WORKING PAPER

PRESENT AND FUTURE ESTIMATES OF EVAPOTRANSPIRATION AND RUNOFF FOR EUROPE

Janusz Olejnik

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IIASA
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Foreword

One of the objectives of IIASA's study *The Future Environments for Europe: Some Implications of Alternative Development Paths* is to characterize the large-scale and long-term environmental transformations that could be associated with plausible scenarios of Europe's socio-economic development over the next century. Special attention is being given to a few low-probability, high-impact transformations. Changes in hydrological cycles and climatic factors are some of the key environmental components being considered.

This Working Paper describes the present conditions of evapotranspiration and runoff for Europe, as well as their future conditions as based on a scenario for climate change.

The paper was prepared by the author during his participation in IIASA's Young Scientists' Summer Program of 1987.

R.E. Munn
Leader, Environment Program

PRESENT AND FUTURE ESTIMATES OF EVAPOTRANSPIRATION AND RUNOFF FOR EUROPE

Janusz Olejnik

1. Introduction

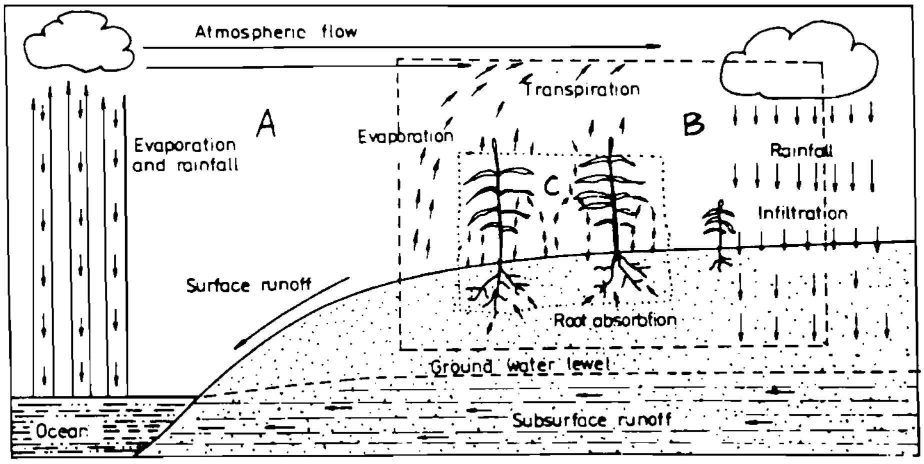
It is well known that the greatest part of the global water supply exists in the oceans and polar ice caps. Only a small part of the total water volume is cycling between the oceans, atmosphere and continents. Table 1 shows the absolute values and percentages of total water volume of the hydrosphere (Lwowicz, 1974).

Table 1: Average water balance of the Earth

Part of the hydrosphere	volume of water ($10^3 km^3$)	per cent of total water volume
oceans	1,370,323	93.96
ice caps	64,000	4.39
underground water	24,000	1.65
lakes	285	0.02
soil moisture	85	<0.01
water vapor in the atmosphere	14	<0.01
rivers	1	<0.01
total	1,458,700	100.0

However, the hydrologic cycle plays the most important role in energy distribution over the Earth's surface as well as in biochemical processes of the biosphere. It is, for example, one of the major phenomena for maintaining a relatively high temperature level at high latitudes.

Figure 1: Components of global (A), local (B), and micro (C) water cycles



From the hydrological point of view, usually three types of cycles can be distinguished (see also Figure 1): global cycle (A), local cycle (B), and micro cycle (C) (Kedziora, 1987). The evapotranspiration process exists in all three types of cycles. The amount of evaporated water depends on different ecosystem parameters (e.g., solar radiation, albedo, soil moisture). The radiation from the sun reaching the Earth's surface is the driving force for the movement of water in the hydrological cycle. Most of this energy is used in the evapotranspiration process. Therefore, from an energy balance viewpoint, the evapotranspiration process (also called latent heat flux) is the most important factor. The amount of evaporated water and energy requirements for this process appears to be a most important ecological factor, particularly in agriculture and in natural ecosystems (Kedziora and Olejnik, 1987). This rate of evapotranspiration usually influences both land use and human activities (Ryszkowski and Kedziora, 1987).

Numerous models are available to estimate evapotranspiration (abbreviated as ET hereafter). These models can be divided into two main groups:

(a) hydrological methods - based on the water balance (Jaworski, 1979).

(b) energy balance methods - based on climatological data (Olejnik, 1987; Holtslag, 1982).

The selection of a model depends on the time- and space-scale of problems and, of course, on the available data. The objective of this paper is to estimate the ET and runoff (abbreviated hereafter as R) for present and future conditions of Europe. The model used will be that of Morton with the Kovacs modifications and the water balance equation (Kovacs, 1988; Morton, 1983).

2. Method for determination of evapotranspiration

Kovacs (1988b) developed an empirical model to calculate ET as a function of latitude, altitude and precipitation:

$$ET = P \exp\left[-(cP)^2 \right] + \frac{\gamma}{c}\left\{1 - exp\left[-(cP)^2 \right]\right\} \tag{1}$$

where;

$$\gamma = \frac{1}{1 + \frac{1}{\cos\varphi}} \quad ,$$

φ is latitude, P is annual precipitation, c is an empirical parameter such that c = f(h, φ), and h is altitude.

