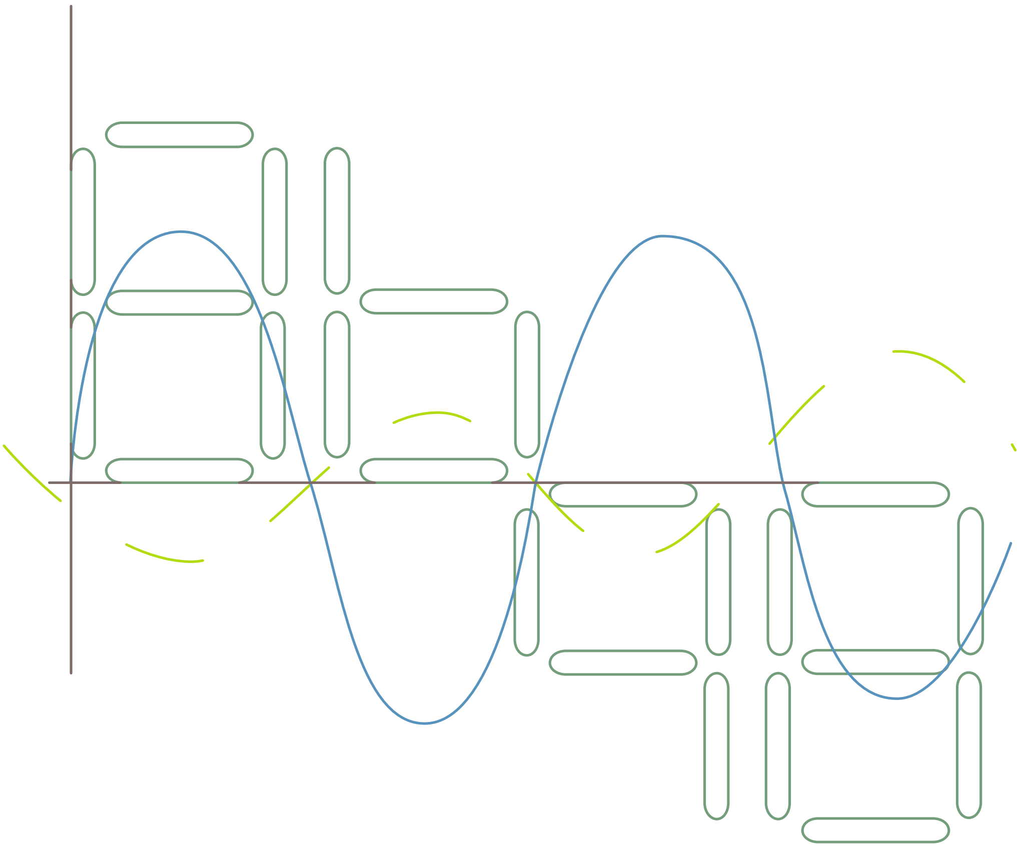
Report 44

GRDC Report Series

Global Freshwater Fluxes into the World Oceans

Technical Report prepared for the GRDC



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Technical Report prepared for the GRDC

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Global Runoff Data Centre

GRDC operates under the auspices of the World Meteorological Organization (WMO) with the support of the Federal Republic of Germany within the Federal Institute of Hydrology (BfG)

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About the Global Runoff Data Centre (GRDC):

The GRDC is acting under the auspices of the World Meteorological Organization (WMO) and is supported by WMO Resolutions 21 (Cg XII, 1995) and 25 (Cg XIII, 1999). Its primary task is to maintain, extend and promote a global database on river discharge aimed at supporting international organizations and programs by serving essential data and products to the international hydrologic and climate research and assessment community in their endeavour to better understand the Earth system. The GRDC was established at the German Federal Institute of Hydrology (BfG) in 1988. The National Hydrological and Meteorological Services of the 191 WMO Member states and territories are the principal data providers for the GRDC.

All questions regarding this document should be directed to the contributing authors.

