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THE IMPACT OF CLIMATIC VARIABILITY ON CHALK RIVER HYDRODYNAMICS, SOUTH-EAST OF ENGLAND, UNITED KINGDOM

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The Impact of Climatic Variability on Chalk River Hydrodynamics, South-East of England, United Kingdom

Ayeni Omotayo

L'impact de la variabilité du climat sur Chalk River hydrodynamique, Sud-Est de l'Angleterre, Royaume-Uni. Le changement climatique est un phénomène mondial et en tant que tel, le changement climatique induit par l'homme, c'est-à-dire, le réchauffement climatique constitue un dilemme de gestion des risques pour les technocrates des ressources en eau, les chercheurs et les décideurs. En substance, la modification significative du climat, y compris le cycle hydrologique pourrait changer le paramètre de risque dans lequel les systèmes de ressources en eau sont planifiés et mises en œuvre. Donc, les mesures de cours d'eau et du débit des rivières sont importantes pour la gestion intégrée des ressources en eau à l'échelle mondiale. Les mesures de débit de la rivière Mimram en utilisant la vitesse de la zone Type d'hélice courantomètre a été réalisée à trois endroits à savoir; Vannes, Pulmer eau et Mill Fulling respectivement, afin d'étudier l'effet de la variabilité climatique sur l'hydrodynamique de la rivière. Résultats obtenus montrent débits anormaux du tronçon de la rivière de Floodgates à Fulling Mill étant donné que le débit de la rivière à l'emplacement d'échantillonnage Pulmer eau a les valeurs les plus faibles. L'interprétation de l'étude montre que le régime d'écoulement de la rivière Mimram est une fonction de l'influence du climat parmi d'autres facteurs; tels que la géologie et les activités anthropiques. Il est prévu que les risques associés au réchauffement planétaire concernant les faibles débits, et la surexploitation des eaux souterraines dans la zone d'étude pourraient résulter en récession pérenne de la rivière à l'avenir si les plans de gestion intégrée des ressources en eau adéquates ne sont pas mises en place.

Mots-clés: la variabilité climatique, de Chalk River, rivière Mimram, débit de la rivière, Velocity-Zone Propeller Type de courant mètres, du Sud-Est de l'Angleterre.

The Impact of Climatic Variability on Chalk River Hydrodynamics, South-East of England, United Kingdom. Climate change is a global phenomenon and as such, human-induced climate change, that is global warming, comprises a risk management dilemma for water resources technocrats, researchers and decision makers. In essence, significant modification of climate, including the hydrologic cycle could change the risk setting in which water resources systems are planned and implemented. Therefore, stream and river flow measurements are important for integrated water resources management on a global scale. Flow measurements of the River Mimram using the velocity-area propeller type current meter was carried out at three locations namely; Floodgates, Pulmer Water and Fulling Mill respectively in order to investigate the effect of climatic variability on the river's hydrodynamics. Results obtained show anomalous discharge rates of the river stretch from Floodgates to Fulling Mill given that the river flow at Pulmer Water sampling location has the lowest values. The interpretation of the results shows that the flow regime of the River Mimram is a function of climatic influence amongst other factors; such as geology and anthropogenic activities. It is projected that the risks associated with global warming regarding low flows, and over-abstraction of groundwater in the study area might result in perennial recession of the river in future if adequate integrated water resources management plans are not put in place.

Keywords: Climatic Variability, Chalk River, River Mimram, River flow, Velocity-Area Propeller Type Current Meter, South-East of England.

1. GENERAL STATEMENT

Drought and declining water levels is as a result of the impact of climate change which leads to water shortages. The Intergovernmental Panel on Climate Change (IPCC, 2001b) asserts that since the industrial revolution, anthropogenic causes have been playing an important role primarily due to the combustion of fossil fuels, agriculture and land-use changes which have increased the atmospheric concentration of aerosols and greenhouse gases. The global average surface temperature is vital to global warming and the 1990s was the warmest decade (Hulme et al, 2002), while (IPCC, 2001b) argues that 1998 was the warmest year on record. In view of this, the observed changes in regional climate have affected many physical systems such as the melting of glaciers and sea levels (Oerlemans, 2005; Barry, 2006; Anwer, 2015; Tielidze et al, 2015; Xie et al, 2015). Furthermore, climate change is expected to continue to change in the future due to the uncertainties associated with the climate which will affect man and his environment (IPCC, 2001b; Kargel, 2005; Bradley et al, 2006; Leclercq et al, 2012). Climate models project that in the next 100 years, the global average temperature could warm 1.4 to 5.8°C (ICPC, 2001; National Assessment Synthesis Team, 2011).