Using equation 1 to calculate the actual evapotranspiration, it was possible to estimate the runoff (R) by making use of the following water balance equation (for long periods and large areas):

$$R = P - ET. \tag{2}$$

The same equations were used to estimate the future runoff and ET in Europe based on a precipitation scenario for the next 100 years. A pattern of annual precipitation in Europe for a doubling of atmospheric carbon dioxide results from use of a General Circulation Model (GCM), namely in this case the model from the Godard Institute for Space Studies (the GISS - model). A justification for this approach is given later.

3. Evapotranspiration and runoff in Europe.

The first step in estimating the evapotranspiration and runoff using the Kovacs equations, is to develop a grid map of the continent. The size of a grid was 0.5° latitude and 1.0° of longitude.

Using the operational navigation charts (scale 1:1,000,000), the average altitude of each grid was estimated. The smallest step of an altitude isoline was 50 m. After completing the calculations, the absolute values of the results were recalculated in eight coding classes. Using the "code matrix", maps of all input and output data were prepared.

3.1 Precipitation - present condition

Figure 2 shows the present levels of annual precipitation in Europe. The present situation of annual precipitation is based on averages of a thirty years period from 1931 - 1960 (see Mueller, 1982). The largest levels of precipitation (>1600 mm/year) are observed in the mountain areas of the Alps and also in northern Scotland. The smallest annual precipitation level is observed in the south-east part of Spain (<400 mm/year).

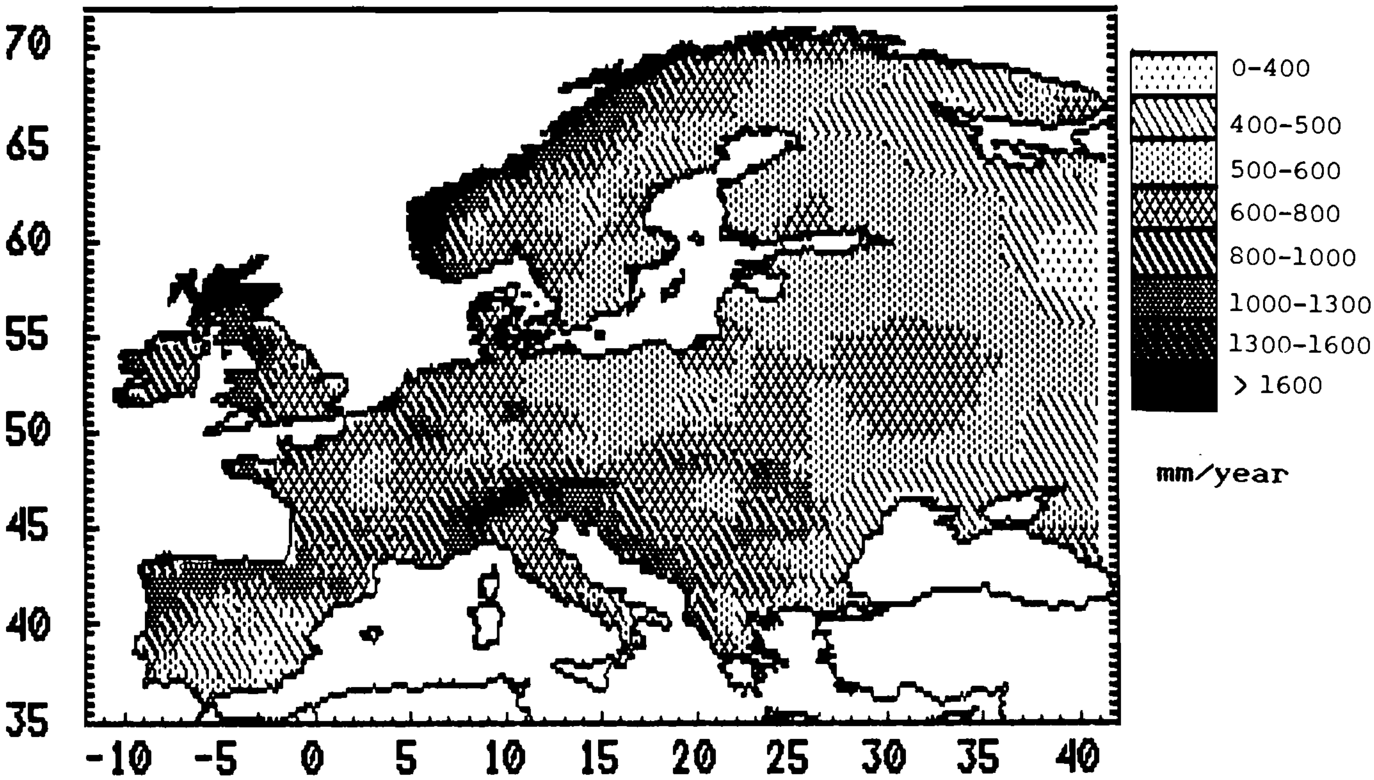


Figure 2: Annual precipitation - present condition (in mm) (Source: Mueller, 1982).

3.2 Evapotranspiration - present condition

Figure 3 shows the resulting evapotranspiration patterns for Europe obtained from eq. (1). The highest value of ET is observed in the north-west part of Spain (which is a region with relatively high precipitation and high temperature). The northern part of Scandinavia and the Alps are regions with a very small level of ET. These areas have large amounts of precipitation which could be evaporated but the temperature is too low (owing to high latitude or altitude). In the central part of Europe the amount of evaporated water varies between 400 to 600 mm/year.