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Preface

Accurate information of surface freshwater fluxes into the World's seas and oceans is of importance to science. Determining freshwater fluxes was originally aimed at closing knowledge gaps in the hydrological cycle and to arrive at an improved world water balance. Furthermore, global monitoring of freshwater resources and the flux of matter into coastal areas and the oceans are of specific interest to research. Especially the influence of freshwater fluxes on oceanic circulation patterns and its impact on climate systems has resulted in numerous studies and requests for improved and timely determination of freshwater fluxes.

In the past the GRDC has calculated and published freshwater fluxes in the years 1996 (GRDC Report 10 (March 1996): Freshwater Fluxes from Continents into the World Oceans based on Data of the Global Runoff Data Base / W. Grabs, Th. de Couet, J. Pauler), 2004 and 2009. Results of the last two versions are available online at the GRDC website. For previous studies different methodologies were used. Selected outputs of the global hydrological model WaterGAP (Döll et al., 2003) were used to estimate freshwater fluxes on a global scale in 2004 and 2009.

Within the framework of the European Commission funded FP7 project GEOWOW the GRDC had the opportunity to develop an automated and standardised procedure for the calculation of freshwater fluxes. The necessary geo-processing workflow was compiled for the GRDC into a specially designed ArcGIS toolbox by UDATA - Umweltschutz und Datenanalyse Neustadt / Weinstraße, Germany (Wilkinson et al., 2014). This workflow will be used to regularly recalculate freshwater fluxes, at least when WaterGAP inputs are updated by the team at Frankfurt University, Germany.

The *Global Freshwater Fluxes into the World Oceans* are provided as a stand-alone Web Service. This service is available at the GRDC website, but has also been registered with the GEOSS Portal in support of GEO (Group on Earth Observations).

I believe that the *Global Freshwater Fluxes into the World Oceans* still attract wide interest. But there might be also an interest in the methodology applied. The GRDC would like to thank Kristina Wilkinson and the UDATA team for describing the calculation workflow and the results in the GRDC Report Series.

Ulrich Looser

Head, GRDC

1 Introduction and background

The Global Runoff Data Centre (GRDC) calculates mean *Global Freshwater Fluxes into the World Oceans* and provides the relevant data products at different spatial scales via its website.

This report summaries the work undertaken by UDATA, a GRDC contracted company, to calculate the 2014 version of freshwater fluxes and to automate the calculation and visualization with the help of specifically developed GIS tools.

Based on modelling results from the global hydrological model WaterGAP 2.2 (Water - Global Assessment and Prognosis, Döll et al., 2003, Müller Schmied et al., 2014) freshwater fluxes for 0.5° grid cells can be analysed and aggregated automatically at various spatial resolutions in the future.

WaterGAP delivers results for water balance components on a global scale for 0.5° cells of the land surface. Freshwater fluxes are accumulated along a river network obtained from a 0.5° global drainage direction map (Döll & Lehner, 2002). Since every single cell can only have *one* downstream cell, no delta formations or river bifurcations are possible. Given the spatial resolution of 0.5°, the modelled results only represent the general water balance of a wider area and should not be used for detailed regional or local hydrological studies.

The WaterGAP 2.2 model does not incorporate glacier dynamics and is largely dependent on the quality of the underlying global datasets (land use, soil maps, hydrogeology etc.) as well as global climate inputs. These model specifications should be kept in mind when looking at results for different regions.

For the calculation of freshwater fluxes *ModelBuilder*, a GIS tool available within ESRI ArcGIS was used. At the same time, an additional Python script was developed to allow the calculation of freshwater fluxes outside an active GIS environment.

2 Base data

The following basic data were used to generate and pre-process the necessary input data:

1. Global drainage direction map with 0.5° spatial resolution to identify coastal cells and internal sinks for the global land surface (except Antarctica) (DDM30, Döll and Lehner, 2002)
2. Global shape file of GIWA regions (GIWA - Global International Waters Assessment, http://www.unep.org/dewa/giwa/)
3. Global shape file of 5° cells along the coastlines of all continents
4. Global shape file to assign cells to continents, oceans and 5 ° latitude bands

