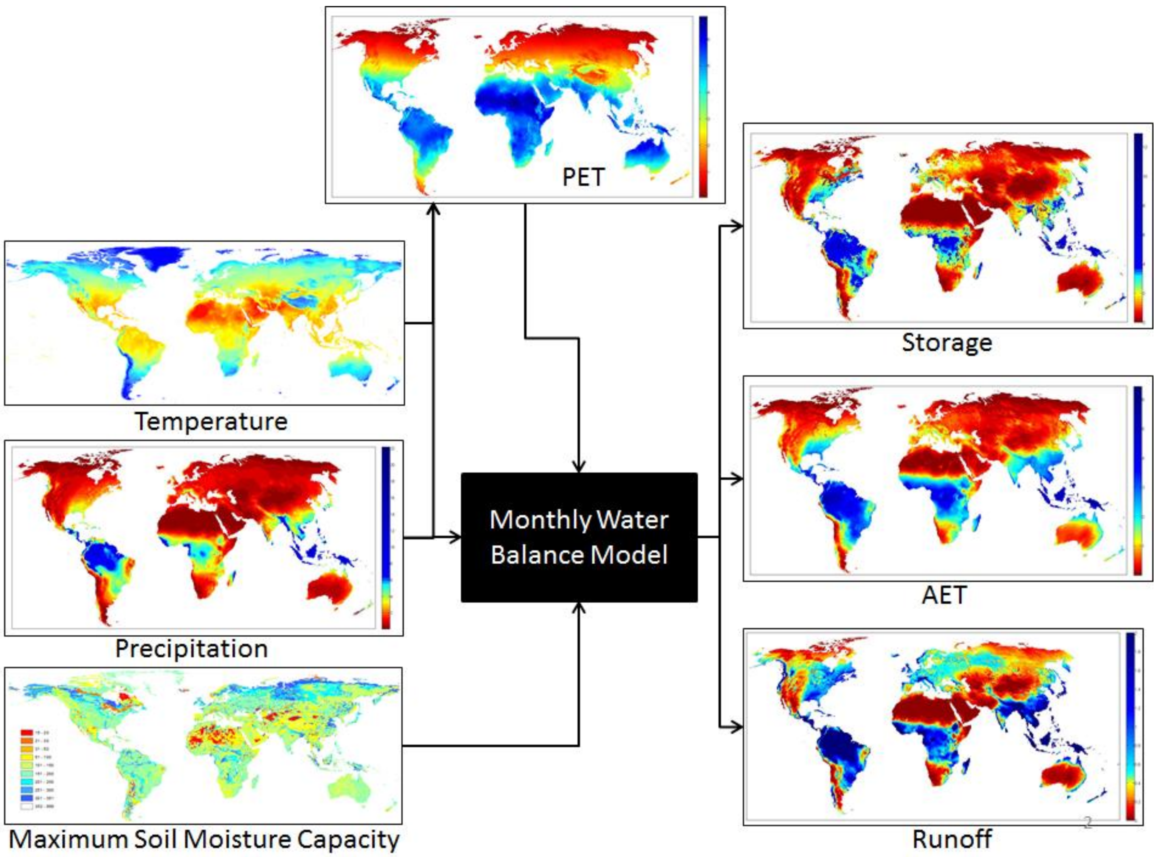


Figure S1: Schematic of the global water availability model (GWAM) structure

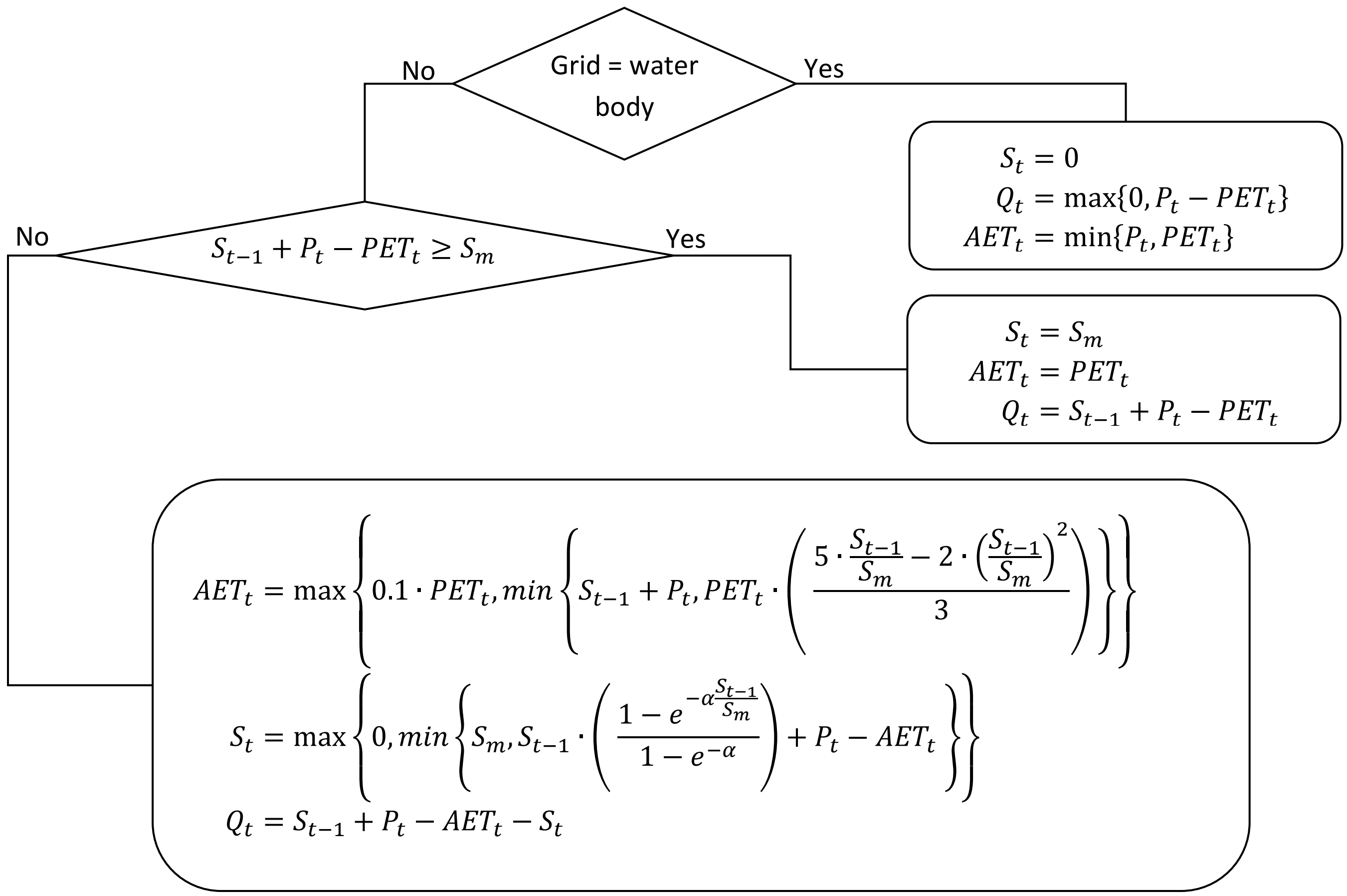
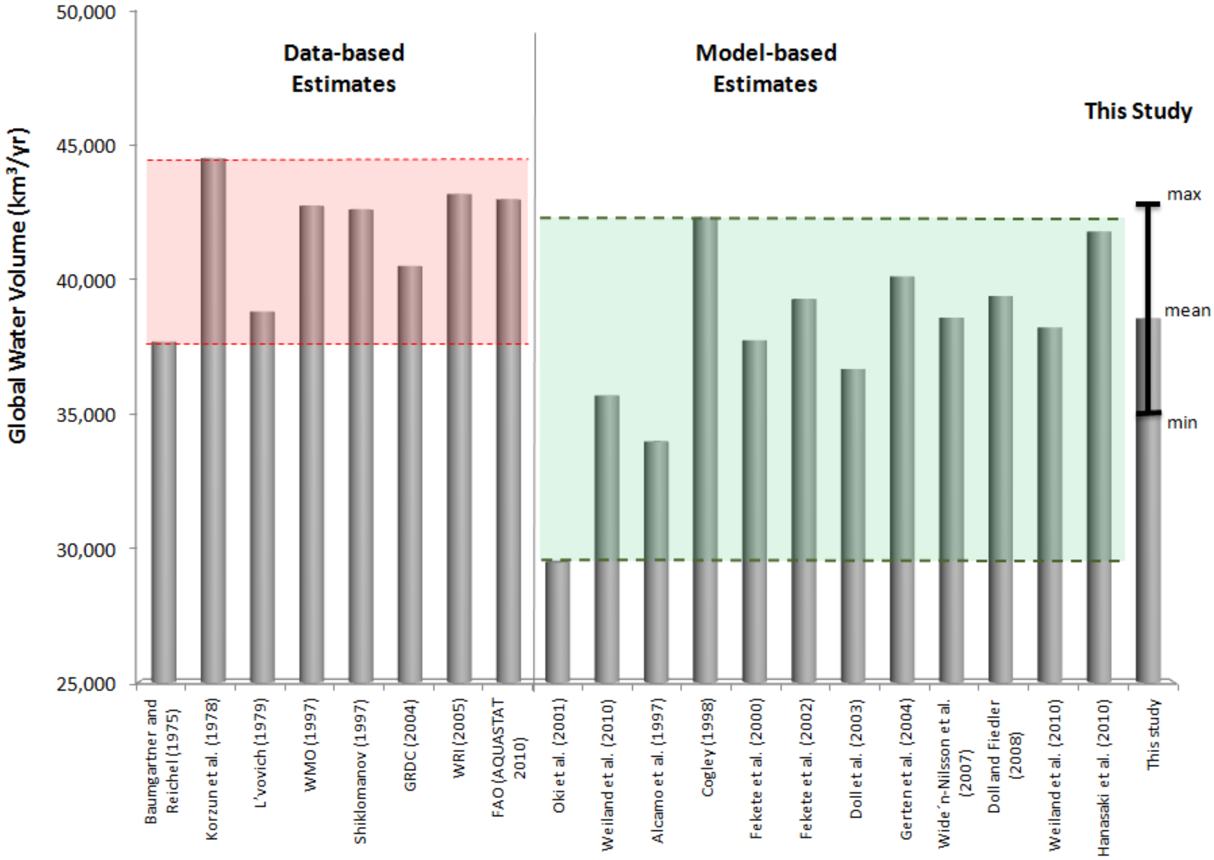


