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Influence of Effluent Discharge on Water Quality and Level for Chalk Aquifer in Hampshire, South-East England

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ORIGINAL ARTICLE

ABSTRACT: Carbonate rocks form important subsurface aquifers in many areas around the world, especially north-west Europe where the Chalk is a primary source of potable water. Chalk is the most widely exploited aquifers in the United Kingdom for public water supply and Chalk groundwater play an important role in the maintenance of flow both in natural and international hydrological systems. Data on water level and effluent discharge concentration of extracted pore-water from core logged at various depths from boreholes (within the Morestead Road Waste Water Treatment Works (WWTW) discharge site) were investigated to determine Chalk groundwater quality changes due to the effluent discharge and the discharge volume of nearby New Alresford site correlated with measured depths to groundwater levels. It was observed that recharge occur mainly by matric flow through pore spaces and matric pulse, while in very few cases flow may have been enhanced by fissures. However, during winter months, high volumes of effluent discharge in addition to intense rainfall sessions cause a rapid decrease in depth to the groundwater level and keep the unsaturated zone matric potentials relatively high. This we suggest to be as a result of fracture flow initiated more quickly in response to the rainfall events than in normal 'undisturbed' chalk. Although the concentration of chloride and nitrate were relatively high, infiltration of water through the unsaturated zone helped reduce the concentration of inorganic ions as a result of dilution. Therefore, this work concluded that recharge of sewage effluent to the Chalk of the Hampshire area is an effective and practical way of recovering and reusing water sustainably, representing valuable contribution to the conservation of water resources.

Keywords: Chalk, Borehole, Effluent Discharge, Aquifers, Groundwater

INTRODUCTION

Groundwater is an important natural resource for drinking, domestic, industrial, and agricultural purposes. Over 35% of public water supply in England and in Wales and 70% of water supply in south and east England comes from groundwater resources (Stuart and Smedley, 2009: Egbuna and Duvbiama, 2013). It has long been seen as a relatively pure natural resource that is stored in subsurface aquifers and its quality under threat from anthropogenic influences. Chemical quality changes occur mainly through direct input of anthropogenic substances during groundwater abstraction, resultant changes in the groundwater flow regime and in processes of artificial recharge (Stuart and Smedley, 2009; Louis and Egbuna, 2012).

Carbonate rocks form important subsurface aquifers in many areas of the world, especially north-west Europe where the Chalk is a primary source of potable water (Bloomfield, 1997). Chalks are major aquifers widely exploited in the United Kingdom for public water supply. Chalk groundwater plays an important role in the maintenance of flow both in national and international hydrological systems (Ander *et al*., 2006). The majority of public supply Chalk boreholes are situated along river valleys usually to exploit the shallow depth to the water table and higher transmissivity in the river valley (Stuart and Smedley, 2009).

The Chalk is a fractured rock having very fine-grained matrix. The nature of its matrix makes much of the water held within the chalk pores not able to be drained by gravity. Aquifer properties of the Chalk are controlled by fractures and larger pores (Bloomfield, 1997). This gives rise to a highly transmissive, but relatively low storage aquifer that is at constant risk from contamination by sea-water or agrochemicals (Jones and Robins, 1999). Alternatively, as the fracture system becomes less hydraulically significant, the matrix porosity is envisaged to increasingly influence solute movement (Bloomfield, 1997).

Hydrogeochemical evolution of groundwater from its composition as rainfall, is dependent on the complex interplay of the processes taking place in the unsaturated zone and overlying composition and the composition of the aquifer and existing groundwater (Ander *et al*., 2006). Therefore, knowledge of the chemical composition of pore water reflects both the origin of the groundwater and the way in which the original composition has been modified by diagenetic reactions with either rock or organic matter (Hancock and Skinner, 2000). Pore-water fills the interstices of sediments and sedimentary rocks. Chloride, sodium and calcium are the most common ions found in pore water of deeply buried carbonate sediments

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(such as Chalk), while other elements are of lesser amount. Fluid mixing and reactions with carbonate minerals and clays exert an important control on the composition of pore-water in Chalk aquifers. Intrusion of saline waters into pore water also influences the contribution of groundwater movement in the matrix of the Chalk. Due to the fine-grained nature of the Chalk matrix, small size of its pore throats and high pore-water suctions, the pores cannot fully drain. However, since pore water pressures are less than atmospheric pressure, the chalk above the water table is described as unsaturated (Ander *et al.*, 2006).

The study area (Figure 1), Morestead Road Waste Water Treatment Works (WWTW), is located on the Chalk downland of Hampshire, east of Winchester, and is split into two parts by the M3 motorway (Mortimore and Duperret, 2004). Pore-water samples extracted from core from boreholes within the study area will be investigated analytically for groundwater quality changes in the Chalk aquifer profile. Also, this study seeks to establish the relationship between water level changes and effluent discharge volumes.

Study area

Morestead is a small village located near the South Downs in the city of Winchester district of Hampshire. It lies 5 km southeast from its county town, Winchester. The site's oldest part is situated west of the M3 motorway, north easterly slope of St. Catherine's Hill (SU 486 277) and boreholes from here are designated by MWC. This location sits on the steep slope of the hill leading northwards down to the River Itchen via a small stream that drains westward out of Morestead Road WWTW ponds (Figure 1). The site's other part is situated east of the M3 motorway towards the northern flanks of Twyford Down (SU 492 277) with boreholes extending from here labelled MWE. The Morestead WWTW is positioned southwards off an east - west valley formed by an erosion along the crest of the Winchester Anticline. High ground surrounding this local valley rises to and above 140mAOD.

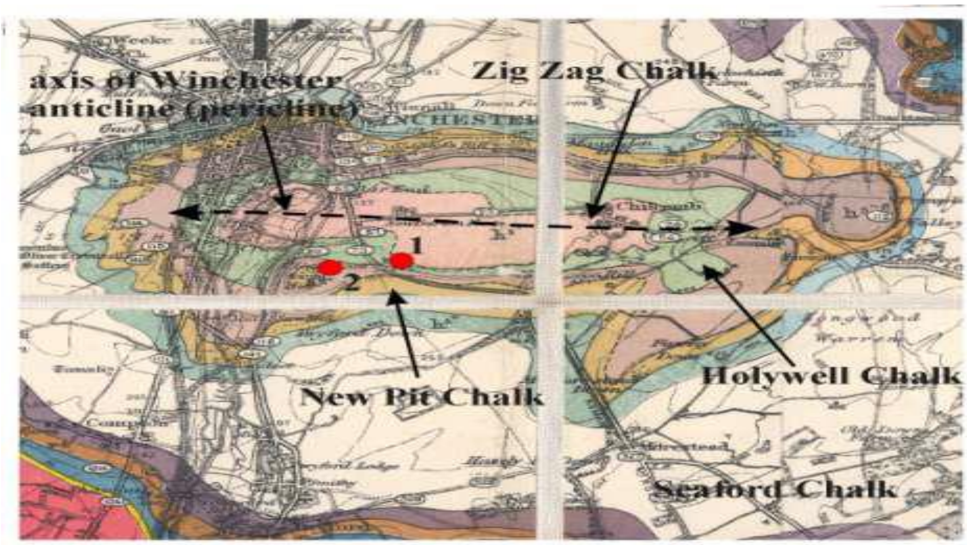

Figure 1: Geologic map of Chalk zones within and around Winchester, Hampshire

It shows the domal structure of the Winchester Anticline with an east - west axis plunging both east and west, forming a pericline. The corresponding Chalk Formations are clearly indicated by the arrow signs, while the red dots are: the Morestead WWTW sites and St. Catherine's Hill WTW (adapted from Mortimore and Duperret, 2004).

