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Assessment of current water pollution loads in Europe: Estimation of gridded loads for use in global water quality models

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Abstract:

A methodology for estimating the loading of pollutants to water courses across all of pan-Europe, an area reaching to the River Don in the East, and including some Mediterranean rim countries in the near East and North Africa is presented. Loadings come from point (domestic effluent, manufacturing discharge and urban runoff) and diffuse (scattered settlements and land use) sources. The loads have been calculated on a countrywide basis using readily available data held by national and international bodies. These loads are downscaled to the grid cells (5 × 5’) used in the model. The paper illustrates the general framework for making these calculations using BOD and Total Dissolved Solids (TDS) and estimated loads for periods representing 1990, 1995, 2000 and 2005 are presented as maps.

According to the model, in 2005 annual BOD loads came mostly from domestic effluent (3Mt) and diffuse sources (5Mt, mainly attributed to livestock). Manufacturing, urban runoff and scattered settlements contributed annual loads of 0.33, 0.15 and 1.2 Mt respectively. For TDS annual manufacturing loads were 65 Mt and annual domestic loads 28 Mt. Diffuse loadings (36 Mt) came from irrigated land and therefore showed a different spatial pattern from BOD. The total annual diffuse load of TDS was 56 Mt. Scattered settlements contributed only 9.6 Mt to the total pan-European load. Some limited comparison of the loads estimated in this study for BOD with those estimated by others for countries and large catchments in the area has been carried out.

INTRODUCTION

While catchment scale modelling of water and solute transport and transformations is a widely used technique to study pollution pathways and effects of policies and mitigation measures (Schob *et al.,* 2006; Bärlund *et al.,* 2007; Hesse *et al.,* 2008; Krause *et al.,* 2008; Volk *et al*,. 2009) there are only few examples of larger scale modelling on chemical loading: e.g. HBV-N (Pettersson *et al.*, 2000), MONERIS (Behrendt *et al*., 2000), CSIM (Mörth *et al.*, 2007). Modelling water quality at the continental or global scale is an evolving field (Green *et al.* 2004; Grizzetti and Bouraoui 2006; Harrison *et al.*, 2010; Bernard *et al.* 2011; He *et al.* 2011), although global scale modelling of water quantity is well established (Alcamo *et al.*, 2008). This probably reflects the different level of complexity required in modelling water quality arising from the number and variability of sources of water quality variables flowing into rivers, internal sinks of chemicals, interactions between chemical forms and the very local nature of some pollution sources. In addition, there is the sheer number of water quality variables and the wide range of metrics that is required to make a water quality assessment. These assessment need to be made because water quality is important to ecological and human well being. There is a need to understand the regional patterns of water quality, how they are influenced by humans through their activities and policies (which might operate across an economic region) and to extrapolate to the future the consequences of human actions should one particular path or another be followed.

In order to link global water resources change with water quality, WaterGAP (Water – Global Assessment and Prognosis, Alcamo *et al.*, 2003; Doll *et al.*, 2003; Flörke and Alcamo 2004; Verzano 2009) a model that calculates water use and availability on global scale is being further developed to include a water quality module and called WorldQual (Voss *et al.*, submitted this volume). The aim of this new water quality sub-model is to determine chemical fluxes in different pathways which will allow the combination of water quantity with water quality analyses.

This paper describes the first approach to modelling point and diffuse source pollutant loading for the continental water quality model WorldQual as it is being developed within the EU project SCENES (Kämäri *et al.*, 2008). The aim of the SCENES (Water Scenarios for Europe and for Neighbouring States) project is to assess the environmental consequences of key socio-economic and political developments as well as climate impacts in Europe with particular regard to the future state of water resources. The SCENES project area covers all of "Greater" Europe, an area that in the following is called pan-Europe, reaching to the River Don in the East and including the Mediterranean rim countries of north Africa and the near East. Estimates of future water quality in Europe are needed for two major reasons: first, to assess the future state of aquatic ecosystems and second, to determine the suitability of surface water supply for different water users (e.g. some industries require water that is low in total dissolved solids, and domestic water must be of acceptable quality).

The simulated key water quality variables have been chosen to indicate the suitability of water for various purposes: household, industrial and agricultural use, but also indicate the overall health of the aquatic ecosystem. Thus, the variables will include in the first phase described here total dissolved solids (TDS), and biochemical oxygen demand (BOD), later dissolved oxygen and nutrients will be added to the modelling system. TDS is a measure of the suitability of water for household, industrial and agricultural use; BOD and dissolved oxygen are indicators of the level of organic pollution and overall health of aquatic ecosystems.

This paper describes the first steps in developing the approaches to quantify point source and diffuse pollution loading on the European scale. This is achieved by calculating national point source and diffuse loading and distributing the load according to certain rules across the grid system used in WaterGAP. As stated above, this initial study shows the approaches and resulting European maps for two water quality parameters, BOD and TDS, but the approach illustrates a general method to include those other water quality measures mentioned above.

SOURCES OF CHEMICAL LOADS

Loadings are calculated across the pan-European area separately for point (domestic effluent, urban runoff and manufacturing discharges) and diffuse sources (atmospheric deposition, natural background, agricultural production and scattered settlements). For the point sources the approach was to calculate national pollutant loads, because the data required is usually available at this scale. These country loads were then disaggregated to the grid cells using a range of scaling factors depending on the pollutant and its source. In the diffuse loads, this same approach was used for scattered settlements, but for the other sources they were calculated directly for each grid cell. A grid cell size of 5 arc minutes by 5 arc minutes was used throughout.

Domestic Effluent – Country Loads

The national load estimates ($Ld_{X,Y}$) for country X and pollutant Y, were calculated as the total influent load to the country's sewage treatment works (STWs). These estimates were based on urban (Pop_U) and rural (Pop_R) populations, urban and rural connectivity (%) (respectively Con_U and Con_R), and a per capita emission factor ($EF_{X,Y}$) of a given determinand Y thus:

$$Ld_{X,Y} = EF_{X,Y} \times \left((Pop_U)_X \times (Con_U)_X + (Pop_R)_X \times (Con_R)_X \right) \qquad \text{Equation 1}$$

Where values for the percentage of rural and urban populations connected were not available from national and international datasets for a particular country (see next section), they were estimated according to Equation 2.

$$\text{If} \quad \%Pop_U < \mathbf{Con_T} : \quad \begin{cases} Con_U = 100 \\ Con_R = \dfrac{Pop_R}{Pop_T} \times \left(Con_T - 100 \times \dfrac{Pop_U}{Pop_T} \right) \end{cases}$$

$$\text{If} \quad \%Pop_U > \mathbf{Con_T} : \quad \begin{cases} Con_U = \dfrac{Pop_T}{Pop_U} \times (Con_T) \\ Con_R = 0 \end{cases} \qquad \text{Equation 2}$$

Where Pop_T is the total national population ($Pop_T = Pop_U + Pop_R$), $\%Pop_U$ is the percentage of the population that is classed as urban and $\mathbf{Con_T}$ is the national figure for the total connected percentage.

Domestic Effluent Loads – Downscaling to grid cells

The national load for a given determinand ($Ld_{X,Y}$) must be distributed across all country cells and then the appropriate treatment removal applied in order to estimate the effluent from each grid cell which will reach a river. The present methodology was developed by adapting the method employed by Grizzetti and Bouraoui (2006) for nitrogen and phosphorous. It is important to note that the national loads have already accounted for connectivity rates, as defined in Equation 1.

The influent load for a country grid cell i, $\left(Ld_{X,Y}\right)_i$ is given by:

$$\left(Ld_{X,Y}\right)_i = Ld_{X,Y} \times \frac{\left(Pop_U\right)_i \times Con_U + \left(Pop_R\right)_i \times Con_R}{Pop_T \times Con_T} \qquad \text{Equation 3}$$

While the effluent load $\left(Eff_{X,Y}\right)_i$, is:

$$\left(Eff_{X,Y}\right)_i = \left(Ld_{X,Y}\right)_i \times \sum_{j=0}^{n} \left(f_j \times (1 - R_{Y,j}) \right) \qquad \text{Equation 4}$$

Where, f_j is the fraction of treatment of type "*j*", with $\sum_{j-0}^{n} f_j = 1$, *j* takes the value: 0 = none, 1 = primary, 2 = secondary, 3 = tertiary and $R_{Y,j}$ is the removal fraction for determinand "Y" in treatment type "*j*".