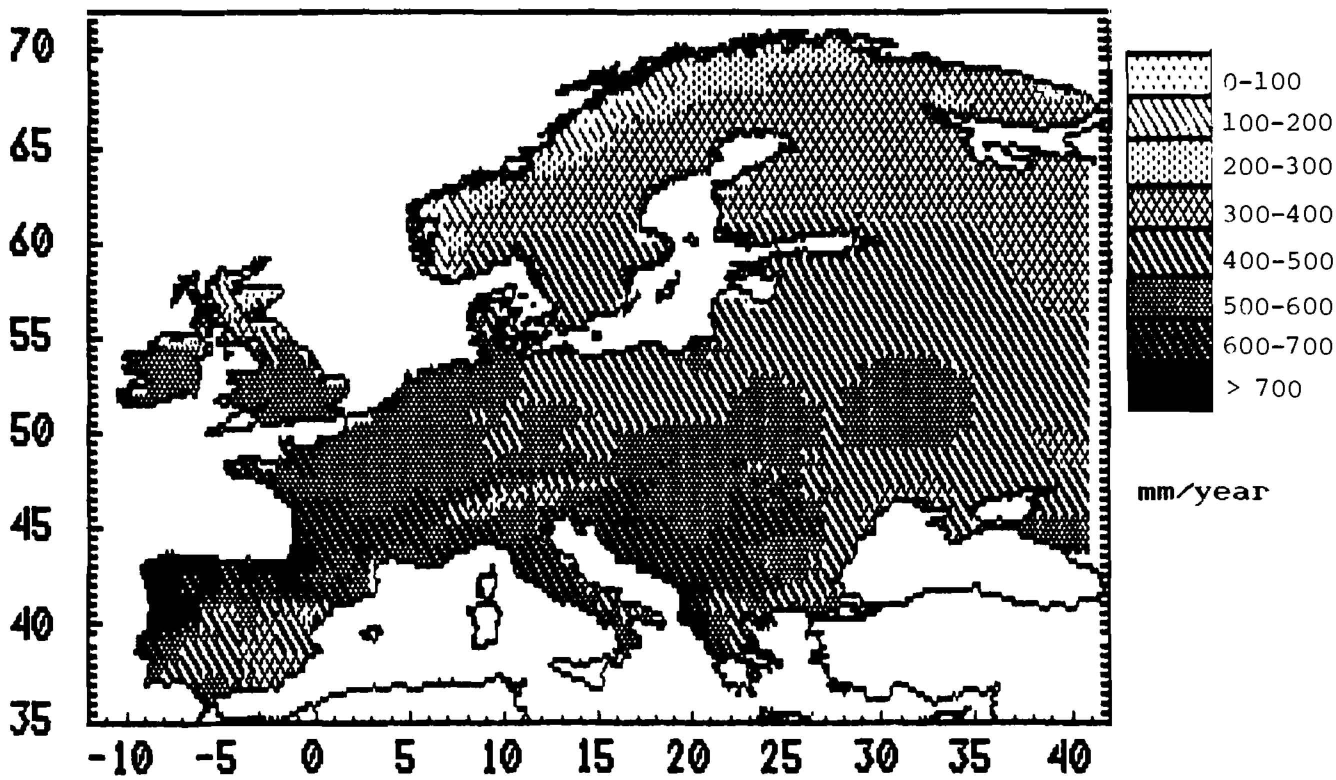


Figure 3: Evapotranspiration - present condition (in mm).

3.3 Runoff - present condition

Figure 4 shows the resulting estimates of runoff obtained from eq. 2. Due to the combination of high precipitation and low evapotranspiration, the runoff in the Alps, Scotland and Norway is relatively high. In Central Europe, the runoff is between 100 and 400 mm/year. The lowest runoff can be found in the southern part of Spain, but also in Italy and the Black Sea region, being less than <500 mm/year.