Recent research publications on climate change and its consequences on hydrologic systems have been profound. The effects of climate change are enormous on river discharge (Monk et al, 2006; Bradley et al, 2006; Environment Agency, 2012). The publication of the Environment Agency (Environment Agency, 2012) confirms that drought is caused by persistent dry weather which has resulted in a continuing decline in groundwater levels and river flows. River flows and groundwater levels have been impacted largely by climate change as a result of dry winters (Veolia Water, 2010).

Water consumption forecast carried out by the Veolia Water team show that there would be an increase in demand of 1.37% by 2020 (Veolia Water, 2010). More so, the Environment Agency (Environment Agency, 2012; Sage, 2012) report that the South-East of England has received only 40% of the February 2012 Long Term Average (LTA) rainfall while the Soil Moisture Deficit (SMD) is relatively high and therefore, there is little of the winter recharge period left for significant groundwater recovery. The research conducted by (Wilby et al, 1997) affirms that the British climate variability has given rise to extreme conditions of rainfall, river flows and aquifer recharge rates while the Department for Environment Food and Rural Affairs (DEFRA, 2012) and the Environment Agency (Environment Agency, 2012) report that if the drought continues, there will be low flows, lower dilution and dispersion of effluent discharges and fish will be in distress. The emergence and availability of modelling and simulation software in recent times, water companies are able to make use of drought prediction models to anticipate future drought years (Veolia Water, 2010; Thames Water, 2013). However, (Harrington, 2011) argues that there is likely to be a greater impact on water supplies as a result of demand initiated by social change rather than climate change scenarios. Therefore, there is need to conserve water because it is fundamental to our lives. Not only do we rely on water to sustain our metabolism and for sanitation, but it is essential for almost all of our food production, is a carrier for our waste, useful to our industries, maintains a habitat for flora and fauna, supports recreation and enhances the aesthetic integrity of our landscape.

The United Kingdom was experiencing a severe drought in the early spring of 2012 with soils at their driest on record at the time of the year. Groundwater levels in many private, industrial and commercial boreholes across Southern England diminished in response to the prevailing climatic condition. As a result, approximately 20 million customers were affected by water use restrictions, such as the hosepipe ban and questions were being asked by the British government and the public about sustainable water supplies if the drought continued (Thames Water, 2013; Veolia Water, 2013). However, a potential water supply crisis was avoided due to record precipitation between April and July 2012 which has been recorded as the highest over England and Wales in a drought timeline according to the British Hydrological Society (BHS, 2014; Rodda et al, 2014). During the following two consecutive winter periods in 2013 and 2014 respectively, the United Kingdom has experienced record high groundwater levels, resulting in the flooding of properties and farmlands. These cycles of climatic and hydrological extremes are phenomenal in the 21st century.

Chalk Rivers generally occur in France, England and New Zealand and are replenished by Chalk groundwater and rely on winter rainfall to maintain summer flows (Westwood et al, 2006; Banks et al, 2009; Allen et al, 2010; Sage, 2012). Chalk Rivers are listed in Annex I of the European Habitats Directive due to their international importance Department for Environment Food and Rural Affairs (DEFRA, 2012). Historically, Chalk Rivers are important for water mills, watercress farming and wildlife endangered species, for example, water vole (Entec, 2005; Environment Agency, 2012; Sage, 2012). In addition, Chalk streams are ecologically important for Ranunculus and Callitriche and a variety of fish and birds (Wilson et al, 2010).

