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Appendix

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Appendix

Appendix A

A1 Available data from GEMStat (1990–2010)

Table A.1: Overview of data availability in the time period 1990-2010 based on GEMStat. Stations were assigned to global river basins (Source: Major River Basins of the World/Global Runoff Data Centre. Koblenz, Germany: Federal Institute of Hydrology BfG). Maximum number of measured parameters = 26. Number of measurements = all measurements of all parameters of all stations within a river basin.

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
North-Africa	Nile	1990-2010	2	15	425
	Oum-Er-Rbia River	1994-2010	1	13	2,186
	Sebou	1990-2010	2	14	3,098
South-Africa	Groot Kei	1990-2010	1	9	1,394
	Groot Vis	1990-2010	1	9	1,686
	Incomati	1990-2009	1	9	1,452
	Indian Ocean Coast	1990-2010	3	9	1,730
	Limpopo	1990-2010	7	9	4,877
	Olifant	1990-2010	1	9	972
	Orange	1990-2010	5	10	6,281
	South Atlantic Coast	1990-2010	1	9	1,874
	Tugela	1990-2010	2	10	1,734
West-Africa	Niger	1992-1996	7	12	463
	Pra	1991-1994	1	11	283
	Senegal	1991-2000	5	11	129
	Volta	1991-1995	1	12	331
Central-America	Colorado (Caribbean Sea)	1990-1996	17	14	2,790
	Grijalva-Usumacinta	1990-1996	2	15	1,366
	Panama Canal	2003-2010	51	14	16,296
	Panuco	1990-1996	1	15	369
	Papaloadan	1990-1996	1	16	622
	Rio Boqueron	2003-2010	1	14	1,075
	Bravo	1990-1996	2	16	1,134
	Santiago-Lerma-Chapala	1990-1996	1	16	257
North-America	Alabama	1990-2001	4	2	307
	Alsek	1992-2004	1	5	172
	Churchill	1990-1997	1	9	181
	Fraser	1990-2004	3	8	1,371
	Hudson	1990-2001	8	9	383
	Mackenzie	1990-2004	4	9	749
	Mississippi	1990-2005	59	11	5,427
	Nelson-Saskatchewan	1990-1997	3	9	600
	Bravo	1990-2005	16	10	2,509
	Sacramento	1990-2002	12	10	694
	Skeena	1990-2004	1	7	561
	St. Croix	1990-1996	1	6	281
	St. John	1992-1994	1	7	69
	St. Lawrence	1990-2005	9	9	891
	Susquehanna	1990-1995	1	10	307
	Yukon	1990-2005	6	9	490

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
South-America	Amazon	1993–2010	461	17	7,223
	Doce River	1997–2010	3	14	1,578
	Guandu River	2001–2010	1	11	1,198
	Jequitinhonha River	1997–2010	3	14	1'457
	Meia Ponte River	2001–2010	1	11	357
	Oyapock	2004	4	5	20
	Paraguacu River	2008–2010	2	11	240
	Parana	1990–2010	169	19	19,660
	Parnaiba	1992–2010	20	14	500
	Sao Francisco	1990–2010	45	16	2,487
	Tocantins	1996–2010	82	15	1,176
	Uruguay	1990–2010	37	15	1,479
East-Asia	Bei Jiang/His	1990–1996	2	15	1,268
	Chang Jiang	1990–1997	3	17	2,276
	Han	1990–2010	3	13	2,939
	Hwang Ho	1990–1997	2	15	1,306
	Japan*	1990–2010	17	18	31,117
	Liao	1990–1997	1	12	892
	Min	1990–1996	1	12	810
	Qiantang	1990–1996	1	12	655
South-Asia	Cauvery	1990–2008	8	15	12,112
	Chaliyar	1990–2008	2	15	4,124
	Ganges-Brahmaputra-Meghna	1994–2010	5	10	513
	Godavari	1990–2008	6	15	8,273
	Indus	1990–2003	4	15	4,589
	Krishna	1990–2008	7	15	13,664
	Mahandi	2001–2008	5	15	2,960
	Mahi	1990–2008	2	15	3,450
	Narmada	1990–2008	5	15	6,260
	Penner	1990–2008	1	15	991
	Periyar	1990–2008	2	15	4,126
	Sabarmati	1990–2008	3	15	4,082
	Sahyadri	1990–2008	10	15	8,329
	Sri Lanka*	2003–2010	27	12	12,198
	Subarnerekha	1992–2008	4	14	3,915
	Tapti	1990–2008	4	15	6,503
South-East-Asia	Chao Phraya	1990–1993	3	11	308
	Indonesia*	1990–1994	6	15	2,163
	Mekong	1990–2009	72	14	50,107
East Europe	Amur	1990–2010	2	8	822
	Danube	1990–1996	2	9	937
	Don	1990–2010	1	8	347
	Dvina-Pechora	1990–2010	5	8	3,070
	Kolyma	1990–2010	1	7	590
	Lena	1990–2010	2	7	620
	Narva	1990–2010	2	7	391
	Ob	1990–2010	9	7	5,611
	Oder	1992–2003	3	9	3,297
	Vistula	1992–2003	3	8	3,168
	Volga	1990–2010	4	7	2,059
	Yenisey	1990–2010	5	7	3,608

Subregion	River basin	Data available from–to	No. of stations/ RB	No. of measured parameters	No. of measurements
Northern Europe	Dee	1990–2005	1	9	923
	Denmark*	1990–1996	4	5	1,070
	Forth	1990–2005	1	9	1,165
	North West England	1990–2005	1	10	1,213
	Northumbria	1990–1995	3	4	598
	Oulu	1993–1995	1	3	101
	Pasvik	1993–1995	1	3	95
	Severn	1990–2005	1	11	1,154
	South West	1990–2005	1	11	1,247
	Thames	1990–2005	1	11	1,110
	Torne	1990–1998	2	7	304
	Trent	1990–2005	1	11	1,253
	Tweed	1990–1996	1	10	827
Southern Europe	Douro	1990–1995	7	5	1,799
	Ebro	1990–1995	3	5	991
	Guadalquivir	1990–1995	3	5	903
	Guadiana	1990–1995	4	5	1,047
	Italy*	1990–1995	8	6	1,609
	Po	1990–1995	8	6	2,295
	Portugal*	1990–1994	2	5	478
	Tagus	1990–1995	6	10	1,872
	Turkey*	1993–2002	7	4	1,170
Western Europe	Danube	1990–1996	7	9	660
	Elbe	1990–1995	4	9	830
	Garonne	1990–1996	4	8	1,224
	Loire	1990–1996	5	8	2,062
	Meuse	1990–2010	18	12	7,178
	Oder	1993–1995	1	4	138
	Rhine	1990–2003	19	12	10,708
	Rhone	1990–2002	8	9	4,729
	Schelde	1990–2010	49	13	25,045
	Seine	1990–1996	4	9	1,904
	Weser	1990–1995	2	9	666
	Yser	2001–2010	3	11	1,671

*Not all of GEMStat stations could be assigned to a river basin. In this case, the number of stations, measurements, and parameters of a country were listed.