Urban Runoff

There are a number of methods for estimating pollution loads from paved areas in urban areas. The method selected for this study was based on the concept of event mean concentration (EMCs). This method assumes that the mass of chemical runoff in an urban rainfall event is principally determined by the volume of the runoff and that each event has a typical concentration (the EMC). The load from paved urban areas is then simply the product of the EMC and the annual runoff from that area. Mitchell (2005) lists the reasons for adopting this approach: these volume-concentration methods often perform better than regression models; observations made in the UK, suggest that the mean EMC of a site is not correlated with the annual runoff volume; many pollutants can be addressed with this method and to add new ones is straight forward when appropriate data become available. Since urban runoff is already available as a grid cell output from the WaterGAP model (see later section), urban pollution loads are calculated directly for each grid cell.

The urban load for a grid cell ($UL_{Y,i}$, mg yr^{-1}) is given by:

$$UL_{Y,i} = EMC_Y \times Q_{upa,i} \qquad \text{Equation 5}$$

Where, the subscript *Y* denotes the determinand of interest, *EMC* (mg L^{-1}) is as defined above and $Q_{upa,\,i}$ (L yr^{-1}) is the annual runoff from the urban paved area within a grid cell. Here, it is assumed that the urban runoff is treated i.e. it is collected by a combined sewerage system and transported to a STW. In this case, the urban influent load for a grid cell is added to the domestic load for the grid cell. This load is then treated in the same way as proposed for the domestic effluent.

Industrial Discharges – Country loads

The method adopted was to try to establish typical concentrations for each determinand of interest for six main manufacturing sectors and if possible different values for each country. Thus the general equation for the emissions to rivers $I\_LdI_{X,Y}$ for country *X* and determinand *Y* is:

$$I\_LdI_{X,Y} = \sum_{k=1}^{6} \frac{C_{X,Y,k}}{1000} \times Rfl_{X,k} \qquad \text{Equation 6}$$

Where, *k* is an index for the six manufacturing sectors, $C_{X,Y,k}$ is the average raw effluent concentration in mg L^{-1} and $Rfl_{X,k}$ is the total return flow from the manufacturing industry *k* in the country *X*, in $m^3 day^{-1}$ as given by the WaterGAP model. The manufacturing sectors used in this model are food, textiles, paper, metal, chemicals and other.

Manufacturing - Downscaling

The downscaling to the grid cells was based on the return flow from the manufacturing industry (*RfI*), dataset calculated in the WaterGAP model. It is important to emphasize that the national load from direct emissions (*I_LdD*) is discharged without treatment to water courses, whereas national load from indirect emissions (*I_LdI*) is treated via sewage treatment works before being discharged to rivers. Although the equation given below allows for direct emissions, only indirect emissions were considered in this analysis (i.e. all manufacturing effluents were assumed to be treated).

The total industrial load (indirect + direct) for country *X* and determinand *Y* discharged in the grid cell *i* $\left(I\_Ld_{X,Y}\right)_i$, is then:

$$\left(I\_Ld_{X,Y}\right)_i = I\_LdD_{X,Y} \frac{(Rfl)_i}{Rfl_X} + I\_LdI_{X,Y} \frac{(Rfl)_i}{Rfl_X} \times \sum_{j=2}^{3} f\_ind_j (1 - R_{Y,j}) \qquad \text{Equation 7}$$

Where, $I\_LdD_{X,Y}$ is the total load from direct emissions, $I\_LdI_{X,Y}$ is the total load from indirect emissions, $(Rfl)_i$ is the return flow from the manufacturing industry in the grid cell i, Rfl_X is the total return flow from the manufacturing industry in country X, f_ind_j is the fraction of treatment for industrial discharges of type "*j*", with $\sum_{j=2}^{3} f\_ind_j = 1$ and *j* takes value: 2 = secondary, 3 = tertiary, $R_{Y,j}$ is the removal fraction for determinand *Y* in treatment type *j*. These equations are for the load from all sectors combined, but can be applied to each manufacturing sector separately.

There were no data available for the fraction of treatment for industrial discharges. Within European countries, industrial wastewaters were generally considered as treated via secondary or tertiary treatment thus the f_ind_j values were derived from the fraction of treatment values used for downscaling the domestic load (f_j):

$$f\_ind_j = \frac{f_j}{\sum_{j=2}^{3} f_j} \qquad \text{Equation 8}$$

Where, *j* takes value: 2 = secondary and 3 = tertiary. The values of $R_{Y,j}$ are the ones used in downscaling the domestic loads.

Model Parameters for estimating point source Total Dissolved Solids (TDS) and Biochemical Oxygen Demand (BOD)

Loading data were generated for four separate time periods representing the year around 1990, 1995, 2000 and 2005. The data were grouped into 5-year periods because, often parameter values required to generate the loads were not available for all countries for any one year. Even using this approach it was not always possible to have data for all time periods for connectivity and treatment levels for all the countries in pan-Europe. In fact for the "typical" manufacturing concentrations the same values were used for all time periods as there was not enough data to derive sensible numbers for different years. In that case only the volume of flow and the level of treatment changed between time slices.

The urban and rural population values originate from the History Database of the Global Environment (HYDE) developed under the authority of the Netherlands Environmental Assessment Agency (Klein Goldewijk, 2005) and were subsequently adapted to the WaterGAP3 land mask. Published values of the emission factors for BOD and TDS were used. For TDS only a single value of the emission factor of 45.6 mgL^{-1} for all the pan-European countries was available (UNEP, 2000). However, for BOD emission values for selected regions and countries had been collated by the Intergovernmental Panel on Climate Change (IPCC 2006) (Table 1).

The connectivity data were derived from the publicly available data (Table 2). The connectivity data were taken from two main data sources: the Statistical Office of the European Communities (Eurostat, 2010) and the World Health Organisation and UNICEF Joint Monitoring Program (WHO/JMP, 2010). Eurostat receives its information directly from member states and some other European countries (Iceland, Macedonia, Norway, Switzerland) and provided values of total connectivity rates to the sewerage system. The rural and urban connectivity rates were not provided in Eurostat, thus these were estimated using Equation 2.

The Joint Monitoring Programme (JMP) reports on the status of water-supply and sanitation and supports countries in their efforts to monitor this sector. The data collected for JMP comes from two main sources; (1) assessment questionnaires normally sent to WHO country representatives, to be completed in liaison with local UNICEF staff and national agencies involved in the sector and (2) household survey results including Demographic Health Surveys (DHS), UNICEF's Multiple Indicator Cluster Surveys (MICS), World Health Surveys (WHS) and national demographic censuses. The DHS and MICS are national cluster sample surveys that cover several thousand households in each country. The samples are stratified to ensure they are representative of urban and rural areas of each country. The JMP provides "house connection" rates for rural and urban population as well as for the total population. The house connections only take into account domestic connections that are connected to a sewerage system and therefore exclude septic tanks or dry sanitation. For the countries for which there were data from both the Eurostat and the JMP, Eurostat data were used because it also provided information on the level of wastewater treatment applied. However for some countries the data were missing from both these sources and were therefore taken from country specific sources (see Supplemental material A for details). The values of removal of BOD in different levels of treatment ($R_{Y,j}$) were taken to be 50%, 90% and 90% in primary, secondary and tertiary treatment respectively (Perry and Venderklein, 1996). For TDS no evidence of removal was found and thus no removal was assumed in all treatment types.

For urban runoff pollution, values of the EMC were taken from Mitchell (2001, unpublished). For BOD these were 8.3 mg L^{-1}, 11.0 mg L^{-1} and 12.0 mg L^{-1} for the UK, Northern Europe and the rest of the World respectively. TDS data are not included in the database given above. However, work has been carried out in California, which estimated the TDS from urban areas (Kent and Belitz, 2004). They studied urban runoff over 100 rainfall events of various intensities and durations for urban watersheds and estimated the storm runoff TDS concentrations by hydrograph separation. The flow weighted mean concentrations for the three watersheds were 130, 250 and 300 mg L^{-1}. In this analysis the median value, 250 mg L^{-1} was used.

The "typical" concentrations of manufacturing effluents were obtained from two sources of data; the Emission Inventory from the International Commission for the Protection of the Danube River (ICPDR, 2010) and from a literature search. The literature review found 45 separate references which gave values of manufacturing effluents from 62 separate sources, providing at least one reference for each of the six manufacturing sectors, although not always for both BOD and TDS. Concentration values were also not available for all countries. These showed a very wide range of concentrations and it was generally not stated if the values were from final treated effluents that would be discharged to rivers or whether they would be further treated by municipal STWs. For this analysis it has been assumed that all manufacturing discharges would receive further treatment (see section on downscaling above).

