# An investigation of the use of the sustainable drainage for groundwater recharge

## A case study

By

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# Abstract

There is a considerable amount of evidence to suggest that the use of groundwater for water supplies in urban areas and developing cities is increasing as surface water supplies become polluted or fully exploited. Other factors include the increase in water demand occurring in response to population growth, with increasing use per capita.

However, groundwater resources are only sustainable if the aquifers that provide them can be recharged, and in many localities, natural recharge is thought to be potentially, adversely affected by urbanisation, as this covers large areas with impermeable surfaces such as roads and buildings, which divert much needed water into surface water courses or artificial drainage.

The aim of this research is therefore to investigate the use of sustainable drainage for groundwater recharge, using a case study of the area around Leighton Buzzard, in Bedfordshire, England. The detailed objectives of the research on which this thesis is based on includes: conducting comprehensive reviews of the geology, aquifers, groundwater pollution and statutory policies that relate to the study of the area. Within these generic studies, particular emphasis has been given to soil properties, infiltration design structure and the impact of urbanisation on groundwater recharge.

Sustainability of groundwater resources have been considered as a primary objective for the authorities, groundwater sustainability and protection goes in parallel with conservation; therefore recharge of groundwater resources through the Sustainable urban drainage system (SuDS) achieves the sustainability objective of the environment, therefore SuDS is the most suitable and effective approach to recharge groundwater resources, to minimise environmental risk and to deliver future environmental benefits.

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# Preface

The research investigating the use of sustainable drainage for groundwater recharge was undertaken at Kingston University in London.

The Leighton Buzzard district as a case study area, which lies about 70km North West of London and which is of national importance as a source for industrial sands and fuller`s earth products, won from the Woburn Sands Formation of the early Cretaceous age. The landscape is for the most rural parts, which includes mixed arable farming and sizeable traces of woodland, but has been locally scarred over the past century by quarrying activities and new housing developments.

The demand for new housing developments and industries around Leighton Buzzard could cause harm to the underground natural resources such as groundwater and it needs to be protected or a key needs to be found to overcome future demands.

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# CHAPTER 1 - INTRODUCTION

## 1.1 Origins of the study

The research described in this thesis has its origins from a design problem faced by Stuart Michael Associates (SMA) in designing an estate of houses on the southern outskirts of Leighton Buzzard, in Bedfordshire, in 2004. When a Greenfield site is developed, the infiltration characteristics of the site are changed radically, with the area covered by impermeable surfaces such as roofs, roads and other paved areas making up a significant portion of the whole area. This cover has two main potential effects: firstly it changes the runoff pattern, making peak discharges higher; and secondly, it reduces the likeliness of infiltration. The former effect may have adverse impacts on surface water drainage networks such as streams, and the latter effect may have adverse impacts on the groundwater regime that are particularly worrisome in connection with the use of that groundwater used as part of the water supply. In the case of the SMA development, the site in question was to cover part of the outcrop of a significant aquifer. The concept of a sustainable (urban) drainage system (SuDS) where the runoff would be captured and used to force infiltration therefore appeared attractive.

In the design and implementation of a SuDS solution, there are numerous factors to consider. They include not only the characteristics of the land and changes to that, but also the need to consider any variation of rainfall pattern due to projected climate change, possible active control of groundwater pollution, and indeed, the current and future demands placed on the groundwater resources by water companies. In short, not only is it a matter of changes to the recharge mechanism to restore those groundwater resources but the entire system of environmental impacts needs to be addressed.

The general aim of this research is therefore to investigate the use of sustainable drainage systems for ground water recharge through a case study of the area around Leighton Buzzard, including, but not limited to, the SMA development. The contribution to knowledge of this research lies in the review of the geology and groundwater environment of this area, together with an understanding of the issues associated with the adoption of SuDS specifically to enhance infiltration.

Within industry, the review of information in the public domain about a site is referred to as a *desk study*. Desk studies are an integral part of site characterisation, and together with a ground investigation or subsurface investigation form an essential precursor to undertaking construction works. Within this research project, the assessment of relevant existing information on the site and its surroundings has been carried out in the form of such a desk study, to provide a site characterisation taking into account all the available geological, hydrogeological and anthropogenic factors that may affect or control groundwater flow and hence contaminant migration *(Walton, 1989)*. The main issues that need to be addressed within each of the above factors are summarised in the next chapters. The integrity such as data is essential to maintain correct interpretations and assessments, thereby ensuring that the data is not only defensible but will enable a cost effective clean-up solution to be put in place if necessary.

In detail, background research was carried out in connection with the following aspects of the research:

> **Geology:** A formal description of the Geology around Leighton Buzzard *(British Geology Survey, 1994)* has been made, identifying the importance of the locally-occurring strata in terms of the economic geology and thus the extraction of critical parts of the sequence. In particular, the thickness variation in the critical sands, which form the principal aquifer. The position and area of the outcrop has been identified. Much related useful descriptive information has been found in the public domain and the findings of this study are presented in Chapter 2.
>
> **Groundwater pollution:** The background study explored the common concept and definition of pollutants *(Deborah et al., 1987)*, the impact of

groundwater contamination and hazards arising from pollutants *(Pitt et al., 1996)*. The key to determining and monitoring issues resulting from groundwater contamination lies with obtaining groundwater samples that are representative of in-situ conditions. Chapter 3 describes this as part of the study, and mainly covers concepts and definitions relating to pollutants; a description of the origin of groundwater pollutants and their impacts on groundwater resources; a description of public health implications from pollutants; together with a study of potential pollutants from housing developments such as the SMA scheme.

**Aquifer:** Chapter 3 also covers the review of aquifer in depth, and describes a review of aquifer characteristics from Leighton Buzzard, aimed at improving the understanding of the impacts of aquifer designations, aquifer productivity and groundwater contamination through a series of maps of the Leighton Buzzard area.

## 1.2 Regulatory Framework

Statutory measures that exist to control groundwater resources and some measures that are implemented by government bodies (for example, the Environment Agency) and water companies are discussed in Chapter 4. Elements are to be considered as part of the regulatory framework measure to protect groundwater and the environment from the impact of human activities and contaminants. Such regulatory frameworks exist, or are being developed worldwide, and the literature is replete with foreign examples. These examples highlight different issues in different countries (Section 4.5), reflecting differences in landscape, history, patterns of urbanisation and possible contaminants, and they are cited where necessary. Groundwater is an important resource in all climatic regions; with many of the major cities in Europe being dependent on groundwater for supplies *(United Nations Environmental Programmes, 1998)*, for example Denmark 98%, Norway 15% and the UK 35% use of groundwater for drinking supplies. Two principal features of groundwater bodies distinguish them from surface water bodies: firstly, the relatively slow movement of the water through aquifers and secondly, there is a considerable degree of physio-chemical and chemical interdependence of water and the contained materials.

The "Policy and Practice" section of the thesis is aimed at all those involved in the regulation and protection of the water environment, directly and indirectly, as well as those involved in the planning control and the carrying out of activities where the impact on the water environment needs to be a consideration. Chapter 4 covers a discussion of the protection of groundwater based on the Environment Agency policy, groundwater protection, and the best use of groundwater resources, how to manage groundwater and surface water and to pay attention to the quantity and quality of groundwater resources.

The whole thesis considers that Sustainable Urban Drainage System (SuDS) could count as part of the solution to minimise the risk of urbanisation due to the coverage of infiltration areas, the need to protect ground resources and to conserve the local environment. These issues can be dealt with through planning authorities and SuDS adopting bodies. Specifics of SuDS structures are discussed in Chapter 5.

The interaction between the physical and chemical properties of water and soil play a significant role in the composition, distribution and abundance of aquatic organisms. A range of chemical and physical tests were carried out to obtain data for analysis purposes. Physical and chemical parameters which are very important in protecting groundwater quality and protecting the environment in the long term are included in Chapter 6, as part of the research works.

The surface water filtration and recharge mechanism *(Seiler and Gat, 2007)* is one of the targets to achieve the aim of the research. Filter types and the filtration mechanism in Leighton Buzzard Sands show that it is capable of acting as a slow sand filter and the application of this sand filter is to protect natural ground water resources and is considered to be central to the solution of the problem. Chapter 7 covers a discussion of the issues surrounding the infiltration and recharge mechanism, relating to the design and implementation of SuDS in the Leighton Buzzard area.

The protection of groundwater is based on the Environment Agency policy *(Environment Agency, 2007)* and is one of the main focal parts of the research and the practical application of the policy within the Leighton Buzzard area is part of the original design. Groundwater quality is of great significance particularly as it can be very costly to clean up once quality deteriorates and it can take a long time to recover. For these reasons, prevention of deterioration of groundwater quality is one of the most important aspects of groundwater quality management.

## 1.3 Design Issues

Drainage systems in urban areas are required, due to the interaction between human activities and the natural water cycle. This interaction has two main forms: (a) the abstraction of water from the natural cycle to provide a water supply and (b) the covering of land with impermeable surfaces that divert rainwater away from the local natural system of drainage. Urban drainage replaces one part of the natural water cycle and as with any artificial system that takes the place of a natural one, it is important that its full effects are understood. Rain water falls on a natural surface and some water returns to the atmosphere through evaporation, or transpiration by plants; some infiltrates the surface and becomes groundwater, and the remainder forms surface runoff. The relative portions depend on the nature of the surface and they vary with time during a storm. Both surface runoff and groundwater are likely to find their way to a river, but surface runoff arrives much faster. Producing a runoff hydrograph is described in Chapter 7. Butler and Davies (2011) describe this process, and state that:

> *"The transformation of rainfall hyetograph into a surface runoff hydrograph involves two principal parts. Firstly, loses due to interception, depression storage, infiltration and evapo-transpiration are deducted from the rainfall. Secondly, the resulting effective rainfall is transformed by surface routing into an overland flow hydrograph. Much of the rainfall that reaches the ground does not, in fact, runoff. It is lost immediately as it runs overland. The water may be completely lost from the catchment surface by processes such as evapo-transpiration, it may be temporarily retained in depression storage or it may eventually find its way to the drainage system via groundwater".*

Since urbanisation covers ground with artificial surfaces and increases the quantity of surface runoff in relation to infiltration, which in turn is reduced, pollutants are less diluted and their impact on the aquifer is increased. It is, therefore advisable to consider urban drainage and public health as significant 'facts of life' in urbanisation.

The design of the runoff control measures on the site was originally carried out in accordance with the *Interim code of practice for sustainable urban drainage system (SuDS, 2004)* and the Environment Agency (EA) policy and guidelines *(Environment Agency, 1998).*

The Environment Agency (EA) now encourages the use of Sustainable Urban Drainage System *(SuDS, 2004)* to control surface water and to recharge the water table. (There is a difference between maintaining the water table locally, which controls soil movement, and recharging the aquifer). The EA also acts in a regulatory capacity to control water quality and to protect rivers and groundwater resources against pollution and finally as a statutory consultee in the planning process *(Planning Policy Statement 25 Supplement, 2010).* On development projects, the planning and design of drainage projects must identify and deliver environmentally-friendly and technically robust surface water drainage systems in consultation with the Environment Agency. In summary, these systems fall within three categories *(Environment Agency, 1998).*

1- Positive (piped) drainage systems discharging to the sea or to water course(s), often via detention basins or ponds.

2- Positive drainage systems discharging to a lake from which water is lost both to evaporation and by recharging of the ground water table.

3- Soakaways or infiltration systems directly discharging to the local water table.

As the future large residential redevelopment project was designed to provide over 1500 new houses, roads and community facilities on land recovered from a redundant and backfilled sand quarry, option 2 above was chosen for SMA scheme. Surface water runoff from the development will discharge to a man-made lake about 9-12 hectares in the plan area and up to 12m deep from which the water would be lost by evaporation and by recharging the water table *(South Beds District Council, 2009)*.

The EA required that effective man-made and natural measures were employed to improve and protect the quality of water and the underlying aquifer against water-borne pollutants. Sizing this lake required an estimation of the volume of water entering and leaving it – all routine design activities, but requiring research into the known factors such as the geology of the area *(described by WBB Minerals, 2003)*.

## 1.4 Detailed objectives and research questions

The general aim of this research is to investigate the use of sustainable drainage for groundwater recharge through a case study of the area around Leighton Buzzard, and "background research" or "literature survey" was carried out as a routine part of the investigation. During this phase of the work, the geology, the hydrogeology and related physical properties of the ground proved to be readily discoverable. The following are detailed objectives set.

- Does SuDS mimic natural drainage processes to reduce the effect on quality or quantity of runoff from development and therefore provide an effective sustainable approach to recharging groundwater?
- Does SuDS provide economies relative to conventional piped systems?
- Can SuDS encourage or facilitate urbanisation of rural areas?
- How can SuDS minimise the risk of groundwater contamination?
- Does SuDS genuinely represent an efficient method for ensuring groundwater sustainability?
- Do water companies benefit from SuDS in fulfilling their statutory duties to comply with demand and supply potable water in Leighton Buzzard?

Therefore to manage the research, the detailed objectives have been distilled down to the following list of **specific research questions**. The contribution to knowledge, alternatively described as the novel part of this study, is a deliberation on the following research questions:

1. Does SuDS provide us with the most efficient sustainable process to recharge groundwater resources around Leighton Buzzard?
2. Does SuDS provide environmentally friendly long term advantages to the community and can the barriers to the adoption of SuDS be overcome, or at least simplified?
3. Is SuDS likely to meet environmental challenges such as climate change?
4. How do we protect groundwater resources through a sustainable natural process?
5. Does SuDS remove the potential impact of urbanisation around Leighton Buzzard and groundwater abstraction by water supply companies?
6. Can we identify user-friendly tools to support SuDS applications regarding data capturing, analysis and reports?
7. Does SuDS and groundwater recharge reflect a prime objective for local authorities, especially in the area similar to Leighton Buzzard?

## 1.5 Research issues

Considering detailed objectives and the specific research questions, there are a number of research issues to be considered in the thesis with some preliminary responses to assess the use of SuDS to recharge groundwater. Although there are a few commonalities between detailed objectives and the research questions, however to link them, it is necessary to discuss briefly the number of research issues with possible remarks which are supported by the review of literature and actual research works. The main analysis of research issues and preliminary responses are to provide research based reasons to the specific research questions (section 1.4).

- Using the case example of the area around water supply boreholes in the Leighton Buzzard area, how has urbanisation affected the "impermeability" of the ground cover through time? This study was carried out using a multi-layered GIS database, with measurement of areas from early editions of large-scale OS maps. Chapters 4 and 8 provide the relevant background study and analysis. There are clear changes in the impermeability of urban areas through time reflecting both socioeconomic and transportation factors.

- Is the water supply actually at risk from "impermeabilisation" of the ground surface, and is this likely to change with future climate change predictions? This is discussed in chapter 5 particularly section 5.6. As 1/3 of the total supply for water in England comes from groundwater, impermeabilisation does have a *potential* impact on aquifer recharge. Considering future climate change which could change rainfall patterns, the temperature, and the incidence of floods in the winter and droughts in the summer could put the water supply at risk. As an example, in the dry summer of 2012 some water companies forbade the use of hoses due to a desire to regulate demand and thus protect supplies.

- Does development far from the water supply boreholes truly affect the water supply? Water protection zones are identified by the Environment Agency and there are many licensed locations to abstract groundwater for supply purposes by water companies. In section 4.7, new developments may cover the catchment area of an aquifer, but they may not significantly affect the aquifer in the vicinity of the supply boreholes. However, it is generally feared that natural infiltration will be impeded by urbanisation and the aquifer will not be recharged adequately to meet demand. In fact, source protection zones designated to prevent pollution in the vicinity of boreholes which may rapidly influence water quality, and the rest of regulatory framework controls pollution elsewhere. Pollution distant from the boreholes is expected to be diluted and dispersed. This is discussed generally in Chapter 4.

- Which substances arise from highways and other paved areas in a housing estate, and do they genuinely constitute potential pollution? How are they intercepted, or is this "disperse and dilute"? These issues are discussed in Chapter 3 where it is determined that pollutants arising from highways and paved areas are considered to be factors that threaten groundwater resources. However, a SuDS structure contains most of potential pollutants, many of which degrade naturally.

- Pollutants arise from both existing and new developments. Is extracting water from ground resources in fact *more* suitable for water companies to supply due to the purity and natural filtration process compared to other resources? Existing environmental policies are reviewed in Chapter 4. It is found that as the demand of water supply is increasing, water companies are under pressure to make the best use of all water resources, including ground and surface water, depending on the regional cost and national environmental policies. Therefore, to supply water from groundwater resources is not only useful for water companies, but is likely to be central to future provision.

- Do the EA regulations and policy in regard to "pollution" truly act to counter the imperative to construct SuDS? Is SuDS relevant in a semi-urban, semi-rural development on the outskirts of a small town? Groundwater protection, policy and practice framework have provided suitable guides and manuals to protect groundwater resources and are encouraging developers to consider SuDS for drainage designs where suitable was discussed in section 4.10; however there are few administrative barriers that have caused problems which are discussed in Chapter 5.

- Finally, is it the case that the Leighton Buzzard area itself is either especially suitable or particularly unsuitable for the application of a SuDS scheme? Does limiting natural infiltration in the SMA development area actually have a direct impact? An important finding early in this research was that the excavation of Leighton Buzzard sands had already reduced the infiltration area and this included the SMA development which was being built over a former sand quarry that had been filled in with an engineered clay filling.

## 1.6 Organisation of the thesis

The purpose of the thesis is to demonstrate the capabilities of sustainable urban drainage to recharge groundwater and can be achieved through a systematic approach by reviewing literature, case studies, understanding of regulations, actual laboratory works and the use of suitable software in a structured method, therefore the thesis is divided into four main parts:

| | |
|---|---|
| Part-1: | Background study and a review of the existing knowledge |
| Part-2: | Policies and Directives |
| Part-3: | Descriptive analysis and modelling |
| Part-4: | Conclusion |

Geological review, local topography, characteristics of Woburn Sands (Lower Greensand) and hydrology of Leighton Buzzard are covered in Chapter 2. Aquifer and groundwater pollution including pollution for highway drainage systems are covered in Chapter 3.

Regulatory Frameworks, groundwater protection policies, the role of water companies and physical disturbance of aquifer and groundwater flow are covered in Chapter 4 and the SuDS options together with the impact of predicted climate change are covered in Chapter 5.

Geotechnical properties of Woburn Sands, and related laboratory results are presented in Chapter 6, Infiltration and modelling in Chapter 7, the impact of urbanisation on the water supply in Chapter 8 and groundwater recharge estimations are discussed in Chapter 9. Chapter 10 provides the conclusion, responses to the specific research questions, the knowledge contribution and recommendations.

Some of the additional reviews and research works can be found in appendices such as soil parameters and the techniques for the derivation of peak flow from undeveloped and partly urbanised catchment, improved methods for determining runoff from ungauged streams and a comparison of the different methods of adjustment for the return period.

### 1.6.1 Geological and aquifer review

A comprehensive geological and groundwater pollution review has been carried out to define the importance of the aquifer and groundwater contamination due to the human and environmental impacts around Leighton Buzzard.

Reviews of the aquifer properties from Leighton Buzzard were conducted as part of this research, to improve understanding of the impacts of aquifer designations, aquifer productivity and the impact of groundwater contamination. Data collected within the review were used to attribute an aquifer property map of Leighton Buzzard.

Lower Greensand (Woburn Sands) is an important aquifer around Leighton Buzzard. Chapter 3 covers the review of aquifers and groundwater pollution in depth.

### 1.6.2 Policies and Directives

Groundwater protection policy and practices (GPPP) is a framework for the Environment Agency's regulations and management of groundwater. GPPP provides references for anyone undertaking an operation or development that could affect groundwater. In 2000, the European Union took a ground breaking step when it adopted the Water Framework Directive (WFD). It introduces a new legislative approach to managing and protecting water, based not on national or political boundaries but on natural geographical and hydrological formations in river basins. It also requires coordination of different EU policies, and sets out a precise timetable for action, with 2015 as the target date for getting all European water into good conditions. The Groundwater Directive 2006/118/EC has been developed in response to the requirements of Article 17 of the Water Framework Directive.

### 1.6.3 Descriptive analysis and modelling

The purpose of the analysis and modelling are to carry out practical research to develop techniques for spatial data analysis, focusing on the implementing of a mechanism to get a realistic outcome. Laboratory tests and computer software applications provide suitable results to achieve the aim of the research.

Geotechnical properties of soil tests carried out on samples of soil as part of the research at the Kingston University laboratory. The parameters determined from laboratory tests are taken together with descriptive data relating to the soil which has been carefully examined. The test results were checked with the national geological index. Chapter 6 covers microscopic evidence from Woburn Sands grain size and shape. Actual procedures for a soil shear test and results are listed in the Appendix - A. Shear strength angle is an important soil parameter for slope stability and landslides which are not discussed as a part of this research.

Infiltration systems play a significant part for the solution to reduce the risk on urbanisation in groundwater resources and the environment to overcome future environmental issues. Chapter 7 covers the type of applicable infiltration system , indicative pond design and computer modelling using WinDes software *(Reed et al., 2002)*, depth of rainfall *(Bulter & Davies, 2011)* and conclusion to demonstrate that SuDS can be the most useful method to control surface water and recharge groundwater resources as a sustainable approach for future groundwater resource management.

WinDes is an industry standard sustainable drainage and flood hazard software (developed by Micro- Drainage Ltd) for Civil Engineering and the Environmental sectors and GIS (Geographical Information system- software is also used to create figures and maps for analysis purposes) are widely used for modelling and analysis purposes in this research. For more detail see section 7.4.

Impacts of urbanisation on water demand and supply, the factors encountered when attempting to boost urbanisation of the rural areas, loss of Greenfields and Anglian Water supply/demand and resource usage are analysed in Chapter 8.

Ground recharge estimations for Leighton Buzzard and recharge estimation techniques through the soil water balance method *(Kumar, 1977 and Sophocleous, 1991)* is essential to get a basic idea of the recharge mechanism and it is important in this area of study. Recharge estimation techniques are used to find the rate of aquifer replenishment and the preferred method with the soil water balance has been discussed in Chapter 9.

The final chapter mainly covers the overall conclusions, recommendations and responses to the research questions.

Environmental policies and Sustainable Urban Drainage System (SuDS) can be effective to facilitate the recharge mechanism of ground aquifers by use of natural filtration in the district due to the geological and aquifer designations to reduce the risk of threat and meet population growth in the future. Urbanisation risk parameters investigated against the occurrence of the threat and national environmental policies are referenced for the purpose of the research.

### 1.6.4 Conclusion

The research findings are summarised in the final chapter, each section in the chapter interprets the general determination to respond research questions and contribution to the knowledge and recommendation.

## 1.7 How the design issues and research questions are related?

The aim of the research is to investigate SuDS to recharge groundwater, therefore an indicative SuDS model is provided to demonstrate comparability between an infiltration system and a conventional system as well as to demonstrate the volume of surface runoff and recharge mechanism to minimise the risk of urbanisation.

On the basis of the geological review of Leighton Buzzard, groundwater protection policies, history of urbanisation around Leighton Buzzard, SuDS application, future climate change impacts and groundwater recharge, the relation between the design issues and the research questions can be established:

1. **To reveal that without an infiltration system what volume of surface water can be discharged away from a site by drainage networks.**
   *Conventional standard drainage systems collecting surface water runoff from the paved surfaces historically create a high flow of water which is discharged over a short concentrated time period to the local watercourse. This creates surges in the watercourse that together with continuing development and urbanisation will increase the risk of localised flooding.*

2. **To demonstrate the benefit of on-site infiltration systems.**
   *The use of on-site infiltration systems are intended to reduce peak flow runoff by a combination of infiltration and/or storage. The vegetation system may also provide additional frictional resistance to reduce the rate of flow.*

3. **To recharge the local aquifer through a natural mechanism.**
   *The SuDS solution is to be recommended as a natural recharge approach to the local aquifer.*

4. **To investigate the suitability of SuDS to recharge groundwater.**
   *SuDS system is essentially aiming to return the groundwater recharge regime to something closer to pre-urbanisation conditions and support groundwater recharge therefore, there are strong ties between design issues and research questions.*

5. **To protect groundwater resources through a sustainability approach.**
   *The Sustainable approach to urban drainage is a success because the systems desire to deal with surface runoff at the point of which it occurs and to manage potential pollution at its source. Sustainability can exist in the simple or complex network of the urban drainage system by*

*implementing suitable design techniques to serve a long term viable drainage system.*

6. **To investigate SuDS and climate change impact.**
   *The need for alternative drainage such as SuDS is likely to increase to meet environmental challenges such as climate change and population growth provision.*

7. **To assess barrier of SuDS adoption.**
   *Although there are many practical benefits to SuDS, there are a number of "administrative" barriers that have caused problems implementing schemes which again relates design issues with research questions.*

8. **To demonstrate the risk of urbanisation and water companies on groundwater resources.**
   *Urbanisation covers an infiltration area allowing surface runoff to be discharged from a site and the use of groundwater resources to meet the water companies supply/demand criteria and consider groundwater as a reliable source could have a long term impact.*

An analytical design model option for lined Soakaways, porous car parks and cascading routes has been analysed. The proposed pond to recharge groundwater effectively, minimising the risk to water supply from urbanisation and maintaining the groundwater resources in a sustainable way are the main related parts to provide responses to the research questions. In addition to the analytical design model section which is shown in chapter 7. The impact of urbanisation, demand of water supply issues and groundwater recharge are considered in chapters 8 and 9.

Chapter 10 summaries and is demonstrated on the research found, the future impacts , the research implications, the contribution to the professional fields, to provide reasonable recommendations for further research possibilities and acceptable responses to the research questions.

# CHAPTER 2 - GEOLOGY AROUND LEIGHTON BUZZARD

## 2.1 Location and Topography

The purpose the chapter is to identify the importance of the soil and its suitability for sustainable urban drainage applications around Leighton Buzzard. Leighton Buzzard is situated about 70km North West of Central London. The surrounding district, which is shown in the location plan, Figure 2.1, is located in the south of Bedfordshire. The district has good road links with the capital and the Midlands and as a result is popular for commuters. The main population centres are Luton, Dunstable and the part of Milton Keynes new town that lies in Bedfordshire. In addition there are smaller country towns of Leighton Buzzard, Ampthill, Woburn and other scattered settlements *(British Geology Survey, 1994).*

There are several quarries active and discussed around Leighton Buzzard, the most notable being to the north of Leighton Buzzard. In the British Geology Survey Memoir (1994) quarrying for chalk, sand, brick clay and Fuller's Earth is stated to have "scarred the landscape" in some areas, but several of the disused quarries are being reclaimed as landfill sites or restored as the work proceeds. Sand has been quarried from the area of Leighton Buzzard for over 150 years, but supplies are finite: eventually some of the quarries will be filled in and covered up, Leighton Buzzard is therefore at risk of losing an important part of its industrial heritage. Figure 2.2 shows the location of quarrying activity around Leighton Buzzard.

Jurassic and Cretaceous formations are exposed at the surface and dip gently in a general south-easterly direction *(Horton et al., 1974).* The more resistant beds and formations give rise to positive features, including escarpments, while the more easily eroded clays and sands give rise to areas of low relief. Drift deposits are presently over 30% of the district and make the topography more rounded; glacial drift and clay with flint are the most extensive deposits *(British Geology Survey, 1994).*

Figure 2.1: Leighton Buzzard indicative location (NTS - ArcGIS, Worldmap)

The district has relief range of some 120m from just less than 60m AOD near Clophill and Dunstable. The Chalk escarpment is the dominant feature in the south-eastern corner of the district near Dunstable. Figure 2.2 and with the lesser Woburn Sands escarpment in the north central portion rising to over 120m AOD, Figure 2.3. In the south-west corner, tile and other glacial deposits, overlying Gault and Upper Jurassic formations, form a plateau rising to over 120m AOD *(Horton et al., 1974)*.

Figure 2.2: Chalk escarpment at Kenswoth quarry, near Dunstable (2009)

Figure 2.3: Woburn Sands at Pratt's Quarry, Leighton Buzzard (2009)

The district remains important in term of economic geology, being a national source of industrial sand and Fuller's Earth products. Chalk is still quarried for cement and lime manufacture. Ground water from the Chalk and Woburn Sands is exploited for public supply. The Woburn Sands formation has been extensively quarried for sand and Fuller's Earth over the past century, notably around Leighton Buzzard *(British Geology Survey, 1994)*. Figure 2.4 outlines the solid geology of the Leighton Buzzard district in general and the relevant Stratigraphic column is given in Table 2.1.

Table 2.1 Geological Series in Leighton Buzzard District.

| Period | | Descriptions | | Thickness (approx.) m |
|---|---|---|---|---|
| Quaternary | | Peat | Organic vegetal matter with silt & clay | 2-3 |
| | | Alluvium | Silty & sandy clay with thin basal gravel | 2-3 |
| | | Dry valley deposits | Angular flint gravel, loamy at top | Up to 3 |
| | | River terrace deposits | Sand & gravel, loamy at top | 2-4 |
| | | Head | Mixed soliflucted material | Up to 3 |
| | | Combe deposits | Loamy - chalky - flinty gravel | Up to 3 |
| | | Sand and gravel unknown age | Clayey , sandy gravel | Up to 3 |
| | | Glacial sand and gravel | Variable chalky - flinty sand & gravel | Up to 5 |
| | | Glacial lake deposits | Finely laminated silty sandy clay | Up to 40 |
| | | Till | Chalky boulder clay with flints & stones | Up to 15 |
| | | Clays with Flint | Stiff red brown Clay with flints | 5-6 |
| Cretaceous | Upper | Upper Chalk | Chalk with bands of flint nodules, rock bands | Up to 35 |
| | | Middle Chalk | Chalk with bands of flint & thin marl seams | 75-90 |
| | | Lower Chalk | Grey marly chalk with thin limestone bands | c.70 |
| | Lower | Upper Greensand | Silts and silty mudstone | 0-10 |
| | | Gault | Grey mudstones with sophistic nodules bands | 70-75 |
| | | Woburn Sand | Fine and coarse sand with local Fuller's Earth seams | 0-120 |

*(British Geological Survey, Geology of the country around Leighton Buzzard, Memoir 220)*

Figure 2.4: Outline solid geology of Bedfordshire (BGS, 2012)

## 2.2 Jurassic

The oldest rocks to crop out in the Leighton Buzzard district belong to the Jurassic System (200 Million years to 145 Million years). Their outcrop occupies the western and northern parts of the district, but elsewhere they occur in the sub crop beneath the Cretaceous strata which overlies them un-conformably *(Callomon, 1968).*

Seven formations are recognised from the Jurassic Era around the district.

1. West Walton
2. Ampthill Clay
3. Kellaways (Hydrogeological importance)
4. Kimmeridge Clay
5. Oxford Clay
6. Portland
7. Purbeck

Although the West Walton and Ampthill Clay formations have been mapped separately, these seven formations represent the Callovian, Oxfordian, Kimmeridge and Portlandian stages *Horton et al. (1974).* Apart from Oxford Clay, the strata underneath are only exposed by river erosion north to north-west of Bedfordshire.

## 2.3 Cretaceous (Woburn Sands)

The Woburn Sands formation is an important aquifer in south Bedfordshire, the Woburn Sand formation is one of the principal aquifers around Leighton Buzzard and part of the research focussed on the Woburn Sands characteristics and infiltration. Woburn Sands are named after the Woburn area within the district Figure 2.4, the Woburn Sands crop out eastward from Leighton Buzzard across the district to Clophill, and from a prominent north-east trending escarpment rising above the subdued topography of the upper Jurassic plain to the north *(Casey, 1963).*

Earliest Cretaceous Period in Britain saw a great diversity in geological environments. Woburn Sands are Lower Greensand belong to early Cretaceous with a thickness of around 90-120m, Figure 2.5 presents the Lower Greensand formation stratigraphy *(Horton, 1995 and Sumbler, 1996).*

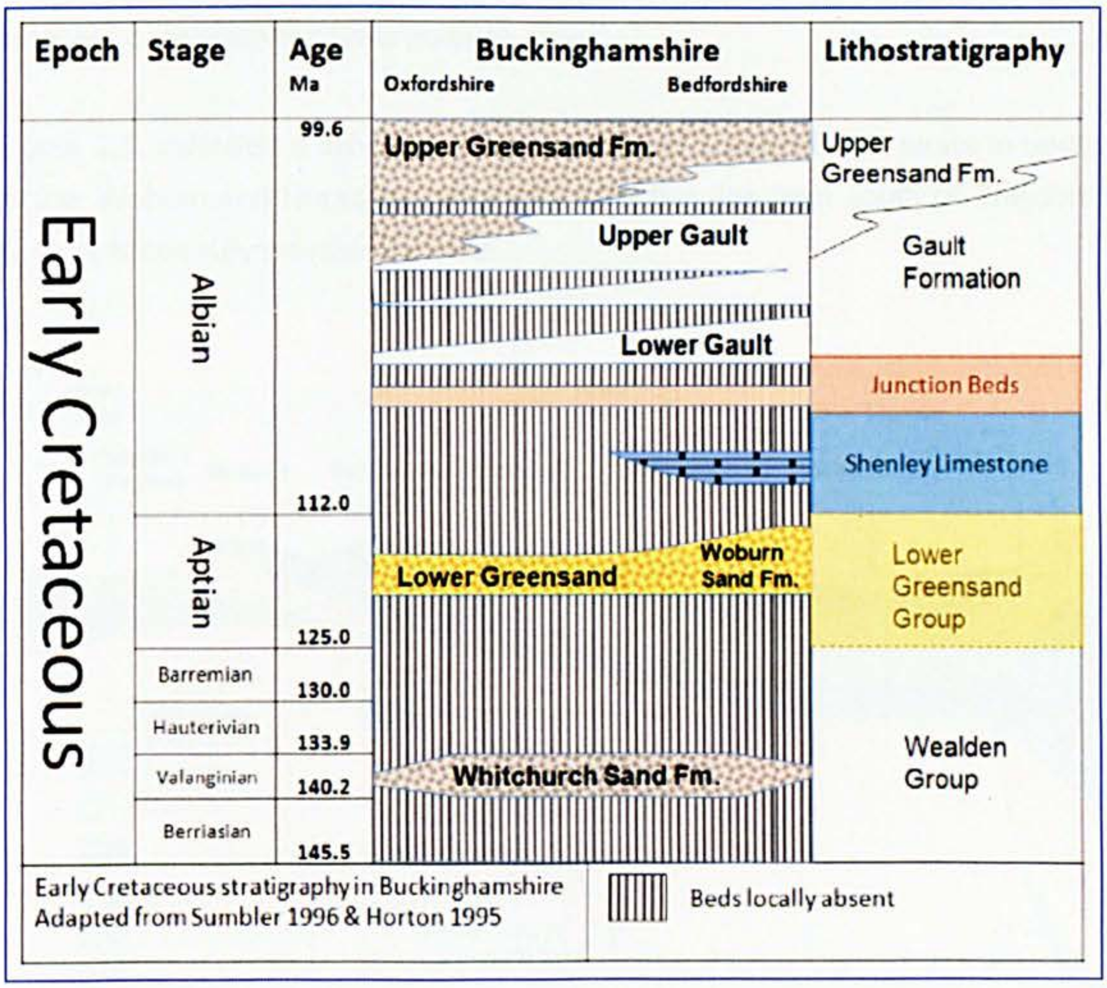


Figure 2.5: The Lower Greensand formation stratigraphy *(Horton, 1995 & Sumbler, 1996).*

A deep embayment in the escarpment is present in the Ampthill area, where the sands are overlain by till the escarpment feature is less well-defined (*British Geology Survey*, 1994), west of Leighton Buzzard the formation thins abruptly beneath the overlying Gault. British Geology Survey states that "This westerly termination appears to coincide with a major north south trending basement lineament".

The Lower Greensand formation Figure 2.5 is of late Aptian and early Albian age are approximately equivalent to the Sandgate Beds and Folkstone Beds of the Lower Greensand of the Weald in Kent. The British Geology Survey (1994) states that, the Woburn Sands rest with marked unconformity on gently folded Upper Jurassic strata, the Oxford Clay, West Walton, Ampthill Clay and Kimmeridge Clay formations. Thus, there is a considerable sedimentary gap representing much of the Cretaceous period. Structural contours on the base of the formation show an irregular, deeply eroded base *(Kirkaldy, 1974).*

Figure 2.6, indicates a schematic cross section of London Basin strata in relation to the Woburn and Dunstable area with a section line from south of Croydon to north of Milton Keynes *(Sumbler, 1996).*

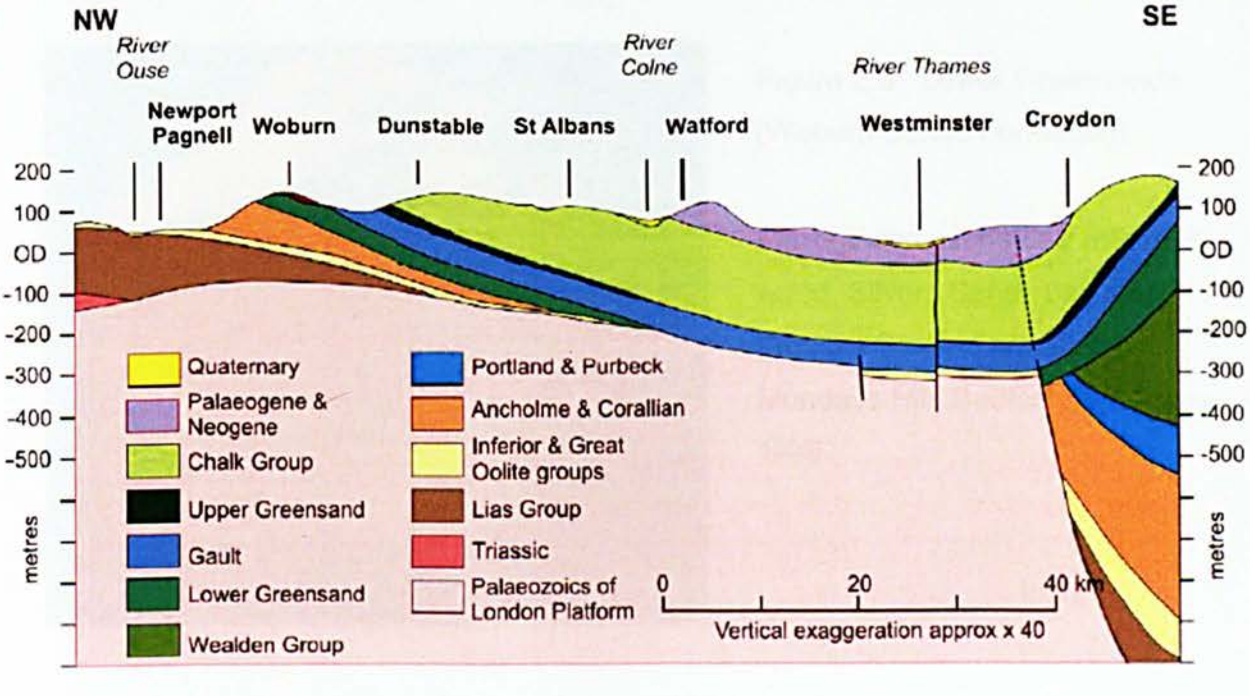


Figure 2.6: Schematic cross-section of London Basin *(Sumbler, 1996)*

The sediments which make up the Woburn Sands are generally quartz sands of variable grain size and tend to be ferruginous and glauconitic (Iron-rich); they are usually oxidised to an ochreous colour in the weathered zone *(British Geology Survey, 1994).* The sands are dug for building and industrial purposes to the north and south of Leighton Buzzard where there are several large working pits, and also there are some pits around Clophill.

Figure 2.7: Lower Greensands (Woburn Sands Formation).

Tidal silts and Muds Beds upper unit of Woburn Sands Formation, Mundays Hill, Bedfordshire *(Horton, 1995)*

Figure 2.8: Lower Greensands (Woburn Sands Formation).

Ferruginous sandstone with fossil wood, Silvers Sands unit and Woburn Sands Formation, Mundays Hill, Bedfordshire *(Horton, 1995)*

Although Lower Greensands typically comprise of loose, unconsolidated sandstones and sands of varying grain size they also contain minor amounts of siltstone, mudstone and limestone. Anisotropic permeability of Woburn Sands mainly interferes with vertical flow and permeability test results on disturbed sample (see chapter - 6) indicates the sand permeability from $2.25\times10^{-3}$ to $7.59\times10^{-3}$ m/sec.

The Lower Greensand is one of the most landslide susceptible formations in the UK and has 288 known occurrences in the south east *(Codd, 2007)*. A common geomorphological feature at the base of the Lower Greensand is an escarpment which is particularly susceptible to land sliding *(Gallois and Morter, 1982)*. Geotechnical properties of Lower Greensands (Woburn Sands) are covered in Chapter-5.

## 2.4 Lithostratigraphy of the Woburn Sands

Several distinct lithological units were recognised by *Horton et al. (1974)*, within the working sand pits near Leighton Buzzard, the location of the principal pits in the Woburn Sands around Leighton Buzzard are shown in Figure 2.10 (which also provides a list of their names). The permeability of principal aquifers around Leighton Buzzard varies according to this Lithostratigraphic variation.

However, these lithostrat units *(Bristow, 1963; Horton et al., 1974 and Wyatt, 1988)*, cannot be mapped at the surface. From top to base these are:

- Red Sand
- Silty Sand
- Silver Sand
- Brown Sand

Eyers (1991) proposed a two-fold division into a Lower Woburn Sands Formation, equivalent to the Brown Sands and an Upper Woburn Sands Formation equivalent to the Silver Sands, Silty Beds and Red Sands, but these formations do not form map able units and have not been adopted here. Indeed, Eyers (1991) states that “the lateral lithological variation within the Woburn Sand is such that it is unlikely that any subdivision within the sands could be traced for more than a few miles”.

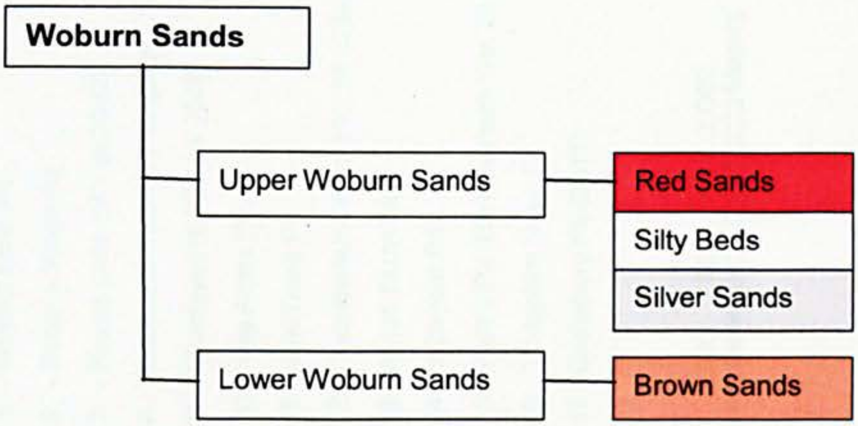


Figure 2.9: Woburn Sands Classification *(Eyers, 1991)*

The indicative location of pits around Leighton Buzzard is shown in Figure 2.10, some of the sand pits are still active and have permission to work until 2042. Research sites for new residential project about 3000 new houses as part of town extension to the south of Leighton Buzzard was Pratt's quarry for the purpose of the thesis and Chapter-8 covers impact of urbanisation on the aquifer and other environmental issues.

Lithostratigraphical correlations of the pits in the Woburn Sands around Leighton Buzzard are shown in Figure 2.11. Indicative ribbon section line from pit No.1 to pit No.17 has been drawn and the horizontal actual distance in Figure 2.10. The Stone Lane Quarry Figure 2.12 has created one of the best cross sections through Lower Greensand, including Silty Beds and the Brown Sands. The phosphate pebble bed found at the base of Lower Greensand is evidence of early pound of the sea level rise that eventually flooded the region. The lowest, Brown Sands, were laid down over the Phosphate beds, they are strongly iron – stained and full of the burrows of shrimp and other animals, the British Geology Survey suggests that the Brown Sands contain seams of Fuller`s Earth (a bentonite clay derived from re-worked ash) which are evidence of volcanic eruption in the region.

Fig 2.10: Indicative location of pits around Leighton Buzzard ( 2012 )

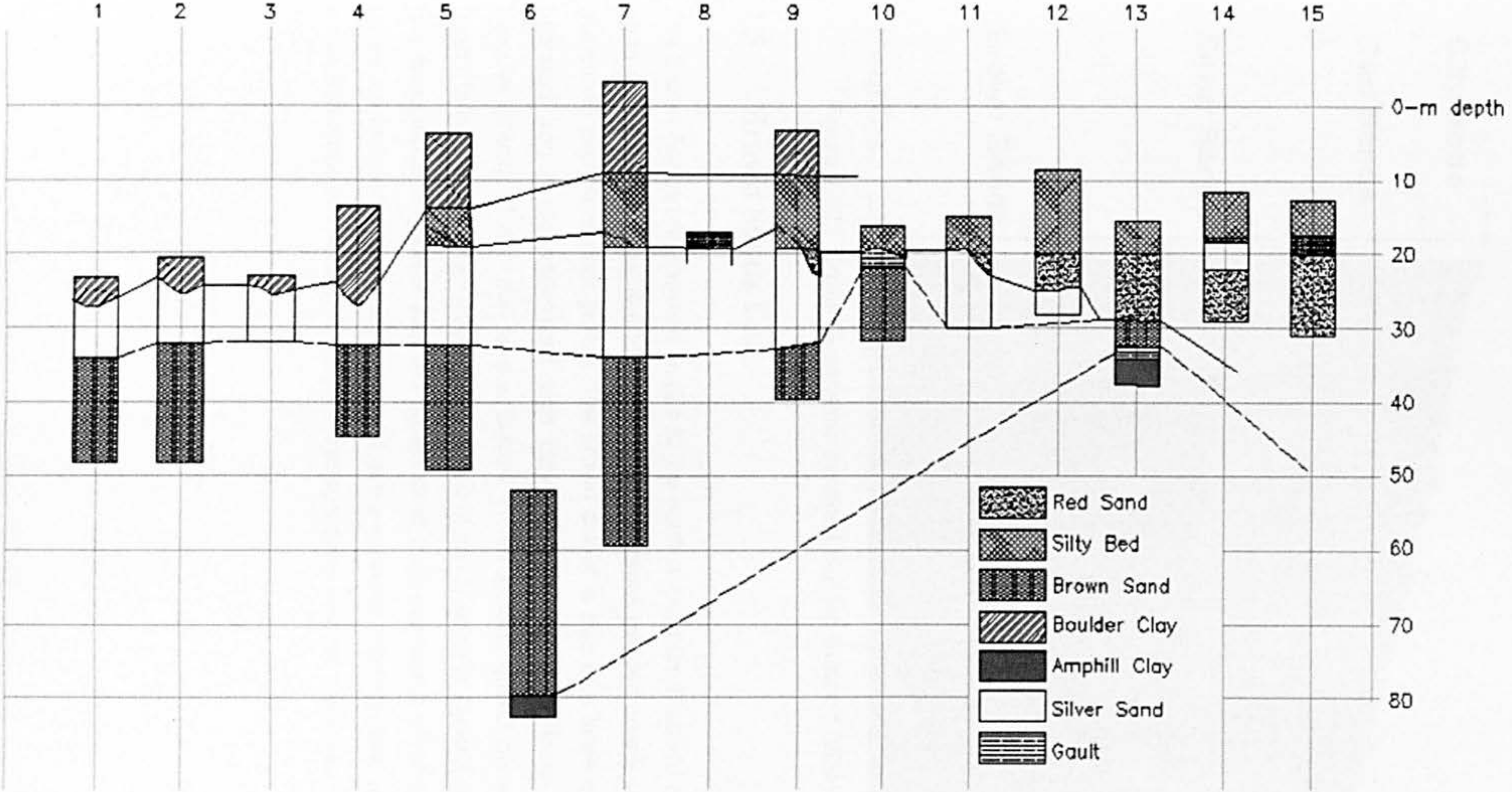


Figure 2.11: Lithostratigraphical correlation of pits in the Woburn Sands around Leighton Buzzard in the form of a "Ribbon Diagram" British Geology Survey, 1994)

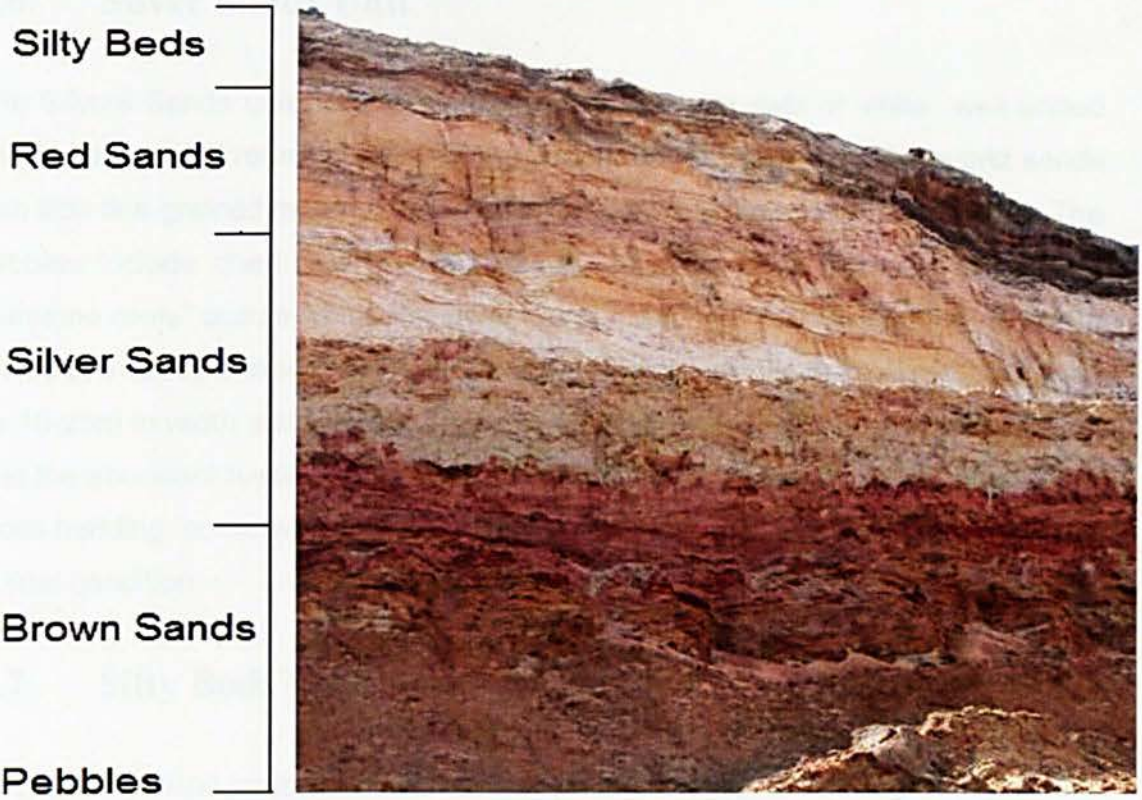


Figure 2.12: Lower Greensand section Leighton Buzzard (2004)

## 2.5 Brown Sands Unit

The Brown Sands unit exposed in pits to the north of Leighton Buzzard comprises up to 45m of ferruginous, fine to medium grained, cross bedded quartz sands with glauconite and other dark grains. The brown colour is due to a large quantity of hydrated iron oxide associated with clay partings and trace fossil burrows. Irregular sheets of iron pan and a burrow in ferruginous quartz on weathered quarry faces *(British Geology Survey, 1994)*. A bed of sandy pebbles (quartz and chert), and ferruginous clay separates the brown sand from overlaying silver sands and forms a prominent marker bed in several of the sandpits. The clay bed represents a non-sequence and was followed by a transgressive episode *(British Geology Survey, 1994)*.

## 2.6 Silver Sands Unit

The Silvers Sands unit from 6m to 15m thick and consists of white well sorted and pebbles , well rounded , medium to coarse grained, almost pure quartz sands with little fine grained material (New Trees Quarry in Shenley Hill Figure 2.10). The pebbles include chert and quartz and are up to 7mm in diameter. In places, "carstone reefs" occurs within the silver sands (Mundays Hill Quarry, Figure 2.10). These are sandstone with ferruginous cement and form linear features; they may be 10-25m in width and 2-3 m in height. The British Geology Survey (1994) states that the abundant fossil wood fragments occur within the sands and strong planar cross bedding, commonly showing reversal of direction, are inductive of deposition in tidal condition.

## 2.7 Silty Beds Unit

The Silt Beds unit up to 4.5m thick are presented locally. According to The British Geology Survey (1994) these comprise mottled silt, silty sand and subordinate clay; are all are characterised by carbonaceous and ferruginous streaks and bands and sporadic coarse pebbly (mainly quartz) lenses. They are overlain abruptly by the red sands except around Shenley Hill, north of Leighton Buzzard, where the Shenley limestone and associated ironstones, which are part of the basal bed of the Gault overlie the Silty Beds *(British Geology Survey, 1994).*

## 2.8 Red Sands Unit

The Red Sand in Pratt's Quarry is up to 5m thick occupies channel cuts through the Silty Beds into the underlying Silver Sands. Elsewhere they overlie the Silver Sands and progressively replace them southward towards Leighton Buzzard, Figure 2.10. South of the town, the Red Sands are up to 11m thick and rest directly on Brown Sands. Brown Sands are fine grained, laminated and contain thin interbeds of black Silty Clay; they are locally known as Compo *(Crux, 1991).*

The Red Sands unit is medium to coarse grained limonitic sands usually slightly silty and commonly pebbly, containing well rounded quartz, quartzite and chert pebbles *(Kirkaldy, 1974)* up to about 5mm in diameter. He noted that concentrations of dark coffee - coloured, highly polished and well-rounded goethite grains diversify the sands with dark streaks and bands picking our cross-bedding structures. Impersistent bands of ferruginous nodules and box-stones concretion are also common. Thin seams of pipe clay or partings of clay are rarely present. Many beds are strongly bioturbated, giving the sands a mottled appearance. Additionally, discrete burrow traces, up to 5 cm in diameter, stand out boldly on weathered surfaces. Much larger, vertical columns with U- shaped distortions of the bedding are locally numerous; these may represent crustacean burrows (the diplocraterrion type). Although typically reddish brown, the Red Sands are predominantly yellow, pale buff and orange in sand pits in south of Leighton Buzzard (*British Geology Survey*, 1994).

Hallsworth (1986) stated, in the northern and eastern part of the district, the Woburn sands appear to be broadly comparable with the brown sands of the Leighton Buzzard area, except that the overall grain size in fine and some of the pebbles are several centimetres in diameter. The pebbles are mostly of quartz and quartzite, but black, smooth, very shiny pebbles, known as Lydites are locally abundant, for example in Woburn Park. A thin section on one of the Lydites showed a quartz-schorlite hornfels (*Hallsworth, 1986)* similar to those found within the aureoles of the south-west of England granite intrusions *(Catt, 1981)*.This shows where the source of the sediments probably lies.

## 2.9 Thickness variations of the Woburn Sands

The Woburn Sands are variable in thickness (Wyatt, and Ambrose, 1988) and (Eyers, 1991). The greatest proved thickness of 88.65m was recorded in the British Geology Survey Potsgrove borehole, Figure 2.13 to the south west of Woburn, However, drilling commenced below the top of the estimated to be at least 120m (Wyatt, and Ambrose, 1988).

A well near Woburn proved 85m, but likewise commenced below the top of the formation. Just east of Leighton Buzzard there are about 60m of sands, but the thickness decreases rapidly westwards and they wedge out abruptly about 2km west of the town; they are absent to the west side (Eyers, 1991).

To the east of Woburn, the maximum recorded thickness of Woburn Sands is 81.05m in the British Geology Survey Froxfield borehole which started within the formation. Although evidence is not enough the sands appear to the thin to the east and to the south of Ampthill only 30m of strata are present. Further east the formation thickens again, and in the Clophill and Shefford area it is some 60m thick.

Figure 2.13, presents Woburn Sands thickness variation from west to east at Potton. Just east of the present district, a British Geology Survey (1994) borehole, which, commenced within the Woburn Sands, penetrated 76.37m of sands before entering the Oxford Clay, proving a further thickening towards the east. The Woburn Sands have also been penetrated in several deep wells in the Dunstable / Luton area.

## 2.10 Hydrogeology of Leighton Buzzard

The Groundwater Vulnerability Map (see chapter - 9) indicates that the Leighton Buzzard site lies on a major aquifer which is identified as the Woburn Sands Formation *(British Geology Survey, 1994)*. The site is not located within a groundwater Source Protection Zone, but lies just outside the south-western edge of the total catchment protection zone (Source Protection Zone III).

Fig 2.13: Woburn Sands Thickness Variation in Bedfordshire ( Wyatt and Ambrose,1988) and (Eyers,1991)

The Woburn Sands formation in Leighton Buzzard is not overlain by any low permeability drift deposits as they have been excavated in the area of interest to facilitate sand extraction. No site specific data have been obtained for the hydraulic properties of the aquifer or the underlying clay as part of this assessment. However, the British Geology Survey major aquifer properties manual describes the transmissivity (the rate which groundwater flows horizontally through an aquifer) of the Woburn Sands as being between 500 and 1000 $m^2$/day *(Allen et al.,1997)* in the area and the range of infiltration values determined in chapter 5.

The Woburn Sands is an important aquifer in South Bedfordshire, yielding smaller quantities of water in SW Cambridgeshire. The current total annual abstraction is about 20$Mm^3$/year, of which about 67% is for public use, 28% for industry and 5% for agriculture. Natural direct recharge is thought to be about equal to current abstraction *(Monkhouse, 1974)* and currently the aquifer is the subject of a number of studies with the basic objective of discovering ways of safely increasing the abstracting by Anglian Water and The British Geology Survey.

## 2.11 Hydrochemistry

Chemical analyses of Woburn Sands waters have been obtained largely from the Anglian Water Authority, the Cambridge Water Company and also from the Environment Agency. In the Woburn Sands aquifer, hydrochemical data, particularly chloride ion analyses can be used in conjunction with other hydrogeological information, to gain a considerable understanding of the recharge to the aquifer *(Irving, 1982)*.

Assuming that the greater chloride concentration of direct recharge waters relative to rainfall is solely due to concentration by evapo-transpiration, an average, annual direct recharge, through the boulder clay-free Woburn Sands outcrop, of 120-250 mm/year is calculated from the average annual rainfall and average chloride concentrations of the recharge and rain waters. These figures compare favourably with the 94-183 mm/year calculated using Penman and Grindley's equations. The corresponding figures for boulder clay covered outcrop are 35-45 mm/year. The typical value for boulder clay covered outcrop, of 38mm/year, is 23% of 168mm/year i.e. that for areas where the Woburn Sands outcrop is not overlain by relatively impermeable drift.