The springs that ooze from the Chalk can be classified as overflow from the groundwater table and at certain horizons determined by the lithology and geometry of the aquifer (Entec, 2005; Environment Agency, 2012). Globally, most of the Chalk Rivers and streams are characterised by winterbourne stretches in their headwaters which often become dry or partially dry in summer due to a lack of precipitation recharging the aquifer system. It is this phenomenon that gives rise to sediment deposition along the river margin (Westwood et al, 2006). However, Chalk streams are known to have the highest flows in spring following winter recharge (Entec, 2005; Veolia Water, 2010; Environment Agency, 2012). It has been reported that Chalk streams normally have a peculiar seasonal cycle known as the ''seasonal cycle of co-dominance'' which relates to the interrelationships between flow, vegetation and sediment (Environment Agency, 2012).

The loss of flow to riverbed leakage has been described by Entec (Entec, 2005) while streamflow leakage from the bed has been established by several researchers (Halcow, 1995, Marcus Hodges Environmental Limited, 1999; Stuart, 2000). Losses from the river are normally detected by physical inspection of the river channel itself (Aston, 1999) but losses may occur when the flow is high especially during the winter peak from December to February (Stuart, 2000). Monitoring wells installed in riverbeds and the nature of the temporal variability in temperature in the subsurface can be used to determine losing and gaining reaches of the river (Anderson, 1997). However, recent studies have analysed the spatial and temporal variations in the complexity of groundwater and surface water interactions (Grapes, 2005; Griffiths, 2006; Krause et al, 2007).

2. STUDY AREA

The study area is characterised by the Middle and Upper Chalk formation. Chalk consists mainly of microscopic calcareous coccoliths, with other carbonate materials and some thin marl seams which contain clay minerals (Hopson et al, 1996). The landscape of Hertfordshire is dominated by farmland with numerous small patches of woodland and a fluvial system of lowland rivers, most of which drain into the Thames (Catt, 2010; Ayeni, 2014).

The River Mimram is one of the most important Chalk Rivers in Hertfordshire, South-East of England. It is replenished by baseflow and becomes dry intermittently (Entec, 2005) (Figs. 1 and 2). Generally, the stream flows in a South-Easterly direction over a length of approximately 23km whereby the upper stretch of the stream is winterbourne (Environment Agency, 2012). The River is subject to anomalous low flows and this is attributable to extreme climatic conditions and abstraction (Environment Agency, 2012; Sage, 2012).

The River Mimram flows from its source upstream of the Whitwell down to the confluence of the River Lea in Hertfordshire (Entec, 2005; Environment Agency, 2012) and has an elevation of above 160m-Above Ordnance Datum (AOD) in the upstream of the catchment, decreasing to less than 50m AOD where it discharges into the River Lea. There are several stream gauge stations managed by the Environment Agency and Veolia Water along the river Mimram stretch, namely, Whitwell, Fulling Mill and Panshanger (Entec, 2005; Environment Agency, 2012) while water abstraction is taking place at various locations within the catchment and this may have impacted the hydrological regime of the river (Veolia Water, 2010; Environment Agency, 2012; Sage, 2012).