Figure S2: Flowchart diagram of the monthly water-balance modeling algorithm



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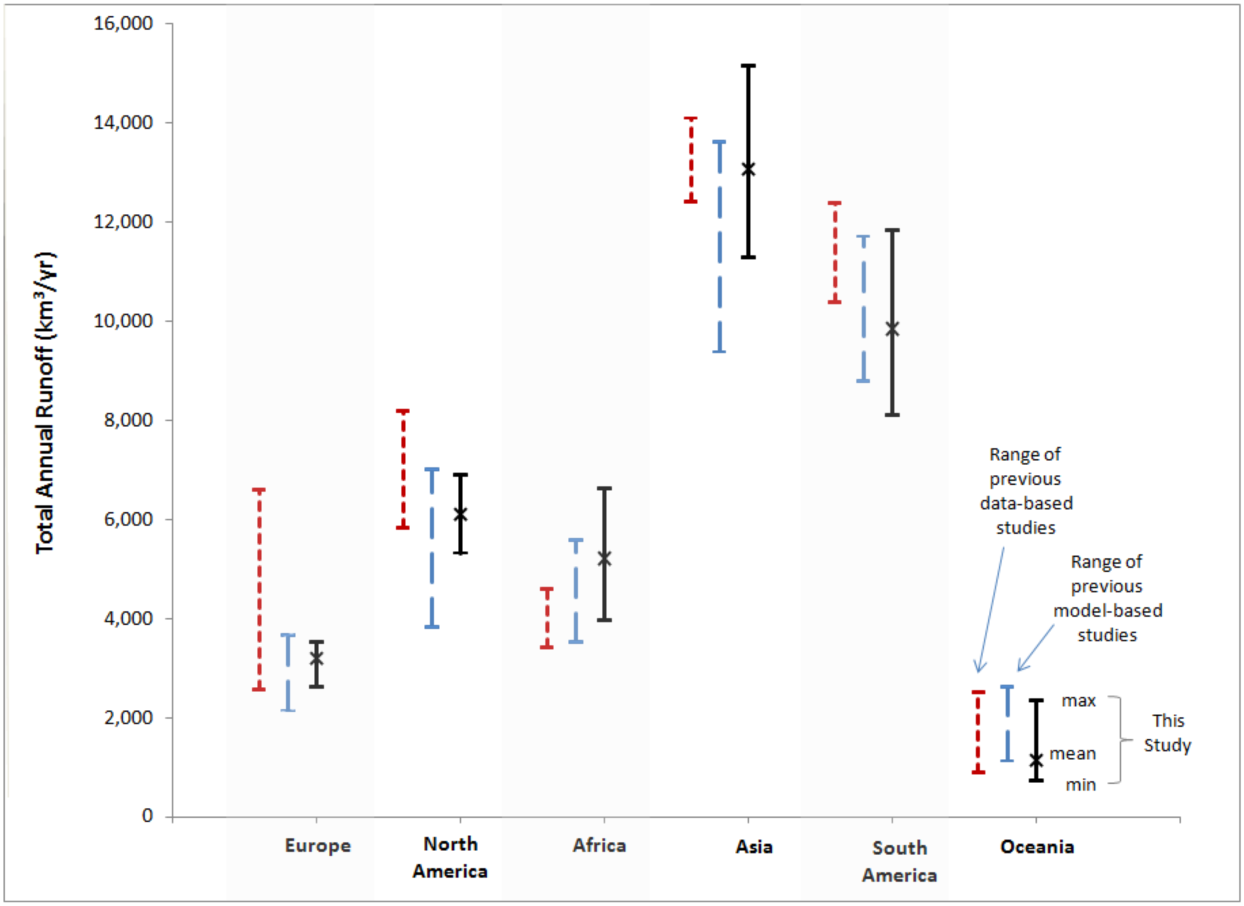

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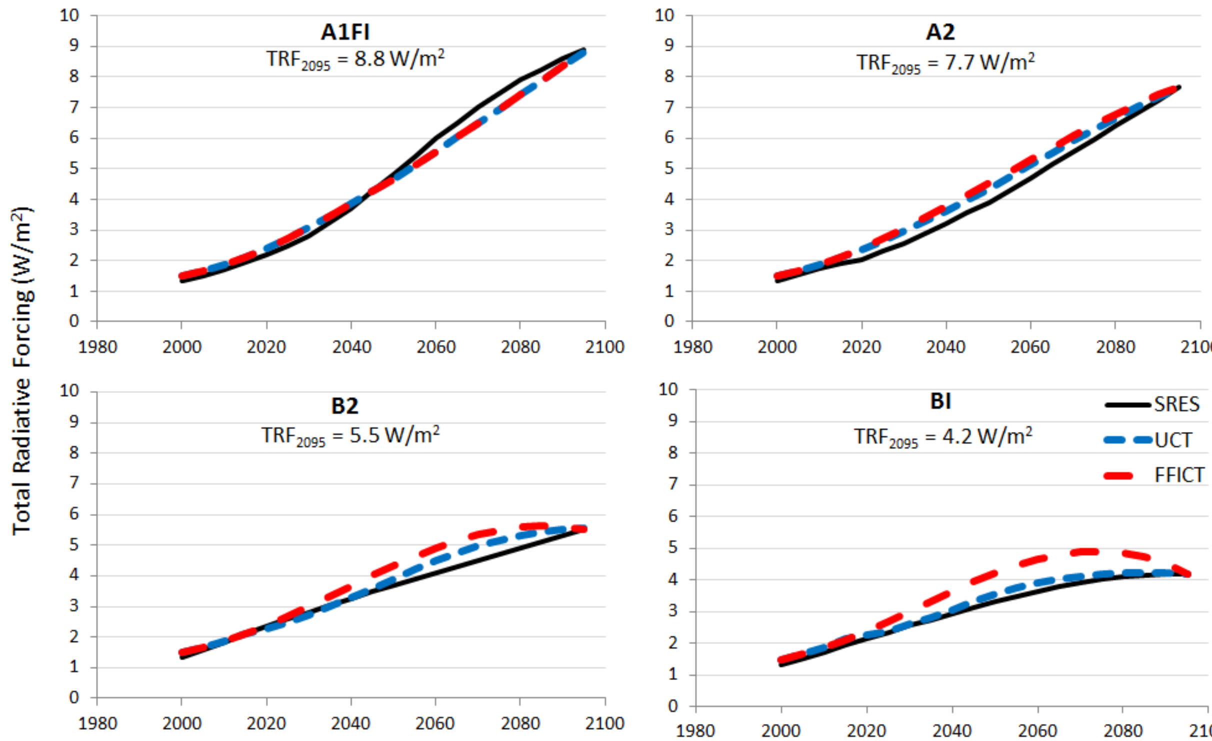
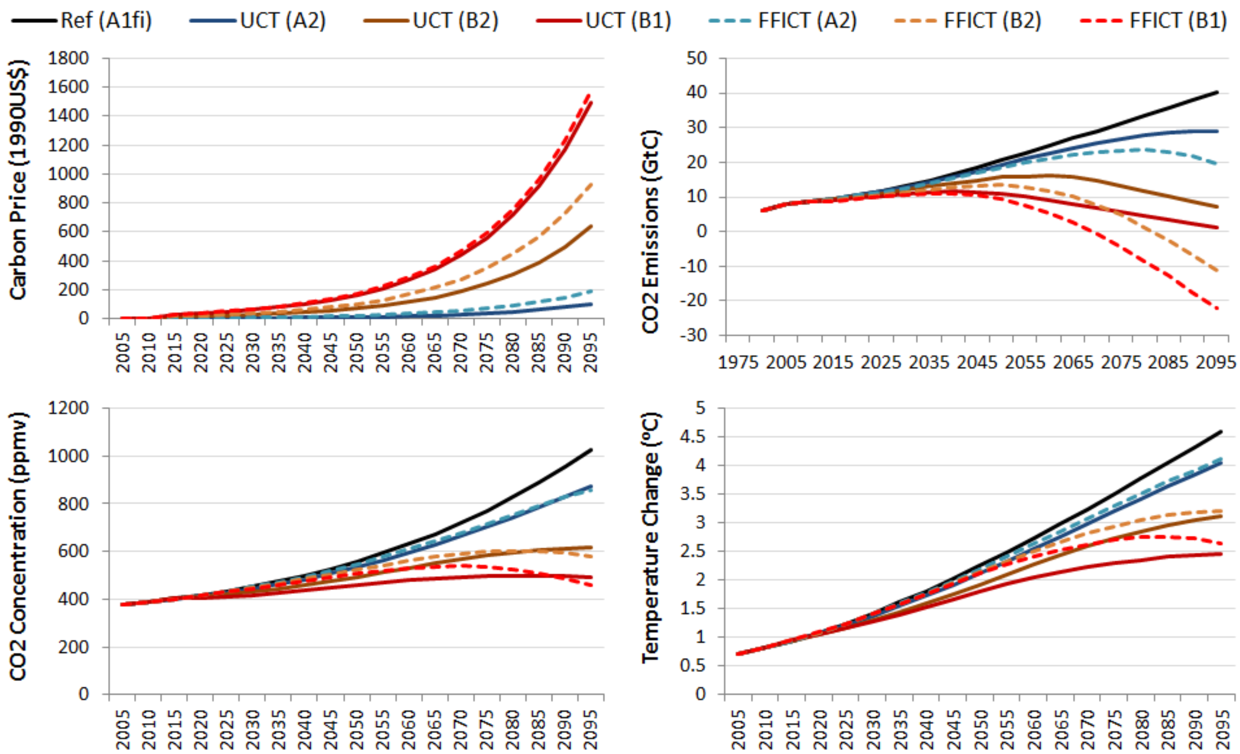


Figure S5: Radiative forcing trajectories based on each of the four SRES emission scenarios (A1fi, A2, B2, and B1); blue and red dashed lines are GCAM equivalent simulations of the UCT and FFICT tax regimes to replicate SRES's emission pathways.