5. EXCEL table with predefined worksheets to calculate global freshwater fluxes along 5° and 10° latitudinal zones (for continents and oceans) using the layout of the GRDC product from 2009
6. Annual WaterGAP files in netCDF format with discharge values for 0.5° grid cells (km³/year) for the global land surface (except Antarctica) for the 50 year period 1960 - 2009
7. Four "empty" shape files where the aggregated discharge values are added as fields in the attribute tables using GIS tools for

	Spatial resolution	Nr. of entities
1.	GIWA regions	61
2.	5° cells along the coastlines	611
3.	5° latitude bands	156
4.	10° latitude bands	86

(3. and 4. - combined zones for oceans, continents and latitude bands)

8. One global shape file which contains the necessary information for every WaterGAP coastal cell (10179 cells total), e.g. to which GIWA region or which latitude band each 0.5° cell belongs to.

3 Pre-processing of input data

3.1 WaterGAP coastal cells

Based on the global drainage direction map (DDM30, Döll & Lehner 2002) hydrological catchments and internal sinks were derived on a global scale. 0.5° cells with a flow direction of "0" are the end points of flow paths, thus marking either cells along the coastline or pour points of internal sinks. Because only freshwater fluxes into the world oceans should be analysed, most of the internal sinks (e.g. the Okavango Delta, Lake Chad or the Tibetan Plateau) are neglected. The only exceptions are the Caspian Sea and the Aral Sea which were kept for data processing because they are also GIWA regions and were already analysed in previous studies (GRDC 2009). Finally, 10179 WaterGAP cells were identified that are of interest for further analysis.

Each one of these 10179 cells was assigned to a

- GIWA region
- Continent
- Ocean
- 5° coastline cell
- 5° latitude band
- 10° latitude band

All of the catchments derived in the previous step are assigned the same attributes. Catchment areas range from 340 km² (single cells in the northern arctic ocean) to a maximum of 5.9 Mio km² for the Amazon, the world's largest drainage basin.

The WaterGAP outlet cell of the Amazon basin lies within the 0°- 5° **North** latitude band. This value was changed manually to 0°- 5° **South**, because the actual ocean outlet of the Amazon river is south of the equator and because in previous studies (GRDC 2009) the Amazon basin outlet was also attributed to the southern hemisphere. This way, the comparability of results can be maintained. In other global water balance studies (Baumgartner et al. 1975), the majority of Amazon stream flow was also assigned to the southern hemisphere (2/3 between 0° and 5° South and 1/3 between 0° and 5° North).

3.2 5° AND 10° LATITUDE BANDS

To identify zones that drain into a specific ocean from a specific continent within one 5° latitude band the 10179 identified WaterGAP cells were dissolved according to their attributes.

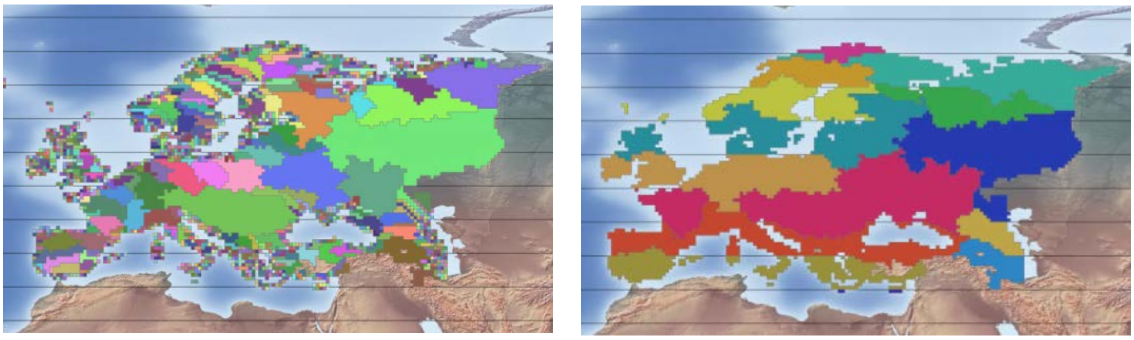

Fig. 1: Drainage basins derived from DDM30 in Europe (left) and the corresponding 5 ° latitude bands (right)

4 Calculation

Freshwater Fluxes into the World Oceans are calculated and delivered as ArcGIS shape files for four different spatial resolutions.