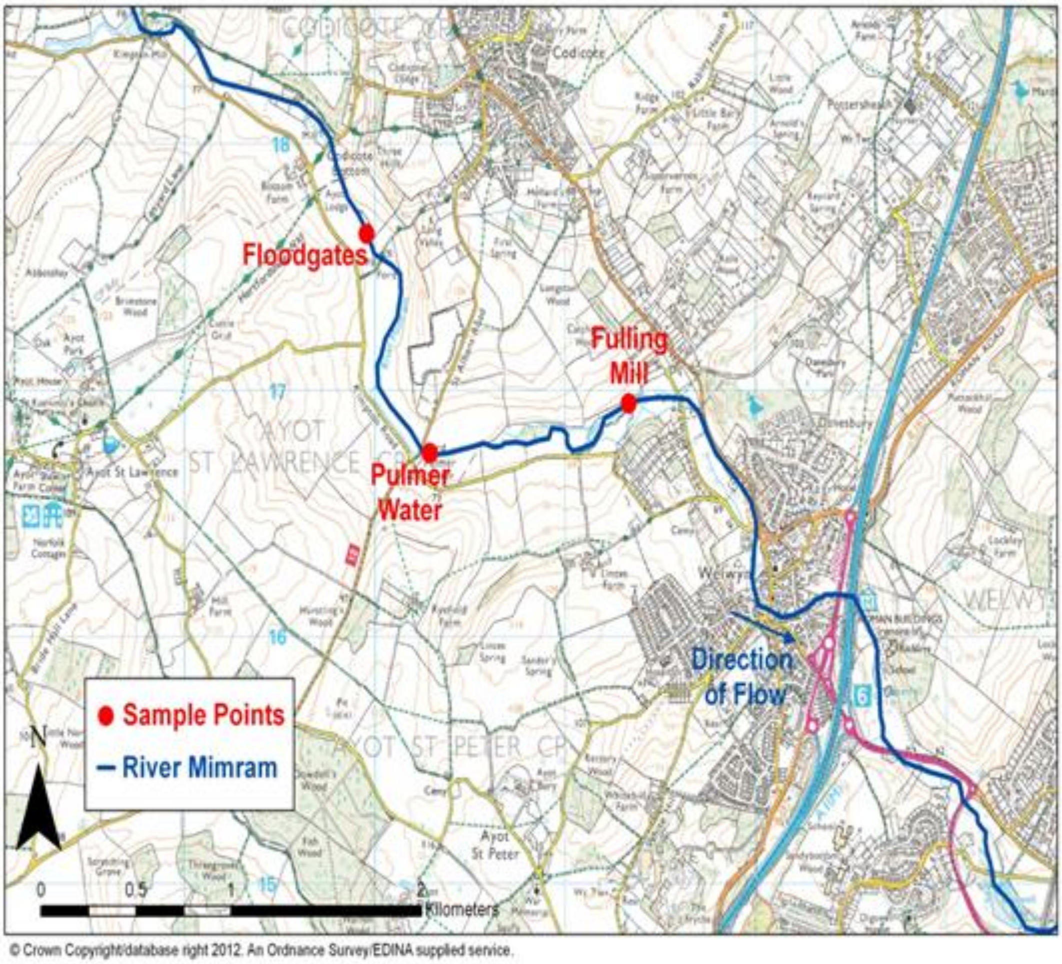

Figure 1: Map of study area showing River Mimram and the sampling points (Source: Crown Copyright-Ordnance Survey, 2012)