Two main potential sources of error in these calculations are losses to surface water as runoff and interflow, especially in boulder clay covered areas and the addition of chloride ions to the recharge water from sources other than rainfall, such as sewage, landfill, fertilizers, irrigation etc. *(Irving, 1982).* One of the most complex problems in hydrogeology is to determine the amount of regional groundwater recharge and chloride model presents for such purposes.

Once the direct recharge has reached the water table, there remains the possibility of groundwater discharges via springs and effluent streams and indirect recharge via influent streams. Since the rivers crossing the Woburn Sands outcrop contain higher chloride concentrations than direct recharge in till free areas and about the same chloride concentrations as direct recharge where the outcrop is covered by till, influent streams can be detected by an increase in chloride concentration in the aquifer in the former case but not in the latter. The River Ouzel is influent to the south of Leighton Buzzard and effluent to the North of that town. Currently water is being abstracted at the south east of the district pumping stations is at least 30% indirect recharge. The River Flit is probably not the source of much indirect recharge, if any. Close to the River level the water being abstracted in one case is probably more indirect recharge than direct recharge (*British Geology Survey, 1994).*

Recharge to the aquifer is greatest beneath influent streams and least beneath boulder clay deposits. The greatest potential yields and the smallest drawdowns would, if all other relevant factors are constant, be achieved by siting abstraction boreholes near influent streams. By depressing the water table below the water level in rivers, where this situation does not already occur, it is possible that additional recharge could be induced into the aquifer,

Although the usefulness of this method has been demonstrated in this case, whether or not hydrogeological conditions are so favourable to its application to other aquifers remains to be seen.

## 2.12 Summary

The Lower Greensand formation known as Woburn Sands is located north of the London Basin (an elongated, sedimentary basin about 3450km$^2$ [GIS area measured by Author] of area age, around 50 Million years), the outcrop appears in the scarp (north) slope surrounding the London Basin and Weald in Kent, Prominent seams are to be found in Bedfordshire, Kent, Surrey, Hampshire and Isle of Wight and sub crop under the Gault in the south of Leighton Buzzard, Figure 2.14 shows indicative location of Lower Greensand formation in UK *(British Geology Survey, 2012)*. The Woburn Sands outcrop because discontinued to the east of Leighton Buzzard. The Lower Greensands outcrop surface area around 1550km$^2$ [GIS measured by Author] in the UK.

The Lower Greensand thickness varies 90-120m in and around the Leighton Buzzard district while, it reaches a maximum thickness of about 220m just west of the western outcrop in the Weald and thins along northern and southern limbs; it is only few metres thick near the coast of Folkestone, *Allen et al. (1997)*.

The Lower Greensand formation forms a major aquifer in the south east of England, providing water for several pumping stations for industrial and public supplies; this aquifer is vulnerable to pollution where high population densities coincide with the surface outcrop of permeable units in the aquifer. Woburn Sands are discontinued underneath the London Basin, but an outcrop in Woburn to the north of the London Basin, Figure 2.6.

About 17 sand pits have been identified within the district for quarrying sand for construction purpose and specific of them backfilled and few they of having permission to carry out quarrying of sand until 2042; the pits will be backfilled for nature wildlife, agriculture or housing estates purpose.

Figure 2.14: Indicative locations of Lower Greensand Formation in the UK (BGS, 2012)

The Woburn Sands aquifer in Leighton Buzzard is the principal aquifer; groundwater pollution and infiltration are the main parameters of the research (see chapter 3 & 5 respectively) with the transmissivity range of infiltration to discuss impact of urbanisation, SuDS application and environmental issues within the district.

# CHAPTER 3 - AQUIFER AND GROUNDWATER POLLUTION

## 3.1 General

The purpose of this chapter is to explore the concept of pollutant and impact of groundwater contamination and hazards arising from pollutants, also identifying of the potential pollutants and source of groundwater pollutions. Before discussing groundwater pollution, this chapter covers the response to the questions “what is groundwater?” and “how does groundwater get polluted?” in relation to the geological properties of the soil around Leighton Buzzard (reviewed in chapter 2).

Groundwater is the term referring to water that occurs under the ground, all water which is below the surface of the ground in the saturation zone and in direct contact with the ground or subsoil *(Water Framework Directive, 2000)*. It is an enormous but not inexhaustible and slow moving resource that greatly exceeds the volume of other available freshwater sources. Most groundwater originates from infiltration from the surface. The study of the interaction between groundwater and geology is known as hydrogeology.

In hydrogeology, rock types are classified on the basis of their permeability and such hydrogeological classifications of the rocks use terminology such as Aquifer, Aquitard, Aquiclude and Aquifuge.

An aquifer is a stratum of relatively porous soil or rock that contains and transmits a substantial quantity of groundwater. An aquitard is a rock type with low permeability and only permit the transport of groundwater in small quantities. An aquiclude is a rock type with very low permeability and hardly transmits any groundwater, although it may well contain a large quantity of groundwater while an aquifuge is a rock type with a negligible permeability and porosity and neither transmits nor contains groundwater *(Nonner, 2009)*. The word aquiclude can be used as an alternative to Aquifuge, subject to the very low permeability justifications.

Aquifers are used on the basis of groundwater protection policy (see chapter 4) by the Environment Agency in 2010 and are displayed on the Hydrogeological UK map as aquifer designations that are consistent with the Water Framework Directive (WFD). These designations reflect the importance of aquifers in terms of groundwater as a resource, but also their role in supporting surface water flow, infiltration and wetland ecosystems *(Environment Agency, 2012)*. Environment Agency maps are divided into two different types of aquifer designation (see chapter 8 for detail):

| | | |
|---|---|---|
| 1- | Superficial | Permeable unconsolidated (loose) deposits e.g. sands and gravel. |
| 2- | Bedrock | Solid permeable formation e.g. sandstone, chalk and limestone. |

Both the above aquifer designations are subdivided into the Principal and Secondary aquifers on the basis of high intergranular and/or fracture permeability, providing high levels of water storage and supporting water supply and /or river base flow on strategic and local scales respectively; the Principal aquifer was previously designated as the major aquifer.

Secondary aquifers are subdivided further into two types ( Secondary A and Secondary B aquifer) but any rock type that doesn’t fall within the secondary A and B can be classed as Secondary undifferentiated and was previously designated as the minor and non-aquifer *(Environment Agency, 2013)*. Figure 3.1 is a diagram that represents the aquifer designation according to the UK Environment Agency.

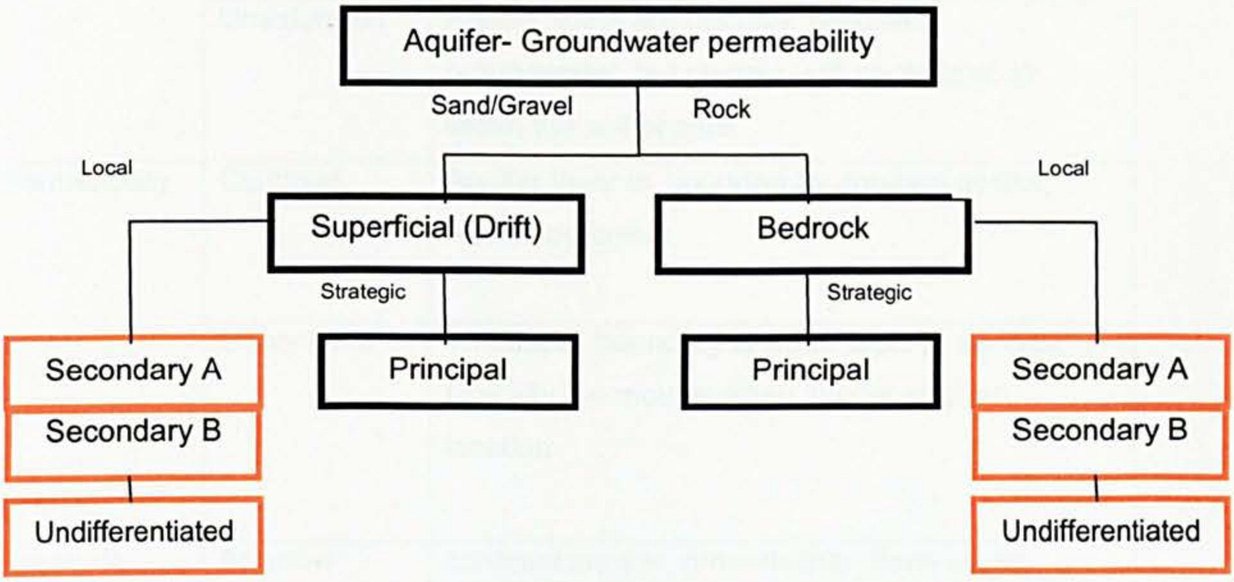


Figure 3.1: Aquifer Designations on groundwater productivity *(Environment Agency, 2012)*

The unproductive strata are the rock layers and drift deposits with low permeability that have negligible significance for water supply and river base flow, and are out of this thesis scope and therefore have not been discussed here.

There are few other types of aquifer classification, depending on the importance of the aquifer characteristic and its conductivity, Table 3.1 summarises these aquifer types.

Table 3.1: Aquifer definition *(McGraw-Hill, 2003)*

| Characteristic | Aquifer Type | Definitions |
|---|---|---|
| Voids | Saturated | Aquifer voids are fully filled with groundwater |
| | Unsaturated | Aquifer voids are not fully filled with groundwater, but contain still pockets of air within the soil phases |
| Permeability | Confined | Aquifer layer is bounded by aquitard and/or Aquiclude layers |
| | Unconfined | The upper boundary is water table or surface, typically the most shallow aquifer in given location |
| Pressure | Artesian | confined aquifer, groundwater flows under pressure and water level rises under hydrostatic equilibrium, |
| | Non Artesian | Unconfined aquifer, groundwater flows at the surface under gravity and atmospheric pressure |
| Directional flow | Isotropic | Aquifer layers with the hydraulic conductivity are equal for flow in all direction |
| | Anisotropic | The Hydraulic conductivity differs, notable in horizontal and vertical directions |

The upper level of this saturated layer of an unconfined aquifer is called the water table; Figure 3.2 represents indicative aquifer definitions.

The movement of groundwater through the aquifer has the effect of removing many impurities from the water, filtering it through the rock so that groundwater is generally much cleaner than surface water. As groundwater is generally very clean it often requires little or no treatment before being used. The level of treatment depends on what it is to be used for; this makes groundwater a very cheap source of 'raw water' for public supply *(Environment Agency, 2013)*. However, fresh water can be accessed by drilling down into the water bearing rock layers and pumping the water out depends on the aquifer layers.

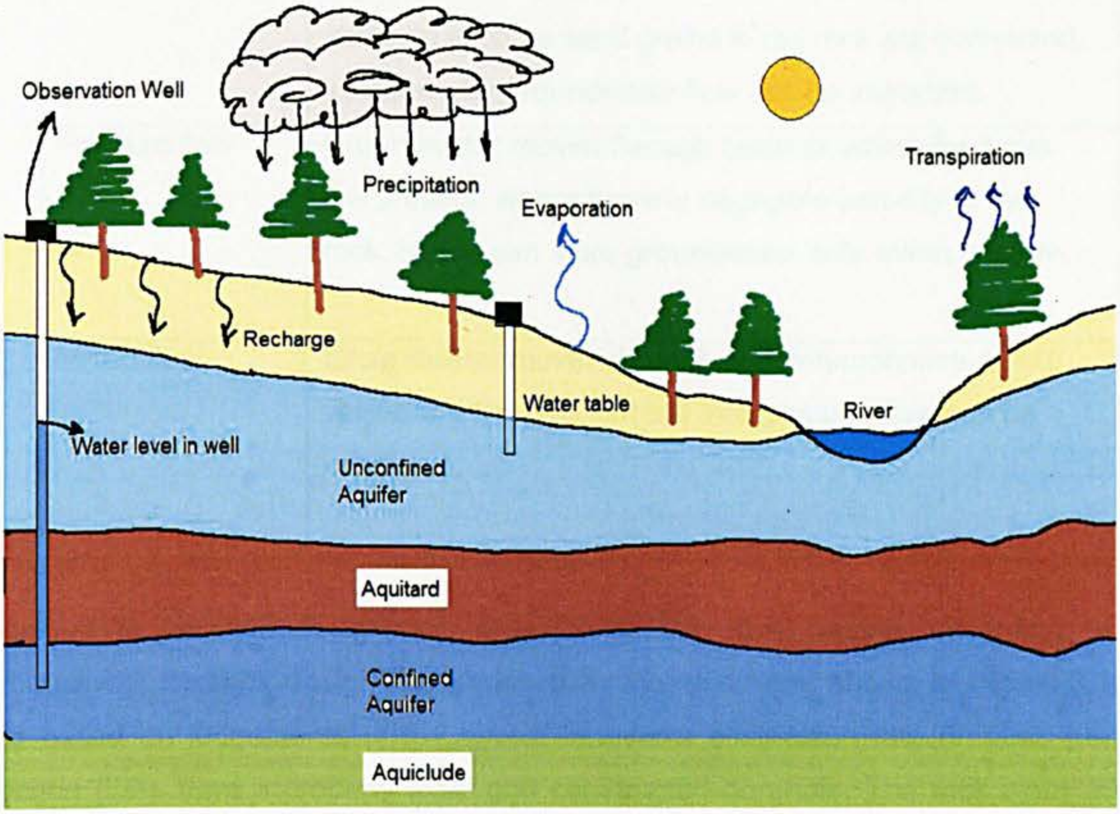


Figure 3.2: Indicative aquifer definitions *(After Johnston, 2011)*

## 3.2 Aquifer groundwater productivity

The British Geology Survey (2013) mapped the aquifer designation according to the proportion on intergranular and fracture flow; the predominant flow mechanism by which fluid migrates from the surface through the unsaturated aquifer of a specific rock unit and lithology is classified in Table 3.2.

Table 3.2: Predominant flow mechanism *(British Geology Survey, 2013)*

| No. | Mechanism | Definition |
|---|---|---|
| 1 | Intergranular flow | Groundwater moves through bedrock through small interconnected pore spaces; where pore space between particles such as sand grains in the rock are connected, intergranular groundwater flow can be important. |
| 2 | Fracture flow | Groundwater moves through bedrock where fractures are present; where there is negligible porosity in the rock, hence can store groundwater only within fracture. |
| 3 | Mixed flow | Groundwater moves through both interconnected pore space and fracture, but still intergranular flow can be important. |

Aquifers in bedrock designation are divided into five classes according to productivity; bedrock designation productivity classifications shown in Figure 3.3 are based on judgements of the typical long-term abstraction rate (in litres per second (l/s)), from a properly sited and constructed borehole. The rock types in each category have been categorised according to information obtained from groundwater databases, the hydrogeological map and pumping tests carried out in various resource assessment projects *(British Geology Survey, 2013)*. The bedrock designation groundwater productivity five classes range from: Very High, High, to Moderate, Low and very low as shown in Figure 3.3.

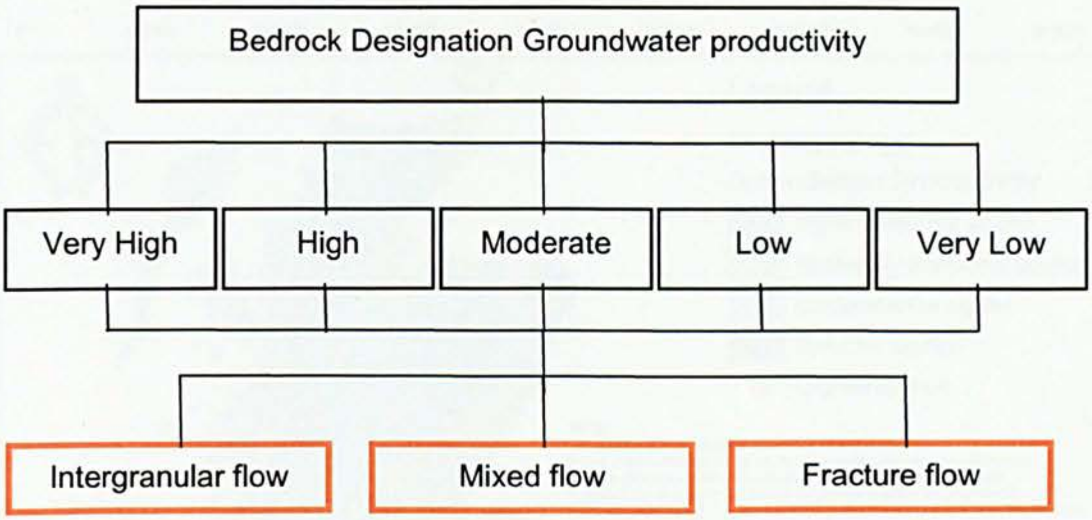


Figure 3.3: Schematic bedrock designation groundwater productivity

The superficial deposits are subdivided into three classes according to groundwater productivity: High, Moderate and Low. In these deposits, groundwater flow assumed to be entirely intergranular is shown in Figure 3.4.

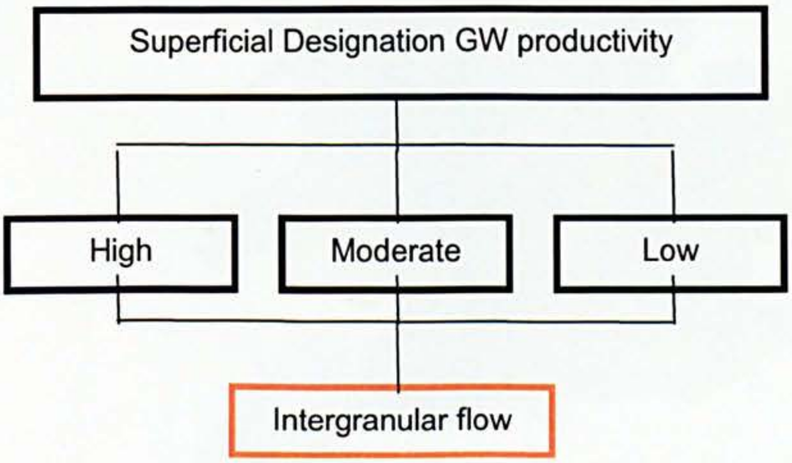


Figure 3.4: Schematic superficial designation groundwater productivity

The UK Hydrogeological aquifer groundwater productivity map is shown in Figure 3.5 (Leighton Buzzard district) and adjacent aquifer productivity is shown in Figure 3.6.

Figure 3.5: UK Hydrogeological aquifer productivity map ( BGS, 2012)

Table 3.3 represents additional information for the aquifer`s name and flow mechanism for the UK groundwater productivity map (Figure 3.5). Leighton Buzzard is the main focal point of the research. Therefore, Leighton Buzzard lies on the principal groundwater productivity aquifer of Lower Greensand (Woburn Sands) with an intergranular flow mechanism and is bounded by very low ( no GW productivity) aquifers, except to the north towards Woburn and Amphill as shown in Figure 3.6.

**Table 3.3: Additional indicative information for Figure 3.5** *(BGS, 2012)*

| **Productivity** | **Aquifer Name** | **Flow Mechanism** |
|---|---|---|
| Highly productive aquifer | White Chalk<br>Lower Greensand<br>Great Oolite Group- Cl.2A<br>Triassic Rocks- Cl.1A<br>.. | Fracture<br>Intergranular flow<br>Fracture<br>Intergranular flow<br>.. |
| Moderately productive aquifer | Neogene to Quaternary Rocks<br>Wealden Group<br>Great Oolite Group Cl.-2B<br>Millstone Grit Group<br>.. | Intergranular flow<br>Intergranular flow<br>Fracture<br>Fracture |
| Low productive aquifer | Triassic Rocks- Cl.2C<br>Pridoli Rockes<br>Solent Group<br>Holsworthy Group<br>.. | Fracture<br>Intergranular flow<br>Intergranular flow<br>Fracture |
| Very Low productive aquifer | Thames Group Clay<br>Wealden Group Clay<br>Kellaways and Oxford Clay | No data<br>No data<br>No data |

Figure 3.6: Leighton Buzzard Hydrogeological aquifer groundwater productivity map (British Geology Survey, 2012)

In the south east of England, dominant groundwater resources are in chalk and also round the edge of chalk outcrop, Lower Greensand (Figure 3.5). Therefore, Lower Greensand is very significant, and usability of the aquifer is a function of:

1. Infiltration area, thickness and permeability/ transmissivity of aquifer
2. Whether the groundwater gets contaminated or polluted

It is also important to review the concept of pollutants, the source of groundwater pollutions and their impact on Woburn Sands and Leighton Buzzard.

## 3.3 Definition of Contaminant and pollutant

As discussed earlier, the Lower Greensand is an important aquifer for groundwater productivity and the aquifer can easily be polluted or contaminated by human activity due to the geological characteristics of the Lower Greensand and infiltration of surface runoff into the unconfined aquifer.

Before covering groundwater pollutant, it is necessary to understand the difference between groundwater contaminants and pollutants by comprehending a definition of them in terms of groundwater implication.

***Contaminant*** in chemistry is usually described as a single constituent but in more specialised fields the term also refers to chemical mixture. In environmental chemistry and soil chemistry, it corresponds to the pollutant *(Sparks, 2003).*

***Pollutant*** is a chemical which is placed in the environment by humans or waste arising from industries/agricultural activities, which is not properly disposed of or contained. The use of the word "chemical" has become synonymous with "pollutant" and there is a tendency to regard all chemicals with deep suspicion. However, in its scientific definitions, all substances are chemicals, whether in combinations or mixture *(Harris, 1994).*

Pollution is the introduction of harmful substance in large scale to the environment, and contamination is the introduction of unwanted contaminant on a small scale. These two terms can be argued in different ways, but I would use them on the basis of the above definitions in this chapter or later.

The need to protect groundwater resources from the effects of human activity is just one element of environmental protection as a whole. For example, a reduction in either the quantity or the quality of the groundwater may prevent associated surface water from achieving a good status, as required by the Water Framework Directive. Growth of population, urbanisation, intensive agriculture, waste disposal, and an increase of industry could put at risk the groundwater and all the above groundwater pollution can be very difficult to detect and may not become evident until a water supply or spring is affected. Pollutants may take months or years to migrate from the source to a receptor or to a point where they can be detected. The risk presented by a pollutant relates not only to its use but also to how it enters the groundwater. However, when groundwater pollution does occur it can go unnoticed for long periods. This is because the pollutants soak into the ground and disappear from view.

Groundwater is at risk from pollution from a wide range of human activities. Some pollution originates from discrete point sources, while other pollution originates from the wider (diffuse) use of substances and highway drainage systems; Highway drainage system pollutions are discussed in section 3.7.

Diffuse pollution (pollution spread over space and time which is not caused by local and specific discharges or events) varies in character between urban and rural areas and it can impact upon the environment through base flow into the river. Diffuse pollution is a problem for both surface water and groundwater. It is hard to detect and it is hard to relate cause to effect. Because of this, and because of a specific identifiable discharge that is often not involved, control under normal pollution and control legislation is rarely possible.

## 3.4 Sources of groundwater pollution

Groundwater pollution is usually traced back to four main sources. Figure 3.7: Industrial, domestic, agriculture and environmental pollution; each family being divided up into continuous and accidental types *(Fried, 1975).*

1- Industrial pollution is carried to the aquifer by:

- Used waters which contain chemical compounds and traced element (such as metals, for instance) or which are at a rather high temperature. Radioactive pollution from atomic plants can also be brought in this way.
- Rain infiltrating through waste disposals.
- Accidents like the breaking of a pipeline.

2- Domestic pollution is carried to the aquifer by:

- Rain infiltration through sanitary landfills.
- Accidents like the breaking of septic tanks

3- Agricultural pollution is due to irrigation water or rain carrying away fertilizers, minerals, salt, herbicides and pesticide.

4- Environmental pollution is mainly due to seawater intrusion in coastal aquifers. Bacteriological pollution mainly originates domestic wastes such as faecal excretions and is not the object of a separate study

CIRIA (1999) states that, there are various causes that can result in on-site groundwater contamination from the source noted below:

- Operational leaks and spillage from tanks and pipes.
- Accident or spillage during storage and transport of raw materials, manufactured products and waste materials.
- Storage of waste materials on or adjacent to the site.
- Leaks from drains from process areas.
- Movement of contaminated groundwater on to the site.
- Demolition of buildings that have contained contaminating materials.

- Migration toxic vapours from adjacent land of underplaying geological strata, which subsequently dissolves.
- Stack/Exhaust emissions (these are of minor importance).

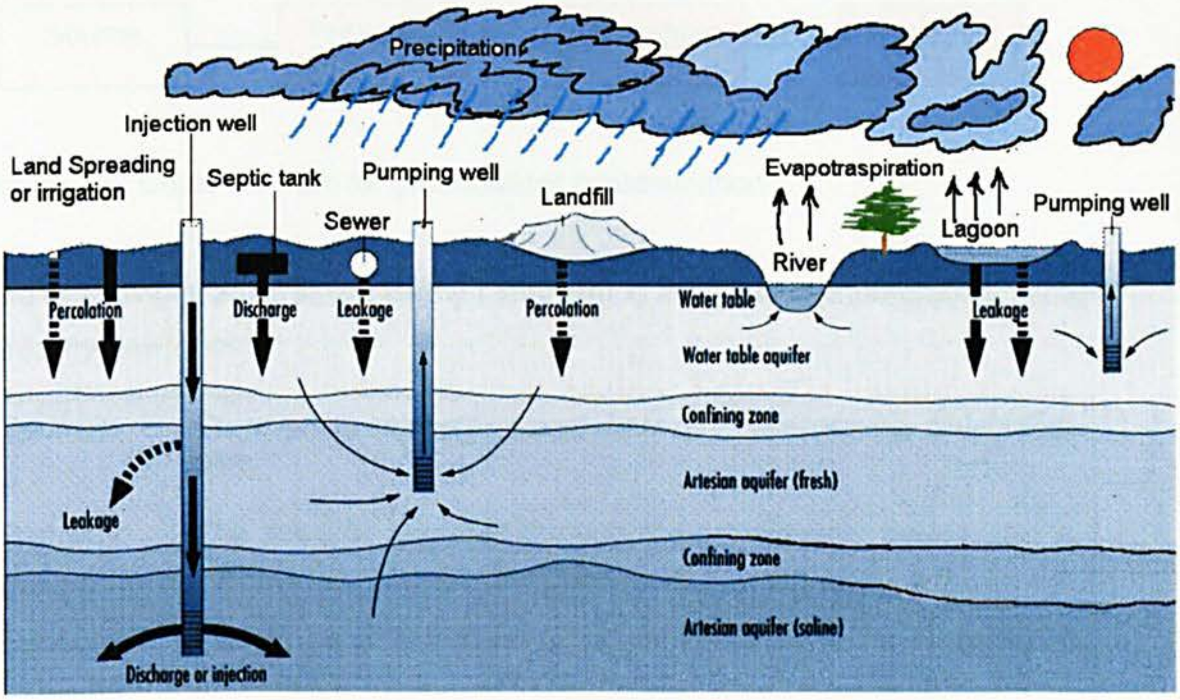


Figure 3.7: Indicative groundwater pollution sources *(After CIRIA, 1999)*

## 3.5 The impact of groundwater contamination

When ground water becomes contaminated, there is a chance that harm will come to a humans or others. For example, harm may result from the drinking of contaminated water abstracted from public water supplies. The chance that harm will result from ground water contamination is termed the risk, but before a risk can exist, a chain of factors must exist:

1. A source of contaminants
2. A pathway for contaminant transport from the source (ground water) discharge into surface waters, ground water abstractions.
3. A receptor to which the contaminants may cause harm; this may be human, plants, animals, or the built environment.
4. A hazard; the event or property associated with contaminated ground water that may potentially cause harm.

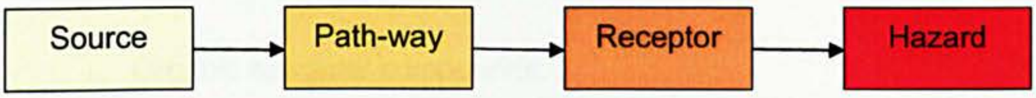


Figure 3.8: Chain diagram for groundwater contamination

The foregoing chain is illustrated by the following incidents in underground storage tanks by (*Harris, 1993)*.

| | |
|---|---|
| Source: | Chlorinated solvents leaked from an underground distribution pipe. |
| Pathway: | The solvents migrated through the groundwater system into a river. |
| Receptor: | People used the solvents, contaminated river for recreational purposes. |
| Hazard: | The solvent was toxic by contact with the skin and ingestion. |

Consideration of such a chain, coupled with the chance that harm will result from it, forms the basis for carrying out a risk assessment. By carrying out a structured risk assessment, a judgement can be made on whether any potential ground water contamination is likely to cause an acceptable impact.

Identification of the groundwater contaminant is important to assess the risk of the contaminant to determine the scale of groundwater pollution within the concerned aquifer zone. Therefore, to briefly review the common groundwater contaminant and Highway drainage pollution within an urban area, at the end of this chapter comments has been added to wrap up the chapter. Chapter 4 mainly covers the statutory measures required to protect groundwater.

## 3.6 Common groundwater contaminants and their hazard

An indication has been given in Table 3.4 and 3.5 of the chemicals that may raise the contamination of groundwater. The chemicals that pose particular threats to ground water cover a wide range, including:

1. Organic solvents/ compounds.
2. Hydrocarbon fuels.
3. Products of coal gas manufacture.
4. Dyes and varnishes.
5. Additives in plastic and textile.
6. Inorganic and organic chemicals used in contraction.
7. Pesticides and herbicides.
8. Trace metals.
9. Other inorganic compounds and elements, including nutrient elements.
10. Radioactive compounds and elements.

Often, several of these chemicals contaminate the same groundwater body, creating a contaminate cocktail *(CIRIA, 1999)*. For example, leachates from landfill sites can often contain such a cocktail.

The hazards that arise from the contamination of groundwater by these chemicals relate essentially to their bio-toxicity and subsequent impact on plants, animals, and human life. Table 3.6 summarises toxicological and other hazards associated with the contaminants likely to be encountered in groundwater *(Halcrow & Sir William Partners, 1988)*.

Table 3.4. Typical pollutant sources, type and general problem areas in the UK. *(Halcrow & Sir William Partners, 1988).*

| Activity or event | Pollutant source | Potential pollutants | Problem area |
|---|---|---|---|
| *Waste disposal* | *Landfill*<br>*Domestic*<br>*Industry: paper solvent, oil, sewage sludge and a wider range of pollutant* | *Leachate with wide range of contaminants; most common are salinity, acidity, biological and chemical oxygen demands.* | *High loadings of contaminants as point source.* |
| *Industrial activities* | *Iron steel industry, chemical and pharmaceutical industries* | *Organic solvents, heavy metals, complex hydrocarbons, organic acids.* | *Heavily urbanised and industrials areas on unconfined aquifers.* |
| *Commercial activities* | *Airport, rail way, roads, petrol stations and weed control.* | *Organic solvent, herbicides, & hydrocarbons* | *Wide scattered location* |
| *Mineral excavation* | *Underground and near surface activities, spoil heaps, setting lagoons, mine drainage discharge.* | *Soluble salt of iron, sulphates of aluminium, Mn, Cl, Mg* | *Coal and metalliferous mining areas* |
| *Military activity* | *Storage tanks leaks, operational spillages.* | *Organic solvents, hydrocarbons.* | *RFA Basis* |
| *Transport of chemicals* | *Pipe line, road and rail traffic.* | *Many reported organic compounds* | *Transport and pipeline routs* |

Table 3.5. Example of ground contamination in UK
*(Halcrow & Sir William Partners, 1988).*

| Location | Aquifer | Contaminants | Contamination source | Reference |
|---|---|---|---|---|
| *Birmingham* | *Triassic sandstone* | *Chlorinated solvents* | *Metal cleaning, electrical and rubber industries, dry cleaning* | *Rivett et al., (1990)* |
| *Coventry* | *Permocarboniferous sandstone* | *Chlorinated solvents bronze, zinc* | *Industry, fire extinguisher discharge, water chlorination* | *Nazari et al., (1993)* |
| *East Kent* | *Chalk* | *Chloride* | *Mine discharge* | *Headworth et al. (1980)* |
| *Luton and Dunstable* | *Chalk* | *Chlorinated solvents* | *Dry cleaning, metal degreasing, leaking drain* | *Longstaff et al.( 1992)* |
| ***Leighton Buzzard*** | ***Woburn Sands*** | ***Nitrate and Chloride*** | ***Inorganic fertilizer domestic animals, residential, nitrogen and leading drain*** | ***Environment Agency*** |
| *Heathrow Airport* | *Alluvial gravel* | *Kerosene Chlorinated solvents* | *Cracked fuel pipe* | *(Clark and Sims, 1993)* |
| *Harwell Oxon* | *Chalk* | *Chlorinated solvents* | *Disposal pits in two waste compounds* | *(Fellingham et al., 1993)* |

Table 3.6: Toxicity and other hazards associated with contaminants in groundwater *(Halcrow & Sir William Partners, 1988).*

| Contaminants | Hazards |
|---|---|
| *Heavy metals, Phenols, coal tars, cyanide* | *Toxicity to humans or animals by ingestion of soil or home- grown produce.* |
| *Oils, tars, Phenols* | *Toxicity to humans or animals by direct contact.* |
| *Hydrogensulphide and other gases (volatile organic compounds )* | *Toxicity to humans by inhesion flowing volatilisation, degassing, etc.* |
| *Phenols, oils, coal tars, sulphates, sulphides, chlorides* | *Attack on services (plastic pipes or building materials, concrete).* |
| *Chloride, ammonia, phenols* | *Test and odour problems* |
| *Zinc, copper, nickel, sulphates* | *Phytotoxicity* |

South of the Leighton Buzzard district, expansion of the urban area may raise concerns over risk to groundwater and aquifer from a variety of pollutant sources and, as far as we can imagine, urbanisation impact; domestic residential waste and Highway drainage pollutant are the two main potential sources of the groundwater and aquifer and need to be covered here.

## 3.7 Pollution from Highway drainage system

Does urbanisation threaten groundwater? Yes, one of the factors of this threat can be considered as highway drainage pollution into the groundwater resources; although the public perceives pollution as being a single definite quantity it is in fact a complex matrix dependent on interrelated substances, e.g. metal comes from a number of sources and exists in highway discharge in several different forms, i.e. soluble, particulate solids and salts. If any of these forms are to be considered in isolation then the involvement of inorganic sediment as a transport medium could be overlooked. To clarify this complex *(CIRIA, 1999)*,a classification has been developed to address the techniques for treatment of highway discharges.

Highway drainage discharge pollutants are divided into following six categories:

1. Sediments
2. Hydrocarbons
3. Metal
4. Salts and nutrients
5. Microbial
6. Others

### 3.7.1 Sediments

Sediment is most simply defined as material that settles to the bottom of a liquid, i.e. material of higher specific gravity than water. Sediments can be defined as a naturally occurring material that is broken down by the processes of weathering and erosion and is subsequently transported by wind, water and ice. Research has indicated that the fraction of sediment smaller than 63µm is the most significant for pollution *(Sarter & Boyd, 1972) and (Ellis, 1979)*. Sediments are not usually a problem in groundwater as they are filtered out before discharge reaches the groundwater resources, but the filtered sediments may still cause a problem by continuing to leach pollutants into the groundwater.

### 3.7.2 Hydrocarbons

Definition of Hydrocarbons in the research is as an organic compound containing only Carbon and Hydrogen, in particular the petrochemical group which can be found on the highway and used by vehicle users. The specific gravity of Hydrocarbons is less than water, but particularly heavy fuel oil may be heavier than water when affecting sediments *(Boxall et al. 1993)*. In the field of chemistry Hydrocarbons are divided into two main types: *Aromatics* (Closed chain), the simplest form of a closed chain hydrocarbon is benzene ring (a hexagon shaped carbon C6H6) and *Aliphatics* (open chain), the simplest form of an opened chain hydrocarbon is methane ($CH_4$).

Petrol, fuel oils, lubricant oils, hydraulic fluid and bitumen are a petrochemical, derived group of hydrocarbons. Typically, 70-75% of hydrocarbon oils show a strong attachment for suspended sediments, but most of them can be milligrams per litre (mg/lit)

### 3.7.3 Metals

The majority of metals in highway runoff are concentrates of lead, cadmium, copper, zinc and iron and sometime nickel, chromium and manganese can be included. Metal can exist in many forms modified and unmodified. They can be attached to inert sediment, soluble salts or insoluble compounds. A number of studies have sought to quantify the soluble portion with the following typical result (*Morrison, 1988).*

| | | |
|---|---|---|
| • Lead | 1-10% | soluble |
| • Copper | 20-40% | soluble |
| • Zinc | 30-50% | soluble |

Cadmium is a very toxic metal that accumulates in the environment. It is present in highway runoff, but its use for all purposes is now restricted, and so the concentrations found in nature are reducing. Lead is also a serious and accumulative poison and a low level may affect tadpoles, frogs and fishes. Iron, although not toxic, can cause discolouration and other physical problems when present at a high level of concentrate.

### 3.7.4 Salts and Nutrients

Salt and nutrients are defined as those generally neutral materials that occur as soluble compounds and have a direct pulling effect upon vegetable matter either by reducing or extinguishing conditioned conducive to spread or by accelerating growth to the detriment of the balance of the environment.

In North America, chloride from highway de-icing has been widely reported as a source of contamination of both groundwater and surface water *(Howard & Beck, 1993)* while chloride is known to be present in high concentration in runoff from the highway in Britain during the winter *(Colwill et al., 1984)*. However, there have been no specific reports on increased chloride levels in UK groundwater.

### 3.7.5 Microbial

Microbial activities are mainly associated with the particulate materials derived from the decay of organic matter or finely divided solids that harbour bacteria or viruses, significant microbial populations that are transported with wind-blown soils.

### 3.7.6 Others

Other substances do not readily fit into the others` class, e.g. pesticides and herbicides; they can be toxic to a variety of aquatic life at very low concentrations, some of them more toxic variations *(CIRIA, 1999).*

## 3.8 Identification of pollutants

There is not a simple definition of a pollutant which will point to a comprehensive list of chemical type or compounds. Any chemical compound in excessive concentration or in combination with other materials could be classified as a potential pollutant. However, certain types of compound and individual species have been implicated in environmental damage and these represent a starting point for any pollutant investigation. The definition of what constitutes as polluted groundwater in the UK rests with the Environment Agency.

The following Tables 3.7 & 3.8, include the contaminants in ground water above which treatment should be considered and that are only for comparing purposes for different species and comparative concentrations in which pollutant is considered to occur.

### 3.8.1 Metal pollutants

These fall into two classes those which affect animal/human (Toxic), and those which affect plants (Phytotoxic). In general, boron, copper, nickel and zinc are Phytotoxic, but not normally hazardous to the health of most animals. An exception to this involves the toxicity of zinc to fish where even low levels have been found to interfere with their metabolism; Table 3.4 shows metal pollutants in groundwater *(Charbeneau, 2006)*, but are not part of this piece research.

Table 3.7. Metal pollutants in groundwater *(Charbeneau, 2006)*

| ***Metal*** | ***Symbols*** | ***µg/l*** |
|---|---|---|
| *Arsenic* | *As* | *100* |
| *Antimony* | *Sb* | - |
| *Selenium* | *Se* | - |
| *Mercury* | *Hg* | *2* |
| *Tin* | *Sn* | *150* |
| *Cadmium* | *Cd* | *10* |
| *Lead* | *Pb* | *200* |
| *Molybdenum* | *Mo* | *100* |
| *Chromium* | *Cr* | *200* |
| *Cobalt* | *Co* | *200* |
| *Barium* | *Ba* | *500* |
| *Nickel* | *Ni* | *200* |
| Copper | Cu | 200 |
| Zinc | Zn | 200 |
| Boron | B | - |

## 3.8.2 Other inorganic pollutants

Ammonia, nitrates and phosphate all promote the growth of algal species in streams and rivers. This places a higher Bio Oxygen Demand (BOD) on the ecosystem when metabolism of dead tissue occurs. Also, nitrate reducing bacteria can produce nitrite which is subject to more research and is implicated in health problem in babies.

Table 3.8: Inorganic pollutant in groundwater *(Charbeneau, 2006)*

| ***Metal*** | ***Symbols*** | ***µg/l*** |
|---|---|---|
| *Ammonia* | $NH_4$ | *3000* |
| *Nitrate* | $NO_3$ | - |
| *Fluoride (total)* | *F* | *4000* |
| *Cyanide (total)* | *CN* | *200* |
| *Sulphur (total)* | *S* | *300* |
| *Bromine (total)* | *Br* | *2000* |
| *Phosphate* | $PO_4$ | *700* |

Cyanide is easily oxidised to Cyanate, which is relatively benign. Sulphur can be present in the form of sulphide, which is very toxic, or sulphate (which can be reduced to sulphide by bacteria); Table 3.5 shows inorganic pollutants in ground water (*Jones, et al., 1994).* Obtaining groundwater samples that are representative of in-situ conditions is the key to determining and monitoring liabilities resulting from groundwater contamination. The four principal factors that govern the collection of representative sampling are:

1. Distribution of boreholes both spatially and vertically.
2. Method for drilling Boreholes.
3. Monitoring well design and installation
4. Sampling techniques.

Within industry much can be gained at an early stage that will be relevant to the planning of the site investigation. A desk study can be initiated that will provide an easy "site characterisation" taking into account all available geological, hydrogeological and anthropogenic factors that may affect or control groundwater flow and hence contaminant migration. The main issues that should be addressed within each of the above factors are summarised within a flow chart. The integrity of such data is essential to maintain a correct interpretation and assessment, thereby ensuring that the data is not only defensible but will enable a cost effective clean-up solution to be put in place if necessary.

## 3.9 Summary

Lower Greensand (Woburn Sands) is an important aquifer around Leighton Buzzard; the aquifer productivity is a function of infiltration, permeability, thickness and potential contaminant, and makes the Woburn Sands unit vulnerable to surface pollutants. Although groundwater forms the part of the natural water cycle which is present within underground strata) it is out of vision and too often out of attention.

Surface waters and groundwater are closely integrated in the water cycles and source of pollutant Figure 3.7, unsustainable concepts of groundwater may affect surface flows and ecological habitats, while policies to protect groundwater quality may lead to polluting activities being directed to areas where runoff to surface water is a threat.

The Water Framework Directive suggested that SuDS can help to achieve the goal of WFD as they can use to trap and treat pollutants and reduce river pollution. SuDS applications/ implementation are discussed the Chapter 5. The Sustainable approach to urban drainage is a success because the systems desire to deal with surface runoff at the point of which it occurs and to manage potential pollution at its source. Sustainability can exist in the simple or complex network of the urban drainage system by implementing suitable design techniques to serve a long term viable drainage system.

Groundwater contamination and source protection zone issues need to be addressed as a key issue; the Environment Agency recognises that there are many factors affecting the risk of groundwater contamination at any location and vary according to the type proposed and the vulnerability of the groundwater to pollution from surface. Therefore, in considering the threat in any given situation, there is need to review and discuss statutory measure to protect groundwater, especially where the aquifer has high productivity, thus chapter 4 covers statutory measures and regulations in England and Wales.

# CHAPTER 4 - A REVIEW OF STATUTORY MEASURES TO PROTECT GROUNDWATER

## 4.1 Introduction

Given the importance of groundwater to the overall water supply of England and Wales (section 2.10), it is understandable that statutory controls exist to control these resources. Some of the measures are implemented by water companies and some by government bodies. Therefore the purpose of this chapter is to review statutory measures to protect groundwater, groundwater directives and regulations, and to investigate the suitability of SuDS structures to control groundwater pollutants.

In 1984 (during Margaret Thatcher's government) the privatisation of water companies was originally proposed, however, there was a very strong public reaction, so to help avoid losing the election in 1987, it was abandoned *(CEL, 2012)*. The idea behind the privatisation was to create positive competition to increase standardisation and force down prices. The 1988 Act created new companies, transferred to them all the assets of the existing water authorities and protected them from competition for 25 years (until 2013). In fact, they were given 25 years` monopoly in their allocated area while £5billion pounds of debts from previous water authorities were written off *(CEL, 2012)*.

CEL (Christian Ecology Link, a charity organisation) states that between 1990-1998 pre-tax profits of all the privatised companies rose by an average of 147%, and the water regulatory body was set up by the act to reduce investment by companies. Scotland and Northern Ireland did not go through the privatisation process; therefore Table 4.1 and Table 4.2 cover only England and Wales.

The Water Service Regulatory Authority (WSRA) is the economic regulator of water and sewerage sectors in England and Wales to ensure water companies provide a good quality of water service for household and business consumers, and value for money.

| Table 4.1 : Water/Sewerage companies in England and Wales | | | | |
|---|---|---|---|---|
| No | Name | Approx. Coverage area ($km^2$) | Coverage (%) | Approx. population (million) |
| 1 | Anglian Water | 28,000 | 18.5 | 6 |
| 2 | Northumbrian water | 9,600 | 6.4 | 2.6 |
| 3 | Severn Trent water | 21,000 | 13.9 | 8 |
| 4 | Southern water | 11,000 | 7.3 | 2 |
| 5 | South West water | 11,000 | 7.3 | 1.6 |
| 6 | Thames Water | 13,000 | 8.6 | 13 |
| 7 | United Utilities Water | 14,000 | 9.3 | 7 |
| 8 | Welsh Water | 20,000 | 13.2 | 1.3 |
| 9 | Wessex Water | 9,400 | 6.2 | 1.2 |
| 10 | Yorkshire Water | 14,000 | 9.3 | 4.7 |
| Total | | 151.000 | 100 | 47.4 |

There are currently 34 companies *(WSRA, 2012):*

- 10 regional companies deliver water & sewerage services, Figure 4.1.
- 11 regional companies providing only water service, Figure 4.2 indicates14 companies, Veolia (all considered one), while Hartlepool Water is a branch of Anglian water.
- 6 local companies providing either water or sewerage services.
  (Other companies can apply for new appointments to serve defined areas)
- 7 water supply licensees offering service to large use customers.
  (Other companies can apply for water supply licences, Table 4.3)

Table 4.4 represents umbrella coverage of regional water/ sewerage and water supply companies. Water industry Act 1991, to perform powers and duties; it is an Act of UK parliament to join the representation relating to water supply and waste water services in England and Wales. Resources and environmental system such as groundwater, land and air are under increasing pressure, with sustainable development about understanding the true value of resources. It is also about joining up economic, social and environmental goals. Chapter 7 covers the environmental goals in further detail.

**Table 4.2 : Water companies England and Wales**

| No | Name | Approx. Coverage area (km$^2$) | Coverage (%) | Comment |
|---|---|---|---|---|
| 1 | Bristol Water | 2400 | 11.6 | |
| 2 | Cambridge Water | 1180 | 5.7 | |
| 3 | Cholderton and district Water | 56 | 0.3 | |
| 4 | Essex and Suffolk Water | 1418 | 6.9 | |
| 5 | Dee Valley Water | 989 | 4.8 | |
| 6 | Hartlepool water | 99 | 0.5 | Anglian |
| 7 | Portsmouth Water | 843 | 4.1 | |
| 8 | Sembcorp Bournemouth water | 1034 | 5.0 | |
| 9 | South East Water (Mid Kent) | 5657 | 27.4 | |
| 10 | South Staffordshire Water | 1526 | 7.4 | |
| 11 | Sutton and East Surrey Water | 861 | 4.2 | |

**Table 4.3 : Water supply licensees in England and Wales**

| **No** | **Name of company** |
|---|---|
| 1 | Avon Valley Water Limited |
| 2 | Osprey Water Service Limited |
| 3 | Satec Limited |
| 4 | *Scottish Water Business Stream Limited |
| 5 | Severn Trent Select Limited |
| 6 | United Utilities Water Sales Limited |
| 7 | Yorkshire Water Limited |

*Scottish Water for business customer in Scotland

Government bodies are required to set and control policy and legislation to protect natural resources and rigid adherence to these policies, particularly in connection with minimising pollution risk, may operate counter to the intention to improve infiltration. Table 4.5 shown regulators for water and sewerage policy and standards. The Environment Agency is the statutory body responsible for the protection and management of groundwater resources in England and Wales.

**Table 4.4: Regional water/ sewerage and water supply companies**

| Water and sewerage companies | Water only companies |
|---|---|
| Anglian Water Services Ltd. | Cambridge Water<br>Essex & Suffolk<br>Veolia Water East<br>Three Valleys Water Services PLC (part) |
| Dwr Cymru Cyfyngedig (Welsh Water) | Dee Valley Water (part) |
| Northumbrian Water Ltd | Hartlepool Water |
| Severn Trent Water Ltd | South Staffordshire Water |
| South West Water Services Ltd | None |
| Southern Water Services Ltd | Sembcorp Bournemouth water (part)<br>Veolia Water South East<br>South East Water<br>Portsmouth Water<br>South East Water<br>Sutton & East Surrey Water (part) |
| Thames Water Utilities Ltd | Essex & Suffolk<br>South East Water (part)<br>Sutton & East Surrey Water (part)<br>Three Valleys Water (part) |
| United Utilities Ltd | Dee Valley Water (part) |
| Wessex Water Services Ltd | Sembcorp Bournemouth water (part)<br>Bristol Water<br>Cholderton and District Water Co. |
| Yorkshire Water Services Ltd | None |

Groundwater resource protection measures are covered in this chapter, also describing the impact of urbanisation on groundwater resources; In terms of aquifers and pollutants from paved areas due to urbanisation; the threats to groundwater resources on either quality or quantity and any significant uncertainty related to groundwater and governing bodies' legislations to protect the resources.

**Table 4.5: Water and sewerage sector regulators**

| Name | Roles |
|---|---|
| Department for environment, Food and Ruler Affairs (Defra) | Sets the overall water and sewerage policy framework in England |
| Welsh Assembly Government | Sets the overall water and sewerage policy framework in Wales |
| European Union | Sets European water, Wastewater and environmental standard |
| OfWat (formerly known As Director General of Water Services) | Regulate economy of water and Sewerage sectors. |
| Environment Agency | Regulate water and sewerage sectors, EA is principal advisor to the government on the environment and leading public body protecting and improving the environment in England and Wales |
| Drinking water inspectorate | Regulate drinking water quality to meet standards in England and Wales. |
| Consumer Council of Water | Represent consumers within the water and sewerage sectors, investigate consumer complaints. |
| Competition commission | To monitor healthy competition between companies, customers and economy, also the bodies for appeal for dispute between Ofwat and water companies. |
| Natural England | Government advisor on the natural environment, provides practical advice, grounded in Science to safeguard natural wealth for the benefit of everyone. |

Figure 4.1: Indicative coverage area of Water/Sewerage companies in England and Wales (Water UK, 2007)

Figure 4.2: Indicative coverage area of Water Supply only companies in England and Wales (Water UK, 2009)

## 4.2 Groundwater protection

Groundwater forms part of the natural water cycle which is present within underground strata (aquifers) that are out of sight from the general public. The volume of water stored in the pores and fracture of the strata vastly exceeds the volume of fresh surface water *(Groundwater Forum, 1995)*. Groundwater has a substantial strategic significance in public water supply; it has provided 30-35 % of present demand and some areas are the only available future resource. It also provides supply for private abstractor, who cannot obtain or prefer not to use water from the public main. Groundwater provides about 33% of the water abstracted for public supplies in England and Wales, 11% in Northern Ireland and 3% in Scotland *(Groundwater Forum, 1995)*.

Quantity and quality of groundwater must be preserved by proper management *(Environment Agency, 2013)*. This is a difficult task. There is a problem of space because, unlike rivers which flow in defined channels, in many parts of the country`s groundwater is present everywhere beneath our feet, at risk from human activities. There is also a problem of time, because due to very slow movement of groundwater through the strata, effects can take a long time to manifest themselves. Groundwater is particularly at risk from distributed and diffuse sources of pollution which accumulate over many years.

Cleaning up of groundwater may be virtually impossible even when the source of the problem is removed. The protection of groundwater quality and yield is therefore of principal concern *(Binnie, 1991)*. Pollution can occur either as discrete, point source(such as from the land filling of waste) or from the wider, more diffuse use of chemicals, such as application to land of fertilizers and pesticides, as discussed in chapter 3 from highway drainage systems. Through mineral extraction and changes in land use, humans can also affect the future availability of ground water resources, by restricting recharge and diverting flow *(Canter & Knox, 1985)*.

Groundwater should be protected to maintain water supply from aquifers. It naturally feeds surface water through springs and by base flow to rivers. Its presence is often important in supporting wetlands and their ecosystem. Removal or diverting of ground water can affect the level of the total river flow. A reduction in either the quantity or the quality of the contributing groundwater can significantly influence surface water and the achievement of water quality standards. Surface water and groundwater are thus intimately linked in the water cycle, with many common issues. The protection of groundwater resources from the effect of human activity is therefore just one part of total protection for the water environment *(Environment Agency, 2008).*

## 4.3 Groundwater Directive

As mentioned earlier the largest available reservoir of fresh water is groundwater. Urbanisation due to increase of population and economic factors from one side solve some of the social and political issues, but on the other hand trigger environmental impacts on natural resources and should be considered very carefully to protect these resources specially groundwater. Identification and description of issues affecting groundwater resources or issues likely to affect them in the future are critical components in the research.

There are a few other issues that can cause threats to groundwater such as pollution and pollutants, source protection zone, vulnerability, sustainable drainage, land remediation, low flows, as well as the environmental impact to be considered. Whether water companies and the Environment Agency overcome these issues or do they still need to review the future impacts; therefore, it is important to understand the groundwater protection polices by water companies and the Environment Agency.

The Council of the European communities (1980) aims to protect groundwater from pollution by controlling discharges and disposals of certain dangerous substances to groundwater. In the UK, the directive is implemented through the Environmental Permitting Regulations (EPR) 2010, EPR 2012 amendment and The Joint Agencies Groundwater Directive Advisory Group (JAGDAG). JAGDAG is there to provide quality assurance for the substance determinations conducted jointly by the Environment Agency, the Scottish Environment Protection Agency

(SEPA) and the Northern Ireland Environment Agency under the Groundwater Daughter Directive (2006).

The existing Groundwater Directive 80/68/EEC is to be repealed by the Water Framework Directive 2000/60/EC in 2013 *(Environment Agency, 2012)*. The purpose of this Directive is to establish a framework for protection of inland surface water, transitional waters, coastal waters and groundwater which:

- Prevents further deterioration and protects and enhances the status of aquatic ecosystems and, with regard to their water needs, terrestrial ecosystems and wetlands directly depending on the aquatic ecosystems.

- Promotes sustainable water use based on a long-term protection of available water resources.

- Aims at enhanced protection and improvement of the aquatic environment, inter alia, through specific measures for the progressive reduction of discharges, emissions and losses of priority substances and the cessation or phasing-out of discharges, emissions and losses of the priority hazardous substances.

- Ensures the progressive reduction of pollution of groundwater and prevents its further pollution.

- Contributes to mitigating the effects of floods and droughts.

Article 17 *(Water Frame Directive, 2000)* is set obvious strategies to prevent and control of pollution in groundwater by the European Parliament and the Council, and measures to achieve objectives of good groundwater chemical status.

## 4.4 Groundwater supply and abstraction

UK Groundwater Forum states that groundwater provides partly public water supply in England and Wales; the majority of groundwater is abstracted in central, eastern and south-eastern England due to the combination of high population and relatively good groundwater productivity aquifers which have been discussed in chapter 3 (Figure 3.5). In total around 2000Mm$^3$ groundwater per year is abstracted; Figure 4.3 represents the percentage of total supply from groundwater and Figure 4.4 represents an annual groundwater abstraction in Million m$^3$. Table 4.6 is a combined interpretation of groundwater supply and abstraction data.