The newly developed GIS tools now available to the GRDC can be run for single years as well as longer periods, depending on the availability of WaterGAP model output. These tools are accessible to the GRDC as a classic ArcGIS tool box with user dialogue for data selection and as a stand-alone Python script.

Four shape files are created in the output folder which contain the calculated annual freshwater fluxes (km³/year) for four different spatial aggregations:

- GIWA regions
- 5° coastline cells
- 5° latitude bands
- 10° latitude bands.

The results obtained for 5° latitude bands are used later for data processing in a pre-formatted EXCEL file to determine mean global Freshwater Fluxes for 5° and 10° latitudinal zones. These tables use the same format as previous studies (GRDC 2009) and follow specifications provided by Baumgartner et al. (1975). Global latitudinal zones are analysed according to the amount of freshwater flowing into the different world oceans and how freshwater fluxes are distributed over hemispheres and continents. The results are briefly presented and discussed in chapter 7.

Additionally long term mean values for the “WMO climate normal periods” 1961-1990 and 1971-2000 are calculated as well as for the entire period 1960 - 2009.

5 Results

Freshwater fluxes from continents to the world oceans were calculated within this study using WaterGAP 2.2 model output and applying newly developed GIS tools. Internal continental sinks (lakes, plateaus etc.) were neglected except for the Caspian Sea and Aral Sea.

Global mean values for surface freshwater fluxes sum up to about 42.000 km³/year for the 30 year long “WMO climate normal periods” (1961 - 1990 and 1971 - 2000). This is in close agreement with recent WaterGAP publications (Müller Schmied et al., 2014) where the global value for long-term average freshwater fluxes was estimated at 42.364 km³/year.

Compared to previous GRDC data products (GRDC 2009) a significant **increase** in the global value (2009: 36109 km³/year) can be seen. This can only be attributed to changes in the model structure and different climate input of WaterGAP as well as a model recalibration. In 2009, results from WaterGAP **2.1** model output were analysed whereas the current study is based on the more recent WaterGAP **2.2** model output.

As already mentioned, WaterGAP 2.2 does not incorporate glacier dynamics. This should be kept in mind when looking at results for areas like Greenland where not only the hydrological processes are difficult to represent but where the necessary input data are also very difficult to obtain. This applies to (measured) climate data as well as hydrological data for model calibration. About 6% of WaterGAP coastal cells are located in Greenland but they only contribute about 1% to the total global freshwater fluxes. Despite those constraints, Greenland was left in all global maps and tables to allow comparison with previous similar data products.

Figures 2 and 3 show results for global 5° and 10° latitudinal zones. The values represent mean freshwater fluxes in km³/year for the “WMO climate normal period” 1961-1990. This table allows direct comparison with previous results from the GRDC (2009).

	EUR	ASI	AFR	AUS	NAM	SAM	ANT	LAND	NAM	SAM	ATL		EUR	ASI	AFR
LATID	Sum Continents								EaC		WeC	EaC	WeC		
N 90-85															
85-80	22	0			12			35	0		0				
80-75	57	80			31			168	0		0	0	0		
75-70	115	1612			96			1823	10		10	0	0		
70-65	595	802			570			1966	75		75	275	275		
65-60	645	215			653			1512	152		152	504	504		
90-60	1434	2708			1362			5504	237		237	779	779		
60-55	412	180			943			1536	470		470	412	412		
55-50	403	489			887			1779	575		575	403	403		
50-45	478	48			1209			1735	727		727	478	478	0	
45-40	500	117			225			843	148		148	500	500	0	
40-35	140	336	30		164			669	120		120	178	140	8	30
35-30	1	1165	64		224			1454	211		211	71	1	6	64
60-30	1933	2336	94		3653			8016	2252		2252	2041	1933	15	94
30-25		246	11		785			1041	773		773	11			11
25-20		2363	2		140			2505	95		95	1			1
20-15		1443	22		515			1980	412		412	14			14
15-10		1059	92		270	266		1688	190	266	456	78			78
10-5		437	488		130	1751		2807	68	1698	1767	476			476
5-0		878	662			445		1985		183	183	650			650
30-0		6425	1277		1841	2462		12007	1539	2147	3686	1229			1229
N 90-0	3367	11470	1371		6856	2462		25526	4028	2147	6175	4049	2712	15	1322
S 0-5		1640	283	221		7315		9459		7272	7272	240			240
5-10		639	1553	659		45		2896		33	33	1494			1494
10-15		5	277	248		143		673		125	125	44			44
15-20			562	222		82		866		74	74	13			13
20-25			122	38		73		233		73	73	3			3
25-30			52	23		41		115		40	40	10			10
0-30		2284	2849	1410		7699		14242		7616	7616	1804			1804
30-35			30	57		932		1019		914	914	4			4
35-40				125		159		285		53	53				
40-45				194		213		406		35	35				
45-50			0	57		122		180		13	13				
50-55				0		203		203		54	54				
55-60				0		5		5		5	5				
30-60		0	30	434		1635		2098		1075	1075	4			4
S 0-60		2284	2879	1844		9333		16340		8691	8691	1808			1808
G 90-60	3367	13754	4250	1844	6856	11796		41867	4028	10838	14866	5856	2712	15	3130