The ICPDR provided discharged pollutant load and waste water volume discharged for industrial plants from the countries that constitute the Danube catchment (Austria, Bosnia-Herzegovina, Bulgaria, Croatia, Czech Republic, Germany, Hungary, Moldova, Romania, Slovakia, Slovenia and Ukraine). These discharges are classified into 12 industrial sectors, which were mapped onto the six sectors used in this study. For each industrial discharge, the concentrations of the chemicals discharged were estimated by dividing the chemical load by the discharge volume. Data were available for both TDS and BOD.

These sets of data were combined to produce the data required to estimate country loads. However, insufficient data were available to provide concentration values for all determinands for each individual country; therefore values were calculated to be used for all countries (Table 3). In addition, where there were sufficient data typical concentrations were given by sector for BOD and TDS (Tables 4 and 5). In the results discussed below the European wide average values were used for all sectors.

Scattered Settlements – country loads

The national load estimates from scattered settlements are based on the fractions of urban (Pop_U) and rural (Pop_R) population that are not connected to public STWs. The *per capita* emission factor (EF_Y) of a given determinand Y is the same as for the effluents from the domestic point sources. The national load estimate, $Ld_{SC,X,Y}$ (X represents the country) is defined as:

$$Ld_{SC,X,Y} = EF_Y \times \left((Pop_U)_X \times \frac{100-(Con_U)_X}{100} + (Pop_R)_X \times \frac{100-(Con_R)_X}{100} \right) \quad \text{Equation 9}$$

Con_R and Con_U are the percentage connectivity to public waste water treatment plants in the calculation of domestic point sources (Equation 2).

Scattered Settlements – downscaling

Like the input from domestic point sources, the input from scattered settlements must be distributed across all country cells and then the appropriate treatment removal applied in order to estimate the effluent in each grid cell. The influent load for a grid cell *i*, $(Ld_{SC,X,Y})_i$ is given by:

$$(Ld_{SC,X,Y})_i = Ld_{SC,X,Y} \times \frac{(Pop_R)_i}{(Pop_R)_X} \quad \text{Equation 10}$$

Sewage treatment from scattered settlements is much more variable than from domestic point sources. One typical treatment is septic tanks, but there are also small private treatment plants that give high removal rates of pollution substances. In the calculations it has been assumed that the average treatment level of scattered settlements is similar to the secondary treatment level of public STWs.

Again the level of sewage treatment must be applied to the influents in order to estimate the effluent load $(Eff_{SC,X,Y})_i$, is:

$$(Eff_{SC,X,Y})_i = (Ld_{SC,X,Y})_i\, f_{Y,i}(1-R_{Y,i})) \quad \text{Equation 11}$$

Where, $f_{Y,i}$ is the fraction of treatment of type *i* and $R_{Y,i}$ is the percentage removal for determinand Y in treatment type *i*. The values of $R_{Y,i}$ were the same as in the domestic effluent calculations above and the fraction treated was the same as for domestic effluent except the highest treatment level assumed was secondary.

Agricultural Input

The pollutant loadings in this section are somewhat dependant on the pollutant considered, so although both, TDS and BOD, originate from agricultural areas, different approaches have been used to calculate the loadings. TDS comes more from irrigated or salt affected soils in semiarid or arid regions and BOD from the livestock based agriculture.

Considering TDS, agricultural areas contribute to the salt emissions into a river system (Davis and Cornwell, 1999*)*. In this analysis it is assumed that the main part of theses salt emissions come from water return flow from irrigated agriculture. The estimation of salt loadings is a function of the salt concentration of the irrigation water return flow within a certain salt emission potential class (SEPC) and the amount of irrigation water return flow (Equation 12).

$$TDS_{i,irr} = RTF_{i,irr} C_{i,j} \quad \text{Equation 12}$$

Where, $TDS_{i,irr}$ (t yr^{-1}) is the salt loading of irrigation water return flow in grid cell *i*,

$RTF_{i,irr}$ (m³) is the irrigation water return flow in grid cell i and $C_{i,j}$ (mg L^{-1}) is the salt concentration of irrigation water for salt emission potential class j in grid cell i. Irrigation water return flow is provided by the WaterGAP model.

In order to calculate the SEPC, information about the natural, primary salinity of soils and the man-made, secondary salinity were used. The main problem of secondary soil salinisation is the application of unsustainable irrigation practices in salt endangered regions. Lack of financial resources often prevents the use of state-of-the-art irrigation methods, or the treatment of irrigation water. Thus, the SEPC is a combination of natural salt classes (SC) and GDP (gross domestic product) per capita classes.

Natural salt classes (SC) are a combination of primary salt enriched soils (S), and arid-humid climate conditions (H). Primary salt enriched soils were taken from the FAO soil map of the world (FAO, 2000). The soil types Solonetz and Solonchaks and soils with calcic or calcaric layers were assumed to be salt enriched soils. These salt enriched soils were divided into two classes: geogenic background salt content (S0) and salt enriched soil (S1). Furthermore, there are more salt affected soils under arid than under humid conditions. Low precipitation and high evaporation can cause a low water discharge and an increase of salt affected soils in endangered regions. The small water amount which can drain off into the river system is assumed to have a high salt concentration. Also arid and humid conditions are divided into two classes: humid (H1) and arid (H2). This classification is based on land cover implemented in WaterGAP, where grassland/steppe, hot desert, scrubland and savannah were considered as arid and the remaining land cover classes as humid (Weiß and Menzel, 2008). Altogether four natural salt classes result from the combination of naturally salt enriched soils and arid-humid climate conditions: SC1 combines S0 and H1, SC2 combines S1 and H1, SC3 combines S0 and H2 and SC4 combines S1 and H2.

Gross domestic product per capita classes (GDPC) have been used to give likely irrigation technique standards of a country. Three GDPC classes were differentiated: countries in GDPC 1 (> 10000 US$) are able to use the best irrigation techniques. Here the salt concentration in irrigation water is low. Countries in GDPC3 (< 1001 US$) are not able to use highly technical irrigation systems and the salt concentration in irrigation water can be highly dependent on the natural salt classes.

Finally, the salt concentration in irrigation water return flow results from the salt emission potential class. The salt emission potential was divided into four classes in relation to the natural salt classes (SC) and the GDPC (see Table 6). The concentrations used for the four different classes were derived from Follett & Soltanpour (1999), who describe the salinity hazard of irrigation water depending on the dissolved salt content. Additionally, it was assumed that every country would use the best irrigation technique that was available, and that high saline irrigation water (> 2000 mg L^{-1}) is not used.

The background salt concentrations within the rivers were assumed to be dependent on the underlying geology of the river basins, and therefore they have a strong geographic variation. At the moment this geologic variation was only considered by using a median salt concentration of all available non-agricultural water quality measurement points within the rivers of a country (derived from electric conductivity) (Salminen, 2005). In countries where no data were available, the drinking water mean value of Germany of 250 mg L^{-1} (German Federal Ministry of Health, 2001) was used.

BOD was calculated using what was effectively a calibrated export coefficient method in which the measured annual average load at a catchment outlet was regressed against a range of catchment characteristics which might influence that load (for full details see Malve *et al*, submitted this volume). The catchments were defined by water quantity (discharge) stations from the European Environment Agency WISE database with nearby WISE stations where BOD data were also available using the drainage direction data of WaterGAP. For each watershed the total area, cropland area, built-up area, and livestock numbers as livestock units (lsu) were calculated from WaterGAP data layers. In addition, modelled grid cell data (using the methods described above) for scattered settlements and point source BOD load (as the sum of manufacturing and domestic loads) were calculated for the watersheds. Köppen – Geiger climate class was also determined (http://koeppen-geiger.vu-wien.ac.at/) as was lake area from European Joint Reseach Centre's River and Catchment database version 2.0 (de Jager and Vogt, 2010).

The analysis of the regression using the datasets described above for the periods representing 1990, 1995 and 2000 revealed a strong, significant linear relationship ($R2 = 0.93$, $p << 0.01$) with three significant explanatory variables; livestock units, point source loads and runoff (criteria $Pr < 0.05$, see Malve et al, submitted this volume for full details).

$$BODflux = (3.24*10^{-3}/5.39*10^{-1})*lsu + point + (1.52*10^{-3}/5.39*10^{-1})*r \quad \text{Equation 13}$$

Where *BODflux* is the total annual load of BOD leaving the catchment (t km^{-2} yr^{-1}), *lsu* is number of livestock units (lsu km^{-2}), *point* is load from point sources and scattered settlements (t km^{-2} yr^{-1}) and *r* is runoff (mm yr^{-1}). The simulated effects of all the explanatory variables were positive. The regression of observed and predicted loadings is shown in Figure 2. This equation was used by rearranging it to move the contribution of point sources to the left hand side of Equation 16 and then applying it to each grid cell in the model.