Geology of the area

Winchester area provides a continuous exposure through the middle and late chalk of the Cretaceous (Turonian to Campanian stages) along the east, through the M3 motorway. Exposure of the upper Turonian stage can be seen near the Bar End, while the Coniacian and Santonian stages exposed through Twyford Down and partly near Shawford. Adjacent to the area of Morestead Road WWTW, cuttings of the M3 motorway show the strata dip and general geological structure in the White Chalk Subgroup, particularly the Lewes Nodular Chalk, and the Seaford Chalf Formations (Mortimore and Duperret, 2004). A northerly dip of 150 was identified on the northern limb of Winchester Anticline, measured on the navigation Marls in the Lewes Nodular Chalk exposed under the Spitfire Chalk Formation (dipping north). The topmost New Pit Chalk of the motorway cuttings of the Twyford Down, expose the entire Lewes Nodular Chalk and basal beds of the Seaford Chalk Formation. The Southerham Marl dip measured in Twyford Down is 60 - 80 southwest on the southern limb of the Winchester Anticline (Mortimore and Duperret, 2004).

Despite good motorway sections in the Chalk, few exposures of the lower formations forming the bedrock chalk in the area are around New Morstead Road WWTW. Previous investigations of five shallow depth (10 to 15m) rotary - cored boreholes (October, 1996, logged by Professor Rory Mortimore) at Morestead Road WWTW indicated, in downwards succession, the presence of basal Holywell Nodular Chalk including the Plenus Marls and Melbourn Rock, and the Zig Zag Chalk Formation, known as the White Bed (Mortimore and Duperret, 2004).

Brydone (1912) zonal map of the Chalk of Hampshire was based on fossil evidence and show the site to situated on *Holaster Subglobosus* Zone (now broadly

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referred to as Zig Zag Chalk Formation) and the *Inoceramus Labiatus* Zone (known as Holywell Nodular Chalk Formation). He also numbered the exposures of chalk where the fossil evidence for the zones measured was obtained. Three of such numbered localities (57, 79, and 80 and 117) are still of relevant to the Morestead Road investigations.

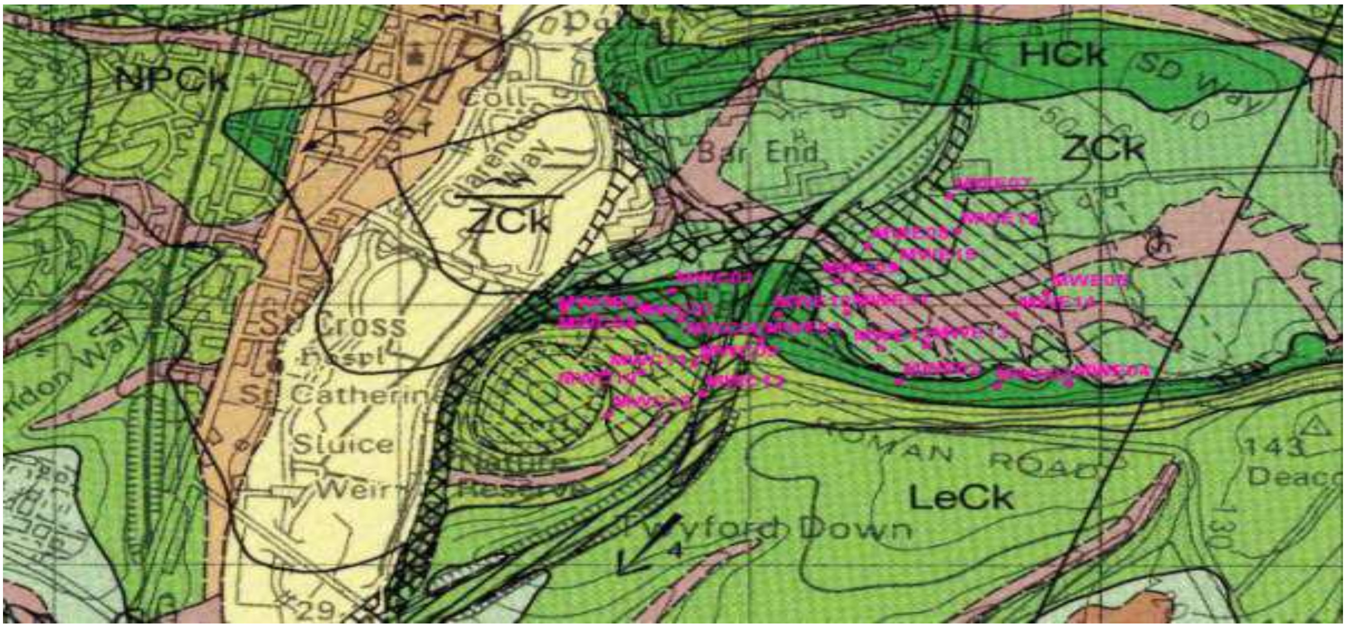

Figure 2: Generalised geology of Morestead Road WWTW site, showing the different borehole locations (adapted from British Geological Society (BGS) Map 299 Winchester, 2001).

MATERIALS AND METHODS

In all, twelve (12) borehole (MWE02, MWE05, MWE06, MWE07, MWE08, MWE09, MWE11, MWE12, MWE13, MWE14, MWE15 and MWE16) locations were studied for this research. Some of the data used were obtained with permission from previous work done by Munn (2008). The boreholes are situated in the Winchester area, Hampshire region. Their locations (Figure 2) are presented in Table 1 below.

Table 1: Position coordinates for each borehole studied within the Morestead WWTW site.

BOREHOLE NAME (MWEXY)	LONGITUDE	LATITUDE	EASTING	NORTHING	ELEVATION (mbgl)
MWE02	-1.7E+308	-1.7E+308	449431	127705	54.66
MWE05	-1.7E+308	-1.7E+308	449852	128044	45.15
MWE06	-1.7E+308	-1.7E+308	449818	128316	53.45
MWE07	-1.7E+308	-1.7E+308	449578	128416	44.54
MWE08	-1.7E+308	-1.7E+308	449342	128226	44.42
MWE09	-1.7E+308	-1.7E+308	449257	128092	43.95
MWE11	-1.7E+308	-1.7E+308	449285	127968	42.98
MWE12	-1.7E+308	-1.7E+308	449380	127831	43.9
MWE13	-1.7E+308	-1.7E+308	449512	127842	44.99
MWE14	-1.7E+308	-1.7E+308	449761	127960	45.18
MWE15	-1.7E+308	-1.7E+308	449420	128143	44.12
MWE16	-1.7E+308	-1.7E+308	449597	128283	47.67

Field sampling technique

Vital to the success of this research was the obtaining of core samples. To fix the research area within a stratigraphic context, core samples with unaltered Chalk and obtained pore-water, for laboratory testing, were collected and analysed. The percussion drilling (U100) technique (a rugged, cheap sampler that produces core samples in most British clays typically heavily over-consolidated) was used to intermittently core the New Alresford site.