		NAM	EUR	ASI	NPO		ASI	AUS	PAC		NAM	SAM	NPO	ATL	IND	PAC	SEA
LATID		NoC			SoC		EaC		WeC	WeC	WeC		Sum Coasts				
N 90-85																	0
85-80		12	22	0	35								35	0			35
80-75		31	57	80	168								168	0			168
75-70		86	115	1612	1813								1813	10			1823
70-65		495	320	800	1615		1		1	0	0		1615	350		1	1966
65-60		303	140	6	450		209		209	198	198		450	656		407	1512
90-60		927	655	2498	4080		210		210	198	198		4080	1015		408	5504
60-55							180		180	473	473			883		653	1536
55-50							489		489	312	312			978		801	1779
50-45	ASI	AFR	IND		ASI	AUS	48		48	482	482			1205		531	1735
45-40	EaC		WeC	EaC	WeC		117		117	77	77			648		195	843
40-35							327		327	44	44			298		371	669
35-30	5		5				1154		1154	13	13			282	5	1166	1454
60-30	5		5				2317		2317	1401	1401			4293	5	3717	8016
30-25	139	0	139				106		106	12	12			784	139	118	1041
25-20	0	1	1	1780	1780		583		583	45	45			96	1781	628	2505
20-15	0	7	7	1227	1227		217		217	103	103			426	1234	320	1980
15-10	0	15	15	217	217		843		843	80	80	0		534	231	923	1688
10-5	0	13	13	124	124		313		313	115	62	53		2242	137	428	2807
5-0		13	13	273	273		605		605	262		262		832	286	867	1985
30-0	139	49	188	3620	3620		2666		2666	618	302	315		4915	3808	3284	12007
N 90-0	144	49	193	3620	3620		5193		5193	2216	1901	315	4080	10223	3813	7409	25526
S 0-5		43	43	83	83	0	1557	221	1778	43		43		7512	126	1821	9459
5-10		59	59	144	144	0	494	659	1154	13		13		1526	204	1166	2896
10-15		233	233	20	5	15		233	233	18		18		169	253	251	673
15-20		548	548	56		56		166	166	8		8		87	605	174	866
20-25		119	119	7		7		31	31	0		0		76	126	32	233
25-30		42	42	3		3		20	20	1		1		50	45	21	115
0-30		1045	1045	313	233	81	2051	1329	3381	83		83		9420	1358	3463	14242
30-35		26	26	35		35		22	22	17		17		918	62	39	1019
35-40				5		5		120	120	107		107		53	5	227	285
40-45				0		0		194	194	178		178		35	0	371	406
45-50		0	0					57	57	109		109		13	0	167	180
50-55										149		149		54		149	203
55-60										0		0		5		0	5
30-60		26	26	40		40		393	393	560		560		1078	67	953	2098
S 0-60		1071	1071	354	233	121	2051	1723	3774	642		642		10499	1425	4417	16340
G 90-60	144	1120	1264	3974	3852	121	7245	1723	8968	2859	1901	958	4080	20722	5238	11826	41867