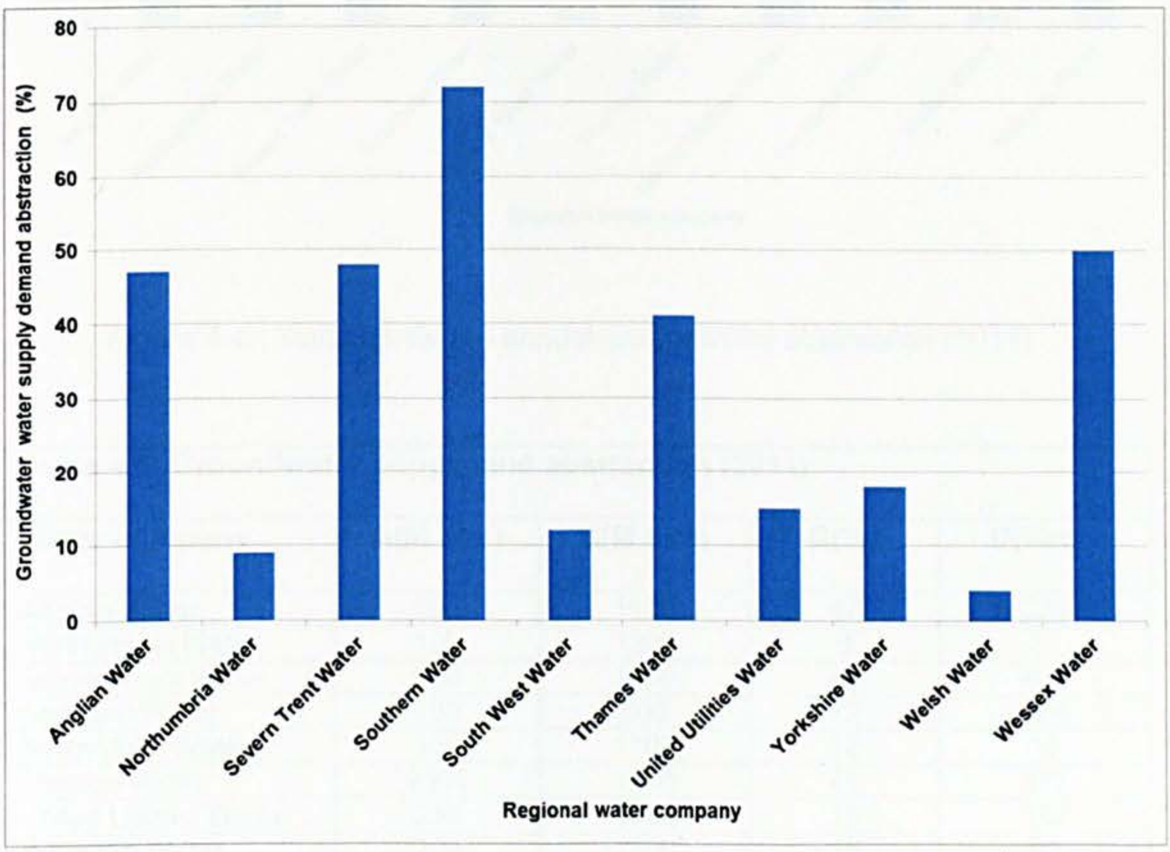


Figure 4.3: Statistics for the use of groundwater in total supply (2011)

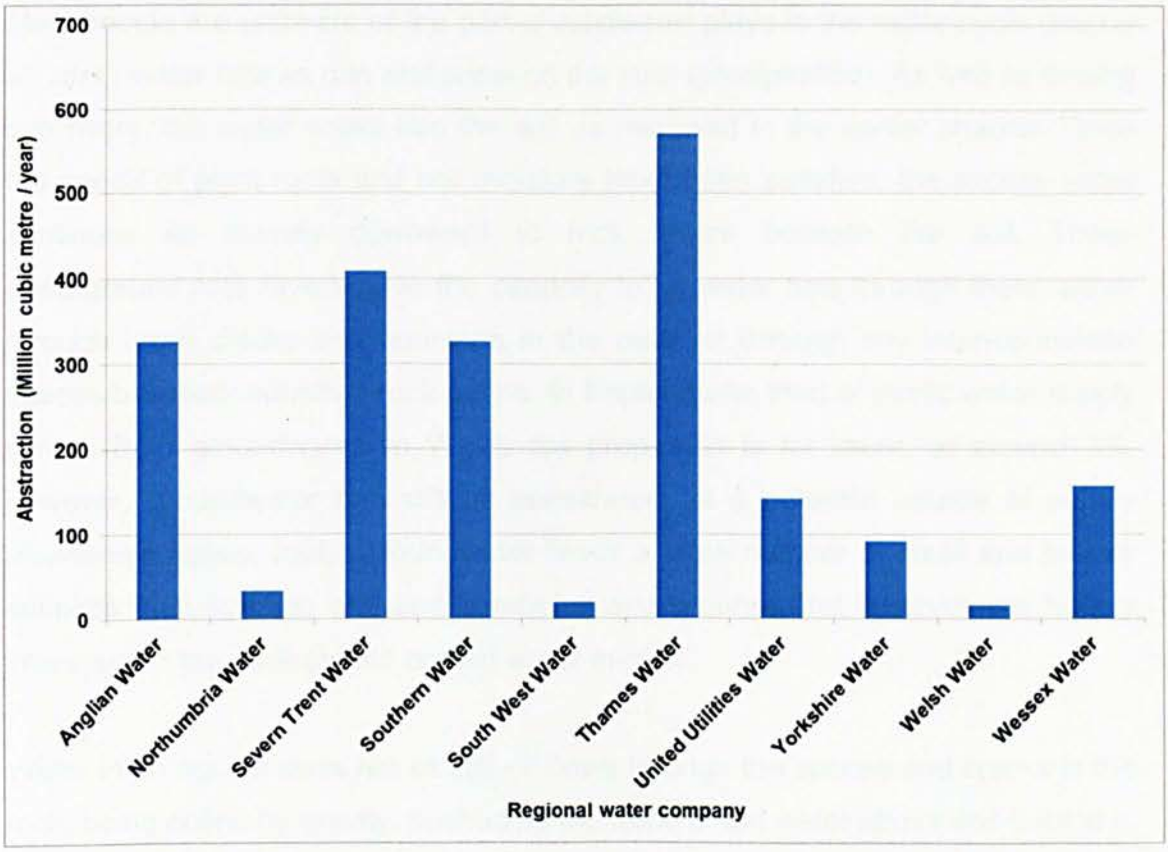


Figure 4.4: Statistics for the annual groundwater abstraction (2011)

**Table 4.6: Groundwater supply and abstraction (2011)**

| Water company | A(M lit/d) | B(M lit/d) | C(%) | D($Mm^3$) |
|---|---|---|---|---|
| Anglian Water | 800 | 1100 | 47 | 326 |
| Northumbria Water | 100 | 1200 | 9 | 33 |
| Severn Trent Water | 900 | 1600 | 48 | 409 |
| Southern Water | 700 | 500 | 72 | 326 |
| South West Water | 100 | 1100 | 12 | 19 |
| Thames Water | 2300 | 1750 | 41 | 572 |
| United Utilities Water | 250 | 1600 | 15 | 142 |
| Yorkshire Water | 200 | 1800 | 18 | 92 |
| Welsh Water | 100 | 2300 | 4 | 16 |
| Wessex Water | 600 | 500 | 50 | 158 |
| Total | 6050 | 13450 | 31.6 | 2093 |

A: Groundwater abstraction
B: Surface water
C: Groundwater supply demand abstraction
D: Annual groundwater abstraction

Most people are unaware of the part groundwater plays in the water cycle *(Shah et al., 2011)*; water falls as rain and snow on the land (precipitation). As well as flowing into rivers, the water soaks into the soil as reviewed in the earlier chapter. Once the needs of plant roots and soil moisture have been satisfied, the excess water continues its journey downward to rock layers beneath the soil. These underground rock layers have the capacity to let water flow through them, either through large cracks and openings in the rock, or through tiny inter-connected spaces between individual rock grains. In England one third of public water supply comes from groundwater. In Wales the proportion is far lower, at around 3%, however, groundwater can still be considered as a potential source of supply *(Environment Agency, 2006)*. Groundwater feeds a large number of small and private supplies from springs, well and boreholes and groundwater reserves are hugely important to the ecology and bottled water market.

Water in an aquifer does not sit still - it flows through the spaces and cracks in the rock, being pulled by gravity; pushed by the force of the water above and behind it. The water moves from an area where water enters the aquifer (the recharge zone) to an area where water exits the aquifer (the discharge zone).

The average annual recharge to the main aquifer is about 7000Mm$^3$ in England, and abstracting at a rate of nearly 7Mm$^3$ per day *(Environment Agency, 2006)*. Figure 4.5 indicates groundwater replenishment and abstraction.

The main aquifers in England and Wales are the Chalk in the south and east of England, sandstone in the west of England and Wales, and limestone. Water flows through cracks and pores in the rock and the flow speed varies with geology and depth. Figure 4.6 indicates the main aquifers in England and Wales.

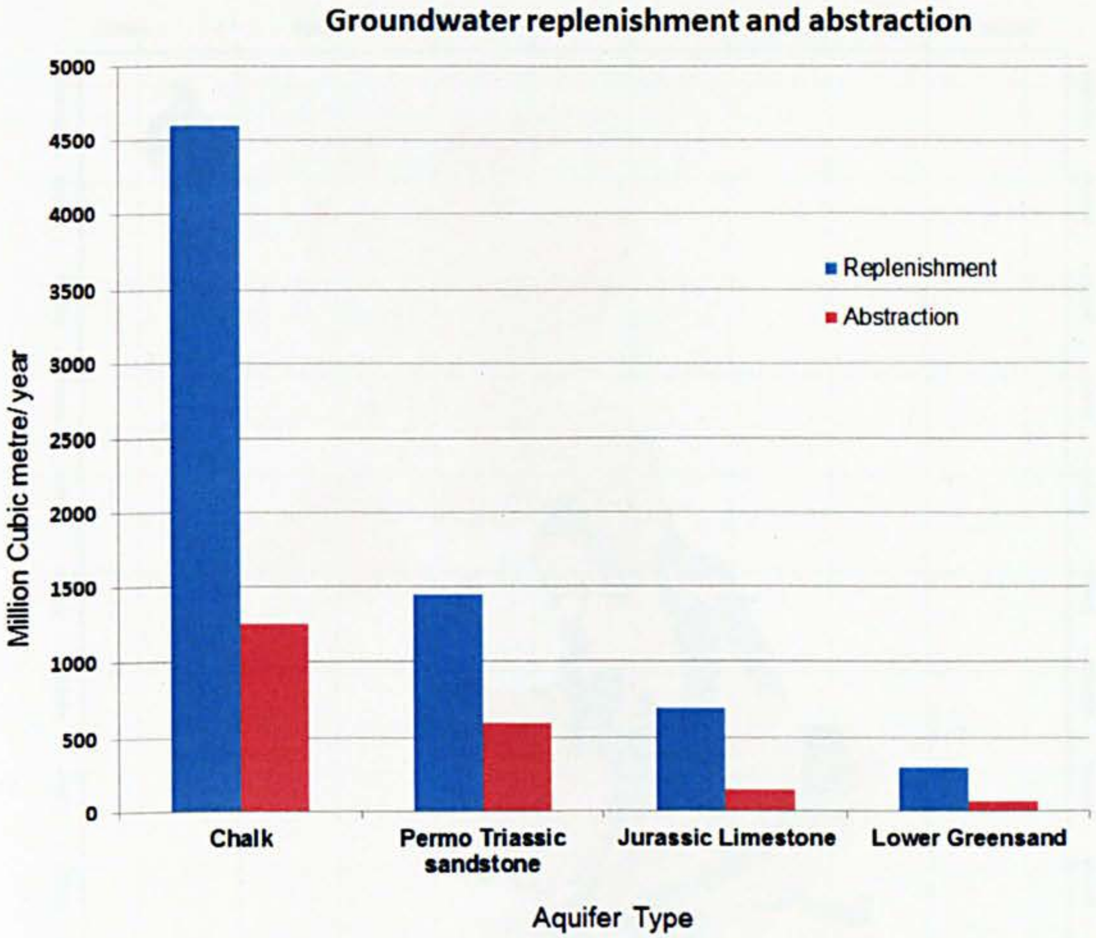


Figure 4.5 Groundwater replenishment and abstraction in England and Wales *(Environment Agency, 2013).*

Where discharge happens, springs may appear, and the aquifer will contribute groundwater to support the flow of rivers and maintain important habitats like fens and marshlands. The movement of groundwater through the aquifer has the effect of removing a lot of impurities from the water, filtering it through the rock so that groundwater is generally much cleaner than surface water. As groundwater is generally very clean it often requires little or no treatment before being used. The level of treatment depends on what it is to be used for. This makes groundwater a very cheap source of 'raw water' for public supply and fresh water can be accessed by drilling down into the water-bearing rock layers and pumping the water out *(Karamouz et al., 2011).*

Figure 4.6: Principle Aquifer on the occurrence of groundwater in England and Wales, Rocks data (BGS, 2012)

Aquifers close to, or outcropping at, the ground surface are more vulnerable to pollution or physical damage that could harm both the quality and flow of the groundwater. The flow of groundwater is slower than surface water, and the deeper into an aquifer the water is, the slower it moves. This means that if groundwater becomes polluted and the pollution moves deep into the aquifer, the water can potentially remain polluted for a very long time. This could subsequently lead to deterioration in the quality of drinking water supplied from a groundwater source or damage vulnerable groundwater dependent rivers and ecosystems *(Environment Agency, 2008).*

Water flows through cracks and pores in the rock and the flow speed varies with geology and depth. Groundwater samples can contain a mixture of water of different ages. Water that stays near the top of an aquifer might only be underground for a month, but some of the deepest water is thought to be millions of years old. Water in the Chalk in the south east of England can be 20,000 years old, originally falling as rain towards the end of the last Ice Age *(Downing, 1998).*

The unsaturated soils and rock above groundwater can protect it from pollution. They often act as a filter, sieving out harmful chemicals and bacteria. But in some places groundwater is closer to the surface, so some contaminants do get through. Natural processes that help clean up groundwater, which take days or weeks in rivers and lakes, can take decades or centuries in groundwater. This is partly because water and pollutant flow is so slow, but also because microbial decay processes are slowed down by a lack of oxygen and nutrients, and low temperatures *(Environment Agency, 2008).*

## 4.5 European Economic Community Policy and sampled other countries

In December 1979 the European Commission introduced a Groundwater Directive (80/68/EEC) which was aimed largely at the control of discharges of specified substances to groundwater. The impact of the directive has been limited. Only a restricted range of substances is controlled. It does not address either diffuse pollution or the essential link to management of abstraction and it does not establish a comprehensive system for the monitoring of groundwater *(Environment Agency, 2008).*

In 2013 the existing Groundwater Directive (80/68/EEC) will be replaced by the Water Framework Directive 2000/60/EC, therefore the Environment Agency policies are to reflect Water Framework Directive (2000/60/EC). The European

Water Framework Directive came into force in December 2000 and became part of UK law in December 2003. It helps us to plan and deliver a better water environment focusing on ecology. The Water Framework Directive will help to protect and enhance the quality of *(Environment Agency, 2013)*:

- Surface freshwater
- Groundwater
- Groundwater dependant ecosystem
- Estuaries
- Coastal water out to one mile from low water

Amended Environmental Permitting (England and Wales) Regulations 2012 came into force in April 2012; in these regulations, the principal regulations are the Environmental Permitting (England and Wales) Regulations 2010. AEPR-2012 amends the Environmental Permitting (England and Wales) Regulations 2010 and other legislation. Reduces regulatory requirements for some anaerobic digestion installations, mobile plant, and for burning waste-derived fuel that has ceased to be waste, makes it easier to transfer permits in certain situations, and makes minor amendments to certain exempt waste operations and radioactive substances activities.

A patchwork of federal and state legislation impacts efforts to protect groundwater resources within the United States. Where a patchwork of federal legislation fails to adequately tackle threats to this important resource *(Thomas, 2009)*. There are regulatory programs that study soil and groundwater, but there are no regulatory mechanisms at the state level to prevent a property owner from discharging pollutants directly into the ground *(Frampton, 2000)*. Without a clear jurisdictional reach, the Clean Water Act (CWA) cannot provide effective regulation of groundwater pollution. In addition, it must also be remembered that the CWA focuses primarily on point sources. The European Groundwater Directive provides a simple framework to achieve comprehensive protection of groundwater resources. While federal legislation could not be quite as comprehensive, because of constitutional limitations on Congressional powers, the Groundwater Directive's "federal" approach could easily be applied to the United States *(William, 2006)*.

The four most significant federal Acts are:

1. The Clean Water Act (CWA);
2. The Safe Drinking Water Act (SDWA);
3. The Comprehensive Environmental Response, Compensation and Liability Act (CERCLA);
4. The Resource Conservation Recovery Act (RCRA).

The above Acts are implemented by the US Environmental protection agency (EPA) was formed in 1972. The EPA was designed to serve as an "umbrella agency" through which most federal environmental laws, regulations, and policies would be administered.

Despite this significant body of legislation which attempts to address elements of groundwater pollution, federal protection of groundwater resources is neither adequate nor comprehensive. Thomas (2009) carried out a comprehensive research and published an article recommending similar provision of the 2006 European groundwater Directive or European framework could or should be imported to the USA.

India has a well-developed regulatory framework supported by strong institutions and qualified staff. However, the magnitude of the challenges is still great:

1. The exploitation of groundwater is unsustainable and there is already a noticeable reduction in the resource
2. Pollution is deteriorating groundwater quality
3. Groundwater resources are subject to geogenic constraints
4. Enforcement of legislation against pollution and over-extraction is weak
5. Monitoring does not support planning and control in groundwater management sufficiently

There is evidence of a strong drive towards improving groundwater management in India, addressing issues in an integrated way. The concern for the sustainability of urban areas and the subsistence of rural populations prompts review of legislation and enforcement and land and water rights *(Rao et al., 2011).*

Based upon an analysis of the current status of groundwater protection in India, it is suggested to develop an Indian version of the groundwater management model applied in the European Union with the Groundwater Directive. The aim is to assist enforcement of Indian legislation against overexploitation and pollution of groundwater and thus to enhance access to clean groundwater for drinking, sanitation and irrigation for rural India.

In Europe, each country has its own Environmental Protection agency to implement and monitor groundwater protection according to Directive (2006/118/EC) and implement EU environmental policies, for example in Germany the agency is called Umwelt Bundes Amt. Water Framework Directive 2000/60/EC entered into force on 22 December 2000 in Germany. Its publication in the Official Journal marked the beginning of an integrated water protection policy in Europe, establishing the coordinated management of water bodies within river basin districts that transcends national and regional boundaries *(EUGRIS, 2013).*

Water Framework Directive 2000/60/EC moved into French law by the Water Law of April 21, 2004 to reach a better balance between water resources and needs from a perspective of sustainable development of economic activities. A new Water Law came into effect on December 31, 2006 to transpose the EU Water Framework Directive *(EUGRIS, 2013)*

During the last decade, the regulatory system of the Spanish groundwater sector has experienced several changes, mainly due to the approval and transposition of the Water Framework Directive (2000/60/EC). WFD (2000/60/EC) transposed in to Spanish law in 2003 and the associated incentive for the protection of groundwater. The Water Framework Directive (2006/118/EC) transposed in 2008 in terms of planning. The WFD involves cleaning of basic groundwater management unit from hydrogeological unit into groundwater bodies *(Stefano & Llamas, 2013).*

In general most European member estates are currently used the European Union Water Framework Directive (2006/118/EC).

## 4.6 Groundwater Regulations 2009 (SI 2009 No.2902)

The Groundwater (England and Wales) Regulations 2009 (SI 2009 No. 2902) came into force on 30 October 2009, replacing the Groundwater Regulations 1998. New regulations were necessary to implement the Water Framework Directive 2000/60/EC and its daughter Directive 2006/118/EC on the protection of groundwater against pollution and deterioration. These apply to those who handle, store or dispose of hazardous substances, such as Agrochemicals, hydrocarbons and solvents, where these are likely to enter the land and contaminate groundwater.

The system for regulating discharges to groundwater has not greatly changed. It is an offence to discharge hazardous substances or non-hazardous pollutants onto or into land without a permit from the Environment Agency (unless an exemption or exclusion has been agreed). Activities which already have an environmental permit under the Environmental Permitting (England and Wales) Regulations 2010, or discharge consent under the Water Resources Act 1991, does not require an additional permit for groundwater.

The main difference between the sets of regulations is the introduction of a new list of hazardous substances to replace the old "List 1" or "black list". For the first time, radioactive substances are classified as hazardous and are subject to the regulations, as well as to existing controls under the Radioactive Substances Act 1993. Groundwater permit conditions will seek to ensure that hazardous substances are kept out of groundwater. The old "Grey List"or "List 2" has also disappeared and instead there is a new category of "non-hazardous pollutants" defined as "any pollutant other than a hazardous substance". The permit conditions will seek to limit discharges of these pollutants.

The Environment Agency delivers a service to its customers with the emphasis on authority and accountability at the most local level possible. It aims to be cost effective and efficient and to offer the best service and value for money. Figure 4.1 indicates national bodies for water supply and sewerage overall policies. Anglian Water covers the largest geographical area of England and Wales for water supply and sewerage services among ten other national bodies, Anglian Water covers **21%** of England and Wales geographical area for sewerage, although a few other water supply companies are within the area such as Cambridge Water, Essex & Suffolk Water, Veolia Water Central and Veolia Water East to provide Water supply only service to the customer. Figure 4.2 indicates the location of water supply companies around England and Wales. Groundwater abstraction by Anglian water is **16%** of total groundwater; 2.4Mm$^3$ per year *(Environment Agency 2006).*

The location of Leighton Buzzard (492500, 225500) is within the coverage area of Anglian Water for water supply and sewerage and the only water authority which has published a sustainable drainage system (SuDS) adoption manual since 2011. Under section 3.0 (The Anglian Water SuDS Adoption Process), it is recognised that SuDS Approval will be given to local authorities as part of the Flood and Water Management Act 2010, however, this guide can be used until the procedures are set out in more detail. Further detail states that Anglian Water will consider adoption and maintenance of SuDS in open spaces *(Anglian Water, 2011).* Source protection is the prime objective of the Environment Agency to protect groundwater and is covered in the next section in detail.

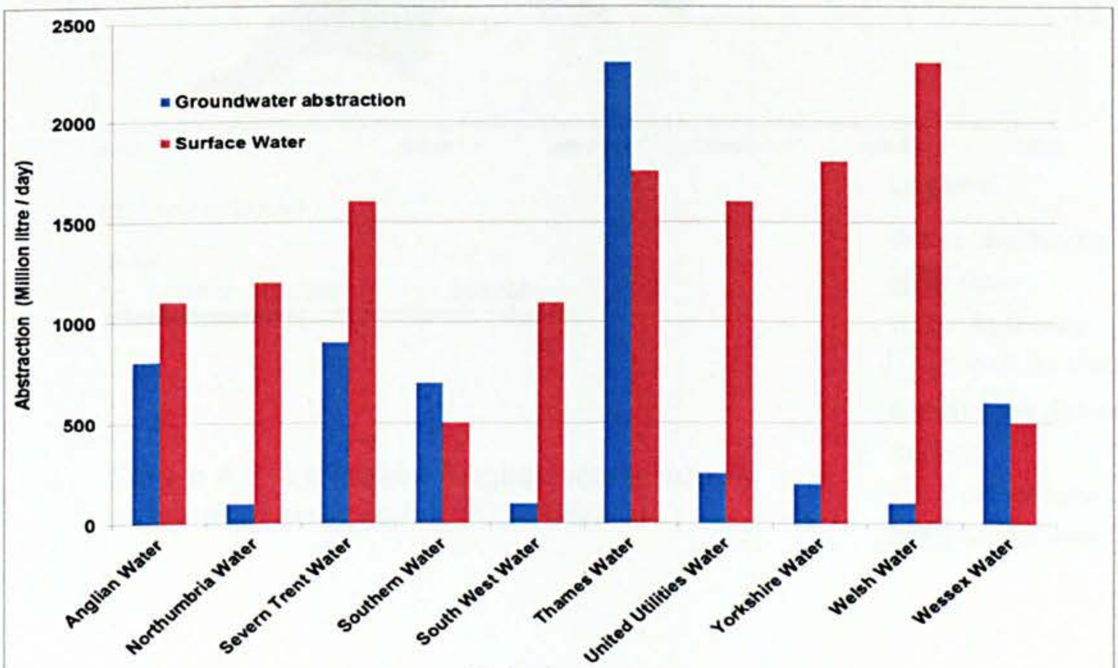


Figure 4.7: Water company groundwater and surface water data *(Environment Agency, 2006)*

Figure 4.8: Indicative Anglian water supply catchment sources (LED053/06/2011)

## 4.7 Definition of source protection zones

The proximity of an activity to a groundwater abstraction is one of the most important factors in assessing the risk to an existing groundwater source. All sources, including springs, wells and boreholes, are liable to contamination and need to be protected.

Four groundwater source protection zones are recognised *(Environment Agency, 2013):*

| | |
|---|---|
| Zone - 1: | (Inner source protection zone) |
| Zone - 2: | (Outer source protection zone) |
| Zone - 3: | (Source catchments protection zone) |
| Zone - 4: | (Former zone of special interest) |

The orientation, shape and size of the zones are determined by the hydrogeological characteristics of the strata and the direction of ground water flow and travel time of the flow. The total number of ground water abstractions in England and Wales is estimated to be in excess of 100,000. There are nearly 2000 major public supply sources and a larger number of licensed private sources. The remainders are unlicensed sources used for private domestic water supply *(Environment Agency, 2006).*

### 4.7.1 Zone - 1 (Inner source protection zone)

Zone -1 is designed to protect against the effects of human activity which might have an immediate effect upon the source. The area is defined by a 50 day travel time from any point below the water table to the source and as a minimum of 50m radius from the source. This 50 day travel time zone is based on the time it takes for biological contaminants to decay. It is an established standard used in many other countries *(Environment Agency, 2013).*

The zone is not usually defined where the aquifer is confined beneath substantial and continuous covering strata of very low permeability since in such case the cover will prevent infiltration. There must be no risk of short circuiting, such as by a solution feature. In situations where there is a deep and saturated zone or thick drift cover, the attenuation properties of the strata or the time of travel to the water table may be sufficient to prevent contamination from minor hazards. However, due to the uncertainties of unsaturated flow (for example the presence of fissuring) this has not been taken into account in defining the limits of zone -1. The land immediately adjacent to the source and controlled by the operators on the source is included within this zone.

Operating procedures designed to minimise pollution should be in force. The lack of good housekeeping by the source owner / operators is one of the most common sources of pollution to ground water. The agency has set out best practice which source owners should apply in this operational area.

### 4.7.2 Zone - 2 (outer source protection zone)

Zone -2 is larger than the zone-1 and is the area defined by a 400 day travel time from any point below the water table to the source. The travel time is based upon the requirement to provide delay and attenuation of a slowly degrading pollutant. It is necessary to further define the outer source protection source in a high storage aquifer such as sand stone to the larger of either the 400 day travel isochron or the recharge catchment area, calculated using 25 percent of the long term abstraction rate (usually the licensed rate) for the source. This will ensure and make adequate zone 2 in all situations. This zone is not generally defined for confined aquifers *(Environment Agency, 2012).*

### 4.7.3 Zone - 3 (source catchments protection zone)

This zone covers the complete catchment area of a ground water source. All ground water within it will eventually discharge to the source. It is defined as an area needed to support an abstraction from long term annual groundwater recharge (effective rainfall). For wells and boreholes the area will be defined on the authorised abstraction rate whilst, for the springs, it will be defined by the best known value of average annual total discharge. In areas where the aquifer is confined beneath an impermeable cover, the source catchment may be some distance from the actual abstraction *(Environment Agency, 2012).*

The relationship between the first three zones and the groundwater source is shown in Figure 4.9. The diagram illustrates the difference in the relationship of the zones in four situations. These are abstraction effective porosity chalk aquifers, a high effective porosity Triassic sandstone aquifer, a confined aquifer and a spring. These situations show a range of possible relationships and a necessarily idealised case. In reality, the size, shape and relationship of the zone will vary significantly depending on the soil, the geology, the amount of recharge and volume of water abstracted. It is unlikely that any two abstractions will have the same shape zones but the broad differences indicated in the diagram will still hold true. For example, the catchment area for a given abstraction will be greater if effective rainfall is lesser. The area drawn on by a pumping borehole in an aquifer with relatively low effective porosity or storage, like the chalk, is greater (and the travel time faster) than in an aquifer with higher storage capacity like the Triassic sandstone. This will have the effect that in a sandstone aquifer zone-2 is likely to be significantly smaller than zone-3 whereas in a chalk aquifer the area will be more comparable.

The area of zone - 3 will largely depend on the volume abstracted and the effective rainfall. It will vary from tens to a few thousands of hectares. The shape will be variable as outlined above. The outer edge of zone-3 will be a few kilometres from an average source in the Triassic sandstone but will be significantly greater than this for a large borehole in the chalk situated in the drier eastern part of the country.

### 4.7.4 Zone - 4 (Former zone of special interest)

Zone – 4 has normally represented a surface water catchment which drains into the aquifer feeding the groundwater supply; in the future, this zone will be included into one of the above three zones, whichever is appropriate in the particular case, or will become the safeguard zone *(Environment Agency ,2013)*.

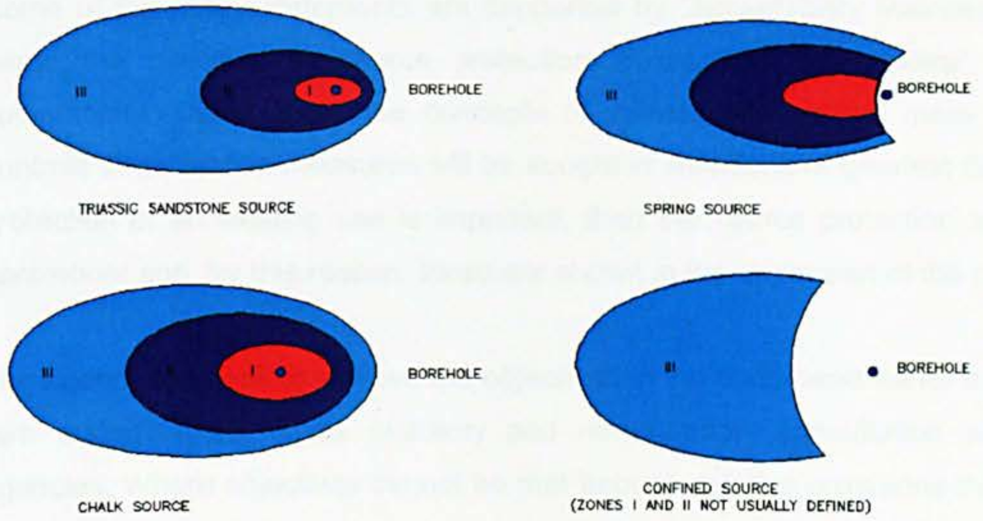


Figure 4.9: Schematic diagrams of the relationships between source protection zones *(Environment Agency, 2008)*.

## 4.8: Groundwater protection policy statements

Groundwater resources, both in quality and yield are put at risk because of a range of human activities. Quality effects can range from specific point sources of potential pollution spreading over a wide area. The yield is affected by physical interference with the aquifer. These activities are controlled to varying degrees by legislation, which is either operated by the agency or by other bodies. They may also be subject to guidelines and codes of practice which will have varying degrees of statutory force *(Environment Agency, 2008)*. The following section sets out the policy objectives of the agency with respect to different types of threat to groundwater resources. The policy statements are divided in to eight of the following categories.

1. Control of groundwater abstractions
2. Physical disturbance of aquifer and groundwater flow
3. Waste disposal to land
4. Land contamination
5. Disposal of liquid effluent, sludge and slurries of land
6. Discharge to underground strata
7. Diffuse pollution of groundwater
8. Additional activities or developments which pose a threat to groundwater quality.

Some of the policy statements are supported by "Acceptability Matrices". These relate the activities to source protection zones and groundwater resource vulnerability. These apply the concepts of vulnerability so that more stringent controls or protection measures will be sought in situations of greatest risk. When protection of an existing use is important, then the source protection zones are paramount and, for this reason, these are shown in the upper part of the matrix.

The agency will seek to achieve the objectives in the statements either through its own authorisations or by statutory and non-statutory consultation with other agencies. Where objectives cannot be met through existing provisions the agency may, in appropriates cases, seek additional powers; for example under section 93 of the Water Resources Act 1991, to establish statutory water protection zones *(Environment Agency, 2008).*

## 4.9 Control of groundwater abstraction

The Environment Agency is responsible for the granting authorisations to abstract groundwater under the Water Resources Act 1991. The grant of new authorisation should not reduce the right of the existing authorised abstractor and abstraction from the groundwater resource should be both sustainable and environmentally acceptable. These powers have existed in their present form since the enactment of the Water Resources Act 1963. In addition the Environment Act 1995 places a duty on the Agency to take action to conserve, redistribute or otherwise augment water resources and secure their proper use. Within the scope of a policy for groundwater protection the agency must ensure that abstractions are managed to prevent *(Environment Agency, 2008):*

1. The loss of further water resources by over abstraction.
2. Damage to environmental features which are dependent upon the presence or level of the groundwater table, including the unacceptable depletion of river base flows.
3. The deterioration of groundwater quality.

The Environment Agency will only authorise abstractions of groundwater within the scope of the Water Resources Act 1991 which will ensure that:

A- Total abstraction from any groundwater resource area does not exceed the long- term annual average rate of replenishment.
The agency wishes to ensure that groundwater levels are stable at an acceptable level in the long-term and that groundwater resources are not depleted at the rates that cannot be sustained by recharge.

B- There is, views the Environment Agency, no unacceptable detriment to a watercourse or other environmental feature depending upon groundwater.
The need to preserve groundwater level or groundwater base flows in rivers for general environmental benefit, or to meet minimum acceptable flows or water quality objectives, will often result in practical limit on abstractions being less than long term average rate of replenishment. In some cases the optimum use of water resources may be achieved by artificial support of rivers or wetlands.

C- Any abstraction does not cause a deterioration of groundwater quality through the intrusion of saline or polluted waters.

In the interests of conserving water resources, and to maintain compliance with water quality objectives, the Agency will not authorise abstraction if there is evidence that they will unacceptably introduce saline waters, from either the sea or from natural connate water or water from the existing polluted surface water or groundwater, into an aquifer. Where existing groundwater abstractions conflict with these policy objectives, the agency will not issue any new permanent licence in the relevant groundwater catchments and will take opportunities as they arise for authorised abstraction *(Environment Agency, 2008)*.

## 4.10 Physical Disturbance of Aquifers and Groundwater Flow

The agency has an interest in the range and intensity of activities which physically disturb aquifers and groundwater flow. In some cases there is a consequential effect on springs, stream flow, ponds and wetlands. The agency's powers under the Water Resources Act 1991 are limited to the control of licensable abstractions (Section 32) and to a limited range of other activities which may disturb aquifers and effect groundwater flow under section 30 and 199.

Activities which may affect groundwater and which are not covered by the agency's own powers include:

- All form of groundwater abstraction outside those controlled by abstraction licences.
- Quarrying and gravel extraction above and below the water table whether worked wet, or dry but de-watering.
- Mining.
- Construction of highways, railways, cutting and tunnels.
- Landfill using low permeability materials and any other activities likely to impede groundwater flow.
- Borehole construction (and abandonment).
- Any activity which interconnects separate aquifers.
- Field drainage that intercepts recharge water.

The agency recognises the economic importance of many of these activities. The major raw materials of the minerals industry often come from major aquifers and there are therefore potential conflicts of interest. The agency, in its advice to mineral planning authorities, will have regard to its duties under the Water Resources Act 1991 to conserve and protect water resources and to preserve and, where appropriate, enhance conservation of the water environment *(Environment Agency, 2008) and (Groundwater Forum, 1995).*

The Environment Agency is the statutory body responsible for the protection and management of groundwater in England and Wales. A framework for the agency regulations and management has been published in a set of documents collectively known as Groundwater Protection: Policy and Practice (GP3), describing aims and objectives for groundwater, technical approaches to its management and protection on the basis of applicable legislation.

GP3 has been divided into 4 parts:

| | |
|---|---|
| Part-1 | Overview |
| Part-2 | The Technical Framework |
| Part-3 | The Tools |
| Part-4 | Legislation and polices |

The aim of GP3 to explain the statutory role of the Environment Agency and its power in a consistent and transparent manner, role clarification between the agency and water companies and local government and providing vital background information for the groundwater protection.

Although there is a set of comprehensive policies and practice to protect groundwater quality, groundwater monitoring and groundwater management framework, groundwater stored in aquifers may be depleted by what is sometimes called "mining". This refers to the pumping out of more water than is replenished by recharge. The effects can be reduced river flows, dried up boreholes and damage to the aquifer system. The covering of infiltration areas could reduce the replenishment of aquifers and demand of water due to population growth and urbanisation can be considered as impacts on groundwater quality and quality in England and Wales.

Catchment Abstraction Management Strategy *(Catchment Abstraction Management Strategy, 2005)* is the agency publication to ensure that the water resources are managed sustainable for the future, with due regard for the environment, abstractors and other water user's needs. Chapter 10 covers a GIS model of CAMS around Leighton Buzzard.

## 4.11 Discussion and Conclusion

Is Water Framework Directive legislation driving the environment to protect groundwater and are there environmental gaps in the legislation? Yes, GP3 (Groundwater Protection Policy and Practice) is a framework for the Environment Agency's regulations and management of groundwater in four associated documents that have been discussed in the earlier section; these associated documents provide reference for anyone carrying out an operation or development that could affect groundwater.

National regulation and delivery mechanisms relate to protecting water resources in the water industry under Water Resource Act 1991 set out the responsibility of the Environment Agency of England and Wales in relation to water pollution, resource management and groundwater. The Water Act 2003 by the Environment Agency aims to improve water conservation and protect public health and the environment; this includes significant changes to the water abstraction authorisation with water company drought plans and water resource management plans becoming a statutory requirement.

EU legislation; the Groundwater Daughter Directive *(GDD, 2006)* clarifies certain objectives of the Water Framework Directive relating to prevention and control of groundwater pollution and groundwater quality standards. It will run alongside the Council of the European Communities (1980) until 2013 when the Groundwater Directive will be repealed. The GDD takes a slightly more comprehensive and more risk-based approach to pollution prevention and control than the Groundwater Directive 1980. The transposition of the GDD into law in England & Wales is achieved through groundwater regulation (2009), these powers are implemented in England & Wales through the Environmental Agency permitting regulation (2010) and two directions to the Environment agency from the Secretary of State and National Assembly for Wales; the first direction sets out the principal for classifying groundwater and surface water bodies and the second direction sets out water quality standards and groundwater threshold value.

There might be environmental gaps in legislation and they might be considered very low hazards and may become a risk in future. Therefore, government advisory bodies need to introduce variation to the legislation to close the environmental gaps. Groundwater protection in terms of chemical status is somewhat different from surface water; the assumption in connection to groundwater should generally be that it should not be polluted at all and the level of pollution needs to be checked regularly. Very few standards have been established at European level for particular issues such as nitrates, pesticides and biocides and these must be observed to and comprised to prohibit direct discharge to groundwater. Other chemicals considered as pollutants could be considered at European level to protect groundwater and this could be argued as an environmental gap to the EU groundwater protect legislation.

The quantitative status of groundwater is also important; there is a certain amount of recharge into groundwater each year and it supports the ecosystem. For good management and control, only a portion of overall recharge can be abstracted. Groundwater is sustainable a resource, so water companies should put in plans for supply and abstraction from groundwater resource; therefore, a Sustainable Drainage System (SuDS) can be part of plans to minimise risk of urbanisation to groundwater resources.

# CHAPTER 5 - SUSTAINABLE URBAN DRAINAGE SYSTEM OPTIONS AND DISCUSSION

## 5.1 General

Infiltration of surface water into the aquifer with a scenario that the surface water can be infiltrated by infiltration systems are discussed in Chapter 7. The risk of urbanisation on groundwater resources and the environment is still the main point of the research. Chapter 6 covers the geotechnical properties of Woburn Sands and chapter 7 covers the natural infiltration of storm water through an infiltration system and suitability of SuDS in the Leighton Buzzard area due to high permeability rate of the aquifer, as well as a possible improved design solution for the Pratt's Quarry. The purpose of this chapter is to review the concept of SuDS to investigate suitability, control of pollutants, impact of climate change and the economy of SuDS to find a recommendable response to the research questions.

As discussed earlier, the current approved drainage arrangement for the new development in Pratt's Quarry is a sewer surface network with an outfall to a retention pond with the size of 8-10 ha plan area. By using a combination of the infiltration structures as a whole system, we can achieve the required storage capacity for the pond to control surface runoff as part of the current drainage planning scheme. Also the indicative design model in chapter 6 provides on-site infiltration on a smaller scale and natural recharge mechanism in a controlled approach scheme.

Urbanisation reduces the amount of rainfall that can soak away into the ground and means that it has to be managed to prevent flooding. Traditionally this surface water has been combined with the foul sewerage system. More recent developments have separate surface water sewers that discharge directly to local watercourses. Whilst this has advantages to combined sewers, there are environmental risks if misconnections occur between the two systems.

Protecting groundwater resources and the local environment from possible pollutants through infiltration systems into ground resources and factors affecting stopping the adoption of the SuDS system by adopting bodies (Anglian Water) is covered in this chapter. Pollutant control can be done in different stages through surface runoff quality control processes and the pollutant removal mechanisms are suggested by CIRIA *(Wood-Ballards et al., 2007)* in the SuDS manual.

As towns have spread and density of development has increased, the volume of the surface water that these piped systems must control surface water. Looking forward, the pressure on urban drainage systems will increase both due to further development to meet the needs of our growing population and also as a result of a changing climate. In the future we can expect to see more intense storms in the summer and more prolonged winter storms than currently, potentially meaning a greater risk of current surface water drainage systems being overwhelmed causing flooding.

## 5.2 SuDS definition

Sustainable Urban Drainage System or SuDS is an alternative to conventional piped means of managing surface water, SuDS aims to achieve within urban areas the way rainfall drains in natural systems.

The prime function of SuDS, as with conventional drainage, is to provide effective surface water drainage, ensuring the greatest degree of flood risk protection over the long term both within and downstream of the development and to prevent pollution. However, SuDS approaches can bring wider benefits too;

- Integrating with the landscape design to add amenity for the community as well as bringing biodiversity value.
- Providing environmental protection by treating the quality as well as the quantity of surface water runoff.

Climate change is happening and is largely due to anthropogenic emissions of greenhouse gases *(Hulme and Jenkins, 1998)*. Whilst changes over the next 30-40 years are largely determined by historic emissions of greenhouse gases, present day emissions will impact on the severity of future climate changes (Hulme et al., 2002). In the UK, climate change will lead to hotter, drier summers and warmer wetter winters, with more extreme events *(Hulme et al., 2002).*

There are two key factors determining how human activities change the climate: the rate of emissions of greenhouse gases and other pollutants, and the response of the climate to these emissions. The rate of emissions can be described using a range of scenarios with differing assumptions about the evolution of the world's population, economy, energy technology and lifestyles. The climate system response can then be explored through the use of global and regional climate models *(Hulme et al., 2002).*

This chapter mainly discusses how can we manage surface water runoff and manage floods due to the change of climate as modelled by The Hadley Centre, how can we control pollutant through the surface runoff by SuDS systems and How does SuDS work in the Leighton Buzzard area and future district urbanisation. Before discussing climate change, control of pollution and SuDS application around the Leighton Buzzard, therefore, it is necessary to know about SuDS (can be found in SuDS manuals) and what prevent use of SuDS.

## 5.3 What does prevent the use of SuDS?

Although there are many practical benefits to SuDS and there are a number of "administrative" barriers that have caused problems implementing schemes states by Anglian Water SuDS Manual (*Anglian Water, 2011)* for example;

- Who takes responsibility for SuDS once they are built?
- How can past practices and regulation be changed to facilitate the use of SuDS?
- Who is checking that SuDS proposals are technically robust?
- How should SuDS be regulated over the lifetime of their operation?

Some of these issues are matters of national policy and work is being done at this level. However, we also believe that solutions can be found at a local level through effective joint working between developers, planners, the Environmental Agency and other interested parties such as Drainage Boards.

## 5.4 Climate Change and SuDS

On the basis of resources reviews in climate changes that global temperature has risen because of the concentration greenhouse gases due to from human activities, the UK climate has changed over the past century, the average sea level is rising by about 1mm per year and winter across the UK is getting wetter with heavier rainfall *(UKCIP, 2002).*

Before discussing anything about climate change and its impact, it is better to understand the difference between weather and climate as has generally been accepted by scientists: Weather is the condition of any given day that is what we get and Climate is the total experience of weather over a longer period of time (30 years or more is what we expect). It is impossible to say what the weather will be like on this day next year, but it is possible to describe a typical day based on the experience of many days in a particular month.

An IPCC fourth assessment report in 2007 states that, global sea level rise has been accelerated between mid-19th century and mid-20th century and now is about 3mm per year and the global average temperature has risen by nearly 0.8°C since the late 19th century and is rising about 0.2°C per decade over past 25 years. The report also observed trends in the UK; Table 5.1 presents a summarised trend in the UK.

| Table 5.1: Observed trends for the UK climate | |
|---|---|
| Temperature | Central England temperature has risen by a degree Celsius since 1970s and less than a degree Celsius in the Scotland |
| Precipitation | All regions of the UK experienced heavy rain fall event over the past 45 years |
| Sea surface temperature | Sea surface temperature around the UK coasts have risen over the past three decade by 0.7°C |
| Sea Level | Sea level around the UK rose by 1mm/year in 20th century and the rate for 1990s to 2000s has been higher than this |
| Average annual precipitation | Increased of annual average precipitation in all UK region between 1960 – 2006 up to 30% |
| Relative humidity | Average annual and seasonal relative humidity decreased by 5% |

The UK Climate Impacts Program (UKCIP), suggests that a number of studies have been undertaken to help and understand how the UK will be affected by climate changes and these studies have been funded by the Department for Environment, Food and Rural Affairs (defra) over ten years. The UKCIP02 report presented a set of scenarios about how climate change may affect the UK climate over the next 100 years. On the basis of UKCIP scenarios and research carried out in the past, summarising the change of climate and using the results for rainfall prediction to find out the impact of Climate changes on urbanisation, groundwater resource and SuDS application in Leighton Buzzard district.

UKCIP scenarios were labelled on the following emissions range to concentrate on global action to tackle its causes by reducing emission of greenhouse gases and UK commitment to meet Kyoto target (reduction of 12.5% greenhouse emission by 2012 and cutting CO2 emission 20% by 2010):

1. Low Emission
2. Medium- Low emission

3. Medium- High emission
4. High emission

UKCIP02 report replaced UKCIP98 scenarios in more detail about geographical variation across the UK and changes of the extremes weather and sea levels using climate models from Hadley Centre (one of the most comprehensive validated climate models in the world).

Climate change prediction and models are not simple. Cases have been studied and researches have been carried out by others. All the results gathered by UKCIP02 form a summarised report which will be used here to find an adaptation response to climate change. The key results from UKCIP02 are summarised here:

- UK climate will become warmer; by 2080s annual temperature averaged across the UK will be between 2°C for the low emission and 3.5°C for the high emissions scenarios.
- Winters will become wetter and summer will become drier everywhere.
- Snow fall decreases across the UK.
- Relative sea level will rise around most of the UK shoreline.
- Heavy winter precipitation (rain and snow) will become more frequent. By the 2080s, winter daily precipitation intensities that are experienced once every two years with an average might become between 5% of the low emission and 20% of the high emission.

The UK Climate Projections (UKCP09) helps organisations to assess how they may be affected by climate changes, so they can be prepared for its impact, UK climate projections are probabilistic; it's slightly different to UNCIP02, in the UKCIP02 for a given location given emission scenario e.g. the UK climate will be warmer by 3.5°C, in high emission as a definitive number. However, in the UK climate projection (UKCP09) for a given location range of changes will be predicted e.g. UK climate will be warmer about 1- 4°C with accumulative probability events and likely ranges. The likely ranges are between 10 - 90%.

The UK Climate change scenarios have produced since 1991 as climate change impact review group (CCIRG91), then CCIRG96. In 1998 UKCIP98 was produced and in 2002 UKCIP02, the final climate change probabilistic scenario being UKCP09.

On the basis of the climate change scenarios and predicted responses above, the climate change should be understood and these responses can be done through mitigation and adaptation processes. Mitigation and Adaptation are two responses to climate change. Mitigation is addressing the cause of climate changes and adaptation deals with consequence of climate changes and was thought that these were alternative, but now scientists see them both as necessary, whatever human do to mitigate climate change to reduce emissions, we will still have some climate change and we will need to cope with it. Therefore, mitigation is reducing human impact on climate and adaptation is reducing the climate's impact on humans, therefore both of them are necessary and running parallel to each other. Figure 5.1 indicates mitigation and adaptation of climate change by the UKCIP.

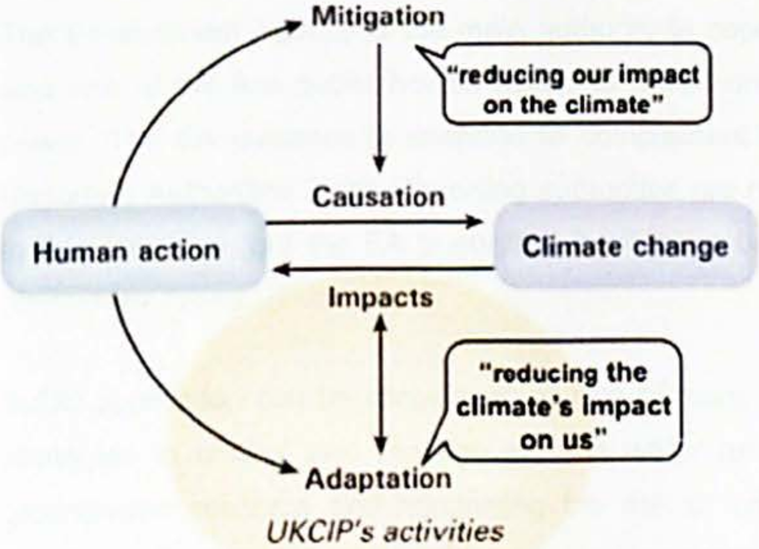


Figure 5.1: Indicative responses to the climate changes *(UKCIP, 2012)*

Few cases have been studied to provide climate change adaptation in action as part of a planned program as a response to a particular event by different sectors. This chapter covers two main aspects of climate change that relate to the SuDS application to reduce risk of urbanisation with increase of annual precipitation and adaptation strategy for the future.

There should be an understanding the questions of why do we need the climate projection and why adaptation is important. Obviously, no one knows how the future will turn out, so we have to plan a necessary strategy. UKCP09 used past observations, an intergovernmental panel on the climate change (IPCC) scenarios and expert judgements to produce scenarios to explore the future climate and the result can be used for the adaptation decisions.

Regarding the importance of adaptation, the climate is changing and in the future humans will experience more extreme conditions than now. For example, more rain in the winter can cause floods, warmer days in the summer can cause drought. Hotter and drier summers will put more pressure on water supply demands and rising sea levels, leading to more coastal flooding and erosion of coastlines.

The Environment Agency is the main authority to cope with climate change and was one of the first public bodies asked to report under the adoption reporting power. The EA guidance is intended to complement the Statutory Guidance to Reporting Authorities 2009. Reporting authorities are not required to have regard to this guidance, but the EA trusts that it will be a useful source of information *(Environment Agency, 2012).*

SuDS application can be considered as one of many climate change adaptation strategies to control and manage surface water runoff as well as recharging groundwater resource and minimising the risk of urbanisation to groundwater resources. Further discussion will be covered in section 7.5.

## 5.5 Control of pollutants and SuDS

Chapter 3 covered the possible pollutants within highways and from development into the surface water networks, or groundwater infiltration system. Chapter 6 covered design alternative under source controls. This section covers source control in SuDS, i.e. the application of techniques close to where rainfall lands. The degree to which SuDS can control pollutants or SuDS carries a risk to groundwater is still under investigation and there is insufficient evidence available to allow safe policy development, although chapter 4 covered the role of the responsible bodies to protect groundwater resources.

On the basis of case studies carried out by others, the risk to groundwater from highway drainage on the soil based SuDS is low. There is evidence of very low rate movement of pollutants downward and the vast majority of the Heavy metal, hydrocarbons and PAHs are retained in the top 70-120mm of soil and the level of pollutants in the pond sediments are higher than in the soil. Dissolved chemicals can reach to the groundwater and it is very difficult to control them in a large scale due to high maintenance and introducing such a filter to remove the dissolved chemicals.

The objective of this section is to determine the risk of pollutant movement through Leighton Buzzard into groundwater and to measure the degradation of pollutants in the form of SuDS application.

Highway drainage pollutant degradation has been studied within two 1.2m depth soakaways and the degradation rate of pollutants for different temperature and moisture content. Change of temperature has a significant impact on degradation of hydrocarbons. With higher temperature the rate of the degradation of hydrocarbons within SuDS is increased. The reduction can be expected to be between 40-50% at 17-20°C in 30 days and between 20-30% at 3-5°C in 30days.

Barrett et. al ( 2004) carried out research of storm water pollutant removal in road side vegetated buffer strips and they concluded that buffer stripes consistently reduced the concentration of suspended solids and total metals in storm water, but the stripes were generally less effective at removing dissolved metal and essentially no change in concentration was observed for nitrogen and phosphorous.

Similar to the above, research was carried out by *(Raskin et al.1997)* on two wet ponds to remove pollutants primarily phosphorous, from storm water runoff. Phosphorous is the pollutant of primary concern to the ecological health of fresh water and it is an essential nutrient required by all biological life. They concluded that detention ponds have become one of more popular SuDS systems by removing some portion of phosphorous carried out with storm water prior to final discharge.

SuDS can reduce pollutants in a variety of ways depending on the type and form of pollutant; wet ponds are suggested as more effective at removing pollutants than dry SuDS system. Some other pollutants such as total suspended solid and particulate phosphorous are basically removed by setting where dissolved pollutants can be removed by chemical or biological means.

## 5.6 Impact of climate change in Leighton Buzzard

The climate is changing and will continue to change over this century and beyond, Leighton Buzzard is located in the East of England according to regional mapping boundaries. The region of the East of England is comprised of Hertfordshire, Bedfordshire, Cambridgeshire, Essex and Norfolk. The area is mainly low lying with diverse landscapes.

Table 5.2: Climate change comment on East of England

| No | Sub Region name | Climate changes impact comments( UNCIP) |
|---|---|---|
| 1 | The Fens | Coastal, fluvial flooding and effect of tem. increase |
| 2 | EoE Northern Heartland | Less impact on coastal, fluvial flooding, but most significant in temperature increase |
| 3 | EoE Southern Heartland | Reduce of soil moisture, deficiencies of water resources due to increase of temperature |
| 4 | The Thames Gateways and Fringes | Water resource deficiencies, sea level rise and risk from subsidence |
| 5 | The coast | Most vulnerable to rises in sea level, strong surges and flooding of coastal habitats |

Impacts of climate change are likely to vary across the region depending on the characteristics of the area and susceptibility of human assets affected. It is difficult to consider climate changes within a particular district; therefore the research for climate change boundaries will cover the East of England region and sub regions. Figure 5.2 shows East of England sub regions. Table 5.2 summarises the impact of climate change to the sub-regions.

Figure 5.2: East of England Sub-Regions *(UKCIP, 2002)*

Figure 5.2 shows the location Leighton Buzzard in relation to the east of England in the sub region of northern Heartland. Although there is less impact on coastal and fluvial, there is a high risk of temperature increase due to aquifer characteristics of sand and chalk. The UKCP09 carried out a climate change projection model on East of England. It shows a temperature increase from 0.5+0.5°C, 1.5+0.5°C to 2+2°C for Low and High emission scenarios for the 2020s, 2050s and 2080s respectively. Figure 5.3 shows the UKCP09 for East of England region.

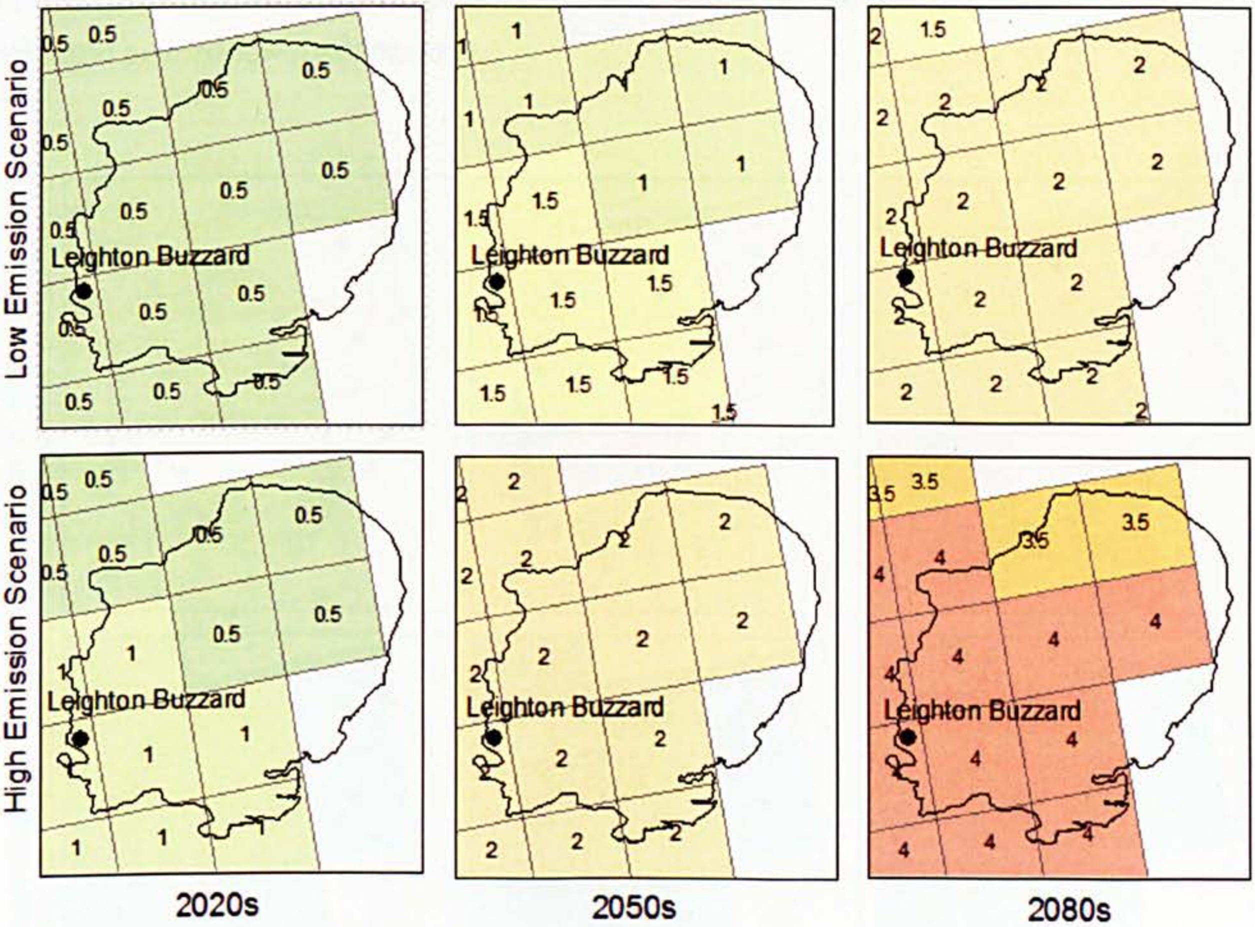


Figure 5.3: Change in annual temperature in degree of Celsius in East of England and surrounding areas *(UKCP09)*

One of the other impacts of climate change relating to SuDS is the change of storm and rainfall events. Change of precipitation could have an adverse impact on the SuDS design and planning requirements in the future around the region in the Leighton Buzzard district. Figure 5.4 indicates the UNCP09 summer and winter predicted changes of precipitation in the East of England and the surrounding areas.

