An Overview of the WaterGAP model

Generally water resource studies focus on municipalities or agricultural areas because of their high density of water users, or on river basins because they are relatively closed systems, e.g. the surface runoff generated at this scale can be stored until needed. However, there is a growing need for analyses on the global and regional scale because of the rising scientific and policy interest in environmental issues at these scales. On the scientific side, there is a keen interest in the large-scale impacts of changes in climate, land cover, and other manifestations of development on water resources (see review in Arnell, 1996). On the policy side, governments and large international funding organizations are interested in assessing and setting global priorities for support of water resources development. This interest has given place to a rising number of global assessments of the world freshwater situation.

Among others, the following new questions for water resource analysts and researchers have arisen: What is the current and future pressure on freshwater resources due to withdrawals from different water sectors? Which river basins are under particular pressure, and how will this situation change under different scenarios of future water use? How will climate change affect the availability of water in different parts of the world? New analytical tools for regional and global assessments of freshwater resources are needed to address these questions. In this project the WaterGAP 2 (**W**ater - **G**lobal **A**ssessment and **P**rognosis) model is used to answer these new questions.

The WaterGAP model, has been developed at the Center for Environmental Systems Research at the University of Kassel in Germany in cooperation with the National Institute of Public Health and the Environment of the Netherlands. The aim of the model is to provide a basis (i) to compare and assess current water resources and water use in different parts of the world, and (ii) to provide an integrated long-term perspective of the impacts of global change on the water sector. WaterGAP belongs to the class of environmental models which can be classified as 'integrated' because they seek to couple and thus integrate different disciplines within a single integrated framework. In this section a brief overview of the model is presented; for more detailed descriptions of the model the reader is referred to Alcamo and Henrichs (2002) and Döll et al. (2002).

WaterGAP comprises two main components, a Global Hydrology Model and a Global Water Use Model (Figure 1). The Global Hydrology Model simulates the characteristic macro-scale behavior of the terrestrial water cycle to estimate water resources, while the Global Water Use Model computes water use for the sectors households, industry, irrigation, and livestock. All calculations cover the entire land surface of the globe (except Antarctica) and are performed on a 0.5° by 0.5° spatial resolution (this is presently the highest feasible resolution for global hydrological models because climatic input is usually not available at higher levels of detail.)

The model was used to calculate the water availability and water withdrawals in more than 10,000 'first-order' river basins that cover the entire land surface of the earth except the ice caps. These river basins either drain into the ocean or into inner-continental sinks and include 3565 basins with drainage areas larger than 2500 km^2. The 34 largest 'first-order' basins (with areas greater than 750,000 km^2) are further sub-divided to improve the assessment of the water resources.

