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Evaluation of Riverbank Hydraulic Conductivity: Implications for Groundwater Recharge

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Author's contribution

The sole author designed, analyzed and interpreted and prepared the manuscript.

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ABSTRACT

This study highlights the relationship between the hydraulic conductivity (K) of riverbank deposits and groundwater recharge in an area adjacent to a Chalk river in Hertfordshire, United Kingdom. Three locations were mapped out for *In situ* permeability measurements based on geological map data indicating changes in superficial deposits along the river Mimram. The study area is predominated by Cretaceous Chalk and overlain by drift deposit such as glacial till and buried channel deposits which include glaciofluvial gravels, sands and silty-clay. Permeability measurements of the riverbank deposits' field saturated hydraulic conductivity (Ksat) using a constant head permeameter was carried out to determine the coefficient of permeability of the superficial soils along a small stretch of the river Mimram in Hatfield. Preliminary results show a variation in the permeability of the superficial deposits which could have a significant impact on groundwater recharge. It is

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hoped that this study will provide a better understanding of the role of near surface geological investigation of riverbank hydraulic properties in groundwater recharge.

Keywords: Hydraulic conductivity; riverbank deposits; River Mimram; groundwater recharge.

1. INTRODUCTION

Groundwater resource is a hidden and precious asset. The continuous growth of population and industrialization in the south-east of England leads to increasing demand for groundwater as the surface water is not sufficient. In recent times, the framework of global changes with respect to environmental and climatic factors, groundwater abstraction and management has become a crucial stake with respect to drinking water supply and management [1,2]. Water stress is one of the challenges facing the entire society as a result of rapid rise in urban population and industrialization which tends to increase the pressure on water resources [3]. Therefore, there is need to preserve groundwater resource and develop it in a sustainable manner with adequate understanding of its recharge and discharge phenomena.

The hydraulic conductivity of the riverbed and the adjacent riverbank sediments is the key element in the study of the flux of water between a river and groundwater system. The rate of groundwater recharge or discharge depends on hydraulic conductivity of the riverbank sediments or the geology of the area among other factors. Flow in porous media has been studied by Henry Darcy and reported by Hiscock [4]. This is a theory of flow and mathematical expression which delineates volumetric flow rate in a porous media, that is, the relationship between the flow of groundwater with respect to hydraulic gradient and hydraulic conductivity. For example, a finite one dimensional flow is given as:

$$Q = AK * \Delta h/L$$

Where:

Q = volumetric flow rate (m^3)
A = flow area perpendicular to L (m^2)
L = flow path length (m)
H = hydraulic head (m), and
Δh= denotes the change in *h* over the path *L*

Many researchers have investigated the hydraulic conductivities of fluvial sediments, riverbank soils and transmissivities in Chalk formation. For example, Freeze et al. [5] estimate the hydraulic conductivity of the superficial soils using the Hazen formula while Allen et al. [6] reiterate that there are high Chalk transmissivities under the riverbeds. Furthermore, Levy and Xu [7] used a combination of two or more types of equipment to determine the hydraulic gradient of water bodies. For instance, Bagarello and Giordano [8], Elrick and Reynolds [9] measured the hydraulic conductivity of the superficial deposits in the field using the Guelph constant head permeameter. The relationship between automated vertical electrical sounding (VES) and hydraulic conductivity (K) for a better description of the subsurface conditions has been studied by Attwa et al. [10]. A number of hydrologic research using field investigation techniques has provided a basis for conceptualizing groundwater recharge and discharge through the study of groundwater flow processes with respect to site-specific hydraulic conductivity (K) heterogeneity [11,12,13]. In general, hydraulic conductivity seems to be influenced by the structure and lithology of the geologic formation [14].

