Chapter 22
Aquifer Recharge Capacity in the Protected Area South of the Basin of Mexico

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Abstract The aim of this study was to conduct a hydrologic analysis to define the boundaries of the 29 watersheds that make up the study area, as well as physiographic characterization through the estimation of parameters governing their hydrological functioning. The results, in summary, is that the evaporation, evapotranspiration and storage in the unsaturated zone, are linked closely to the functioning of the soil where it is concluded that more than two thirds hasty return of the water to the atmosphere through the three processes described. The estimate of recharge capacity or volume of infiltration was carried out through a methodology whose structure is based on three concepts: location, climate, hydrology and hydrographic aspects of micro, water balance of the Valley of Mexico Basin; and water balance of the Conservation Area.

Keywords Watersheds • Aquifer recharge capacity • Hydrology • Mexico City

22.1 Location, Climate, Hydrology and Hydrographic Aspects of Watersheds in the Protected Zones

22.1.1 Location Area

Mexico City is located southwest of the Basin of Mexico; it has a total area of 150,156 ha, 59.04 % of the territory, which corresponds to an area with rural characteristics. In this region, agricultural areas and natural ecosystems play an

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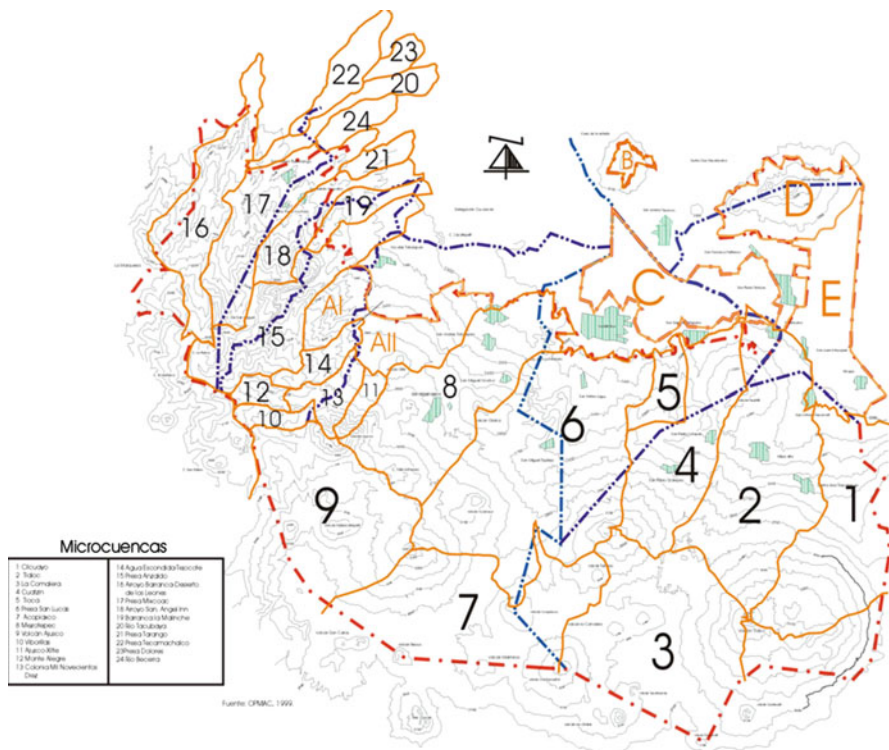e-mail: puyol88@yahoo.com

Fig. 22.1 Watersheds

important role in maintaining environmental balance. At an altitude of over 2,240 m.a.s.l, it has four types of climate; and it is characterized by an annual average temperature between 12°C and –18 °C. The rainy season occurs between the months of May to October and the average annual precipitation varies in a range of 600 mm in the northeast, and 1,500 mm in the west.

22.1.2 Hydrology

The aim of the hydrologic analysis conducted on the surface of the Protected Area was to define the boundaries of the 29 hydrologic units or watersheds from the study area.

In each of the hydrologic units a characterization was made through the estimation of parameters such as: area of the basin hypsometric curve (area distribution as a function of elevation); perimeter of the unit, length of the larger axis, elongation ratio, shape index, total length of channels, stream order and drainage density.

The previous parameters define the hydrological behavior of the watersheds, and the results of the analysis are presented in Fig. 22.1:

22.1.3 Hydrographic Aspects of Watersheds

The characteristics presented by the micro-basins are fundamental to understand the hydrological functioning. Figure 22.1 shows the delineation of the 29 watersheds: Basin water balance of the Valley of Mexico, Conceptual Model, Estimation of hydrological balance variables.

22.2 Conceptual Model

The hypothesis used for the water balance is the principle of conservation of mass within the limits established by its watershed. To estimate the water balance of a catchment and to identify the variables involved in this process, the principle of continuity to a control volume that surrounds the main stream was applied, including the eight hydrological variables involved in the balance (Fig. 22.2).

22.2.1 Estimated Balance Hydrological Variables

With the support of the mean values of hydrological variables recorded during a period of 45 years (1960–2004), the water balance of the Basin of Mexico was estimated. Table 22.1 shows the annual average values of its components in hm^3 (million cubic meters) and m^3/s (cubic meters/second) and its corresponding percentages (CNA 2007).

Table 22.2 shows the situation of surface water and groundwater. Analyzing the values in Table 22.2 reveals a number of important conclusions related to the use of surface water and groundwater. In the Mexico City Basin, rainfall runoff generated hm^3 748 (23.7 m^3/s), however, only advantage through rivers and springs a cost of 92 hm^3 (2.9 m^3/s), i.e. only total runoff uses 12 %.

22.3 Water Balance Study, Conceptual Model, Estimation of Hydrological Balance Variables

22.3.1 Conceptual Model

The conceptual model is based on the hydrological processes that occur in the atmosphere, as well as surface and subsurface layers.

