The water balance of Moscow

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Abstract. The results of water balance estimates are given for the whole of the Moscow area and for the most built-up part within the Sadovoye ring. The technique of estimation is presented. Water balance data for the urban area are compared with those for the natural Moscow River basin to Zvenigorod. Conclusions are drawn concerning the effect of changes in the water balance of an urban area on the environment.

Le bilan d'eau de Moscou

Résumé. On présente les résultats des calculs du bilan d'eau pour toute la région de Moscou et pour sa partie la plus bâtie dans les limites de la Ceinture des Jardins. On propose une méthodologie de calcul. On compare les données du bilan hydrologique en régions urbaines avec celle du bassin hydrographique naturel, la Moskova jusqu'à Zvenigorod. On tire des conclusions concernant l'influence des changements du bilan hydrologique d'une région urbaine sur l'environnement.

A city is a major factor of environmental transformation. The concentration of people in the urban area, building developments and the extension of the urban area cause significant changes in the landscape. The roughness of the area is reduced and considerable network changes occur due to the deepening and the widening of river channels and the building of dams and reservoirs. The nature of the urban surface also changes, its major part becomes impervious as a result of buildings and asphalt. Water surfaces increase and the nature of vegetation changes.

All the above changes occur in Moscow (present area 877 km^2). The relief of Moscow has been reduced, the zonal type of podzolic soil has long been replaced by a cultural soil layer as deep as 20 m in low places. In the urban area, parks, gardens and lawns account for 30 per cent of the area and are the predominant type of development.

A major part of the urban area (of the order of 20 per cent) is under agricultural use, providing fruit and vegetables for the city. At present streets and pavements are almost completely covered with asphalt. Together with the area occupied by buildings the impervious surface is approximately equal to the area of parks, gardens and lawns.

Surface runoff from the urban area (rain, snow and from street watering) is diverted with the help of open and closed sewerage systems and is discharged into the Moscow and Yauza rivers. The time lag of the surface runoff, especially snow, to the river has greatly decreased since in winter huge masses of snow from roofs and asphalt highways are removed and dumped directly into river channels. The volume of individual snow dumps is as great as 300 000 m^3 which is equivalent to 100 000 m^3 of water.

In the urban area the rate of infiltration of rain and snowmelt is much smaller than that in rural areas, and this has caused a decrease in groundwater recharge. Changes in deep-lying confined water have taken place as well. Exploitation of confined waters for almost a hundred years has lead to their significant depletion and to a sharp local decrease in the level of the groundwater table.

Changes in air circulation, cloudiness conditions and the heat regime result in changes in the amount of precipitation falling within the urban area. Shver (1976) showed that the difference between the annual totals of precipitation for the western and eastern suburbs of Moscow is about 10 per cent/year. The annual total precipitation for Moscow as a whole does not differ from that of the neighbouring rural areas.

In the present water balance calculations the precipitation of Moscow is assumed to be 700 mm. This estimate is based on all gauging stations situated within the urban area (*Guidebook on the Climate of the USSR,* 1967). A major part of the precipitation consists of summer and autumn rainfalls and about 200 mm is from snow.

The water balance of Moscow was calculated separately for the warm and cold periods of the year with due regard to the different types of urban areas. The total river runoff was defined as the sum of the surface and groundwater runoffs. Evaporation is the difference between precipitation and river runoff. The groundwater recharge from the permeable part of the city is taken to be similar to the groundwater runoff from the rural basin of the Moscow River as far as the town of Zvenigorod. It is defined by analysing river runoff hydrographs. However, the recharge of the groundwater, drained by rivers within the urban area, decreases as compared to the rural basin in proportion to the part of the impervious area.

Since a major part of the snow removed from the streets and the squares of the city is dumped into the Moscow and Yauza rivers, the runoff coefficient of this part of the snow approaches unity. The same is true of the snow which is melted with the help of moving and stationary snow melters and is discharged into the river through the sewerage system.

For the impervious area the spring runoff coefficient is taken as 0.95, bearing in mind that about 5 per cent of snowmelt water fills surface depressions and then evaporates.

The coefficients of spring surface runoff from the agricultural lands and areas under trees and lawns were taken to be similar to the runoff coefficients from the forest and agricultural lands at the Podmoskovnaya gauging station (Subbotin, 1966). According to the results of experiments conducted over many years, the coefficient of the spring surface runoff from the agricultural lands is about 0.75 and the coefficient of surface runoff from forests is about 0.20. However, considering that urban lawns and parks are more trodden down than forests and that their litter-fall is removed (leaf litter is practically non-existent) we assume that the coefficient of spring surface runoff from urban areas under trees and lawns is somewhat higher than that under natural conditions.

