HYDROGEOLOGY OF LARGE PLAINS

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Summary

This Chapter attempts to describe the hydrogeological characteristics of large plains in semi-humid climates, which are quite different from that usually found in other natural environments with high to medium morphological energy. Indeed, watersheds in large plains often do not have clear boundaries because the relief is scarcely noticeable. Likewise, the drainage network is diffuse, not very organized, and with a water-carrying capacity that depends on the magnitude of individual rainfall events. As for the overall water budget, its terms indicate a overwhelming preponderance of the vertical water flows (evapotranspiration, infiltration) over the horizontal ones (surface runoff, groundwater flow). Thus, major efforts have to be devoted to estimate properly such heavy weighing components. Inasmuch as groundwater levels are normally close to the surface, there is a close relationship between the rainfall, the hydraulics of the unsaturated zone, and the recharge to aquifers. Such a unsaturated zone is not thick enough to be considered a good buffer in case of contaminants/pollutants which may enter the system and travel downwards. In essence, either natural or human-related

contaminations do have a profound effect on the underlying groundwater, a fact that should be addressed seriously by water resources managers.

The conceptual framework has been illustrated with examples by studies carried on in a sector of the Argentine Humid Pampas, the Azul River Basin, where conventional methodologies and *ad hoc* techniques had to be applied in order to understand the behavior of such an unusual hydrogeological scenario.

1. Introduction

Most concepts and methodologies used by today's hydrogeologists are clearly related to conventional hydrological scenarios that, typically, include well-defined basin boundaries, an integrated and fully developed drainage network, and land slopes greater than 0.5%. That is not the case in the large plains. Consequently, their study requires the thoughtful customization of available methodologies to unravel the secrets of such particular hydrogeological settings.

It should be said that the world does not offer many examples of large plains, and that fact would explain the relatively low importance given to the knowledge of their behavior. Indeed, large plains are mainly found in China, Hungary, Argentina, the United States of America, and Australia. However, in those and other minor flatland regions, the most productive activities are closely related to their water resources. Hence, a rather comprehensive knowledge on their quality and quantity is needed for planning and management purposes. Most authors agree on the fact that the hydrogeology of large plains can best be assessed in semi-humid climates, because in humid environments they become wetlands, whereas in arid conditions they end up being deserts.

This paper attempts to highlight those characteristics that make the large plains be considered as unusual hydrogeological scenarios, and the way that such features can be studied and understood. Additionally, some dedicated studies will be shown of an actual large plain and the conclusions drawn from several years of observations.

2. Hydrological Features of Large Plains

2.1. Surface Drainage Network

Water, either surface water or groundwater, does not move spontaneously. Some kind of energy is needed to trigger such a movement. Aside from energy sources related to differences in temperature, the most effective type of water-moving energy is that given by its position (height) with respect to its surroundings. Thus, water will move faster along a 30 °-tilted plane than along flatter surfaces. This simple example illustrates what can be expected from water moving in flatlands.

Inasmuch as land slopes are meager (generally less than 0.1%), there is no enough morphological energy leading to the carving of surface drainage networks. Watercourses do exist (as relicts of past geological times), and most of them may carry water all year long, but their drainage direction is variable depending on the short-term rainfall regime and on the antecedent moisture of the unsaturated zone. Part of a given rainfall event is dissipated in the form of surface flows, part of it is accumulated in depressions commonly found in the plains, and most of it replenishes the soil's moisture storage. If the rainfall event is long enough and/or with high intensity, the soil is filled up, recharge to the aquifers starts, a greater amount of surface runoff is generated (rainfall intensity exceeds the infiltration capacity), and the above-mentioned depressions grow to the point of connecting to each other and finding their way to discharge water into the major watercourses. In fact, one can imagine extreme situations: low water status (scarce to normal precipitation and relatively thicker unsaturated zone), and high water status (above-normal precipitation and groundwater levels very close to the surface). A good research challenge would be to find, on a case-by-case basis, the threshold between those situations and the elements that contribute to either of them.

Those watercourses are usually shallow, wide, and surrounded by ample alluvial plains. Their water-carrying capacity depends on the water level and the slope of the energy line, which varies in transient regimes (rising or recessing water levels). This is very important in that is does not lend itself to building up a simple relationship between h (water level in the course) and Q (discharge). In fact, and because of the changing of the energy slope, a set of h-Q curves is needed.

Therefore, the most widely known models of R–Q (rainfall–surface discharge) are not longer valid in large plains. The usually long pounding periods of water in surface depressions, with inherent delayed and high infiltration rates, and the time needed for those depressions to be connected and discharge to major water courses, make the use of simple transformations of rainfall in surface runoff difficult if not erroneous.

2.2. The Drainage Basin and Water Divides

It is sometimes difficult to delineate the basin boundaries because they are not much dependent on topography as they are on the spatial distribution, amount and intensity of rainfall. In regions with slopes as small as 0.01%, the role of hardly noticeable elevations and depressions is central in determining the final destiny of water reaching the surface. Therefore, the water divides are drawn out of practical considerations, and the underlying assumption is that they remain approximately constant while in fact they vary.

2.3. The Water Budget

Having established that the main components of a simple water budget for long time periods can be solved by considering a single input (rainfall) and three major outputs (runoff, deep infiltration, and evapotranspiration), their relative importance in typical hydrological scenarios is much different than that found in large plains. In flatland hydrology, the runoff is small as well as the deep infiltration (i.e., recharge to the aquifers), and the evapotranspiration becomes by far the most important item to be looked at. This is the case because: (a) water tends to be stored for long periods in depressions and its chance to be evapotranspirated are much enhanced, and (b) by the same token, the infiltration is also greater, which causes the groundwater level be close to the surface, allowing the direct evaporation from the capillary fringe (favored by surface soils made up of fine materials).