Appendix B

B1 WorldQual – model description

B1.1 The modelling framework

WorldQual is a continental scale water quality model used to increase understanding of large scale water quality patterns, support large scale assessments of water quality degradation, and relate water quality degradation to threats to human health, food security, and aquatic ecosystems.

WorldQual simulates loadings and in-stream concentrations of different water quality parameters on a 5 by 5 arc minute spatial grid (about 9 by 9 km at the equator). It has been tested and applied in several previous studies, e.g. Malve et al. (2012), Punzet at al. (2012), Reder et al. (2013), Reder et al. (2015), Voß et al. (2012), and Williams et al. (2012).

WorldQual calculates loadings to rivers and the resulting in-stream concentrations based on the hydrological information simulated by WaterGAP3 (see below) and based on standard equations of water quality dynamics. It has a monthly temporal resolution. Up to now it has been used to simulate biochemical oxygen demand (BOD5), faecal coliform bacteria (FC), total phosphorus (TP), total nitrogen (TN) and total dissolved solids (TDS) (Malve et al., 2012; Voß et al., 2012; Reder et al., 2013; Reder et al., 2015; Williams et al., 2012).

WorldQual is linked to a global integrated water model "WaterGAP3" within a common modeling framework. WaterGAP3 is made up of two main components: (i) a water balance model to simulate the characteristic macro-scale behavior of the terrestrial water cycle in order to estimate water availability (Alcamo et al., 2003; Müller Schmied et al., 2014; Schneider et al., 2011; Verzano 2009; Verzano et al., 2012), and (ii) a water use model to estimate water withdrawals and consumptive water uses for agriculture, industry, and domestic purposes (aus der Beek et al., 2010; Flörke et al., 2013). WaterGAP3 also operates on a 5 x 5 arc minute spatial resolution (see Figure B.1).

Using a time series of climatic data as input, the hydrological model calculates the daily water balance for each grid cell, taking into account physiographic characteristics such as soil type, vegetation, slope, and aquifer type. Runoff generated on the grid cells is routed to the rier basin outlet on the basis of a global drainage direction map (Lehner et al., 2008), taking into account the extent and hydrological influence of lakes, reservoirs, dams, and wetlands. The climate input for the hydrology model consists of precipitation, air temperature, and solar radiation. These data come from the WATCH data set (Water and Global Change) applied to ERA-Interim data (WFDEI) for the time period 1979–2010 (Weedon et al. 2014). The climate data have a temporal resolution of one day and a spatial resolution of 0.5° by 0.5° (latitude and longitude, respectively) downscaled to the 5 arc minute grid cells.

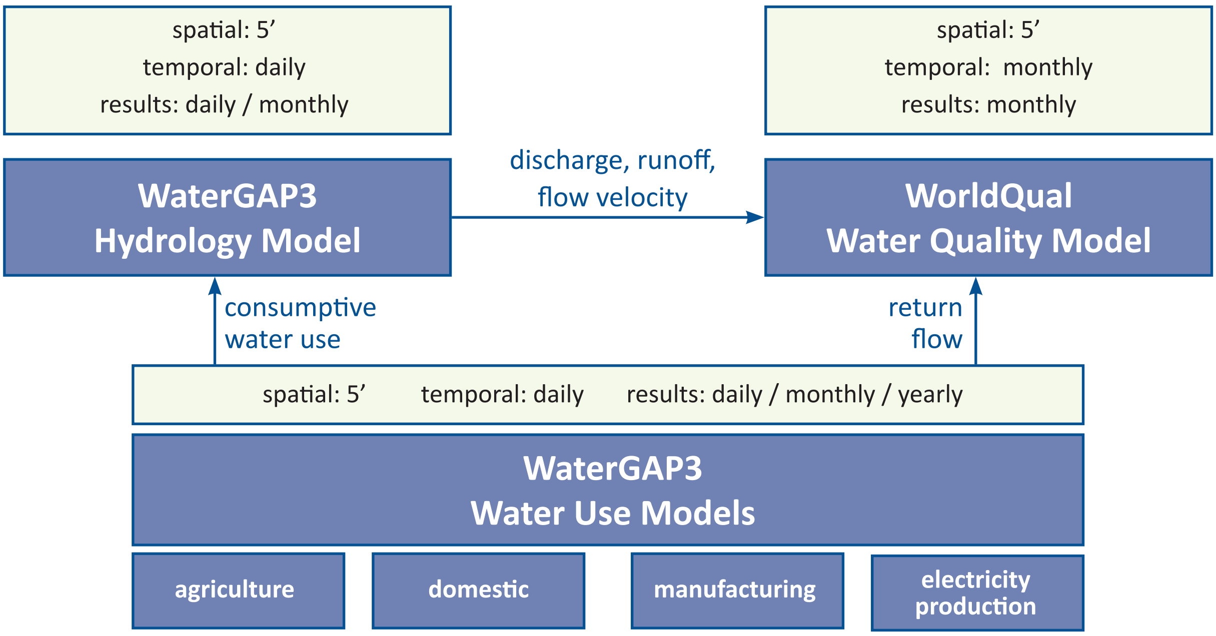

Figure B.1: Overview of the WaterGAP3 modelling framework (Verzano 2009, modified).

B1.2 Pollution loadings

B1.2.1 Sources of pollution

Loadings are calculated for point sources and diffuse sources for the following parameters:

- faecal coliform bacteria (FC; pathogen pollution),
- biological oxygen demand (BOD; organic pollution),
- total dissolved solids (TDS; salinity pollution), and
- total phosphorous (TP; eutrophication).

Figure B.2 illustrates the point and diffuse sources represented in the WorldQual model. Point sources include domestic sewered wastewater, wastewater from manufacturing industries and urban surface runoff. Diffuse sources include agriculture and background. The model also takes into account non-sewered domestic sources, of which some sources are handled as point sources, and some as diffuse sources (See B1.2.3).

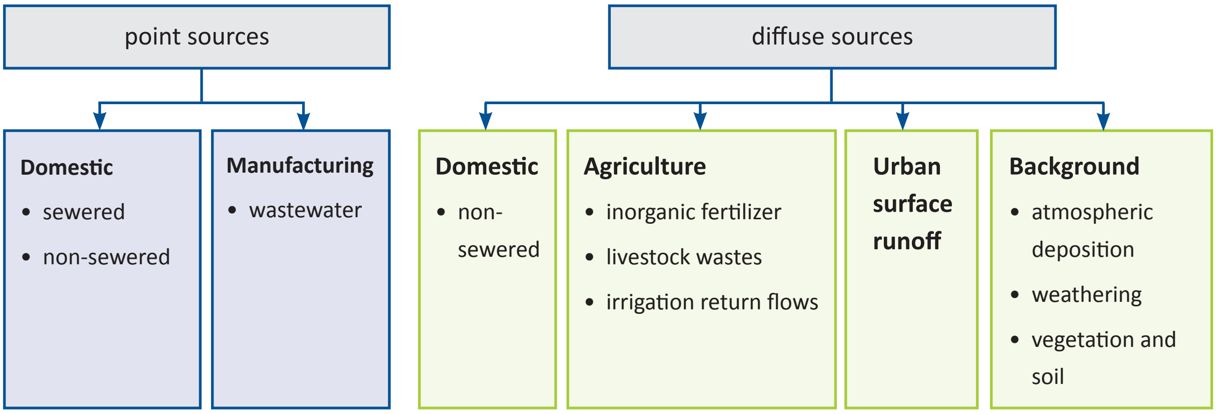

Figure B.2: Pollutant loading sectors in WorldQual categorized as either point sources or diffuse sources.