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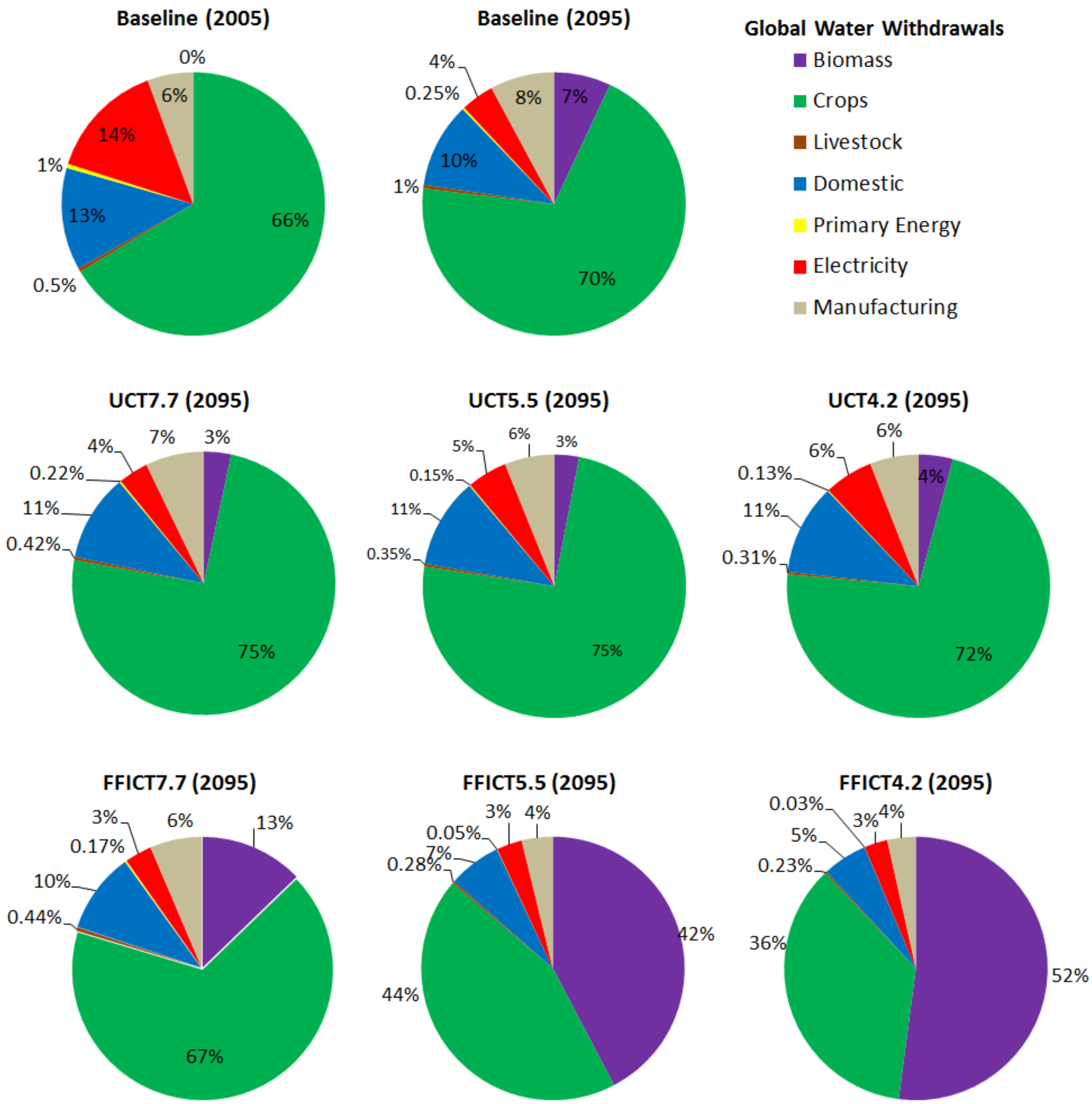


Figure S7: Piechart distributions of global water demands (withdrawals) by sector for the baseline scenario (A1fi) in years 2005 & 2095, and for each of the climate change mitigation policies (2 tax regimes (UCT & FFICT) x 3 emission scenarios (A2, B2, and B1)

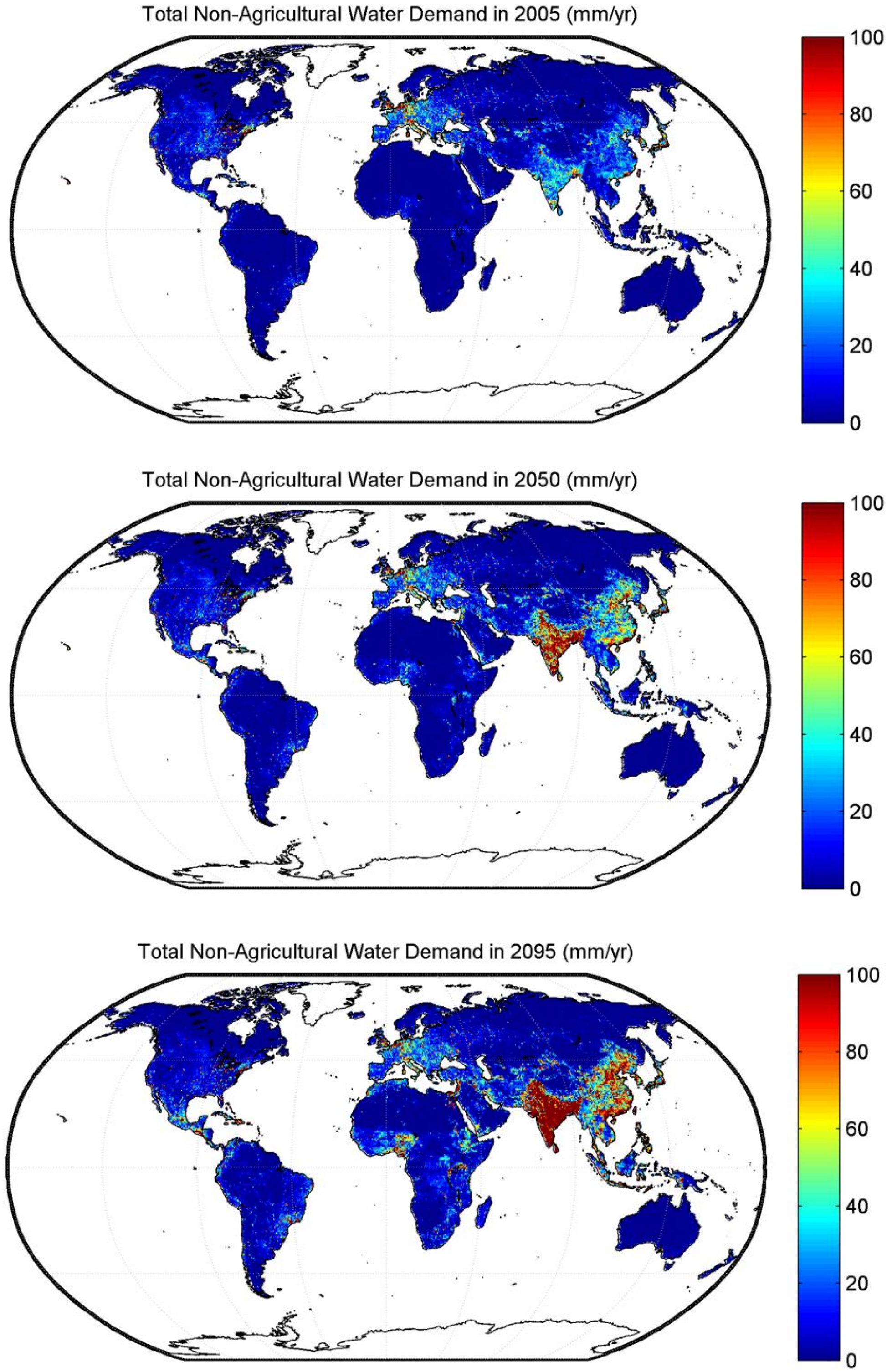


Figure S8: Total non-agricultural water demand (e.g., municipal, electricity generation, primary energy, manufacturing water demands) in years 2005, 2050, and 2095