The geomorphological setting of the study area is an important factor in this study. The landscape of Hertfordshire is dominated by farmland with numerous small patches of woodland and fluvial network of lowland rivers, most of which drain into the Thames [15], and almost all of the county lies within 50m and 200m above sea level (ASL) in terms of the topography of the region in accordance with the British Ordnance Datum (OD). The rock formation in Hertfordshire belongs to the shallow syncline known as the London Basin and the beds dip in a south-east direction and the most important rock formations are the Cretaceous Chalk which outcrops in the north and west of the county, forming the Chiltern Hills and the younger Palaeocene, Reading Beds and Eocene, and London Clay which dominates the remaining southern part [6,15,16]. The region is underlain entirely by Chalk with drift deposits in the east and south while the London Clays cover the south-east of Hertford and is part of the London Basin area [6,15]. The soil profile and the geology of riverbed and the floodplain are important factors that have been considered in assessing groundwater recharge in the study area.

The study area is characterised by the Middle and Upper Chalk and the bedding plane is identified by the Chalk Rock layer. Chalk consists predominantly of microscopic calcareous coccoliths, with other carbonate materials and some thin marl seams which contain clay minerals. The study carried out by Hopson [17] affirms that the Turonian (c.90.5 to 88.5 Ma) and Coniacian (c.88.5 to 86.5 Ma) stages are represented with the Chalk Rock Member and overlying rock being the major lithostratigraphic units at the top and bottom of these stages respectively. The Chalk deposits found in the study area are mainly soft, white, and very fine grained and very pure, micro-porous limestone with subordinate hard grounds known as Chalk Rock, and layers of marl and calcarenite and flint nodule comprising chert. The Middle Chalk underlies the Upper Chalk and consists of 'white, pure, massively bedded chalk', with marl and nodular flint courses [17]. The Upper Chalk dips gently to the south-east and is overlain by Palaeogene deposits and clay with flints.

2. MATERIALS AND METHODS

An Ordnance Survey map (Hertford Drift Sheet 239) of the Geological Survey [18] was used as a base map for the study whereby three locations, namely; Floodgates, Pulmer Water and Fulling Mill (Fig. 1) were mapped out based on geological map data delineating changes in superficial deposits along the river Mimram. The hydraulic conductivity measurements were taken using the Guelph permeameter, which enables a constant head permeability test to be carried out using the Marriott principle. Guelph permeameter provides a quick and simple method for simultaneously determining field saturated hydraulic conductivity, matrix flux potential and soil sorptivity in the field [19]. The Guelph permeameter method has been widely used as an *In situ* technique for determining saturated soil hydraulic properties [8,9]. These authors have established the relationship between permeability of soils and infiltration of water into the groundwater system.

The holes were drilled using the standard auger, cleaned using the baler, and any clay smeared around the hole scratched using the wire brush. The sizing auger is designed to produce a hole that is uniformly 6 cm in diameter with a flat bottom while the brush provides a means of removing any smear layer that exists in the well hole that may create a barrier to the natural flow of water out of the well into the surrounding soil. The holes ranged in depth from 250 to 300 mm. The permeameter was inserted into the hole and mounted firmly in the tripod while the inner and outer reservoirs were filled with water until no air bubbles emerged from the fill hole and the ground surrounding the hole saturated.

The fill plug in the reservoir cap was removed and the reservoir valve was adjusted such that the inner and the outer reservoirs are connected. The fill plug was replaced and made air-tight with the clamping ring. The air tube was raised until a height of 5 cm was established and the same technique was repeated for 10 cm head height and measurements were taken in accordance with Soil Moisture and Equipment Corporation operating procedure [19]. A range of holes were drilled and permeabilities measured at each location, next to the river, approximately 10 m.