Some basic assumption and common misconception in climate modelling have been noticed and, as UKCP09 states, climate models are based on fundamental physics laws (Newton`s third law of motion) in terms of mathematical equations. They do not as in some prediction events, statistically fit to past observation. Each component of a model is thoroughly tested, often using data from field experiment or dedicated process model representation and model component are subject to scientific peer review *(UKCP09, 2009).*

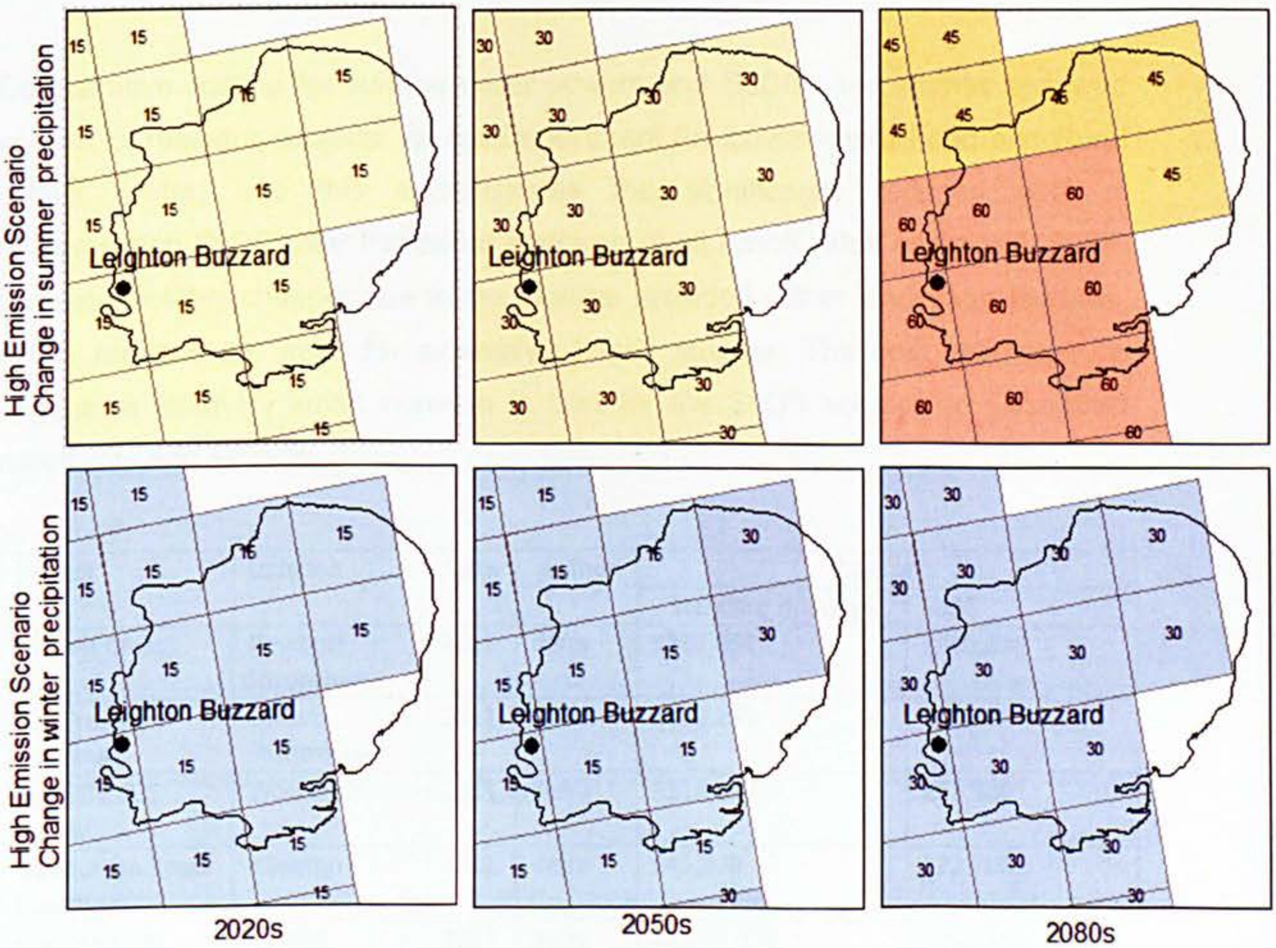


Figure 5.4: Summer and winter predicted change of precipitation in the East of England and surrounding areas *(UKPC09)*

The critical scenarios for change of precipitations are the high emissions scenarios for summer and winter. In low emission scenarios the models indicate up to 15% dryness in summer and up to 15% more precipitation in winter. In Figure 5.4, the change of precipitation in 2080s is up to 60% i.e. more water will be abstracted from groundwater resources to meet water supply demand and in winter up to 30% more rainfall and flood expectation. The next section covers SuDS applications and their demand for water to cope with climate changes predicated scenarios to reduce risk of climate changes and urbanisation to the district and some advisory comment will be considered in future which will contribute to existing design and planning process of SuDS.

## 5.7 SuDS and Standard drainage costing

Comparative costing for surface water sewers and SuDS case studies reviewed as part of research projects for the Department for Environment Food and Rural Affairs (defra) and this demonstrates the significantly reduced cost of implementing SuDS over traditional drainage at all runoff rates examined. SuDS are considerably cheaper due to the storage provided within landscape features, which reduces the need for expensive boxed storage. The cost estimates do suggest a relatively small increase in cost for the SuDS solution to Greenfield runoff rate and storage.

| Project | Location | Date | Author | Cost only | |
|---|---|---|---|---|---|
| | | | | Standard drainage | SuDS |
| Daniels Cross | Newport Shropshire | 2011 | defra | £889,052 | £780,836 |
| Rail Freight Terminal | Telford Shropshire | 2011 | defra | £372,259 | £51,087 |
| Redhill C & E School | Worcester | 2011 | defra | £114,000 | £51,900 |
| Caledonian Road housing | Islington | 2011 | defra | £45,200 | £22,700 |
| Marlborough Road | Telford | 2011 | defra | £1,074,528 | £966,119 |

The evidence available also suggests SuDS solutions have lower maintenance costs than comparable traditional drainage solutions; this is likely to be particularly true where they are surface features which can be easily maintained as part of standard maintenance contract.

A green roof was not included within the cost comparison exercise as, following planning policy in Islington and many other urban areas, this would be required for reasons not relating to SuDS, such as biodiversity, and therefore can be assumed to be included in both drainage scenarios. The SuDS solution also does not rely on a green roof; the cleaning and storage benefits can be provided by other techniques such as permeable paving with additional storage. However the cost of the green roof was estimated as part of this exercise to provide additional information for consideration. The drainage benefits of green roofs have not been fully factored into the equation as a widely accepted runoff coefficient for green roofs is currently not available; however use of green roofs could reduce the storage volume required in both the SUDS and traditional drainage scenarios and therefore may become more cost effective in development terms.

The cost exercise demonstrates the potential for even dense urban sites to incorporate SuDS to meet even the most stringent quantity criteria as well as delivering benefits for biodiversity and amenity. The opportunities for, and associated costs of, achieving a greenfield runoff rate would vary on similar schemes depending on the site characteristics and specifically the availability of open space. Where additional open space was available, it should be possible to provide all the required storage within the landscape without the need for boxes; conversely; where less open space/parking was included on a site, additional box storage may become necessary and therefore the cost would be likely to increase. However, this variation in costs would be balanced to some extent by associated changes in density of a scheme which would alter the cost of the drainage solution per unit.

## 5.8 Discussion

Sustainable development is a fundamental and overarching objective of the European Union; the 2006 EU Sustainable Development Strategy (EU SDS) describes how the EU will most effectively meet the challenge of sustainable development. Originally the term SuDS described the UK approach to sustainable urban drainage systems. These developments may not necessarily be in "urban" areas, and thus the "urban" part of SuDS is now usually dropped to reduce confusion. Other countries have similar approaches in place using a different terminology such as Best management practice for water pollution (BMP) and Low Impact Development (LID) in the USA*(Environmental Protection Agency, 2000)* and water sensitive urban design (WSUD) in Australia *(JSCWSC, 2009)*. However, it describes land planning and engineering design approach to managing storm water runoff.

The prime aim of SuDS is to provide effective surface drainage, ensuring a high degree of flood risk protection for long term and prevention of pollutants to groundwater or other resources. Climate change as predicted by scientists are happening due to greenhouse gas and human activities and, by 2100 there is a suggestion of up to 4.5°C temperature increase around the UK and up to 60% summer and 30% winter precipitation changes.

Leighton Buzzard is located away from the East of England coast and will not be affected by sea level rise or flooding, however, an increase in temperature and change of precipitation events could have future impact on the district and surrounding area.

Currently on-site small SuDS system are designed according to the past hydrological data for 30years events without considering climate changes in summer and winter in future, although for ponds, the Environment Agency suggested 10% capacity increase to cope with climate changes.

A 30% change in winter precipitation by 2080s due to high emission can be managed by an increase in design capacity to manage surface water runoff during storm events. However, 60% change in summer precipitation due to high emission means. That society will experience hot summer weather with no rain, and more water supply demand and groundwater abstraction could damage environmental natural balances.

SuDS applications can be very effective to restore balance to natural resources by putting more than 95% of the surface runoff back in to the ground by simple natural filtration mechanism, but if the planning authorities continue to approve sewer networks for new developments due to demand of urbanisation and population growth than about 50-75% of the surface runoff will be taken away from the site and groundwater refurbishment balance will not happen. Therefore giving SuDS priority to new urban development and removing the conditions that prevent SuDS and thinking of lifetime adoption.

Alternatively, the rise of temperature data has been reviewed since 1845 until 2011 for winter and summer without considering any emission scenarios and probabilistic models. If we consider a linear temperature rise, it shows 0.6°C rise in temperature. If we extend the line linearly until 2080, the temperature rise will be higher 0.45 - 0.5°C in winter (see Figure 5.5). Similarly, Figure 5.6 shows a rising temperature in summer up to 0.8°C and, if we extend the linear line until 2080, it shows higher 0.45-0.5 ° C. It means we can expect a rise in temperature on the basis of past data, but UKCP09 models have considered low and high emission scenarios up to 2-4°C until 2080s on the basis of probability.

Whichever way we may consider the changes of climate, adaptation should be considered for the rise in temperature and the summer/ winter change of precipitation to reduce its impact on groundwater resources and surface runoff management.

The next chapter covers the risk of urbanisation in conjunction with climate changes, adaptation measure and recharge estimation of ground resource to analysis SuDS application and climate change impact on the Leighton Buzzard district.

Climate change is a serious issue with global causes and global consequences, a reality the human race is now beginning to realise as an immediate threat to the continued success of society. Climate change is accepted by the scientific community to be a reality the human race is experiencing now. Yet the public, on both national and international levels, are consistently shown to lack of the individual engagement in tackling the issue despite appearing to be fully aware of it. To overcome the problems involved with engagement, further research is needed on understanding of the scientific terminology, and also on the availability to the public of peer reviewed literature.

Climate change as an important, prevalent issue has existed within the public domain for approximately the last twenty five years. During this time numerous studies have been done on the changing public attitudes towards it. A review of the major studies on public views, undertaken by Lorenzoni and Pidgeon (2006), found European and American opinions to be generally within the same sphere of categorisation and, of key importance to this study, a consensus within the literature that while the public are aware of the climate change issue they do not possess an equivalent level of understanding in regards to the causes of and solutions to climate change. The review also found that the public tend to consider climate change to be less important than other issues, particularly on the social and personal nature. This is further enforced by findings which show the public (in both the UK and USA) perceive the risk of climate change as a "distant threat, of limited personal importance" *(Lorenzoni et al., 2006).* These aspects are shown to apply specifically to the UK public in a defra survey (2001) in which questioned members of the public indicated a belief in climate change being due to human activities, yet offered a view of the causes and impacts which, while more sure than previous surveys, was still indicative of confusion.

The existing literature indicates a distinct difference between individual intentions to engage in mitigation and actual action *(Pidgeon et al., 2008)*. Explaining this discrepancy in greater detail, Lorenzoni et al. (2007) first define engagement as an individual's three elements of the state (of the connection) – being cognitive, affective and behavioural - and show that being aware of the issue is not significant enough to initiate engagement actions; there needs to be careful and motivation as well. The results of that particular study lead to an argument that "targeted and tailored information should be supported by wider structural change". Another important aspect noted in the literature is the difference in reasoning for individual engagement; often it is the case that persons who do engage in activities that can be considered as contributing to the mitigation of climate change do not do so for that purpose, rather they engage for reasons such as financial saving *(Whitmarsh, 2009)*.

From the review of literatures, I can conclude briefly the comparison between authors` findings. Their studies have focused primarily on the transmission of information along a communicative pathway, looking at how it is both transmitted and received in an attempt to locate any potential errors in communication. It has shed valuable light on the issue of public perceptions to global climate change, adding weight to previous studies conducted and providing new pathways for future research.

Of particular importance is the impact the media has upon public perceptions, with the resulting confusion associated with its communication of climate science allowing for a continuous cycle of misrepresentation of the science, the accuracy and truth of the topic being hidden beneath a tangle of media narratives. Media formats, terminology and reliability all play key roles in the process of the public forming a false opinion of its own level of knowledge on the issue. Climate change is shown as an international problem and the public therefore believe responsibility for tackling it lies on an international level, making only small contributions themselves yet believing this to be significant and all they can do.

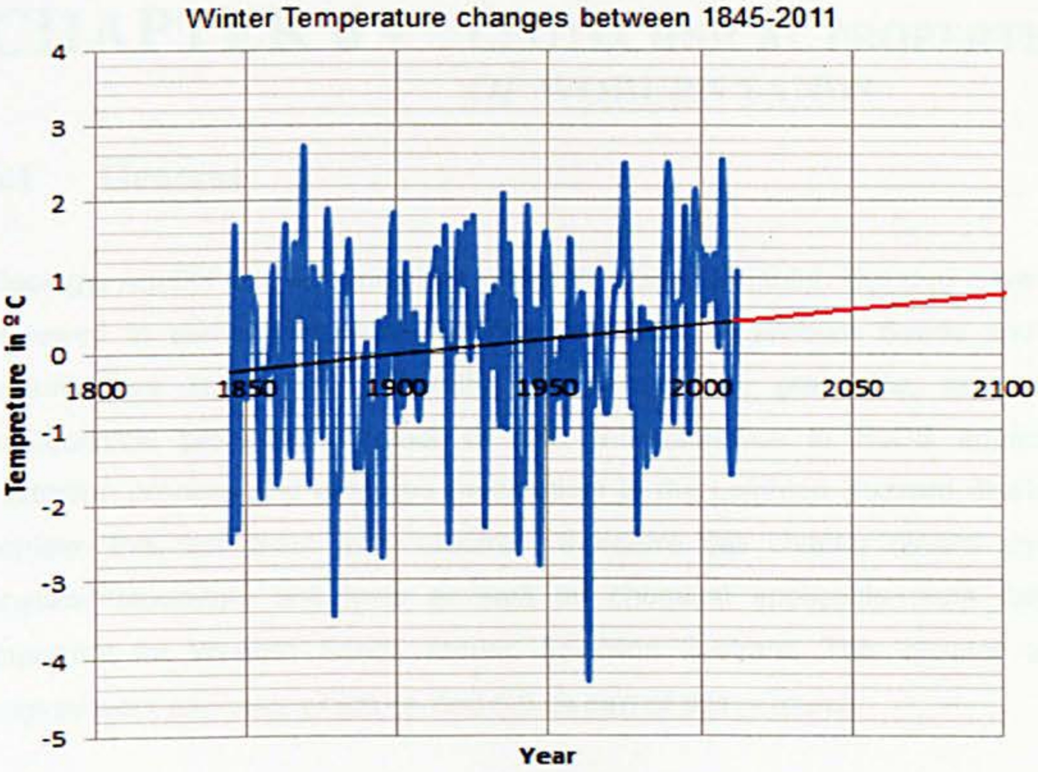


Figure 5.5: Winter temperature changes between 1845 - 2011

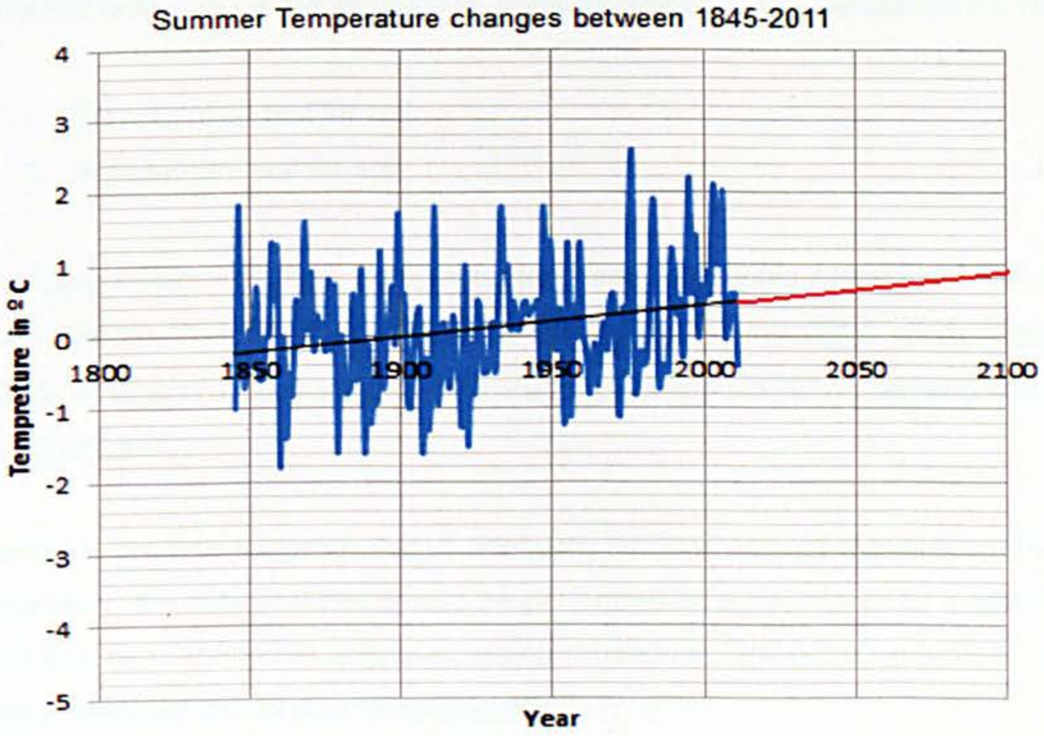


Figure 5.6: Summer temperature changes between 1845 to 2011

# CHAPTER 6 - GEOTECHNICAL PROPERTIES OF WOBURN SANDS

## 6.1 General

Geology, Aquifer and Groundwater pollution around Leighton Buzzard have been reviewed in earlier chapters. The characteristics of Woburn Sands and their textures are important to identify soil parameters, grain-size, grain-shape, geotechnical properties, impact of soil Characteristics to SuDS application, infiltration process and recharge mechanism in the Leighton Buzzard district. To achieve this, soil tests were required; therefore this chapter covers principle physical laboratory soil tests as well as chemical applicable tests that are important for Woburn Sands around Leighton Buzzard. This chapter covers original work and tests which carried out as part of this research.

The soil properties are important to identify the permeability and infiltration rate which usually determined by carrying out tests on samples of soil in a laboratory. Physical tests can be divided into two main categories *(British Standard 1377-2, 1990)*:

1. Classification test for soil
2. Assessment test for soil

The parameters identified from laboratory tests. Analyses carried out for many purposes on Woburn Sands such as grain size, permeability, shear strength, acidity or alkalinity, sulphate content, organic content, carbonate content and total dissolved solid.

Common practice suggests that, if adequate facilities are not available in the soil laboratory, the chemical test should be performed by a chemist or by a technician who has been trained in chemical testing procedure. Soil tests carried out to the British standard soil laboratory testing BS1377.

## 6.2 Advantage of laboratory testing

The determination of soil properties by means of laboratory tests offers a number of advantages:

1. Full control of test condition
2. A greater degree of accuracy
3. Control over choice of material and samples
4. Changes of condition can be simulated

All the tests carried out part of the original works for the research on Leighton Buzzard sand at Kingston University checked with the national geological and geotechnical data and satisfied with the result which was obtained from the laboratory tests in this section.

The following tests carried out by me according to BSI *(British Standard 1377-2, 1990)*:

1. Sand grain size and shapes (physical)
2. Simple dry sieving (physical)
3. Permeability soil test (physical)
4. Chemical test
    - Acidity or alkalinity
    - Sulphate content
    - Organic content
    - Total dissolved solid

## 6.3: Sand grain-size and shape

The behaviour of granular soils is known to be influenced by characteristics of the soil such as particle size, the distribution of particle sizes making up the soil as well as attributes of the particles such as shape, roundness, surface roughness and specific gravity. Soil is made up of a mixture of mineral and organic particles produced by the interaction of wind, water, and organic decay *(Barnes, 2010).* The physical structure of soil at any location is determined by many factors such as type of geologic material from which it originates, vegetation, length of time that the soil has been weathered, topography, and artificial changes caused by human activities. However, the general texture of a soil depends on the proportions of particles of various sizes of which it is composed. Soil particles are divided into sand, silt, clay and colloids *(Barnes, 2010).*

Sediment characteristics can provide information about source materials, the depositional environment and other physical and chemical factors. When rocks are broken down into fragments (small pieces), either through mechanical means of weathering or through chemical reactions, the fragments are called sediments. When those sediments are compacted or cemented together, they form a sedimentary rock. Sediments are either Clastic (mechanical weathering processes such as wind, water and ice) or chemical (containing fossils & rocks that were dissolved in water & transported, then precipitated chemically) *(Boggs, 2010).*

Texture refers to properties of sediment such as particle size and shape, roundness and sorting. Roundness is often a function of distance transported since the edges wear down form cut with other particles *(Boggs, 2010).*

The following Figure 6.1 - 6.4 are microscopic evidence (test carried out at Kingston University, Science Lab) from the Woburn Sands grain size that the sand grains are sub rounded or rounded and confirm that the sands are transported to the area. Geotechnical Engineers and Scientists are interested on sub sampling to characterise the sediment through sieve analysis. The next section covers the sieve analysis procedure and test result in detail.

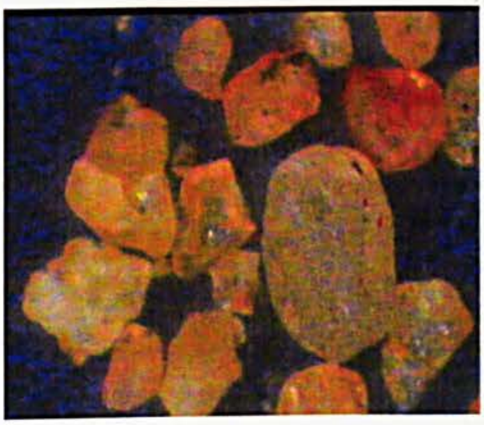


Figure 6.1: Woburn Sands grain shape

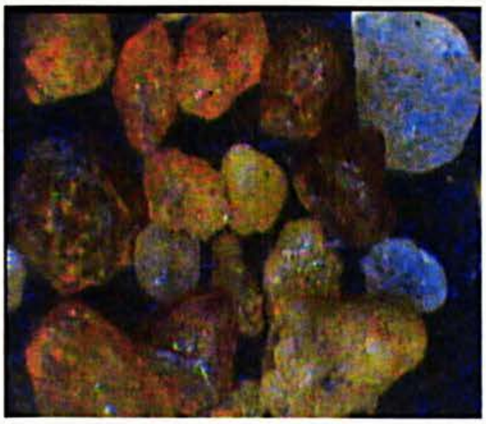


Figure 6.2: Woburn Sands sub rounded grain shape

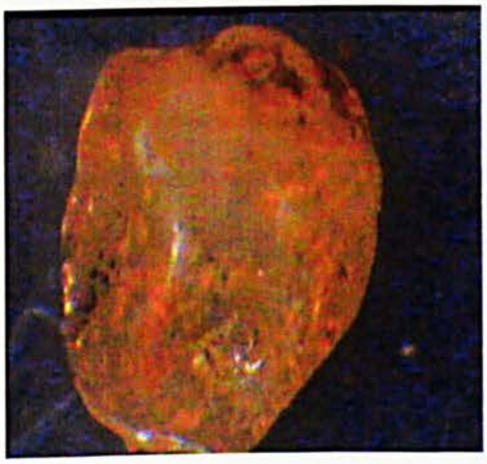


Figure 6.3: Woburn Sand single-rounded grain shape

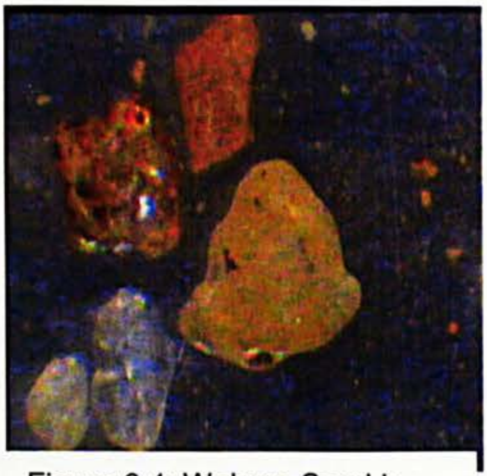


Figure 6.4: Woburn Sand in different colour

The sediments which make up the Woburn Sands are generally **quartz** ($SiO_2$) sands of variable grain size and tend to be ferruginous ( Iron- bearing) and glauconitic (iron, potassium phyllosilicate – mica group) *(British Geology Survey, 1994)*; Woburn Sands are composed of loose, finely grained minerals that are the product of chemical and mechanical decomposition of rocks over long periods of time.

*Mica:* *A shiny silicate mineral with layered structure (from different rocks) and uses in electrical equipment.*

*Feldspar:* *A rock that doesn't contain ore (iron).*

*Magnetite:* *A natural magnet, an oxide of iron or a ferromagnetic mineral ($Fe_3O_4$)*

Leighton Buzzard sand was formed over 100 million years ago during the Cretaceous period. This was the period when the dinosaurs were around and the area was a sea. The waves of the sea made the different sand grain sizes settle into different layers *(British Geology Survey, 1994)*.

Leighton Buzzard sand is SILICA SAND. It has a high content of the mineral silica (90 %+), which makes it hard wearing and durable compared to other types of sand. The sand is dried and then graded (sorted) into grain sizes that are useful to industry. It has a rounded or sub-rounded and consistent grain size and shape making it suitable for certain specialist applications. There are only certain areas in the country where high purity silica sand can be found (Bedfordshire, Surrey and Cheshire). Silica sand from Leighton Buzzard, therefore sells for a much higher price than other more commonly found sand.

Silicon dioxide (**$SiO_2$**) is the most abundant and widely distributed mineral on the surface of the earth. With its unique properties making it the most useful natural substance. It is abundant in *igneous*, *metamorphic* and *sedimentary* rocks, and with high durability to both mechanical and chemical weathering, harness around 7/10 on the Mohs scale, quartz can be found virtually in every colour, (common colours are clear, white, grey, purple, yellow, black, green and red *(Bideaux et al., 1995))*. Silicon dioxide commonly is known as Silica and quartz are crystal form of Silicon dioxide and is used primarily in production of glasses for windows, drinking glasses and also is very important food supplement.

## 6.4 Simple dry sieving (BS1377 part2: 1990.9.3)

The grain size analysis is widely used in the classification of soil. The data obtained from the grain size distribution curve is used for soil properties, permeability; soil water movement tests are more generally used. Dry sieving is the simplest of all methods of particle size analysis. The apparatus used, the test procedure and the method of calculation are described here in brief.

British Standard 1377 states that this method covers the quantitative determination of the particle size distribution in cohesionless soil down to the fine-sand size. This method should not be used unless it has been shown that for the type of material under test it gives the same result as the method of analysis by wet sieving. In cases of doubt, the method should not be used. Test sieves having the following aperture sizes may be used:

75 mm, 63 mm, 50 mm, 37.5 mm, 28 mm, 20 mm,14 mm, 10 mm, 6.3 mm, 5 mm, 3.35 mm, 2 mm, 1.18 mm, 600 µm, 425 µm, 300 µm, 212 µm, 150 µm, 63 µm and appropriate receivers

Procedure:

- Calculating the percentage by mass of material retained on each test sieve.
- The percentage passing the 63 µm test sieve by difference, and check by weighing the amount in the receiver.
- Calculating of the cumulative percentage (by mass of the total sample) passing each of the sieves.
- Presenting the results obtained on a semi logarithmic chart, the results are reported as a table showing to the nearest 1 %, the percentage by mass passing each of the sieves used.

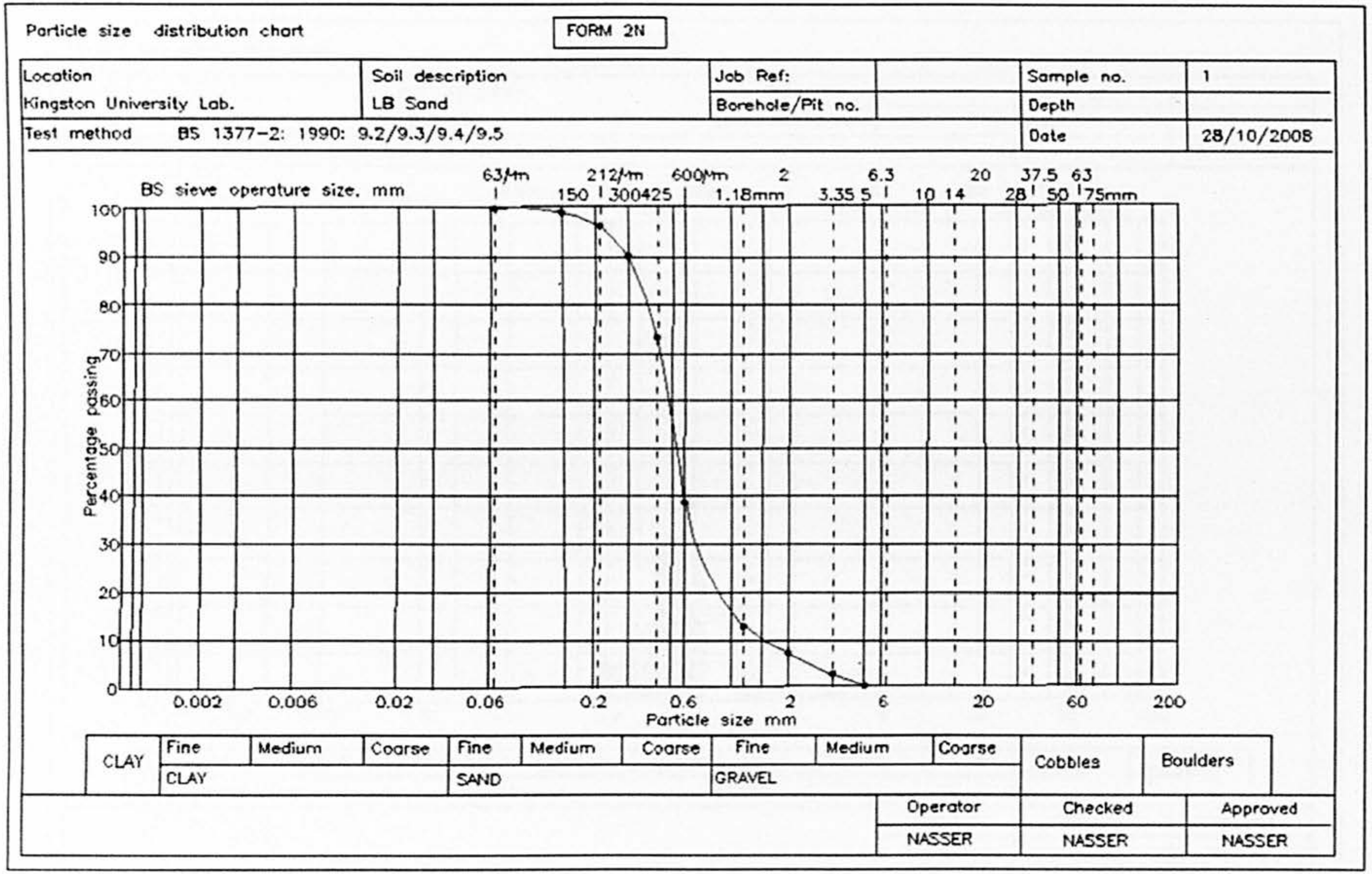
| | | | | | |
|---|---|---|---|---|---|
| Table 6.1: Particle size (sieving ) BS1377-2:1990 Form 2.M | | | | | |
| Location:<br>Leighton Buzzard Pratt's Quarry | | | Job Ref: | LT-1 | |
| | | | Borehole co-ordinates | (493679, 223746) | |
| Soil Description:<br>Clean sand direct from site | | | Sample no. | 1 | |
| | | | Depth | 15-17m | |
| Initial dry mass $m_1$ = 267.2 gr | | | Date | 23/10/2008 | |
| | Mass retained gr | | % retained $(m/m_1)$ 100 | Cumulative % passing | Percent-age finer |
| BS Test Sieve | actual | corrected m | | A | B |
| 5.0mm | 2.3 | 2.3 | 0.86 | 0.86 | 99.1 |
| 3.35mm | 4.3 | 4.3 | 1.61 | 2.47 | 97.5 |
| 2.0mm | 10.8 | 10.8 | 4.04 | 6.51 | 93.5 |
| 1.18mm | 16.5 | 16.5 | 6.18 | 12.69 | 87.3 |
| 600µm | 68.5 | 68.6 | 25.67 | 38.36 | 87.3 |
| 425µm | 94.6 | 94.6 | 35.40 | 73.76 | 61.6 |
| 300µm | 43.4 | 43.5 | 16.28 | 90.04 | 26.2 |
| 212µm | 20.8 | 20.8 | 7.78 | 97.83 | 10 |
| 150µm | 4.2 | 4.2 | 1.57 | 99.40 | 2.2 |
| 63µm | 1.1 | 1.1 | 0.41 | 99.81 | 0.6 |
| Passing 63µm $m_F$ or $m_E$ | 0.5 | 0.5 | 0.19 | 100 | 0.2 |
| Total (check with $m_6$) | | $(m_1)$=267.2gr | | | |
| * Delete as appropriate | | | | | |
| | | Operator | Checked | | |
| | | Nasser | Nasser | | |
| | | | | | |

The test report prepared in accordance with BS 1377-2:1990 and includes the following information.

a - The method of test used;
b - The particle size distribution curve, or the tabulated percentages,
c - The information required by clause 9 of BS 1377-1:1990.

The specific gravity of Woburn Sands in the sample-1 determined G= 2.65. Table 6.1 indicates the cumulative percentage of passing (Colum A) and percentage of fine (Column B).

Figure 6.5 indicates a curve of the cumulative percentage of passing and Figure 6.6 indicates a particle distribution for the sampled sounds from Parra's quarry. The grain size distribution of the sample-1 Woburn Sands are between 63µ to 6mm with three main sizes 300µm (16.3%), 425 µm (35.4%) and 600 µm (25.7%) in Figure 6.6.



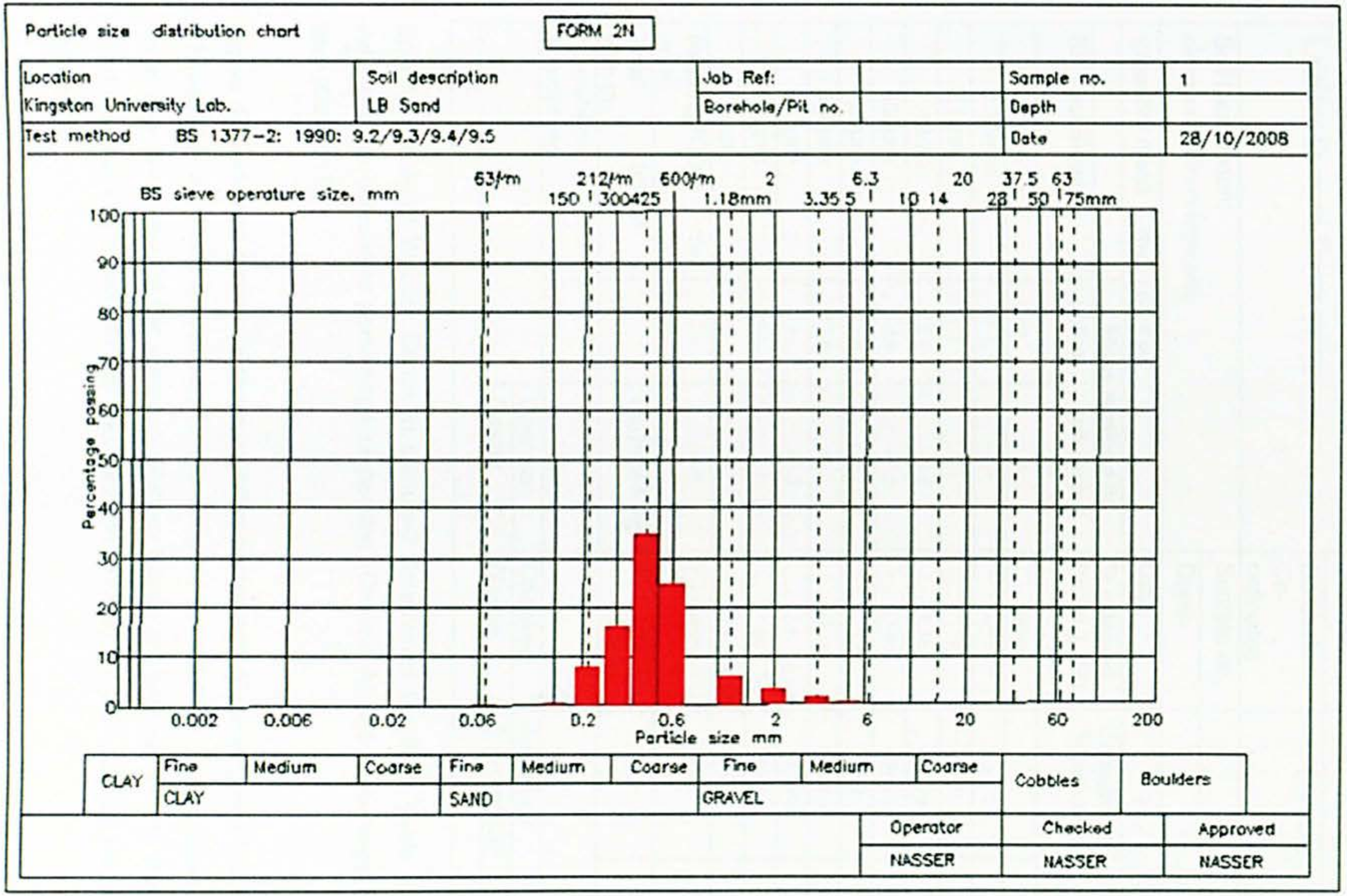
Particle size distribution chart FORM 2N

| | | | | | |
|---|---|---|---|---|---|
| Location | Soil description | Job Ref: | | Sample no. | 1 |
| Kingston University Lab. | LB Sand | Borehole/Pit no. | | Depth | |
| Test method BS 1377-2: 1990: 9.2/9.3/9.4/9.5 | | | | Date | 28/10/2008 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles | Boulders |
| | CLAY | | | SAND | | | GRAVEL | | | | |

| Operator | Checked | Approved |
|---|---|---|
| NASSER | NASSER | NASSER |

Figure 6.5: Table 6.1 Percentage of passing column A



Particle size distribution chart

FORM 2N

| | | | | | |
|---|---|---|---|---|---|
| Location | Soil description | Job Ref: | | Sample no. | 1 |
| Kingston University Lab. | LB Sand | Borehole/Pit no. | | Depth | |
| Test method | BS 1377-2: 1990: 9.2/9.3/9.4/9.5 | | | Date | 28/10/2008 |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles | Boulders |
| | CLAY | | | SAND | | | GRAVEL | | | | |

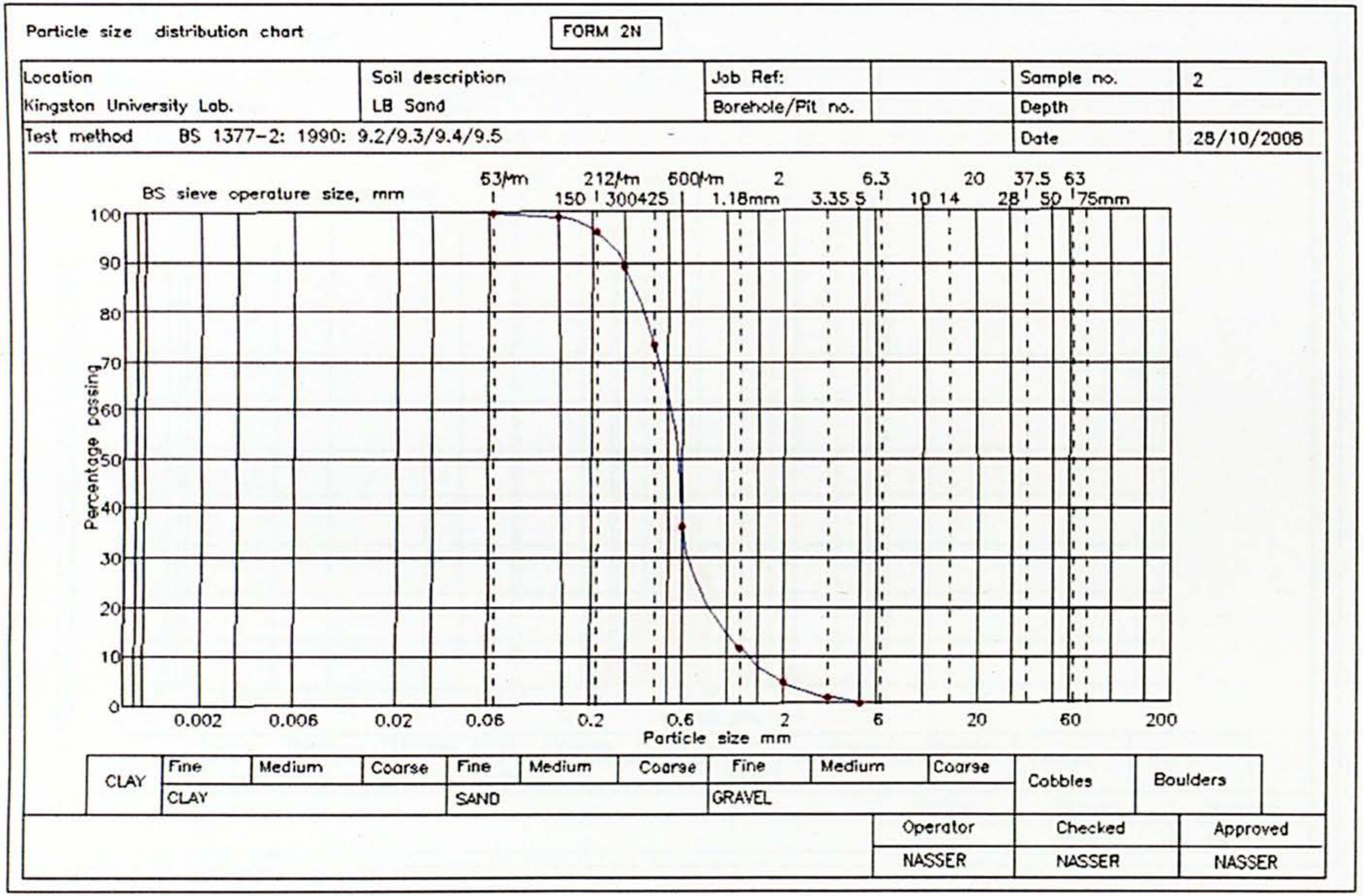
| | | |
|---|---|---|
| Operator | Checked | Approved |
| NASSER | NASSER | NASSER |

Figure 6.6: Table 6.1 Percentage of passing and particles distribution

| | | | | | |
|---|---|---|---|---|---|
| Table 6.2: Particle size (sieving ) BS1377-2:1990 Form 2.M | | | | | |
| Location:<br>Leighton Buzzard Pratt's quarry | | | Job Ref: | LT-2 | |
| | | | Borehole Co-ordinates | (493246, 224078) | |
| Soil Description:<br>clean sand direct from site | | | Sample no. | 2 | |
| | | | Depth | 15-17m | |
| Initial dry mass $m_1$ = 268.9 gr | | | Date | 23/10/2008 | |
| | Mass retained gr | | % retained | Cumulative | Percentage |
| BS Test Sieve | actual | corrected m | ($m$ /$m_1$) 100 | % passing A | finer B |
| 5.0mm | 0 | 0 | 0.00 | 0 | 100 |
| 3.35mm | 4.1 | 4.1 | 1.52 | 1.52 | 98.5 |
| 2.0mm | 9.1 | 9.1 | 3.38 | 4.91 | 95.1 |
| 1.18mm | 15.8 | 15.8 | 5.88 | 10.78 | 89.2 |
| 600µm | 69.4 | 69.5 | 25.85 | 36.63 | 63.4 |
| 425µm | 99.6 | 99.7 | 37.08 | 73.71 | 26.3 |
| 300µm | 43.6 | 43.7 | 16.25 | 89.96 | 10 |
| 212µm | 21.2 | 21.3 | 7.92 | 97.88 | 2.1 |
| 150µm | 4.2 | 4.2 | 1.56 | 99.44 | 0.6 |
| 63µm | 1 | 1 | 0.37 | 99.81 | 0.2 |
| Passing 63µm $m_F$ or $m_E$ | 0.5 | 0.5 | 0.19 | 100 | 0 |
| Total (check with $m_6$) | | ($m_1$)=268.9gr | | | |
| * Delete as appropriate | | | | | |
| | | *Operator* | *Checked* | *Approved* | |
| | | *Nasser* | *Nasser* | *E Bromhead* | |

Specific gravity of Woburn Sands in sample-2 determined **G= 2.63**, Table 6.2 indicates the cumulative percentage of passing (Column A) and percentage of finer (Column B).

Figure 6.7 indicates a curve of the cumulative percentage of passing and Figure 6.6 indicates a particle distribution for the sampled sounds from Parra's quarry. Grain size distribution of the sample-1 Woburn Sands are between 63µ to 6mm with three main sizes 300µm (16.3%), 425 µm (37.1%) and 600 µm (25.9%) in Figure 6.8.



Particle size distribution chart

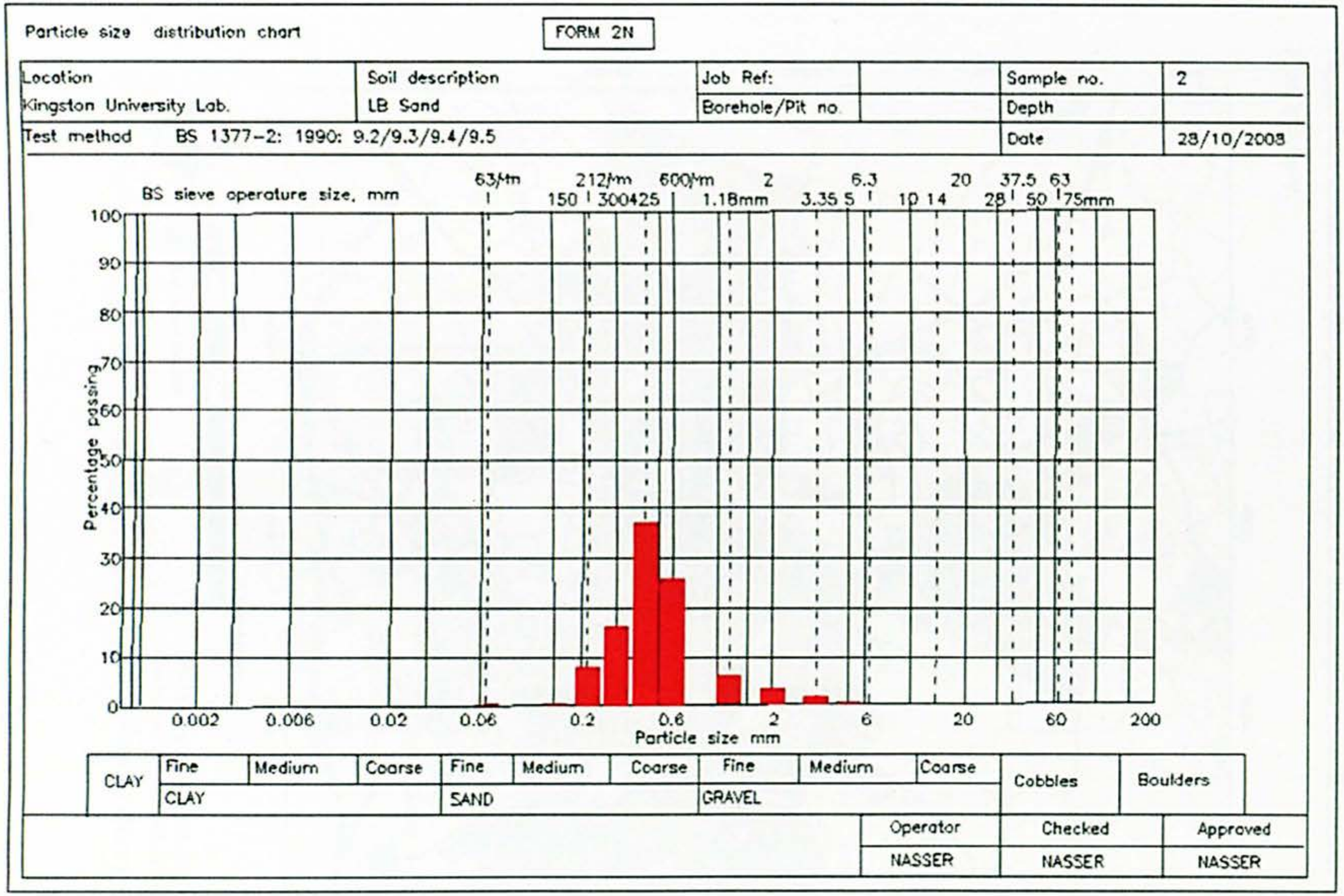
FORM 2N

| | | | | | |
|---|---|---|---|---|---|
| Location | Soil description | Job Ref: | | Sample no. | 2 |
| Kingston University Lab. | LB Sand | Borehole/Pit no. | | Depth | |
| Test method BS 1377-2: 1990: 9.2/9.3/9.4/9.5 | | | | Date | 28/10/2008 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles | Boulders |
| | CLAY | | | SAND | | | GRAVEL | | | | |

| Operator | Checked | Approved |
|---|---|---|
| NASSER | NASSER | NASSER |

Figure 6.7: Table 6.2 Percentage of passing



Particle size distribution chart

FORM 2N

| | | | | | |
|---|---|---|---|---|---|
| Location<br>Kingston University Lab. | Soil description<br>LB Sand | Job Ref: | | Sample no. | 2 |
| | | Borehole/Pit no. | | Depth | |
| Test method BS 1377-2: 1990: 9.2/9.3/9.4/9.5 | | | | Date | 28/10/2008 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| CLAY | Fine | Medium | Coarse | Fine | Medium | Coarse | Fine | Medium | Coarse | Cobbles | Boulders |
| | CLAY | | | SAND | | | GRAVEL | | | | |

| Operator | Checked | Approved |
|---|---|---|
| NASSER | NASSER | NASSER |

Figure 6.8: Table 6.2 Percentage of passing and particles distribution

Figure 6.9 indicates the geographical location of the samples co-ordinates in Pratt's quarry.

Figure 6.9: Indicative location of soil samples in Pratt`s Quarry

## 6.5 Permeability of Woburn Sands

The Permeability of a soil is a measure of its capacity to allow the flow of a fluid through it. The fluid may be either a liquid or a gas , but soil engineering is concerned only with the liquid permeability and the liquid is usually understood to be water, the procedure was used in the laboratory at Kingston University; measuring the permeability of the Leighton Buzzard sand by the constant head apparatus.

**The Constant head test** is a suitable test for measurement of the permeability of high permeable soil such as Woburn Sands around Leighton Buzzard. Factors affecting permeability of soil are not fundamental properties of the soil, but depend upon a number of factors *(Barnes, 2010)* such as:

1. Particle size distribution
2. Particle shape and texture
3. Mineralogical composition
4. Void ratio
5. Degree of saturation
6. Soil fabric
7. Nature of fluid
8. Type of flow
9. Temperature

Particle size distribution, particle shape, texture and mineralogical composition are invariable for a given soil; the others depend upon the placing and treatment of the soil *(Barnes, 2010)*.

***Equations- Darcy law***

$$q = \frac{Q}{t} \qquad \text{.............} (1)$$

$$V = ki \qquad \text{.............} (2)$$

$$q = AV = kiA \qquad \text{.............} (3)$$

$$k = \frac{Q}{Ait} \qquad \text{............ (4)}$$

$$i = \frac{(ha - hc)}{L} \qquad \text{............. (5)}$$

| | | |
|---|---|---|
| V | Velocity | (m/sec) |
| K | Permeability coefficient | (m/sec) |
| i | Hydraulic gradient | (unit less) |
| Q | Volume | ($m^3$) |
| q | Discharge | ($m^3$/sec) |
| A | Cross section area of soil column | ($m^2$) |
| L | Length of soil column | (m) |
| ha & hc | Height of water in tubes | (m) |
| t | Time | (sec) |

The permeability test carried out using the above formula and definitions in three different sample states such as **very loose**, **loose** and **compact.** Soil sample locations are shown in Figure 6.9. The results of the tests indicate the permeability of Leighton Buzzard sand.

As measurement units in the lab according to BS1377 in Manual Soil Laboratory Testing

| | | |
|---|---|---|
| Q | Flow | (ml= $10^{-6}$ $m^3$) |
| A | Cross section area of soil column | ($mm^2$ =$10^{-6}$ $m^2$) |
| t | Time | (min =60sec) |

The permeability formula is expressed in terms of the above units see table 6.4:

$$k = \frac{Q}{60Ait} \qquad \text{.......... (6)}$$

The test procedure and laboratory apparatus are used according to BS 1377 in Manual Soil Laboratory Testing by *(Head, 2011)*. Figure 6.10 and Figure 6.11 specify the constant head cell and manometer.

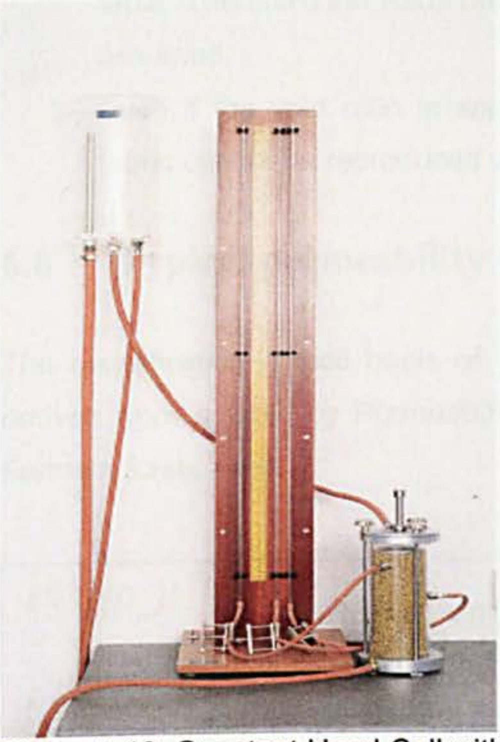


Figure 6.10: Constant Head Cell with manometer tubes and Constant Level Tank

Figure 6.11: Constant Head Permeability Cells

The constant head procedure is used for the measurement of the permeability of sand and gravel containing little or no silt. The most common permeability cell is 75mm diameter and is intended for sand containing particles of up to about 5mm. A larger cell of 114mm diameter can be used for testing sand containing particles up to 10mm. In the constant head test, water is made to flow through a column of soil under the application of a pressure difference which remains constant. The amount of water passing through the soil is a known time is measured and the permeability of soil is calculated using the equation *(Head, 2011)*.

The result of laboratory permeability tests on Leighton Buzzard sand is obtained from disturbed samples. The obtained results are the true permeability; there are two main reasons for using disturbed samples

1– Without specialised equipment it is very difficult to measure the density and hence the void ratio, of granular soil in situ, especially below the water table. Therefore the voids ratio at which to set up samples test can only be assumed.

2- Even if the void ratio is approximately assessed, the feature of the soil fabric cannot be reproduced when it is re-compacted in the laboratory

## 6.6 Typical permeability value

The classification of soil basis of permeability is given in Table 6.3, which is derived from a table by Permeability of soil that can be estimated by Hazen's Formula *(Craig, 1997)*.

$k = C(D_{10})^2$ Where C = 0.004 - 0.012, typically 0.01 for sand and D measured in mm

$k = C(D_{10})^2$ Where C = 0.4 -1.2, typically 1.0, and D measured in cm
$D_{10}$ grain size of 10% passing (mm or cm)

Table 6.3

| Degree of permeability | Range of coefficient of permeability k (m/sec) |
|---|---|
| High | Greater than $1\text{x}10^{-3}$ |
| Medium | $1\text{x}10^{-3}$- $1\text{x}10^{-5}$ |
| Low | $1\text{x}10^{-5}$- $1\text{x}10^{-7}$ |
| Very low | $1\text{x}10^{-7}$- $1\text{x}10^{-9}$ |
| Practically impermeable | Less than $1\text{x}10^{-9}$ |

The only satisfactory way of taking these factors into account is to carry out the permeability test in situ. *(Head, 2011)* see section (7.5). Table 6.4 indicates the test result for a very loose soil sample. Table 6.5 for a loose sample and Table 6.6 for compacted sand sample.