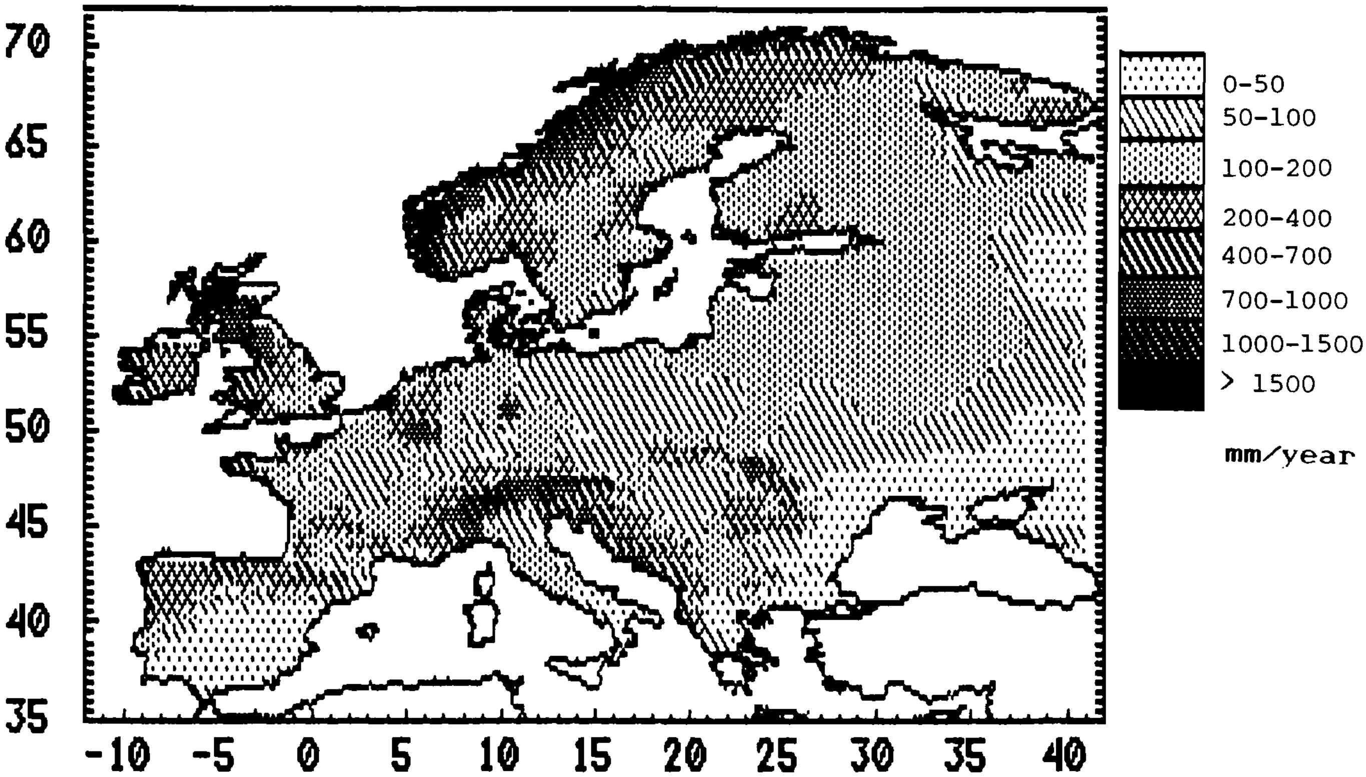


Figure 4: Annual runoff - present condition (in mm).

3.4 Precipitation - future condition

Assuming one of the GCM model results, the distribution of precipitation is estimated to be as shown in Figure 5. In general, the distribution is similar to the present conditions, but in many parts of the continent absolute values are larger: 150 mm/year and more, especially in the northern part of the continent. In addition, in the central part of Europe the increase of precipitation is estimated to be close to 100 mm/year. It is only in southern Europe where the changes are relatively small (<50 mm/year).

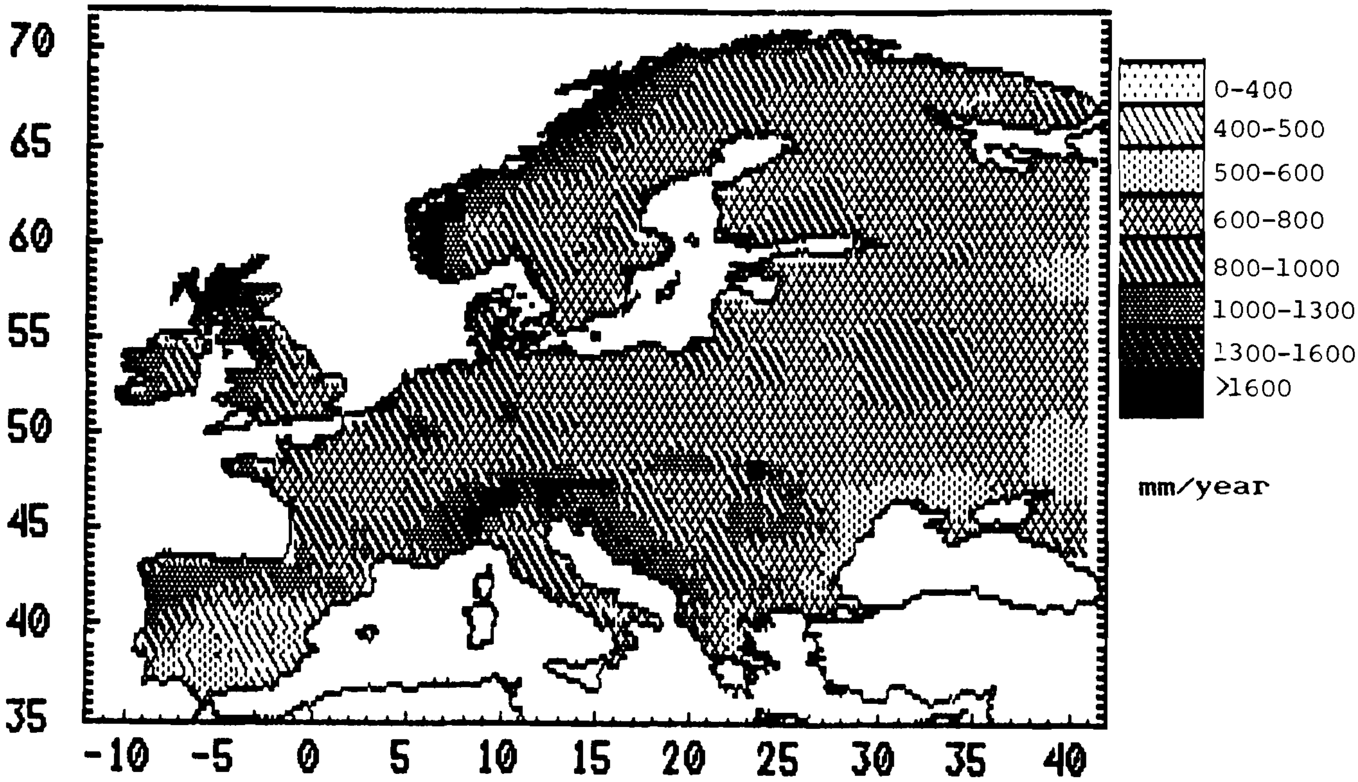


Figure 5: Annual precipitation - future condition (in mm).