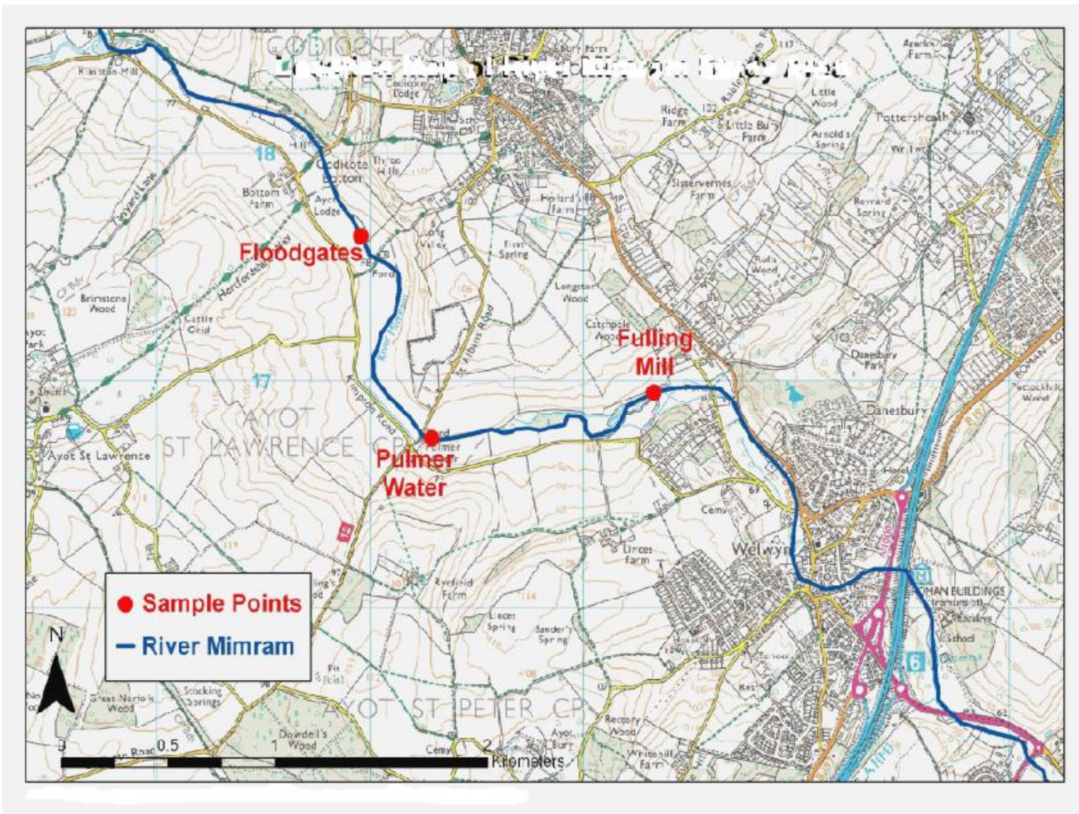

Fig. 1. Location map of the study area showing the sampling points
(Adapted from crown copyright ordnance survey, 2012)

3. RESULTS AND DISCUSSION

The hydraulic conductivity measurements of the superficial materials, their mean values and graphical illustration are presented below in Table 1 and Fig. 2 respectively.

Table 1. Summary of the saturated hydraulic conductivity (Ksat) values of the superficial soils at the three locations (m/s)

Location	1st reading	2nd reading	3rd reading	Mean
Floodgates	0.00000000	0.00000212	0.00000598	0.0000027
Pulmer Water	0.00002949	0.00002396	0.00000642	0.0000199
Fulling Mill	0.00000226	0.00000967	0.00000214	0.00000469