For the Morestead road WWTW, air-flush rotary drilling technique was employed instead of percussion drilling to recover U100 samples, since it has been observed that the rotary coring method is far superior in the Chalk. The agreement by Southern Water to this additional cost was to give more reliable results.

Morestead Road was rotary cored, using a mist flush method. Obtained cores were transferred to a thin – walled PVC tube, which were waxed and capped (Munn, 2008). This approach gave a near continuous recovery and eventually a much better understanding of the site. On site, the cores were stored in refrigerated containers before they were later transferred in a refrigerated lorry to the refrigerated core store at the University of Brighton, Cockcroft Building. The cores experienced a steady temperature of 2 – 8°C after they were extracted (Munn, 2008).

Core logging and pore-water extraction technique

The initial research phase required the extraction of pore water from Chalk cores extracted from the Morestead road site. This required that cross contamination of samples be kept at an absolute minimum, and that maximum pore water recovery was achieved. In addition to the above, it was deemed desirable that the obtained pore water underwent as little chemical alteration during centrifugation process and subsequent storage prior to analysis (Munn, 2008).

Core logging and storage technique

Before they were then transferred to the soils laboratory for logging, the collected cores were stored at temperatures between 2 and 80C. Heavy polythene bags were used to cover the surface upon which logging of the samples was to be carried out. These were renewed for each logged sample. After logging was successfully carried out, all implements used for logging were cleaned using a propriety combined detergent and bactericide (Munn, 2008). The core logging was carried out by Professor Rory Mortimore, due to his expertise in this field. A geological hammer was then used by Munn to render the Chalk down into pieces of approximately 5 mm diameter ready for centrifugation.

Pore-water extraction technique

Several approaches exist for extracting pore water from soils and porous rocks. However no single methodology is appropriate to all applications. The choice of a method will hence depend on the particular aim for which the study was carried out.

Therefore, description of the methodology employed is very important as well as stating the assumptions made. Generally, most field sampling methods have been employed to interpret both the static and dynamic perspective of Chalk pore water chemistry, without much relevance paid to the Chalk water being sampled and its chemical reactivity (Wolt, 1994).

Core sample pore water can be extracted by either a field-based approach (such as tension samplers, monolith, and passive samplers etc. – all referred to as lysimeters) or laboratory-based methods (such as rhizon™ samplers, centrifugation, and pressure filtering) (Tyler, 2000). For this study we focus on pore water extraction using centrifugation technique. This is because centrifugation can be used to fractionate the pore water by selecting several centrifugation rates. Therefore, when increasing the centrifugal speed, and therefore the relative centrifugal force (RCF) value, during several stages of soil centrifugation, less available water may gradually be released and collected (Tyler, 2000).

Centrifugation

The use of centrifuge method to extract water from porous media has a long history. It was originally developed to establish “moisture equivalent” of a soil, i.e. the moisture content of a sample after the excess water has been reduced by centrifugation and brought to a state of capillary equilibrium with the applied force (Nuclear Energy Agency, 2000). Centrifuge technique relies on the difference in pressure developed across a sample exceeding the capillary tension holding the water in the pores. Chalk cores centrifugation was undertaken in order to extract pore water without severely altering the pore water chemistry. In order to limit gaseous exchange, both of the water itself and of any volatile or semi-volatile contaminants, refrigerated centrifuges were utilised. We used Rotanta 460R centrifuge, in which the rotor arm and bucket are in Computer Numerical Control (CNC) machined units. These made them able to withstand the cyclic loadings that could be applied to them during centrifugation.

Measurement of ionic and determinand concentrations

Inorganic cations, trace elements and sulphates were measured by inductively coupled plasma optical-emission spectrometry (ICP-OES) and anion species by automated colorimetry at Southern Water’s laboratories. Sample preparation and analysis were carried out at the same laboratory. Ionic balances for the analyses were within appreciable limits and the precision for the trace elements were verified. The pH was analysed using ion selective electrode (ISE). The concentration of ions and determinands in the final effluent were evaluated from analytical results obtained from Southern Waters laboratory. Data handling and plots were done using Microsoft office Excel 2010 spreadsheet. Measured depth to the water level in each borehole was averaged on a daily basis to enable suitability of the obtained data (Munn, 2008) be used to evaluate and correlate effluent discharge volume to the measured groundwater level in the boreholes.

RESULTS AND DISCUSSIONS

Variation in Groundwater Level Response

Data for the depth to water table of twelve (12) Boreholes investigated within the study area was taken from previous research conducted by Munn (2008) for which these values are presented in the Table 1.

The depth to groundwater was measured between the months of July to December. The daily average for each borehole as corresponding to the time of measurement was determined for correlation purposes. It was observed in all boreholes that measure water level depths (see water depth variation-time section) are above their corresponding depth to water table, respectively. This is suggestive that flow to the groundwater system in the Chalks essentially passes through the unsaturated zone. Boreholes MWE02, MWE05, MWE08 and MWE09 are characterized by two to three peak rises in water level and an almost steady decline in the depth to water – level as we approach winter months from autumn. It could hence be inferred that recharge occur more or less gradually and not typified by rapidness, hence matric flow through either pore spaces or matric pulse (displacing water by a piston – type movement), is suggestive as the mode of flow through the unsaturated zone (Price, 1987), rather than by fissures.

Borehole MWE06 and MWE07 (Figures 5 and 6) display an even water depth distribution throughout the entire study period. Difference in depth between the highest and lowest water level values in both wells are 8.314 and 2.047 mAOD, respectively. The large difference in depth to the water level in MWE06, characterised early decrease to water depth (July) and late increase (December), suggests that groundwater recharge may occur via both matric and fissure flows. Observed decrease to water depth in July and an increase in November – December, may have arisen from flow through the matrix enhanced by fissure flows, which rapidly move through the unsaturated zone to the groundwater table (Price, 1987) because fissure flows are characteristic of sometimes rapid flow through unsaturated Chalk zone (Headworth 1972).

Borehole MWE13 and MWE14 (Figures 9 and 10) are similar to MWE02, MWE05, MWE08 and MWE09 but experience less fluctuation during decreasing water depth as the winter months are approached. Specifically, from around September, depth to groundwater steadily decreases as we approach winter months. It is assumed that these are period of constant rainfall (autumn) and hence recharge through the unsaturated zone is not only enabled via the matrix but also influenced by plausible fissure in the Chalk Formation.

Finally, worthy of unique description is the steady or maintained water depth value of 37.922 mAOD observed in borehole MWE15 beginning from the end of August. This observed constant depth to groundwater suggests a steady unsaturated flow recharge to the groundwater via the matrix, with no drainage of matric pore space at the pore-water suction involved (Price, 1987).

Water depth variation – time

In an attempt to determine potential source and rate of recharge (in both summer and winter months) from the surrounding vicinity of the boreholes at Morestead Road WWTW site, several plots where made of measured water level (using in situ pressure loggers with recordings at 15 minutes interval) as function of averaged date and time, for the same period. For this study, data from 12 borehole drilled through the Chalk at Morestead Road WWTW site were considered and the discussion of observed findings are presented below.

Borehole MWE02

An average temperature of about 15.56^{o}C was measured. It can be seen (Figure 3) that the water level depth is between 36.448 to 43.036 mAOD. It is at a minimum during winter months (November to December) than in summer where a peak of 43.036 mAOD is observed for Early August.