WATERGAP

The loading equations described here are designed to be used with the WaterGAP model which provided information on water flows. Water use variables like water return flows from the industry and the irrigation sector are needed to calculate the point loadings from industry and diffuse salt loadings from agricultural irrigation areas as described above. Also hydrological inputs for urban runoff are required to calculate loadings from paved areas and cell runoff to estimate diffuse BOD loading from agricultural areas.

WaterGAP is a global model developed at the Center for Environmental Systems Research of the University of Kassel, Germany. WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model (Alcamo *et al.*, 2003; Döll *et al.*, 2003; Flörke and Alcamo, 2004; Verzano, 2009). WaterGAP3 has been calibrated for Europe on a 5' grid. The Global Hydrology Model simulates the macro scale behaviour of the terrestrial water cycle to estimate water resources. Only a short overview of the global water use model of WaterGAP is provided here and the reader is directed to the references for further information.

The global water use model of WaterGAP consists of five sub-models to determine the water withdrawals and water consumption in the household, electricity, manufacturing, irrigation, and livestock sectors. In this context, water withdrawals depict the total amount of water used in each sector while the consumptive water use indicates the part of withdrawn water. The water use sectors only consume a part of the water withdrawals and the remaining water returns into the river system. The water return flow is calculated as in Equation 14.

$$RTF_{sec} = WWD_{sec} - CON_{sec} \qquad \text{Equation 14}$$

Where, RTF_{sec} is the water return flow from a particular sector into the river system ($m^3 yr^{-1}$), WWD_{sec} is the water withdrawal for that sector ($m^3 yr^{-1}$) and CON_{sec} is the water consumption for the sector ($m^3 yr^{-1}$).

The manufacturing water use model computes the annual amount of water withdrawn and consumed in production processes and cooling of the manufacturing industry on a national scale. The manufacturing water use is based on national, regional and international statistics (Flörke and Alcamo, 2004). Technological improvements and shifts in processes are taken into account by technological and structural change factors..

Irrigation water uses are computed with a global irrigation model (Aus der Beek *et al* 2010), which is integrated in the WaterGAP framework. Water consumption of irrigated crops relies on calculating net irrigation requirements as a product of a crop coefficient and evapotranspiration. Withdrawals are computed by assigning an irrigation water use efficiency based on transport losses, field sizes and management practices. In addition to climate variables, the model takes into account real irrigated crop areas, types of cropping, and the improvement in water use efficiency with time because of technological changes in irrigation methods.

RESULTS AND DISCUSSION

The results are described for the 2005s which in SCENES is the base line year against which future scenarios are evaluated. The results for 1990s, 1995s and 2000s are given in the Supplemental Material (sections B (tables) and C (figures)).

Biochemical Oxygen Demand

The loads arriving in rivers from domestic STWs showed generally low levels (< 10 $t^{-1} yr^{-1}$ per grid cell), except for those areas of high population, which stand out clearly in yellow and orange (Figure 2a). Countries in central Eastern Europe show only loads from grid cells in urban areas reflecting the low level of connection to sewerage systems in rural areas. Loads from manufacturing are naturally confined to cells where there is industrial activity and again the levels are generally low (Figure 2b). Across all the area modelled, the annual load from manufacturing discharges is about 10 times lower than from domestic effluent (0.33 Mt vs. 3.0 Mt, Table 7). Loads from urban areas are also at a low level contributing 0.15 Mt annually to the pan-European region and naturally confined to areas of high population (Table 7 and figure 2e).

The distribution of diffuse pollution BOD loads showed higher levels than domestic sewage effluent (Figure 2c). As would be expected all grid cells show a diffuse load, with highest values in the Low Countries reflecting the density of animal production. Over all of pan-Europe, annual diffuse loads were estimated to be just less than 60% of the domestic sewage annual load at 5.0 Mt. Scattered settlements are an addition to the diffuse load and account for the part of the population not connected to public sewerage systems. Northern and Western Europe (with the exception of Portugal and Belgium) showed grid cell loadings of less than 10 t^{-1} yr^{-1} per grid cell (Figure 2d). Areas of high loading from scattered settlements were found in the Balkans, Northern Italy, Turkey and the Middle East. Spain is notable for having a zero load from scattered settlements, which is due to official figures showing 100% of the population was connected to public sewerage systems. Across pan-Europe the annual load from scattered settlements was 1.2 Mt; approximately a quarter of the loading from diffuse pollution sources.

The sum of all BOD loading sources showed a pattern in which lowest loadings are in Scandinavia and highest loading running in a North West to South East Band from the Irish Republic to Western Turkey and the Eastern Mediterranean. There were also high concentrations on the West coast of Portugal (Figure 2f). Total points sources (domestic, manufacturing and paved areas) accounted for 34% of the BOD annual loading across pan-Europe. There is some variation in this value between individual countries, for example Macedonia had a 78% loading contribution from point sources whereas Poland had only 17%. The inter-quartile range was from 29% to 47%.

Total Dissolved Solids

Domestic annual loads were estimated to be less than manufacturing loads across the region as a whole; 28 Mt compared with 65 Mt (Table 8). The pattern of the distribution of the loads of TDS for point source loads was very similar to the corresponding BOD distributions (Figures 3a, b and e). Urban runoff was a very small part of the point loadings of TDS accounting for only 1.7 Mt across pan-Europe over the year.

Diffuse loadings patterns of TDS were rather different to those predicted for BOD, reflecting the different origins of these water quality variables. The highest loadings were for grid cells in the more arid regions surrounding the Black Sea and the Iberian Peninsula (Figure 3c), although there are also grid cells in these areas that show zero TDS loading. The levels of TDS loading from scattered settlements was low (Figure 3d) and again very similar in its distribution pattern to BOD. For the pan-Europe region on an annual basis, irrigation contributed 36 Mt against only 8.7 Mt from scattered settlements. On an annual basis the contribution of point sources was on average 68% of the total loading of TDS. There was slightly more variability than for BOD with and inter-quartile range of 58% to 80%.

How good are these modelled estimates?

Even for point sources it is difficult to assess, at this scale, the quality of the methods presented in the paper to estimate the loading across pan-Europe because of the paucity of easily accessible datasets at this scale. However, data from European Union member states on the discharges from waste water collection systems are collated by Eurostat (Nagy *et al.*, 2008). Model estimates of inputs to domestic STWs compared well with data values submitted by countries (Figure 4). A linear regression fitted to these data showed a gradient of 1.0 and an R^2 value of 0.97, although this is very influenced by the large values for France (F1995 and F2000 in Figure 4) which are reproduced well by the model. Effluent data are also available for some countries and while these show a good correlation ($R^2 = 0.88$) the model overestimated the reported values by approximately 62% (Figure 5). Since there is some confidence in the calculated input values, it follows that for BOD STWs are performing better than the percentage removals given in the literature. Voss *et al* (submitted this volume) modelled BOD concentrations in the River Thames using the loading data presented here and needed to increase BOD removal to 97% in STWs order to fit well the observed in-river BOD concentrations. This values is close to published values for United Kingdom STWs (Butwell *et al.,* 2009)

The gridded data presented above can also be presented as loading per river basin rather than per country. This has been done for BOD in 2000 for selected basins for calculated and observed point source loads from the Thames (UK), Danube and Kokemäenjoki (Finland) basins (Table 9). For the River Danube the total point source loads are in good agreement. Industrial and domestic effluent loads are available separately (ICPDR, 2005) and this shows that the model over-estimates the domestic fraction (342 t yr^{-1} vs. 407 t yr^{-1}) and under-estimates the manufacturing load (60 t yr^{-1} vs 27 t yr^{-1}). For the Kokemäenjoki basin the total loading is also in good agreement but again the manufacturing load is under-estimated (1.6 t yr^{-1} vs. 1.9 t yr^{-1}) and the domestic load over-estimated (1.3 t yr^{-1} vs. 0.7 t yr^{-1}). There was for the Thames basin more than an order of magnitude over-estimate for the point loads (predicted to be 83% domestic effluent). This shows a pitfall in this scale of modelling. The national treatment level values for the UK were applied to the basin which showed that 11% was untreated and 9% was treated at only primary level. An analysis of the basin sewage treatment works indicated that there are no works with only primary treatment and none of the effluent is untreated. In addition, the local performance of sewage treatment works was estimated to be in excess of 97% removal of BOD compared to the 90 % assumed in this study.