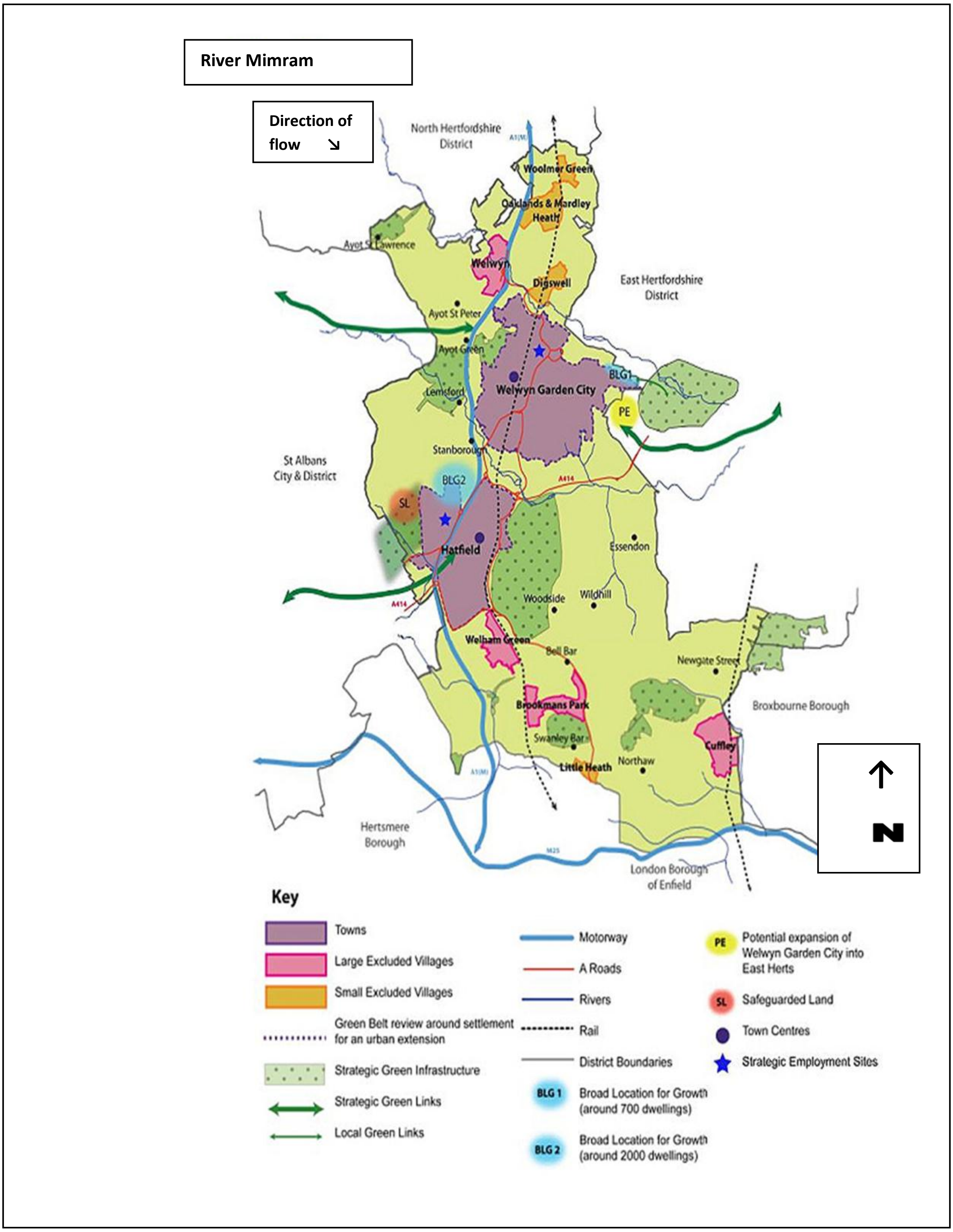

Figure 2. Map Showing River Mimram on Hertfordshire District Map, United Kingdom (Adapted from: Panshanger People 2009 Welwyn Hatfield Proposal Map)

3. MATERIALS AND METHODS

A reconnaissance survey of the study area was carried out prior to fieldwork. This involved familiarising with the physical environment of the area such as the hydro-geomorphic features which include surface drainage systems, geology, hydrogeology and topography. This approach involved observing and walking the length of the river within the study area. Three locations were chosen based on geological map data indicating changes in superficial deposits along the river Mimram, namely, Floodgates, Pulmer Water and Fulling Mill respectively. The Floodgates and Pulmer water sampling points are both located in Codicote which is situated upstream of the river Mimram while Fulling Mill is located in Welwyn, downstream of the river course. Discharge measurements were carried out on the 25 May, 8 and 14 June, 2012 at the chosen locations respectively.

Primary data was generated from the sampling points using a Braystoke 0012B/BF002 model of the velocity-area propeller type current meter to measure the discharge along the river course. The Current Display Unit (CDU) is a Real Time Speed display device offering user selectable measurement of pulse against time averaging (moving, fixed or free running) for all contact closure current meters (United States Geological Survey (USGS, 2008). It also calculates the standard deviation of the measured average data. The propeller-type current meter consists of a propeller revolving a horizontal shaft and the body containing the electric cable that connects it to the current display chamber. Regarding the accuracy and confidence level of the current meter, the range of most of the flow speed that is above 0.15m/s is expected to perform within ± 1.5% of the indication of the group calibration at 95% confidence level (Herschy, 1999; Hiscock, 2005).

Discharge measurements using the propeller current meter are useful for streamflow measurements (Herschy, 1999; Hiscock, 2005; United States Geological Survey USGS, 2008; Bruckner, 2012) to establish the relationship between river discharge and the local geology. The measurement of velocity by current meter is undertaken by placing a rotating current meter point in a stream and counting the revolutions of the rotor during a measured time interval, the velocity of the water at each point was determined. Convenient and representative points were selected across the river channel at the designated locations in accordance with the methods proposed by (Herschy, 1999; Hiscock, 2005; United States Geological Survey USGS, 2008).