Borehole MWE05

An average temperature of about 10.83^{o}C was measured. It can be seen (Figure 4) that the water level depth is between 38.617 to 43.532 mAOD. It is at a minimum during winter months (November to December) than in summer where a peak of 41.835 mAOD can be observed for Early August.

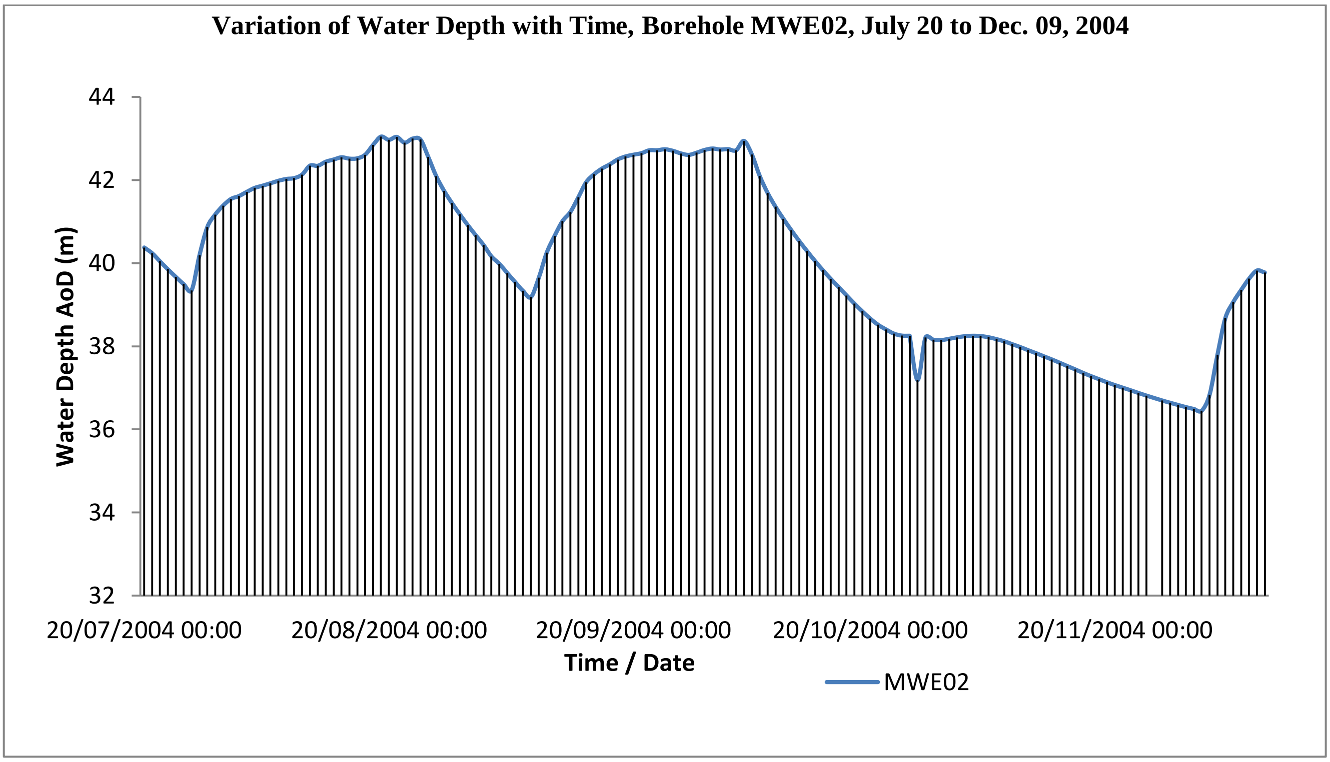

Figure 3: Water depth variation – Time plot for borehole MWE02

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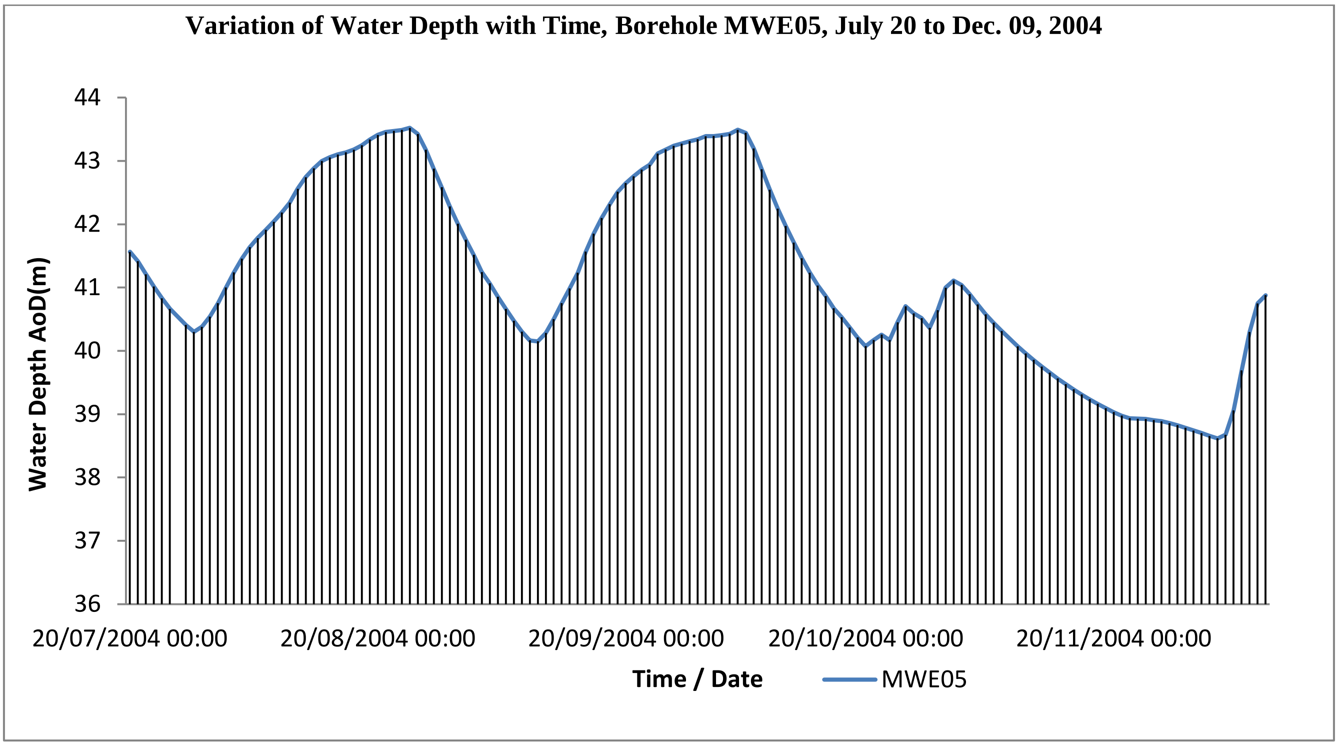

Figure 4: Water depth variation – Time plot for borehole MWE05

Borehole MWE06

An average temperature of about 10.68°C was measured. Water depth ranges between 39.574 to 47.888 mAOD. An almost evenly distributed water depth variation can be seen (Figure 5) from the plot.