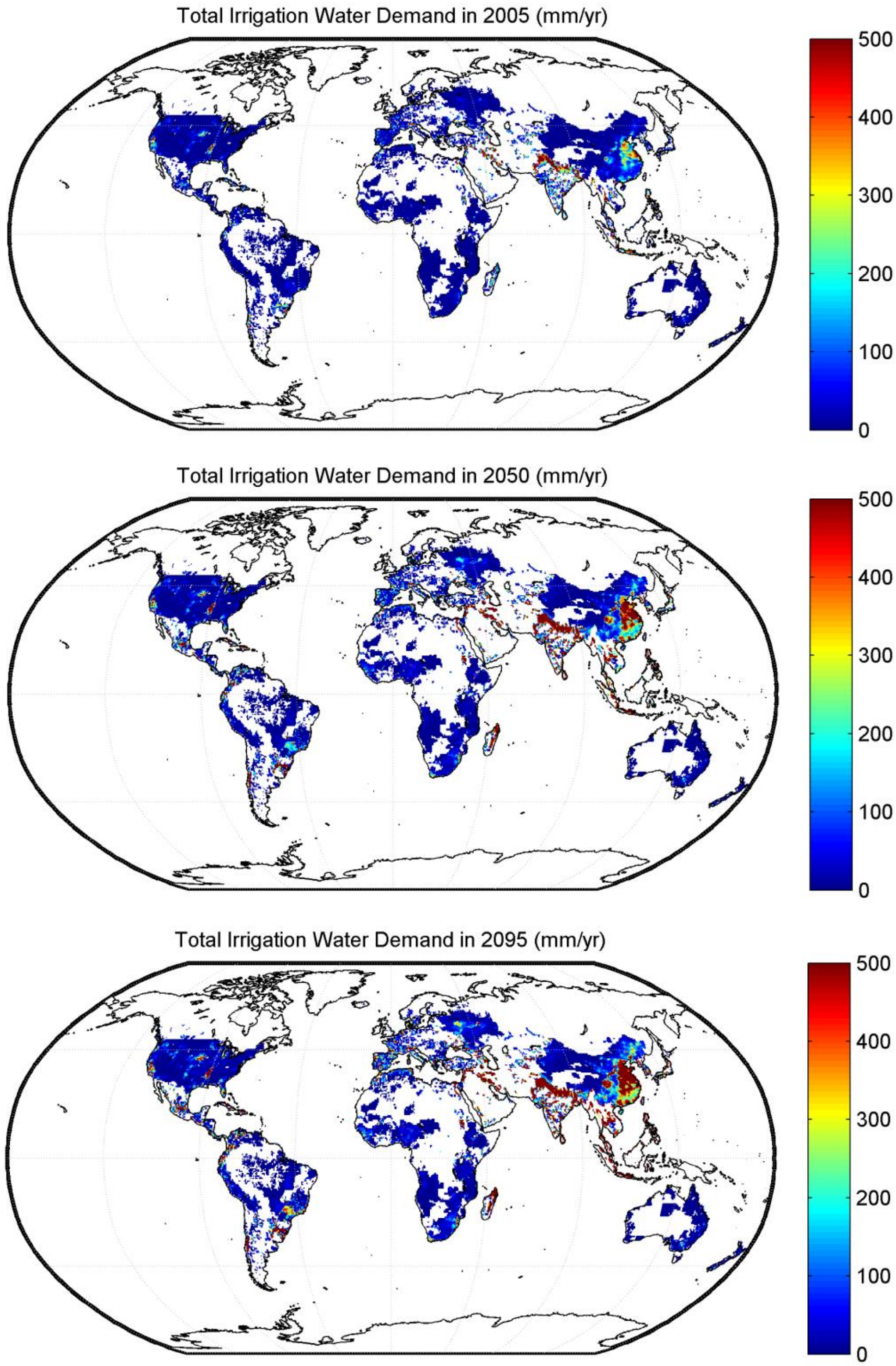


Figure S9: Total irrigation water demand in years 2005, 2050, and 2095

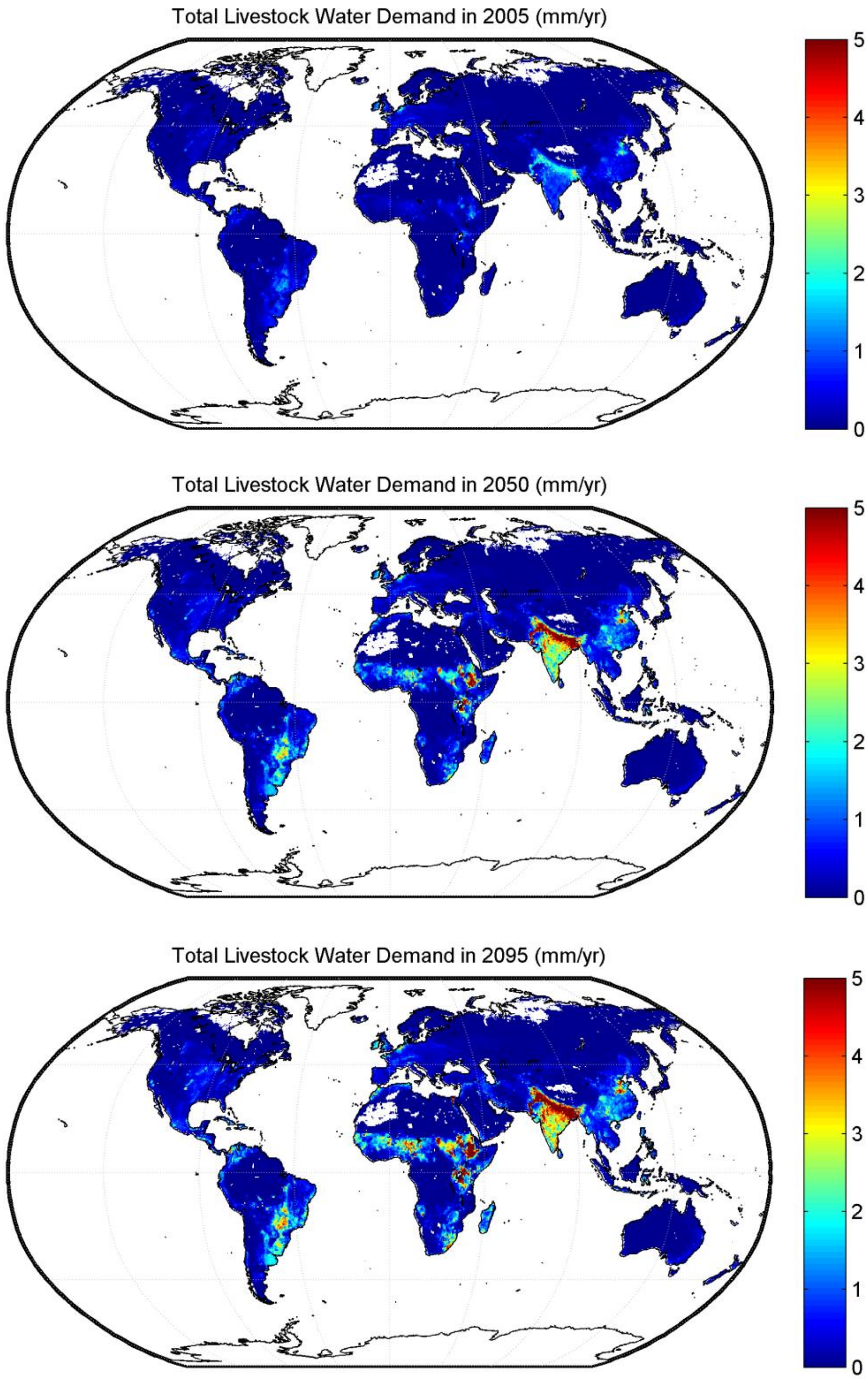


Figure S10: Total livestock water demand in years 2005, 2050, and 2095

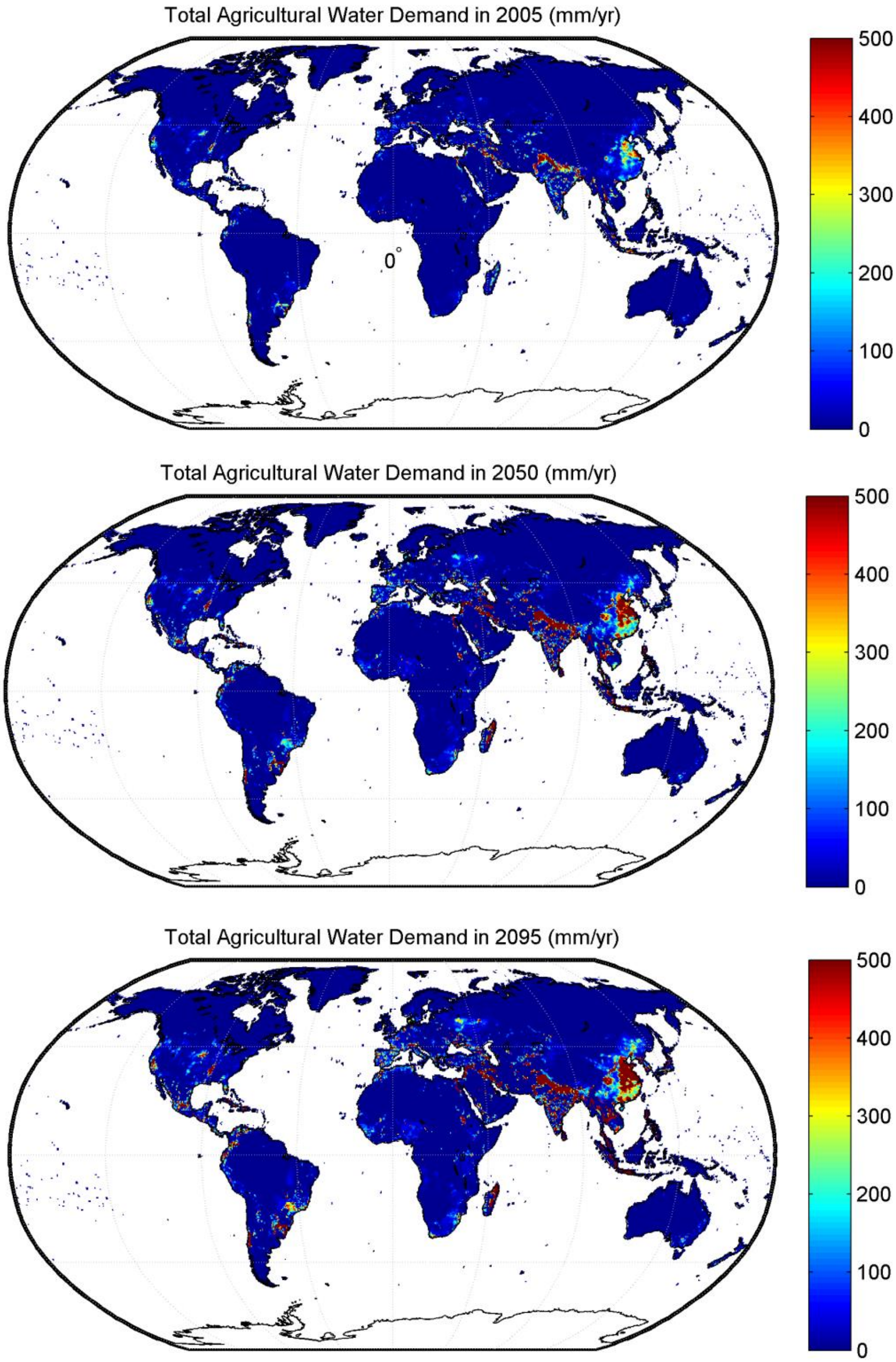