In comparing these observed and estimated values, it is worth noting that the observed values are themselves only estimates and the methods used to calculate loads can give a wide range of answers with differing accuracy and precision (Littlewood, 1995; Littlewood *et al.*, 1998). In this context, the performance of the model for load inflows to STWs seems acceptable. The effluents are less convincing for the country loads and for the Thames basin; however the data from the Danube and the Kokemäenjoki basin are encouraging.

Considering the estimation of diffuse loads, these have been calculated using a regression equation that relates the BOD mass loss to runoff volume and number of livestock units. This expression has been developed based on data from over 100 catchments across the pan-European area and produced a strong relationship. In addition the same relationship could be applied to data across a decade. It is reasonable therefore to assume that this relationship will hold widely.

CONCLUSIONS AND OUTLOOK

This paper has presented a first assessment of the spatial distribution of the loads of BOD and TDS entering the pan-European river systems. This systematic analysis has identified the point and non-point source contributions and explains how they will drive a new pan-European water quality model. An initial comparison between the loads generated from point sources suggests that the current methods give a good estimate of loads into STWs, but over-estimate the observed loads exiting these works. This implies perhaps a better performance of STWs in the countries than that assumed in standard texts for secondary and tertiary treatment levels. It should be noted however, that large scale data of this sort are not common place and further testing would certainly improve confidence in the model.

Currently no data have been found to test the TDS model. In addition the model will be extended to estimate loadings for nutrients for which a larger potential data set and alternative model approaches exist for comparison. The output from the WorldQual model that will be driven by these data is being compared with observed water quality concentrations across pan-Europe (which are more plentiful than loads), which will serve as a further check on the performance of the modelling system (Voss *et al.,* submitted this journal).

These data sets have been put together to drive a grid based water quality model with a view to estimate the impacts on water quality of future socio-economic and policy driven changes. The WaterGAP model has already been used to show impacts on water resources from such drivers (Flörke & Alcamo, 2004; Alcamo *et al.,* 2007; Weiß *et al.,* 2007; Bärlund *et al.,* 2008; Verzano, 2009) and similar techniques will be used for combined water quality and water quantity projections. The data set presented in this study and the resulting outputs from the WorldQual model will form a base line against which the impact of future scenarios can be measured. The next stage, and running alongside further refinement, is to provide plausible future scenarios which take account of the way society will develop in the future (for example along the lines described in the GEO4 scenarios, UNEP, 2007). The difficulty comes in quantifying how qualitative scenarios can be interpreted in terms of changed model parameters and input variables. Within the SCENES project this is partly being addressed through the use of a panel of experts drawn from across Europe, who provide such values within a structure where their outputs are directed, but not controlled by those responsible for the modelling. This quantification step is part of the SAS "Story and Simulation" approach (Alcamo, 2001) used in the SCENES scenario development process. It will then be possible for the first time to try to quantify future water quality across pan-Europe resulting from socio-economic storylines.

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Table 1 Estimated BOD values in domestic wastewater for selected regions and countries.

Country/Region	BOD ($g\ cap^{-1}\ day^{-1}$)
Africa	37
Egypt	34
Asia, Middle East, Latin America	40
West Bank and Gaza Strip (Palestine)	50
Canada, Europe, Russia, Oceania	60
Denmark	62
Germany	62
Greece	57
Italy	60
Sweden	75
Turkey	38

Source: Intergovernmental Panel on Climate Change (IPCC, 2006)

Table 2 Percentage values for total, rural and urban populations connected to a sewerage system for 2005. The percentage of the effluent treated at a particular level is also shown. Values in bold were estimated using the equation given in the text.

Country	Connected (%)	Rural (%)	Urban (%)	Prim.	Second	Tert.	Not Treated	Source
Albania	77	61	97	0	0	0	77	1
Algeria	76	50	92	0	10	0	67	1
Austria	90	**71**	**100**	0	5	85	0	3
Belarus	73	38	86	0	46	0	27	1
Belgium	85	**0**	**88**	0	19	36	30	3
Bosnia and Herzegovina	56	**37**	**79**	0	5	0	51	1
Bulgaria	69	**0**	**99**	3	38	0	28	3
Croatia	68	**27**	**100**	37	1	0	30	2
Cyprus	28	**0**	**41**	0	11	17	0	3
Czech Republic	78	**15**	**100**	0	16	58	4	3
Denmark	89	**21**	**100**	2	3	84	0	3
Egypt	40	17	71	6	9	0	25	1
Estonia	73	**13**	**100**	1	21	51	0	3
Ethiopia	nd*	0	2	0	0	0	0	1
Faroe Islands	0	**0**	**0**	0	0	0	0	
Finland	80	**47**	**100**	0	0	80	0	3
France	82	**22**	**100**	1	37	42	2	3
Georgia	44	4	80	1	0	0	43	1
Germany	96	**85**	**100**	0	2	93	1	3
Greece	85	**62**	**100**	0	7	78	0	3
Hungary	65	**0**	**98**	10	25	22	8	3
Iceland	90	**0**	**98**	51	2	0	37	3
Iraq	57	**0**	**95**	2	5	0	50	6
Ireland	95	**87**	**100**	2	70	12	11	3
Israel	96	**74**	**100**	22	33	28	13	7
Italy	94	**81**	**100**	0	10	84	0	3
Jordan	59	6	74	0	20	0	39	5
Latvia	67	54	73	2	27	38	0	3
Lebanon	90	**23**	**100**	3	0	0	87	5
Libyan Arab Jamahiriya	54	55	54	0	8	0	46	8
Lithuania	69	**6**	**100**	15	19	32	3	3
Luxembourg	100	**100**	**100**	7	66	22	5	3
Macedonia, former Yugoslav republic	100	**100**	**100**	5	5	0	90	3
Malta	100	**100**	**100**	0	0	13	87	3
Moldova, republic of	56	**23**	**100**	0	18	0	38	9
Morocco	41	**0**	**74**	0	5	0	36	5
Netherlands	99	**95**	**100**	0	7	92	0	3
Norway	83	**26**	**100**	20	2	56	5	3
Poland	60	20	85	2	22	36	0	3
Portugal	57	**0**	**98**	10	28	11	8	3
Romania	42	1	77	9	19	0	14	3

Russian Federation	75	**7**	**100**	2	54	1	18	4
Saudi Arabia	28	**0**	**35**	0	19	9	0	5
Slovakia	57	**2**	**100**	7	48	0	2	3
Slovenia	54	**8**	**100**	5	24	11	14	3
Spain	100	**100**	**100**	2	61	32	5	3
Sudan	1	**0**	**2**	0	1	0	0	5
Sweden	86	**12**	**100**	0	5	81	0	3
Switzerland	97	**89**	**100**	0	20	77	0	3
Syrian Arab Republic	72	45	96	0	16	0	56	1
Tunisia	42	**0**	**65**	0	40	0	2	5
Turkey	69	**6**	**100**	12	19	5	33	3
Ukraine	57	21	74	2	50	0	5	10
United Kingdom	99	**90**	**100**	0	56	43	0	3
Western Sahara	4	nd	nd	0	1	0	3	As morocco
Yougoslavia/Serbia and Motenegro	49	**0**	**94**	4	11	0	34	1

Source: 1 = WHO/UNICEF/UNECE
2 = IREAS, Institute for Structural Policy
3 = EUROSTAT
4 = WHO/UNICEF/EEA
5 = WHO/UNICEF/WHO EMRO
6 = WHO EMRO
7 = Israel Ministry of Environment
8 = WHO/UNICEF
9 = OECD/UNECE
10 = WHO/UNICEF/Derzhbud
*nd = no data

Table 3 Statistics describing the European wide values for concentrations of selected chemicals discharged by industrial plants.

Determinand	Mean	Std Dev.	Min	25%	50%	75%	Max	Sample size
BOD	1076	4262.6	0	22.7	153.0	817.1	53500.0	209
TN	104.9	230.5	0.1	5.0	21.2	77.0	1538.5	121
TP	11.2	23.6	0.1	0.7	3.0	190.6	277.0	111
TDS	4736.9	5211.6	170.0	1980.0	3000.0	6656.0	17000.0	9

Table 4 Statistics describing the European wide values for concentrations of BOD discharged by industrial plants in six different sectors.