3.5 Evapotranspiration - future condition

Figure 6 provides an estimate of future ET patterns in Europe. As with the present conditions, the future ET is expected to be largest in the north-west part of Spain, but several areas near the Adriatic Sea and Greece may have ET rates of roughly over 700 mm/year. The smallest ET is expected in the northern part of Scandinavia.

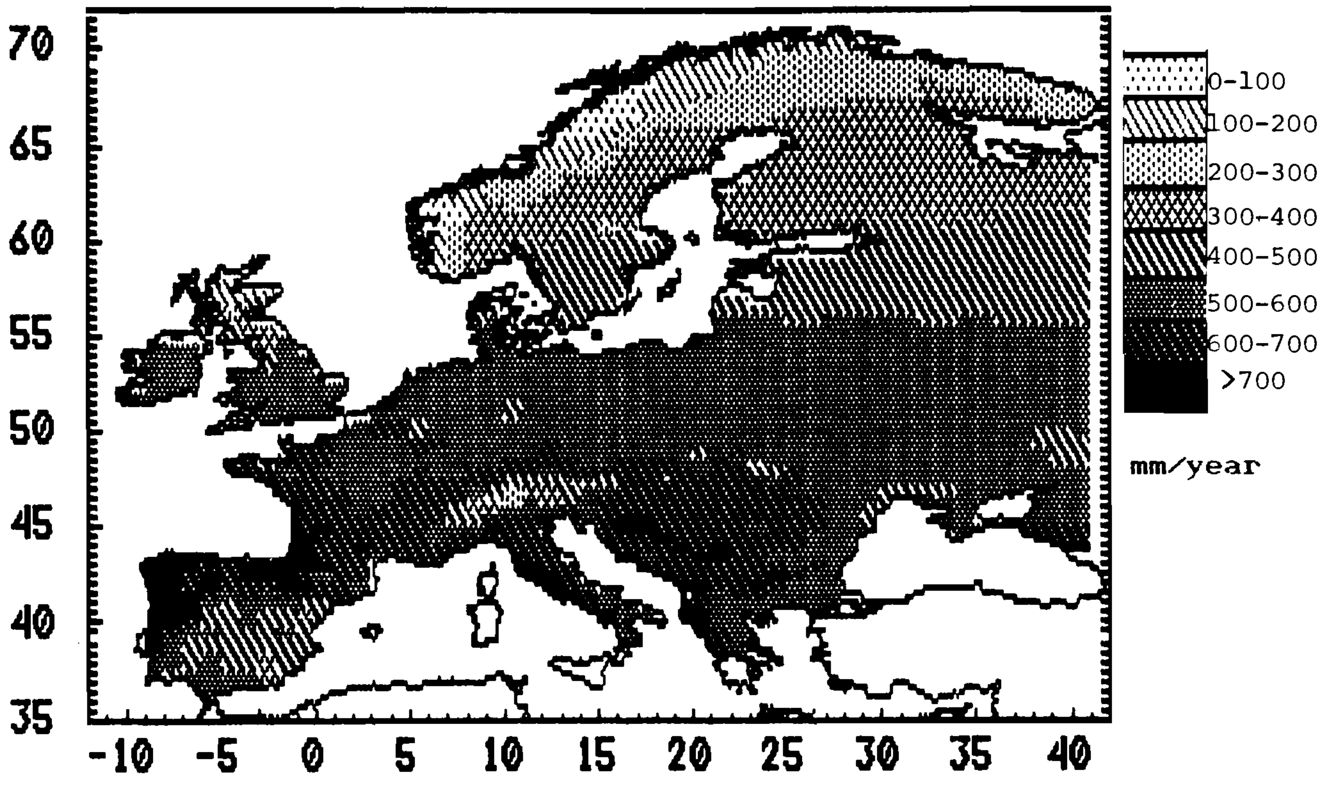


Figure 6: Annual evapotranspiration - future condition (in mm.)

3.6 Runoff - future condition

Figure 7 shows future runoff patterns for Europe. Areas with the highest increase in precipitation roughly corresponds to the areas with the highest increase of runoff. In some parts of southwestern Europe no change is expected from present and future conditions. The highest and lowest values of runoff are likely to have a similar distribution to that of the present condition.