## Table - 6.4

**Constant Head Permeability Test** 1

| | | | | | |
|---|---|---|---|---|---|
| Name: | Nasser | | | Date: | 29/10/2008 |
| Sample description: | | Leighton Buzzard sand | | Location: | KU |
| Method of preparation: | | Constant Head Test | | **Very loose sand sample** | |

**Sample Data:**

| | | | | | |
|---|---|---|---|---|---|
| Diameter | 80.00 | mm | Area | 5026.55 | mm2 |
| Length | 190.00 | mm | Volume | 955044.17 | mm3 |
| Dry mass | 1787.00 | gr | Dry density | | |

**Height above datum(bench)** 380 mm

| | | | | | | |
|---|---|---|---|---|---|---|
| Intel: | 1500.00 | mm | Manometer A | 100.00 | Head diffidence A to C | 89.10 |
| Outlet: | 270.00 | mm | Manometer B | 51.00 | Distance between A & C | 140.00 |
| temperature: | | | Manometer C | 10.90 | Hydraulic Gradient | 0.64 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 1:14:18 | 500.00 | 437.91 | K=(Q/60Ait)= | $2.28\times10^{-05}$ | |
| 00:00:00 | 1:14:50 | 500.00 | 436.68 | K=(Q/60Ait)= | $2.28\times10^{-05}$ | |
| 00:00:00 | 1:14:35 | 500.00 | 437.25 | K=(Q/60Ait)= | $2.28\times10^{-05}$ | |
| 00:00:00 | 1:14:40 | 500.00 | 437.06 | K=(Q/60Ait)= | $2.28\times10^{-05}$ | |
| 00:00:00 | 1:14:35 | 500.00 | 437.25 | K=(Q/60Ait)= | $2.28\times10^{-05}$ | |
| | | | | Ave | $2.28\times10^{-05}$ | m/sec |

**Constant Head Permeability Test** 2

| | | | | | |
|---|---|---|---|---|---|
| Name: | Nasser | | | Date: | 29/10/2008 |
| Sample description: | | Leighton Buzzard sand | | Location: | KU |
| Method of preparation: | | Constant Head Test | | **Very Loose sand sample** | |

**Sample Data:**

| | | | | | |
|---|---|---|---|---|---|
| Diameter | 80 | mm | Area | 5026.55 | mm2 |
| Length | 190 | mm | Volume | 955044.17 | mm3 |
| Dry mass | 1250 | gr | Dry density | | |

**Height above datum(bench)** 380 mm

| | | | | | | |
|---|---|---|---|---|---|---|
| Intel: | 1500 | mm | Manometer A | 95.00 | Head diffidence A to C | 67.4 |
| Outlet: | 152 | mm | Manometer B | 65.00 | Distance between A & C | 140 |
| temperature: | 20 | °C | Manometer C | 27.60 | Hydraulic Gradient | 0.481 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow Q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 01:21:49 | 500 | 411.56 | K=(Q/60Ait)= | $2.83\times10^{-05}$ | |
| 00:00:00 | 01:21:00 | 500 | 416.67 | K=(Q/60Ait)= | $2.87\times10^{-05}$ | |
| 00:00:00 | 01:21:57 | 500 | 411.29 | K=(Q/60Ait)= | $2.83\times10^{-05}$ | |
| 00:00:00 | 01:21:59 | 500 | 411.22 | K=(Q/60Ait)= | $2.83\times10^{-05}$ | |
| 00:00:00 | 01:21:59 | 500 | 411.22 | K=(Q/60Ait)= | $2.83\times10^{-05}$ | |
| Ave | | | | Ave | $2.84\times10^{-05}$ | m/sec |

## Table - 6.5

**Constant Head Permeability Test** 3

| | | | | |
|---|---|---|---|---|
| Name: | Nasser | | Date: | 29/10/2008 |
| Sample description: | | Leighton Buzzard sand | Location: | KU |
| Method of preparation: | | Constant Head Test | Loose sand sample | |

**Sample Data:**

| | | | |
|---|---|---|---|
| Diameter | 80 mm | Area | 5026.55 mm2 |
| Length | 190 mm | Volume | 955044.17 mm3 |
| Dry mass | 1250 gr | Dry density | |

**Height above datum(bench)** 380 mm

| | | | | | |
|---|---|---|---|---|---|
| Intel: | 1500 mm | Manometer A | 91.7 | Head diffidence A to C | 60.2 |
| Outlet: | 255 mm | Manometer B | 68.3 | Distance between A & C | 140 |
| temperature: | 20 °C | Manometer C | 31.5 | Hydraulic Gradient | 0.43 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 01:28:40 | 500 | 389.41 | K=(Q/60Ait)= | $3.00 \times 10^{-03}$ | |
| 00:00:00 | 01:28:47 | 500 | 389.11 | K=(Q/60Ait)= | $3.00 \times 10^{-03}$ | |
| 00:00:00 | 01:28:50 | 500 | 389.11 | K=(Q/60Ait)= | $3.00 \times 10^{-03}$ | |
| 00:00:00 | 01:28:50 | 500 | 389.11 | K=(Q/60Ait)= | $3.00 \times 10^{-03}$ | |
| 00:00:00 | 01:28:59 | 500 | 388.83 | K=(Q/60Ait)= | $3.00 \times 10^{-03}$ | |
| | | | | Ave | $3.00 \times 10^{-03}$ | m/sec |

**Constant Head Permeability Test** 4

| | | | | |
|---|---|---|---|---|
| Name: | Nasser | | Date: | 29/10/2008 |
| Sample description: | | Leighton Buzzard sand | Location: | KU |
| Method of preparation: | | Constant Head Test | Loose sand sample | |

**Sample Data:**

| | | | |
|---|---|---|---|
| Diameter | 80 mm | Area | 5026.55 mm2 |
| Length | 190 mm | Volume | 955044.17 mm3 |
| Dry mass | 1250 gr | Dry density | |

**Height above datum(bench)** 380 mm

| | | | | | |
|---|---|---|---|---|---|
| Intel: | 1500 mm | Manometer A | 93 | Head diffidence A to C | 57.65 |
| Outlet: | 355 mm | Manometer B | 72 | Distance between A & C | 140 |
| temperature: | | Manometer C | 35.5 | Hydraulic Gradient | 0.41 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 01:36:82 | 500 | 365.44 | K=(Q/60Ait)= | $2.94 \times 10^{-03}$ | |
| 00:00:00 | 01:36:83 | 500 | 365.42 | K=(Q/60Ait)= | $2.94 \times 10^{-03}$ | |
| 00:00:00 | 01:36:40 | 500 | 366.57 | K=(Q/60Ait)= | $2.95 \times 10^{-03}$ | |
| 00:00:00 | 01:36:45 | 500 | 366.43 | K=(Q/60Ait)= | $2.95 \times 10^{-03}$ | |
| 00:00:00 | 01:36:70 | 500 | 365.76 | K=(Q/60Ait)= | $2.95 \times 10^{-03}$ | |
| | | | | Ave | $2.95 \times 10^{-03}$ | m/sec |

## Table – 6.6

Constant Head Permeability Test 5

| | | | |
|---|---|---|---|
| Name: | Nasser | Date: | 29/10/2008 |
| Sample description: | Leighton Buzzard sand | Location: | KU |
| Method of preparation: | Constant Head Test | **Compacted sand sample** | |

**Sample Data:**

| | | | | | |
|---|---|---|---|---|---|
| Diameter | 80 | mm | Area | 5026.55 | mm2 |
| Length | 190 | mm | Volume | 955044.17 | mm3 |
| Dry mass | 1596 | gr | Dry density | | |

**Height above datum(bench)** 380 mm

| | | | | | | |
|---|---|---|---|---|---|---|
| Intel: | 1500.00 | mm | Manometer A | 89.50 | Head diffidence A to C | 63.20 |
| Outlet: | 145.00 | mm | Manometer B | 70.30 | Distance between A & C | 140.00 |
| temperature: | | | Manometer C | 26.30 | Hydraulic Gradient | 0.45 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 00:49:81 | 500.00 | 1003.81 | K=(Q/60Ait)= | $7.37 \times 10^{-03}$ | |
| 00:00:00 | 00:49:87 | 500.00 | 1002.61 | K=(Q/60Ait)= | $7.36 \times 10^{-03}$ | |
| 00:00:00 | 00:49:69 | 500.00 | 1006.24 | K=(Q/60Ait)= | $7.39 \times 10^{-03}$ | |
| 00:00:00 | 00:49:69 | 500.00 | 1006.24 | K=(Q/60Ait)= | $7.39 \times 10^{-03}$ | |
| 00:00:00 | 00:49:69 | 500.00 | 1006.24 | K=(Q/60Ait)= | $7.39 \times 10^{-03}$ | |
| | | | | Ave | $7.38 \times 10^{-03}$ | m/sec |

Constant Head Permeability Test 6

| | | | |
|---|---|---|---|
| Name: | Nasser | Date: | 29/10/2008 |
| Sample description: | Leighton Buzzard sand | Location: | KU |
| Method of preparation: | Constant Head Test | **Compacted sand sample** | |

**Sample Data:**

| | | | | | |
|---|---|---|---|---|---|
| Diameter | 80.00 | mm | Area | 5026.55 | mm2 |
| Length | 190.00 | mm | Volume | 955044.17 | mm3 |
| Dry mass | 1596.00 | gr | Dry density | | |

**Height above datum(bench)** 380 mm

| | | | | | | |
|---|---|---|---|---|---|---|
| Intel: | 1500.00 | mm | Manometer A | 91.70 | Head diffidence A to C | 58.50 |
| Outlet: | 215.00 | mm | Manometer B | 73.30 | Distance between A & C | 140.00 |
| temperature: | | | Manometer C | 33.20 | Hydraulic Gradient | 0.42 |

**Reading( Flow up or down)**

| Time Start (min) | Time Interval t (min) | Measured Flow Q (ml) | Rate of flow q (ml/min) | | | |
|---|---|---|---|---|---|---|
| 00:00:00 | 00:51:84 | 500 | 964.51 | K=(Q/60Ait)= | $7.65 \times 10^{-03}$ | |
| 00:00:00 | 00:51:80 | 500 | 965.25 | K=(Q/60Ait)= | $7.66 \times 10^{-03}$ | |
| 00:00:00 | 00:51:75 | 500 | 966.18 | K=(Q/60Ait)= | $7.67 \times 10^{-03}$ | |
| 00:00:00 | 00:51:78 | 500 | 965.62 | K=(Q/60Ait)= | $7.66 \times 10^{-03}$ | |
| 00:00:00 | 00:51:85 | 500 | 964.32 | K=(Q/60Ait)= | $7.65 \times 10^{-03}$ | |
| | | | | Ave | $7.66 \times 10^{-03}$ | m/sec |

Table 6.7 shows the average Woburn Sands permeability. If we compare the result with Table 6.3, it confirms that Woburn Sands are highly permeable sands. Table 6.8 shows the empirical test result from the sieve analysis as high permeability, and therefore, Woburn Sands are high permeable aquifers. This is a good indication for Natural infiltration and SuDS application to control surface water runoff, recharge the aquifer and reduce risk of the urbanisation to the groundwater.

SuDS techniques can be used to reduce the rate and volume and improve the water quality of surface water discharge from the site to the receiving environments as groundwater or water course, however, the techniques operate on two main principals:

1. Infiltration (high permeable soil)
2. Attenuation

Infiltration SuDS relies on discharge to the ground where suitable ground condition allows, therefore infiltration SuDS are reliant to the ground or aquifer condition for their successful operation. Infiltration and SuDS are covered in the next chapters.

Table 6.7: Summary of the tests result (m/sec)

| Sample | Test-1 | Test-2 | AVE |
|---|---|---|---|
| Very loose sand | $2.20 \times 10^{-03}$ | $2.84 \times 10^{-03}$ | $2.52 \times 10^{-03}$ |
| Loose sand | $3.00 \times 10^{-03}$ | $2.95 \times 10^{-03}$ | $2.97 \times 10^{-03}$ |
| Compacted sand | $7.38 \times 10^{-03}$ | $7.66 \times 10^{-03}$ | $7.52 \times 10^{-03}$ |
| Permeability of sand varies from | $2.52 \times 10^{-03}$ to | $7.52 \times 10^{-03}$ | m/sec |

| Table 6.8: Empirical calculation of soil permeability based on grain size of 10% passing in sieve analysis |
|---|
| Hezan's Formula $k=C(D_{10})^2$ |
| C= 0.4 to 1.2 , C = 1(0.01) typical for Leighton Buzzard sand.<br>$D_{10}$=0.6 mm from sieve analysis<br>$K= C(D_{10})^2=0.01 \times (0.6)^2 =3.6\times10^{-3}$ m/sec |

## 6.7 Chemical Tests

Chemical composition of sand is very important for infiltration and the recharge mechanism of surface water through sand to groundwater that is the presence of certain constituents can be very significant. These include organic matter, sulphates, carbonates, chlorides and pH reaction of the groundwater and aquifer. In general chemical testing in a soil laboratory is usually limited to routine tests for determination of the following:

- Acidity or alkalinity
- Sulphate content
- Organic content
- Total dissolved solid

The entire test was carried out in the Kingston University Lab according to the BS1377: Part 3:1990 with a few additional relevant to the tests and discussions.

### 6.7.1 pH value

The test was carried out on samples according BS1377 Part: 3 1990. 100mg quality of sand is placed in a test tube, adding distilled water and shacked, dipping the test paper in the water, with the quantity of water about twice of quantity of the sand. The pH value result shows weak acidic (pH = 4), see the test procedure in Appendix A2.

### 6.7.2 Sulphates Content

The water soluble sulphates usually found in the soils are sodium sulphates ($Na_2SO_4$) and magnesium sulphate ($MgSO_4$) (as commonly found as gypsum and is only slightly soluble in water, but is readily soluble in dilute hydrochloric acid (HCl). Treatment with acid is therefore necessary if the total amount of sulphates is required *(Head, 2011)*.

Groundwater containing dissolved sulphates can attack concrete and other material containing cement placed in the ground or on the surface. A reaction takes place between the sulphates and the aluminium compounds in cement, causing crystallisation of complex compounds. Sulphates in soil can also cause disintegration of precise members such as slab and concrete pipes and can lead to corrosion of metal pipes placed in contact with the soil.

Water described as "hard" means it is high in dissolved minerals, specifically calcium and magnesium. Hard water is not a health risk, but a nuisance because of its tendency to cause mineral build-up in water pipe and heating systems, and its poor soap and/or detergent performance when compared with soft water.

Sulphates in water are a very common problem, affecting water in more than 85% of the country. It is a result of the dissolved minerals calcium, magnesium and manganese. With an increase in these minerals, the following are seen *(Head, 2011)*:

- Soap scum in sinks and bathtubs
- Bathtub rings
- Spots on dishes or shower doors
- Reduced foaming and cleaning abilities of soaps and detergents
- Dingy and yellowed clothes with soapy residues that require extra rinsing to remove
- Clogged pipes from build-up of minerals
- Increased water heating costs from build-up of minerals, reducing efficiency of water heaters
- Possible skin infections from bacteria trapped in pores underneath soap scum
- While these are all unpleasant effects, hard water is not a hazard to human health and can be treated.

The Ion exchange method is quicker and easier than the gravimetric method but cannot be used if the soil contains chlorides, nitrate or phosphates or other anions *(Kassim & Williamson, 2005)*. Table 5.9 indicates the test result for sulphate content.

**Table 6.9: Form3 (d) Sulphate Content: Ion exchange method; Sample of sand**

| | | |
|---|---|---|
| location: *Kingston University Lab.* | Ref: | NH1 |
| | Borehole no. | 1 |
| Soil Description: *Leighton Buzzard Sand* | Sample no. | 1 |
| | Depth | 15 |
| | Date | 11/10 |
| Test Method: BS1377, Part3:1990:5.6 | | |
| Specimen Ref: | 1 | 2 |
| Groundwater GW or Soil sample SS | *T1* | *T2* |
| Initial mass of sample m1- gr | *267.2* | *268.9* |
| mass of soil sample passing 2mm test sieve m2 - gr | *260.6* | *264.8* |
| $\frac{m2}{m1}x100$<br>% finer than 2 mm in original sample | *97.5%* | *98.4%* |
| Mass of watch glass and soil - gr | *200* | *250* |
| Mass of soil used - gr | *80* | *100* |
| Volume of NaOH in burette before titration - ml | 5 | 5 |
| Volume of NaOH in burette after titration - ml | 3 | 2.5 |
| Volume of NaOH used V - ml | 2 | 2.5 |
| Concentration of NaOH solution B - ml | *0.046* | *0.033* |
| Sulphate content of water-soil extract<br>$SO3 = 0.8BV$ g/l<br>or<br>$SO3 = 0.16BV$ % | *0.074*<br>*1.5%* | *0.066*<br>*1.3%* |
| Sulphate content of ground water<br>$SO3 = 0.4BV$ | *0.037* | *0.033* |
| Remarks: | *Nasser Hashemi* | |

## 6.7.3 Organic matter content

To determine if the organic matter levels in the soil are high, medium or low. Organic matter is important in the soil to improve soil structure, nutrient holding capacity, water holding capacity, and infiltration. Leighton Buzzard sand organic matter content has been measured to determine whether it is within the allowable limit and will not affect the natural filtrations of surface water into groundwater or contain high-level of organic content.

1. 100g (m1) dried sand passing 2mm sieve is placed in a clean dry wide-month conical flask and add 150ml of hydrogen peroxide and mixed gently with a glass road, covered and kept overnight.
2. Heat gently to a temperature about 60 °C mixing to release bubbles of gas. Chemical reaction will take place until gas will no longer at a very rapid rate.
3. Boil the mixture to reduce the volume to about 50ml to decompose peroxide, while cooling and adding more peroxide to complete the oxidation reaction.
4. The sample is then filtered through a Whatman No.50 filter paper.
5. Soil is then transferred to a weighted and dried glass evaporating dish ($m^2$).
6. The sample is then dried at 100-110°C and weighted ($m^3$).

Calculation of loss due to hydrogen peroxide treatment presented in percentage which is determined the organic matter content.

$$loss = \frac{m3 - m2}{m1} x100\% = \frac{98 - 97.9}{100} x100 = 0.1\% \text{ Very low}$$

## 6.7.4 Total Dissolved Solids (TDS)

Some dissolved solids come from organic sources such as leaves, silt, plankton, and industrial waste and sewage. Other sources come from runoff from urban areas, road salts used on the streets during the winter, and fertilizers and pesticides used on lawns and farms. Dissolved solids also come from inorganic materials such as rocks and air that may contain calcium bicarbonate, nitrogen, iron phosphorous, sulphur, and other minerals. Many of these materials form salts, which are compounds that contain both a metal and a non-metal. Salts usually dissolve in water forming ions. Ions are particles that have a positive or negative charge.

TDS are the total weight of all solids that are dissolved in a given volume of water, expressed in units of mg per unit volume of water (mg/L), also referred to as parts per million (PPM). Maximum contaminant level (MCL) of 500mg/litre (500 parts per million (ppm)) for TDS. Numerous water supplies exceed this level. When TDS levels exceed 1000mg/L it is generally considered unfit for human consumption. High level of TDS is an indicator of potential concerns, and warrants further investigation. Most often, high levels of TDS are caused by the presence of potassium, chlorides and sodium. These ions have little or no short-term effects, but toxic ions (lead arsenic, cadmium, nitrate and others) may also be dissolved in the water *(Tebbutt,1992)*.

A sample has been tested for TDS from Leighton Buzzard surface runoff and compared with the national continental crest and drinking water standard, it is difficult to remove the TDS with a simple filtration system. Also it will be possible to prevent the occurrence of the traced element by a special scheme or scheme.

For drinking purposes, it is possible to set a mechanism to reduce or remove total dissolved solids with common filter and water purification systems such as carbon filtration, reverse osmosis, distillation and de-ionization. There are good reasons to constantly test the TDS in water either for drinking purposes or recharge into groundwater, Figure 6.12 represents the TDS colour code and Table 6.10 result of surface runoff in Highways around Leighton Buzzard.

- Taste/Health
- Hardness
- Level of minerals
- Hydroponic solution
- Colloidal silver

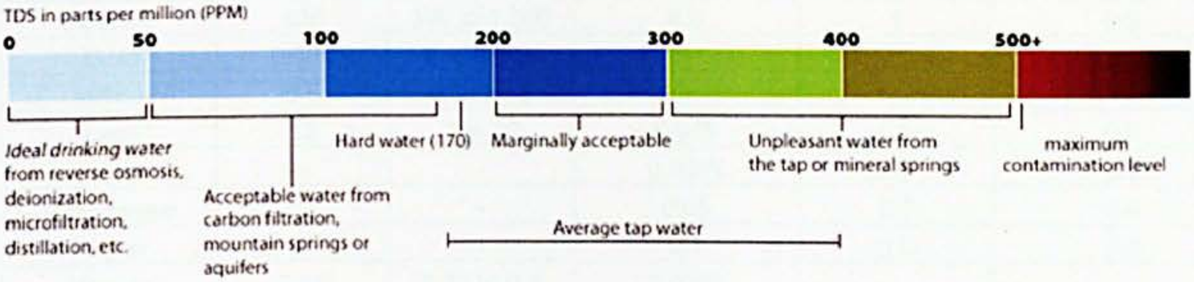


Figure 6.12: Total Dissolved Solid colour code

Water containing TDS concentrations below 1000 mg/litre is usually acceptable to consumers, although acceptability may vary according to circumstances. However, the presence of high levels of TDS in water may be objectionable to consumers owing to the resulting taste and to excessive scaling in water pipes, heaters, boilers, and household appliances (see also the section on Hardness). Water with extremely low concentrations of TDS may also be unacceptable to consumers because of its flat, insipid taste; it is also often corrosive to water-supply systems *(Mather, 1998)*.

**Table 6.10: Occurrence of selected trace elements[1]**

| Element | Continental crust | | Drinking water standard[2] | Leighton Buzzard sample-1<br>t=15°c | Leighton Buzzard sample-2<br>t=11°c |
|---|---|---|---|---|---|
| | Average | Range | | | |
| Arsenic | 1.8 | 1 to 10 | 0.05 | 0.5 | 1.9 |
| Cadmium | 0.2 | 0.1 to 0.3 | 0.005 | 0.05 | 0.27 |
| Chromium | 100 | 10 to 200 | 0.10 | 2.0 | 2.1 |
| Copper | 55 | 5 to 100 | 1.3 | 1 | 0.9 |
| Fluorine | 625 | 300 to 1,000 | 4.0 | 1 | 0.9 |
| Gold | 0.004 | 0 to 0.006 | - | | |
| Iodine | 0.5 | 0.3 to 2.2 | - | | |
| Lead | 13 | 7 to 20 | 0.015 | 0.5 | 0.8 |
| Cobalt | - | - | 0.0025 | 0.3 | 0.2 |
| Manganese | - | - | 0.05 | 3.7 | 3.6 |
| Nickel | - | - | 0.1 | 3.0 | 3.4 |
| Mercury | 0.08 | 0.03 to 0.4 | 0.0002 | | |
| Silver | 0.07 | 0.01 to 0.1 | 0.05 | | |
| Sulphur | 260 | 200 to 2,400 | 250 | | |
| Uranium | 1.8 | 1 to 4 | - | 30.0 | 34.0 |
| Total dissolved Solid | | | | 1070 | 807 |

[1] *All concentrations are given in parts per million (ppm), which is roughly equivalent to 0.0001 % on a weight per weight basis.*

[2] *Drinking water standards are the maximum concentrations allowed in drinking water to prevent human health problems (e.g. cancer) from developing over 70 years of exposure ("-" means that the element is not regulated).*

## 6.8 Conclusion

Tests and analysed results show that Leighton Buzzard sand is Silica sand and generally called quartz ($SiO_2$) with grain size ranging from sub-rounded to rounded and contains Iron, Potassium phyllosilicate and mica group.

A dry sieve test analysis carried out according to (BS1377 Part2: 1990.9.3) and test results indicate that sand size is between 63 µm and 6mm with three main sizes as 300 µm, 425 µm and 600 µm. Table 6.11 summarises the dry sieve test result.

Table 6.11: Dry sieve test summarised result

| Sample | G | 300 µm | 425 µm | 600 µm |
|---|---|---|---|---|
| 1 | 2.65 | 16.3% | 35.4% | 25.7% |
| 2 |  | 16.3% | 31.7% | 25.9% |
| Average | 2.65 | 16.3% | 33.55% | 25.8% |

Permeability test carried out to measure to find out rate of flow for 3 different type of sample states as Very loose, loose and compact. It found as high permeable soil (Woburn Sands) varies from 2.52 x$10^{-3}$ m/s - 7.52x$10^{-3}$ m/s, the result indicates suitability of soil for SuDS application.

The shear strength angle ($\Phi$- internal friction) in Woburn Sands around Pratt's Quarry has been found $\Phi$= 42.5 degrees and it is a very important soil parameter for slope stability, landslide and retention pond design (see Appendix- A).

Chemical tests are very important for infiltration, protection of aquifer and environment. Various tests carried out on the Woburn Sands (around Leighton Buzzard) and found the result within the recommended guidance range.

| | |
|---|---|
| • Acidity or alkalinity | pH value 4.0 (acidic) |
| • Sulphate content | Range between (0.033 - 0.037 ppm) |
| • Organic content | Very low |
| • Total dissolved solid | Range between ( 807-1070 ppm)<br>Maximum contamination level |

The above conclusion generally provides a satisfactory response to some of the research questions that soil properties are suitable to utilise SuDS and provide a long term sustainable approach to recharge groundwater.

# CHAPTER 7 - INFILTRATION

## 7.1 General

Earlier chapters provided adequate information about geology, aquifers, soil characteristics and groundwater protection policy and the impact of urbanisation on groundwater. As discussed in chapter 1, natural infiltration and SuDS application can be considered to reduce the urbanisation and environmental risks on groundwater in response to the reaches question; therefore this chapter covers in detail the impact of Infiltration and SuDS application on the Woburn Sands in the Leighton Buzzard Area.

Pratt's Quarry drainage proposal comprises a surface water sewer network and storage pond to collect surface water from the road, car park, roof and impermeable area and outfall to a pond. The surface area of the proposed pond is designated **71/2 ha**, the proposed pond to be used to control storm water and to provide a natural aquifer recharge mechanism.

The infiltration systems play a significant part for the solution to reduce risk of urbanisation to groundwater resource and the environment, and provide space for development as well as control of surface runoff and recharge of the aquifer.

Around 3000 houses are planned, of which some already have been built in the Pratt's Quarry with associated roads and green areas. The proposed pond has been designed to provide surface water runoff storage in the critical event. Figure 7.1 indicates location plan for the proposed development.

The infiltration drainage system may be used instead to dispose of storm water (surface water) from urban area and highway areas by recharge into groundwater. These systems allow storm water to infiltrate the ground over a period of time and also provide detention storage during an event of a storm depending on the types. Before discussing the type of infiltration, it is important to understand the role of infiltration in practice and the purpose of an indicative detailed design infiltration system.

Figure 7.1 shows the proposed location of pond to control surface water part of SuDS and planned housing development around Pratt's Quarry.

Figure 7.1: Indicative plan for the planned housing development around Pratt's Quarry

Infiltration should be seen as one of a number of methods of controlling storm water runoff. The use of infiltration drainage system reduce the quantity of water that has to be disposed of through surface water drains or sewers to the watercourse or treatment works. It can be useful in on site drainage (sustainable) of new small and large developments which would otherwise require having new sewers built to accept the additional runoff. Infiltration of storm water also increases the recharge of aquifers in natural mechanism; in addition, the water companies abstracting water for supply purposes future growth of population and new development to meet the demand. Infiltration can be part of the solution to protect natural aquifers and groundwater resource as well as controlling storm water runoff. Soil characteristics have already been discussed in Chapter 6.

Figure 7.2 shows the common route for storm water to follow between a development site and the river and infiltration types. The infiltration method was suggested by CIRIA (1996) and may be considered as particularly appropriate for the on-site drainage of a small scale (up to 10ha) residential, commercial or leisure development. The infiltration technique should, therefore, be seen as an alternative to provide a new or upgraded storm sewerage system within and downstream of the development, either on their own or in conjunction with conventional sewerage.

The main purpose of this chapter is to discuss what type of infiltration system can be used and how we can minimise the risk of urbanisation through natural recharge mechanisms to the groundwater to provide a satisfactory response to the research question (1) that SuDS consider as the effective method to recharge groundwater. Therefore, in section 7.6, an indicative design provided part of this research to compare sewer network system from development to a storage pond with an infiltration system with storage pond and some discussion. Some basic data and soil parameters for the purpose of the calculation come from the previous chapters. Before explaining the proposed pond design and its parameters, a brief highlight to explain the type of ground surface infiltration system and WinDes software application in the next sections.

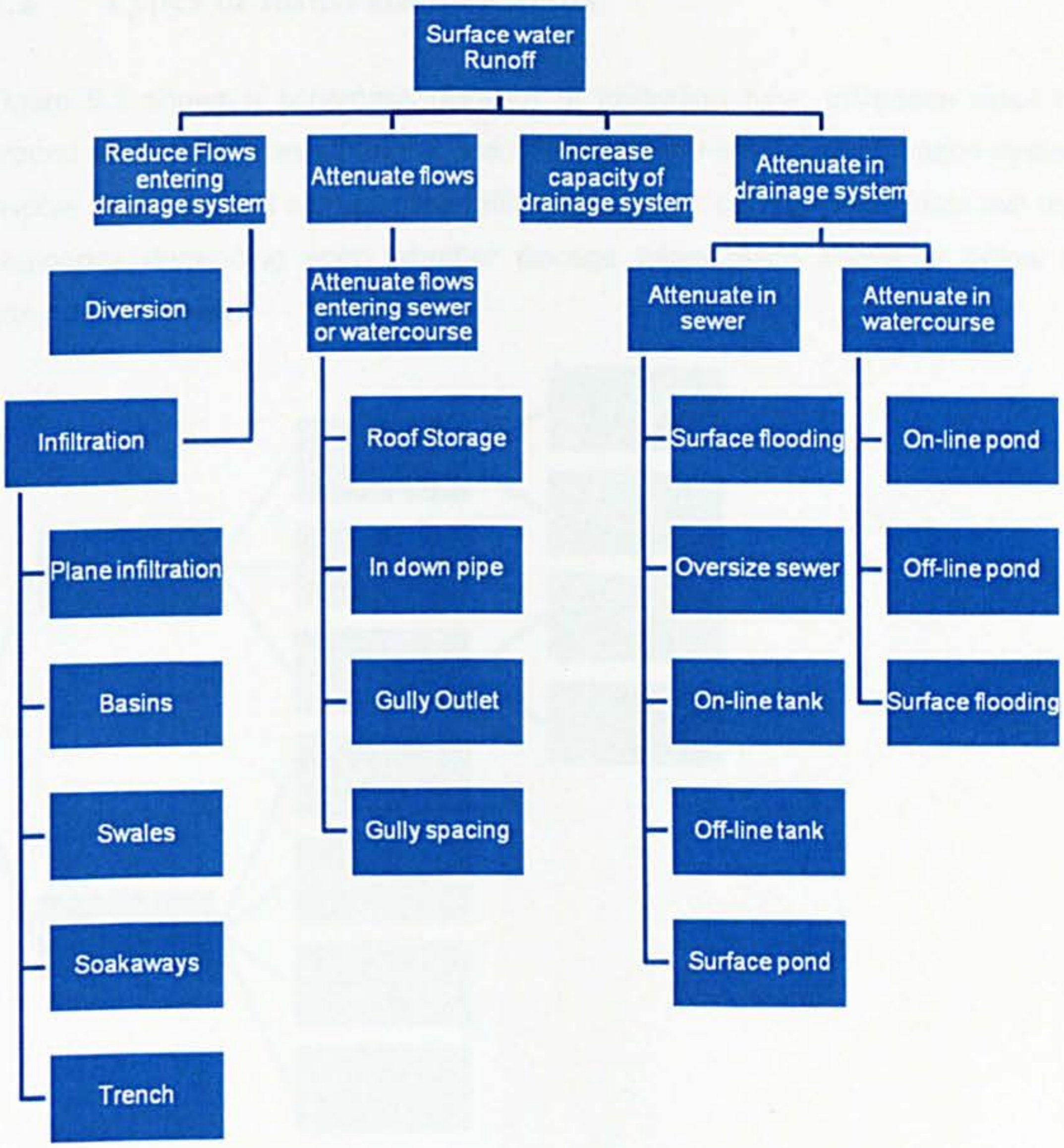


Figure: 7.2 Option for control of Urban Runoff *(CIRIA, 1996)*

It is desirable that infiltration takes place into the unsaturated zone above the groundwater table. Where the discharge is below the groundwater table it is more commonly thought of as direct recharge to the groundwater. For a system to be effective it must have sufficient volume of storage for the runoff and have sufficient surface area in contact with the soil to allow infiltration of storm water runoff. The size required depends on the hydraulic properties on the soil, the area in which the system in draining and the chosen design rainfall event.

## 7.2 Types of infiltration systems

Figure 6.3 shows a schematic diagram of infiltration type. Infiltration rates into ground are normally less than the rate of storm water inflow; all infiltration systems involve an element of storage. The infiltration system can be divided into two main categories depending upon whether storage takes place above or below the ground *(CIRIA, 1996).*

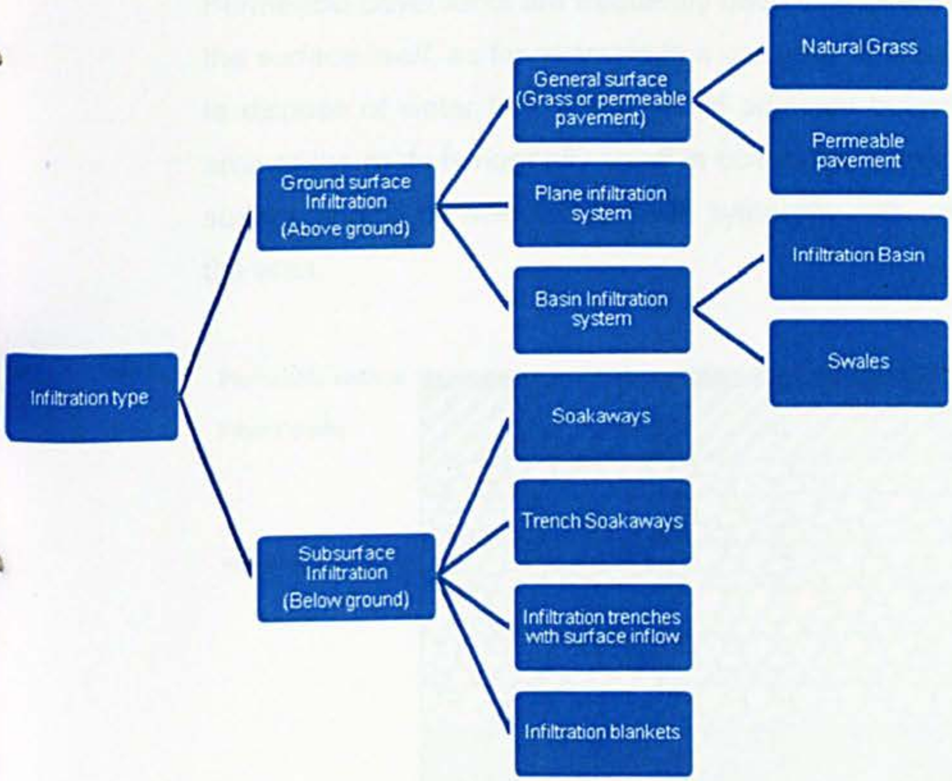


Figure 7.3: Schematic diagram of infiltration type.

Ground surface infiltration systems can utilise natural or artificial surfaces ranging from grass to permeable pavements. The shape of these systems may vary from near horizontal surfaces to basins or swales with distinct sides. Though there is a continuum of shapes they are conveniently divided into plane infiltration systems and basin infiltration systems.

### 7.2.1 Ground surface infiltration system

***Permeable pavement***

Plane infiltration systems are represented by infiltration or permeable pavements (Figure 7.4). Surface of such systems may range from grass through permeable macadam to cellular concrete blocks. These systems are predominantly flat and their shape is commonly such that there is little storage per unit of infiltration area. Permeable pavements are frequently used to dispose of just the rainfall falling into the surface itself, as for example in a car park. Sometimes they may also be used to dispose of water from the roofs of adjacent buildings, but in these cases the area of the roofs is normally small in comparison with the infiltration area. Type of surface should be selected to be in sympathy with any use that is to be made of the area.

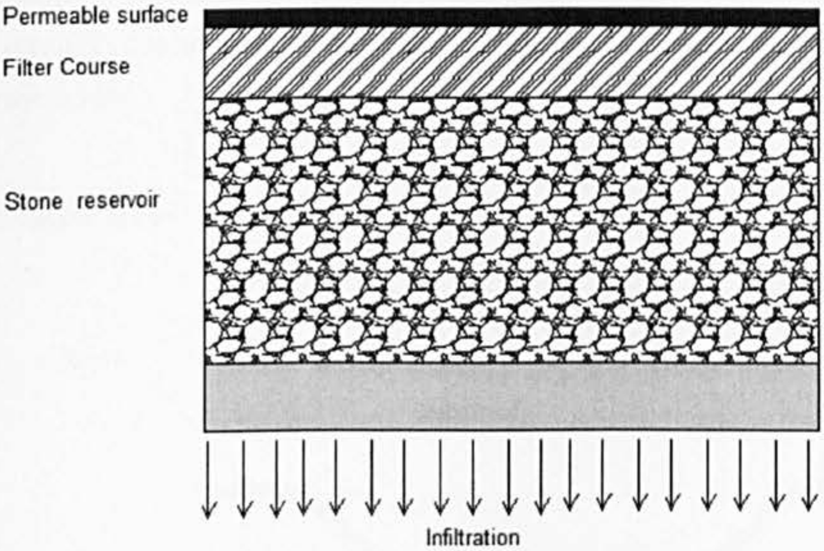


Figure 7.4: Plane infiltration or permeable pavement

***Infiltration basins***

To increase the amount of storage available per unit of infiltration area over plane infiltration systems, a basin can be used (Figure 7.5). Increase in storage means that these can be used to dispose of water from areas which are many times larger than the basin itself. An infiltration basin is an area of land surrounded by a bank or berm, which detains storm water until it has infiltrated through the base and sides of the basin. Infiltration basins are sometimes also referred to as dry retention ponds.

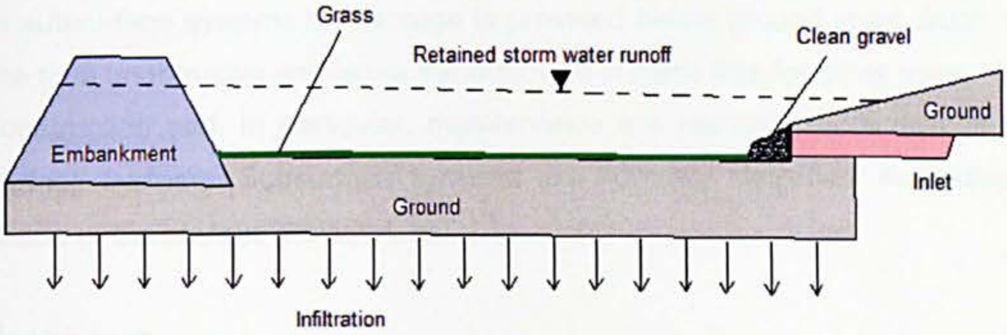


Figure 7.5: Infiltration basin section

### ***Swale***

A swale is a grass-lined channel with shallow side-slopes which may be used both to convey and to infiltrate storm water (Figure 7.6). To increase the infiltration and detention capacity of swales they can be provided with low check dams across their width.

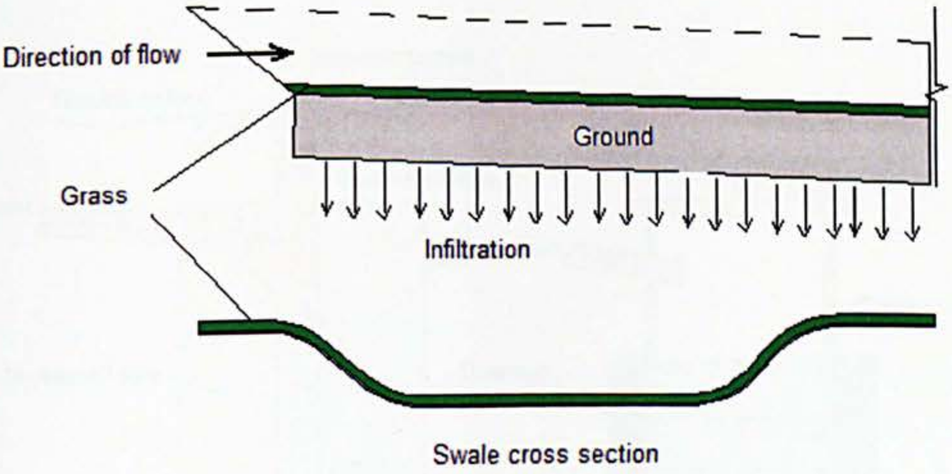


Figure 7.6: Swale

## 7.2.2 Subsurface infiltration system

In subsurface systems the storage is provided below ground level. Such systems are thus unobtrusive and leave the overlying surface free for other uses. However, construction and, in particular, maintenance are normally more difficult than for surface systems. Subsurface systems are normally classified, according to the shape of the storage provided, as:

***Soakaways***

These may range from structures constructed, for example, of pre-cast, perforated concrete rings or loose-laid bricks to a simple rock-filled excavation. Traditionally, they have consisted of a cylindrical or rectangular hole excavated into the ground with a structure or stone-fill to maintain the shape of the excavation (Figure 7.7). On large sites, individual soakaways can be linked together by pipes; for a given volume and storage, linked soakaways are likely to provide a greater infiltration area than an equivalent single soakaway.

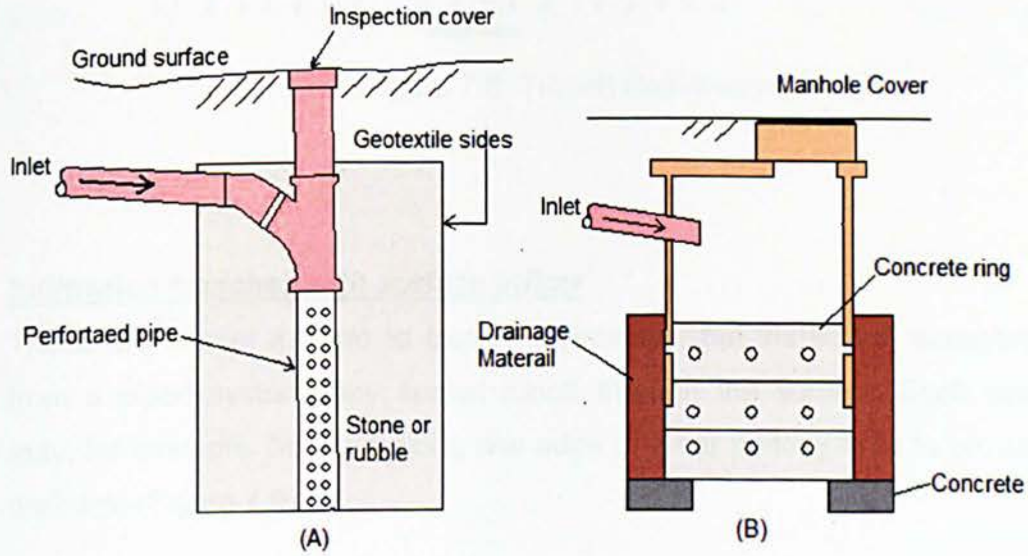


Figure 7.7: Two Conventional Soakaways for house and with rigid wall

## *Trench Soakaways*

For a given volume of excavation, better infiltration characteristics can be obtained from a Soakaways in the form of a trench whose length is significantly longer than its width or depth *(British Research Establishment, 2003)*. These trenches are usually stone-filled. Such shapes of soakaways are normally called trench soakaways Figure 7.8.

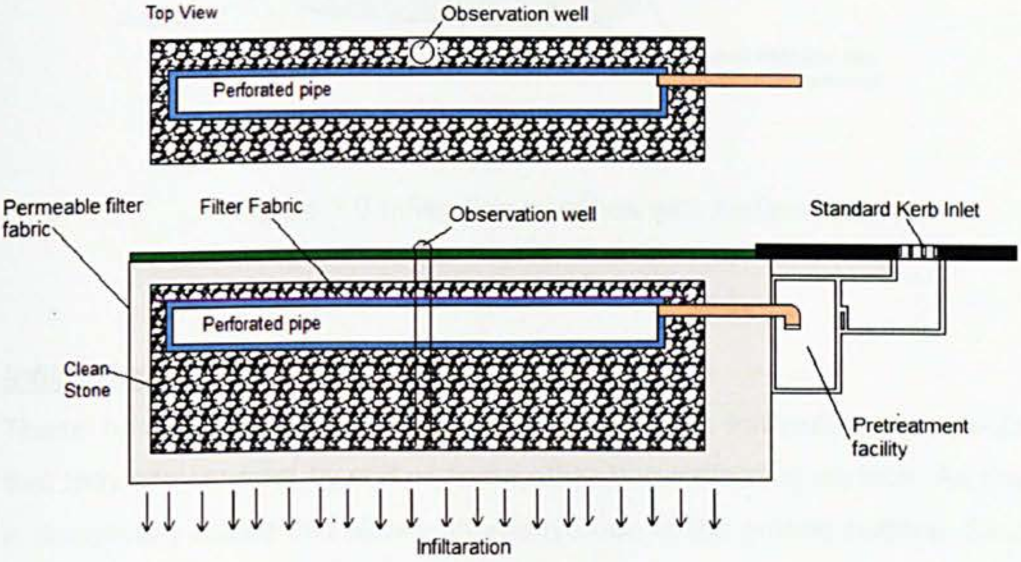


Figure 7.8: Trench Soakaways

## *Infiltration trenches with surface inflow*

These are similar in form to trench soakaways, but instead of accepting runoff from a piped system they accept runoff through the surface. Such soakaways may, for example, be used along one edge of a car parking area to provide storm drainage (Figure 7.9).

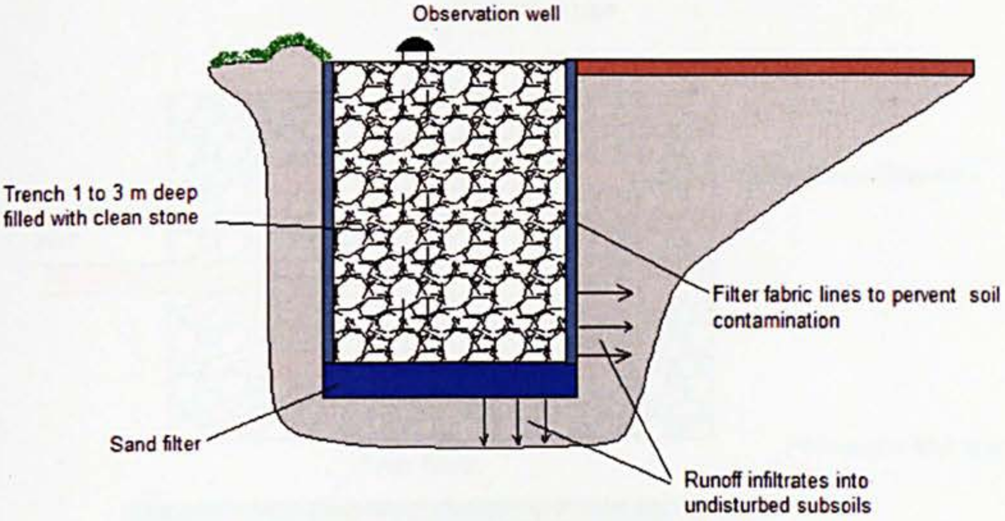


Figure 7.9 Infiltration trenches with surface inflow

***Infiltration blankets***

These have many characteristics in common with infiltration pavements except that they are covered by soil or some other non-infiltrating surface. As the system is completely buried this allows alternative use of the ground surface. Storm water is normally introduced into the blanket from one or more point sources (Figure 7.10).

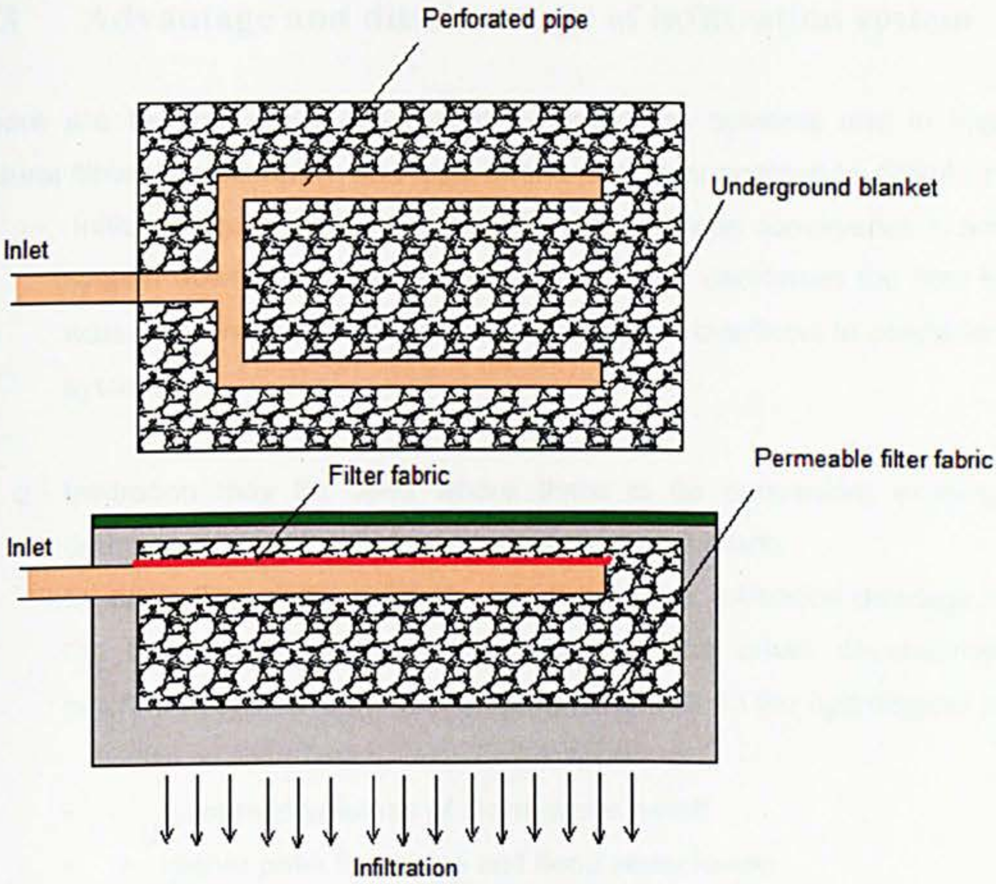


Figure 7.10: Infiltration blankets

Although the use of other types of infiltration systems has, until recently, been much less common in the UK, a growing range of types and sizes of infiltration systems are coming into use, especially by encouraging the developer to use SuDS as the first option for development and SuDS guidance and manual. Leighton Buzzard appears to be a good area for the use of such a system to control storm water runoff and recharge aquifer to minimise risk of urbanisation on groundwater and the environment.

## 7.3 Advantage and disadvantage of infiltration system

There are few beneficial advantages of infiltration systems and in support of natural filtration mechanism and local economies as suggested by CIRIA (1996):

1- Infiltration reduces the quantity of water requiring conveyance in any piped system downstream of the development and decreases the flow in storm water sewers and the risks of discharge from overflows in combined sewer systems.

2- Infiltration may be used where there is no convenient existing storm drainage system to which a connection can be made.
By controlling storm water close to the source, infiltration drainage reduces the hydrological impact of urbanisation. The urban development of a catchment can have the following major effects on the hydrological regime:

- Increased volumes of storm water runoff
- Higher peak flow rates and flood water levels
- Lower base flows in water courses
- Reduction of available storage in and conveyance capacity of river valleys
- Reduction in soil moisture recharges leading to a reduction of groundwater resources
- Increase in pollutant loads carried into sewers or surface waters.

The objectives of urban runoff control are to limit the quantity, location and frequency of flooding to an acceptable level and to maintain natural and artificial watercourses and surface water sources in a fit state for their other functions.

3- Infiltration may be used where existing piped systems, or treatment works, are at capacity loading. It thus saves on the cost of enlarging the existing drainage system or providing additional detention storage with all the disruption and cost that this normally involves.

4- Infiltration can be used to enhance recharge to groundwater in situations where the quality of storm water runoff does not pose a threat to groundwater quality.
5- Construction is normally simple and rapid.
6- Entire lifetime costs may be less than for alternative systems.

There are disadvantage of the infiltration system:

1- The performance of infiltration systems depends on the properties of the soil in which they are constructed.
2- Field tests are necessary in order to determine infiltration coefficients for design purposes.
3- If the storm runoff is polluted, there is a risk that infiltration systems may introduce pollutants into the soil and ultimately into the groundwater. Various methods are available for reducing this risk. This is of particular concern when the system is used for drainage from industrial sites and highways and in such cases the use of infiltration may not be appropriate. Simple biological treatment methods may reduce levels of biodegradable pollutants but normally such methods are not adequate for non-biodegradable pollutants.
4- The introduction of water into the soil may cause geotechnical problems.
5- The adjacent soil can become blinded through ingress of silt and so infiltration systems require regular maintenance. Appropriate arrangements must be made for this to be carried out.
6- It is the policy of the Statutory Sewerage Undertakers in England and Wales not to adopt infiltration systems.
7- There may be a legal liability on the owner of the infiltration system for any pollution of the groundwater.

As mentioned earlier, field tests are necessary to determine infiltration coefficient. It is not the same soil permeability, but mostly they are used interchangeably. Permeability is the rate which fluid flows through a porous material under given conditions, and infiltration is the movement of a fluid into the surface of porous material. Therefore, to design and select an infiltration system a field test for infiltration coefficient must be carried out. Performance of infiltration site tests can be found in any soil mechanic textbooks, however, here we have chosen to use the procedure as described in Micro Drainage (industry standard sustainable drainage and flood hazard software for Civil engineering) and the software has been used for infiltration system analysis. Table 7.1 shows the typical infiltration coefficient *(CIRIA, 2007).*

Table 7.1

| **Soil Type** | **Infiltration Coefficient (m/hr)** |
|---|---|
| Gravel | 10 - 1000 |
| **Sand** | **0.1 – 100 ( $2.7x10^{-5}$ to $2.7x10^{-3}$m/sec)** |
| Loamy Sand | 0.01 - 1 |
| Sandy Loam | 0.05 - 0.5 |
| Loam | 0.001 - 0.1 |
| Silt Loam | 0.0005 - 0.005 |
| Chalk | 0.001 - 100 |
| | |
| Cut off point for most infiltration drainage systems | 0.001 |
| | |
| Sandy Clay Loam | 0.001 - 0.01 |
| Silty Clay Loam | 0.00005 - 0.005 |
| Clay | < 0.0001 |
| Till | 0.00001 - 0.01 |
| Rock | 0.00001 - 1 |

The actual infiltration to be tested on site to get accurate infiltration coefficient, next section considers the infiltration coefficient calculation in brief.

## 7.4 WinDes Software application

WinDes is a Windows version of the original DOS drainage design suite developed by Micro-Drainage. WinDes provides drainage network design on the basis of the Modified Rational Method or a combined drainage network.

Source control provides the technical feasibility of employing storage with (or without) infiltration may be investigated in seconds. The programme generates an extensive range of options represented in graphical forms to illustrate the storage requirements of your site. This may be combined with an analysis of the likely impact of infiltration as a cost saving approach. In many cases infiltration systems may not be technically applicable and this may be determined quickly to avoid further abortive work. Where infiltration is feasible, it may reduce the storage requirements of a site very significantly. Sustainable Urban Drainage Design (SuDS) requires the design engineer to apply the techniques adopted by this module. The range of different storage structures are considered including ponds, tanks, soakaways, infiltration blankets, porous car parks, swales and etc.

Source Control provides a complete analysis and design solution for engineers, which can integrate infiltration techniques seamlessly with conventional design solutions. BRE 365, Sewers for Adoption, building regulations and CIRIA guidance recognise the importance of adequate storage at both source and throughout a drainage network. Source Control has been designed to comply with these regulations. It employs a full hydrograph method to design, size and test storage structures. Furthermore, Source Control can calculate green field runoff rates as required by the Code for Sustainable Homes and SuDS application.

A design procedure under source control covers the following:

1- Full range of (online and offline) traditional and infiltration (SuDS) structures supported.
2- A large range of controls can be chosen to model separate outflow and overflow controls.
3- Support for both FSR and FEH rainfall in the UK and Ireland.
4- Specify rainfall profiles directly for international use or undertake continuous analysis of time series rainfall.
5- Generate inflow from rainfall profile and time area diagram.
6- Specify an input hydrograph or model inflow from a green roof.
7- Model inflow via a rainwater harvesting tank.
8- Scale rainfall to model climate change.

Analysis and result under source control covers the following:

1- Analyse multiple storms for a required return period, collate results and identify critical duration.
2- Output minute by minute results in tabular or graphical form.

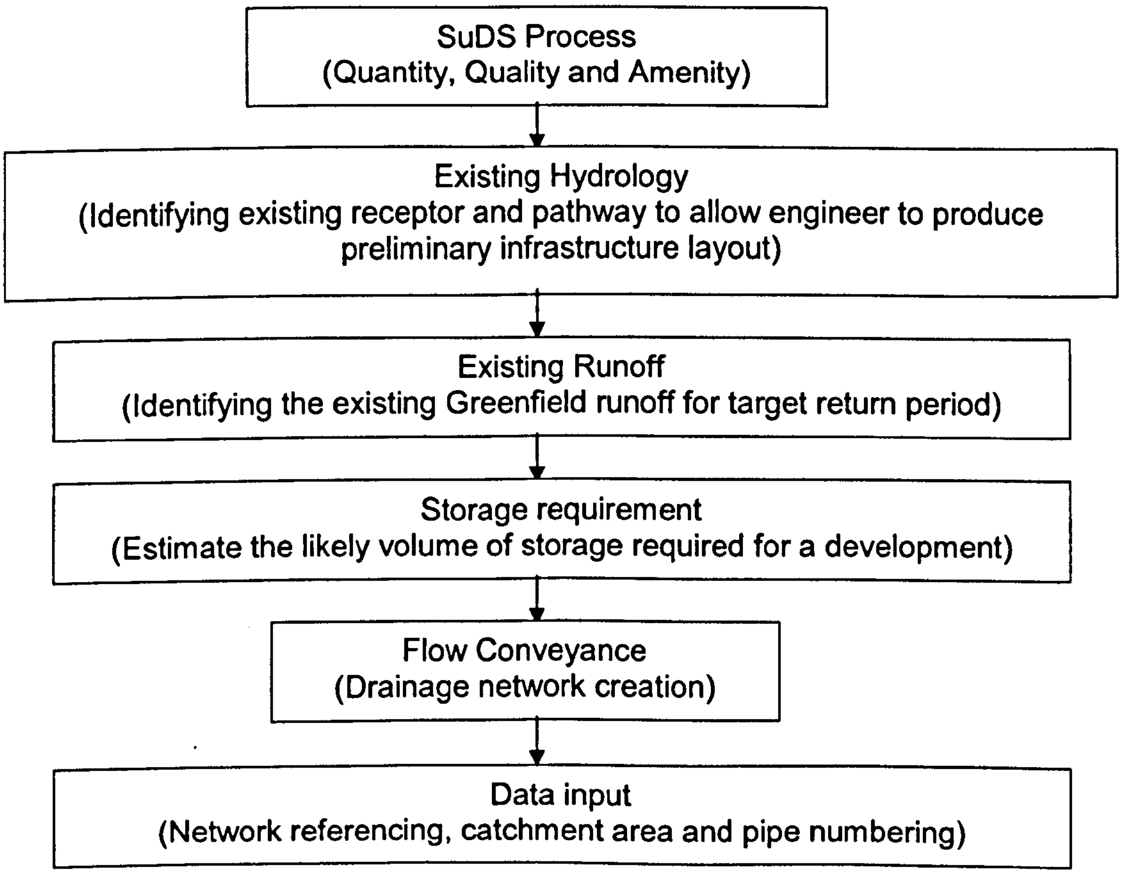
3- Both Flooded Volumes and Discharge Volume columns can now be viewed as real-time animation of water levels in the structure.

4- Rural Runoff Calculator allows the peak runoff rates and volumes to be calculated for undeveloped or partially developed catchments.

Global variable parameters in WinDes consist specific of hydrological data, storage structure type, outflow control, overflow control and consideration of climate change.

As SuDS are mandatory for all new developments, except where the developer can demonstrate that it would be impractical due to site circumstances. The Flood and Water Management Act 2010 passed by parliament on the 8th April 2010 and making sustainable drainage systems (SuDS) such as permeable paving mandatory, has now been published. It includes far-reaching requirements for SuDS on future construction work carried out in England and Wales.

A SuDS design process in WinDes requires the following systematic approach to facilitate a successful outcome.