In this case, the movements of water in all three phases have a very close relationship, highlighting their behavior in surface and underground layers, as it

Fig. 22.2 Shows the geohydrological condition of aquifers, overexploited and underexploited

Table 22.1 Hydrological balance for the Basin of Mexico

Component	Volume (hm³)	Streamflow (m³/s)	Percentage (%)
Precipitation	6771	214.7	100.0
Evapotranspiration	5014	159.0	74.1
Water storage evaporation	126	4.0	1.9
Superficial recharge	883	28.0	13.0
Runoff	748	23.7	11.0

Table 22.2   Situation of surface water and groundwater in Basin of Mexico

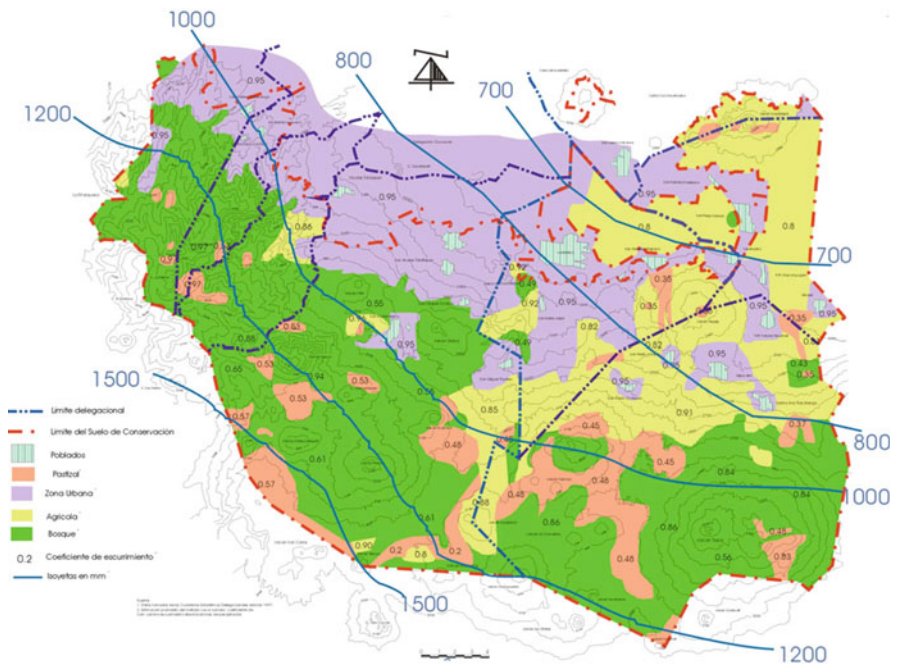| Aquifer	Recharge (hm^3)	Recharge (%)	Concession water volume (hm^3)	Average availability (hm^3)
México city metropolitan area	328	37.2	1249	−921
Cuautitlán-Pachuca	239	27.0	243	−4
Texcoco	57	6.5	93	−36
Chalco-Amecameca	87	9.9	90	−3
Tecocomulco	33	3.7	0	33
Apan	117	13.2	8	109
Soltepec	22	2.5	18	4
Total	883	100.0	1683	−818

Fig. 22.3   Isohyets in mm OPMAC (1999)

depends on vegetation cover and the dominant subsoil type. Figure 22.3 illustrates the map of isohyets defined, including the current land use and runoff coefficient values. At a later stage, with the support of Fig. 22.3, it upheld the method of isohyets, the height of average rainfall and the areas between two consecutive isohyets. Derived from the values described above, the volume of rain between isohyets was calculated by multiplying the height of average rainfall for the area between isohyets, and adding the partial values, which gives the total volume of rain that rushes over the test area.

Table 22.3 Estimation of rainfall volumes

High of average rainfall	Area between isohyets (m)	Area between isohyets (km^2)	Precipitation volume (hm^3)
0.70	4.10	59.45	41.615
0.75	4.90	71.05	53.287
0.90	15.50	224.75	202.275
1.10	32.40	469.80	516.780
1.35	35.70	517.65	698.828
1.50	7.40	107.30	160.950
Total	100.00	1,450.00	1,673.735

Table 22.4 Hydrological balance

Components	Volume (hm^3)	Streamflow (m^3/s)	Percentage (%)
Precipitation	1,674	53.1	100.0
Subsurface flow	73	2.3	4.4
Runoff	57	1.8	3.4
Deep recharge	209	6.7	12.5
Evapotranspiration + unsaturated zone storage	1,335	42.3	79.7

The calculation process is summarized in Table 22.3, which analyzes the results; it appears that on average they fall onto the surface of the study area of 1,674 billion cubic meters per year.

By solving Darcy's equation for each cell formed by the streamlines, the volume of water traveling was obtained from the upper parts and finally reaching the south and southwest of the basin. The volume of deep percolation or recharge generated was 209 million cubic meters. The soils were highly permeable and exhibit high moisture content and their depths ranged from several tens of centimeters to 2 m. Moreover, as displacing downstream, soil depths are of the order of several tens of meters, showing a great heterogeneity and anisotropy, key features to eliminate these parts as deep recharge (Jacobo 1992, 1993; Jacobo and Morales 1997, 1998). For its part, Table 22.4 shows the results of each of the components involved in the water balance. The results are presented in hm^3 (million cubic meters), m^3/s (cubic meters/second) and their corresponding percentage.

22.4   Conclusion

In summary, evaporation, evapotranspiration and storage in the unsaturated zone have joint values of 1.335 billion m^3 per year; and according to the average value of 1674 million m^3 per year of precipitation, it can be concluded that more than two thirds of precipitation returns to the atmosphere through the processes previously described.

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