This represents a problem as far as the study of water availability and distribution. It is a well known fact that the evapotranspiration rate is not easy to calculate. Direct measurement methods (lysimeters, continuous monitoring of soil moisture changes) are costly and prone to errors when their results are regionalized, as also are energy balances. On the other hand, the semi-empirical methods used to estimate the actual evapotranspiration have proved rather ineffective in the sense that they underestimate such a rate. In spite of that, they continue to be used because their data requirement is readily available (rainfall amount, mean monthly air temperature, mean monthly wind speed, and, sometimes, a correction factor to account for the various crops in the area). Evapotranspiration under-estimations translate directly into aquifer recharge over-estimations, which can lead to gross errors when used for management purposes.

The above statement suggests that the evapotranspiration rates have to be estimated: (a) avoiding the blind extrapolation of site-specific results, (b) using different methods whenever possible, (c) addressing the fact that all data used should reflect the interplay of natural characteristics valid for large regions of the domain, and (d) being conscious that any major mistake would virtually render useless the estimates of other parameters of the water budget. It is then not surprising that the assessment of the overall water budget for large plains requires combining several methods, which include hydrological modeling, chloride-mass balances, and satellite image processing.

Runoff in large plains has been referred to in Section 2.1, while deep infiltration (or recharge) will be treated in the following sections.

As for the rainfall, many authors have pointed out that the lack of relief in large plains facilitates the interpolation of rainfall data because the "mountain-barrier" effect is null. However, that might not be a true general statement. Other meteorological factors are active and, very often, they determine uneven rainfall distributions in the basin of interest.

2.4. The Central Role of the Unsaturated Zone

The interplay of most of the elements mentioned thus far (evapotranspiration, infiltration, runoff) depends on the characteristics (thickness, materials) of the unsaturated zone, which includes the soil and the underlying horizons up to the groundwater level.

If the unsaturated zone is slim, as it is in many flatland regions, meaningful rainfall events will fill up the pore space (until saturation) and both deep infiltration (gravity flow) and runoff will occur. The point is that, unless the unsaturated zone is extremely dry and/or the rainfall is not important, there will be a rapid response of the groundwater levels (rising).

The materials that made up the unsaturated zone are important in that their grain-size and degree of compactness—texture and structure, in agronomical terms—define the ability to channel-in the water coming from rainfall (infiltration capacity). Fine, structured materials will generally have an infiltration capacity smaller than the average rainfall intensity. That means that, although the unsaturated zone is not completely filled up, runoff or surface pounding will occur. In coarser, less structured materials, the pore space is filled up first.

It has been also noticed, especially in fine materials and/or heavily vegetated areas, that infiltrating water may circulate downwards very fast through macropores. It has been termed by-pass flow, meaning that the water goes directly from the surface to the aquifer.

This phenomenon may be present in any environment, although in flatland hydrology it does lead to groundwater level fluctuations that may not agree with the measured rainfall and its eventual infiltration.

According to soil physics methods, in order to fully characterize the unsaturated zone, a set of curves is needed for each distinct horizon. Those are the tension–soil moisture and the hydraulic conductivity–soil moisture curves. The existence of by-pass flow is not actually recognized by those curves, and should be treated separately.

2.5. Deep Infiltration or Recharge to Aquifers

This section is closely related to the one above, in that all water reaching (recharging) the aquifer has first gone through the overlying unsaturated zone. In a more general view, however, the overall recharge to aquifers in large plains has to take into account several other aspects.

The recharge component of the water budget cannot easily be obtained. The uncertainties attached to the estimation of reliable values for evapotranspiration are central aspects of it. On the other hand, any hydrologist knows that the recharge to aquifers may be highly variable in space (sometimes, with non-trivial patterns of variation), so that a certain number of regional characteristics have to come into play in order to assess the rate to which waters do reach the aquifers.

Knowing that groundwater levels are close to the surface, one major factor determining deep infiltration is the material that the unsaturated zone is made up of (or the surface soils present).

This will determine how fast the water can move downwards. Of course, as was said in Section 2.3, the moisture content of the soils when rainfall starts is also important, as well as the intensity and duration of the precipitation.

As a general statement, many studies have found that, despite the proximity of the groundwater levels to the surface, recharge in flatlands does not occur regularly but only when the individual rainfall events are long enough.

Water pounded on the surface (either by rainfall intensity exceeding the infiltration capacity of soils, or stored in depressions), given time, will also percolate and eventually reach the aquifer. This effect lags well behind the bulk of rainfall events.

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Biographical Sketch

Eduardo Jorge Usunoff was born in Bahía Blanca, Buenos Aires Province, Argentina in 1953. He graduated in Geosciences (Universidad Nacional del Sur, Bahía Blanca, Argentina) in March 1979, and was hired by that university to teach and do research on hydrogeology. Early on, he showed his interest on groundwater hydrology, so that in 1980 took a six-month leave for further research in Spain (Curso Internacional de Hidrología Subterránea, Barcelona). In 1982 he went to the Hydrology and Water Resources Department (University of Arizona, Tucson, United States of America) where he received a M.Sc. in Hydrology (May 1984) and a Ph.D. in Hydrology with minor in Geosciences (August 1988).

On returning to Argentina, he was hired by the Universidad Nacional del Centro de la Provincia de Buenos Aires and the Comisión de Investigaciones Científicas de la Provincia de Buenos Aires to head a research institute dealing with hydrological topics, the Instituto de Hidrología de Llanuras (IHLLA). His main professional interests are: hydrochemistry, hydrogeology of large plains, and integrated water resources management. In his spare time he likes to play basketball and volleyball, as well as listening to music (jazz, pop, blues, and rock).