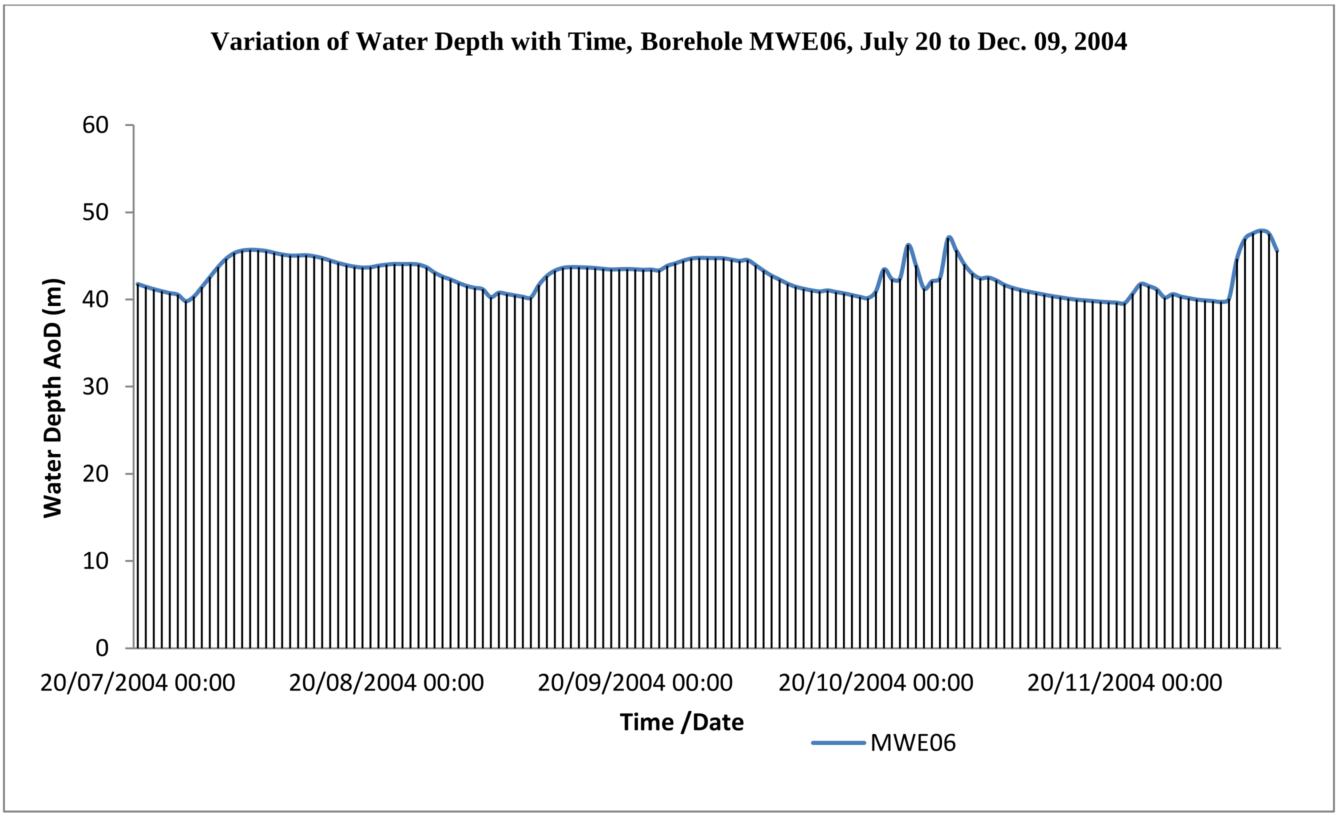

Figure 5: Water Depth Variation – Time plot for Borehole MWE06

Borehole MWE07

An average temperature of about 10.87°C was measured. Water depth ranges between 33.132 to 35.179 mAOD. Also, an almost evenly distributed water depth variation can be seen (Figure 6) but not as defined as with MWE06, from the plot. A zig zag arrangement is easily identified.

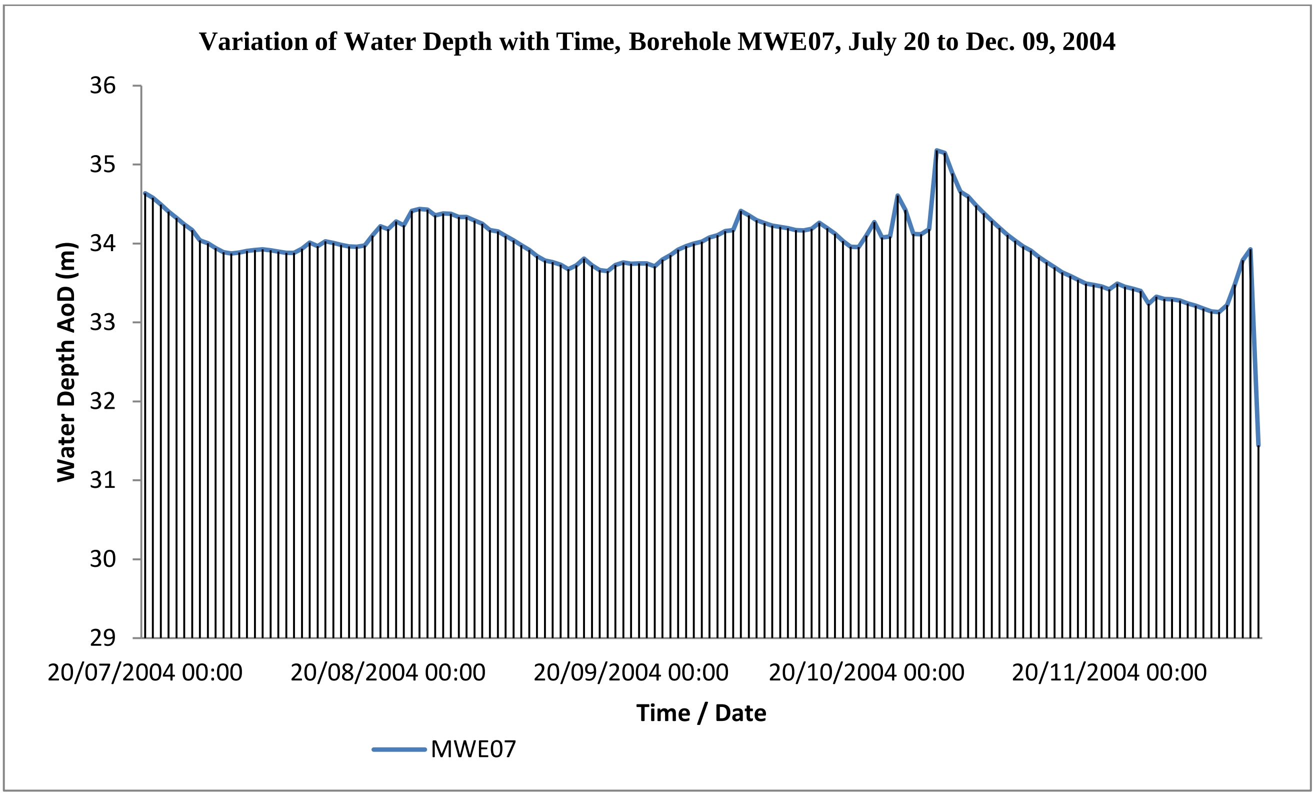

Figure 6: Water Depth Variation – Time plot for Borehole MWE07

Borehole MWE08

An average temperature of about 11.27°C was measured. Water depth ranges between 33.571 to 36.863 mAOD. Water depth variation is at a minimum during winter months (November to December) than in summer and autumn with a peak of 36.863 mAOD observed in Early August (Figure 7).