B1.2.2 Domestic sewered sector

Loadings from the domestic sewered sector are calculated on a grid cell level by multiplying a per capita emission factor (BOD, FC, TDS, and TP) with the urban and rural populations connected to a sewage system (Williams et al., 2012). The resulting domestic sewered loadings are then abated depending on the level of wastewater treatment. National values for percentages of primary, secondary, and tertiary wastewater treatment of sewage treatment plants (STPs) are downscaled to the grid-cell level to define a cell-specific reduction rate. Additionally, reduced treatment efficiency due to deficiencies of STPs is taken into account. Data are available from the WHO/UNICEF Joint Monitoring Programme (2013) for the years 1990, 2000 and 2010. These data are applied to the years 1990–1995, 1996–2004 and 2005–2010, respectively. Further information on efficiencies of STPs were collected for several countries and applied as continental averages (Table B.1).

Gridded population data are available from the History Database of the Global Environment (HYDE) version 3.1 (Klein Goldewijk, 2005; Klein Goldewijk et al., 2010) for the time period 1990–2005. For the remaining period 2006–2010, national data from UNEP (2015) were allocated to grid cells based on the gridded population density of the year 2005.

BOD per capita emission factors were collected from the literature. If no data were available, an average per capita emission factor was calculated per region.

Table B.1: Default sewage treatment plants efficiency.

Region	Regional average [%]	Reference
Africa	58	Murray and Drechsel (2011), UNEP/GEF (2009), FAO and WHO (2003), WHO CEHA (2005), Water Affairs South Africa.(2011)
Asia	59	Tacis (2000), CPCB (2005), CPCB (2009), MoP COSIT (2011), UNECE (2009), Government of Mongolia (2012), Shukla et al. (2012), Murtaza and Zia (2012), UNDESA-DSD (2004), UNECE (2012 a, b)
Latin America	47	UNEP (1998), Ojeda and Uribe (2000), Lopera Gomez et al. (2012)

Table B.2: Default BOD per capita emission factors per GEO region.

Region	Regional average [g/cap/day]	Reference
Africa	37	Metcalf & Eddy et al. (2014), UNEP (2000), Williams et al. (2012)
Asia	40	IPCC (2006), Williams et al. (2012)
Latin America	56	Metcalf & Eddy et al. (2014), Williams et al. (2012)

Regional numbers (Table B.3) have been derived from the concentration of FC in human excreta taking into account differences in diet, climate, and state of health (Feachem et al., 1983). Assumed reduction rates for primary, secondary, and tertiary treatment are intermediate values from Dorner (2004); Endale et al. (2012); George et al. (2002), Hwang (2012), Qureshi and Qureshi (1990), Saleem et al. (2000), Samhan et al. (2007). Several values within the range given by the different references for the human per capita FC excretion were tested with the model. During this testing all parameters except the human per capita excretion were kept constant. Best results of simulated FC in-stream concentrations compared to measured FC in-stream concentrations were achieved with the numbers provided in Table B3 (see Reder et al., 2015).

Table B.3: Default FC per capita emission factors per GEO region. Regional differences arise from diet, climate, and state of health.

Region	Regional average [cfu*/cap/year]	Reference
Africa	$170*10^{10}$	Feachem et al. (1983), Finegold (1969), Maier et al. (2009), Moore and Holdeman (1974); Reder et al. (2015), Schueler and Holland (2000), van Houte and Gibbons (1966), Zubrzychi and Spaulding (1962).
Asia	$700*10^{10}$	
Latin America	$500*10^{10}$	

* cfu: colony forming unit

Based on UNEP (2000) and Mesdaghinia et al. (2015) a TDS emission factor of 100 g/cap/day was assigned to all three continents.

The TP per capita emission factors were calculated as follows. First, the protein per capita consumption per country and year was used from FAOSTAT (FAO, 2014). It is assumed that about 16 per cent of the protein is nitrogen whereof, on average, 36.5 per cent is excreted by the human digestive tract (van Drecht et al., 2009). Second, the TP per capita emission is about one-sixth of the nitrogen emission (van Drecht et al. 2004). Continent-specific averages of protein consumption were taken in case country-specific protein consumption data were not available.

B1.2.3 Domestic non-sewered sector

For the human waste produced where sewers are not used, three types of sanitation practices are accounted for: (i) waste produced with some type of private on-site disposal, such as septic tanks, pit toilets, bucket latrines etc. (diffuse source), (ii) waste produced where people practice open defecation (diffuse source), and (iii) waste produced where people use hanging latrines (point source).

Waste loadings from onsite disposal (e.g. septic tanks) are calculated by multiplying a per capita emission factor with the population connected to these disposal types. A release factor is applied to estimate the final loading which enters the stream.

Waste loadings from open defecation are calculated by multiplying the emissions per capita per year times a release rate of 0.1 per cent (from Section B1.2.7). This annual loading is then transported to a stream on a monthly basis proportional to monthly runoff from WaterGAP3. The emissions per capita for BOD, FC, TDS, and TP follow the assumptions in Section B1.2.2.

Waste loadings from hanging latrines are calculated by multiplying the emissions per capita per year times the population using this sanitation practice. No reduction takes place as the feces are directly disposed into the surface waters.

Data on different sanitation practices are derived from the WHO/UNICEF Joint Monitoring Programme (JMP) for Water Supply and Sanitation country files between 1980 and 2011 (JMP, 2013), national databases, reports, and a literature search. As for the domestic sewered sector, data are only available for the years

1990, 2000, and 2010, and assumed to be unchanged over 5 year periods.

B1.2.4 Manufacturing sector

Loadings from the manufacturing sector are calculated by multiplying the average raw effluent concentration times the return flow from manufacturing industries (Williams et al., 2012). The manufacturing load is reduced by a reduction factor depending on the treatment level following the assumptions made for the domestic sector. Treatment rates and deficiencies of sewage treatment plants are assumed to be the same as in the domestic sewered sector. Manufacturing wastewater volumes are calculated by the water use model of WaterGAP3.

A representative value of 400 mg/l was assigned to the effluent concentration of BOD from industrial sources based on literature (Al-Kdasi et al., 2004; Azmi and Yunos, 2014; EEAA, 2002; Haydar et al., 2014; Mortula and Shabani, 2012; UNEP, 1998; UNEP, 2000; Williams et al., 2012).