Industrial sector	Mean	Std Dev.	Min	25%	50%	75%	Max	Sample size
Food	2331.8	6752.3	0.8	230.3	629.9	1510.9	53500	78
Textile	909.8	1091.8	22.9	139.4	467.0	1287.4	3644	19
Paper	441.1	1070.4	1.1	21.7	65.9	308.9	5150	24
Metal	10.7	7.8	2.4	4.2	8.8	14.3	26.6	11
Mixed	203.5	480.7	0.1	2.2	22.7	146.0	2040	23
Chemical	37.9	49.8	0.1	8.9	20.0	39.6	197.0	33

Table 5 Statistics describing the European wide values for concentrations of TDS discharged by industrial plants in six different sectors. Note there were no data for the mixed and chemical sectors

Industrial sector	Mean	Std Dev.	Min	25%	50%	75%	Max	Sample size
Food	3413	4586.3	170	1791.5	3413.0	5034.5	6656	2
Textile	6473.3	7024.5	2573	2893.3	3160.0	6740.0	17000	4
Paper	1980	nd	1980	nd	nd	nd	1980	1
Metal	7421	nd	7421	nd	nd	nd	7421	1
Mixed	nd	nd	nd	nd	nd	nd	nd	nd
Chemical	nd	nd	nd	nd	nd	nd	nd	nd

nd = no data

Table 6. Concentrations (mg L^{-1}) of salt used in salt emission classes based on natural salt class (SC) and Classes based on Gross Domestic Product (GDPC).

	GDPC 1	GDPC 2	GDPC 3
SC 1	250	250	250
SC 2	250	500	500
SC 3	250	750	750
SC 4	500	750	1000

Table 7 Loads of BOD reaching rivers in each country by source in the 2005s (t yr^{-1})

Country	Manufacturing	Domestic	Urban	Scattered Settlements	Diffuse	Total
Albania	2257	52453	22	15668	27559	97959
Andorra	nd[1]	nd	nd	nd	nd	nd
Azerbaijan	750	0	0	12341	79314	92405
Austria	14732	16226	83	1803	62922	95765
Armenia	610	nd	nd	4475	16577	21662
Belgium	7624	84579	371	14926	98485	205984
Bosnia and Herzegovina	399	42647	5	33509	20472	97032
Bulgaria	1919	56441	166	25358	36826	120710
Belarus	3947	67933	156	25126	116255	213417
Croatia	849	47288	229	22253	23174	93793
Cyprus	29	342	7	879	6729	7986
Czech Republic	2888	25452	63	7179	50739	86321
Denmark	473	11891	118	1470	98491	112443
Estonia	156	2271	24	840	8283	11573
Faroe islands	nd	nd	nd	nd	2	2
Finland	8473	9188	19	2297	32455	52433
France	20089	138964	568	30504	585128	775253
Georgia	1973	28354	411	36087	35747	102573
Germany	22646	195816	1001	8159	449098	676720
Greece	1499	19565	39	3453	68636	93192
Hungary	2212	39063	160	21034	51530	114000
Iceland	180	4061	7	451	4396	9095
Iran	2369	nd	nd	26476	27	28872
Iraq	3396	211923	242	159872	69430	444864
Ireland	3736	18523	415	975	179219	202868
Israel	1568	45941	330	1914	17041	66795
Italy	68733	120726	293	7706	257630	455088
Jordan	646	31272	29	21731	1	53678
Kuwait	nd	nd	nd	1	nd	1
Lebanon	186	52738	277	5860	12228	71289
Latvia	308	3765	69	1854	12165	18160

Liechtenstein	nd	nd	nd	nd	nd	Nd
Lithuania	485	11671	37	5244	25950	43387
Malta	6	7785	18	0	1136	8945
Moldova	5174	32767	215	25746	17505	81406
Netherlands	28173	35375	157	357	156894	220956
Norway	8265	21115	635	4325	32454	66794
Poland	6538	56885	133	37923	266871	368350
Portugal	1481	39034	154	29447	67754	137869
Romania	6115	96655	396	133476	156694	393336
Russian Federation	30824	204363	2253	68121	237329	542890
Saudi arabia	11	134	0	344	0	489
Slovakia	2728	12149	10	9165	23750	47801
Slovenia	1007	8765	13	7467	14836	32088
Spain	15459	144008	140	0	393067	552674
Sweden	13617	21345	504	3475	48660	87601
Switzerland	2428	15807	50	489	45195	63969
Syrian Arab Republic	2715	156405	103	60824	80546	300593
Turkey	9758	408666	890	183603	402683	1005600
Ukraine	14922	113070	1573	85298	232891	447753
Macedonia	382	41453	54	0	12136	54026
Egypt	102	985	0	1477	2776	5340
United Kingdom	4470	130651	2484	1320	381223	520147
Yugoslavia	1560	85153	146	88628	56746	232232
Total	330867	2971663	15070	1240928	5077654	9636182

1. Not enough data to calculate a value

Table 8 Loadings of TDS in each country reaching rivers by source in the 2005s (10^3 t yr^{-1})

Country	Manufacturing	Domestic	Urban	Scattered Settlements	Irrigation	Total
Albania	442.5	109.3	0.5	32.6	125.3	710.1
Andorra	nd[1]	nd	nd	nd	nd	nd
Azerbaijan	147.1	nd	0.0	385.7	2811.1	3343.9
Austria	2888.7	338.0	17.2	37.6	19.4	3300.9
Armenia	119.7	nd	0.0	139.9	358.4	618.0
Belgium	1494.9	421.9	18.5	74.5	1.1	2010.8
Bosnia and Herzegovina	78.3	96.6	0.1	75.9	2.2	253.1
Bulgaria	376.2	243.6	7.2	109.5	162.1	898.6
Belarus	773.9	326.9	7.5	120.9	60.3	1289.5
Croatia	166.5	137.8	6.7	64.9	0.7	376.6
Cyprus	5.7	10.7	1.5	27.5	14.2	59.6
Czech Republic	566.2	362.8	9.0	102.3	4.0	1044.3
Denmark	92.7	220.0	22.6	27.2	22.6	385.2
Estonia	30.6	44.8	4.7	16.6	0.4	97.2

Faroe Islands	nd	nd	nd	nd	nd	nd
Finland	1661.4	191.4	4.0	47.9	5.5	1910.2
France	3939.1	2282.7	93.3	501.1	630.1	7446.1
Georgia	386.9	89.6	8.7	114.1	271.4	870.7
Germany	4440.3	3609.5	190.8	150.4	89.4	8480.4
Greece	293.9	429.1	8.2	75.7	456.7	1263.5
Hungary	433.8	298.9	12.2	160.9	58.0	963.8
Iceland	35.3	12.1	0.2	1.3	0.0	49.0
Iran	464.5	0.0	0.0	827.5	5154.3	6446.3
Iraq	666.0	733.0	5.6	553.0	3635.0	5592.4
Ireland	732.6	181.5	40.7	9.6	0.6	965.0
Israel	307.5	457.9	21.9	19.1	81.3	887.8
Italy	13477.1	2515.1	61.1	160.5	921.4	17135.3
Jordan	126.6	140.6	0.9	97.7	72.2	438.0
Kuwait	nd	nd	nd	nd	nd	nd
Lebanon	36.5	167.6	5.9	18.6	202.7	431.3
Latvia	60.3	70.1	12.8	34.5	0.3	178.0
Liechtenstein	nd	nd	nd	nd	nd	nd
Lithuania	95.1	107.5	3.4	48.3	2.2	256.6
Malta	1.1	18.4	0.4	0.0	1.2	21.1
Moldova	1014.4	96.1	6.3	75.5	1047.7	2239.9
Netherlands	5524.2	737.0	32.6	7.4	31.7	6332.9
Norway	1620.6	175.5	52.8	36.0	11.0	1895.9
Poland	1281.9	1045.7	24.4	697.1	53.2	3102.3
Portugal	290.3	274.3	10.8	206.9	363.2	1145.6
Romania	1199.1	414.6	17.0	572.5	592.2	2795.3
Russian Federation	6043.9	1303.3	143.7	434.4	802.0	8727.3
Saudi Arabia	2.2	4.2	0.0	10.8	0.6	17.8
Slovakia	534.9	140.1	1.1	105.7	66.6	848.4
Slovenia	197.4	49.3	0.7	42.0	0.4	289.9
Spain	3031.2	1960.9	19.1	0.0	1446.4	6457.5
Sweden	2670.0	355.7	105.0	57.9	12.3	3201.0
Switzerland	476.0	329.3	10.3	10.2	4.6	830.4
Syrian Arab Republic	532.4	611.0	2.7	237.6	5079.9	6463.6
Turkey	1913.3	2240.5	30.9	1006.6	10054.8	15246.1
Ukraine	2925.8	1220.6	169.8	920.8	1530.9	6768.0
Macedonia	75.0	92.9	1.2	0.0	29.6	198.7
Egypt	20.0	5.0	0.0	7.5	23.2	55.8
United Kingdom	876.4	2721.9	517.5	27.5	25.8	4169.1
Yugoslavia	305.8	234.3	4.0	243.9	32.1	820.0
Total	64875.9	27629.6	1715.5	8735.4	36372.4	139328.7

1. Not enough data to calculate a value

Table 9 Comparison of estimated and observed point source loads (t yr^{-1}) for the year 2000 from three river basins.