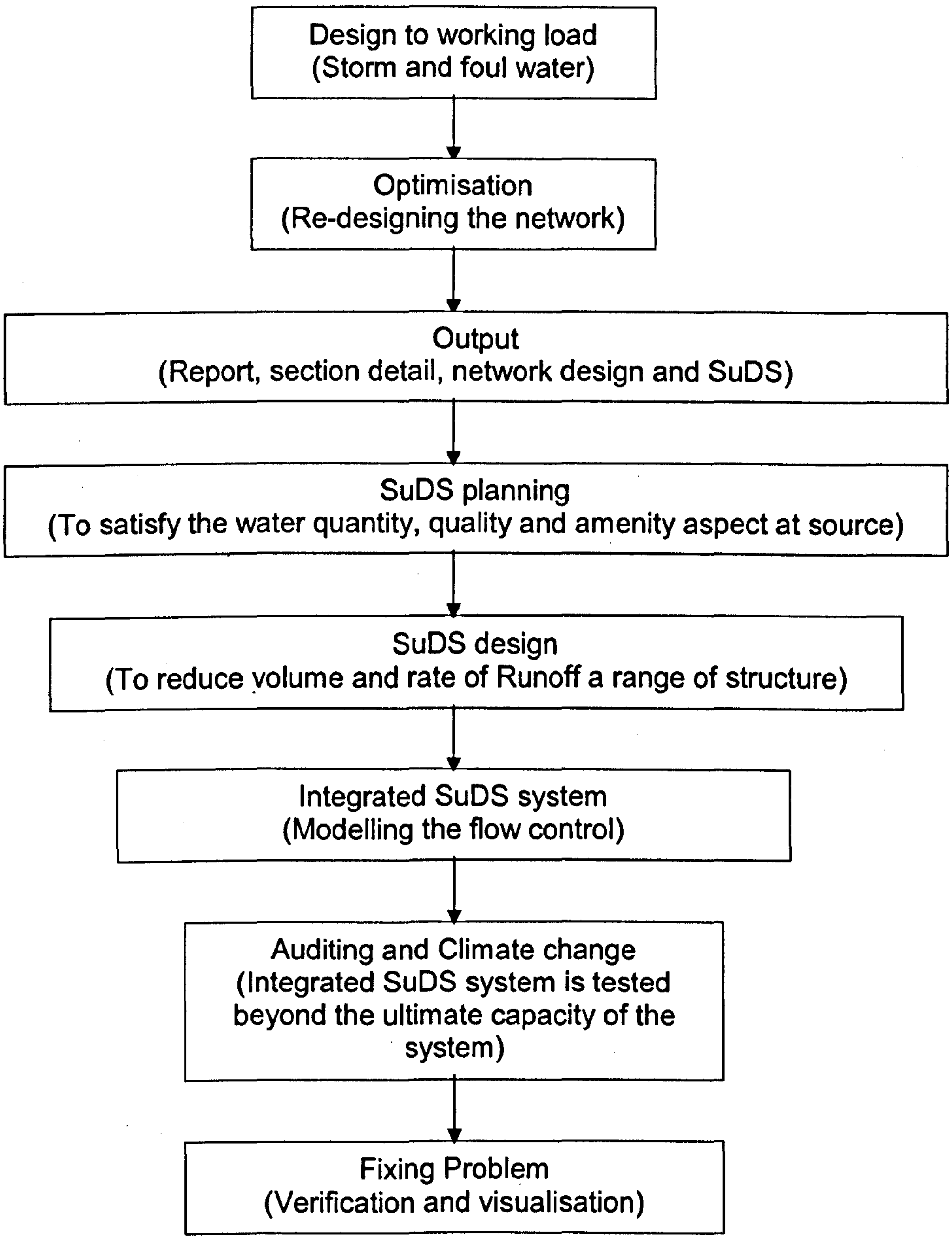


Figure 7.11 SuDS Process flowchart.

## 7.5 Infiltration calculation

Micro Drainage (2012) suggests the following condition before carry out the site test for infiltration coefficient according to BRE Digest 365:

- The depth of the test pit should be approximately the same as the anticipated depth of the full infiltration system.
- The size of the test pit should be related to the size of the area to be drained. If the area to be drained is less than 100m$^2$ then the volume of water used for the test should be at least 0.5 m$^3$ otherwise at least 1 m$^3$ of water should be used.

## Procedure

1. Excavate a trial pit of the appropriate size.
2. Record the wetted area of the internal surface of the pit when the pit would be half full of water.
3. Record the volume of water that can be retained between 25% and 75% of the depth of the pit.
4. Fill the pit with water several times (at least 3) then fill to the invert of the lowest incoming pipe.
5. Record the amount of time required for the pit to drain from 75% full to 25% full.

These figures can then be fed into the Infiltration Coefficient calculator to yield q. (q is soil infiltration m/s)

$$q = \frac{(Vp75-25)}{(Ap50\ x\ tp75-25)}$$

Where

Vp75-25 = Volume of pit between 25% and 75% of depth (m$^3$)

Ap50 = Wetted Area of Pit at 50% of depth (m$^2$)

tp75-25 = Time for pit to drain from 75% to 25% full (hours).

Infiltration coefficient found **0.2m/h** for design calculation, comparing field infiltration rate and Lab permeability, decided to use actual filed infiltration rate in the design model.

## 7.6 Pratt's Quarry pond per-design consideration

Considering Hydrological and Hydrogeological principles of infiltration when allowing for the infiltration drainage system, a desk study review carried out, such as rain intensity, ground surface slope, soil type, soil moisture content and considering whether the infiltration system will increase or decrease the runoff from the site.

The Leighton Buzzard district is mostly covered with Woburn Sands and with high permeability and high infiltration coefficient; it is easy to control surface runoff by using infiltration systems. In the new urbanised site around Leighton Buzzard, impermeable surfaces such as roofs, roads and paved areas alter the proportions on evapo-transpiration, runoff and infiltration of rainfall. Source control is the option to restore the balance either by slowing down and storing water in a balancing chamber, or detention pond or by enhanced infiltration of water into the ground using an appropriate infiltration drainage system which many of them are feasible from large open ponds to small soakaways.

In most cases, the area of infiltration systems are considerably is smaller than the impermeable area being contributed and inflow exceeds the outflow rate. It is necessary to store the water on-site and allow time to percolate slowly through the infiltration system; therefore provision of storage capacity is essential for the infiltration system to perform properly. Determination of design rainfall events described in terms of intensity, duration and frequency. Statistical values of these for the Leighton Buzzard area obtained from FSR (Flood Studies Report) or FEH (Flood Estimate Handbook). Figure 6.12 represents the infiltration system used for storm water runoff control and disposal.

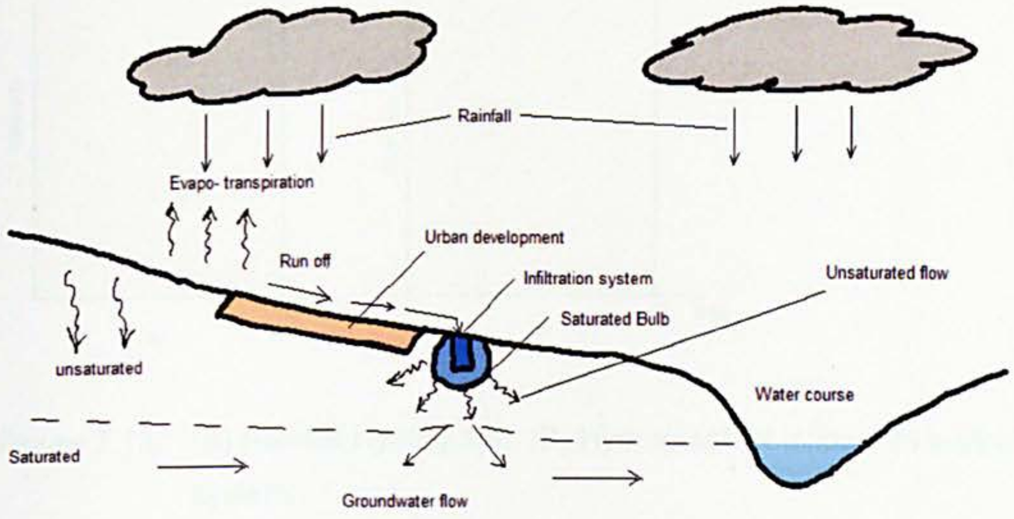


Figure 7.12: Infiltration system used for storm water runoff control and disposal.

For a given return period, the volume of runoff to the infiltration system is given by:

$$Volume\ of\ runoff\ =\ Q.D\ =\ i.A.D$$

where:

i = rainstorm intensity (m/h) A = impermeable area drained ($m^2$)

D = rainstorm duration (h) Q = inflow ($m^3/h$)

For the purpose of design calculations, it's assumed that the design rainfall hyetographs have a 'block' nature (constant intensity or flow during the duration of the storm) and that there is no attenuation of flow between the rainfall landing on the impermeable surface and the inflow to the infiltration system (see Figure 7.13). Rainfall ratio map "R" used for the proposed location (Figure 7.14).

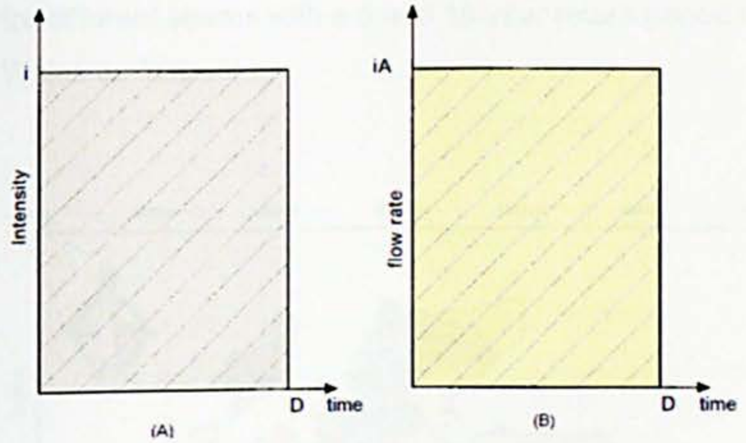


Figure 7.13: (A) Rainfall Hyetograph, (B) Hydrograph of inflow into infiltration system

The Institute of Hydrology (1975) has carried out an extensive analysis of rainfall statistics and has provided a method to determine the relationship between depth, duration and return period. This has formed the basis for the method described below.

The notation *MT-D* is used to identify a storm, where:
M is the depth of rain in mm
T is the return period in years
D is the storm duration

The Flood Studied Report (FSR) and the Wallington Procedure both use a standard notation when specifying rainfall information. Thus MT-D represent the depth of rainfall (in mm) occurring for duration D (min) with a return period T (years) *(Bulter & Davies, 2011).*

Thus a *M10-15* minute is the depth of rainfall of a 10-year return period storm event of 15 minutes duration. A design storm is assumed to be a rainfall event of duration D with a 10-year return period i.e. *M10-D*. The average rainfall intensity, i, is obtained by dividing the rainfall depth by the duration. Values of design rainfall depth, intensity and duration can be determined using Figure 7.14 and Table 7.2

for different storms with a 5 and 10 year return period respectively for England and Wales as follows:

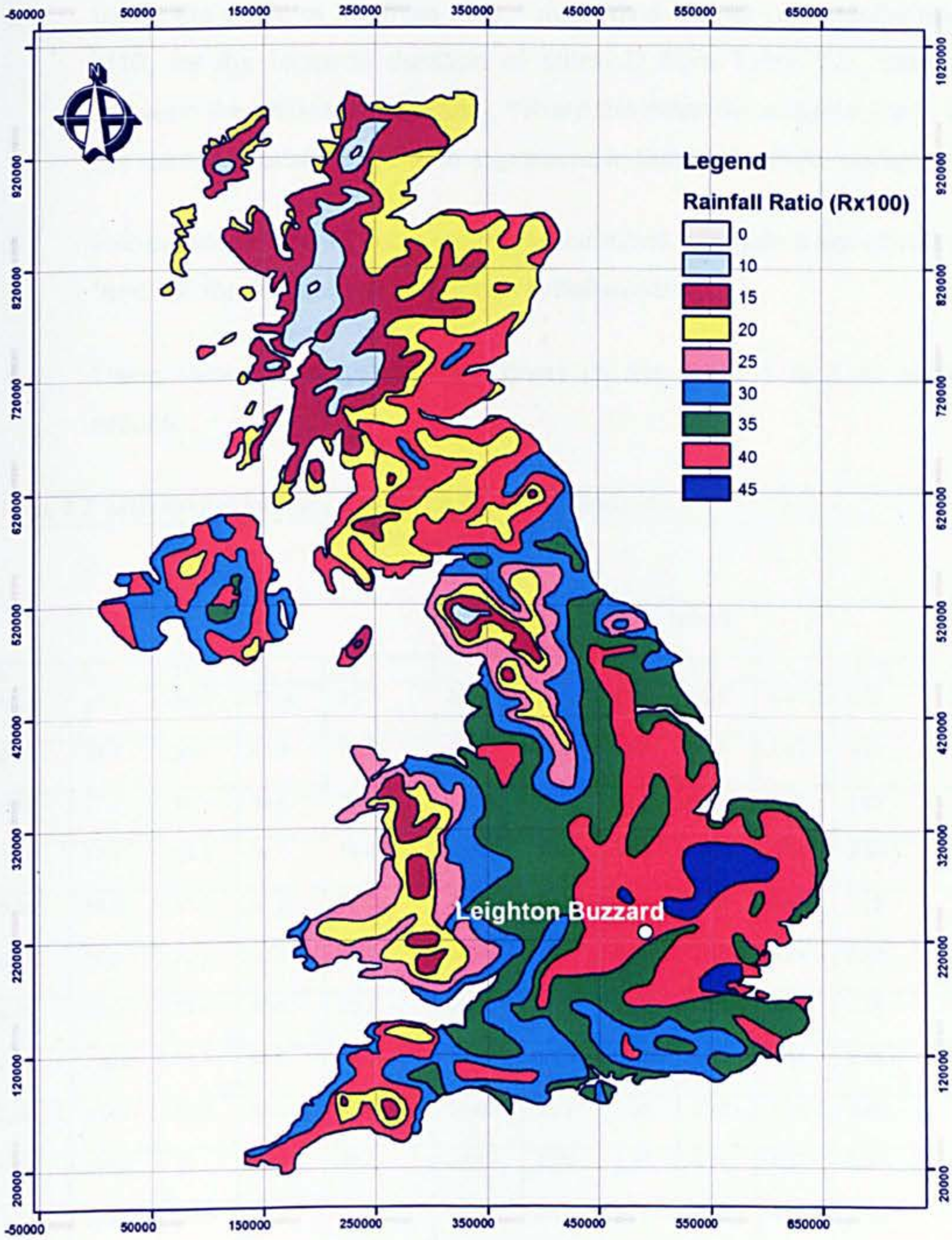


Figure 7.14: Value of rainfall ratio R for UK [R= (M5-60min) / (M5-2 day)], Leighton Buzzard Grid Ref. (492500, 225500)

1- From the map in Figure 7.13 determine the rainfall ratio, R, for the location of the infiltration system, interpolating between contours. Note that “R” is the ratio of the 60 minutes to two day rainfalls of five-year return period.

2- Using the value of “R” from step 1 determine the 10-year rainfall intensity, M10, for the required duration of storm D from Table 7.2, interpolating between the values if necessary. Where the other dimensions are in metres the rainfall intensity should be expressed in terms of m/h for consistency.

3- Repeat steps 1 and 2 for a variety of durations to obtain a set of values of” *i* “and “D” for 10-year return period rainfall events.

4- Using micro drainage software gives us the steps 1 to 3 as automated results.

Table 7.2 M10 Rainfall intensity (mm/h) for duration D and ratio R

| | **Rainfall duration (*D*)** | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | **Minutes** | | | | **Hours** | | | | | |
| *R* | 5 | 10 | 15 | 30 | 1 | 2 | 4 | 6 | 8 | 10 |
| 0.12 | 62.9 | 49.0 | 43.16 | 33.0 | 24.80 | 18.1 | 12.8 | 10.6 | 8.44 | 5.67 |
| 0.15 | 71.4 | 55.2 | 46.8 | 39.2 | 24.80 | 17.5 | 12.0 | 9.59 | 7.43 | 4.61 |
| 0.18 | 77.2 | 59.5 | 49.8 | 35.2 | 24.80 | 16.7 | 11.2 | 8.85 | 6.63 | 4.08 |
| 0.21 | 82.8 | 62.5 | 52.7 | 36.2 | 24.80 | 16.4 | 10.6 | 8.41 | 6.13 | 3.42 |
| 0.24 | 89.3 | 67.3 | 54.6 | 37.2 | 24.80 | 16.1 | 10.3 | 7.93 | 5.62 | 3.21 |
| 0.27 | 95.0 | 70.3 | 57.1 | 37.7 | 24.80 | 15.7 | 9.92 | 7.52 | 5.29 | 2.97 |
| 0.30 | 97.9 | 71.8 | 58.0 | 38.2 | 24.80 | 15.5 | 9.58 | 7.12 | 5.05 | 2.75 |
| 0.33 | 100.0 | 73.2 | 60.0 | 38.7 | 24.80 | 15.2 | 9.33 | 6.98 | 4.85 | 2.53 |
| 0.36 | 104.0 | 74.6 | 61.0 | 39.2 | 24.80 | 15.1 | 9.03 | 6.73 | 4.56 | 2.36 |
| 0.39 | 107.0 | 76.1 | 62.0 | 39.7 | 24.80 | 15.0 | 8.90 | 6.53 | 4.37 | 2.24 |
| 0.42 | 111.0 | 77.6 | 63.0 | 40.2 | 24.80 | 14.9 | 8.73 | 6.38 | 4.21 | 2.12 |
| 0.45 | 114.0 | 79.1 | 64.0 | 40.7 | 24.80 | 14.8 | 8.49 | 6.14 | 4.07 | 2.01 |

The prime objective of the infiltration system is to dispose of storm water effectively into the ground, therefore hydraulic property of a system is one of the main parts of the design, and the procedure for carrying out a hydraulic design is shown in Figure 7.15.

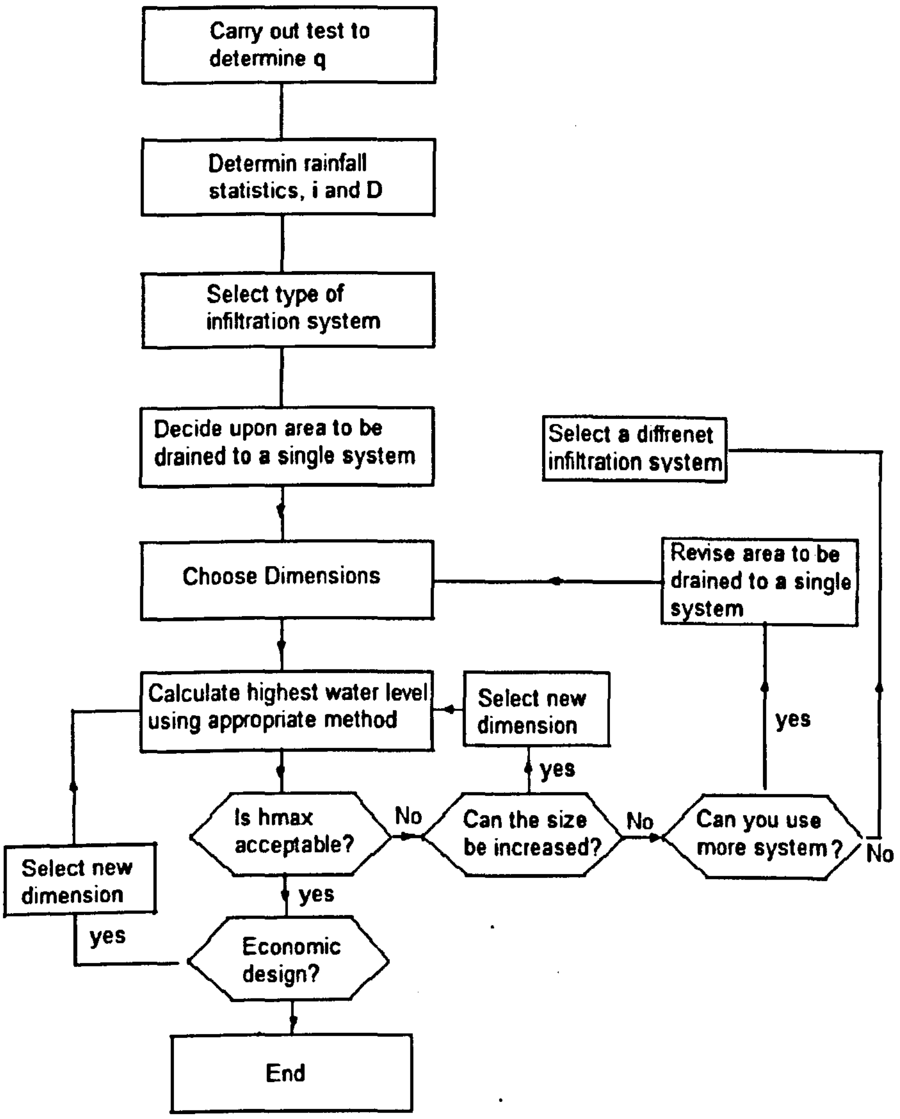


Figure 7.15: Infiltration Hydraulic design flow chart *(CIRIA, 1996)*

## 7.6.1 Design of an indicative model

Pratt's Quarry, Figure 7.16, is one of the housing development projects in the south of the Leighton Buzzard. The criteria for the indicative Infiltration system to control surface water runoff and recharge a local aquifer which covers about 100 hectares area with 36% impermeable [20 hectares road paved, 6 hectares porous car park, 10 hectares roofed and allowable discharge of 10 l/s to be implemented. Figure 6.16 show the indicative drainage scheme].

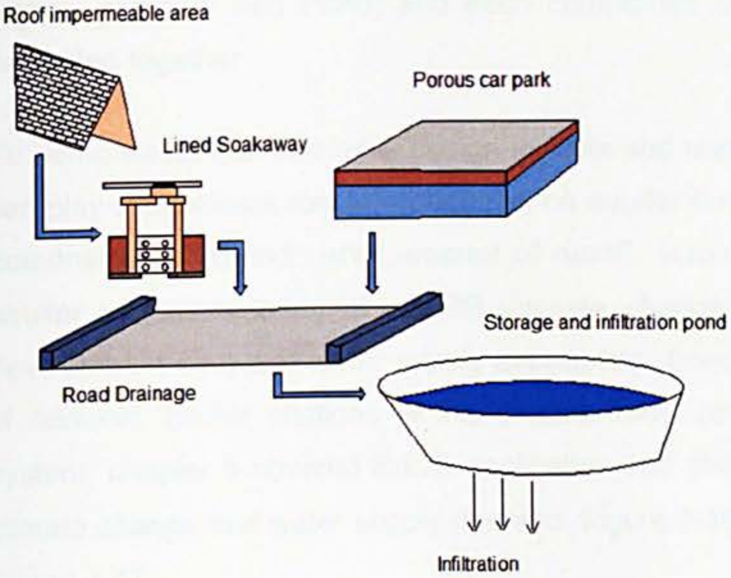


Figure 7.16: Pratt's Quarry indicative drainage scheme

Using WinDes (see 7.4 for software application) is used to estimate storage infiltration pond and Table 7.3, summarises coverage area for the indicative drainage scheme.

Table 7.3: Pratt`s Quarry indicative coverage area

| **Description** | Area (ha) |
|---|---|
| **Roof + Road** | 10 + 20 = 30 |
| **Porous car park** | 6 |
| **Total** | 36 (36% of 100ha) |
| **Permeability** | 2.52 - 7.52 x $10^{-3}$ m/sec (section 5.6) |
| **Infiltration rate** | 0.2m/h (section 7.5) |

Design carried out under source control; design guide leads to simplify the complex process of designing a solution incorporating the use of infiltration system. Some of the design parameters used according to CIRIA (2007) guidance. This indicative drainage scheme has 3 components (Roof & Road, Porous car park and Pond) and each component can be designed and finally cascaded together.

To demonstrate the indicative design models and support the idea that infiltration can play a significant role to reduce risk on aquifer due to urbanisation. a scenario demonstrated to find what amount of runoff volume can be infiltrated to the aquifer and considering of SuDS, climate change impact (no impact on pre development site) and water supply abstraction from the aquifer due to increase of demand. Earlier sections of this chapter have covered options for infiltration system, chapter 5 covered SuDS application and chapter 8 covers the impact of climate change and water supply demand. Figure 7.16 explained by the flow chart Figure 7.17.

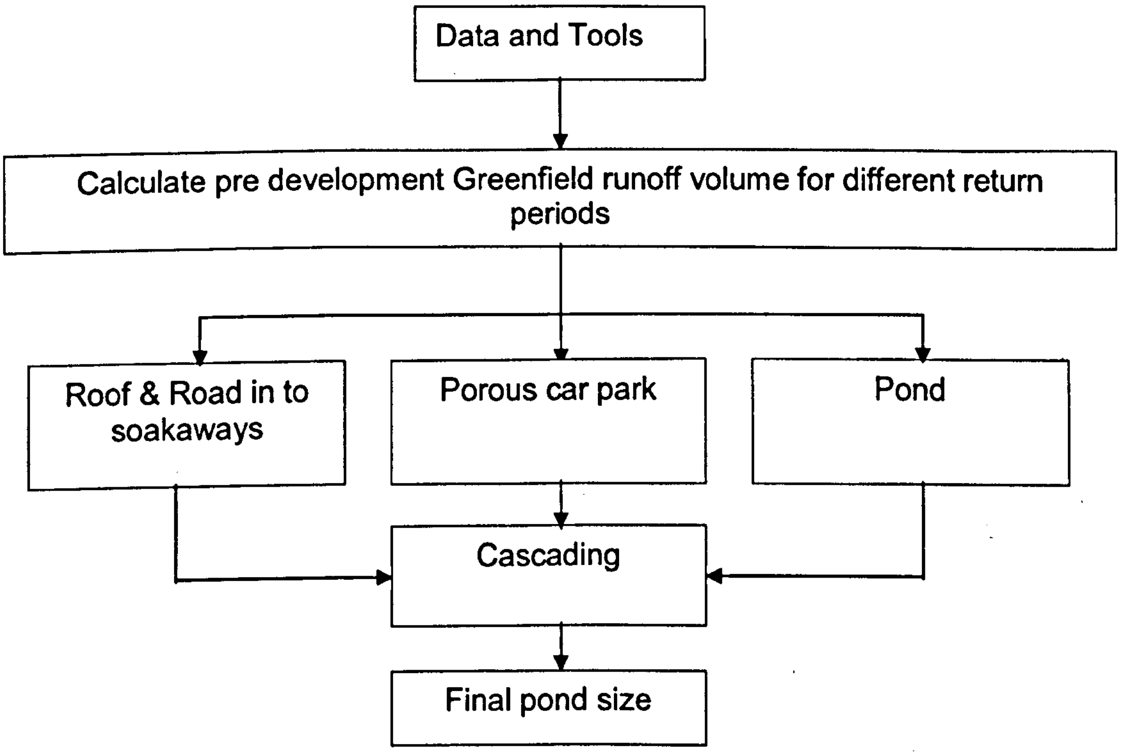


Figure 7.17: Design model calculation process flowchart

### 7.6.1.1 Pre-development Greenfield runoff volume

Greenfield runoff (1) is a concept for which a flow rate discharge constraint is needed for surface water from a site. If there is no provision for infiltration of surface runoff, most of the surface water needs to be discharged from the site by a positive pipe system. This concept used to calculate the Greenfield runoff from the proposed development site in the Leighton.

WinDes and GIS software are used as tools for the purpose of calculating Greenfield runoff volume; however, it is important to understand the parameters of the rainfall model (FSR) for other part of calculations such as SAAR, SPR, CWI and some formulas.

Runoff volume= PR * Areal Reduction Factor * Total Rainfall * Area

PR is defined as a percentage of runoff from a catchment and is expressed as:

**FSR**

$$PR_{total} = PR_{rural} \times (1 - 0.3 \times URBAN/100) + 70 \times (0.3 \times URBAN/100)$$

*where*

$$PR_{rural} = SPR + DPR_{cwi} + DPR_{rain}$$

*and*

$$DPR_{rain} = 0.45 \times (P - 40)^{0.7} \text{ for } P > 40mm$$

$$DPR_{rain} = 0 \text{ for } P \leq 40mm$$

P is the rainfall depth

$$DPR_{cwi} = 0.25 \times (CWI - 125)$$

Defra and the Environment Agency (2005) published a joint research and development program guide for preliminary rainfall runoff management for development for the regulator, developer and Local authorities to advise on management of surface water. This guide explains how to calculate the Greenfield runoff and other related concepts, however, due to the limitation of word counts in this thesis, Greenfield runoff volume calculated by WinDes and the results

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(1) Greenfield runoff can be calculated by different method such as IH124, ICPSUDS and ADAS345.

tabulated for analysis purpose. Following parameters are considered to calculate Greenfield runoff volume for Pratt's Quarry in Leighton Buzzard.

| | | |
|---|---|---|
| M5-60: | The 5 year 60 minute depth of rainfall= | 20 |
| R: | Rainfall ration= | 0.40 |
| SAAR: | Standard Average Annual Rainfall= | 650mm |
| CWI: | Catchment Wetness Index= | 96 |
| SPR: | Standard percentage runoff= | 47 |
| Area1: | Area for roof and road | 30ha |
| Area2: | Area for Porous car park | 6ha |

Table 7.4 presents ruler Greenfield runoff volume on the pre-development catchment for Roof/Road and porous car park as proposed for Pratt's Quarry development for 1 and 30 year return period.

Table 7.4: Ruler Greenfield runoff volume (m3) for 30ha ( Roof & Road)

| Storm Duration | 60min | 120min | 180min | 240min | 300min | 360min |
|---|---|---|---|---|---|---|
| Greenfield runoff volume 1 year RP | 1526 | 1894 | 2139 | 228 | 2482 | 2608 |
| Greenfield runoff volume 30 year RP | 3674 | 4459 | 4967 | 5400 | 5740 | **6032** |

Ruler Greenfield runoff volume (m3) for 6ha ( porous car park)

| Storm Duration | 60min | 120min | 180min | 240min | 300min | 360min |
|---|---|---|---|---|---|---|
| Greenfield runoff volume 1 year RP | 305 | 378 | 427 | 465 | 496 | 522 |
| Greenfield runoff volume 30 year RP | 734 | 888 | 993 | 1080 | 1148 | **1206** |

*(Hint: 360min is the critical time found in next section)*

Above table calculation described that for 360min, 30years return period for Roof and Road impermeable area the Greenfield runoff volume is 6032m$^3$ and for 360min, 30years return period for a porous car park area the Greenfield runoff volume is 1206m$^3$.

The next two sections describe the Roof & Road calculation to lined soakaways and a porous car park design overflow volumes after infiltration. A Pond designed to utilise the overflow runoff volumes total = 6032+ 1206 =7238m$^3$.

### 7.6.1.2 Roof and impermeable area into lined Soakaways

For Pratt's quarry location using Figure 7.14 and Table 7.2, the Rainfall ratio found R= 0.40. It can be calculated on the map option of WinDes. Infiltration Field tests carried out part of the research and most of the design parameters and results tabulated.

Table 7.5a: Field Infiltration coefficient test result

| **Volume of test pit between 75% and 25% of depth (m$^3$)** | **Time taken to drain from 75% to 25% of depth (hrs)** | **Wetted area of pit at 50% of depth (m$^2$)** | **Result (m/hr)** |
|---|---|---|---|
| 1.0 | 1.0 | 5 | 0.2 |
| soil permeability result 2.52 - 7.52 x 10$^{-3}$ m/sec from section 6.6 | | | |

Hydrological data for Leighton Buzzard obtained from Flood Studies Handbook (FSR) for return periods of 30 years without considering climate change. Table 7.5b data and results.

Table 7.5b: Quick storage estimate variable and result for Roof & Road

| **Rainfall data** | **Return period** | **M5-60** | **R** | **Cv (summer)** | **Cv (Winter)** | **Area (ha)** | **Q (l/s)** |
|---|---|---|---|---|---|---|---|
| FSR | 30 | 20 | 0.40 | 0.75 | 0.84 | 30 | 10 |

| **Infiltration coefficient** | **Factor of safety** | **Climate change %** | **Global variable requires storage m$^3$** | **Infiltration into account storage requires m$^3$** |
|---|---|---|---|---|
| 0.2 | 2.0 | 0 | 17660 - 21551 | 2662 - 9077 |

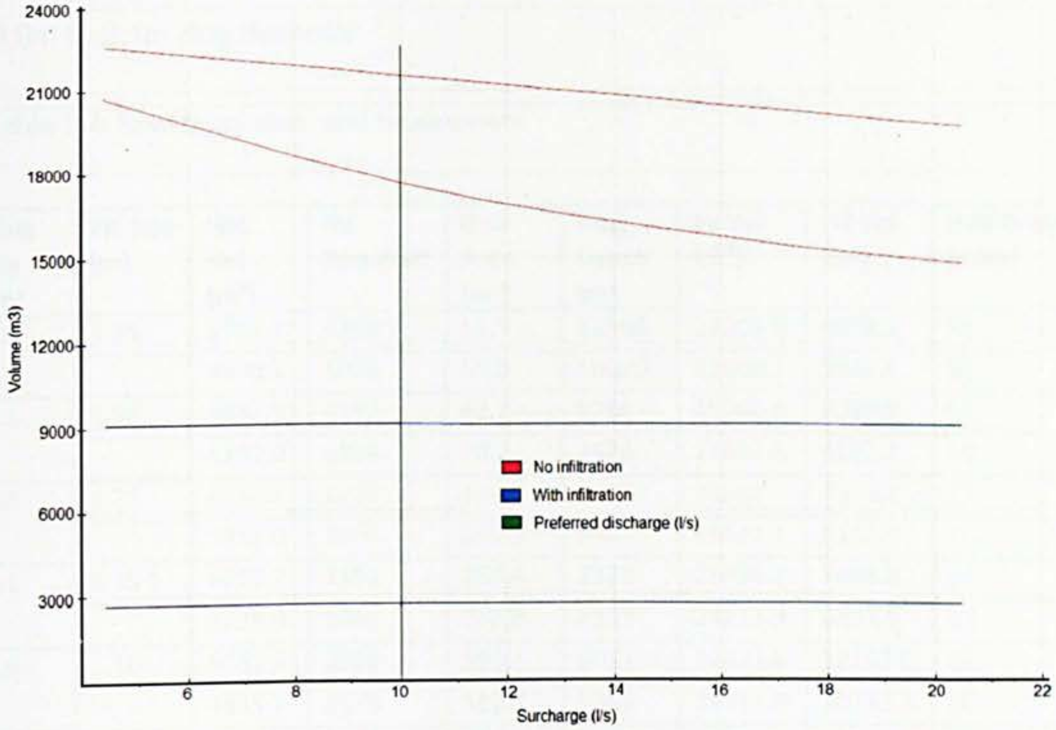


Figure 7.18: Required storage for varying discharge rate

Knowing the required storage size gives the chance to select the infiltration system as a lined soakaway with equal side and base infiltration rates and porosity of 0.3. Table 7.6 shows the required number of lined soakaways.

Table 7.6: Quick design Infiltration System

| **Rainfall data** | **Return period** | **M5-60** | **R** | **Cv** (summer) | **Cv** (Winter) | **Area** (ha) | **Q** (l/s) |
|---|---|---|---|---|---|---|---|
| FSR | 30 | 20 | 0.40 | 0.75 | 0.84 | 30 | 10 |

| **Infiltration structure** | **Infiltration coefficient** **Base/side** | **Factor of safety** | **Porosity** | Result |
|---|---|---|---|---|
| Lined Soakaway | 0.2 | 2 | 0.30 | 1990 - 2225 no. soakaways required for Ring diameter 1.5m with 2.25m pit size, refer to Table 7.7 |

To identify the size of soakaway, Table 7.7 provides soakaway size requirements depending on the design result from Table 7.6 shows Soakaway size ranging from 0.9m to 2.1m ring diameter.

Table 7.7: Soakaway size and requirement

| Ring Dia (m) | Pit Size (m) | Net Vol ($m^3$) | No Required | Unit Area ($m^2$) | Ring Depth (m) | Ex Vol ($m^3$) | Fill Vol ($m^3$) | Half Drain (mins) |
|---|---|---|---|---|---|---|---|---|
| 0.9 | 1.35 | 5751.7 | 5798 | 51.7 | 11596 | 24303.8 | 6878.3 | 51 |
| | | 4970.1 | 5010 | 59.9 | 10020 | 21000.7 | 5943.5 | 51 |
| 1.1 | 1.58 | 5937.3 | 4397 | 68.2 | 8794 | 25086.8 | 7099.9 | 57 |
| | | 5182.0 | 3838 | 78.2 | 7676 | 21897.5 | 6197.3 | 56 |
| **1.5** | **2.25** | **6130.2** | **2225** | **134.8** | **4450** | **25907.3** | **7332.2** | **71** |
| | | **5483.8** | **1990** | **150.8** | **3980** | **23171.1** | **6557.8** | **70** |
| 2.1 | 3.15 | 6269.7 | 1161 | 258.4 | 2322 | 26496.1 | 7498.8 | 84 |
| | | 5728.0 | 1061 | 282.8 | 2122 | 24213.9 | 6852.9 | 83 |
| 0.9 | 2.16 | 5581.6 | 3026 | 99.1 | 6052 | 32471.6 | 12193.0 | 51 |
| | | 4935.7 | 2676 | 112.1 | 5352 | 28715.8 | 10782.7 | 50 |
| 1.1 | 2.52 | 5640.1 | 2246 | 133.6 | 4492 | 32804.9 | 12318.2 | 55 |
| | | 5130.7 | 2044 | 146.8 | 4088 | 29854.5 | 11210.3 | 55 |
| 1.5 | 3.60 | 5792.4 | 1131 | 265.3 | 2262 | 33712.8 | 12659.1 | 66 |
| | | 5351.1 | 1045 | 287.1 | 2090 | 31149.4 | 11696.5 | 65 |
| 2.1 | 5.04 | 5964.3 | 594 | 505.1 | 1188 | 34703.7 | 13031.2 | 75 |
| | | 5555.3 | 554 | 541.5 | 1108 | 32366.7 | 12153.6 | 74 |

Detailed design for infiltration systems as lined soakaways carried out in order to introduce outflow control. There are several online outflow controls available, but the most common are orifice and Hydro-Brake (Self activating vortex flow control device).Table 7.8 shows that global variable data are considered for the design purpose.

Table 7.8: Global variable for detailed design

| **Inflow** | **Additional flow** | **Storage structure** | **Outflow control** | **Overflow control** | **Climate change %** |
|---|---|---|---|---|---|
| Rainfall data | None | Lined Soakaway | Hydro-Brake | None | 0 |

The total contributing area is 30ha, with a cover level of 102.30m and invert level 100.00 (assumed). Hydro-Brake control flow device diameter 131mm is calculated for design head of 1 m. From Table 7.6, the required numbers of soakaways are between 1990 - 2225, selecting 2200 soakaways for the purpose of design to check the maximum depth of storm water in the system. Table 7.9 shows the result on the basis of the storm for 15 min to 10080 min (7 days) summer and winter events. The critical event with maximum depth of water is coloured as red.

Table 7.9: Detailed design infiltration system result

| **Storm Event** | **Rain (mm/h)** | **Time to Vol Peak (min)** | **Max Water Level (m)** | **Max Depth (m)** | **Max Control (l/s)** | **Max Filtration (l/s)** | **ΣMax Out flow (l/s)** | **Max Vol ($m^3$)** | **Status** |
|---|---|---|---|---|---|---|---|---|---|
| 15 min Summer | 77.235 | 22 | 100.625 | 0.625 | 9.4 | 653.0 | 661.6 | 3786.7 | O K |
| 30 min Summer | 49.899 | 35 | 100.760 | 0.760 | 9.4 | 727.5 | 736.5 | 4607.9 | O K |
| 60 min Summer | 30.811 | 58 | 100.829 | 0.829 | 9.4 | 765.2 | 774.4 | 5024.6 | O K |
| 120 min Summer | 18.470 | 90 | 100.826 | 0.826 | 9.4 | 763.5 | 772.7 | 5006.2 | O K |
| 180 min Summer | 13.552 | 124 | 100.788 | 0.788 | 9.4 | 742.6 | 751.7 | 4777.2 | O K |
| 240 min Summer | 10.835 | 160 | 100.744 | 0.744 | 9.4 | 718.7 | 727.6 | 4511.8 | O K |
| 360 min Summer | 7.880 | 226 | 100.663 | 0.663 | 9.4 | 674.2 | 682.9 | 4021.0 | O K |
| 480 min Summer | 6.286 | 294 | 100.593 | 0.593 | 9.4 | 635.7 | 644.3 | 3596.9 | O K |
| 600 min Summer | 5.271 | 358 | 100.532 | 0.532 | 9.4 | 601.8 | 610.5 | 3223.2 | O K |
| 720 min Summer | 4.564 | 422 | 100.477 | 0.477 | 9.4 | 571.6 | 580.3 | 2891.4 | O K |
| 960 min Summer | 3.634 | 546 | 100.385 | 0.385 | 9.4 | 521.3 | 530.4 | 2335.6 | O K |
| 1440 min Summer | 2.633 | 786 | 100.252 | 0.252 | 9.3 | 447.8 | 457.1 | 1527.6 | O K |
| 2160 min Summer | 1.906 | 1148 | 100.130 | 0.130 | 5.9 | 380.7 | 386.6 | 788.1 | O K |
| 2880 min Summer | 1.514 | 1476 | 100.065 | 0.065 | 2.3 | 345.0 | 347.3 | 392.7 | O K |
| 4320 min Summer | 1.094 | 2176 | 100.040 | 0.040 | 1.1 | 267.8 | 268.9 | 239.9 | O K |
| 5760 min Summer | 0.868 | 2912 | 100.032 | 0.032 | 0.7 | 213.9 | 214.6 | 191.3 | O K |
| 7200 min Summer | 0.725 | 3672 | 100.026 | 0.026 | 0.5 | 176.9 | 177.4 | 160.3 | O K |
| 8640 min Summer | 0.626 | 4304 | 100.023 | 0.023 | 0.4 | 153.3 | 153.7 | 137.4 | O K |
| 10080 min Summer | 0.553 | 5000 | 100.020 | 0.020 | 0.3 | 136.4 | 136.8 | 121.8 | O K |
| 15 min Winter | 77.235 | 22 | 100.706 | 0.706 | 9.4 | 697.5 | 706.3 | 4277.3 | O K |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 30 min Winter | 49.899 | 35 | 100.863 | 0.863 | 9.4 | 784.2 | 793.5 | 5233.3 | O K |
| **60 min Winter** | **30.811** | **60** | **100.949** | **0.949** | **9.7** | **831.2** | **840.9** | **5752.6** | **O K** |
| 120 min Winter | 18.470 | 96 | 100.940 | 0.940 | 9.6 | 826.2 | 835.9 | 5698.4 | O K |
| 180 min Winter | 13.552 | 134 | 100.886 | 0.886 | 9.4 | 796.5 | 806.0 | 5368.8 | O K |
| 240 min Winter | 10.835 | 170 | 100.821 | 0.821 | 9.4 | 761.1 | 770.2 | 4978.7 | O K |
| 360 min Winter | 7.880 | 242 | 100.703 | 0.703 | 9.4 | 696.2 | 704.9 | 4262.5 | O K |
| 480 min Winter | 6.286 | 310 | 100.603 | 0.603 | 9.4 | 641.2 | 649.8 | 3656.4 | O K |
| 600 min Winter | 5.271 | 378 | 100.518 | 0.518 | 9.4 | 594.1 | 602.8 | 3139.1 | O K |
| 720 min Winter | 4.564 | 442 | 100.444 | 0.444 | 9.4 | 553.7 | 562.6 | 2694.0 | O K |
| 960 min Winter | 3.634 | 570 | 100.326 | 0.326 | 9.4 | 488.5 | 497.9 | 1974.7 | O K |
| 1440 min Winter | 2.633 | 810 | 100.166 | 0.166 | 7.6 | 400.8 | 408.4 | 1008.3 | O K |
| 2160 min Winter | 1.906 | 1104 | 100.050 | 0.050 | 1.5 | 335.2 | 336.7 | 300.8 | O K |
| 2880 min Winter | 1.514 | 1460 | 100.040 | 0.040 | 1.1 | 267.8 | 268.9 | 239.8 | O K |
| 4320 min Winter | 1.094 | 2204 | 100.029 | 0.029 | 2.5 | 193.7 | 194.3 | 173.2 | O K |
| 5760 min Winter | 0.868 | 2984 | 100.023 | 0.023 | 2.0 | 153.3 | 153.7 | 136.8 | O K |
| 7200 min Winter | 0.725 | 3632 | 100.019 | 0.019 | 1.7 | 129.7 | 130.0 | 115.6 | O K |
| 8640 min Winter | 0.626 | 4392 | 100.017 | 0.017 | 1.4 | 112.9 | 113.1 | 100.2 | O K |
| 10080 min Winter | 0.553 | 5176 | 100.015 | 0.015 | 1.3 | 99.4 | 99.6 | 88.2 | O K |

The result shows that a maximum depth of **0.949 m** is reached during the 60 minutes winter storm. This is within the available soakaway depth on 1m, thus the result is satisfactory. Figure 7.19 presents inflow/out flow, volume and depth verse time diagrams for the proposed infiltration system. The maximum infiltration found 831.2 l/s for 60 min winter storm event with the maximum volume of 5752.6 m$^3$.

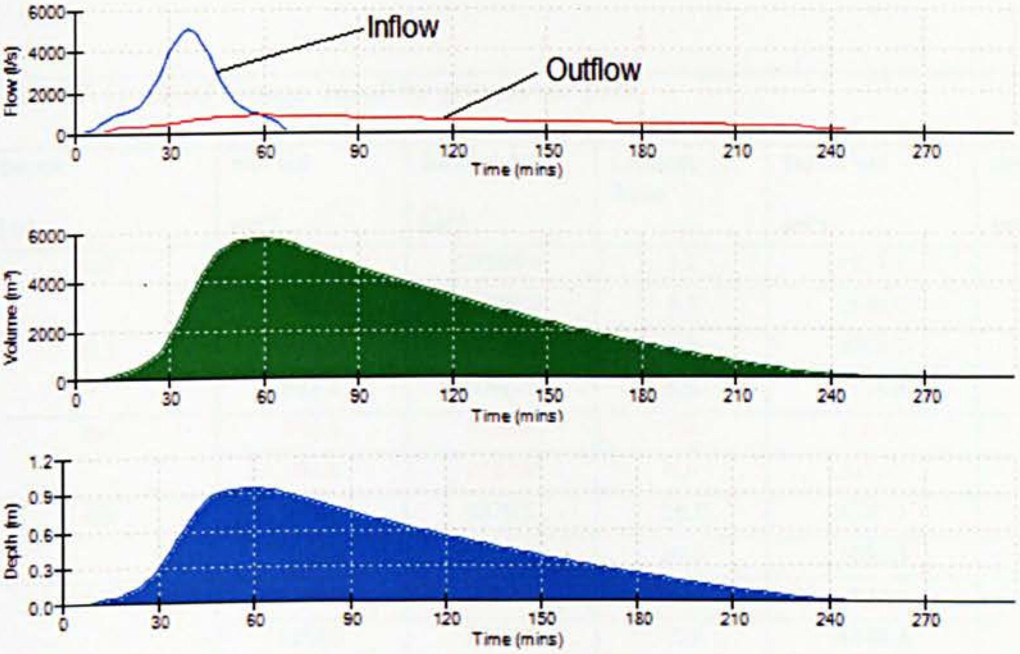


Figure 7.19: 60 min winter critical diagrams for flow, volume and depth

### 7.6.1.3 Porous Car Park

The design of porous car park, following a similar process to the one used for the soakaways, for a car park of by 0.4m storage depth as the permeable pavement infiltration system detailed earlier. Table 7.10 shows quick design data and the result of the infiltration structure at the porous car park with 6ha area taken from Table 7.3.

Table 7.10: Quick design Infiltration system for porous car park

| **Rainfall data** | **Return period** | **M5-60** | **R** | **Cv (summer)** | **Cv (Winter)** | **Area (ha)** | **Q (l/s)** |
|---|---|---|---|---|---|---|---|
| FSR | 30 | 20 | 0.40 | 0.75 | 0.84 | 6 | 10 |
| | | | | | | | |
| **Infiltration structure** | **Infiltration coefficient Base/side** | **Factor of safety** | **Porosity** | Result | | | |
| Porous car park | 0.2 | 2 | 0.30 | For 0.4m depth, surface area is requires between 7527.6 - 8135.6 (8100 $m^2$) from Table 6.11. | | | |

Table 7.11: Quick design result for porous car park

| Depth (m) | Net Vol (m³) | Surface Area (m²) | Capacity Ratio | Ex/Fill Vol (m³) | Half Drain (mins) |
|---|---|---|---|---|---|
| 0.2 | 873.5 | 14558.6 | 4.1 | 2911.7 | 24 |
| | 761.4 | 12689.9 | 4.7 | 2538.0 | 23 |
| 0.3 | 919.1 | 10212.3 | 5.9 | 3063.7 | 32 |
| | 833.4 | 9260.5 | 6.5 | 2778.1 | 31 |
| 0.4 | 976.3 | 8135.6 | 7.4 | 3254.2 | 41 |
| | 903.3 | 7527.6 | 8.0 | 3011.1 | 39 |
| 0.6 | 1058.3 | 5879.5 | 10.2 | 3527.7 | 58 |
| | 1014.4 | 5635.5 | 10.6 | 3381.3 | 55 |
| 1.0 | 1178.2 | 3927.4 | 15.3 | 3927.4 | 92 |
| | 1154.5 | 3848.4 | 15.6 | 3848.4 | 86 |
| 1.5 | 1317.5 | 2927.8 | 20.5 | 4391.6 | 135 |
| | 1283.0 | 2851.1 | 21.0 | 4276.7 | 124 |
| 2.0 | 1399.6 | 2332.6 | 25.7 | 4665.2 | 176 |
| | 1360.0 | 2266.6 | 26.5 | 4533.2 | 159 |

Similar to the lined soakaway detailed design Table 7.12 presents Global variable for porous car park storage structure and outflow control. Depth of 400mm for the storage structure is according to the availability of standard Aquavoid crates.

Table 7.12: Global variable for detailed design

| Inflow | Additional flow | Storage structure | Outflow control | Overflow control | Climate change % |
|---|---|---|---|---|---|
| Rainfall data | None | Porous car park | Hydro-Brake | None | 0 |

The total contributing area is 6ha with a cover level of 100.70m and invert level 100.00m. Hydro-Brake control flow device 157mm diameter is calculated for design head of 400mm. The size of car park is considered as squared with dimension 90x90m to provide required surface area within the range (8100 m$^2$) with maximum infiltration 225 l/s for 60min winter storm event with maximum volume of 873.9 m$^3$ as Table 7.13.

Table 7.13 shows the result on the basis of storm for 15 minutes to 7 days summer and winter events. The critical event with maximum depth of water is coloured as red.

Table 7.13: Detailed design infiltration system result

| Storm Event | Rain (mm/h) | Time to Vol Peak (mins) | Max Water Level (m) | Max Depth (m) | Max Cot-rol (l/s) | Max Filtr-ation (l/s) | ΣMax Out flow (l/s) | Max Vol (m³) | Status |
|---|---|---|---|---|---|---|---|---|---|
| 15 min Summer | 77.235 | 21 | 100.294 | 0.294 | 7.0 | 225.0 | 232.0 | 605.7 | O K |
| 30 min Summer | 49.899 | 32 | 100.348 | 0.348 | 7.6 | 225.0 | 232.6 | 737.1 | O K |
| 60 min Summer | 30.811 | 50 | 100.353 | 0.353 | 7.7 | 225.0 | 232.7 | 749.3 | O K |
| 120 min Summer | 18.470 | 84 | 100.317 | 0.317 | 7.3 | 225.0 | 232.3 | 661.5 | O K |
| 180 min Summer | 13.552 | 118 | 100.275 | 0.275 | 6.8 | 225.0 | 231.8 | 558.2 | O K |
| 240 min Summer | 10.835 | 148 | 100.234 | 0.234 | 6.3 | 225.0 | 231.3 | 459.5 | O K |
| 360 min Summer | 7.880 | 208 | 100.167 | 0.167 | 5.0 | 225.0 | 230.0 | 295.4 | O K |
| 480 min Summer | 6.286 | 264 | 100.120 | 0.120 | 3.7 | 225.0 | 228.7 | 182.5 | O K |
| 600 min Summer | 5.271 | 318 | 100.093 | 0.093 | 2.8 | 225.0 | 227.8 | 116.8 | O K |
| 720 min Summer | 4.564 | 376 | 100.082 | 0.082 | 2.4 | 205.6 | 208.0 | 91.4 | O K |
| 960 min Summer | 3.634 | 494 | 100.068 | 0.068 | 1.9 | 169.4 | 171.3 | 62.1 | O K |
| 1440 min Summer | 2.633 | 734 | 100.051 | 0.051 | 1.4 | 126.9 | 128.2 | 34.7 | O K |
| 2160 min Summer | 1.906 | 1100 | 100.043 | 0.043 | 1.1 | 93.5 | 94.7 | 25.0 | O K |
| 2880 min Summer | 1.514 | 1432 | 100.038 | 0.038 | 1.0 | 73.2 | 74.1 | 19.8 | O K |
| 4320 min Summer | 1.094 | 2140 | 100.033 | 0.033 | 0.8 | 53.6 | 54.4 | 14.3 | O K |
| 5760 min Summer | 0.868 | 2872 | 100.029 | 0.029 | 0.7 | 42.8 | 43.5 | 11.5 | O K |
| 7200 min Summer | 0.725 | 3656 | 100.027 | 0.027 | 0.6 | 35.8 | 36.4 | 9.6 | O K |
| 8640 min Summer | 0.626 | 4320 | 100.025 | 0.025 | 0.6 | 30.6 | 31.2 | 8.2 | O K |
| 10080 min Summer | 0.553 | 4992 | 100.023 | 0.023 | 0.5 | 27.0 | 27.5 | 7.2 | O K |
| 15 min Winter | 77.235 | 22 | 100.333 | 0.333 | 7.5 | 225.0 | 232.5 | 700.5 | O K |
| 30 min Winter | 49.899 | 33 | 100.397 | 0.397 | 8.1 | 225.0 | 233.1 | 856.1 | O K |
| 60 min Winter | 30.811 | 54 | 100.405 | 0.405 | 8.2 | 225.0 | 233.2 | 873.9 | O K |
| 120 min Winter | 18.470 | 90 | 100.348 | 0.348 | 7.6 | 225.0 | 232.6 | 736.9 | O K |
| 180 min Winter | 13.552 | 126 | 100.281 | 0.281 | 6.9 | 225.0 | 231.9 | 574.4 | O K |
| 240 min Winter | 10.835 | 158 | 100.219 | 0.219 | 6.1 | 225.0 | 231.1 | 422.4 | O K |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| 360 min Winter | 7.880 | 212 | 100.124 | 0.124 | 3.8 | 225.0 | 228.8 | 190.9 | O K |
| 480 min Winter | 6.286 | 258 | 100.085 | 0.085 | 2.5 | 211.9 | 214.4 | 97.5 | O K |
| 600 min Winter | 5.271 | 316 | 100.072 | 0.072 | 2.1 | 180.6 | 182.7 | 70.6 | O K |
| 720 min Winter | 4.564 | 374 | 100.063 | 0.063 | 1.8 | 158.1 | 159.9 | 53.7 | O K |
| 960 min Winter | 3.634 | 490 | 100.051 | 0.051 | 1.4 | 126.9 | 128.2 | 34.6 | O K |
| 1440 min Winter | 2.633 | 734 | 100.043 | 0.043 | 1.1 | 93.5 | 94.7 | 25.0 | O K |
| 2160 min Winter | 1.906 | 1080 | 100.037 | 0.037 | 0.9 | 67.5 | 68.5 | 18.0 | O K |
| 2880 min Winter | 1.514 | 1428 | 100.033 | 0.033 | 0.8 | 53.6 | 54.4 | 14.2 | O K |
| 4320 min Winter | 1.094 | 2216 | 100.028 | 0.028 | 0.6 | 38.5 | 39.2 | 10.3 | O K |
| 5760 min Winter | 0.868 | 2936 | 100.025 | 0.025 | 0.6 | 30.6 | 31.2 | 8.2 | O K |
| 7200 min Winter | 0.725 | 3576 | 100.023 | 0.023 | 0.5 | 25.9 | 26.4 | 6.9 | O K |
| 8640 min Winter | 0.626 | 4312 | 100.021 | 0.021 | 0.4 | 21.5 | 22.0 | 6.0 | O K |
| 10080 min Winter | 0.553 | 5024 | 100.020 | 0.020 | 0.4 | 19.5 | 19.9 | 5.2 | O K |

The result shows a maximum depth of **405mm** for the 60 minutes winter storm. This is within designated maximum of 600mm for the car park storage depth, therefore it is a satisfactory design. Figure 7.20 presents inflow/out flow, volume and depth verse time diagrams for the proposed infiltration system.

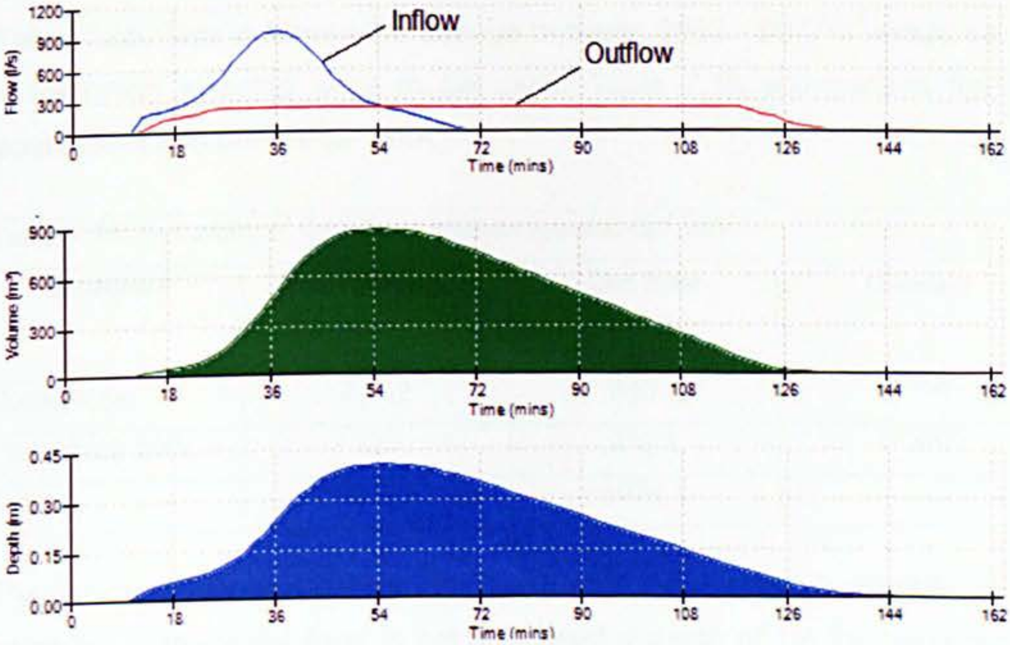


Figure 7.20: 60 min winter diagrams for critical flow, volume and depth for porous car park

### 7.6.1.4 Pond design

The last element of the tripartite approach to storage is the infiltration pond; in this case, the required storage is dependent upon the outflow from the car park and the soakaway. A quick design cannot give a starting point. Therefore it is straight to detailed design variables. Table 7.14 shows global variable for a detailed design for pond. The outflow control and overflow control are different from Soakaways and Porous car park.

Table 7.14: Global variable for detailed design

| Inflow | Additional flow | Storage structure | Outflow control | Overflow control | Climate change % |
|---|---|---|---|---|---|
| Rainfall data | None | Tank or pond or infiltration basin | Crown Vortex valve | Weir | 0 |

*Crown Vortex valve : self-activated device to control flow*

The area can be calculated for the pond using quick storage estimate result from Table 7.5b. This indicated the storage between 2662 - 9077m$^3$ would be required if infiltration systems were to be used. Table 7.15 summarises the data for soakaways and porous car park.