Figure S11: Total agricultural water demand (e.g., irrigation and livestock) in years 2005, 2050, and 2095

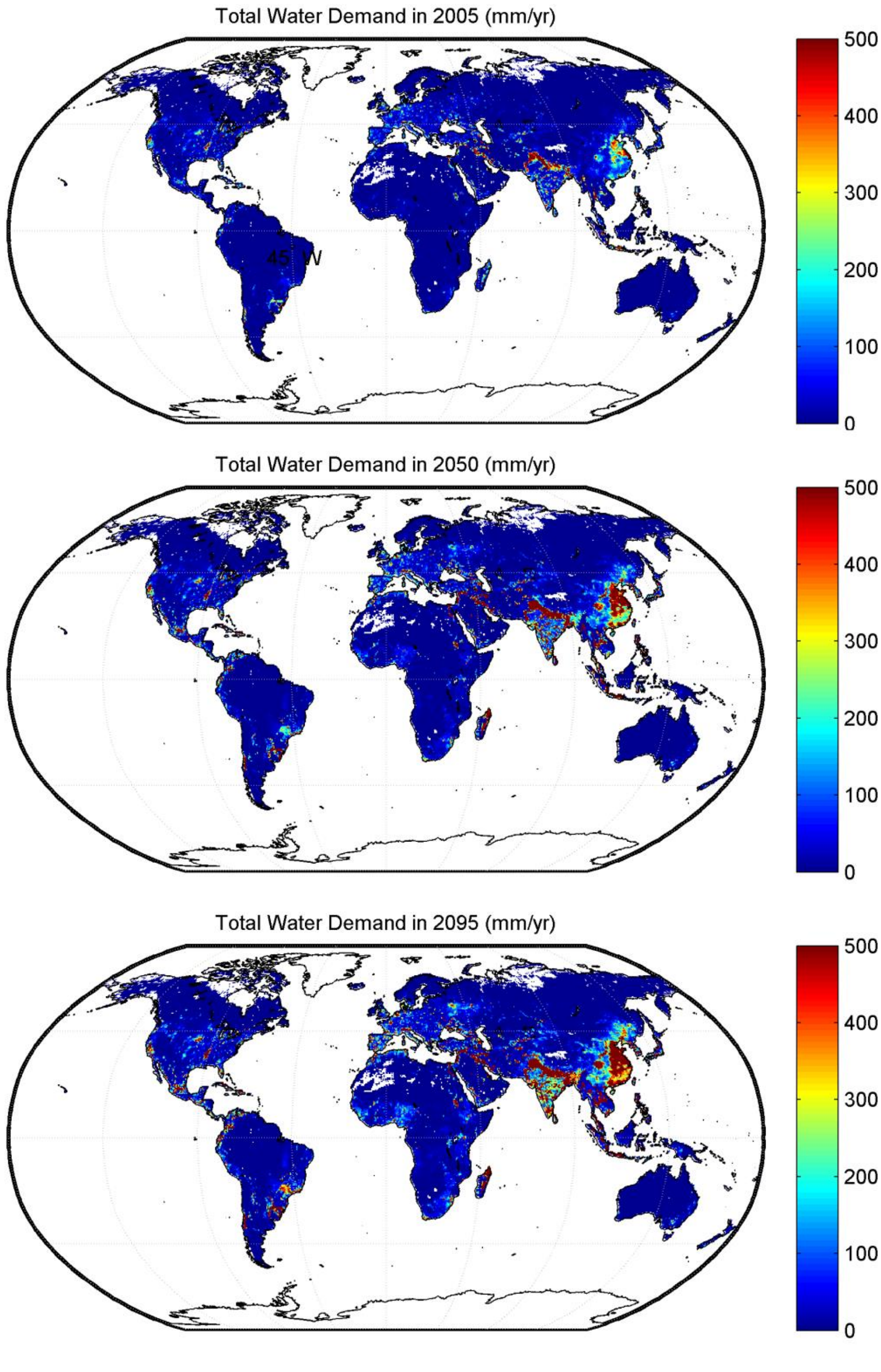


Figure S12: Total water demand (including both agricultural and non-agricultural sectors) in years 2005, 2050, and 2095