For TDS, the effluent concentration was assumed to be 3000 mg/l according to Al-Kdasi et al., 2004; Azmi and Junos, 2014; EEAA, 2002; Haydar et al., 2014; Jain et al., 2003; Kang and Choo, 2003; Metcalf & Eddy, 2014; Mortula and Shabani, 2012; Tas et al., 2009; Williams et al., 2012).

For FC, the effluent concentration was assumed to $3.55*10^6$ cfu/100ml according to Ayoub et al. (2000), Bordner and Carrol (1972), Caplenas et al. (1981), Caplenas and Kanarek (1984), Clark and Donnison (1992), Das et al. (2010), Ekundayo and Fodeke (2000), Gauthier and Archibald (2001), Hoyle-Dodson (1993), Knittel et al. (1977), McCarthy et al. 2001), Megraw and M. Farkas (1993), Pramanik and Abdullah-Al-Shoeb (2011).

For TP raw effluent concentrations from Europe (6.2 mg/l) are also applied to industrial sources in Africa, Asia and Latin America (Demirel et al., 2005; Johns, 1995; Gönen, 2005; Kim et al., 2007).

B1.2.5 Urban surface runoff

Loadings generated from urban surface runoff are calculated by multiplying the typical event mean concentration by the urban surface runoff produced on each cell (Williams et al., 2012). The resulting load is assumed to be reduced to the same treatment levels assumed for the domestic sewered sector. The hydrology module of WaterGAP3 provides the urban surface runoff rates.

Assumptions and literature for the event mean concentrations (EMCs) of BOD and TDS for different sub-regions are shown in Tables B.4 and B.5.

Table B.4: Default BOD event mean concentrations (EMC).

Region/Sub-region	Regional EMC* [mg/l]	Reference
Northern Africa, South Africa	19	Chrystal (2006)
Central Africa, Eastern Africa, Western Africa, Southern Africa (except South Africa)	62	Adedeji and Olayinka (2013), Adekunle et al. (2012), Alo et al. (2007)
South Africa	12	Chrystal (2006)
West Asia	19	Chrystal (2006)
Asia and the Pacific	105	Choe et al. (2002), Chow et al. (2013), Dom et al. (2012), Ho & Quan (2012),Luo et al. (2009), Karn & Harada (2001), Lee & Bang (2000), Li (2010), Maniquiz et al. (2010), Nazahiyah et al. (2007), Sharma et al. (2012), Yusop et al. (2005)
Latin America	12	Derived from Europe

Table B.5: Default TDS event mean concentrations (EMC).

Region/Sub-region	Regional EMC [mg/l]	Reference
Africa	178	Wondie (2009)
Asia	246	Sharma et al. (2012), Zope et al. (2008)
Latin America	205	Al-Houri et al. (2011)

FC event concentrations vary widely. For example, they were measured to be around 10^4 cfu/100ml to 10^6 cfu/100ml in stormwater runoff in South Africa (Jagals, 1997), 10^9 cfu/100 ml in China (Thomann and Mueller, 1987), and 10^4 to 10^6 in the USA (Erickson et al. 2013). An intermediate value of 10^6 cfu/100 ml was assumed for all three continents.

An average TP event mean concentration of 2.04 mg/l was assumed for all three continents based on Lee and Bang (2000), Ho and Quan (2012), Luo et. al (2009), and Taebi and Droste (2004).

B1.2.6 Agricultural inorganic fertilizer

Inorganic fertilizer is assumed to be applied to all agricultural grid cells and is an important source of TP loadings. Baseline fertilizer application rates of phosphorus were estimated from FAO (2006) for the 21 different crop types distinguished by the WaterGAP3 model. The baseline data are representative for the time period 1995 to 1999.

For earlier and later time periods, baseline data are scaled by national fertilizer application rates (IFA, 2014) averaged over 5-years-periods 1990–1994, 2000–2004 and 2005–2010. (Five year periods are used to smooth out uncertainties of annual fertilizer use.)

TP loadings from industrial fertilizer that reach the surface water system are calculated as a function of land surface runoff and soil loss.

B1.2.7 Agricultural livestock wastes

To calculate the amount of BOD, FC, TDS, and TP loadings from livestock (manure) the approach of Sadeghi and Arnold (2002) is applied. Here, the amount of the relevant constituent in manure is multiplied with an appropriate release rate and the surface runoff. The amounts of BOD, FC, TDS, and TP in different types of manure are derived from ASAE (2003) and SCS (1992). To consider different levels of animal nutrition on different continents, the amount of manure constituents are corrected by a livestock conversion factor from FAO (2003) following the approach of Potter et al. (2010) for nutrients. For FC and BOD the release rates of manure vary with manure type and differ according to the source of literature (e.g. EPA, 2003; Ferguson et al., 2007). The best estimate of release rates was found to be 0.1 per cent. Release rates for TP are calculated as a function of land surface runoff and soil erosion. The decay of FC contained in stored manure or after manure is applied to soil is described by Chicks law (Crane and Moore, 1986). The FC decay rate in this case is assumed to be the same as in Europe (Reder et al., 2015). Manure application is assumed to take place all year round because of the continuous presence of livestock. To calculate the wash-off of pollutants from land surfaces, the land surface runoff from the hydrology module of WaterGAP3 is used.

B1.2.8 Agricultural irrigation

In WorldQual TDS loadings from irrigated agriculture were estimated by multiplying a mean irrigation drainage concentration by the irrigation surface return flows calculated by the water use model of WaterGAP3. Mean irrigation drainage concentrations show high variations from 1,000 mg/l up to 8,000 mg/l in Asia. To account for the regional differences, salt emission potential classes (SEPC) were defined as described in Voß et al. (2012) and Williams et al. (2012). The definition of SEPC is based on natural salt classes (SC) and the gross domestic product per capita classes (GDPC). Natural SC are a combination of primary salt enriched soils (S) and arid–humid climate conditions (H). The highest SEPC was set to 3,500 mg/l for developing countries (Bakker et al., 1999; Chen et l., 2011; Irrigation Department Lahore, 2014; World Bank, 1999), while the lowest SEPC was set to 165 mg/l (cf. B1.2.9). These values reflect the range from arid regions with salt affected soils and low irrigation technique standards (highest SEPC class) to humid regions with no salt affected soils, and likely high irrigation technique standards (lowest SEPC class).

B1.2.9 Background loadings

A certain amount of phosphorus enters drainage basins in the form of atmospheric deposition. In the present study, global gridded estimates of TP deposition rates were taken from Mahowald et al. (2008). Additionally, natural phosphorus loads also originate from weathering. WorldQual's estimates of P-release by chemical weathering are derived from data of the global analysis of Hartmann et al. (2014).