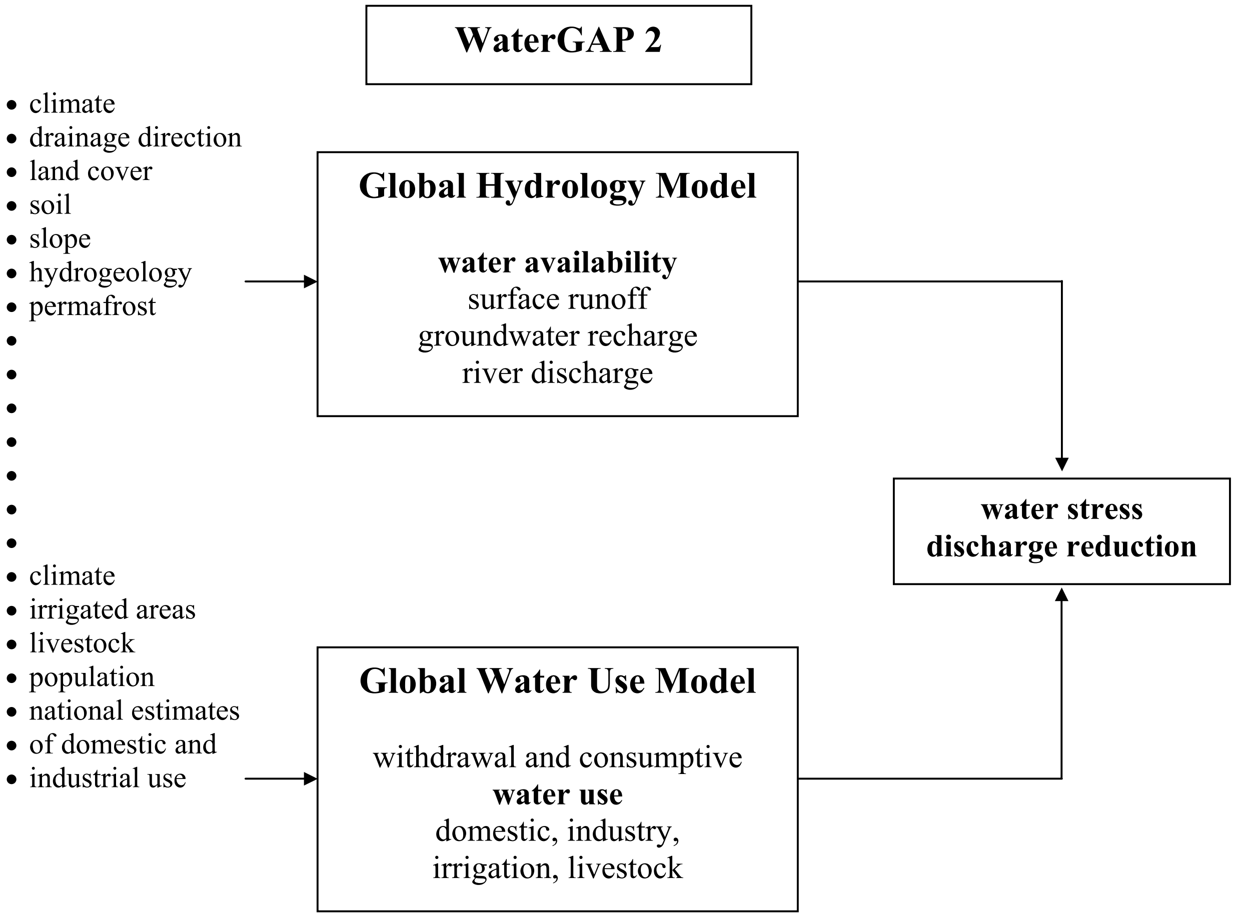

Fig. 1: Schematic representation of the global model of water availability and water use WaterGAP 2

The Global Hydrology Model of WaterGAP

The WaterGAP Global Hydrology Model calculates a daily vertical water balance for both the land area and the open water bodies at each of the 0.5° cells (Figure 2). The vertical water balance for the land fraction in a cell consists of a canopy water balance and a soil water balance. These are calculated as functions of land cover, soil water capacity, and monthly climate variables (i.e. temperature, radiation, and precipitation). The canopy water balance determines which part of the precipitation is intercepted by the canopy and directly evaporates, and which part reaches the soil as throughfall. At this level, the soil water balance subdivides the throughfall into evapotranspiration and total runoff. A different vertical water balance for open water bodies is applied to lakes, reservoirs, and wetlands (based on a global 1-minute wetlands, lakes, and reservoirs map by Lehner and Döll (2001)), where the runoff is computed as the difference between precipitation and open water evaporation. The sum of the runoff produced within a cell and the discharge flowing into a cell from upstream is transported through a series of storages that represent groundwater, lakes, reservoirs, wetlands, and the river itself. Finally, the total cell discharge is routed to the next downstream cell following a global drainage direction map (Döll and Lehner 2002) to compute river discharge.

A tuning of the total discharge against measured values (GRDC 2000) is performed for 724 drainage basins world-wide (i.e. covering half the global land area, except Antarctic), such that the long-term average annual discharge is within one per cent of measured discharge. For drainage basins without measured discharge data, runoff factors are regionalized with the application of a multiple regression approach. A detailed description of the validation of the WaterGAP Global Hydrology Model is provided elsewhere (Döll and others 2002).