Table 7.15: Summary of flow from soakaways and car park

| Structure | Max infiltration (l/s) | Out flow (l/s) | Comment |
|---|---|---|---|
| Soakaways | 831.2 | 840.9 | 30 YRP |
| Porous car park | 225 | 233.2 | 30 YRP |
| Total | 1056.2 | 1074.1 | |

Pond size assumed **2000m$^3$** for start with 20% extra in storage for climate changes. If the water level is not to exceed a depth of 1m the pond area will be **2000m$^2$**, Table 7.16 shows the pond levels and Figure 7.21 shows for clarity of level.

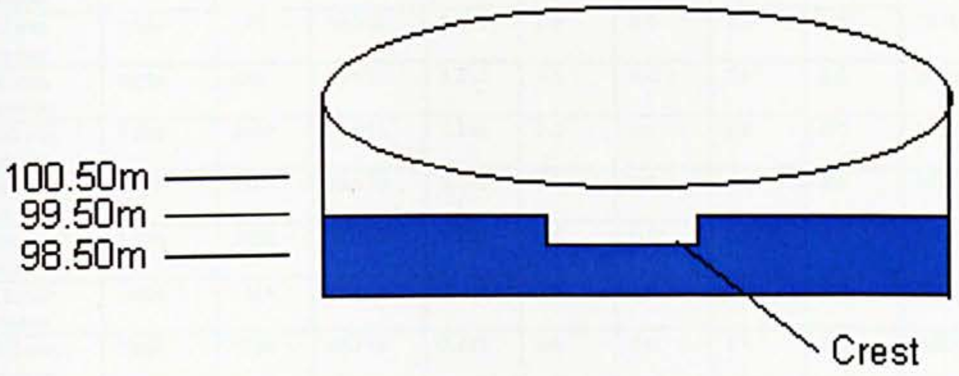


Figure 7.21: Pond Level

| Table 7.16: Pond Level | |
|---|---|
| **Level** | **m (AOD)** |
| Cover Level | 100.50 |
| Inver level | 98.50 |
| Crest Level | 99.50 |

Table 7.17 shows pond detailed design result with no overflow and maximum **3478.7m$^3$** capacity volume. The whole volume supposed to recharge to the aquifer due to no overflow.

Table 7.17: Pond detailed design result

| **Storm Event** | **Rain (mm/h)** | **Time to Vol Peak (min)** | **Max Water Level (m)** | **Max D (m)** | **Max Control (l/s)** | **Max Over flow (l/s)** | **Σ Max Out flow (l/s)** | **Over flow Vol (m³)** | **Max Vol (m³)** | **Status** |
|---|---|---|---|---|---|---|---|---|---|---|
| 15 min Summer | 77.235 | 27 | 98.904 | 0.404 | 1.9 | 0.0 | 1.9 | 0.0 | 866.2 | O K |
| 30 min Summer | 49.899 | 42 | 99.013 | 0.513 | 2.0 | 0.0 | 2.0 | 0.0 | 1118.4 | O K |
| 60 min Summer | 30.811 | 72 | 99.122 | 0.622 | 2.1 | 0.0 | 2.1 | 0.0 | 1378.9 | O K |
| 120 min Summer | 18.470 | 132 | 99.231 | 0.731 | 2.2 | 0.0 | 2.2 | 0.0 | 1647.8 | O K |
| 180 min Summer | 13.552 | 192 | 99.294 | 0.794 | 2.3 | 0.0 | 2.3 | 0.0 | 1808.1 | O K |
| 240 min Summer | 10.835 | 252 | 99.338 | 0.838 | 2.3 | 0.0 | 2.3 | 0.0 | 1921.8 | O K |
| 360 min Summer | 7.880 | 372 | 99.401 | 0.901 | 2.4 | 0.0 | 2.4 | 0.0 | 2084.9 | O K |
| 480 min Summer | 6.286 | 490 | 99.446 | 0.946 | 2.4 | 0.0 | 2.4 | 0.0 | 2205.6 | O K |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| 600 min Summer | 5.271 | 610 | 99.482 | 0.982 | 2.4 | 0.0 | 2.4 | 0.0 | 2300.4 | O K |
| 720 min Summer | 4.564 | 730 | 99.510 | 1.010 | 2.4 | 0.0 | 2.4 | 0.0 | 2378.2 | O K |
| 960 min Summer | 3.634 | 970 | 99.555 | 1.055 | 2.5 | 0.0 | 2.5 | 0.0 | 2500.3 | O K |
| 1440 min Summer | 2.633 | 1450 | 99.616 | 1.116 | 2.5 | 0.0 | 2.5 | 0.0 | 2667.6 | O K |
| 2160 min Summer | 1.906 | 2168 | 99.670 | 1.170 | 2.6 | 0.0 | 2.6 | 0.0 | 2820.3 | O K |
| 2880 min Summer | 1.514 | 2888 | 99.702 | 1.202 | 2.6 | 0.0 | 2.6 | 0.0 | 2912.5 | O K |
| 4320 min Summer | 1.094 | 4324 | 99.734 | 1.234 | 2.6 | 0.0 | 2.6 | 0.0 | 3004.1 | O K |
| 5760 min Summer | 0.868 | 5760 | 99.743 | 1.243 | 2.6 | 0.0 | 2.6 | 0.0 | 3028.3 | O K |
| 7200 min Summer | 0.725 | 7200 | 99.738 | 1.238 | 2.6 | 0.0 | 2.6 | 0.0 | 3015.1 | O K |
| 8640 min Summer | 0.626 | 8392 | 99.725 | 1.225 | 2.6 | 0.0 | 2.6 | 0.0 | 2978.7 | O K |
| 10080 min Summer | 0.553 | 8976 | 99.711 | 1.211 | 2.6 | 0.0 | 2.6 | 0.0 | 2937.5 | O K |
| 15 min Winter | 77.235 | 27 | 98.950 | 0.450 | 1.9 | 0.0 | 1.9 | 0.0 | 970.5 | O K |
| 30 min Winter | 49.899 | 42 | 99.070 | 0.570 | 2.1 | 0.0 | 2.1 | 0.0 | 1253.1 | O K |
| 60 min Winter | 30.811 | 72 | 99.189 | 0.689 | 2.2 | 0.0 | 2.2 | 0.0 | 1545.1 | O K |
| 120 min Winter | 18.470 | 130 | 99.309 | 0.809 | 2.3 | 0.0 | 2.3 | 0.0 | 1847.1 | O K |
| 180 min Winter | 13.552 | 190 | 99.379 | 0.879 | 2.3 | 0.0 | 2.3 | 0.0 | 2027.3 | O K |
| 240 min Winter | 10.835 | 248 | 99.427 | 0.927 | 2.4 | 0.0 | 2.4 | 0.0 | 2155.5 | O K |
| 360 min Winter | 7.880 | 368 | 99.496 | 0.996 | 2.4 | 0.0 | 2.4 | 0.0 | 2339.7 | O K |
| 480 min Winter | 6.286 | 486 | 99.547 | 1.047 | 2.5 | 0.0 | 2.5 | 0.0 | 2476.4 | O K |
| 600 min Winter | 5.271 | 604 | 99.586 | 1.086 | 2.5 | 0.0 | 2.5 | 0.0 | 2584.1 | O K |
| 720 min Winter | 4.564 | 722 | 99.617 | 1.117 | 2.5 | 0.0 | 2.5 | 0.0 | 2672.7 | O K |
| 960 min Winter | 3.634 | 960 | 99.667 | 1.167 | 2.6 | 0.0 | 2.6 | 0.0 | 2812.6 | O K |
| 1440 min Winter | 2.633 | 1432 | 99.735 | 1.235 | 2.6 | 0.0 | 2.6 | 0.0 | 3006.0 | O K |
| 2160 min Winter | 1.906 | 2140 | 99.797 | 1.297 | 2.7 | 0.0 | 2.7 | 0.0 | 3186.7 | O K |
| 2880 min Winter | 1.514 | 2848 | 99.835 | 1.335 | 2.7 | 0.0 | 2.7 | 0.0 | 3299.6 | O K |
| 4320 min Winter | 1.094 | 4240 | 99.876 | 1.376 | 2.7 | 0.0 | 2.7 | 0.0 | 3422.8 | O K |
| 5760 min Winter | 0.868 | 5600 | 99.892 | 1.392 | 2.7 | 0.0 | 2.7 | 0.0 | 3471.3 | O K |
| **7200 min Winter** | **0.725** | **6984** | **99.895** | **1.395** | **2.7** | **0.0** | **2.7** | **0.0** | **3478.8** | **O K** |
| 8640 min Winter | 0.626 | 8296 | 99.889 | 1.389 | 2.7 | 0.0 | 2.7 | 0.0 | 3460.9 | O K |
| 10080 min Winter | 0.553 | 9576 | 99.877 | 1.377 | 2.7 | 0.0 | 2.7 | 0.0 | 3425.8 | O K |

Figure 7.22 presents inflow/out flow, volume and depth verse time diagrams for the proposed pond. The provided weir overflow control depth line indicates that the storm water will not reach 1.5m depth during the 30 years events.

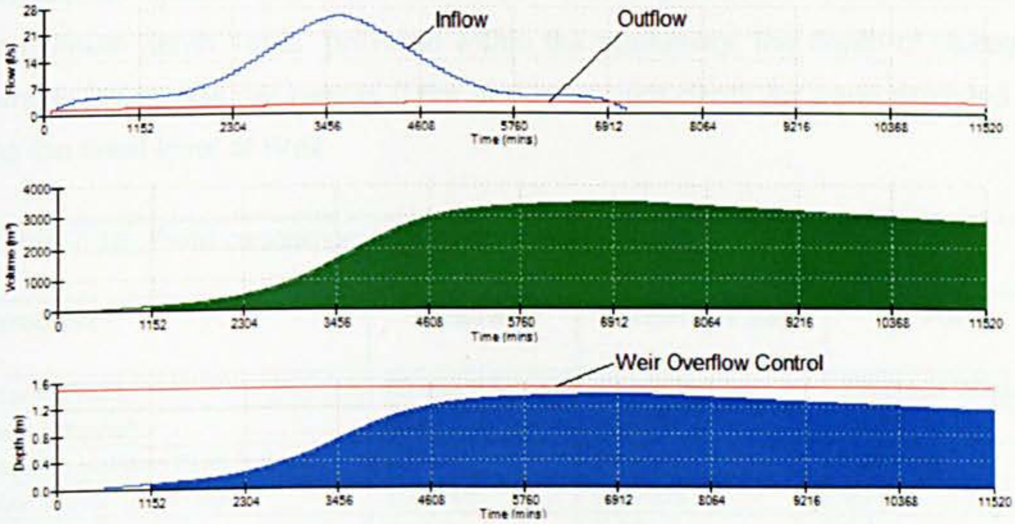


Figure 7.22: 60 min winter diagrams for critical flow, volume and depth for pond

## 7.7 Cascading the SuDS structures

Pond size maximum volume of **3478.8m$^3$** gave the required storage to control soakaways and car park overflow, still the final part is to cascade all the structures together and check to provide a satisfactory design result in terms of size. Figure 7.23 shows the cascade scheme of the structure and Table 7.18 shows the final infiltration system results.

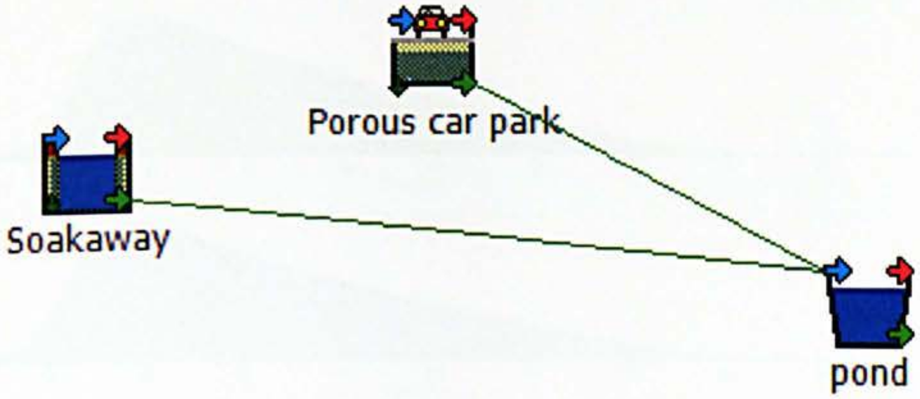


Figure 7.23: Cascade scheme for structures

Table 7.18 shows the final cascading infiltration system result for the indicative infiltration system structures (lined soakaway, porous car park and pond). The maximum depth 1m is provided within the soakaway, the depth of storage Crete under for porous car park is 0.6m and maximum depth for pond provided is 1.5m to the crest level of Weir.

Table 7.18: Final cascading infiltration system result

| **Structure** | **Soakaway** | **Porous Car park** | **Pond** |
|---|---|---|---|
| Storm Event | 60 min Winter | 60 min Winter | 7200 min Winter |
| Rain (mm/hr) | 30.811 | 30.811 | 0.725 |
| Time to Volume Peak (mins) | 60 | 54 | 6984 |
| Max Water Level (m) | 100.949 | 100.405 | 99.939 |
| Max Depth (m) | 0.949 | 0.405 | 1.439 |
| Max Control (l/s) | 9.7 | 8.2 | 2.8 |
| Σ Max Outflow (l/s) | 831.2 | 225.0 | 0.0 |
| Overflow Volume(m$^3$) | 840.9 | 233.2 | 2.8 |
| Max Volume (m$^3$) | 5752.6 | 873.9 | 3613.5 |
| Status | ok | ok | ok |
| Graph refer to Figure | 7.24 | 7.25 | 7.26 |

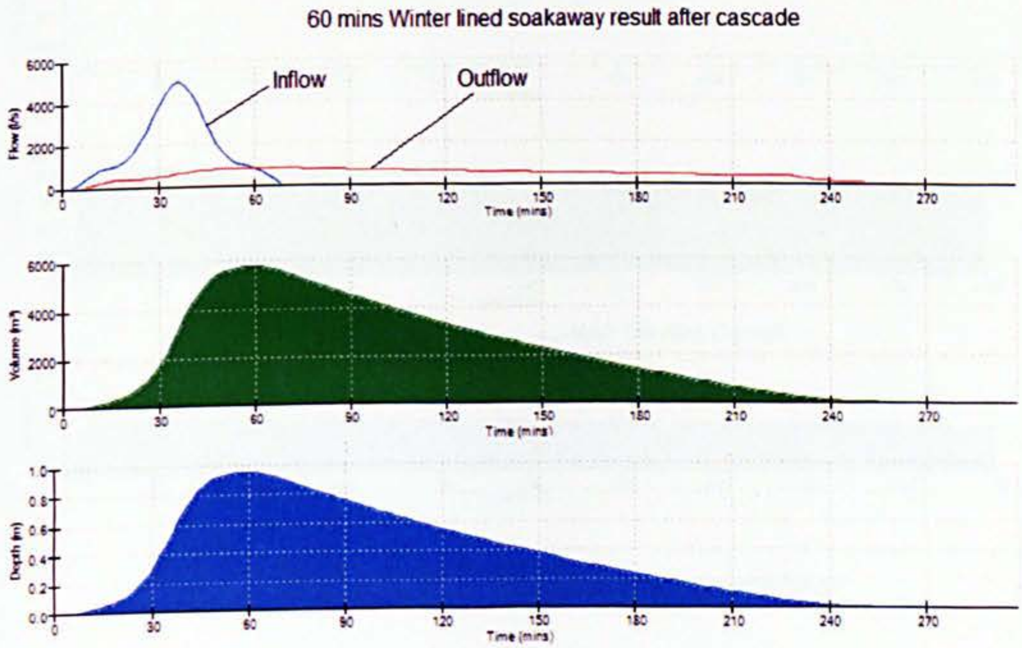


Figure 7.24: Soakaways result after cascading

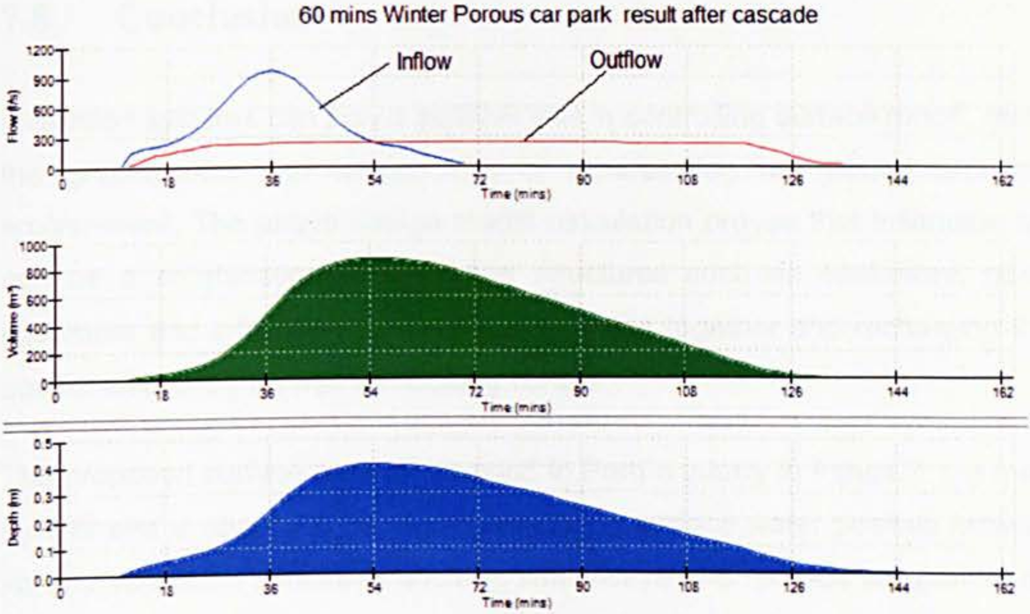


Figure 7.25: Porous car park result after cascading

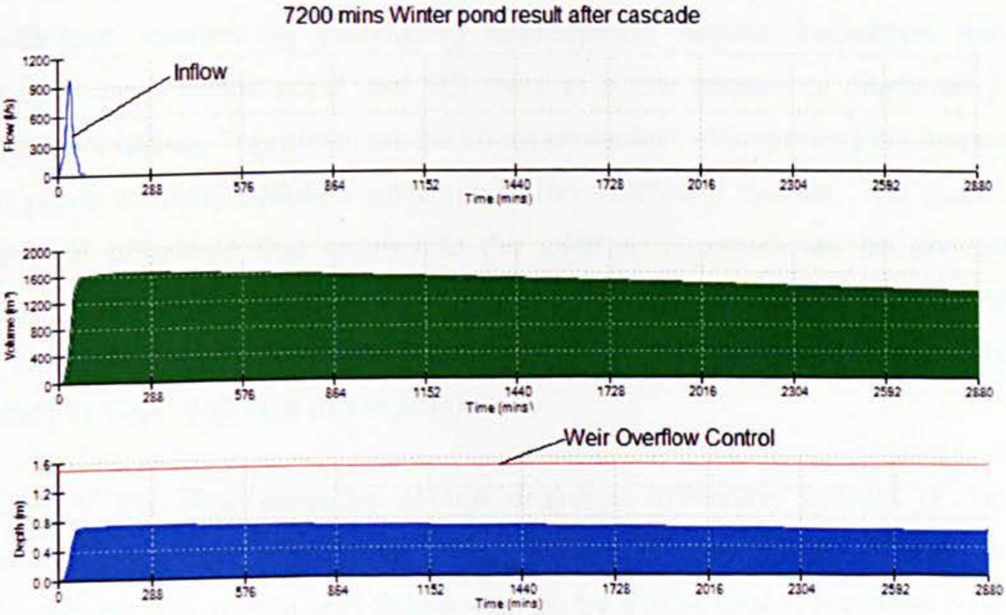


Figure 7.26: Pond result after cascading

The required pond storage volume is 3613.5m$^3$ and assumed depth 1m thus the surface area of the pond is 3613.5m$^2$.

## 7.8 Conclusion

Infiltration systems can play a positive role in controlling surface runoff, recharging the groundwater and reduce risk of urbanisation on groundwater and the environment. The above design model calculation proves that infiltration systems can be a combination of infiltration structures such as soakaway, permeable pavement and infiltration basin of ponds acting together and recharging the local aquifer effectively as well as flooding control.

The proposed surface area of the pond in Pratt`s quarry in Figure 7.1 is measured by GIS and is about 7.5 ha, and considering surface water positive network, with no any infiltration structures such as soakaways and porous car park in addition to future adjacent development meeting design requirements. Figure 7.27 shows an indicative design model for infiltration system that the majority of surface runoff infiltrating to the groundwater resource through a natural infiltration mechanism.

Careful consideration should be taken to avoid entry of pollutants into the infiltration system by introducing interceptors, regular inspection and proper maintenance of the pond, but still there is a low chance of dissolved pollutants being identified. Therefore, environment protection enforcement is necessary to be in place to avoid pollutant entrance to the infiltration system. The most common type of pollutants that come into the infiltration system will be pollutants from highways and car parks, which have been discussed in section 3.7 of chapter 3. Petrol interceptors collecting hydrocarbons from highways drainage can also be used to avoid pollutant to the pond.

One of the disadvantages of the drainage infiltration system is the regular maintenance and monitoring which require full consideration when a plan to implement the system and SuDS manual by CIRIA (2007) provides best practice on the planning, design, construction, operation and maintenance of sustainable drainage system to facilitate their effective implementation within development. Impacts of urbanisation are not only reducing natural infiltration area, groundwater abstraction and increasing surface runoff, but also impact on rainfall runoff, water quality (pollutants from human activities), and climate change.

There is increasing evidence that the earth's climate is changing. The most recent predictions (from the revised scenarios published by the UK Climate Impacts Programme *(Hulme et al., 2002)*, suggest that, by the 2080s:

- Winters may become milder and wetter, with more intense rainfall events.
- Summers may be hotter and drier across all of the UK, particularly in the south and east.
- Some types of extreme weather events may become more frequent, such as heat waves, extreme coastal high water levels and heavy spells of rain.

SuDS application can reduce impact of urbanisation and can be considered part of the future solution to protect groundwater resource and the environment.

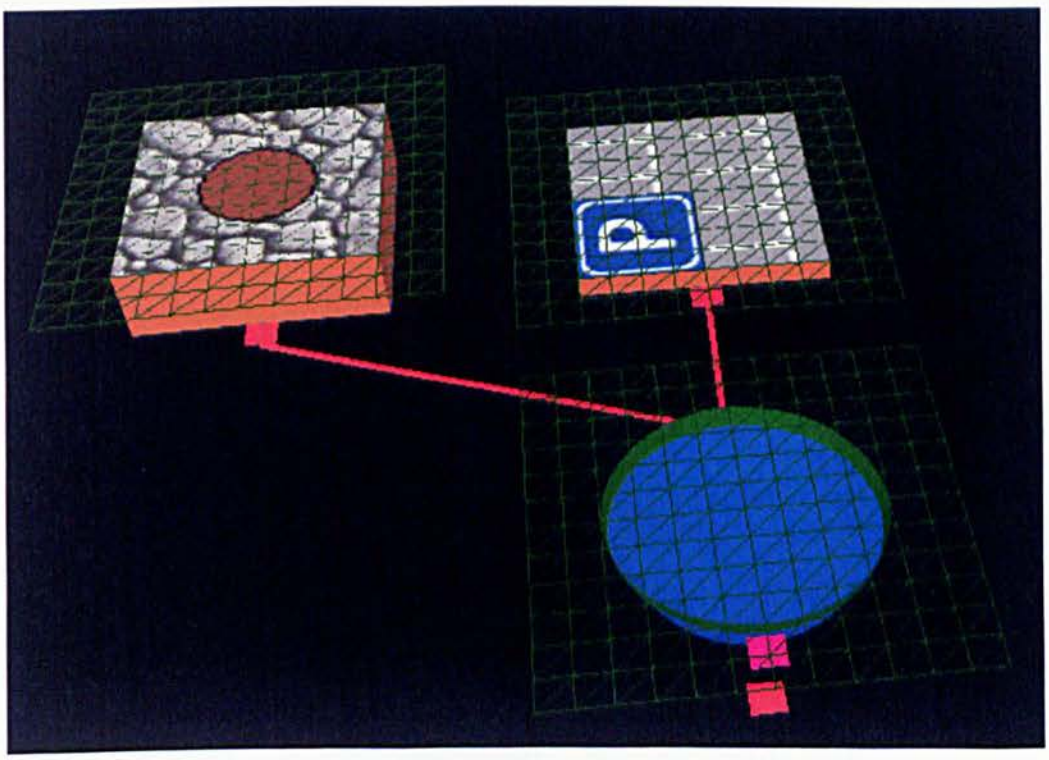


Figure 7.27: An indicative design model for the infiltration system.

Greenfield runoff volume for 30ha (Roof & Road) calculated 6032 $m^3$ for 30 year return period and Greenfield runoff volume for 6ha (Car park) calculated between 1206 $m^3$ for 30 year return period.

Urbanisation impact on hydrological regime is the main focal point of this research. Due to urbanisation and coverage of natural infiltration area, the volume of surface water runoff increases, higher peak flow rate, flood level, reduction of soil moisture recharge which prevent natural infiltration and reduction of groundwater resource can be considered as urbanisation impact. Sustainable urban drainage systems (SuDS) can be utilised for two objectives:

1- Control of urban surface water runoff, limit the quantity and frequency of flooding to an acceptable level.
2- To maintain groundwater resource sustainable by natural recharge mechanism.

The result found from the indicative design model sections (7.6.1 -7.7) show that using SuDS combined structures with suitable design concept; the expected surface water runoff can be recharged fully to the aquifer. Surface water runoff from the roof, paved area of highway can be managed by on-site Soakaways and, porous car park for car park designated area. The overflow volume of surface water runoff form soakaways and porous car park can be directed.

From the design and analysis of the data concluded that SuDS are suitable method to recharge groundwater in term of quantity and quality in response to the research questions (1 & 7).

# CHAPTER 8 - IMPACT OF URBANISATION, HYDRO-GEOLOGICAL AND WATER SUPPLY

## 8.1 General

It is widely believed that Climate changes and urbanisation are threatening natural groundwater resources where the portable supply of water demand depends on the natural resources; the groundwater resource contributes 10-12% of fresh water around the world and about 10% in England and Wales.

In England and Wales over the next 30 years, there will be increasing pressures from the rising population and associated development and environmental impact. Looking further ahead, the impact of climate changes (see chapter 5) and urbanisation could have a major impact on the water that will be available for all uses.

The amount of water available in England and Wales to meet the needs of people and to sustain the water environment varies greatly between different places and seasons, and from one year to another. The annual rainfall over England and Wales is 890mm. Nearly half of this is lost by evaporation and evapo-transpiration leaves 465mm for runoff to river and stream (*Environment Agency, 2008*).

Over England and Wales only about 10 per cent of freshwater resources for abstraction are used (excluding abstraction to support power production, which is often returned directly to the environment) Water resources are considered to be 'under stress' or over stretched if this index is more than 20% If abstraction is more than 20%, water resources can be considered to be under stress. The level of water stress and headroom for the UK and Leighton Buzzard is covered in Chapter 9.

The abstraction of water for supply purpose from groundwater resources has remained fairly constant over time and over a ¾ of the total abstracted from groundwater is used for public water supply under licence scheme in England and Wales. Table 8.1 shows water abstraction in England and Wales.

Table 8.1: Water abstraction in England and Wales *(Environment Agency, 2011)*

| Year | Groundwater (Million Litre /day) |
|---|---|
| 2011 | 5910 |
| 2010 | 5900 |
| 2009 | 5920 |
| 2008 | 5860 |
| 2007 | 6100 |
| 2006 | 6300 |
| 2005 | 6600 |
| 2004 | 6325 |
| 2003 | 6400 |
| 2002 | 6500 |

Groundwater plays a fundamental, but often unappreciated, role in the economic and social well-being of urban areas, although there are no comprehensive statistics on the proportion of urban water supply derived from groundwater. Urbanisation affects the quantity and quality of the underlying groundwater by:

- Change in rate of recharge
- Adversely affecting groundwater quality
- Initiating new abstraction regimes

An assessment of the risk to groundwater from urban processes needs to take into account the interaction between the recharge and discharge pressures and the pollutant loading on the one hand, and the nature of the subsurface environment on the other. The potential for urbanisation processes to have an impact on the underlying groundwater is a function of the aquifer vulnerability to pollution, its susceptibility to the consequences of excessive abstraction, change in the rate of infiltration/ recharge and groundwater level depletion/ restoration.

Experts strongly believe that urbanisation reduces infiltration to groundwater due to the impermeabilisation of the catchment by paved areas, buildings and roads. Recharge due to the change of population water demand in a civilised urban area is less than the pre-urban area because the waste water and surface runoff are managed by a sewer network and substantially will have an impact on the rate of recharge for the groundwater resources.

In cities or towns in an undeveloped country where waste water is not exported, e.g. cities without sewers for waste water network, 90 % of abstracted and/or imported water may return as groundwater recharge *(Lerner et al., 1990)*. In these cities, the most important recharge source would be the infiltration of waste water from large numbers of septic tanks, latrines and soakaways. The effect of urban recharge sources will be always significantly larger than precipitation recharge, but there is a high risk of pollutant and groundwater contamination *(Lerner, 2003)*.

## 8.2 Does urbanisation threaten groundwater resources?

According to the experts` opinions urbanisation can cause a potential threat to groundwater resources, although some these threats may well damage groundwater resource permanently due to impact of urbanisation, climate changes and potential of pollutant movement to groundwater resource.

There are many concepts relating to definition of urbanisation from different point of views. Urbanisation is a process of transferring ideas into practice from urban area to surrounding vicinities or the physical growth of urban areas as a result of global change as more and more people leave the villages and farms to live in cities or due to cities` population densities, the rural area can be changed to an urban area to accommodate physical growth of the population.

The higher the population size of an area, the more urbanised it will be and it is positively or directly related to the growth of urbanization .The increase of population size is caused by both migration and lower mortality. Migration flows occur because of employment available in nearby cities and towns, ethnic connections in particular cities, the development of roads and the accessibility of transportation.

Some research has stated that the economic imbalance resulting in wage disparities in urban and rural areas is a major reason for high levels of rural-to-urban migration. The size of population in an urban area will be in line with the needs of water for these urban dwellers.

The impact of population growth is not the only factor for urbanisation; there are a few other factors which can boost urbanisation of rural area such as:

- Economic growth
- Demand for housing
- Transportation link between cities
- Migration
- Industrialisation
- Employment

Figure 8.1 shows the location of Leighton Buzzard within the county of Bedfordshire. The impact of urbanisation can be negative or positive depending on the level of investigation or research. This research shows the level of threat to groundwater resources, groundwater management and recharge mechanism of aquifers. Therefore part of the data analysis will concentrate on the occurrence of a threat to groundwater resources, factor, parameter, groundwater depletion and groundwater recharge on the Leighton Buzzard district due to urbanisation and its impact.

- One of the reasons and the data analysis hypothesis behind the fact that urbanisation covers the area of infiltration is due to avoidance of infiltration through the paved impermeable area by housing, highways and industries in the area of Leighton Buzzard. The groundwater resource will not be recharged adequately and most of the surface runoff is discharged through the sewer network away from the area.

- One of the other reasons that urbanisation has an adverse impact on the groundwater resource is that pollutants can be easily transferred into the groundwater resources.

On the basis of the above reasons, the analysis carried out on demographic data, the rate of urbanisation, water demand and rate of discharge for surface water in the area of Leighton Buzzard was supporting the fact that urbanisation impacts on groundwater depletion and that sustainable urban drainage (SuDS) can be marginally part of the solution to recharge groundwater resources and protect to some extent the environmental issues within the environmental policies.

There is such a view, although it is not well supported by evidence because although areas are being covered, problem is that if the abstraction rate is too high, the recharge cannot be made up from infiltration, also areas urbanised in source protection zone greater than 100 years ago. Figure 8.1 shows the location of Leighton Buzzard within the Bedfordshire County and Figure 8.2 shows Leighton Buzzard Wards and population.

The Geographical Information System (GIS) is one of the most promising and exciting pieces of technology of the decade in the field of research and Civil Engineering, GIS applications offer numerous advantages and also provide the power of integration, effective communication tools, mapping facilities, data analysis, data management and decision support framework. The term "geographic" relates to geographic scale of measurement and is referenced by some coordinated system to locate on the surface of the earth.

The GIS applications provide fairly accurate data from the site, mapping layers and data analysis to achieve the objectives of this thesis as well as to provide enough information for water and planning policy authorities to consider the outcome of the research while approving plans for new developments.

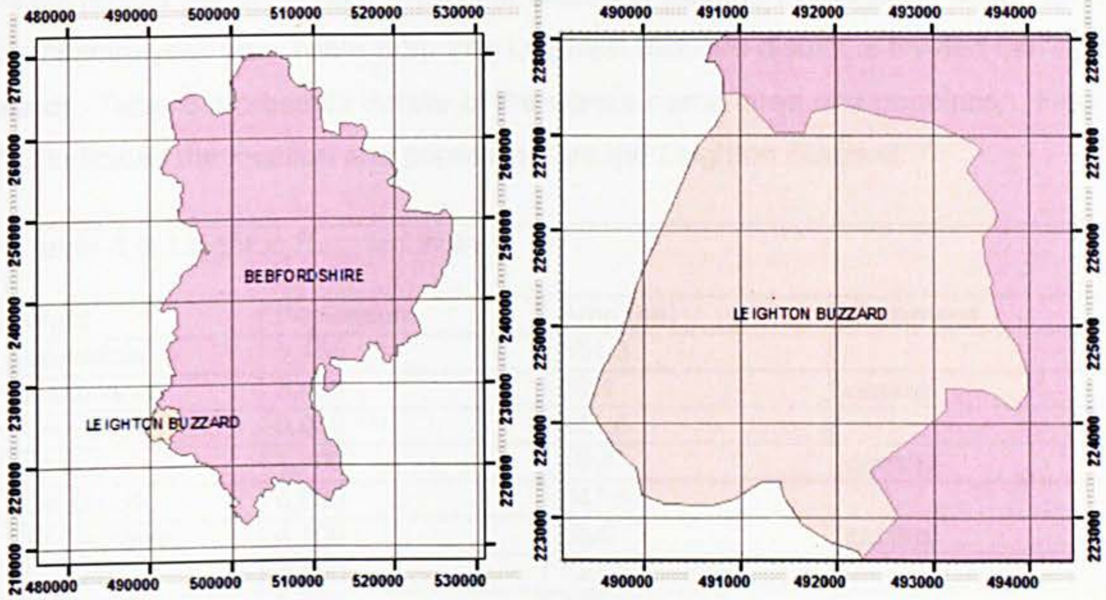


Figure 8.1 Location of Leighton Buzzard within the county of Bedfordshire
*(Bedfordshire County Council, 2011)*

Bedfordshire county has an estimated area 12,262ha with the total population of 615,000 (2009) being divided into three unitaries as Bedford, Central Bedfordshire and Luton. Most of Bedfordshire rocks are clay and sandstone from the Jurassic and Cretaceous period with some limestone. Bedfordshire is relatively dry with average annual rainfall 545mm. The geological review refers to chapter 2 of this thesis.

Leighton Buzzard falls within the central Bedfordshire unitary and has an estimated area 1,700 ha with the total population of 37000 (2009) and annual rainfall of 788 mm. Leighton Buzzard has an oceanic climate similar to the rest of UK. Table 8.2 shows Leighton Buzzard's average weather for 12 months.

Table 8.2 : Average 12 months weather statistics for Leighton Buzzard

| Month | JAN | FEB | MAR | APR | MAY | JUN | JUL | AUG | SEP | OCT | NOV | DEC |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Ave-High (C) | 6 | 7 | 10 | 12 | 16 | 19 | 21 | 22 | 18 | 14 | 9 | 6 |
| Ave-Low (C) | 3 | 3 | 4 | 5 | 8 | 10 | 12 | 13 | 11 | 8 | 5 | 3 |
| Minimum Precipitation (mm) | 69.3 | 59.4 | 46.5 | 70.1 | 58.1 | 58.9 | 46.0 | 68.9 | 51.7 | 84.3 | 93.9 | 80.9 |

The average annual rainfall within the district of Leighton Buzzard is estimated to be 788mm/year (see Table 8.2). The Leighton Buzzard district is divided into eight wards. Table 8.3 presents details of the ward's name, area and population. Figure 8.3 indicates the location and population around Leighton Buzzard.

Table 8.3: Leighton Buzzard Wards

| Ward | Population | Area (ha) | Comment |
|---|---|---|---|
| Barnabas | 5,150 | 351.3 | |
| Brooklands | 3,450 | 60.4 | central |
| Grovebury | 6,050 | 411.6 | |
| Leston | 1,700 | 48.4 | central |
| Southcott | 6,800 | 347.6 | |
| St George's | 4,100 | 65.8 | central |
| Planets | 4,550 | 127.8 | |
| Plantation | 5,600 | 285.4 | |
| Total | 37400 | 1698.3 | |

Figure 8.2: Leighton Buzzard wards location and population *(Bedfordshire County Council, 2011)*

The Southern Leighton Buzzard expansion covers a group of sites allocated for housing development in the South Bedfordshire Local Plan Review 2004, some of which are mineral sites. The Pratt's Quarry site and Brickyard Quarry are sand quarries which are in the process of being worked out and progressively restored to enable residential development to take place there.

Following some data from different sources are pulled together to present true a GIS model to the Leighton Buzzard to support the opinion that urbanisation threatens the groundwater resource.

1. District housing development data
    - Site area
    - Roof footprint
    - Paver area
2. Geological Data
    - Solid drift
    - Borehole data
    - Aquifer designation
    - Permeability
    - Geological indicators flooding
    - Hydro Solid
3. Anglian water supply and protection zone

## 8.3 District housing development data

Leighton Buzzard's area development history is recorded from 1870 to 2010 from different locations to find out the impact of the development on the aquifers and to check the growth of housing and paved area.

Table 8.4 and 8.5 show the collection of data from 7 locations within the Leighton Buzzard wards to demonstrate urbanisation development during a period of 140 years. In 1870 it shows the housing development started with the larger size of house and average 42% dedicated green site, compared to 1980 as a smaller housing size scheme with large green field site. From 2000 to present, due to living standard requirements and an increase in population around the district the housing scheme size is slightly larger than in 1970, but the green site dedication for environmental purposes remains the same. An average of 36% of the district has transformed into an urbanised area.

Table 8.4: Site data

| Year | Site Area (m2) | Roof Foot print area (m2) | Paved area (m2) | Green site (m2) |
|---|---|---|---|---|
| 1870 | 22465 | 5627 | 7313 | 9525 |
| 1900 | 45116 | 8547 | 8638 | 27931 |
| 1920 | 70060 | 11019 | 10953 | 48088 |
| 1930 | 69805 | 12389 | 10430 | 46986 |
| 1970 | 95247 | 16101 | 16714 | 62432 |
| 1980 | 61203 | 8257 | 9953 | 42993 |
| 2000 | 431139 | 85122 | 37385 | 37385 |
| | | | | |

Table 8.5: Site data

| Year | Site Area (%) | Roof Foot print area (%) | Paved area (%) | Green site (%) | Total Paved (%) |
|---|---|---|---|---|---|
| 1870 | 100 | 25 | 32.5 | 42.5 | 57.5 |
| 1900 | 100 | 19 | 19.1 | 61.9 | 38.1 |
| 1920 | 100 | 15.7 | 15.6 | 68.7 | 31.3 |
| 1930 | 100 | 17.7 | 14.9 | 67.4 | 32.6 |
| 1970 | 100 | 16.9 | 17.5 | 65.6 | 34.4 |
| 1980 | 100 | 13.5 | 16.2 | 70.3 | 29.7 |
| 2000 | 100 | 19.7 | 8.7 | 62.9 | 28.4 |
| | | | | | AVE=36% |

The above tables also indicate that due to the urbanisation in Leighton Buzzard the district lost 36% of the greenfield area in the past 140 years as well as demand for more use of natural groundwater resource to provide water to meet the demands of the growing population.

Supply of water by boreholes from the aquifer is not a new procedure and people in the past have managed to extract portable water from the aquifer. If we assume most of the boreholes were built over 100 years ago located near the vicinity of town and over the years the town is expanded and developed, still the water supply boreholes are active and abstract water from them by Water Companies. Therefore aquifers near and urban area lost the recharge volume of water due to existence of the sewers and highway drainage networks compared to the site as a Greenfield.

As discussed in Chapter 5, due to climate changes the temperature will increase in the summer and the mitigation of climate changes will be dryness to the district rather than the adaptation process which might require a recharge mechanism for aquifer replenishment to restore the groundwater resource. Otherwise losing 36% of the Greenfield site in total, avoiding considerable infiltration area within the district are potential problem areas. Using Micro drainage tools to find Greenfield runoff and the volume of water restricted by urbanised area may provide an effective solution to this problem.

## 8.4 Hydro-Geological data

Further to the geological review in chapter 2, this section covers boreholes, aquifer designations and hydro-geological characteristics of Leighton Buzzard and the surrounding area to demonstrate the authority's measures on solid drift, bedrock designation, and permeability of the aquifer.

Leighton Buzzard solid drift map produced in 1992 by The British Geological Survey sheet 220 shows that the Woburn Sands layer is overlaid by a Gault formation and drift deposits, and underlaid by clay layer. Figure 8.3 is a snap of the sheet 220.

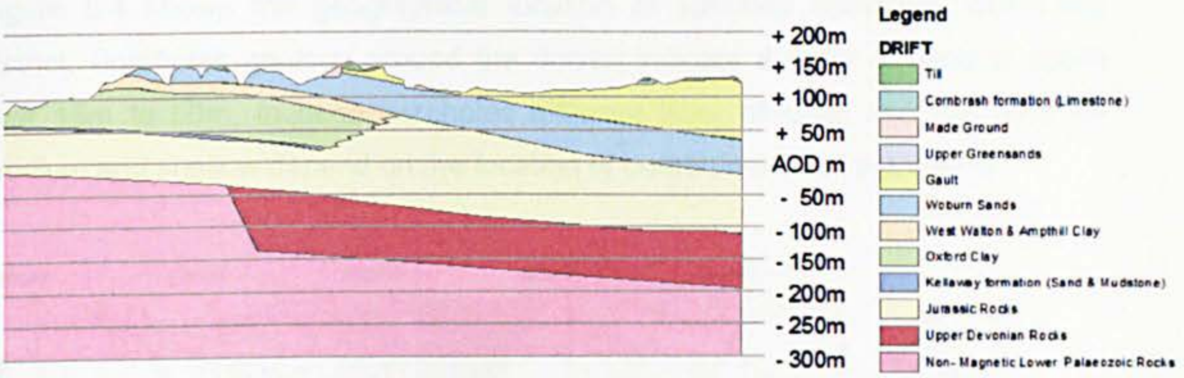


Figure 8.3: Snapshot cross section of British Geology Survey solid drifts Sheet 220 (1992)

Table 8.6 incorporates sampled borehole data around Leighton Buzzard, the data collected by the British Geological Survey (2012) for boreholes and there are mainly three types of boreholes:

1. Deep boreholes
2. Medium boreholes
3. Shallow boreholes

Looking through the detail of boreholes in different categories, it is evident that sand layers overlaid with layers of Gault or clay and water tables lie within the sand layer, and urbanisation of Leighton Buzzard could have an environmental impact on the natural groundwater. Transport of pollutants to the natural groundwater could be facilitated by the expansion of the rural area to an urban area.

Table 8.6: Sampled boreholes location

| Borehole Type | Ref | Easting | Northing |
|---|---|---|---|
| DEEP | SP92SW142 | 490783 | 224081 |
| DEEP | SP92NW27 | 492200 | 225301 |
| DEEP | SP92NW25 | 491140 | 225872 |
| MEDIUM | SP92SW47 | 493514 | 223492 |
| MEDIUM | SP92NW256 | 491670 | 225391 |
| MEDIUM | SP92SW144 | 493730 | 224680 |
| MEDIUM | SP92SW157 | 492099 | 223801 |
| SHALLOW | SP92NW151 | 490700 | 225560 |
| SHALLOW | SP92SW120 | 493842 | 223849 |
| SHALLOW | SP92SW220 | 492470 | 224730 |

Figure 8.4 shows the geographical location of sampled boreholes within the district. Boreholes geology around the district indicate a layer of sand in depth over 15m to 50m. In deep boreholes different layer of sand and clay and for medium and shallow depend on the location of borehole around the district.

Figure 8.4: Geographical location of sampled boreholes

One of the elements of the geological data to look at, is an aquifer designation in Leighton Buzzard, understanding of aquifer and site characteristics to find a method to protect natural groundwater resources. From 1 April 2010 the Environment Agency's Groundwater Protection Policy use aquifer designations that are consistent with the Water Framework Directive as covered in chapter 4. Aquifer designations mirror the importance of aquifers in terms of groundwater as a resource and supporting surface water flows and wetland ecosystems. Aquifer designation splits into two different types as superficial and bedrocks. Table 8.6 explains the definitions:

Table 8.7: Aquifer designation definitions

| Aquifer designation | Description |
|---|---|
| 1. *Superficial (drift)* | *Permeable unconsolidated (loose) deposits such as sand and gravel* |
| 2. *Bedrock* | *Solid permeable formation such as sandstone, chalk and limestone.* |

Source: Environment agency and British Geological Survey

The above superficial and bedrock are sub classified as

Table 8.8: Aquifer sub class definitions

| Aquifer designation | Description |
|---|---|
| *Principle* | *These are layers of rock or drift deposits that have high inter-granular and/or fracture permeability - meaning they usually provide a high level of water storage. They may support water supply and/or river base flow on a strategic scale. In most cases, principal aquifers are aquifers previously designated as major aquifers* |
| *Secondary A* | *Permeable layers capable of supporting water supplies at a local rather than strategic scale, and in some cases forming an important source of base flow to rivers. These are generally aquifers formerly classified as minor aquifers.* |
| *Secondary B* | *Predominantly lower permeability layers which may store and yield limited amounts of groundwater due to localised features such as fissures, thin permeable horizons and weathering. These are generally the water-bearing parts of the former non-aquifers* |
| *Undifferentiated* | *Has been assigned in cases where it has not been possible to attribute either category A or B to a rock type. In most cases this means that the layer in question has previously been designated as both minor and non-aquifer in different locations due to the variable characteristics of the rock type* |
| *Unproductive* | *These are rock layers or drift deposits with low permeability that have negligible significance for water supply or river base flow* |
| *Unknown* | *There are a small number of areas where data has not yet been digitised by British Geology Survey and is unavailable* |

GIS models present bedrock and superficial designations for the Leighton Buzzard district in Figure 8.5.

Figure 8.5: Aquifer designations in Leighton Buzzard

During bedrock designation, most of the Leighton Buzzard district is covered by principle aquifer and partly unproductive, in superficial designation the district is covered by secondary A, secondary undifferentiated and unproductive.

This reveals that the aquifers within the Leighton Buzzard district are permeable and groundwater resource could be recharged easily, but urbanisation can avoid natural recharge mechanism of the aquifer. Sustainable urban drainage system (SuDS) can be part of the solution to recharge the groundwater resource as discussed in chapter 7. Figure 8.7 shows aquifer permeability range.

The permeability index of the Leighton Buzzard district is based as Maximum and Minimum values which indicate the range of flow rates likely to be encountered in the unsaturated zone for each rock unit and lithology combination. Five classes are used:

1. Very high
2. High
3. Moderate
4. Low
5. Very low

The Maximum and Minimum Permeability values represent a likely permeability range for the specified rock unit and lithology combination at, and immediately below, outcrop (rather than at any significant depth).

The Maximum Permeability represents the fastest potential vertical rate of migration through the unsaturated zone likely to be encountered in the specified rock unit and lithology combination. The Minimum Permeability represents the minimum, and in some cases more normal, bulk rate of vertical movement likely to be encountered. Where a widely variable combination of lithologies occurs within a rock unit this value reflects the probable movement rate likely to be encountered in the least permeable horizons. Soil permeability coefficient determination has been covered in Chapter 5.

Figure 8.6: Aquifer permeability range

Artificial permeability areas around the Leighton Buzzard have been identified to recharge through natural filtration mechanism and flood management measures to protect groundwater resources. Figure 8.7 shows the location of artificial permeability areas or detention ponds.

Figure 8.7: Location of artificial permeability area

Geological Indicator Flooding (GIF) characterises superficial deposits in terms of their likely susceptibility/ vulnerability to flooding, either from coastal flood or fluvial (inland) water flow; Leighton Buzzard is far from coastal flooding, and therefore the district is vulnerable to the flooding from fluvial. Coastal and fluvial flood are further categorised as Zone 1 (higher) and Zone 2 (lower) vulnerability.

Development and flood risk (PPS25- Planning policy statement 25) recognise that flooding is a natural process and can happen at any time with a variety of location and geographical setting proving vulnerable.

Flood from river Ouzel (A River which flows from Leighton Buzzard through a narrow valley into Milton Keynes town) can cause higher or lower flood risk to the Leighton Buzzard district. Figure 8.9 presents the zones with higher and lower potential flood areas from inland flooding in river catchment areas and as a result of prolonging flooding events respectively.

Flooding from rivers occurs when the amount of water in them exceed the flow capacity of the river channel. Most rivers are surrounded by a floodplain and flooding from land happens when intense rainfall occurs, often in short duration either:

- Runs rapidly down slopes

or

- Is unable to soak into the ground or enter drainage systems before causing local flooding.

Covering the natural infiltration area or urbanisation reduces rainfall to be soaked into the local aquifer a groundwater resource, therefore flooding due to inability of rainfall infiltration in the area could be considered as an impact of urbanisation to the river and flood risk.

Figure 8.8: Zones with higher and lower potential flood from inland flooding

## 8.5 Anglian-Water supply

Water resources management plan WRMP is a new statutory process to enable water companies to comply with the Environmental Agency guidelines and the main issues are growth, climate changes, sustainability reduction and environmental legislations.

The history of public water supply starts with the development of location groundwater sources in the form of a piped natural spring or hand-pumped well and in the 20th century, most of the above were replaced and still around 1% of the population are now using private water resources in the Anglian Water region.

The preferred option for water supply has traditionally been controlled by the availability of local groundwater and surface sources. As the demand increased and local supplies were developed to their sustainable level, waste and treated water networks developed along storage reservoirs. Figure 8.9 indicates available water resource for supply in the Anglian Water region which provides supply to the Leighton Buzzard district.

Figure 8.9: Location of water resources for supply by Anglian Water

Generally 121 recorded sources within the Anglian Water region, 12 surface water sources and 109 sources of groundwater, around Leighton Buzzard 6 groundwater sources and 1 surface water source.

WRMP is structured on 12 water resource zones (WRZs). The WRZs are based on the existing water supply system and present the largest area in which water resource can be shared, Leighton Buzzard falls within WRZ11 and planning zone PZ73. The proportion of supplies developed from the use of current unused licences, reallocating or licensing new groundwater resources and through the re-use of surface water discharges is shown in Figure 8.10.

175 million litre/day freshwater supplied by Anglian Water, 42.3% of the total supplies abstracted from groundwater resources and 57.5% supplies from surface water.

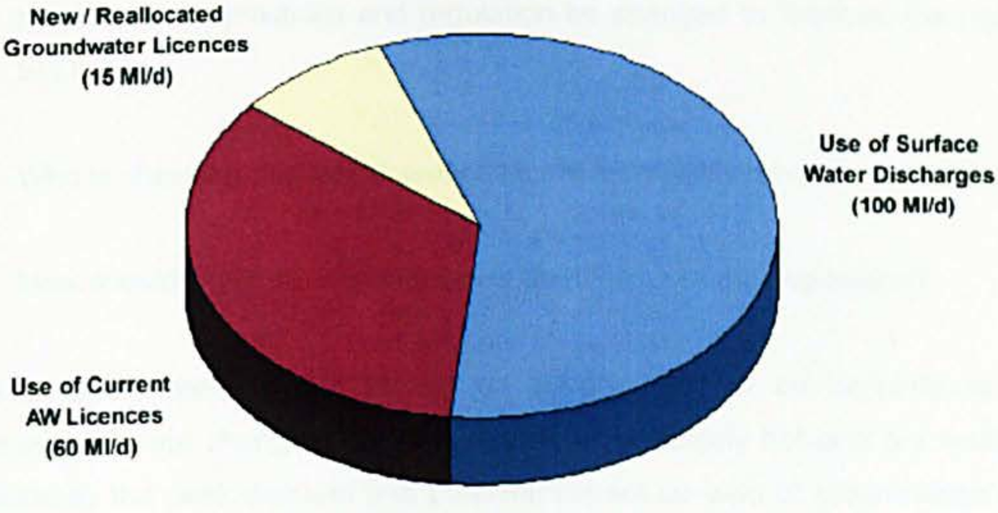


Figure 8.10: Fresh water supply resource by Anglian Water

Figure 8.10 shows that a supply of fresh water in Leighton Buzzard depends on ground source, urbanisation, town development, population density. These could be a contributory risk to groundwater resources and the aquifers, therefore urbanisation of the Leighton Buzzard district and planning policy to recharge the aquifer adequately, SuDS application should be given priority over other town and planning guidance to reduce the risk of groundwater resource in the future.

The alternative to conventional piped means of managing surface water, Anglian Water promotes the use of sustainable drainage systems (SuDS), however, SuDS approaches can bring wider benefits too such as:

1. Integrating with the landscape design to add amenity for the community as well as bringing biodiversity value.
2. Providing environmental protection by treating the quality as well as the quantity of surface water runoff

Although there are many practical benefits to SuDS. There are a number of "administrative" barriers that have caused problems within implementing schemes, for example;

1. Who takes responsibility for SuDS once they are built?
2. How can past practices and regulation be changed to facilitate the use of SuDS?
3. Who is checking that SuDS proposals are technically robust?
4. How should SuDS be regulated over the lifetime of their operation?

The impact on demand and impact on supply need to be carefully to be considered, climate change relates to periods of extremely hot and dry weather that increase the peak demand and potential impact on yield of groundwater and surface resources. One of the main actions for WRMP guidelines is that water companies are expected to do where the Environment Agency considers that which abstraction is having a detrimental effect on the environment, and the Environment Agency will require Anglian Water to implement a solution to reduce the impact to an acceptable level (known as sustainability reduction).

Anglian Water is the only water company that has published Sustainable Drainage Systems (SuDS) adoption manual, which delivers effectively and efficiently across four key criteria as quantity, quality, amenity and biodiversity.

Chapter 9 covers more discussion on groundwater recharge mechanisms on the basis of soil water balance methods and estimation of recharge amounts for 0, 1, 5, 10 and 15 percent rainfall increases in the Leighton Buzzard district.

# CHAPTER 9 - GROUNDWATER RECHARGE AND ESTIMATION

## 9.1 General

Groundwater recharge can be explained as the process whereby the amount of water present in or flowing through the interstices of the sub-soil increases by natural or artificial means. The amount of water that may be extracted from an aquifer without causing depletion is primarily dependent upon the groundwater recharge. Rainfall is the principal source of replenishment of moisture in the soil water system and recharge of groundwater. Also, other sources such as rivers, streams, irrigation water etc. plays important roles for recharge.

Moisture movement in the unsaturated zone is controlled by suction pressure, moisture content and hydraulic conductivity relationships. The amount of moisture that will eventually reach the water table is defined as natural groundwater recharge, which depends on the rate and duration of rainfall, the subsequent conditions at the upper boundary, the antecedent soil moisture conditions, the water table depth and the soil type *(Sanders, 2004)*.

## 9.2 Recharge Estimation Techniques

Estimating the rate of aquifer replenishment is probably the most difficult of all measures in the evaluation of groundwater resources. The methods available for the estimation of groundwater recharge directly from precipitation can be broadly divided into three aspects - inflow, aquifer responses and outflow methods according to how the studies are conducted (*Kumar, 1977*).

The following methods are commonly in use for estimating natural groundwater recharge:

- The Soil water balance method
- The Zero flux plane method
- The One-dimensional soil water flow model

- The Inverse modelling technique
- The groundwater level fluctuation method
- The Hybrid water fluctuation method
- The groundwater balance method
- The Isotope and solute profile techniques

## 9.3 Soil Water Balance Method

Water balance models were developed in the 1940s by Thornthwaite (1948) and were later revised. The method is essentially a book-keeping procedure, which estimates the balance between the inflow and outflow of water. Here, the volume of water required to saturate the soil is expressed as an equivalent depth of water and is called soil water deficit. The soil water balance can be represented by:

$$Ri = P - Ea + \Delta W - Ro$$

Where,

$Ri$= *Recharge*

$P$= *Precipitation*

$Ea$= *Actual Evaporation*

$\Delta W$= *Change in soil water storage*

$Ro$= *runoff*

One condition that is enforced, is that if the soil water deficit is greater than a critical value (called the root constant), evapo-transpiration will occur at a rate less than the potential rate. The magnitude of the root constant depends on the vegetation, the stage of plant growth and the nature of the soil. Various techniques for estimating **Ea**, are usually based on Penman-type equations, can be used. The data requirement of the soil water balance method is large. When applying this method to estimate the recharge for a catchment area, the calculation should be repeated in areas with different precipitation, evapo-transpiration, crop type and soil type. This method is of limited practical value, because $\Delta W$ is not directly measurable. Moreover, storage of moisture in the saturated zone and the rates of infiltration along the various possible routes to the aquifer, form important and uncertain factors. Another aspect is that the depth of the root zone may vary in semi-arid regions between 1 and 3 meters. Results from this model are of very limited value without calibration and validation, because of the substantial uncertainty in input data. The model parameters do not have a direct physical representation which can be measured in the field *(Kumar,* 1977*)*.

In order to estimate the groundwater recharge for the Leighton Buzzard area, a spreadsheet part of this thesis to estimate groundwater recharge according to the Flow chart Figure 9.1A has been created. The spreadsheet Figure 9.1B to follow the soil water balance method (*De Silva, 1998*) to estimate the groundwater recharge.

The main Soil and Vegetation parameters are: permanent wilting point, field capacity, an average root zone thickness, interception storage capacity, runoff threshold, runoff coefficient, preferential flow threshold and preferential flow coefficient. Table 9.1 explains the definition of the parameters. Values for some of the parameters are determined from the soil sample and external sources for Leighton Buzzard *(Eagleson, 1978)*.