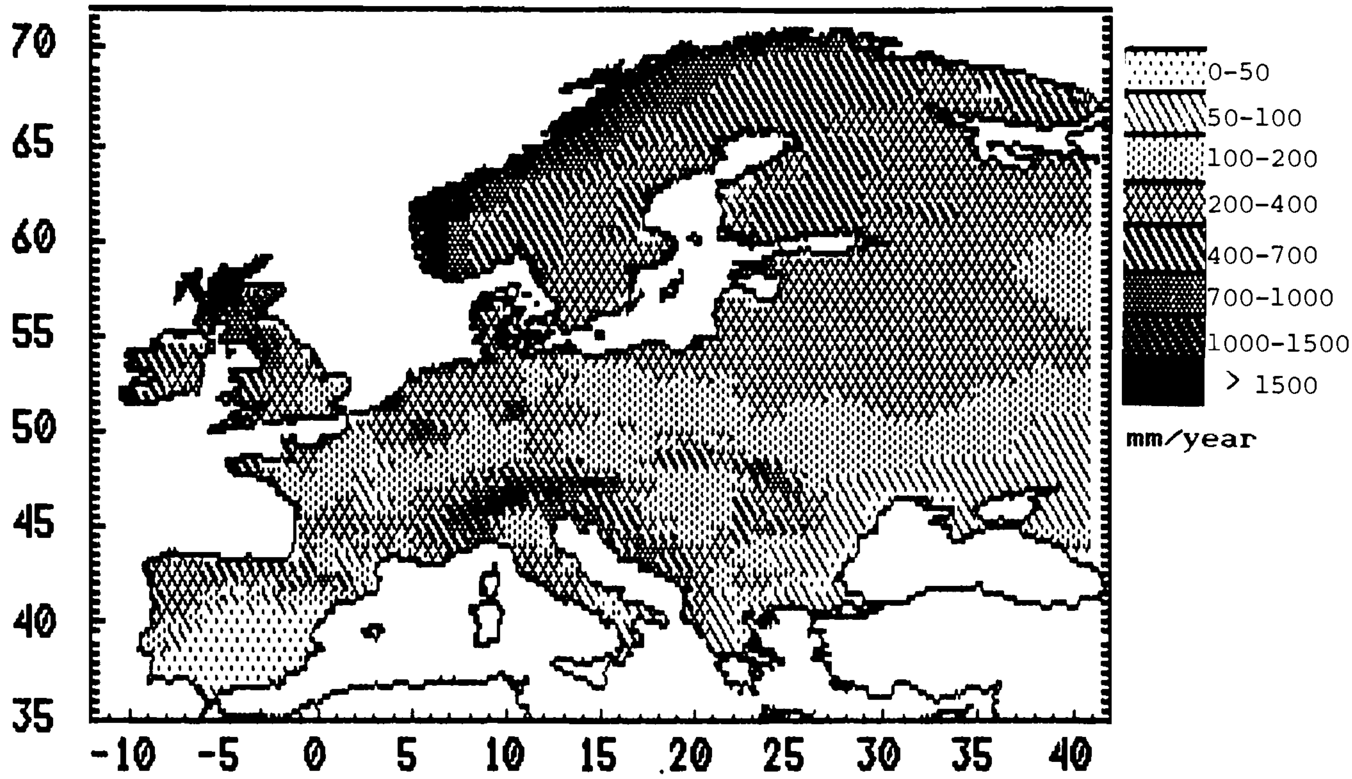


Figure 7: Annual runoff - future condition (in mm.)

4. Discussion

Two "difference maps" were prepared to illustrate the expected change between present and future values of the considered parameters.

4.1 Evapotranspiration

The difference between the present and future ET is shown in Figure 8. There are some parts of the continent where the ET will not change (shading class from -10 to +10 mm/year). There are two plausible reasons for that: (i) the increase of precipitation is too small for a radical change in ET (northwest Spain), (ii) the changes in precipitation are rather big, but there is not enough incoming solar energy to evaporate this water (parts of Sweden, Finland and the USSR). A large decrease of ET is expected in the northern part of Europe. This is connected with a large decrease of incoming solar radiation in that area. The higher precipitation causes more cloudiness, which triggers a decrease in the solar radiation reaching the ground surface. This situation applies in some parts of Norway, Sweden, Finland and USSR with very important implications for runoff. The largest increase in ET is expected in some parts of central and southern Europe. Near the Black Sea, for example, the increase of ET could be more than 90 mm/year. This change may have fundamental implications for the agriculture of this region (in terms of water availability).

4.2 Runoff

The largest increase in runoff is expected in the northern part of Europe (Figure 9). Because of an increase of precipitation and a decrease in ET, the runoff may increase greatly (according to the water balance from equation 2), in some cases more than 250 mm/year. A similar increase of runoff is likely in the Alps, the Karpatian mountains and also in Scotland and the Netherlands. In these areas climate change will have a very strong influence on water management. The change in runoff is likely to be rather small in southern Europe (40 mm/year), being less than 20mm/year in the southern part of Spain. In this region, any increase of water due to higher precipitation will be evaporated (see Figure 8).