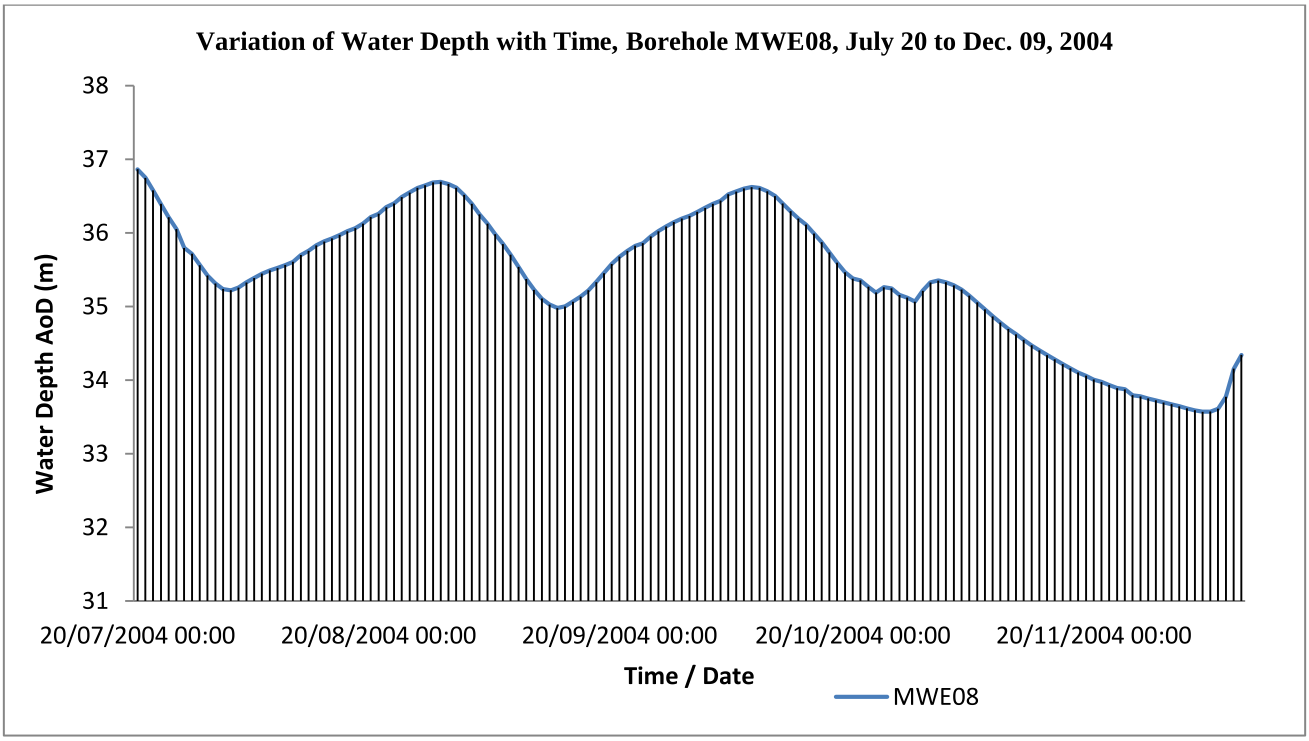

Figure 7: Water Depth Variation – Time plot for Borehole MWE08

Borehole MWE09

An average temperature of about 12.90°C was measured. Water depth ranges between 34.588 to 38.842 mAOD. Water depth variation is at a minimum during winter months (November to December) than in summer and autumn with a peak of 38.842 mAOD observed in Early August (Figure 8). The plot is similar to MWE08.

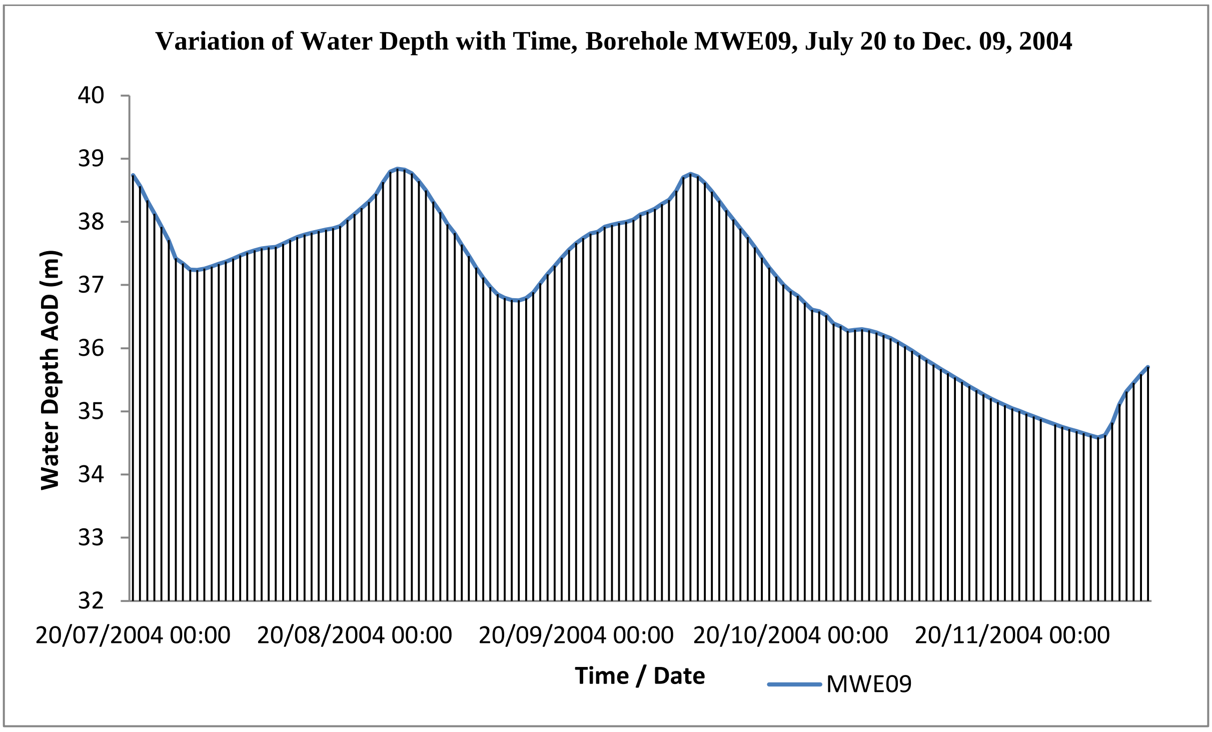

Figure 8: Water Depth Variation – Time plot for Borehole MWE09

Borehole MWE13

An average temperature of about 12.90°C was measured. Water depth ranges between 37.721 to 43.122 mAOD. Water depth variation is at a minimum during winter months (November to December) than in summer and autumn with a peak of 43.122 mAOD observed in Early August (Figure 9). From September to October the variation is relatively constant before a steep decline occurs until the end of November and early December.