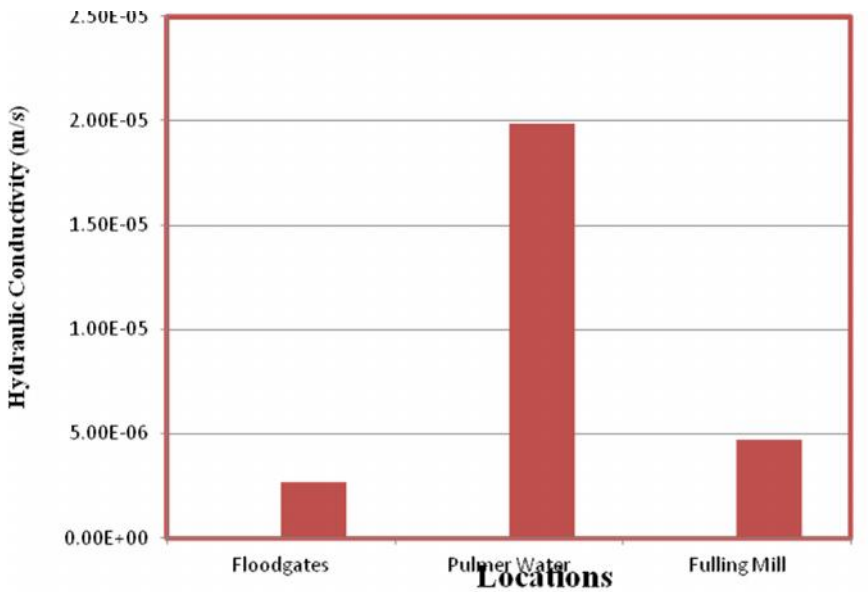

Fig. 2. Average saturated hydraulic conductivity of riverbank deposits at the three locations

Mean hydraulic conductivity values obtained show that the superficial soils at Pulmer Water are more permeable than the soils of Floodgates and Fulling Mill with values which are 0.0000027 m/s at Floodgates, 0.0000199 m/s at Pulmer Water and 0.00000469 m/s at Fulling Mill respectively. The average Ksat is lowest at Floodgates which is typical of glacial till and silt deposits, which appears to support the geological map that shows glacial till at this location. The Ksat is highest at Pulmer Water typical of sand deposits. For comparison, the Ksat for Chalk ranges from 1.2 x 10^{-8} m/s for Chalk matrix to 1.2 x 10^{-4} m/s for fractured white Chalk [20]. It is likely that the river bank deposits are therefore more permeable than the Chalk matrix of intact rock in the study area. More so, it is also likely that any fractures in the Chalk that have been exploited by glacial melt-water have presumably been filled with glacial deposits and therefore the riverbank deposits are probably having the highest permeability, by several orders of magnitude.

The coefficient of permeability depends primarily on the average size of the pore spaces which is a function of the particulate size distribution, particle shape, orientation, soil structure and cement. The obtained values of the coefficient of permeabilities were compared with the standard permeability coefficient values (BS80004:1986) recommended by [21]. The comparison shows that the soils at Pulmer Water and Fulling Mill are in the category of between 10^{-5} – 10^{-6} m/s (very fine sands, silts and clay-silt laminate, while the soils at Floodgates is in the category of 10^{-7} – 10^{-10} m/s (unfissured clays and clay-silts, >20%). Systematic hydraulic studies carried out by Watson and Burnet [22] affirms that the rate at which a river loses water into the ground (recharge) is a function of many variables including the volumetric flow rate of the stream, the respective permeabilities of the streambed, floodplain, riverbank and the aquifer material.

The relationship between the hydraulic conductivity characteristics of superficial sediments and groundwater replenishment has been studied by many hydrogeologists, hydrologists and civil engineers. The rate of recharge of groundwater and baseflow recharge of rivers depends largely on permeabilities of superficial soils across the hydrologic landscape which is influenced by climate, topography and geology [23]. It has been established that whether a river gains water from an underlying aquifer or loses it to the aquifer depends on the hydraulic conductivity of the river's bank and bed deposits and on whether the groundwater head in the aquifer is higher or lower than the water level in the river [15]. Therefore, the result of the research suggests that the river Mimram might be losing water to the subsurface more rapidly at Pulmer Water than at Fulling Mill and Floodgates respectively. This phenomenon has been described by Watson and Burnet [22] with respect to the influence of soil permeabilities on river flow, while Levy and Xu [7], Lee and Cherry [24] have quantified and characterised groundwater and baseflow interactions by studying the seepage fluxes across the superficial soils.

4. CONCLUSION

The findings of this research show that the riverbank sediments are indicative of the riverbed deposits in the study area. This appears to show that high groundwater recharge at Pulmer Water is largely controlled by the hydraulic conductivity characteristics of the riverbank deposits and local geology compared with the hydraulic phenomena taking place at the other two locations which may have a considerable input to groundwater resource in the area. Therefore, further research would be required to determine the dynamics of the hyporheic zone with regard to water fluxes in the subsurface as a veritable tool in comprehending a detailed hydrogeological phenomenon taking place in the study area.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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