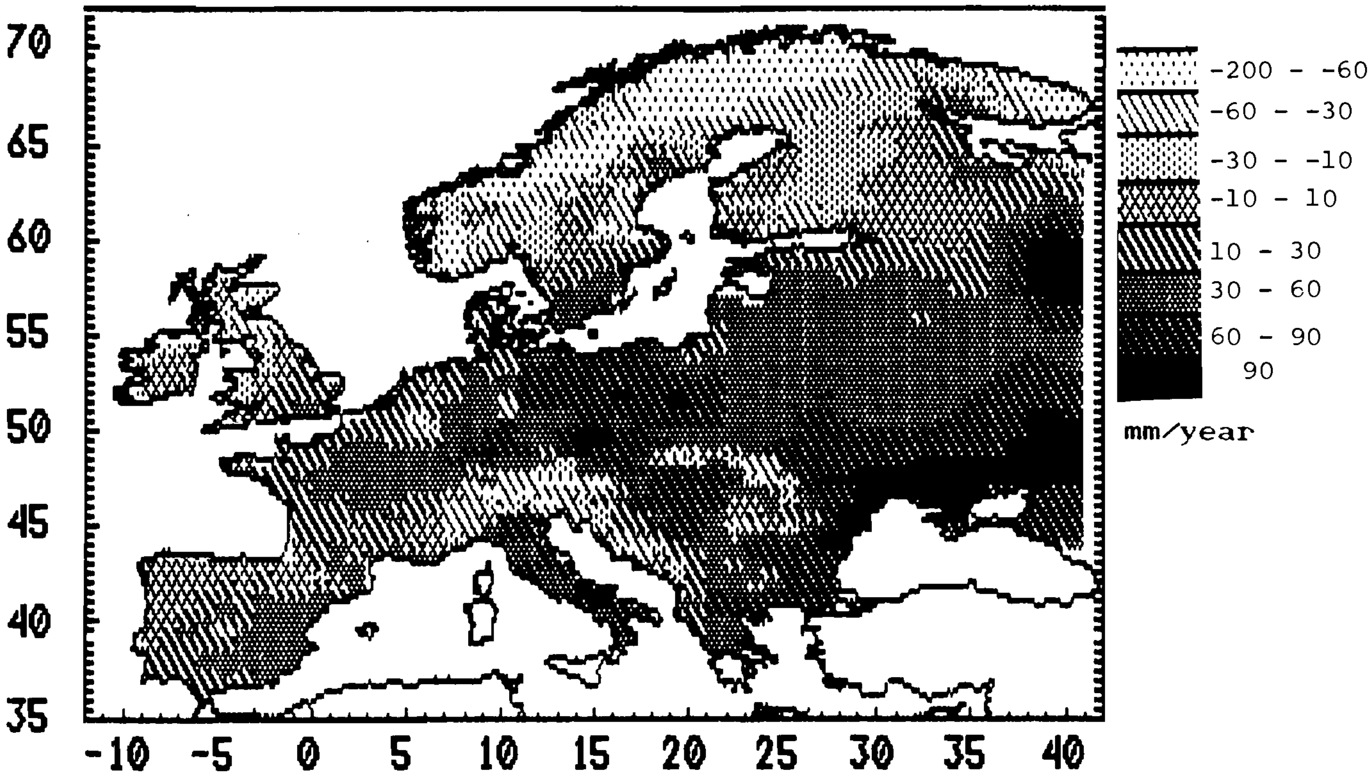


Figure 8: Annual evapotranspiration - difference between future and present conditions (in mm.)