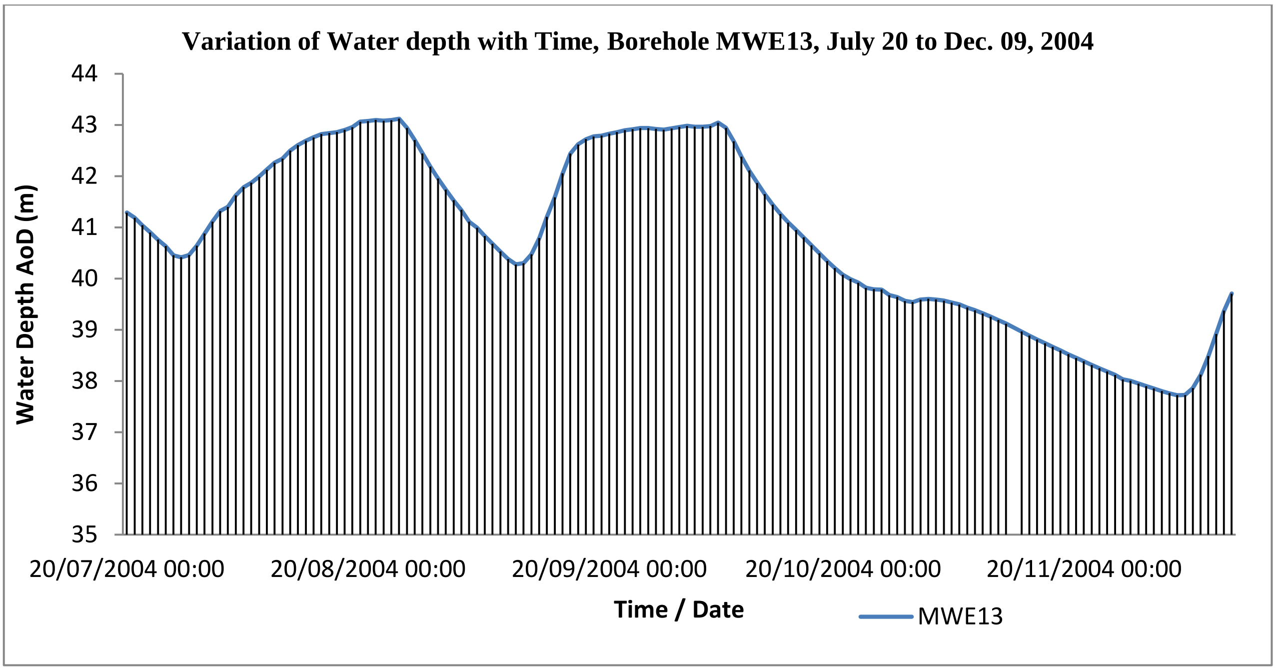

Figure 9: Water Depth Variation – Time plot for Borehole MWE13

Borehole MWE14

An average temperature of about 11.50°C was measured. Water depth ranges between 38.380 to 43.979 mAOD. Water depth variation is at a minimum during winter months (November to December) than in summer and autumn with a peak of 43.979 mAOD observed in Early August (Figure 10). From September to October the variation is relatively constant before a steep decline occurs until the end of November, where few peaks and falls are observed before another decline to lowest in December.

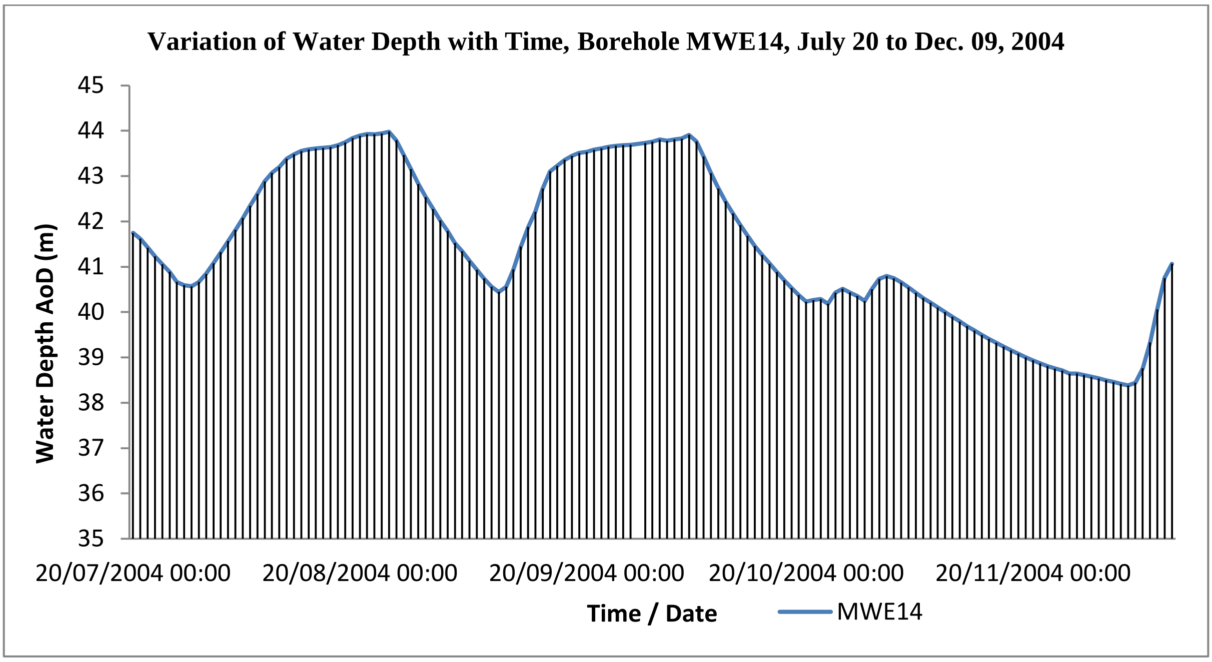

Figure 10: Water Depth Variation – Time plot for Borehole MWE14

Borehole MWE15

An average temperature of about 8.29^{o}C was measured. Water depth ranges between 37.679 to 39.512 mAOD. Water level experiences a decline from July to Early August before a sharp increase is observed to a peak value of 39.512 mAOD. Thereafter, a steep decline is occurs to early September before a steady and constant value of 37.922 mAOD stretches the entire distribution to December (Figure 11).