A relatively straight, uniform channel was chosen such that the flow is parallel to the banks flanking the river while a tag line and 30m measuring tape was set up across the river at a right angle. The approximate water width was measured and was then divided into equal spacing to give 10 current measurements. Water depth was also measured and the impeller was fixed to 0.6 multiplied by the depth which is 60% of the way 'down' from the surface of the river. Individual discharge for each segment is then summed up to obtain the total discharge for the section by multiplying the velocity in meter per second (m/s) by the area (m2) which is equal to m3/s using the formulae q=w [(d1+d2)/2]*[(v1+v2)/2] proposed by (Herschy, 1999; Hiscock, 2005), where;

q= stream discharge, in cubic meter per second (m3/s)
w= width, in meters (m)
d= depth, in meters (m), and;
v= velocity, in meter per second (m/s)

4. RESULTS AND DISCUSSIONS

The results obtained from the processing and analysis of the field data are presented in Table 1 and Figures 3-5 respectively. Flow measurements of the River Mimram using the velocity-area propeller type current meter were carried out at Floodgates, Pulmer Water and Fulling Mill sampling points respectively in order to investigate the effect of climatic variability on the River's hydrodynamics. The research conducted by (Hipolito et al, 1988; Hiscock, 2005; United States Geological Survey USGS, 2008; Bruckner, 2012) applied the principle of velocity-area propeller type current meter to river discharge measurements.

Table 1. Mean Discharge for the three Sampling Locations (m3/s)

Date (2012)	Floodgates	Pulmer Water	Fulling Mill	Mean
May 25	0.081108	0.077605	0.079213	**0.079309**
June 8	0.113364	0.112767	0.127965	**0.118032**
June 14	0.148799	0.128687	0.133290	**0.136925**
Mean	**0.114424**	**0.106353**	**0.113489**	

(Source: Omotayo Ayeni, 2012)

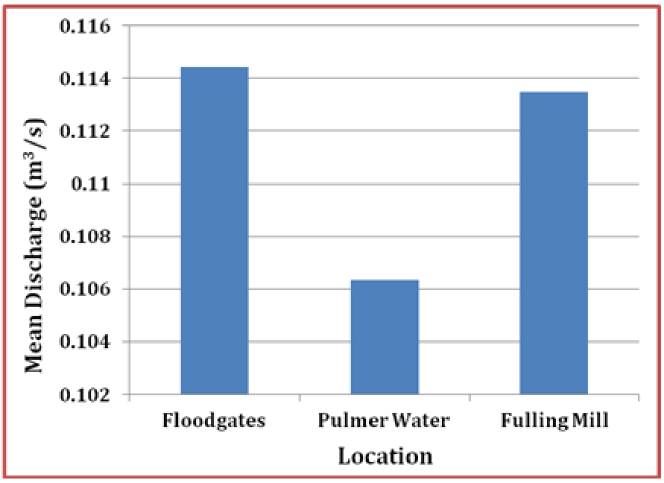

Figure 3. Mean discharge at the sampling locations

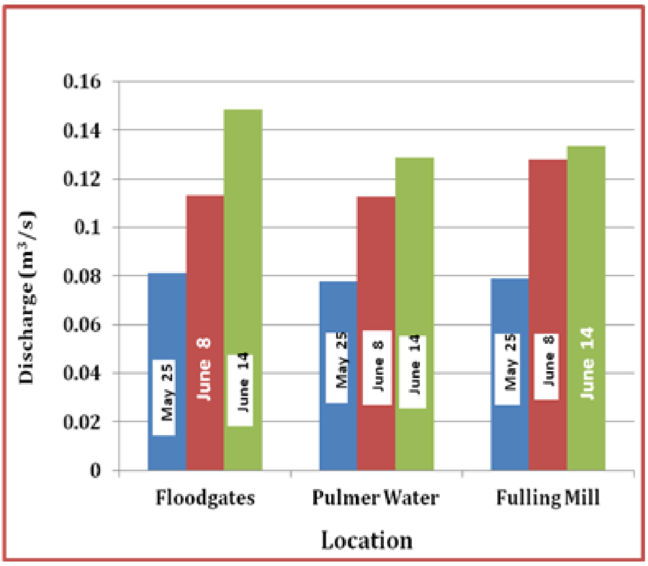

Figure 4. River discharge variations versus sampling dates at the three sampling locations