Large amounts of background salinity in rivers come from weathering processes or surface salt deposits in river basins. Background concentrations of TDS were estimated by averaging GEMStat TDS measurements from pristine stations and sorting these data according to 55 soil types from the FAO Harmonized World Soil Database (Fischer et al. 2008). These data were then applied as background concentrations in each grid cell according to the type of soil in that grid cell. For respective soil types, these background TDS concentrations ranged between 5 mg/l and 832 mg/l. However, about 10 per cent of all river reaches have natural background greater than 450 mg/l the level used in this pre-study to designate "moderate" salinity pollution. For soil types not covered by GEMStat measurements, an average background concentration of 165 mg/l was used.

B1.3 Calculation of in-stream concentrations

River concentrations are computed by combining the loadings of the various substances with the dilution capability of the river discharge in each grid cell. Non-conservative substances (FC and BOD) then decay downstream. Standard one dimensional stream equations from Thomann and Mueller (1987) as described in Voß et al. (2012) are used for these calculations. These equations perform a mass balance between loadings and receiving water and account for the decay of non-conservative pollutants as they travel downstream by assuming first order decay.

The decay coefficient of BOD is assumed to be a function of river temperature (Thomann and Mueller, 1987, Punzet et al., 2012). The decay coefficient of FC is assumed to be a function of solar radiation, temperature, and the settling rate of bacteria (Thomann and Mueller, 1987; Reder et al., 2015). TDS is modelled as a conservative substance with no decay.

The final concentration of each grid cell is routed towards the river mouth following a high-resolution drainage direction map (Lehner et al., 2008).

B1.4 TP retention in surface waters

TP retention is calculated on river basin scale. The conceptual approach and the parameter settings are based on Behrendt et al. (2002), where nutrient retention is empirically calculated with hydraulic load (Behrendt and Opitz, 1999). Hydraulic load is defined as the annual runoff as calculated by WaterGAP3 divided by the surface area of the respective lake (Hejzlar et al., 2009).

B1.5 Model testing

Data used for model calibration and testing were kindly provided from national and international databases of the Agencia Nacional de Aguas, Brasil; Department of Water and Sanitation, Republic of South Africa; Dirección Ejecutiva de la Comisión Trinacional para el desarrollo de la Cuenca del Río Pilcomayo; Instituto de Hidrología, Meteorología y Estudios Ambientales, Colombia; Instituto Nacional de Meterologia e Hidrologia (INAMHI), Ecuador; Mekong River Commission; Ministerio del Medio Ambiente, Gobierno de Chile, Chile; Pollution Control Department (PCD), Ministry of Natural Resources and Environment, Thailand; Secretaría de Ambiente y Desarrollo Sustentable de la Nación (SADS), Argentina; United Nations Global Environment Monitoring System (GEMS) Water Programme; Water Resources Information System of India, India, and literature research.

Biochemical Oxygen Demand Model

The BOD model calculations are compared to observations in Figure B.3a. This figure contains measured data from 2902 Latin American stations (in total 36,756 measurements), 21 African stations (in total 523 measurements), and 648 Asian stations (in total 41,851 measurements). The agreement of model outcomes with observations is considered acceptable considering the approximations of the model, the uncertainties in the data, and the scale of the coverage of the model. Thousands of points are quite close to the 1:1 line in Figure B.3a but not visible because they are overlapping.

An important criterion for judging the performance of any model is to consider the purpose of the model and modelling application. In the case of this pre-study, the purpose of the model was not to compute concentrations exactly, but to estimate "pollution classes" (e.g. low, moderate, severe) as defined in Chapter 3, Table 3.8 for BOD, for example. Results in this form are more meaningful for assessments because they conform to the approach used by countries and river basin managers to interpret the status of their own freshwaters (national water quality standards typically divide the range of water quality conditions into "high", "low" and "medium" classes of water quality).

Figure B.3b shows that the model computes the same pollution class for BOD as observed in two-thirds of the grid cells with measurements. In more than 80 per cent of the grid cells the model computes the correct class plus or minus one class.

Faecal Coliform Bacteria Model

The model results of FC versus observations are shown in Figure B.4a. The following measurements were available for this comparison: 2818 Latin American stations (in total 47,888 measurements), 485 African stations (in total 14,068 measurements), and 501 Asian stations (in total 24,577 measurements). Again, most of these measurements are close to the 1:1 line, but not visible because they overlap.

The model performance as indicated by the scatter plot (B.4a), and comparison of FC pollution classes (B.4b) is as satisfactory as that of BOD.

Total Dissolved Solids Model

A comparison of calculated versus observed TDS is shown in Figure B.5a. The figure is based on a set of measurements that were available for Latin America, Africa and Asia: 760 Latin American stations (in total 18,040 measurements), 1,544 African stations (in total 162,551 measurements), and 655 Asian stations (in total 33,656 measurements).

The scatter plot (Figure B.5a) shows the same spread as for BOD and FC. However, the agreement between model and observations is not as symmetrical as it is for BOD and FC, indicating more bias in the TDS model than in the other models. On the other hand, the comparison of computed and observed pollution classes (Figure B.5b) shows a more than 80per cent agreement in pollution classes between model results and observations. In 90 per cent of the grid cells the model computes the correct class plus or minus one class.

Total Phosphorus (TP) Loading Model

The testing for phosphorus was somewhat different than for BOD, FC or TDS, because in this pre-study the model was used only to compute the loadings of total phosphorus from lake basins into lakes, not the in-stream concentrations of phosphorus.

In testing the model, its performance was examined through computing TP loads from both lake basins and river basins due to insufficient lake data, and because the model should perform equally well in computing loads from large lake basins as large river basins.

A comparison of calculated versus measured TP loadings into selected lakes is given in Figure B.6. Far fewer data were used for this comparison than for the other water quality parameters. For this selection of data, agreement of the model with measurements is quite good.