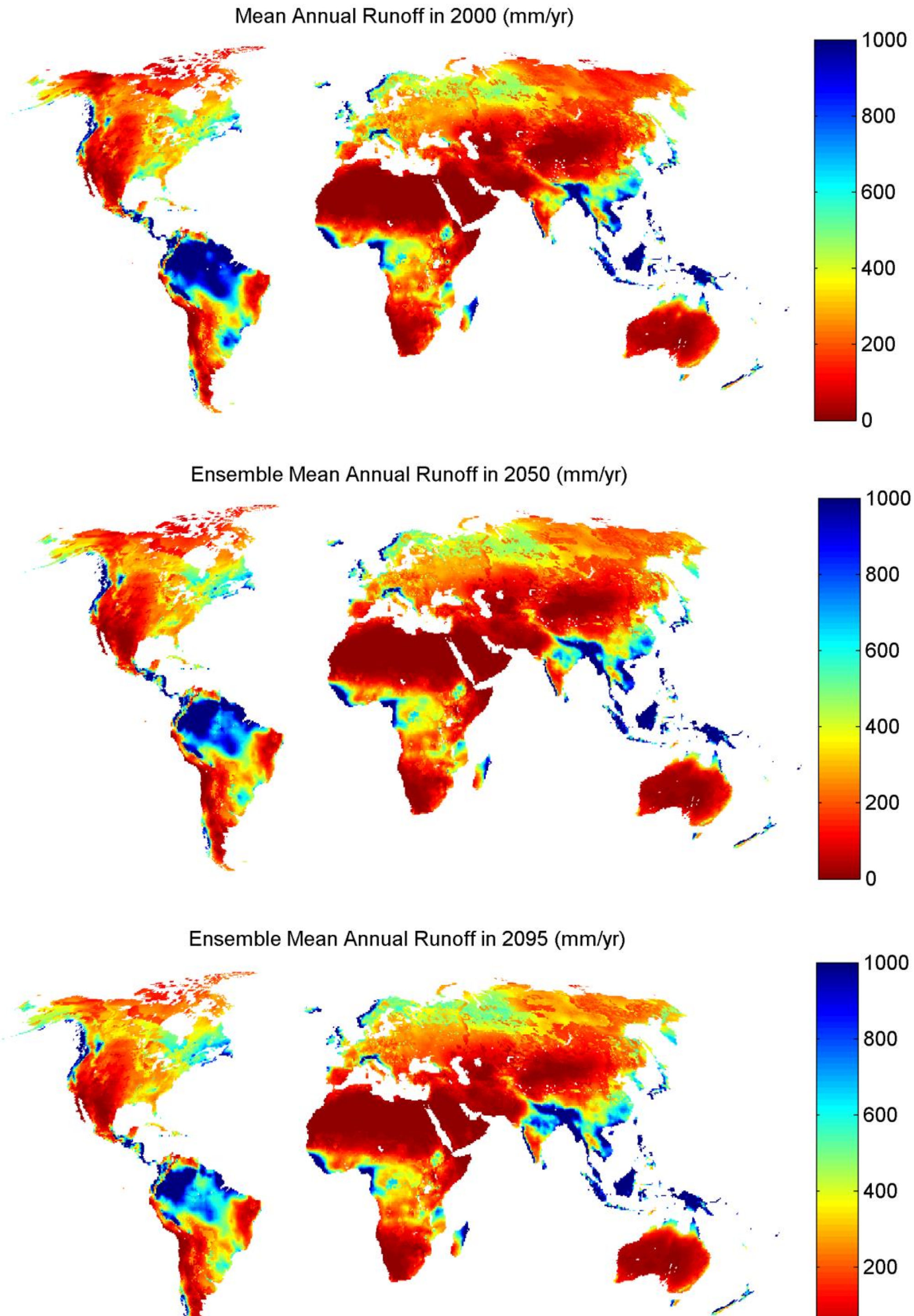
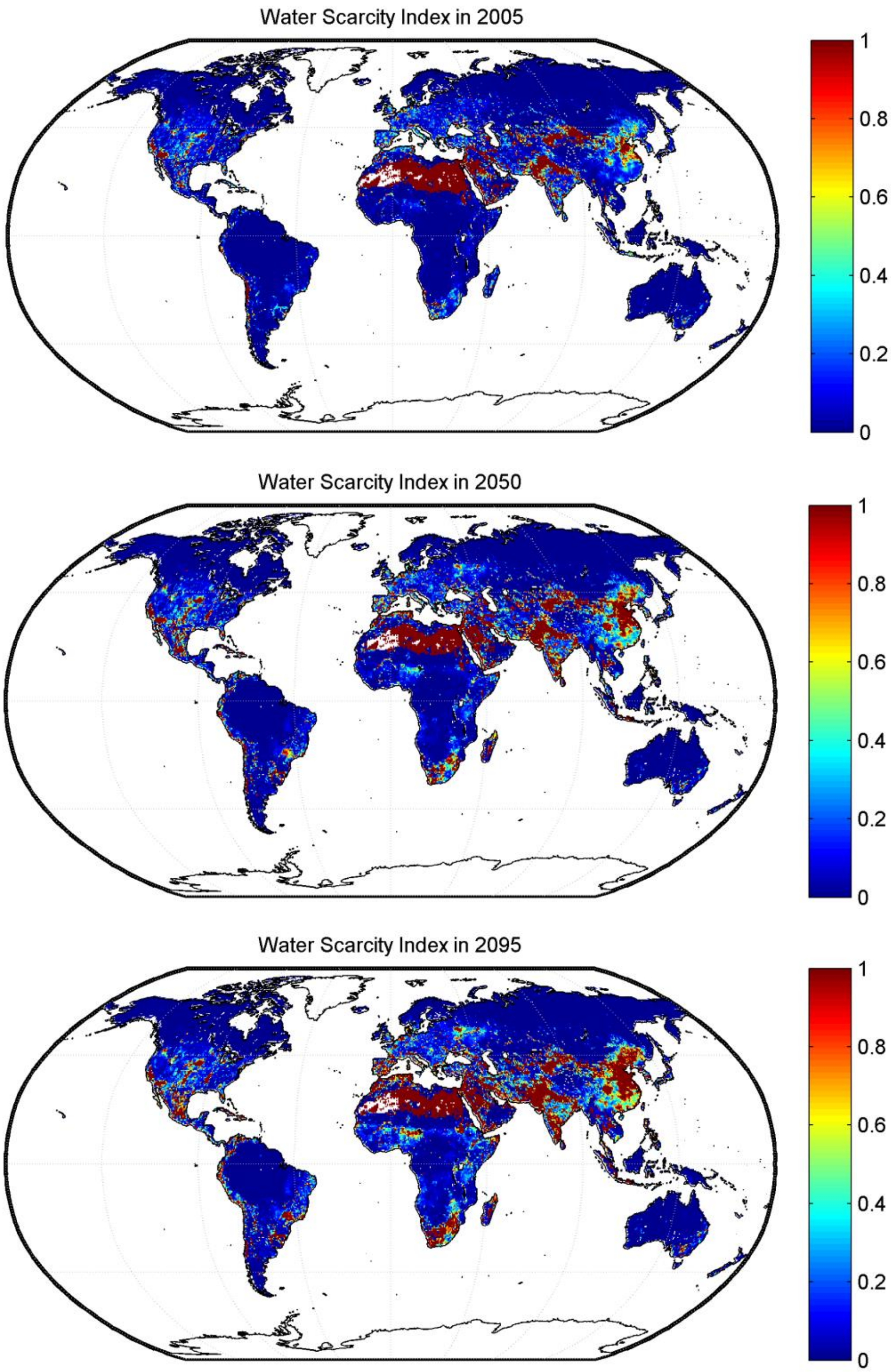
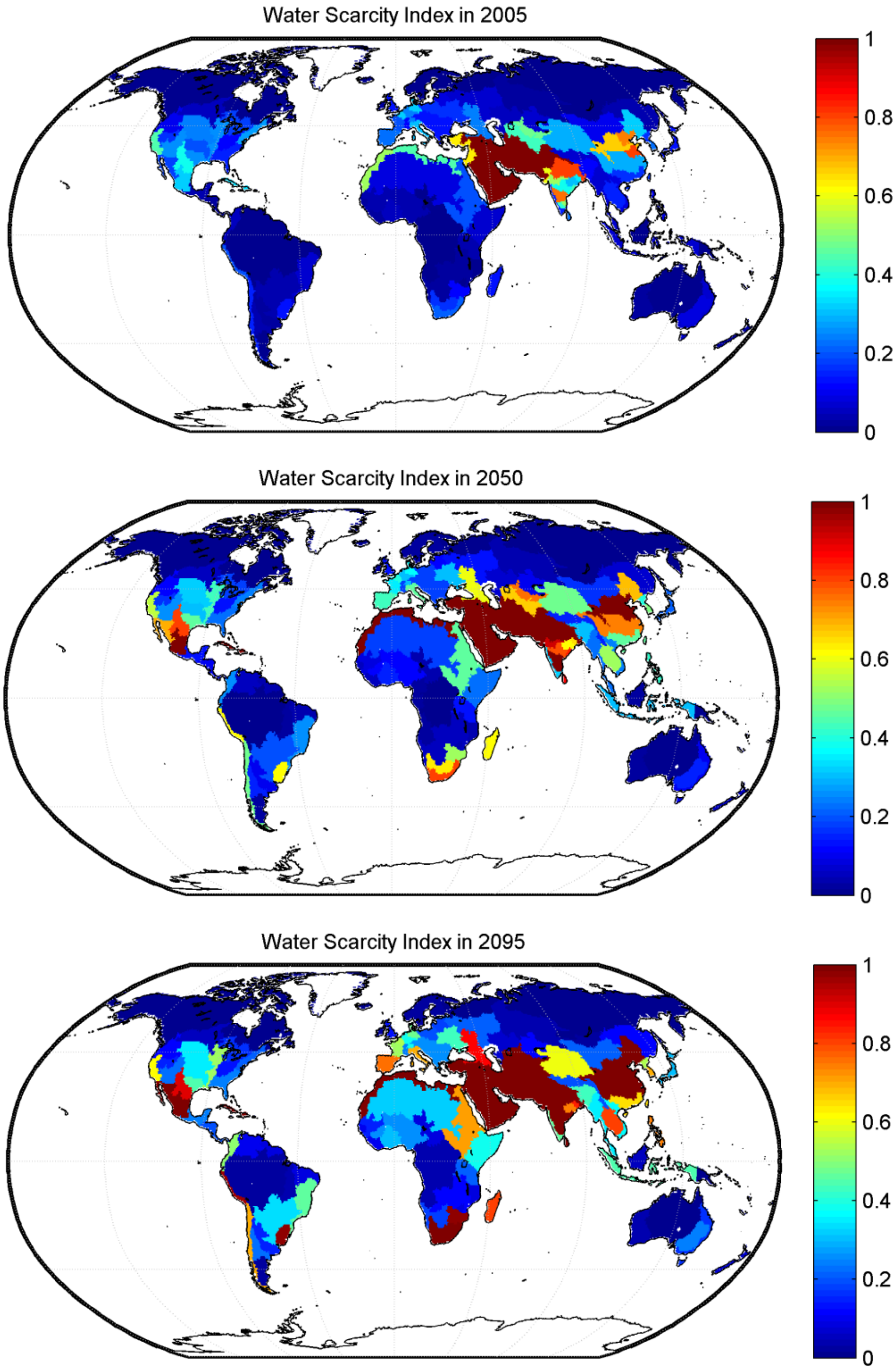


Figure S13: Ensemble mean annual runoff in year 2005, 2050, and 2095; annual values are averaged over 2001-2010, 2046-2055, and 2091-2100, respectively; ensemble is based on four GCMs and the A1fi emission scenario.



(a) Grid-scale water scarcity



(b) Basin-scale water scarcity

Figure S14: The water scarcity index (WSI) in years 2005, 2050, and 2095; a value close to one indicates extreme water stress condition while a value close to zero indicates abundant water resources as compared to demands.