		Point Source BOD Load (10^3 t yr^{-1})	
Basin	Area (km^2)	Observed	Estimated
Thames[1]	10,000	2.0	64.8
Kokemäenjoki[2]	27,000	2.8	2.9
Danube[3]	801,000	560	435

1. Calculated from UK Environment Agency monitoring data from all STPs in the catchment. These receive both industrial and domestic effluent, although not all the industrial effluent.
2. Data provided by Environmental Information System (HERTTA) database at the Finnish Environment Institute.
3. ICPDR, 2005.

Figures

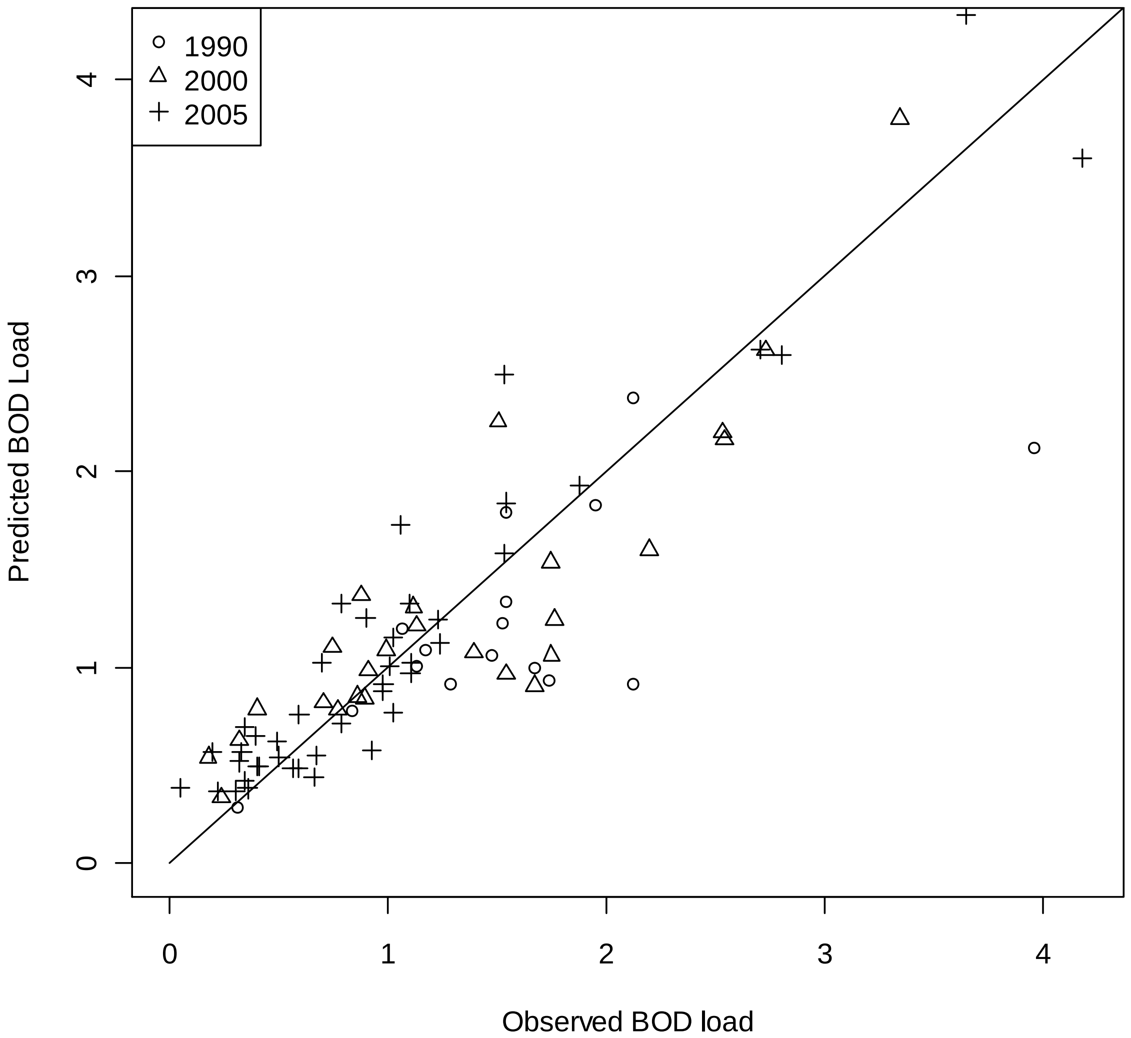

Figure 1 Predicted and observed annual BOD loads (t^{-1} km^{-2} yr^{-1}) for the periods 1990 (circles), 1995(crosses) and 2000 (inverted triangles) using the linear regression model.

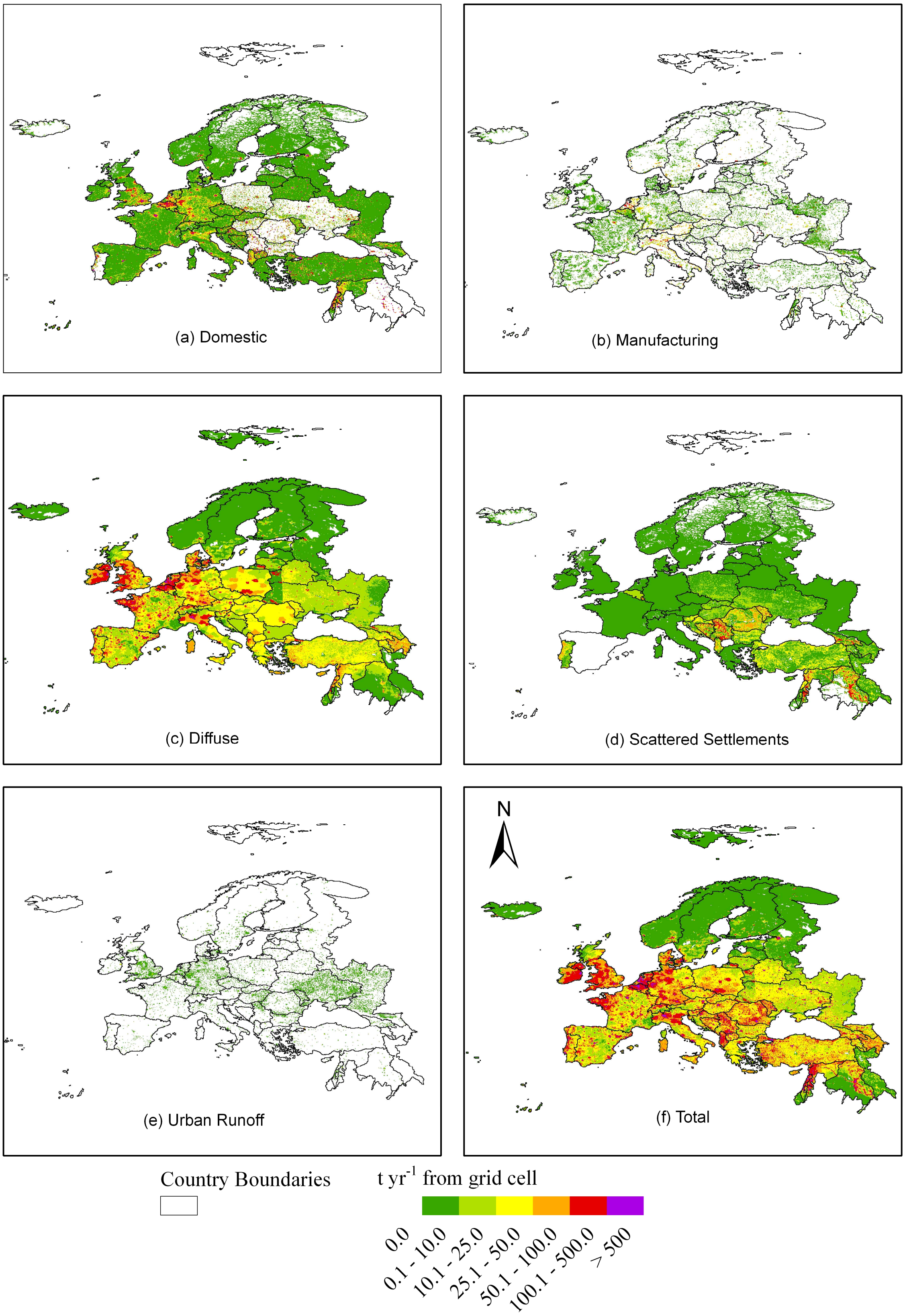

Figure 2 BOD loads (t yr^{-1}) for each grid cell reaching rivers across the pan-European area in 2005 from (a) Domestic effluent, (b) Industrial effluent, (c) Diffuse runoff, (d) Scattered Settlements (e) Urban runoff and (f) all sources combined.