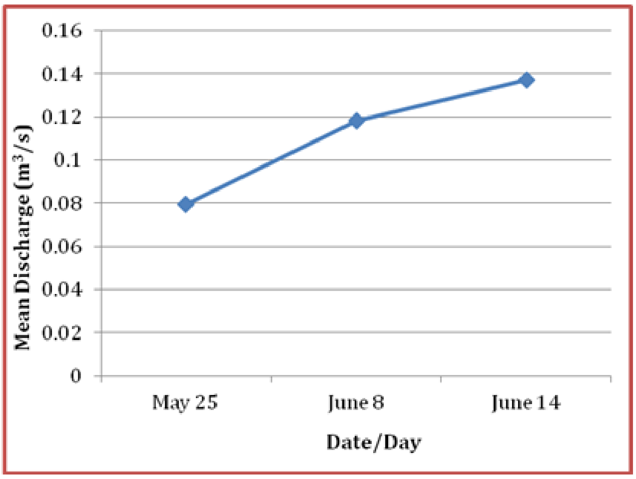

Figure 5. Mean discharge versus dates of discharge measurements

In principle, it has been reported that in most hydrometric analyses, precipitation is the primary input and flow is the primary output (Manscel-Monillin, 1986; Herschy, 1999). Therefore, the flow of the River Mimram has been computed using the continuity equation Q=v*A as stated above. This research has established that Floodgates has the highest mean discharge value of 0.114424m3/s. Mean discharge at Fulling Mill was 0.113489m3/s and Pulmer water has the least value of 0.106353m3/s (Table 1, Figs. 3 and 4) . These results reveal anomalous discharge rates of the river stretch from Floodgates to Fulling Mill because the discharge at Pulmer Water sampling point was the lowest. Figure 5 depicts a differential river flow rates scenario on the days when measurements were carried out which could be indicative of local climatic variations over time.

Darcy's law established a theory of flow and a mathematical expression which delineates the flow of groundwater with respect to the relationship between flow, hydraulic gradient and hydraulic conductivity which is given as Q= -K*h/L (Hiscock, 2005). This concept could be adopted for stream discharge in respect of the relationship between the flow rates and the hydraulic gradient of the River Mimram in the study area.

In view of this, the study reveals that the hydraulic phenomenon taking place in the study area deviates from Darcy's theory because of the lowest mean values obtained at Pulmer Water which is indicative of loss of water to riverbed and the subsurface system. This hydraulic phenomenon has been reported in previous studies, for example (Halcow, 1995, Marcus Hodges Environmental Limited, 1999; Stuart, 2000; Hiscock, 2005; Poff, et al, 2015) respectively. Meanwhile, Stuart (2000) argued that stream loses may occur when the flow is high especially during the winter peak period from December to February. However, it is expected that there would be low flows during the summer due to low rainfalls, high evapotranspiration and groundwater abstraction. In essence, these factors might be essentially responsible for the anomalous flows as depicted in Figures 3, 4 and 5 respectively.

The hydrologic phenomenon taking place in the study area could have some territorial or regional agricultural and hydrogeological implications due to the anomalous flow regime of the river. The crops growing in the farmlands where the Pulmer Water sampling point is located could be at risk of having low water intake due to the susceptibility of the area to the 'winterbourne effect' and Soil Moisture Deficit (SMD). In essence, this may lead to stunted growth of arable crops and could indirectly contribute to food insecurity in the local area in future.

5. CONCLUSIONS

The impact of climatic variability on Chalk River hydrodynamics has been evaluated at a localised level in Hatfield, South-East of England. River Mimram flow measurements using the velocity-area propeller type current meter were carried out at three designated locations of hydrogeologic importance, namely; Floodgates, Pulmer Water and Fulling Mill along the river stretch. These locations were mapped out for hydrologic investigation based on the geological map data indicating changes in the geology of the area in order to investigate the effect of climatic variability on the river's hydrodynamics.

The results of the research indicate that the flow regime of the river is a function of the climatic influence amongst other factors; such as geology and anthropogenic activities in the study area. Therefore, the output of this work could be utilised as a platform for future research in other areas susceptible to similar hydrologic phenomenon for the purpose of integrated water resources management due to the interactions between rivers and groundwater.

6. ACKNOWLEDGEMENTS

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7. AUTHOR CONTRIBUTION

The sole author designed, analysed and interpreted and prepared the manuscript for peer-review.

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