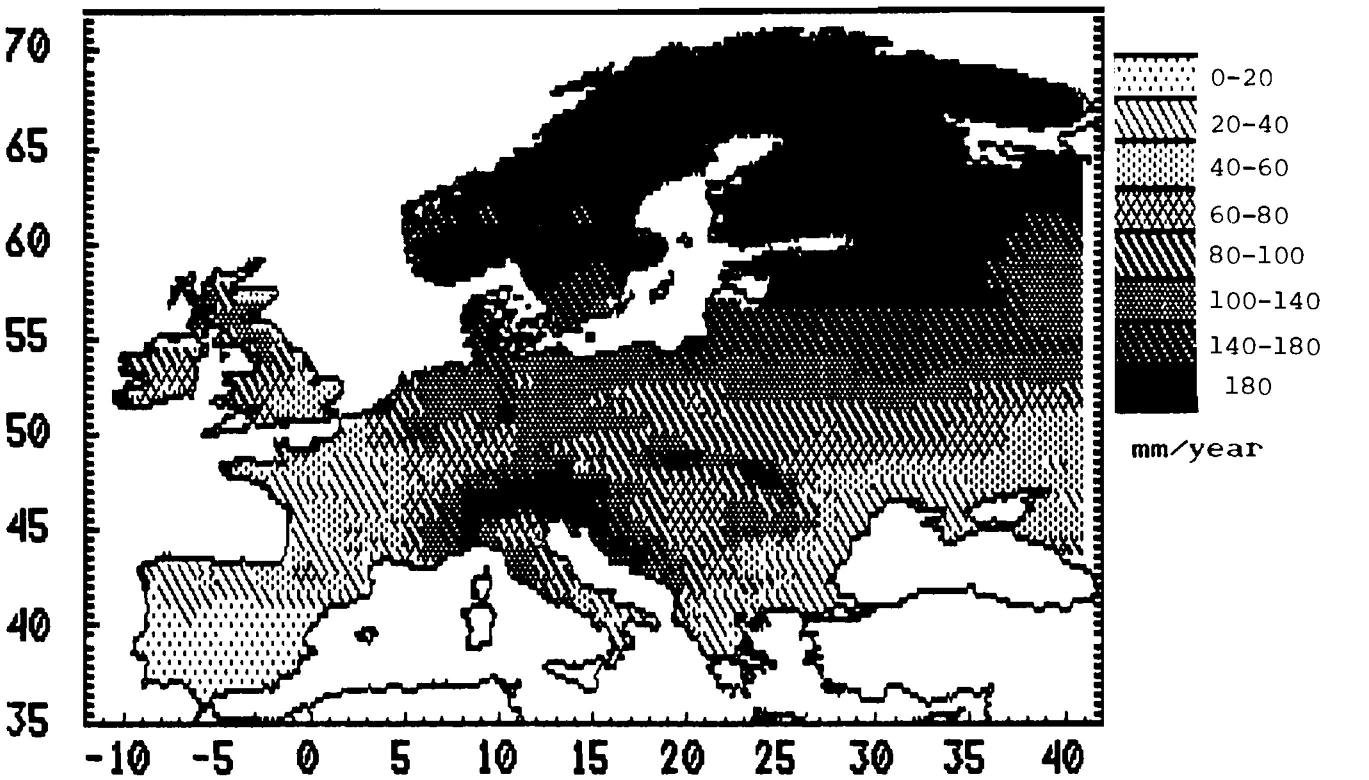


Figure 9: Annual runoff - difference between future and present conditions (in mm).

4.3 The absolute and percentage values of changes in precipitation, ET and runoff.

The average values of precipitation, ET, runoff and the differences between the present and future condition are shown in Table 2. The table is divided into five parts, each of them showing the results of a change in the considered values for different parts of Europe. The upper box shows the results of the calculations for all of Europe. The lower boxes show disaggregated results.

Table 2: The absolute and relative changes in precipitation, ET and runoff (P - present, F - future).

Latitude		Prec.	ET	Runoff
Europe	P	681	462	219
	F	845	485	360
	Change	164 (+24%)	23 (+5%)	141 (+64%)
65°-72°	P	668	286	382
	F	901	245	656
	Change	233 (+35%)	-41 (-14%)	274 (+72%)
55°-65°	P	645	390	255
	F	856	400	455
	Change	211 (+33%)	10 (+2%)	200 (+78%)
45°-55°	P	692	518	175
	F	834	564	270
	Change	142 (+20%)	46 (+9%)	95 (+54%)
35°-45°	P	726	585	141
	F	807	620	187
	Change	81 (+11%)	35 (+6%)	46 (+33%)

The annual precipitation for Europe is expected to increase by about 164 mm, i.e., about 24%. This leads to an increase of ET (23 mm/year) and an increase of runoff (141 mm/year). In percentages, the increases of ET and runoff will be 5% and 64% respectively.

Europe between 65° and 72° of latitude

In this part of Europe, a very large decrease (-14%) of ET is likely (for all Europe it is +5%, Table 2) causing a large increase in runoff (72%). This area is the only part of Europe where a decrease in ET is expected. In absolute values, in this part of Europe, the increase in runoff is likely to be 274 mm/year, which would have a very strong influence on human activities in countries such as Norway, Sweden, Finland, and the USSR.

Europe between 55° and 65° of latitude

Changes in all the parameters in this part of Europe are expected to be very similar to the changes described above. The countries noted above, as well as the northern part of Great Britain, Denmark and the Netherlands would probably need to invest in building new dikes due to the large increases in runoff (78% or 200 mm/year!). In this part of Europe, there would be no essential changes in ET, being only 10 mm/year (2%).

Europe between 45° and 55° of latitude

This part of Europe is expected to have a smaller change in runoff than Northern Europe, although the increase would still be considerable (about 95 mm/year or 24%). A lot of water, connected with the increase in precipitation, would be evaporated due to the availability of solar energy. There would also be an increase of about 9% in ET, compared to the present condition.

Europe between 35° and 45° of latitude

Table 2 shows that nearly half of the water connected to an increase in precipitation would be evaporated, i.e. 35 mm/year or a 6% increase of ET compared to the present condition. The runoff would increase only 46 mm/year. These results show that in this part of Europe the water deficit could be reduced. This phenomenon would have strong implications for agriculture and general land use.

Summarizing these results, it can be stated that the region most sensitive to an increase in ET is the southern part of Europe. The area most sensitive to an increase in runoff is the northern part of the continent, but it is necessary to remember that all results presented in this paper disregard changes in temperature in the next 100 years.

A basic problem with equation 1 is the determination of 1/c. A rough approximation of this parameter can be given as a function of altitude and latitude. A more correct approach would be to determine the 1/c parameter as a function of latitude and temperature. Because of the time limitation only the first simplified method was used and, therefore, only a scenario was analyzed which assumes a change in precipitation and no change in temperature. Since the impact of greenhouse gases will also change the temperature, the investigation has to be extended in the future including both a change in precipitation and temperature. Temperature, like precipitation, is fundamentally important in the evapotranspiration process. In addition, further work is needed to examine different time steps (from annual to monthly), permitting estimates to be made of monthly values, which are very important for vegetation studies.

5. Conclusion

The results presented here show that considerable changes in runoff and evapotranspiration may be associated with climate change. The results obtained for the present conditions are in accordance with hydrological data measured or calculated independently from this assessment (see for example Chernogaeva, 1971, who prepared a water balance for Europe based on present climatic conditions). The future increase in precipitation can have fundamental importance for human activities:

(i) intensive runoff can result in very intensive soil erosion. Thus, high runoff could also have an important economic influence as it would be necessary to build new dikes along rivers, especially in central and northern Europe. The change in runoff could also change the soil moisture regime in some parts of the continent, depending on the type of soils.

(ii) changes in ET could have major implications for agriculture and land use in general. It is probable that there will be some areas in Europe where the water deficit will decrease, causing higher yields in agricultural production.

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