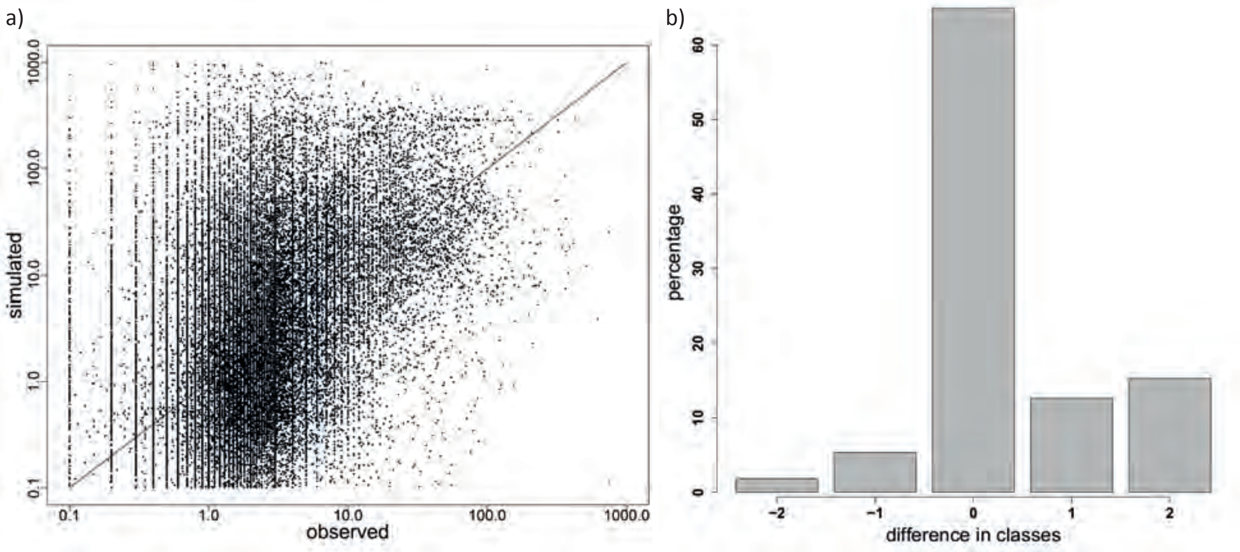

Figure B.3: a) Observed versus calculated (WorldQual) biochemical oxygen demand for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Vertical streaks of data are an artefact of data collection and processing. Units are in mg/l. b) Measured and simulated BOD in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.8) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. Same data set as for Figure B.3 (a).

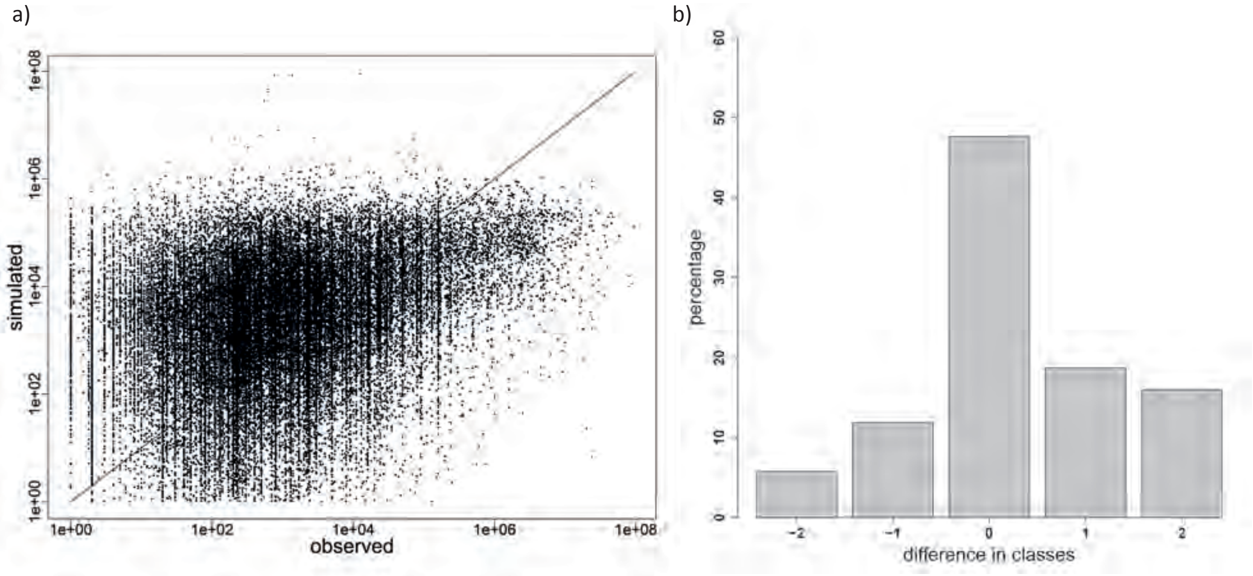

Figure B.4: a) Observed versus calculated (WorldQual) faecal coliform bacteria for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Vertical streaks of data are an artefact of data collection and processing. Units are in cfu/100ml. b) Measured and simulated FC in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.1) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. Same data set as for Figure B.3 (a).

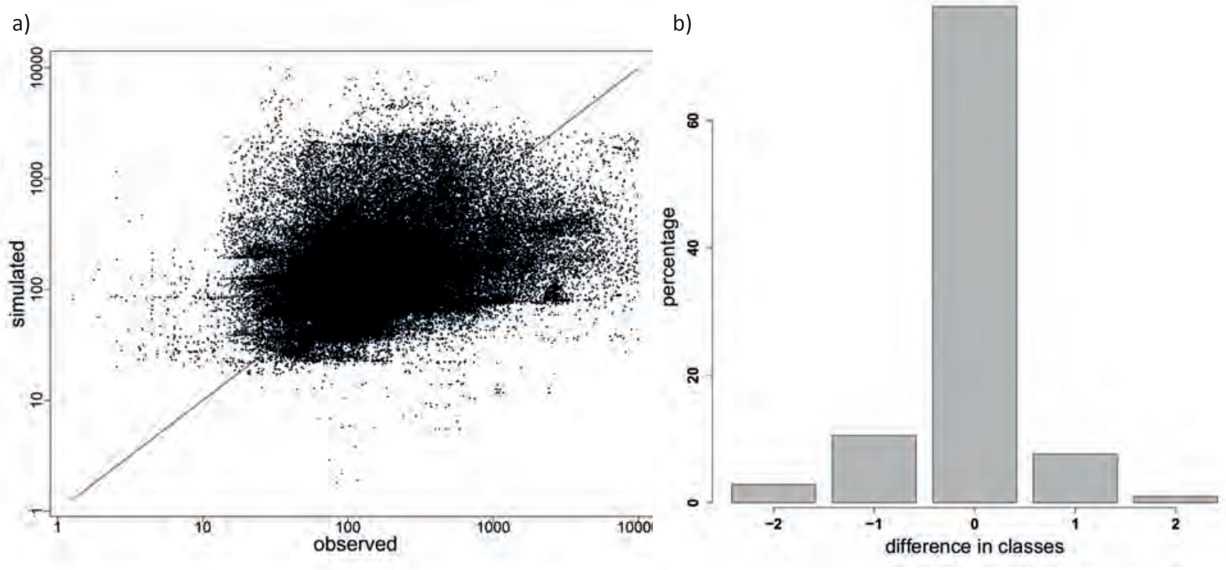

Figure B.5: a) Observed versus calculated (WorldQual) total dissolved solids for the period 1990–2010 for stations from Latin America, Africa, and Asia between 1990 and 2010. Units are in mg/l. b) Measured and simulated TDS in-stream concentrations were grouped into three water pollution classes which were derived from thresholds given by governments and international organizations. The difference in classes between observed and simulated in-stream concentrations was determined and displayed as percentage of grid cells (having measurements) in which a difference occurred between the observed class (see Table 3.12) and the computed pollution class. "0" indicates that there was no difference between the observed and computed pollution class. GEMStat data are not used for this scatter plot so as to avoid overlap with the stations used to estimate TDS background concentrations (Section B1.2.9). Also stations influenced by marine saltwater intrusion were omitted.