Summer–autumn rainfall–runoff relations in Moscow are characterized by an increase in the soil infiltration capacity in pervious areas, an increase in evaporation from all types of urban environments, and by a decrease in the surface runoff coefficients. According to data from the Podmoskovnaya gauging station, in summer there is practically no runoff from small basins under forests and agricultural lands. Therefore areas under trees and lawns, agricultural lands and unused lands within the city were not taken into consideration in calculating the summer surface runoff. For the summer–autumn period the coefficient of surface runoff from the impervious areas was taken as 0.80 for roofs and 0.75 for asphalt surfaces with due regard to evaporation from the surface and micro-depressions. Some decrease as compared to the snow runoff coefficient is assumed, due to additional losses of water through the wetting of surfaces and the filling of hollows which take place repeatedly after every rain. In a warm season the runoff from the water surface was taken as the difference between precipitation and evaporation from the water surface.

These are the basic principles of the method used in calculating the water balance of the Moscow area. The method is based on assumptions which should be considered as a working hypothesis. The latter needs to be developed and revised. For this reason the results of the calculations are approximate.

TABLE 1. Comparison between water balances of the urban and rural areas [mm]

Water balance elements	Area of Moscow: Within the Sadovoye ring	Area of Moscow: The whole area	Rural area: Basin of the Moscow River to Zvenigorod
Precipitation	700	700	700
Total river runoff	510	300	200
Groundwater runoff	35	50	70
Surface runoff	475	250	130
Evaporation	190	400	500
Infiltration	225	450	570
Total runoff coefficient	0.73	0.43	0.28
Coefficient of groundwater discharge into rivers	0.15	0.11	0.12
Per cent of the groundwater runoff in the total river runoff	7	16	35

The water balance of the Moscow area is compared to the water balance of the Moscow River basin to Zvenigorod where the natural water balance has been disturbed very little. The water balance for the rural area was calculated for the period before the building of the Mozhayskoe Reservoir.

The two first columns of Table 1 show that the water balance of the urban area is not homogeneous. In the most built-up part of Moscow, within the Sadovoye ring, separate elements of the water balance greatly differ from the data obtained for the whole area of the city. Thus the infiltration within the Sadovoye ring is one half that for the whole of Moscow. Hence the loss of water through evaporation is also less. However, the surface runoff within the Sadovoye ring is almost twice as high and the groundwater recharge is about 30 per cent less as compared to the whole area of the city.

The comparison with the water balance for the agricultural area shows the magnitude of changes as a result of urbanization. Major trends in the changes are a decrease in infiltration and an increase in the surface runoff. Regardless of artificial watering of the streets, trees and lawns in the warm season the losses of water through evaporation significantly decline; within the Sadovoye ring they decrease approximately 2.5 times. At the same time the surface runoff from the mostly built-up area of the city is almost 4 times higher and the total runoff is 2.5 times higher than the values for the agricultural area; the groundwater recharge for the built-up area is half that for the agricultural area.

These changes are so great that even though the areas covered by cities are relatively small the general changes in the water balance may be significant. For instance, if the urban areas increase by 1 per cent, the surface runoff from the whole of the area may rise by 2–4 per cent. Farming causes the same changes but in an opposite direction. The intensification of farming reduces the runoff from arable lands and consequently the flood part of the river runoff (Lvovich, 1963; Koronkevich, 1973). The increase of urban areas somehow makes up for the added amount of water used in arable lands due to a rise in crop yields which is of special importance in regions of insufficient moisture. However, the assessment of these quantitative relations does not give a true idea of the effect of the water balance on the environment under urban and agricultural conditions. The quality of water running from the area of the city during snowmelt and rain is of great importance. It depends on the cleanliness of streets and interblock areas.

Even in such a clean city as Moscow, the surface runoff has some pollutants which transported by water enter the nearest river or water body. Thus, the cleanliness of the city affects not only its sanitary conditions but also those of the surrounding area. In some cities and also in cattle-breeding farms, ponds are likely to be required to store water running from the surface. First, they are needed for settling and cleaning water prior to draining into rivers and water bodies. Second, in some cases ponds for storage of water will act as water reservoirs regulating floods.

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