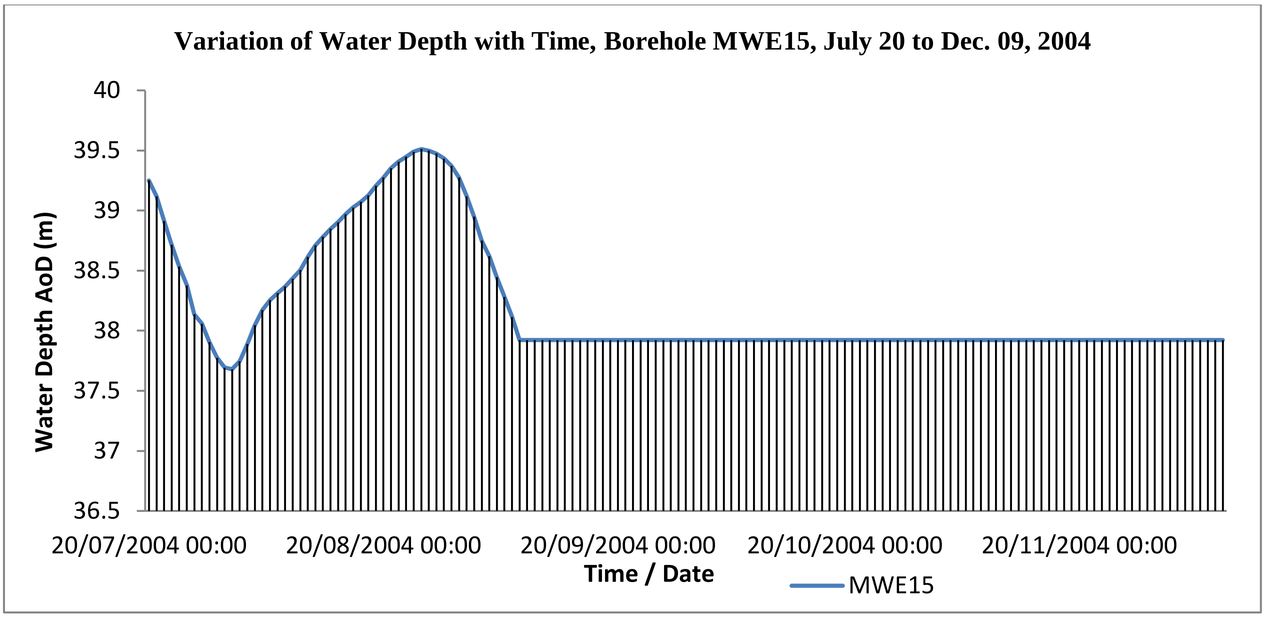

Figure 11: Water Depth Variation – Time plot for Borehole MWE15

Effect on Pore-water Chemisrty from Effluent Discharge

In Chalk formations, drainage of water to the water table occurs predominantly by flow through the Chalk matrix in the unsaturated zone (Wellings and Bell, 1980). Inorganic and organic quality of the pore water samples obtained from cores dug from boreholes MWE02, MWE07, MWE09, MWE13 and MWE15 were analysed as a function of depth. Core samples obtained at varied depths in these boreholes were subjected to chemical analysis to determine their concentrations.

An excellent removal of bacteria, viruses, organic carbon and the inorganic nutrients tends to occur during infiltration through the unsaturated zone (Baxter, 1985). Also, while in the unsaturated zone, levels of major inorganic cations and anions are generally reduced as a result of dilution.

The concentration of Ammonia, in borehole MWE02, is below 0.1mg/l to depths of 13 m before an increase to over 4mg/l is observed at same depth of 13m and thereafter a gradual increase is observed as the depth increases to about 10mg/l at 28m. Ammonia is known to

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originate mostly from metabolic and agricultural processes and from disinfection treatment of chloroamine (Schmoll *et al.*, 2006). Ammonia in groundwater is usually below 0.2mg/l (Schmoll *et al.*, 2006), so the observed high concentration of ammonia suggests groundwater in this borehole is anaerobic. In borehole MWE07, concentration of ammonia can be seen to be less than 0.1mg/l to depths of about 20m before it increase rapidly to 5mg/l at 35m depth and gradually decline to 4mg/l at about 36.5mg/l. It therefore suggested that the low concentration of ammonia even at depths of 20m is as a result of a thick unsaturated zone, while the decreased concentration of less than 5mg/l at depths of over 36m suggests that infiltration through the thick unsaturated zone has helped reduce its concentration. In MWE09, ammonia concentration is seen to be less that 1mg/l through the entire depth investigated of 18.5m suggesting a high level of treatment occurring within the discharge lagoon prior to infiltration into the Chalk aquifer. Similar observations were seen for MWE13 and MWE15 (i.e. all below 0.1mg/l) inferring that in these boreholes, prior purification may have occurred in the discharge network before infiltrating into the aquifer.

The concentration ammonia is only above 10mg/l with increasing depth in boreholes MWE02 and MWE13 while in other boreholes, the concentration of ammonia is below 5mg/l. The results of the groundwater quality for this study are similar to the chemical quality of groundwater studied at Winchester site by Beard and Giles (1990).

The organic carbon (TOC) in all the boreholes is below 10mg/l at the studied depths. These levels show no form of organic contamination occurring within the areal extent of the boreholes, confirming Baxter (1985) assertion that Chalk generally provides an excellent removal of TOC during infiltration through the unsaturated zone.

The effluent concentration of chloride are generally high in all studied boreholes but to a maximum of 131mg/l. Chloride in groundwater originates mostly from sewage, industrial effluent, saline intrusion and urban runoff (Schmoll *et al.*, 2006). There are no health base guidelines values for chloride but its concentration is not to be in excess of about 250mg/l to avoid the detection of taste. The concentration of chloride can be seen to be stable within the entire depth range in each borehole inferring that the chloride observed in the groundwater are mainly from natural sources as the treatment facility is only to a secondary treatment level. Chloride concentrations in borehole MWE05, MWE09, MWE13 are similar to that studied by Beard and Giles (1990) and where an acceptable disposal deemed practice of recharge of domestic sewage effluent to the Hampshire Chalk.

Nitrate (NO_3) is found naturally in the environment while Nitrite (NO_2) is usually not in significant concentration except in reducing environment because nitrate has a more stable oxidation state. Nitrate can reach groundwater as a consequence of agricultural activity (including excess application of inorganic nitrogenous fertilizers), from wastewater disposal and from oxidation of nitrogenous substances from septic tanks (Schmoll *et al.*, 2006). Concentration of nitrate in groundwater has a guideline value of 50mg/l to protect against methaemoglobinaemia in bottle-fed infants (giving a short-term exposure) while that of nitrite is 3mg/l (Egbuna *et al.*, 2013). While the concentration of nitrite in all studied boreholes are below the guideline limits of 3mg/l, nitrate concentrations in borehole MWE09 and MWE13 are greater that 50mg/l at increased depth and close to the surface, respectively. The observed increase in nitrate at the surface is thought to be nitrate contamination resulting from the leaching of natural vegetation or/and the oxidation of the discharged effluent eliminating any process of nitrogen removal (Beard and Giles, 1990). While the increased concentration of nitrate with depth for borehole MWE09 could have arisen from the infiltration of nitrate from wastewater disposal or application of inorganic nitrogenous fertilizers.

Effluent discharge concentration as a function of depth as analysed from core samples obtained from the various boreholes are within limits of safe disposal to groundwater of the Chalk in Hampshire area (Baxter, 1985: Beard and Giles, 1990) but little concern arise for the concentration of nitrogen as nitrate and chloride. However, self-purification occurring as infiltration takes place within the unsaturated zone limits these concentrations to appreciable levels of no concern.

CONCLUSION

In conclusion, movement of water through the unsaturated zone to groundwater in the Chalk of Hampshire area occurs mainly by matric flow through pore spaces or matric pulse, while in very few cases flow may have been enhanced by fissures in some boreholes. Also depth to the water level generally decreases during the winter months but increases in summer months.

Effluent discharge volumes of New Alresford Site where used to make correlation with depth to water level in five of the studied boreholes. Except borehole MWE13, a rather stable and steady vertical flow rate is observed for boreholes within the study area that correlates with the observed depth to water table. However in borehole MWE13 it is anticipated that the increase vertical flow rate causing a quick diminishing of infiltrating water which leads to the observed increase in depth to the water level even as effluent discharge is continuing.

Finally, concentrations of the effluent discharge in all boreholes are within the United Nations admissible level and the programme of investigation confirms that the practice of domestic sewage effluent recharge to the Chalk in the Hampshire area is an acceptable method of disposal as it poses no serious threat to the quality of groundwater within the area.

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