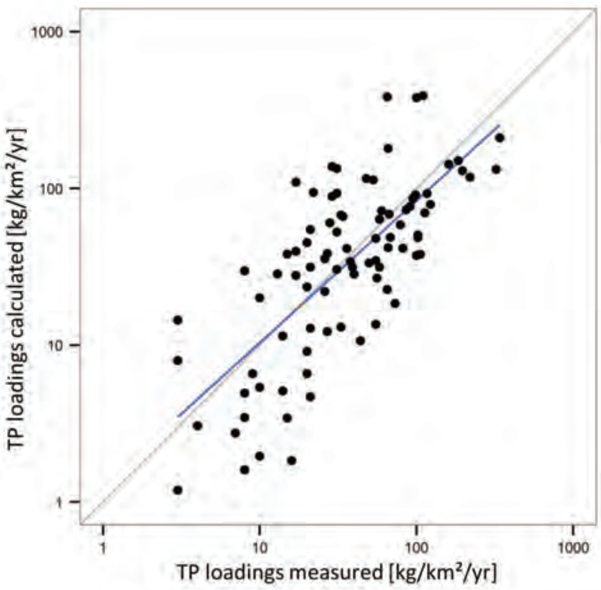

Figure B.6: Observed versus calculated (WorldQual) total phosphorus loads per lake basin or river basin area for the period 1990–2010 for worldwide stations. Units are in kg/km^2/year.

B2 Water quality standards

To establish the thresholds of water pollution classes for FC, BOD and TDS (Tables 3.1, 3.8, 3.12 in Chapter 3.) the below water quality standards from African, Latin American and Asian countries were compiled. European and American standards were also consulted.

Table B.6: Collected FC water quality standards of different countries.

Description	Country	Reference
Water quality standards for protected areas, source water, drinking water, aquatic fauna, industry, agriculture	China	MEP (2002)
Water quality standards for primary contact, irrigation, aquaculture, sailing, and animal farming	Costa Rica	Mora and Calvo (2010)
Water quality standards for primary contact	Europe, EEC	WHO (2000)
Water quality standards for bathing and swimming, irrigation	South Africa	DWA (1996), Britz (2013)
Water quality standards for primary contact	Colombia	WHO (2000)
Water quality standards for primary contact	Cuba	WHO (2000)
Water quality standards for primary contact	Ecuador	WHO (2000)
Water quality standards for primary contact	Puerto Rico	WHO (2000)
Water quality standards for primary contact	USA, California	WHO (2000)
Water quality standards for primary contact	Venezuela	WHO (2000)
Water quality standards for primary contact	France	WHO (2000)
Water quality standards for primary contact	Uruguay	WHO (2000)
Water quality standards for primary contact	Peru	WHO (2000)
Water quality standards for primary contact	Brazil	WHO (2000)
Water quality standards for primary contact	Israel	WHO (2000)
Water quality standards for primary contact	Japan	WHO (2000)
Water quality standards for primary contact	Mexico	WHO (2000)

Table B.7: Collected BOD water quality standards of different countries.

Description	Country	Reference
Freshwater standards	Brazil	Ministry of the Environment, Brazil (1984–2012)
Agriculture water use standards	China	Ministry of Agriculture of the People's Republic of China + FAO
River water quality	Egypt	El Bouraie et al. (2011), Egyptian law 48/1982
Drinking water quality and outdoor bathing standards	India	CPCB (2007–2008)
Freshwater quality standards (fisheries, conservation)	Japan	Ministry of the Environment, Japan
Freshwater standards	Mexico	Mexican Official Standard (NOM-001-ECOL-1996)
Water quality standards for drinking water, aquatic water, and irrigation water	Pakistan	adopted from WWF (2007)
freshwater species	South Africa	DWA (1996)
Surface water quality standards	Taiwan	EPA Taiwan (2010)
Drinking water quality standards	Tanzania	Environmental Management Act (2004)
Surface water quality standards	Thailand	Pollution Control Department (2004)

Table B.8: Collected TDS water quality standards of different countries.

Description	Country	Reference
Freshwater standards	Brazil	Ministry of the Environment, Brazil (1984–2012)
Agriculture water use standards	China	FAO (2013)
River water quality	Egypt	Egyptian law 48/1982 in El Bouraie et al. (2011)
Water quality guidelines for irrigation water use	FAO	Ayers and Westcot (1985)
Water quality standards for irrigation, industrial cooling, controlled waste disposal	Japan	Ministry of the Environment, Japan
Water quality standards for domestic, industry, and agriculture water use	South Africa	DWA (1996)
Water quality standards for domestic and irrigation water use	Kenya	Water Quality Regulations (2006)
Water quality standards for irrigation water use	Morocco	Moroccan regulation on irrigation water quality (2002)
Water quality standards for drinking water use	Oman	Victor and Al-Ujaili (1999)
Water quality standards for drinking water, aquatic water, and irrigation water	Pakistan	Government of Pakistan (2008), WWF (2007)

To establish levels of concern of water quality parameters with respect to inland fisheries, water quality standards were consulted (Table 3.7 in Chapter 3).

Table B.9: Collected water quality standards also with respect to inland fisheries

Reference	Water quality parameter
EPD (2011)	Chloride
European Commission (2006)	BOD, Oxygen
Geneviève M.C. & C.J. Rickwood (2008)	Ammonia, Oxygen, pH
LAWA (1998)	Ammonia, BOD, Chloride, Oxygen
Manivanan, R. (2008)	BOD
Michigan Water Quality Standards (1994)	Oxygen, pH
U.S. EPA (1986, 2015)	Ammonia, Chloride, Oxygen, pH
UNECE (1994)	Oxygen

B3 Literature on vulnerable groups

Table B.10: Literature consulted for data on percentage of population coming in contact with polluted water, and for estimating the most vulnerable groups to pathogen pollution.

Publication	Continent/country/region within country	Most vulnerable groups (e.g. "women washing clothes, children bathing; … ")	Other vulnerable groups For example: "Poor people bathing; poor farmers using polluted irrigation water;…"
Adeoye et al. (2013)	Nigeria		
North central	children fetching water	women (more "young female" than "adult female") fetching water	
Aiga et al. (2004)	Ghana, Ashanti Region	children (2–14 years) swimming (play and exercise)	adult men fishing, fetching water, bathing
Barbir and Prats Ferret (2011)	Mozambique, N'Hambita Village, Sofala Province	women body and laundry washing	
Choy et al. (2014)	Malaysia, Peninsular (West) and Sabah (East)	people in the Peninsular Malaysia compared to the state of Sabah (East Malaysia)	children under 12 years & large households (more than 7 family members)
Day and Mourato (1998)	China, Beijing Region	children playing in and around the river	
Engel et al. (2005)	Ghana, Volta River Basin	children	
Feachem (1973)	Papua New Guinea, Highlands	women journeys to collect water	children or teenagers journeys to collect water
Gazzinelli et al. (1998)	Brazil, Nova União	children playing and fishing	
Gazzinelli et al. (2001)	Brazil, Rua da Grota	female (10–19 yrs.) using water for domestic and hygienic activities	
Kabonesa and Happy, March (2003)	Uganda	women using water for domestic purposes	children collecting water for domestic use
Lindskog and Lundquvist (1989)	Malawi, Rift Valley	women collecting water, bathing, laundry	children bathing
Manyanhaire and Kamuzungu (2009)	Zimbabwe, Mutasa District	women collecting water, bathing, doing laundry, cooking	
Mazvimavi and Mmopelwa (2006)	Botswana, Ngamiland	men carrying water for drinking and cooking	
North and Griffin (1993)	Philippines, Bicol Region	28% of poorest income quintile using water from springs, lakes, or rivers as main source	second, third and fourth income quintile using water from springs, lakes, or rivers as main source (20% each)
Sow et al. (2011)	Senegal, Ndombo village	female adolescents (10–19 yrs.) bathing, collecting water	women collecting water, household activities
Thompson et al. (2001)	Kenya, Uganda, Tanzania	women drawing water	children drawing water