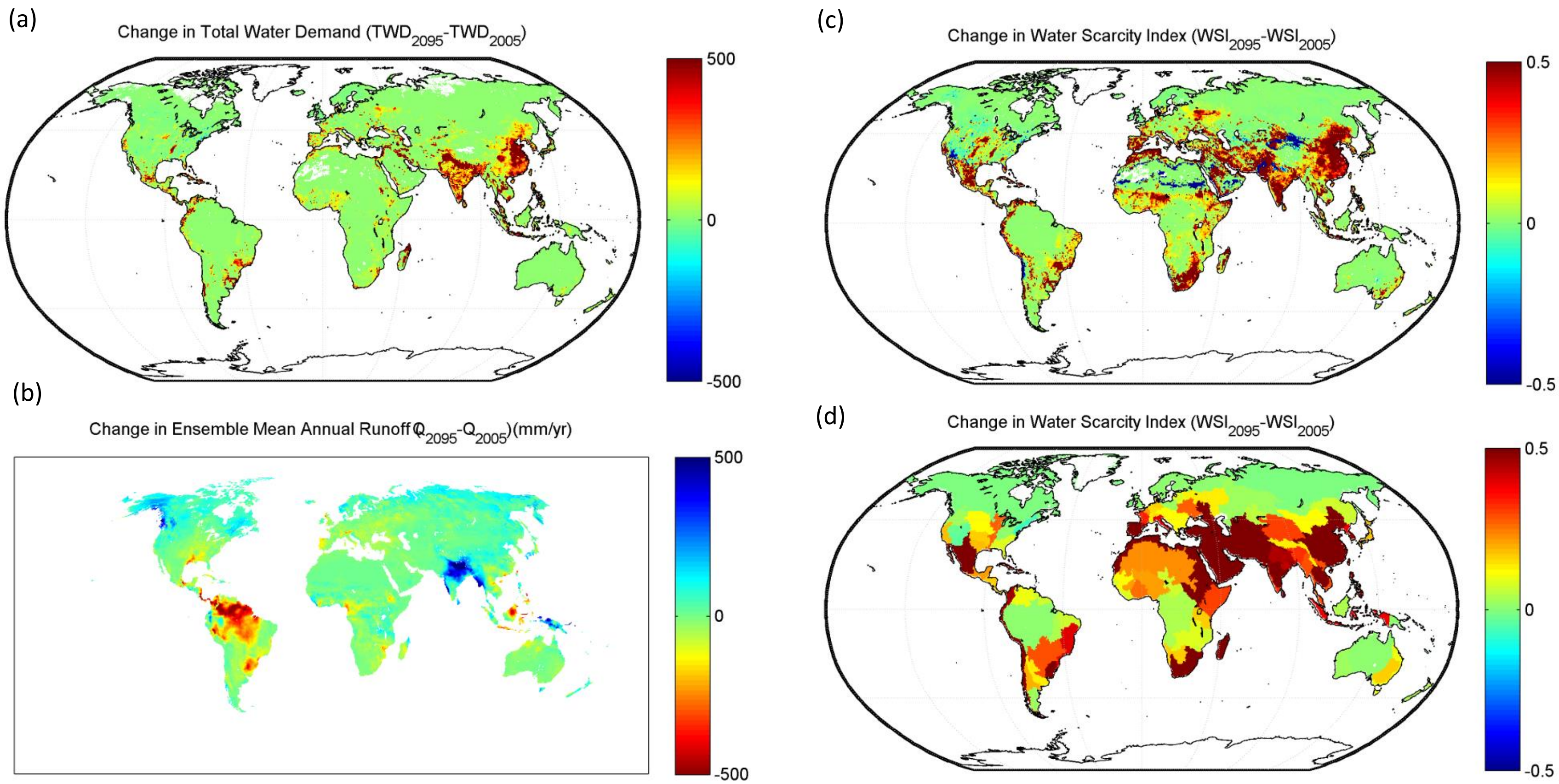


Figure S15: change in (a) total water demands, (b) total water availability, and (c) water scarcity index between 2095 and 2005

Table S1: Average annual runoff [km^3/yr] at the country scale in comparison with other data-based and model based estimates.

Country Name	AQUASTAT FAO* (2010)	WRI (2005)	Shiklomanov (2000)	WBM Fekete et al. (2000)	WBMc Fekete et al. (2000)	WGHM* Doll & Fiedler (2008)	This Study
Afghanistan	55	55		56	70	58	57
Albania	27	27	19	23	23	19	12
Algeria	11	14		16	16	37	41
Angola	148	184		339	307	221	275
Argentina	276	276	270	245	256	348	419
Armenia	6.9	9.0	6.6	4.0	1.6	2.9	4.0
Australia	492	492	352	266	291	774	758
Austria	55	55		57	43	52	52
Azerbaijan	8	8.0	7.6	21	17	7.3	13
Bangladesh	105	105		143	131	108	181
Belarus	37	37	35	50	35	29	58
Belgium	12	12		10	8.3	12	12
Belize	16	16		20	20	17	16
Benin	10	10		42	22	16	28
Bhutan	78	95		41	41	24	33
Bolivia	304	304	361	260	324	357	311
Bosnia & Herzegovina	36	36		42	41	31	22
Botswana	2.4	3		3.7	3.8	-7.8	31
Brazil	5,418	5,418	6,220	6,333	6,904	5,359	5,270
Brunei	8.5			11	11	0.0	10
Bulgaria	21	21		15	21	22	22
Burkina Faso	13	13		47	14	13	47
Burundi	10	4		10	6.9	6.7	8.1
Cambodia	121	121		122	122	116	168
Cameroon	273	273		343	264	233	272
Canada	2,850	2,850	3,287	2,114	2,555	2,702	2,751

Central African Republic	141	141		230	120	120	225
Chad	15	15	10	78	44	23	87
Chile	884	884	354	379	376	381	198
China	2,813	2,812	2,701	1,680	2,160	2,267	1,897
Colombia	2,112	2,112	1,200	1,402	1,668	1,836	1,354
Congo	222	222		174	145	169	154
Congo, DRC	900	900	989	1,138	847	955	786
Costa Rica	112	112	110	99	99	90	85
Cote d'Ivoire	77	77		101	84	92	126
Croatia	38	38		28	25	28	27
Cuba	38	38	35	20	20	31	38
Cyprus	0.8			1.0	1.0	0.0	1.0
Czech Republic	13	13		22	15	16	20
Denmark	6.0	6		15	15	20	13
Djibouti	0.3			0.0	0.0	0.7	0.5
Dominican Republic	21	21		13	13	17	19
Ecuador	432	432	265	210	126	368	212
Egypt	1.8	2		0.0	0.0	-9.1	2.6
El Salvador	18	18	19	15	15	12	13
Equatorial Guinea	26	26		30	30	32	23
Eritrea	2.8	3		1.0	0.7	7.4	5.4
Estonia	13	13	12	20	19	13	12
Ethiopia	122	110		310	218	154	251
Falkland Is.	0.0					3.8	3.2
Fiji	29	29		29	29	21	14
Finland	107	107		104	96	101	110
France	179	179	168	163	172	227	190
French Guiana	134			118	108	105	114
Gabon	164	164	205	188	190	226	168
Gaza Strip & West Bank	0.8						1.0
Georgia	58	58	51	44	34	40	23

Germany	107	107		132	109	112	112
Ghana	30	30		80	41	34	64
Greece	58	58		41	41	39	28
Greenland	603			254	254	306	60
Guatemala	109	109		130	123	124	168
Guinea	226	226		246	194	156	205
Guinea-Bissau	16	16		34	32	18	25
Guyana	241	241		215	226	182	220
Haiti	13	13		11	11	10	11
Honduras	96	96	93	73	73	83	92
Hungary	6.0	6		6.9	5.1	10	25
Iceland	170	170		74	74	119	68
India	1,280	1,261	1,456	1,248	1,468	1,435	1,399
Indonesia	2,838	2,838		2,512	2,512	2,292	2,163
Iran	129	129		120	128	82	88
Iraq	35	35		24	24	5.7	21
Ireland	49	49		48	48	52	37
Israel	0.8	1.0		1.2	1.2	3.2	1.3
Italy	183	183		133	135	135	124
Jamaica	9.4	9.0	8.2	8.3	8.3	6.6	9.5
Japan	430	430		400	405	367	265
Jordan	0.7	1.0		0.7	0.7	3.1	2.0
Kazakhstan	75	75	68	122	105	95	266
Kenya	21	20		43	44	50	73
Kuwait	0.0	0.0				0.5	0.2
Kyrgyzstan	49	47	49	20	35	21	23
Laos	190	190		207	204	197	196
Latvia	17	17	16	20	19	18	17
Lebanon	4.8	5.0		7.7	7.7	4.0	2.6
Lesotho	5.2	5.0		5.3	6.3	4.0	5.0
Liberia	200	200		118	118	149	111

Libya	0.6	1		0.8	0.8	18	13
Lithuania	16	16	14	17	16	16	22
Luxembourg	1.0			0.6	0.7	0.0	0.7
Macedonia	5.4	5.0		4.3	4.4	6.2	6.1
Madagascar	337	337		359	369	348	319
Malawi	16	16		58	18	-2.9	39
Malaysia	580	580		539	529	431	482
Mali	60	60	40	78	32	6.8	94
Mauritania	0.4	0		0.8	0.7	8.3	13
Mexico	409	409	345	303	291	378	359
Moldova	1.0	1.0	1.2	1.1	1.3	3.9	8.1
Mongolia	35	35		17	27	45	94
Morocco	29	29		11	11	26	34
Mozambique	100	99		183	173	159	206
Myanmar	1,003	881		736	882	792	736
Namibia	6.2	6		0.6	0.6	13	26
Nepal	198	198		125	162	158	98
Netherlands	11	11		7.4	7.3	14	13
New Caledonia	0.0					7.7	5.7
New Zealand	327	327	313	250	250	283	258
Nicaragua	190	190	176	140	140	152	155
Niger	3.5	4.0	2.3	4.1	2.8	50	29
Nigeria	221	221	275	337	345	278	354
North Korea	67	67		55	55	55	49
Norway	382	382		224	233	289	214
Oman	1.4	1		1.0	1.0	13	2.7
Pakistan	55	52		26	27	55	44
Panama	147	147	144	110	110	81	78
Papua New Guinea	801	801		723	723	724	589
Paraguay	94	94		64	63	72	109
Peru	1,616	1,616	1,100	785	531	1,306	691

Philippines	479	479		343	343	278	251
Poland	54	54		58	57	62	80
Portugal	38	38	19	35	35	41	30
Puerto Rico	7.1			6.7	6.7	0.0	5.0
Qatar	0.1			0.0	0.0	0.1	0.0
Romania	42	42		38	32	51	57
Russia	4,313	4,313	4,053	2,909	3,704	3,550	4,251
Rwanda	10	5		5.8	4.5	4.4	7.9
Saudi Arabia	2.4	2		-0.1	-0.1	25	6.0
Senegal	26	26	21	37	25	8.8	51
Serbia & Montenegro	44						31
Sierra Leone	160	160		120	120	103	113
Slovakia	13	13		17	15	12	16
Slovenia	19	19		21	20	14	15
Solomon Is.	45	45		26	26	30	2
Somalia	6.0	6		0.2	0.2	13	18
South Africa	45	45		39	39	59	99
South Korea	65	65		55	60	51	47
Spain	111	111	109	83	106	115	100
Sri Lanka	53	50		52	52	39	47
Sudan	30	30	35	139	127	30	199
Suriname	88	88		138	130	102	162
Swaziland	2.6			1.8	1.8	2.8	2.5
Sweden	171	171		108	125	177	151
Switzerland	40	40		50	46	45	38
Syria	7.1	7		8.1	8.1	11	17
Tajikistan	66	66	47	5.6	28	38	34
Tanzania	84	82		187	125	129	246
Thailand	225	210		268	243	201	286
The Bahamas	0.0			0.0	0.0	2.4	1.6
The Gambia	3.0	3.0	4.0	6.4	6.4	0.6	1.4