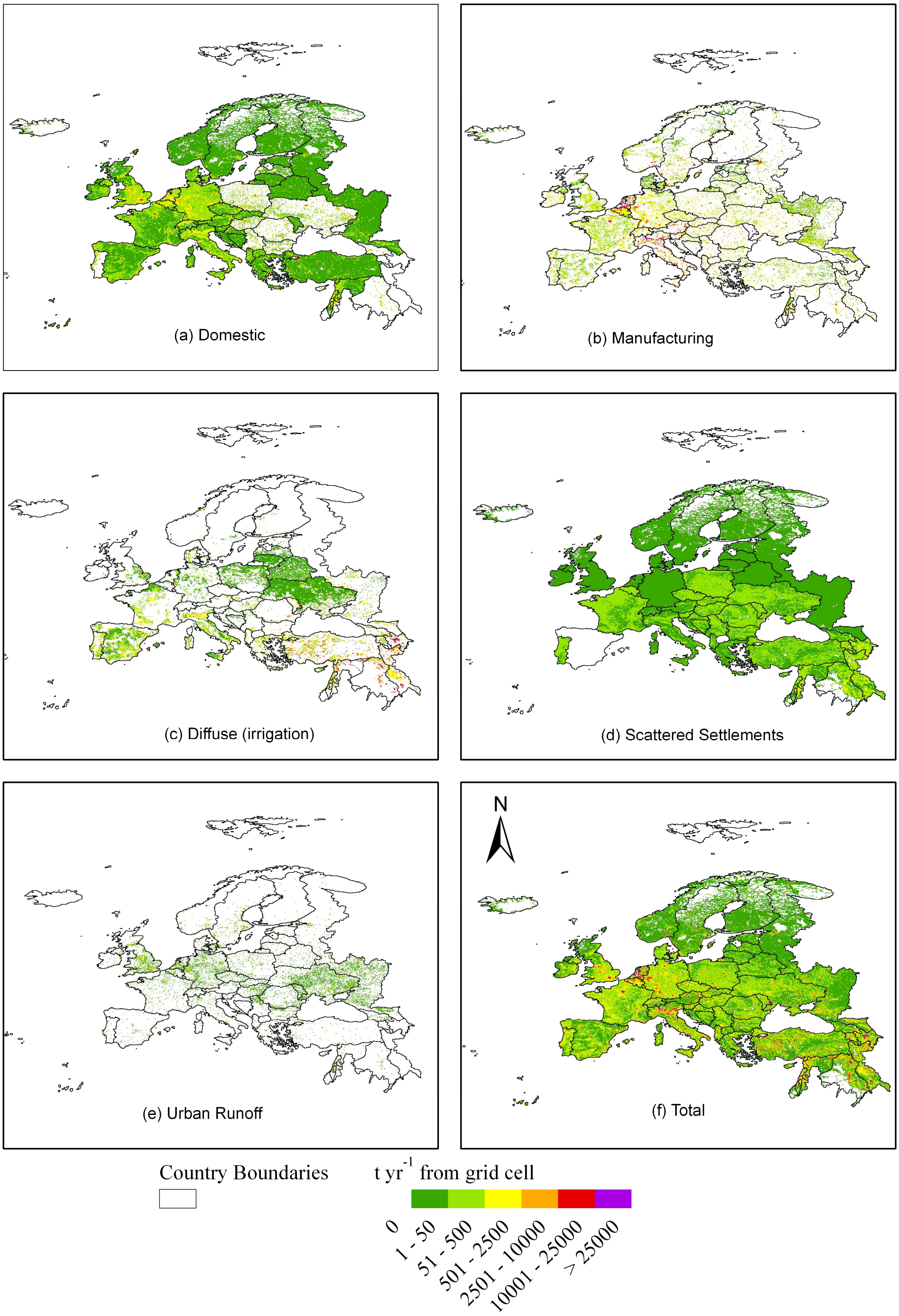

Figure 3 TDS loadings (t yr^{-1}) for each grid cell across the pan-European area in 2005 from (a) Domestic effluent, (b) Industrial effluent, (c) Diffuse (irrigation) runoff, (d) Scattered Settlements (e) Urban runoff and (f) all sources combined.

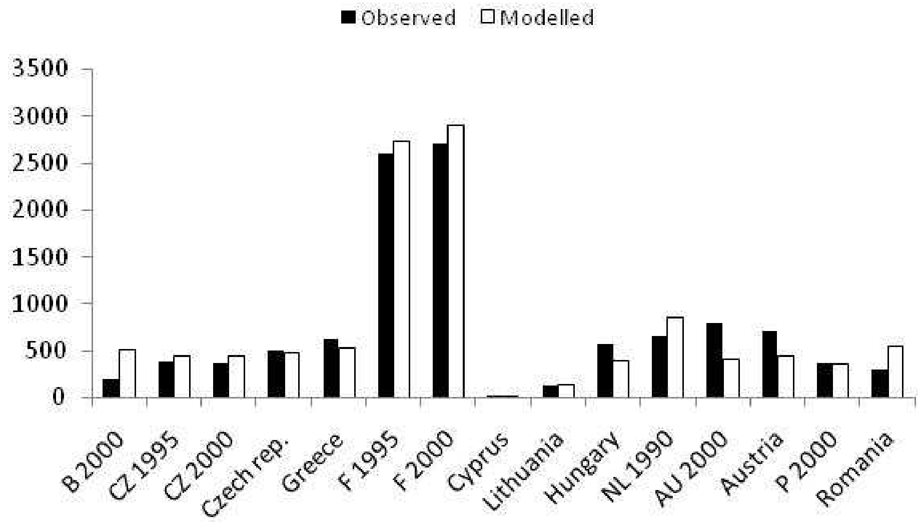

Figure 4 Observed and modelled BOD loads (tonnes day^{-1}) entering sewage treatment in some EU countries. Date indicates the year for which the data apply. No year is 2005. (B = Belgium, CZ = Czech republic, F = France, NL = Netherlands, P = Portugal).

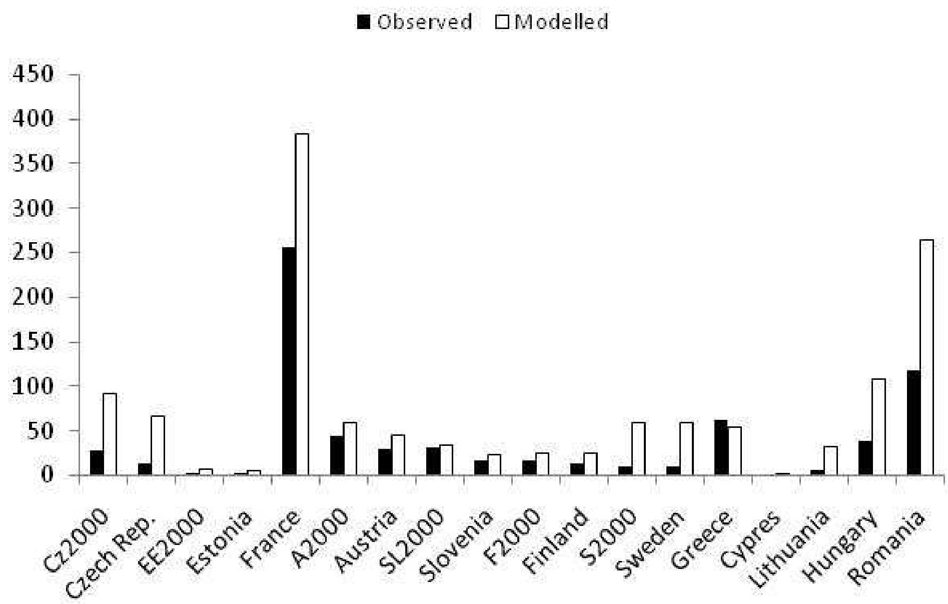

Figure 5 Observed and modelled BOD loads (tonnes day^{-1}) leaving sewage treatment in some EU countries. Date indicates the year for which the data apply. No year is 2005. (CZ = Czech republic, EE = Estonia, A = Austria, SL = Slovenia, FI = Finland, S= Sweden).