B4 Lake data

Table B.11: Data for lakes used in Chapter 3.

Continent	Lake/reservoir	Basin area [million km^2]	Lake surface area [million km^2]
Africa	Victoria	0.263	0.0670
Africa	Tanganyika	0.238	0.0328
Africa	Malawi	0.130	0.0296
Africa	Turkana	0.073	0.0077
Africa	Volta	0.402	0.0074
Asia	Balkhash	0.174	0.0174
Asia	Issyk-kul	0.010	0.0062
Asia	Urmia	0.051	0.0049
Asia	Qinghai Lake	0.019	0.0044
Asia	Boeng Tonle Chhma	0.058	0.0026
Europe	Baikal	0.584	0.0317
Europe	Ladoga	0.271	0.0177
Europe	Onega	0.054	0.0098
Europe	Vaenern	0.048	0.0056
Europe	Kuybyshevskoye	1.187	0.0050
North America	Superior	0.207	0.0819
North America	Huron	0.575	0.0597
North America	Michigan	0.180	0.0573
North America	Great Bear Lake	0.145	0.0305
North America	Great Slave Lake	1.006	0.0278
South America	Itaparica	0.497	0.0087
South America	Titicaca	0.057	0.0082
South America	Lagoa Mirim	0.046	0.0039
South America	Tucurui	0.757	0.0034
South America	Itaipu	0.840	0.0024

B5 References

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Appendix C

C1 Case study 4 – Chao Phraya

Table C.1: Water Quality Index in the Chao Phraya River Basin and Tha Chin River Basin (DO = dissolved oxygen, BOD = biological oxygen demand, TC = total coliform bacteria, FC = fecal coliform bacteria, NH_3 – N = ammonia nitrogen).

Min - Max, Median, and Percentage*						
Water Body	**WQ Class**	**DO (mg/l)**	**BOD (mg/l)**	**TC (MPN/100 ml)**	**FC (MPN/100 ml)**	**NH_3 – N (mg/l)**
Upper Chao Phraya	2	3.2 – 8.2 5.4 18% (5/28)	0.7 – 2.8 1.4 57% (16/28)	450 - >160,000 6,000 50% (14/28)	<180 – 54,000 1,350 43% (12/28)	ND – 0.45 0.12 100% (28/28)
Central Chao Phraya	3	1.1 – 7.6 3.1 20% (4/20)	0.9 – 4.4 2.0 55% (11/20)	3,300 – 35,000 7,900 85% (17/20)	200 – 17,000 1,300 90% (18/20)	<0.02 – 0.51 0.19 95% (19/20)
Lower Chao Phraya	4	0.1 – 5.5 1.2 38% (9/24)	1.8 – 7.7 4.1 50% (12/24)	1,100 - >160,000 24,000 46% (11/24)	400 - >160,000 7,900 29% (7/24)	0.20 - 2.30 0.85 29% (7/24)
Upper Tha Chin	2	1.8 – 7.5 3.1 19% (3/16)	1.1 – 8.2 3.8 6% (1/16)	200 – 54,000 4,900 63% (10/16)	120 – 4,900 780 53% (8/15)	<0.10 – 0.18 0.10 100% (16/16)
Central Tha Chin	3	1.0 – 7.0 2.4 25% (3/12)	1.2 – 8.2 4.2 17% (2/12)	2,700 – 160,000 11,000 67% (8/12)	450 – 92,000 1,200 75% (9/12)	<0.10 – 0.49 0.10 100% (12/12)
Lower Tha Chin	4	0.7 – 5.6 2.2 50% (14/28)	1.4 – 9.6 4.5 43% (12/28)	3,300 – 540,000 28,500 39% (11/28)	200 – 240,000 4,900 32% (9/28)	<0.10 – 2.09 0.61 39% (11/28)
Standard Class 2		> 6.0	< 1.5	< 5,000	< 1,000	< 0.5
Standard Class 3		> 4.0	< 2.0	< 20,000	< 4,000	< 0.5
Standard Class 4		> 2.0	< 4.0	-	-	< 0.5

* Percentage of the measurement that meets the standard of surface water quality (a total of the standardized measurement/a total of all measurements) (Source: Thailand State of Pollution Report 2013, PCD)

C2 Case study 5 – Vaal

Table C.2: Resource Quality Objectives (RQOs) for salinity in priority Resource Units in the Upper Vaal WMA (only a few results are illustrated here).

RU	RQO	Indicator/ measure	Numerical limit	95th %ile	Context of the RQO	Threshold of Potential Concern (TPC)
RU67	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	79.1	Local industrial activities are having a negative impact on the water quality causing salinization of the Taaibosspruit. Salt concentrations should be improved to a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
RU71	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	87	Salts: Upstream mining activity releases have causes acid mine drainage conditions in the system. The salts need to be returned to a state where it is not having a serious impact on the ecosystem, i.e. a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
RU73	Salts need to be improved to levels that do not threaten the ecosystem and to provide for users.	Electrical conductivity*	≤ 111 mS/m	90.5	Salt loads associated with acid mine drainage impacts from upstream mining activities are of concern for the ecosystem and also for downstream users. The salt concentrations should be managed to a D category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	98 mS/m
		Sulphates*	≤ 500 mg/L	132		350 mg/L
RU75	Salts need to be improved to levels that do not threaten the ecosystem especially fish and to provide for users.	Electrical conductivity*	≤ 85 mS/m	84	Excessive salt in this system causes salinisation of agricultural land and also fouling of industries. It is also a potential problem for maintenance of the Orange-Vaal largemouth yellowfish population, recruitment of which may be sensitive to high salt loads. Salt concentrations must be improved to a C category. Where available the 95th percentile of observed or modelled data has been provided. The 95th percentile threshold is a standard procedure which has been selected to remove the extreme values considered to represent outliers.	70 mS/m
		Sulphates*	≤ 200 mg/L	173		140 mg/L