Timor-Leste	0.0					4.0	3.9
Togo	12	12		25	11	11	17
Trinidad & Tobago	3.8	4.0		2.1	2.1	0.0	1.9
Tunisia	4.2	4		5.5	5.5	8.1	8.6
Turkey	227	227		187	182	183	148
Turkmenistan	1.4	1.0	1.1	4.7	4.7	7.9	13
Uganda	39	39		47	22	3.3	59
Ukraine	53	53	51	71	55	70	152
United Arab Emirates	0.2	0.0		0.8	0.8	0.8	0.5
United Kingdom	145	145		126	126	177	152
United States	2,818	2,818	2,930	2,208	2,297	2,382	2,254
Uruguay	59	59	68	65	63	92	62
Uzbekistan	16	16	10	11	12	14	25
Vanuatu	0.0					11	4.3
Venezuela	722	723		852	765	773	728
Vietnam	359	367		263	265	235	269
Western Sahara	0.0					2.1	0.4
Yemen	2.1	4		0.1	0.1	17	6.0
Zambia	80	80		275	254	71	202
Zimbabwe	12	14		35	40	31	53

* The values of FAO, WRI, and WGHM are defined as renewable water resources. The remaining sources show the average annual runoff

Table S2: Characteristics of the selected 29 world basins.

No	River Basin Name	SAGE* (2010)			GRDC (1999)				This Study		
		Station Name	Data Period	Basin Area [km2]	GRDC station number	Station Name	Data Period	Basin Area [km2]	IWMI Basin #	Data Period	Basin Area [km2]
1	Amazon	Obidos	1928-1983	4,618,746	3629000	Obidos - Porto	1927-1998	4,680,000	1	1901-2002	6,255,815
2	Amur	Komsomolsk	1933-1984	1,730,000	2906901	Bogorodskoye	1963-1987	1,790,000	3	1901-2002	1,655,920
3	Brahmaputra	Bahadurabad	1969-1975	636,130	2651100	Bahadurabad	1969-1992	636,130	9	1901-2002	635,779
4	Colorado	Limite Internacional Norte	1976-1979	631,960	4352100	Lindero Internacional Norte	1961-1995	631,960	23	1901-2002	728,567
5	Columbia	The Dalles	1960-1993	613,794	4115201	Beaver Army Terminal Near Quincy	1968-2010	665,371	24	1901-2002	685,718
6	Congo	Brazzaville	1984-2002	3,475,000	1447150	Brazzaville	1971-1983	3,475,000	25	1901-2002	3,082,792
7	Danube	CeatalIzmail	1921-1984	807,000	6742900	Ceatal Izmail	1921-2008	807,000	27	1901-2002	1,142,044
8	Dnieper	Dnieper Hydroelectric Plant	1952-1984	463,000	6980802	Kakhovskoye Vodokhranilishche Ges	1959-1988	482,000	28	1901-2002	767,324
9	Ganges	Paksay	1965-1975	846,900	2646100	Paksey	1969-1975	846,900	34	1901-2002	1,032,334
10	Huang He (Yellow River)	Sanmenxia	1976-1979	688,421	2180800	Huayuankou	1946-2004	730,036	41	1901-2002	1,047,855
11	Indus	Kotri	1973-1979	832,418	2335950	Kotri	1936-1979	832,418	45	1901-2002	1,092,691
12	Mekong	Mukdahan	1924-1987	391,000	2569002	Phnom Penh (Chroui Changvar)	1960-1973	663,000	60	1901-2002	826,867
13	Mississippi	Vicksburg, Missisippi	1965-1983	2,964,254	4127800	Vicksburg, Ms	1928-2009	2,964,255	62	1901-2002	3,144,274
14	Murray	Lock9 Upper	1965-1984	991,000	5204268	Lock 9 Upstream	1965-1984	991,000	64	1901-2002	1,032,479
15	Niger	Gaya	1952-1990	1,000,000	1834101	Lokoja	1970-2006	---	66	1901-2002	2,229,504
16	Nile	AswanDam	1869-1984	---	1362600	Aswan Dam	1869-1984	---	67	1901-2002	2,788,360
17	Ob	Salekhard	1930-1984	2,430,000	2912600	Salekhard	1930-2003	2,949,998	75	1901-2002	2,790,218
18	Orange	Vioolsdrif	1964-1986	850,530	1159100	Vioolsdrif	1935-2001	850,530	78	1901-2002	613,453
19	Orinoco	Musinacio	1973-1975	---	3206720	Puente Angostura	1923-1989	836,000	79	1901-2002	1,203,565
20	Parana	Corrientes	1969-1979	2,300,000	3618001	Careiro	1977-2010	2,583,079	81	1901-2002	2,659,381
21	Rhine	Rees	1936-1984	159,680	6435060	Lobith	1901-2007	160,800	85	1901-2002	220,414
22	Rio Grande	Laredo,Texas	1900-1972	352,178	4351900	Matamoros	1934-2000	450,902	88	1901-2002	690,266
23	Syr Darya	Tyumen-Aryk	1930-1984	219,000	2916200	Tyumen-Aryk	1930-1986	219,000	104	1901-2002	465,312
	Euphrates	D.S.Hindiya B.	1968-1972	274,100	2595400	Hindiya	1923-1972	274,100	---	---	---
24	Tigris	Baghdad	1968-1972	134,000	2595700	Baghdad	1906-1972	134,000	---	---	---

	Tigris-Euphrates	---	---	408,100	---	---	---	408,100	107	1901-2002	841,321
25	Ural	Kushum	1915-1984	190,000	2919200	Kushum	1915-1988	190,000	111	1901-2002	922,085
26	Volga	Volgograd Hydroelectric Plant	1879-1984	1,360,000	6977100	Volgograd Power Plant	1879-2002	1,360,000	114	1901-2002	1,603,982
27	Yenisei	Igarka	1936-1984	2,440,000	2909150	Igarka	1936-2003	2,440,000	120	1901-2002	2,566,163
28	Zambezi	Matundo- Cais	1976-1979	940,000	1891500	Matundo-Cais	1976-1979	940,000	123	1901-2002	2,007,908
29	Zhu Jiang (Xi Jiang)	Wuzhou3	1976-1983	329,705	2186800	Wuzhou 3	1915-2004	329,705	124	1901-2002	682,308

* SAGE: contains a compilation of monthly mean river discharge data for over 3500 sites worldwide from various data sources (RivDis2.0, the United States Geological Survey, Brazilian National Department of Water and Electrical Energy, and HYDAT-Environment Canada); the period of record for each station is variable, from 3 years to greater than 100.

Table S3: Average annual runoff [km^3/yr] at the basin scale in comparison with other data-based and model based estimates.

No.	River Basin Name	Observed Data		Data-Based			Model-Based				
		SAGE (2010)	GRDC (1999)	Shiklomanov (2000)	WRI (2000)	Probst & Tardy (1987)	PCR-GLOBWB Weiland et al. (2010)	WaterGAP 2 Alcamo et al. (2003)	WBM Fekete et al. (2000)	WBMc Fekete et al. (2000)	This Study
1	Amazon	5,326	4,902	6,923	6,729	4,729	5,992	5,436	5,658	6,813	4,928
2	Amur	323	307	360	323	---	---	---	334	402	361
3	Brahmaputra	690	620	---	---	---	1,519	---	651	861	587
4	Colorado	4	2	---	15	---	---	---	13	17	58
5	Columbia	205	172	236	234	---	---	---	147	226	197
6	Congo	1,297	1,264	1,320	1,273	---	1,318	---	1,484	1,087	1,074
7	Danube	203	205	225	204	172	202	185	370	333	365
8	Dnieper	43	47	53	51	---	---	---	119	84	202
9	Ganges	381	351	1,386	---	---	379	357	391	427	471
10	Huang He (Yellow River)	44	38	---	54	---	---	---	76	93	139
11	Indus	90	76	226	146	---	208	---	172	151	98
12	Mekong	410	252	505	511	262	505	233	473	458	533
13	Mississippi	543	537	510	632	---	402	442	652	626	732
14	Murray	8	8	24	24	---	24	---	15	15	109
15	Niger	158	36	302	295	---	189	---	521	456	549
16	Nile	87	87	161	316	---	---	36	355	249	343
17	Ob	400	393	404	444	---	---	---	392	392	714
18	Orange	9	5	---	11	---	12	---	9	9	30
19	Orinoco	980	906	1,007	1,467	---	---	---	1,281	1,152	1,171
20	Parana	391	546	---	560	---	568	---	726	561	788
21	Rhine	70	72	---	---	---	69	---	103	93	99
22	Rio Grande	1	4	---	7	---	---	---	5	4	36
23	Syr Darya	17	17	---	26	---	---	---	28	38	44
24	Tigris-Euphrates*	57	50	---	96	---	---	---	113	108	93
25	Ural	9	9	---	7	---	---	---	21	17	83
26	Volga	257	255	255	252	257	254	240	309	296	425

27	Yenisey	583	558	618	606	---	---	---	458	733	757
28	Zambezi	105	105	154	---	---	107	---	532	453	456
29	Zhu Jiang (Xi Jiang)	217	223	---	---	---	---	165	374	464	420

*For RivSim and GRDC, Euphrates and Tigris runoff values are, 19, 18, 38, and 32, respectively.