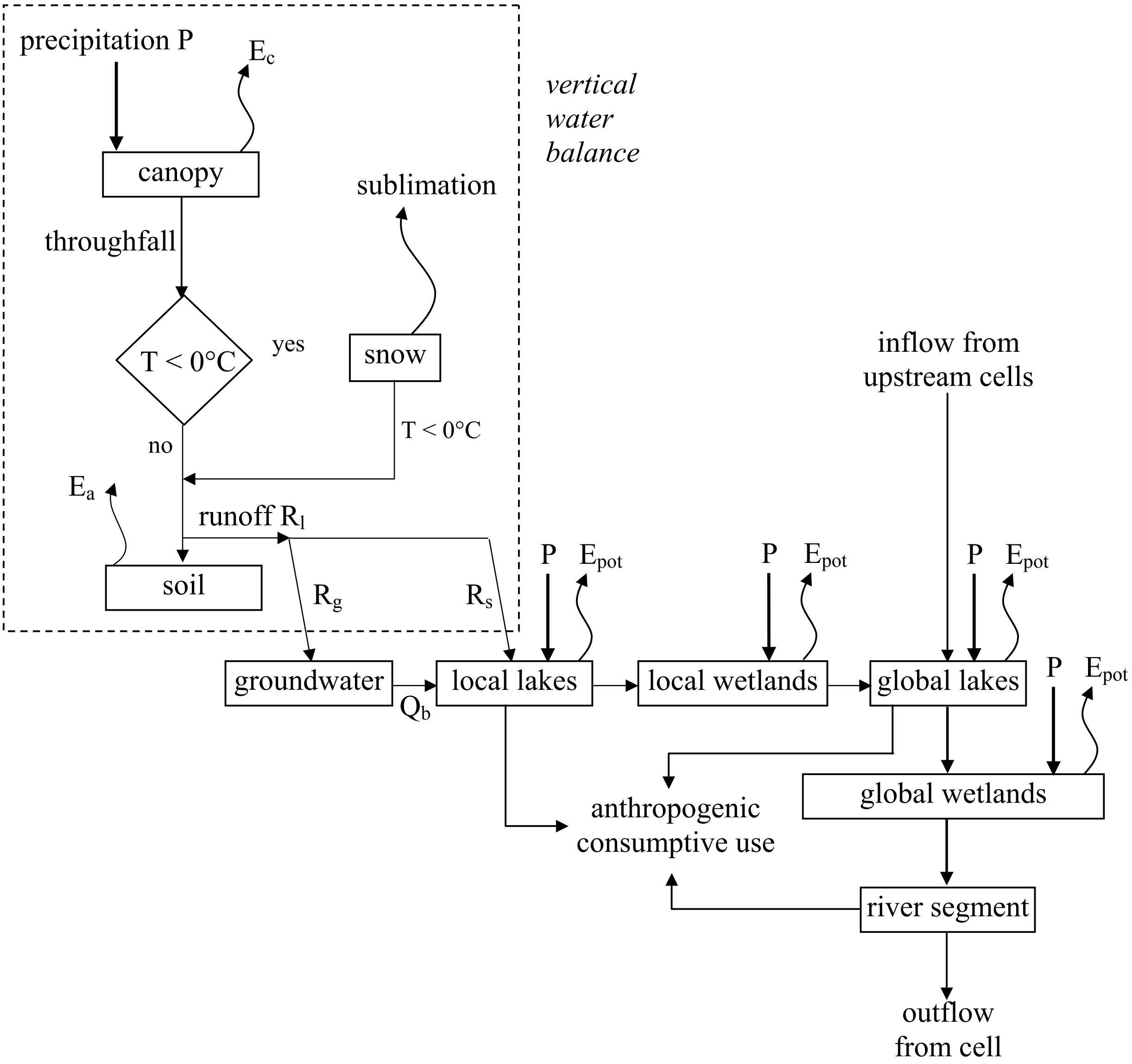

Fig. 2: Schematic representation of the Global Hydrological Model of WaterGAP 2 (from Döll and others 2002). The vertical water balance of the land and open water fractions of each 0.5° by 0.5° cell is linked to a lateral transport scheme, which first routes the runoff through a series of storages within the cell. The resulting cell's outflow is routed to the downstream cell following a global drainage direction map to calculate river discharge. [P: precipitation, E_c: evapotranspiration from canopy, E_a: actual evapotranspiration from soil, R_l: runoff from land, R_g: groundwater recharge, R_s: surface runoff, Q_b: baseflow, E_{pot}: potential evapotranspiration]

The Global Water Use Model of WaterGAP

The WaterGAP Global Water Use Model computes water withdrawals and consumptive water use for main water use sectors: households, industry, irrigation, and livestock. Water withdrawal is the total amount of water that is taken from the terrestrial part of the water cycle. Consumption is understood as the part of the withdrawal that does not return to the terrestrial water cycle. In other words, it is the proportion of water withdrawal that is lost by evapotranspiration during the various use processes. Water use in the households and industry sectors is computed annually, while for the irrigation sector the sub-model operates on a daily basis.

Each sector's water use is computed as a function of a 'water use intensity' and a 'driving force'. Variables representing 'water use intensity' are per-capita water withdrawals (households), water withdrawals per unit of produced electricity (industry), gross irrigation water requirement per unit of irrigated area (irrigation), and per-animal drinking water use (livestock).

Over time, societies are subjected to 'structural changes' and 'technological changes', which can lead to changes in the water use intensity. Structural changes are introduced in the model to reflect the idea that variations in water use intensity are connected to the development of economies and lifestyles (households), the shifting of thermal to non-thermal power plants (industry), or changes in climate or the types of crops grown (irrigation). Technological changes run parallel to structural changes and usually lead to improvements in the efficiency of water use, and thus a decrease in water use intensities.

For households and industry sectors, historical structural changes are estimated from data published by Shiklomanov (1997, 2000a, 2000b) for 26 different world regions. To be able to compute scenarios of country-specific future water use in these two sectors, assumptions on regional structural and technological changes are applied to country estimates for present-day (1995) sectoral water use (Shiklomanov 2000b, WRI 2000). These country-specific values are finally distributed to grid cells following the spatial distribution of population as well as information on urbanization and access to safe drinking water.

Estimates for the irrigation sector rely on an irrigation sub-model, which calculates irrigation water requirements by cell that reflect an optimal supply of water to irrigated crops (Döll and Siebert 2001). To compute net irrigation requirements (i.e. water consumption), first the cropping patterns (rice and non-rice crops) and optimal growing seasons for each cell with irrigated land are modeled. Then, for each day of the growing season, the net irrigation water intensities are computed as the difference between the crop-specific potential evapotranspiration and the plant-available precipitation. Taking into account region-specific irrigation efficiencies (i.e. consumption to withdrawal ratio), gross irrigation water requirement per unit of irrigated area are computed. Irrigation efficiency and thus water withdrawals for irrigation is subjected to technological change (while irrigation water consumption is assumed to remain unaffected in the model by technological change).

Once the water use intensities have been determined for each sector, total water use is obtained by multiplying water use intensities by the respective 'driving forces'. The corresponding driving forces for each sector are country-level scenarios for population (households), electricity production (industry), irrigated area (irrigation), and number of livestock (livestock).