Fig. 2 – Mean freshwater fluxes into the world oceans (1961-1990) – results for 5° latitudinal zones (km³/a)

	EUR	ASI	AFR	AUS	NAM	SAM	ANT	LAND	NAM	SAM	ATL		EUR	ASI	AFR		NAM	EUR	ASI	NPO		ASI	AUS	PAC		NAM	SAM	NPO	ATL	IND	PAC	SEA
LATID	Sum Continents								EaC		WeC	EaC	WeC					NoC			SoC		EaC		WeC	WeC	WeC		Sum Coasts				
N 90-80	22	0			12			35	0		0						12	22	0	35								35	0			35
80-70	172	1691			127			1991	10		10	0	0				117	172	1691	1981								1981	10			1991
70-60	1240	1017			1223			3479	227		227	779	779				798	461	806	2065		210		210	198	198		2065	1005		408	3479
90-60	1434	2708			1362			5504	237		237	779	779				927	655	2498	4080		210		210	198	198		4080	1015		408	5504
60-50	815	670			1830			3315	1046		1046	815	815			ASI	AFR	IND		ASI	AUS	670		670	784	784			1861		1454	3315
50-40	977	166			1435			2578	875		875	977	977	0		EaC		WeC	EaC	WeC		166		166	560	560			1852		725	2578
40-30	141	1501	94		388			2123	331		331	249	141	15	94	5		5				1481		1481	57	57			580	5	1538	2123
60-30	1933	2336	94		3653			8016	2252		2252	2041	1933	15	94	5		5				2317		2317	1401	1401			4293	5	3717	8016
30-20		2609	13	0	925			3547	868		868	11			11	139	1,4	140,7	1780	1780		690	0	690	57	57			880	1920	747	3547
20-10		2502	114	0	786	266		3668	602	266	868	92			92	0	22	22	1443	1443		1059	0	1059	183	183	0		960	1465	1242	3668
10-0		1314	1151	0	130	2196		4792	68	1881	1950	1125			1125	0	25	25	397	397		917	0	917	377	62	315		3075	422	1295	4792
30-0		6425	1277	0	1841	2462		12007	1539	2147	3686	1229			1229	139	49	188	3620	3620		2666	0	2666	618	302	315		4915	3808	3284	12007
N 90-0	3367	11470	1371	0	6856	2462		25526	4028	2147	6175	4049	2712	15	1322	144	49	193	3620	3620		5193	0	5193	2216	1901	315	4080	10223	3813	7409	25526
S 0-10		2279	1836	880		7360		12355		7305	7305	1734			1734		102	102	228	228	0	2051	880	2931	56		56		9038	330	2987	12355
10-20		5	839	470		225		1538		199	199	57			57		782	782	76	5	71		399	399	26		26		256	858	424	1538
20-30			174	61		114		349		113	113	13			13		161	161	10		10		51	51	1		1		126	171	52	349
0-30		2284	2849	1410		7699		14242		7616	7616	1804			1804		1045	1045	313	233	81	2051	1329	3381	83		83		9420	1358	3463	14242
30-40			30	182		1091		1304		967	967	4			4		26	26	40		40		142	142	124		124		971	67	266	1304
40-50			0	251		335		586		48	48						0	0	0		0		251	251	287		287		48	0	538	586
50-60						209		209		60	60														149		149		60		149	209
30-60		0	30	434		1635		2098		1075	1075	4			4		26	26	40		40		393	393	560		560		1078	67	953	2098
S 0-60		2284	2879	1844		9333		16340		8691	8691	1808			1808		1071	1071	354	233	121	2051	1723	3774	642		642		10499	1425	4417	16340
G 90-60	3367	13754	4250	1844	6856	11796		41867	4028	10838	14866	5856	2712	15	3130	144	1120	1264	3974	3852	121	7245	1723	8968	2859	1901	958	4080	20722	5238	11826	41867

Fig. 3 – Mean freshwater fluxes into the world oceans (1961-1990) – results for 10° latitudinal zones (km³/a)

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