Table 9.1: Soil and Vegetation Parameter for Leighton Buzzard

| No | Soil and Vegetation Parameter | Symbol | Value | Data | Definition |
|---|---|---|---|---|---|
| 1* | Permanent wilting point (mm/m) | Pwp | 100mm/m<br>(Tested) | Soil:<br>Water content at -1500J/Kg or Negative hydraulic pressure | Minimal point of soil moisture Little by little, the water stored in the soil is taken up by the plant roots or evaporated from the topsoil into the atmosphere. If no additional water is supplied to the soil, it gradually dries out |
| 2* | Field capacity (mm/m) | Fc | 235mm/m<br>(Tested) | Soil:<br>Water content of soil | After the drainage has stopped, the large soil pores are filled with both air and water while the smaller pores are still full of water. At this stage, the soil is said to be at field capacity. At field capacity, the water and air contents of the soil are considered ideal for crop growth. |
| 3* | Average roots zone thickness (m) | Art | 1m | Vegetation | |

| | | | | | |
|---|---|---|---|---|---|
| 4 | Interception storage capacity (mm/d) | Isc | 2mm/d<br>(1.0- 3.0) | Vegetation | Precipitation that does not reach the soil, but is instead intercepted by leaves and branches. |
| 5 | runoff threshold (mm) | Rot | 5mm<br>(WinDes) | Factor | Threshold runoff is the amount of excess rainfall accumulated during a given time period over a basin that is just enough to cause flooding at the outlet of the draining stream. Threshold runoff estimates are indicators of maximal sustainable surface runoff for a given catchment, and are thus an essential component of flash flood warning systems |
| 6 | Runoff coefficient | Roc | 0.3<br>(0.25 – 0.4) | Factor | Express as percentage |
| 7 | Preferential flow threshold (mm) | PFt | 5mm<br>(5 – 7) | Factor | The occurrence of flow of water through preferred pathways |
| 8 | Preferential flow coefficient | PFc | 0.1<br>(0.1- 0.3) | Factor | Express as percentage |

Flow chart Figure 9.1 represents the soil balance model to estimate soil moisture deficit considered by De Silva (1996) for a research purpose. Using the flowchart procedure created Figure 9.2 for Leighton Buzzard.

Start

Metrological data
Daily rain (R) and daily potential evapo-transpiration (ETp)

Daily surface Runoff (Ro)
If R > Runoff threshold Ro = Roc x (R) Roc : Runoff Coefficient
If R < =Runoff threshold Ro = 0

Daily Preferential flow (PF)
If (R)> Preferential flow threshold PF=PFc x (R)
If (R) <= Preferential flow threshold PF = 0
PFc : Preferential Coefficient

Daily Matrix Flow (MF)
MF= R - I- Ro - PF

Estimate F (Ratio for the day)
If SMD < P*AWC F= (ETa/ETp)=1
All other cases F= (AWC-SMD) / {(1-P)*AWC}
SMD: Soil moisture deficit
AWC: Average Wilting Capacity = (Field capacity - Permanent wilting point) x Roots zone thickness
F: Ratio of the day

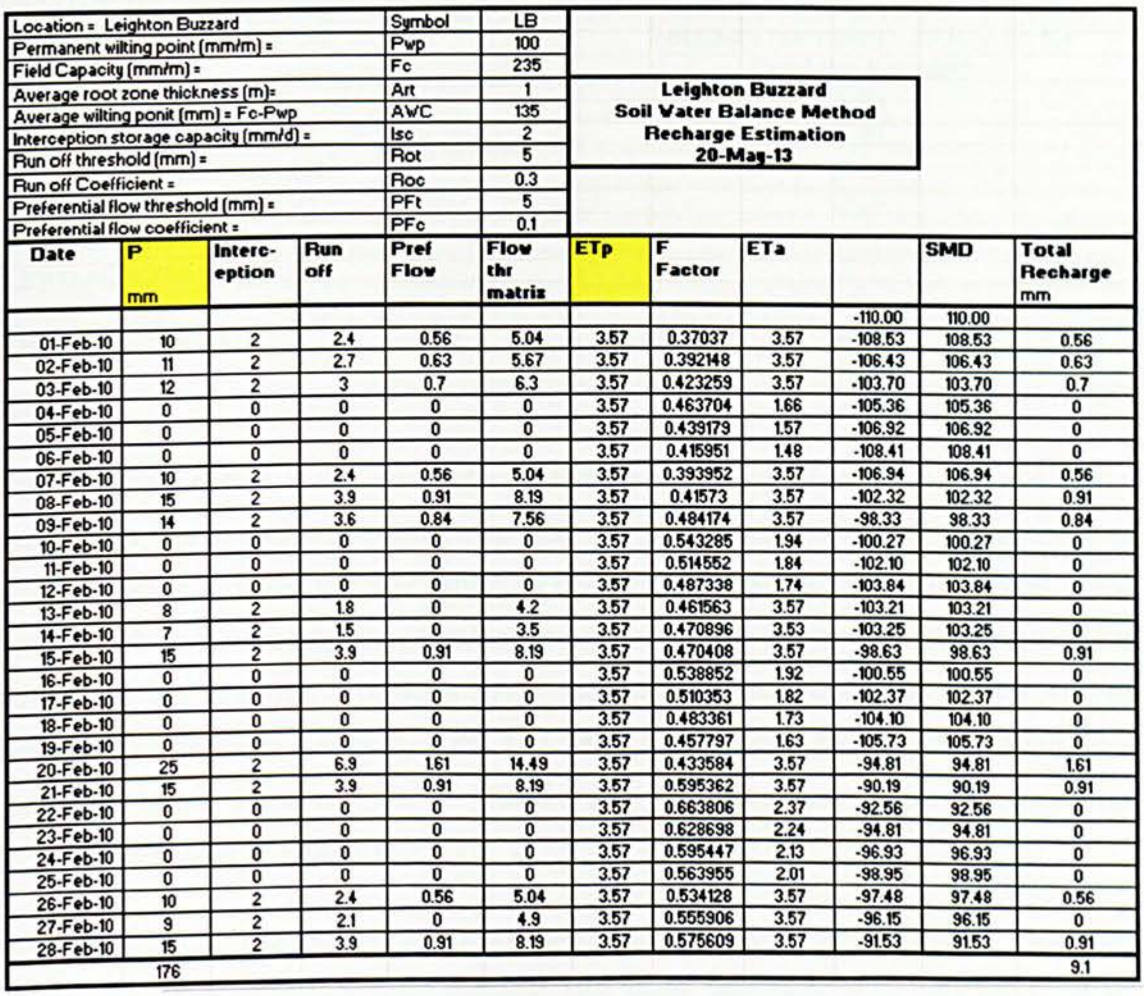
Estimate actual evaporation (ETa) for the day
(If SMD < p*AWC, or ETp<=R ETa=ETp
(If AWC < SMD <=P*AWC and ETp>R) ETa=R + F * (ETp - R)
(If SMD = AWC and ETp>R) ETa =R

Estimate soil moisture deficit (SMD)

If SMDi -1 + MF –ETa > 0, SMD=0
If SMDi-1 + MF –ETa < AWC, SMD=AWC
All other cases SMD=SMDi-1 + MF –ETa
SMDi : Initial Soil moisture deficit

Estimate Recharge (Re)

If SMD = 0, Re = MF - ETa- SMDi-1 + PF
All other cases Re = PF



| | | |
|---|---|---|
| Location = Leighton Buzzard | Symbol | LB |
| Permanent wilting point (mm/m) = | Pwp | 100 |
| Field Capacity (mm/m) = | Fc | 235 |
| Average root zone thickness (m)= | Art | 1 |
| Average wilting ponit (mm) = Fc-Pwp | AWC | 135 |
| Interception storage capacity (mm/d) = | Isc | 2 |
| Run off threshold (mm) = | Rot | 5 |
| Run off Coefficient = | Roc | 0.3 |
| Preferential flow threshold (mm) = | PFt | 5 |
| Preferential flow coefficient = | PFc | 0.1 |

**Leighton Buzzard**
**Soil Water Balance Method**
**Recharge Estimation**
**20-May-13**

| Date | P mm | Interc-eption | Run off | Pref Flow | Flow thr matrix | ETp | F Factor | ETa | | SMD | Total Recharge mm |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | -110.00 | 110.00 | |
| 01-Feb-10 | 10 | 2 | 2.4 | 0.56 | 5.04 | 3.57 | 0.37037 | 3.57 | -108.53 | 108.53 | 0.56 |
| 02-Feb-10 | 11 | 2 | 2.7 | 0.63 | 5.67 | 3.57 | 0.392148 | 3.57 | -106.43 | 106.43 | 0.63 |
| 03-Feb-10 | 12 | 2 | 3 | 0.7 | 6.3 | 3.57 | 0.423259 | 3.57 | -103.70 | 103.70 | 0.7 |
| 04-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.463704 | 1.66 | -105.36 | 105.36 | 0 |
| 05-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.439179 | 1.57 | -106.92 | 106.92 | 0 |
| 06-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.415951 | 1.48 | -108.41 | 108.41 | 0 |
| 07-Feb-10 | 10 | 2 | 2.4 | 0.56 | 5.04 | 3.57 | 0.393952 | 3.57 | -106.94 | 106.94 | 0.56 |
| 08-Feb-10 | 15 | 2 | 3.9 | 0.91 | 8.19 | 3.57 | 0.41573 | 3.57 | -102.32 | 102.32 | 0.91 |
| 09-Feb-10 | 14 | 2 | 3.6 | 0.84 | 7.56 | 3.57 | 0.484174 | 3.57 | -98.33 | 98.33 | 0.84 |
| 10-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.543285 | 1.94 | -100.27 | 100.27 | 0 |
| 11-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.514552 | 1.84 | -102.10 | 102.10 | 0 |
| 12-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.487338 | 1.74 | -103.84 | 103.84 | 0 |
| 13-Feb-10 | 8 | 2 | 1.8 | 0 | 4.2 | 3.57 | 0.461563 | 3.57 | -103.21 | 103.21 | 0 |
| 14-Feb-10 | 7 | 2 | 1.5 | 0 | 3.5 | 3.57 | 0.470896 | 3.53 | -103.25 | 103.25 | 0 |
| 15-Feb-10 | 15 | 2 | 3.9 | 0.91 | 8.19 | 3.57 | 0.470408 | 3.57 | -98.63 | 98.63 | 0.91 |
| 16-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.538852 | 1.92 | -100.55 | 100.55 | 0 |
| 17-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.510353 | 1.82 | -102.37 | 102.37 | 0 |
| 18-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.483361 | 1.73 | -104.10 | 104.10 | 0 |
| 19-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.457797 | 1.63 | -105.73 | 105.73 | 0 |
| 20-Feb-10 | 25 | 2 | 6.9 | 1.61 | 14.49 | 3.57 | 0.433584 | 3.57 | -94.81 | 94.81 | 1.61 |
| 21-Feb-10 | 15 | 2 | 3.9 | 0.91 | 8.19 | 3.57 | 0.595362 | 3.57 | -90.19 | 90.19 | 0.91 |
| 22-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.663806 | 2.37 | -92.56 | 92.56 | 0 |
| 23-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.628698 | 2.24 | -94.81 | 94.81 | 0 |
| 24-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.595447 | 2.13 | -96.93 | 96.93 | 0 |
| 25-Feb-10 | 0 | 0 | 0 | 0 | 0 | 3.57 | 0.563955 | 2.01 | -98.95 | 98.95 | 0 |
| 26-Feb-10 | 10 | 2 | 2.4 | 0.56 | 5.04 | 3.57 | 0.534128 | 3.57 | -97.48 | 97.48 | 0.56 |
| 27-Feb-10 | 9 | 2 | 2.1 | 0 | 4.9 | 3.57 | 0.555906 | 3.57 | -96.15 | 96.15 | 0 |
| 28-Feb-10 | 15 | 2 | 3.9 | 0.91 | 8.19 | 3.57 | 0.575609 | 3.57 | -91.53 | 91.53 | 0.91 |
| | 176 | | | | | | | | | | 9.1 |

Figure 9.2: Snap of computer generated calculation that follows the estimate groundwater recharge-process

Figure 9.2 shows that during a month of rainfall data the total recharge is the sum of total recharge (9.1mm) and indicates that 5.17% of total rainfall can be recharged back to the ground via the soil water balance method. SuDS application can recharge fully (Chapter 7) and is considered to be very effective. The evapo-transpiration process consists of conversion of water to vapour from the liquid phase. The source of energy for this process is the radiation received from the sun. Solar radiation reaches the outer surface of the earth's atmosphere measured perpendicularly to the beam. Eight different methods of calculation are suggested. The actual calculation of the evapo-transpiration is out of the scope of the thesis, therefore a tabulated ETp for Leighton Buzzard is presented in Table 9.2. The average value of ETp= 3.57 used in Figure 9.2.

Table 9.2: evapo-transpiration for Leighton Buzzard

| Method | February (sampled) 2010 ETp for Leighton Buzzard |
|---|---|
| Pan evaporation method | 3.61 |
| Penman Method | 3.61 |
| Penman- Monteith method | 2.95 |
| Kimberly-penman method | 3.2 |
| Priestley Taylor method | 4.0 |
| Blanney-Criddle method | 3.1 |
| Samani- Hargreaves method | 4.1 |
| Hargreaves method | 4.05 |
| | |
| Average | 3.57 |

Soil moisture deficit is the amount of available water removed from the soil within the crop`s active root depth, likewise soil moisture deficit (SMD) is the amount of water needed to bring the soil moisture content back to field capacity which is the amount of water the soil can hold against. Too much water indicates a negative value and too little has a positive SMD. Figure 9.3 shows the SMD total assumed grass cover depth in mm in the UK. The SMD typical value for Leighton Buzzard is assumed to be between 100 - 119mm and for calculation purposes assumed 110mm and used in Figure 9.2.

While estimating natural groundwater recharge, it is essential to have a good idea of the different recharge mechanisms and their importance in the study area. Choice of methods guided by the objectives of the study, available data and the possibilities to get supplementary data. Economy too is an important factor. However, estimates are normally subject to large errors. No single comprehensive estimation technique can be identified as of yet from the spectrum of those available, which give reliable results. Hence, it is desirable to apply more than one method based on independent input data. Figure 9.4 indicates soil water balance model structure.

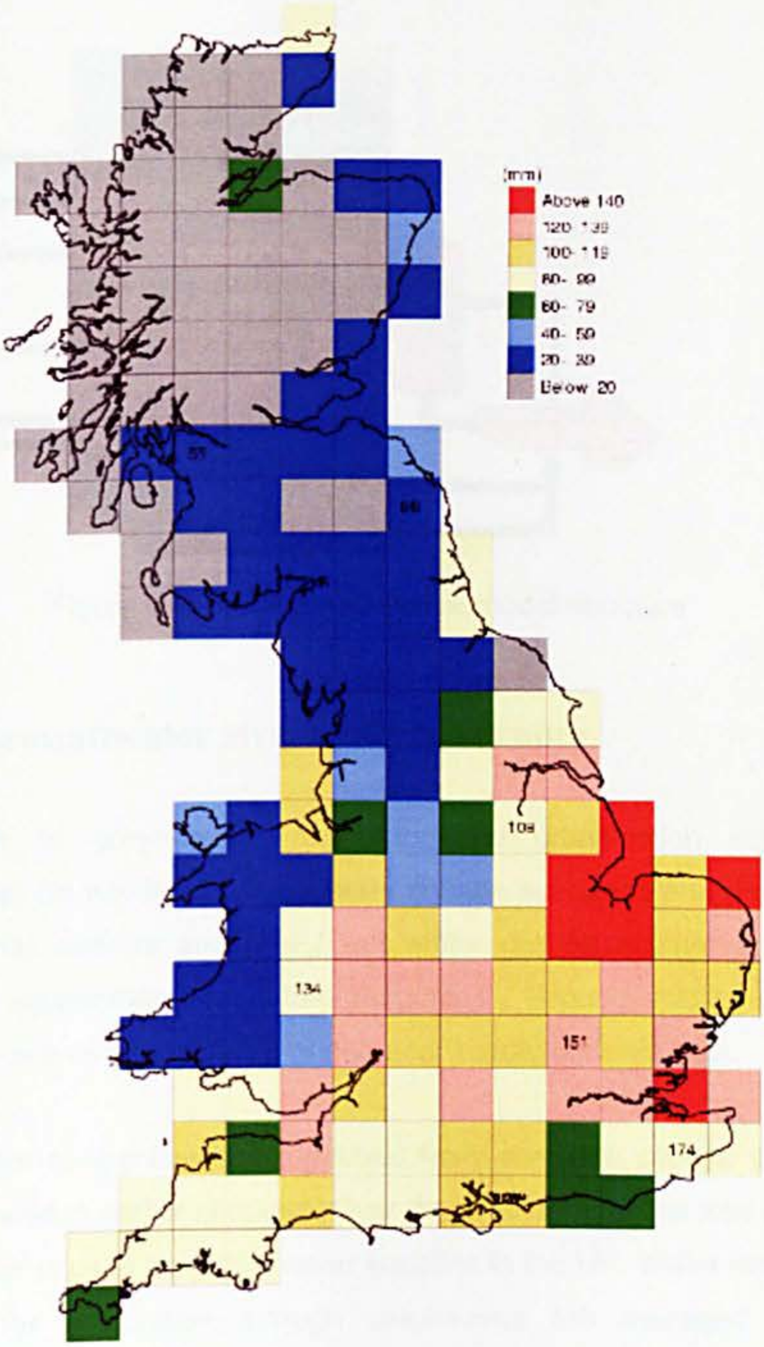


Figure 9.3: Soil Moisture Deficit total assumes grass cover in mm (MORECS, 2002)

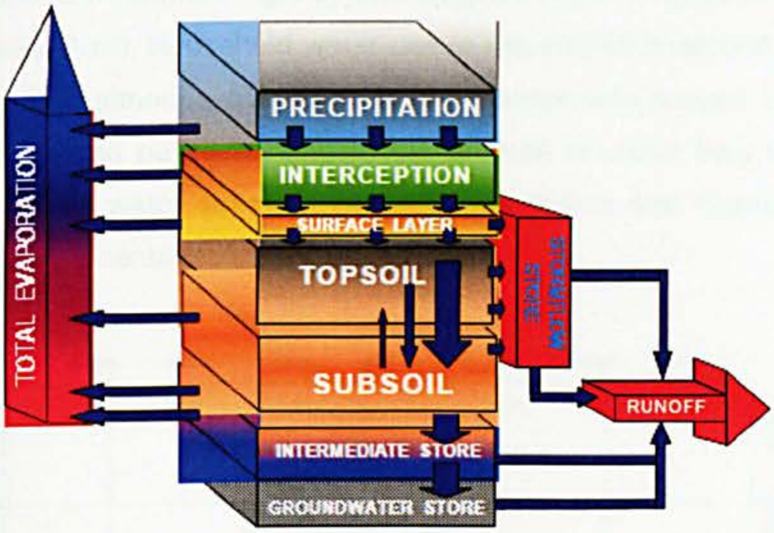


Figure 9.4: Soil Water Balance model structure

## 9.4 Groundwater stress and headroom

Abstraction of groundwater resources and urbanisation act mutually on groundwater (in addition to the climate change scenarios and prediction to have hotter / drier summer and cold / wet winter can be another adverse factor to impact the environment and natural resources). Groundwater stress analysis and headroom give us an indication of demand/ supply and recharge.

Groundwater abstraction has remained fairly constant; around 10% of the total was discussed in earlier chapters. Over three quarters of the total abstracted from groundwater is used for public water supplies in the UK. Water resources that are available for abstraction through catchments are managed by Catchment Abstraction Management Strategies (CAMS).

Freshwater resources are most heavily exploited in the South East and Eastern England and can be considered to be under stress by international standards according to the Environment Agency sources *(EA, 2012)*. Taking the population density into account, available fresh water per person is less and it is the responsibility of the Environment Agency to manage water resources so that people have adequate supply water whilst minimising the impact of abstracting water on the environment. ***Level of water stress*** in Leighton Buzzard according to the Environment Agency and Anglian Water is classed as serious *(Environment Agency, 2008)*. Household water use in the district is around 160-170 lit per person per day, although over 50% of the households around Leighton Buzzard have metres and pay according to the amount of water they use. Figure 9.5 shows Levels of water stress in England and Wales and Figure 9.6 shows the water stress percentage.

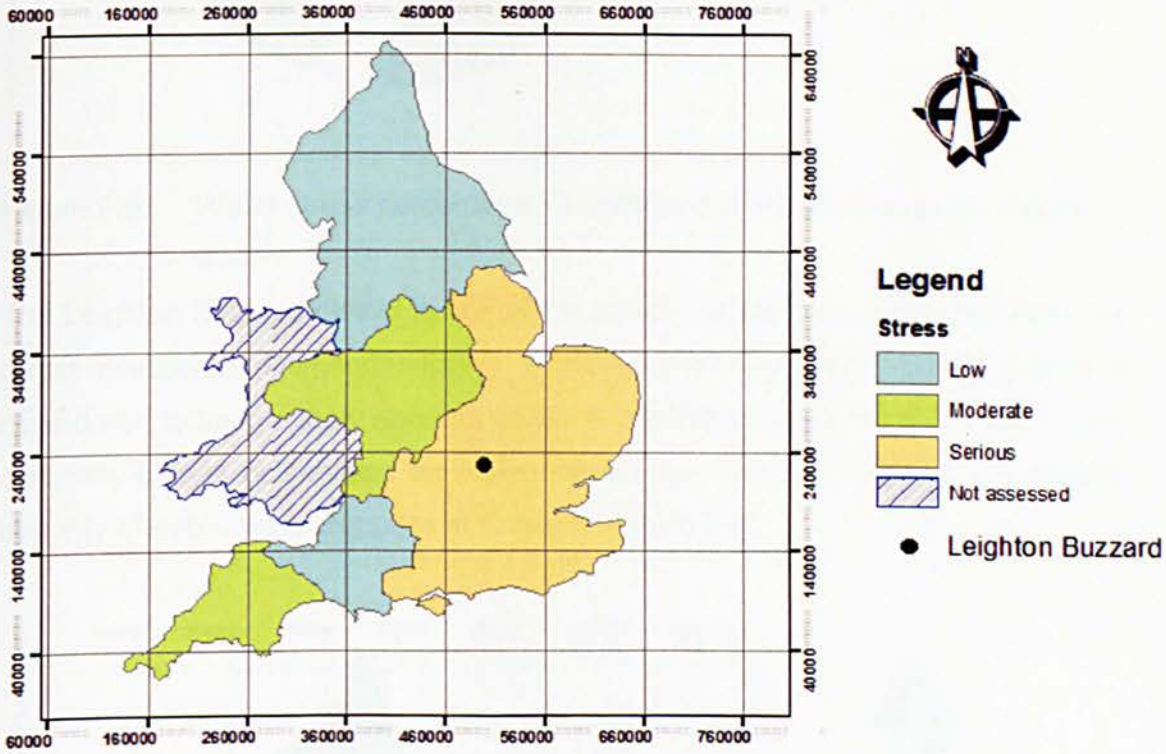


Figure 9.5: Level of water stress in England and Wales *(Environment Agency, 2008)*

The total amount of water put into supply by water companies is less than it was years ago. About half the water put into supply is to meet household demand. The amount used to supply business and industry has slowly declined in recent years and is now about 20 per cent of the total quantity supplied *(Environment Agency, 2008)*. Figure 9.5 shows the percentage of the headroom of public supply in England and Wales. **Headroom** of Public supply is defined as a planning allowance that a careful water company should take into account when developing plans to balance supply and demand and to deliver its desired Level of Service or the difference between water available and demand.

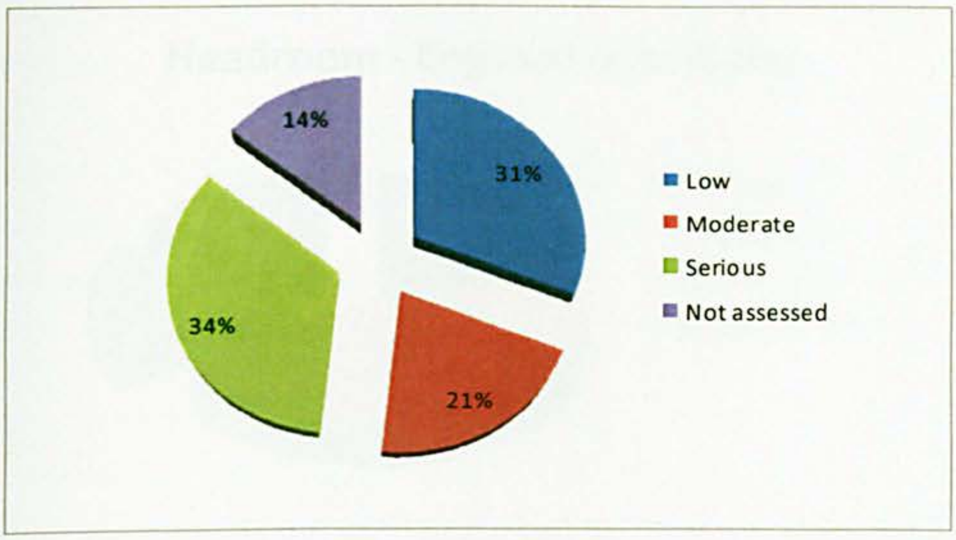


Figure 9.6: Water stress percentage - contributed area percentage for Figure 9.5.

The Leighton Buzzard district is one of the areas that supply is currently below the target headroom (Demand>supply). It means that the water resource zone is considered to be in supply demand balance shortfall as it does not meet the water company's level of services for water resources. Figure 9.7 shows the relative security of public water supplies in England and Wales.

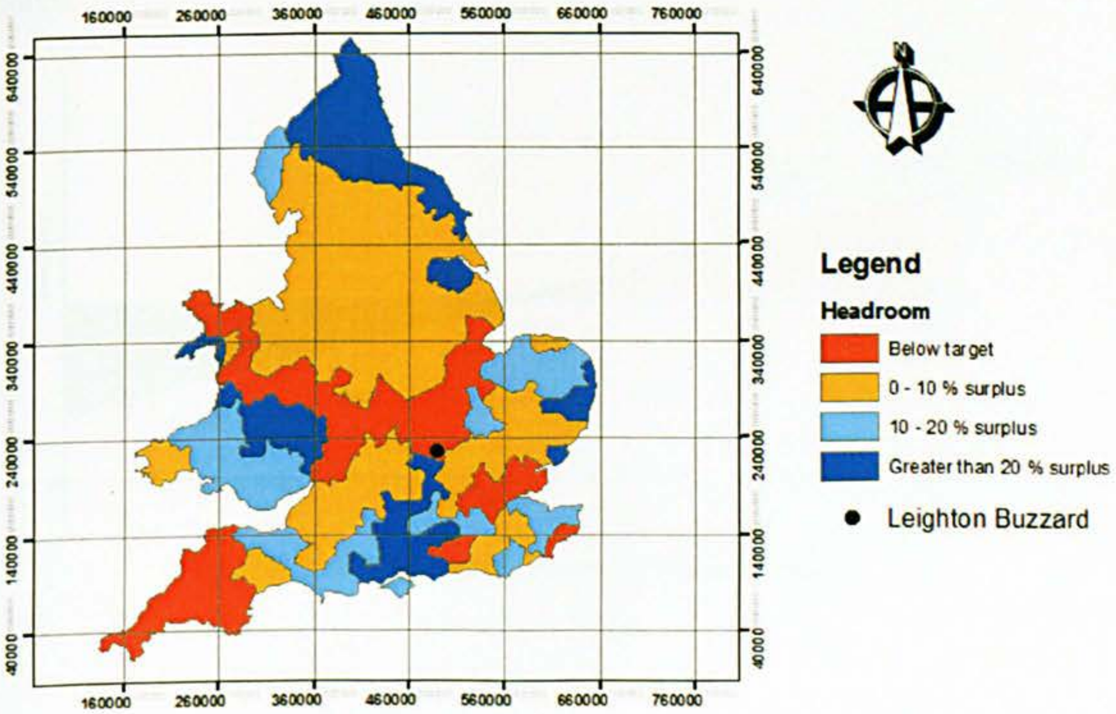


Figure 9.7: Relative security of public water supply in England and Wales *(Environment Agency, 2008)*

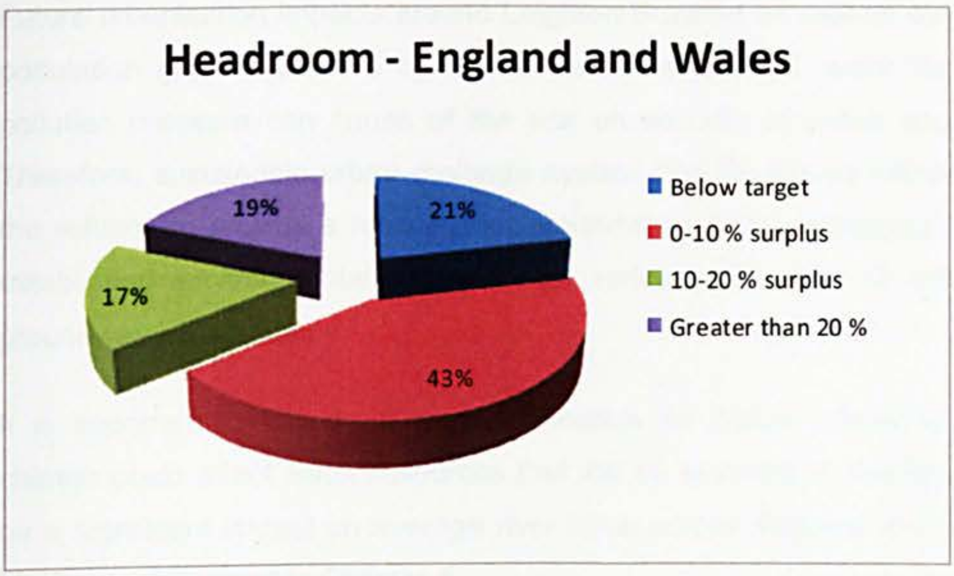


Figure 9.8: Water resources headroom - contributed area percentage for Figure 9.7.

As discussed the difference between available supply and demand is known as headroom and the Water Company always target the headroom to ensure it can meet user demand in a dry year. For a better understanding of headroom, Figure 9.8 explains supply versus time to show the difference between surplus and deficit.

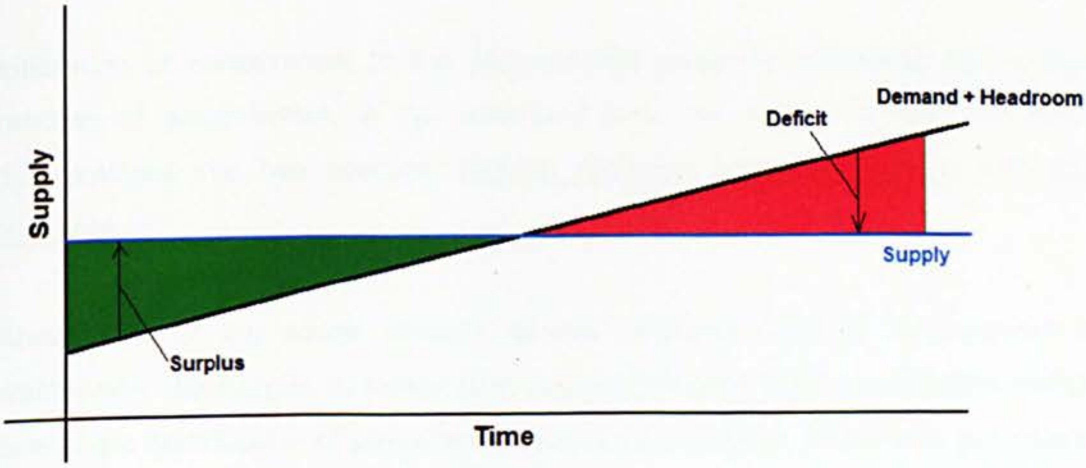


Figure 9.9: Definition of surplus and deficit

Future urbanisation impacts around Leighton Buzzard as well as climate change, population growth (20-30% by 2031), water for wetland, water for wildlife and pollution pressure can cause of the risk on security of public supply demand. Therefore, sustainable urban drainage system (SuDS) can be considered part of the solution to provide a resource for groundwater to be recharged under a well-established environmental policy which reduces the risk of urbanisation to groundwater resources.

It is important to include a recommendation for future reference that climate change could affect water resources that will be available in the future; there will be a significant impact on average river flows across England and Wales by the 2050s, as discussed in Chapter 5.

By 2050, river flows in the winter may increase by 10 to 15%, but with lower flows in most rivers between April to December. River flow in the late summer and early autumn could fall by over 50%, and by as much as 80% in some catchment areas. Overall, this could mean a drop in the annual river flow of up to 15%, so the future management of this precious resource is too important to be left to chance. In early 2009, the Environment Agency published the strategy for managing water resources in England, and Wales for the next 50 years *(Environment Agency, 2011)*.

Infiltration of contaminant to the groundwater generally relates to the recharge process of groundwater. In the urbanised area, the source of recharge can be differentiated into two sources; Natural recharge from precipitation and urban recharge.

About 75% of the sewer network covers Leighton Buzzard. It assumed that wastewater discharges to sewer and natural recharge from precipitation reduces due to the contribution of paved area toward urbanisation. Therefore, groundwater in not recharged adequately and this process will have both environmental and groundwater risk impacts in the long term. It is widely believed and experienced that urban groundwater recharge extremely affects the local aquifer system in terms of quality and quantity. Impact of improper urbanisation with shallow groundwater resources should be a catastrophic disaster for future generations and the environment.

On the basis of significant land use data from 1870 to 2000 around Leighton Buzzard and the rapid urbanisation of south Leighton Buzzard between 2000 - 2010, there are still great risk on aquifer and groundwater depletion. Hydrological changes such as reduction of natural infiltration and the catchment area, contamination due to local land use for different purposes, water demand and abstraction to meet requirements, sewer network and waste water disposal and climate change impacts could be considered as urbanisation risks to the district in addition to natural groundwater resources.

To manage surface water with a number of a few following concepts from development using the SuDS idea can reduce risk of water resources in terms of groundwater quantity due to limitation of natural filtration and town development in addition to district urbanisation.

1- **Management train**: Employs drainage techniques in series to reduce pollution and control flow rate and volume as water flow along the SuDS. Each part of the SuDS management train reduces the impact of the quantity of water leaving a development and improve the quality before releasing to the wider environment. Lakes and ponds would be an ideal final destination to infiltrate the surface water into the ground through natural and recharge groundwater resource and provide good and suitable amenity and biodiversity to the area. An example of such systems can be found in the south of Leighton Buzzard district (Pratt's Quarry development).

2- **Source control**: Deals with surface water runoff as close as possible to where it falls as rain, Hydro-brake, orifice, etc. Widely use now a day in drainage design reduces the rate of flow from development to sewer network and provide attenuation storage to avoid floods and in the meantime, water can infiltrate naturally into the ground resource.

3- **Sub-catchment**: Manage surface water runoff locally in small scale SuDS drainage area.

4- **Storage Hierarchy**: Stores water throughout the site in SuDS feature

5- **SuDS maintenance**: Manage SuDS by using landscape maintenance techniques.

SuDS efficiency can be achieved by a proper management and maintenance plan and it should include:

- Designing for maintenance
- Landscape maintenance
- SuDS management plan
- SuDS outfall route

Sustainable drainage is the practice of controlling surface water runoff as close to its origin as possible, before it is discharged to a watercourse or sewer. This involves moving away from traditional piped drainage systems towards softer engineering solutions which seek to mimic natural drainage regimes. Sustainable drainage techniques have many benefits such as reducing flood risk, improving water quality, encouraging groundwater recharge and providing amenity and wildlife benefits *(Environment Agency, 2011).*

One of the environmental objectives by using SuDS to reduce the runoff rate by achieving Greenfield discharge rate is to accommodate surface drainage system for any event up to the critical 1 to 100 years storm events without bypassing flow balancing and surface water discharge to a watercourse (not exceeding a velocity 1m/sec). Pratt's Quarry pond has been designed to the above environmental standards and I have had an active role in the designing process of the pond.

SuDS techniques to reduce pollution can be achieved by permeable surface /filter drain, filter strip/ Swales, Basin/Pond and infiltration devices/ soakaways as groundwater recharge mechanism, but source protection zones need to be carefully addressed as a key issue.

Leighton Buzzard's main supply sources are surface water and groundwater and source protection zones are identified by the Environment Agency. Figure 9.10 indicates an extract model of source protection zones within the district and beyond and Figure 9.11 shows groundwater vulnerability, and although groundwater protection zones are away from the district itself, in terms of groundwater vulnerability, Leighton Buzzard is within the major aquifer high groundwater vulnerability zones to represent the intrinsic geological characteristics that determine the area with which groundwater may be contaminated by human activities. The vulnerability of groundwater depends on:

- Infiltrating water travel time
- Relative quantity of contaminants that can reach  to groundwater
- Contaminate attenuation capacity of geological materials through which water and contaminants infiltrate

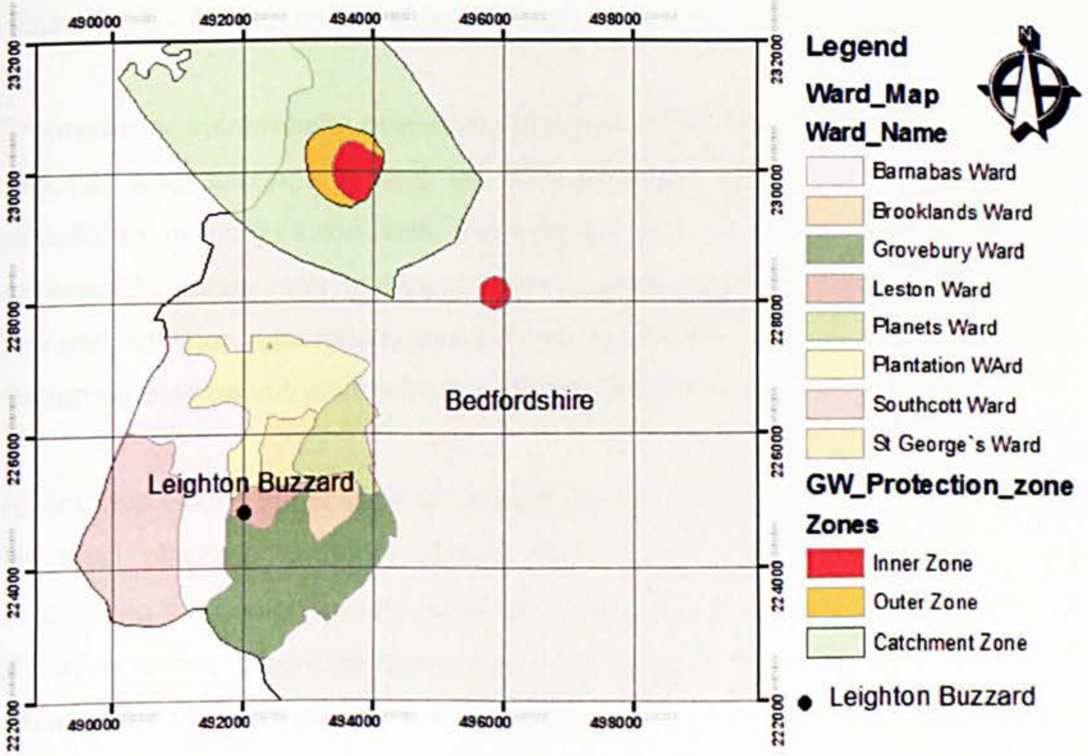


Figure 9.10: Extract model of source protection zones and groundwater vulnerability *(Environment Agency, 2012)*

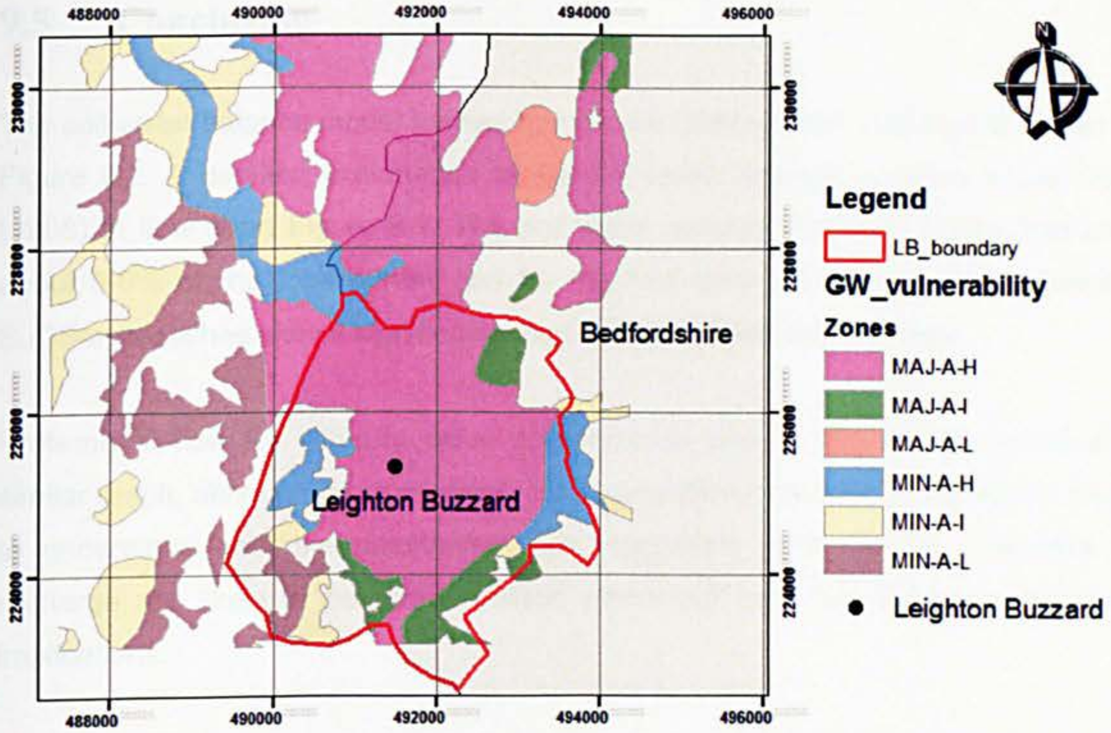


Figure 9.11: Extract model of groundwater vulnerability *(Environment Agency, 2012)*

Groundwater vulnerability previously designated as major and minor (recently as principal and secondary) and the Groundwater vulnerability map should be considered in conjunction with the surface soil. In Figure 9.11, Groundwater vulnerability zones refer to Major/ Minor aquifers as high, intermediate and low. The groundwater vulnerability dataset can be used to indicate where groundwater resources may be vulnerable from activities carried out on the surface land.

To achieve SuDS application to reduce risk of groundwater due to urbanisation, the local planning authority should have a very restricted planning process considering the design criteria, protection zones as well as long term maintenance of the systems; otherwise there will be a greater environmental risk from the urbanisation for groundwater and its recharge mechanism.

## 9.5 Conclusion

The soil water balance model formed to estimate groundwater recharge is shown in Figure 9.2. A detailed explanation of the soil water balance is given in De Silva (1998) in flow chart Figure 9.1. The soil water balance model indicates that only about 5-6% of the total rainfall can be reached back into the ground, however, SuDS approaches shows significantly higher percentage recharge rate.

Preferential flow for different value compared to see all the models produce a similar result, although more research work on preferential flow is required in order to understand both the mechanism and magnitude of it. So the estimates of recharge are likely to be more realistic which will have far reaching economic implications.

Groundwater stress and headroom give us an indication of demand and supply. Leighton Buzzard district lies within the serious level of water stress zone according to the Environment Agency and headroom of public supply falls below target according to Anglian Water demand is more than supply and Anglian Water does not meet the level of service to provide satisfactory supply unless we abstract more pure water using ground resources.

To reduce environmental impacts due to excess of abstraction by Anglian Water and make a sustainable approach to recharge groundwater, SuDS can reduce the risk of water resource in terms of groundwater quantity by using an effective method, proper management and maintenance plan to achieve a sustainable drainage practice in the district.

# CHAPTER 10 - CONCLUSION

## 10.1 General

The aim of this research is to investigate the use of sustainable drainage for groundwater recharge, using a case study of the area around Leighton Buzzard, Bedfordshire, England. The research findings are summarised in this chapter. Each section in the chapter interprets the general determination of the related chapter to respond to the research questions and detailed objectives.

## 10.2 Geology and land use around Leighton Buzzard

A review of the geology and hydrogeology of the area surrounding Leighton Buzzard confirms that the Woburn Sands Formation belonging to the Cretaceous period is an important aquifer in the district. The sediments which makes Woburn sands are quartz ($SiO_2$). Lower Greensands such as the Woburn Sands typically comprise of loose, unconsolidated sandstone and sands of varying grain size with a minor amount of siltstone, mudstone and limestone (with high permeability in the range 2.25 $\times 10^{-3}$ - 7.59$\times 10^{-3}$ m/sec).These formations are not homogeneous, but they are stratified, such that the Woburn Sands Formation is subdivided into a upper unit (Red, Silty and Silver sands) and a lower unit (Brown sands).

The overall thickness of Woburn Sands varies from 90-120m; with the greatest proven thickness (88.65m) recorded by the British Geology Survey (1994) at the Potsgrove borehole between the settlements of Leighton Buzzard and Woburn. Woburn Sands are underlain by the Oxford Clay Formation and overlain (eventually) by Gault Clay. Within this "sandwich". The Woburn Sands are most suitable for natural infiltration and recharge.

Land use data for selected sites in and around the Leighton Buzzard district as published in the past on OS maps which covered over 140 years have been reviewed. Overall, the district measured by GIS covers an area of about 1700 ha. Figure 10.1 shows the location of the sampled areas that were first developed between the years 1870 to 2005, although the dates given are from the first map on which the development is shown. The total population of the district has been recorded to be around 37400 (2009). Due to good transport links and the ease of commuting daily in London, the population has grown, stimulating housing demand considerably over the past 20 years. In response, housing development planning applications for large developments have been granted successfully.

Figure 10.1: Sampled development area from 1870 to 2005

The nature of land use considered in different sample locations have been described and analysed in Figure 10.1. The total paved area in 1870 of the houses was larger than the green (open) site. However, from 1900 onwards the green site compared to the paved area remains in constant proportion and the average paved area for development assumed to be around 36% in Leighton Buzzard and the remaining 64% of the land used as Greenfields, gardens etc. In the early part of the 20th century, building plots often contained large gardens, but many modern developments are denser (Section 8.3).

The most obvious change in recent times has been the Pratt's Quarry development (Figure 7.1), where a significant part of the development land has been dedicated to pond and SuDS applications (which the authorities considered to counter the impact of urbanisation on groundwater resources).

Urbanisation and paved areas reduce natural infiltration of surface runoff into groundwater. However, proposing a suitable pond (SuDS) to infiltrate surface runoff back to ground resources was considered as part of the environmental solution to reduce the impact of urbanisation on the district and maintain the groundwater resources in a sustainable way for future use by utilising this natural recharge mechanism.

There is little doubt that the spread of urbanisation in the 20th century was driven by social and economic factors, such as the appeal of the area to commuters as the house prices in London rocketed, the increasing level of car ownership which eventually largely supplanted the bicycle and the local transport buses. The surprise is that the areas that have been urbanised are not particularly "impermeable" in comparison with the past, and this does not appear to be an increasing trend.

The spread of urbanisation, which appears to be a worry, is less significant when it is considered that some of it takes place where the aquifer is confined beneath a cover of clay, or, indeed, as in the case of Pratt's Quarry, where the sands of the aquifer had been quarried away and the site reinstated with engineered Clay. In this case, the SuDS application has less to do with the infiltration option, and more to do with surface water runoff management. However the SuDS application has been considered as a long term urbanisation objective to control surface water runoff where the aquifer had been quarried.

From the review of the geology and land use around Leighton Buzzard, this research concluded that the aquifer around Leighton Buzzard is the Woburn

Sands and it is an important aquifer to provide a reliable groundwater source to use. Although the Woburn Sands thickness has an average of 90m with highly permeable characteristics proved to be suitable in the use of the aquifer for SuDS applications. Referring to the detailed objectives and the specific research questions (1) surface water can easily be infiltrated into the ground through a natural mechanism. The analytical design model (chapter 7) indicated that an accurate wet pond design considering future climate change impacts can control surface runoff fully and infiltrates naturally into the aquifer without discharging away to a watercourse where the proposed pond bed aquifer remains untouched. In terms of the groundwater recharge process, this research also found that SuDS is the most effective approach to recharge aquifers naturally, to control the quality of groundwater resource at the source point and to minimise the risk of surface water runoff that impacts on the area where the aquifer is made from the Woburn Sands or a similar highly permeable formation.

## 10.3 Aquifer and groundwater pollution

The water below the surface in the saturation zone and in direct contact with the subsoil refers to Groundwater. The hydrogeological rocks are classified in terms of their permeability and an aquifer is a stratum of relatively porous soil or rocks that contains and transmit a substantial quantity of groundwater.

The Environment Agency (EA) is an executive, non departmental public body of the Department for Environment, Food & Rural Affairs (defra), plays a central role in implementing the government's environmental strategy and the lead role in managing flood risks and works to minimise the impact of flooding in England. The EA aquifer designation according to the Water Framework Directive are of two types: (1) Superficial such as sand and gravel (2) Bedrock such as chalk and limestone. The above two designations are subdivided into the Principal and Secondary aquifers.

Woburn Sands Formation (Lower Greensands) is a superficial principal aquifer (Figure 2.14) with a high rate of groundwater productivity (Figure 3.6) Therefore, Lower Greensand is a very important aquifer, and the usability of the aquifer is a function of:

1. Infiltration area, thickness and permeability
2. Whether the groundwater gets contaminated or polluted

A discussion on what constitutes a pollutant, how pollutants reach the groundwater, and what effect they have on water quality has been discussed in Section 3.7. Pollutants that are of significance to this research arise from the construction of highways, the general urban environment, from maintenance activities, and from routine operations as well as deliberate or accidental releases of unusual materials.

As reviewed and discussed (section 3.8), there is not a simple definition of a pollutant. Any chemical compounds in excessive concentrations or in combinations with other materials could be classified as a potential pollutant. Some chemical tests carried out on the Woburn Sands around Leighton Buzzard found that they are within the recommended range of the groundwater and aquifer protection guide (section 6.7).

In response to the research question (4) regarding protection of groundwater through sustainable, natural processes to minimise the risk of groundwater contamination, this research found that the degree to which SuDS can control pollutants carries a risk to groundwater and is still under investigation. On the basis of the case studies carried out (section 5.5), evidence found a very low movement rate downwards of the pollutants towards the ground and the vast majority of the heavy metals, hydrocarbons and PAHs are retained in the top 70-120mm of soil and the level of pollutants in the pond sediments are higher than that the soil.

There is no doubt that dissolved chemicals can reach the groundwater and it is very difficult to control them on a large scale due to high maintenance and introducing such a mechanism to remove them, therefore SuDS can reduce pollutants in a variety of ways depending on the type and form of the pollutant; wet ponds are suggested as more effective at removing pollutants than dry SuDS.

This research concluded that detention ponds and lined Soakaways have become more popular as a combined SuDS by removing some portion of chemicals and bacteria and it could be considered as part of the natural process to protect groundwater somehow or to minimise the risk in the long term. Highway drainage pollutant degradation within SuDS have been studied (Section 5.5). The reduction can be expected to be between 40-50% at 17-20°C in 30 days and between 20-30% at 3-5°C in 30days.

The principal findings of this research are that most pollutants occur in very small concentrations, and that the pond/lagoon style of SuDS provides for:

(a) The capture of many pollutants in the base sediments of the pond.
(b) A number of them to degrade naturally anyway, so that entry of pollutants to the groundwater is at least partly inhibited, thus further improving quality.

## 10.4 Statutory measures, Directives and protection zones

The Statutory controls exist to control these resources. Some of the measures are implemented by water companies and some by government bodies. There are currently 34 companies: 10 regional water supply and sewerage, 11 regional water supply only, the 13 local and licensed companies and the Water Service Regulatory Authority (WSRA) which is the economic regulator of water and sewerage sectors in England and Wales to ensure water companies provide a good quality of water service for household and business consumers, and a good value for money.

Anglian Water is the water & sewerage company that provides the service for over 6 million people and covers about 28000 km$^2$ in area which is 18.5 % of the England and wales geographical area including the Leighton Buzzard district (Figure 4.1 & 4.2).

In December 1979 the European Commission introduced a Groundwater Directive (80/68/EEC) which was aimed largely at the control of discharges of specified substances to groundwater. The European Water Framework Directive came into force in December 2000 and became part of UK law in December 2003. In 2013 the existing Groundwater Directive (80/68/EEC) was replaced by the Water Framework Directive 2000/60/EC, therefore the Environment Agency policies are to reflect the Water Framework Directive (2000/60/EC). Eventually all European state members will join the Water Framework Directive and a proposal recommending similar provision of the 2006 European groundwater Directive or the European framework should be imported to the USA.

The groundwater abstraction is one of the most important factors in assessing the risk to an existing groundwater source and four groundwater source protection zones (inner, outer, catchment and special interest) are recognised by the EA. A general discussion of this area is provided in Sections 4.5 - 4.9, The findings are that the Environmental Policy does contain contradictions, such that SuDS while in general may be seen as a "good thing" may well be set about by difficulties in achieving the set standards in the pond itself while the infiltrating water is of better quality than the input to the pond. The water companies know that the entire catchment cannot be protected fully. What comes from this research is that the boreholes are located in and/or close to old areas of the Leighton Buzzard development, in which the urbanisation or impermeability has not changed greatly: ongoing urbanisation takes place distant from the wells/boreholes, and more distant from the source protection zones. This renders the loss of the infiltration areas that might be thought to be less significant, it renders the likelihood of pollution that cannot be dealt with by diluting and dispersing it, and finally, it makes the use of SuDS applications for groundwater recharge is also less effective than when it is closer to the well.

## 10.5 SuDS and climate change impact

Sustainable Urban Drainage System (SuDS) is an alternative to conventional piped means of managing surface water. SuDS aims to achieve within urban areas the way rainfall drains in natural systems. Although there are many practical benefits to SuDS and there are a number of "administrative" barriers that have caused problems implementing schemes such as ownership, change of regulation, technical approval, maintenance and lifetime operations.

Climate change as predicted by scientists is happening due to greenhouse gasses and human activities. By 2100 there is a suggestion of up to a 4.5°C increase in temperature around the UK and up to 60% summer and 30% winter precipitation changes. Some basic assumptions and common misconceptions in climate modelling have been noticed and, as UKCP09 states, climate models are based on fundamental physics laws in terms of mathematical equations. They do not as in some prediction events, statistically fit to past observations. The prime aim of SuDS is to provide effective surface drainage, ensuring a high degree of flood risk protection in the long term and prevention of pollutants to groundwater and/or other resources.

A detailed discussion for SuDS is covered in Section 5.2. In response to the research question (2) the research findings concluded that SuDS provides environmentally friendly long term advantages to the community (chapters 7, 8 & 9) and the administrative barriers will be resolved after a while or they may get simpler to adopt SuDS more easily. Also in response to the research question (3) SuDS is expected to meet environmental challenges such as climate change. The research found regarding to climate change is determined that if the climate change projections and debates (Section 5.6) are 100% realisable then SuDS is the best option to be implemented, if not the groundwater resources are sustainable.

## 10.6 Geotechnical properties of Woburn Sands

Chapter 6 has provided Geotechnical properties of Woburn Sands and results from laboratory tests. It concluded that the Woburn Sands are suitable material for SuDS application.

## 10.7 Infiltration and design model

The infiltration systems play a significant part of the solution to reduce the risk of urbanisation in groundwater resources and the environment, and to provide a better chance for the construction of new developments as well as control of surface runoff and recharge of the aquifer. The Infiltration drainage system may be used instead to dispose of storm water (surface water) from urban areas and highway areas by recharge into groundwater. The role of infiltration in practice and different types of infiltrations have been discussed in chapter 7.

### 10.7.1 Leighton Buzzard and Pratt's Quarry as a site for SuDS

The SMA development is being built over a reclaimed sand quarry that had already been largely exhausted, and so had reduced the infiltration area to a fraction of its former extent. Ground levels in the reclaimed quarry were reinstated with an engineered fill sourced largely from the former overburden, i.e. from Gault Clay. Without a SuDS application, the infiltration capability of the area of Pratt's Quarry was therefore close to zero. Even without the reinstatement of levels, the recharge capability would have been extremely small, with little direct contact with the Woburn Sands.

The planned SuDS application goes some way to replacing the original surface area available for infiltration, because the pond will provide continuous infiltration, and not discontinuous infiltration (alternating with evapo-transpiration) corresponding to an overall possibly lesser infiltration behaviour. Moreover, the drainage network via roads etc. extends the catchment to an area much greater than that of the pond alone.

As the philosophy behind SuDS is to mimic natural drainage processes, remove pollutants and manage the flood risks at the source, whilst proving to be a significant contributor to increased biodiversity, the proposed SuDS pond for SMA Pratt's Quarry housing development demonstrates reasonable benefits overall. Specific potential benefits of the following type are indicated.

1. Flood risk management: reducing the risk of flooding from the development, this alters natural drainage processes.
2. Water quality management: reducing the impact of diffused pollution caused by human activities.
3. Improving amenity and biodiversity: the integration of green infrastructure with SuDS solutions can help to create habitats, recreational and biodiversity areas.
4. Water resources: SuDS can help to recharge groundwater supplies, where appropriate, and capture rainwater for re-use purposes.
5. Community benefits: attractive, well designed public open space that incorporates SuDS can help to create better communities through social cohesion and quality of life improvements.
6. Enabling development: SuDS can help to free up capacity in already established drainage networks, and the provision of SuDS is a requirement of planning permission for new development if applicable.

Comparative costing for surface water sewers and SuDS case studies reviewed (Section 5.7) for different projects and this demonstrates the significantly reduced cost of implementing SuDS over traditional drainage at all runoff rates examined in response to the detailed objective of the research.

## 10.8 Impact of Urbanisation and water supply

Urbanisation can cause a potential threat to groundwater resources, although some of these threats may damage groundwater resources permanently. There is such a view, the areas that are being covered might restrict the natural infiltration however it is not well supported by evidence if the abstraction rate is too high, the recharge cannot be made up from infiltration, also areas urbanised in source protection zones greater than 100 years ago, therefore by urbanisation of the catchment area and abstraction of more water to meet the demand, in addition to climate change impacts and human activities in the urbanised area could be considered as potential risk (Section 8.2).

Water resources management plan (WRMP) is a new statutory process to enable water companies to comply with the Environmental Agency guidelines and the main focal points with the plans are: growth in climate change, sustainability and environmental legislations. Anglian Water source points are 121 in total (Figure 8.9). 42.3% of Anglian Water is supplied from groundwater sources and 57.5% from surface sources. In and around Leighton Buzzard, Anglian Water has one surface source point, 6 ground source points and 33% of the supplies come from groundwater. Considering future district urbanisation and possible climate change predictions, Anglian Water will increase abstraction of groundwater to meet supply & demand and groundwater will be the most reliable source and the cheapest to clean.

The impact of urbanisation can be negative or positive depending on the level of the investigation. This research found a reasonable response to the research question (5) that the level of threat to groundwater resources is due to urbanisation and groundwater abstraction. Therefore part of the data analysis process is concentrated on the occurrence of a threat to groundwater resources, factors, parameters, groundwater depletion and groundwater recharge on the Leighton Buzzard district.

One of the findings of the research is the fact that urbanisation covers the area of infiltration due to avoidance of infiltration through the paved impermeable area of housing, highways and industries in the area of Leighton Buzzard. The aquifer is not recharged adequately and most of the surface runoff is discharged through the sewer network away from the area and another urbanisation impact on the groundwater resources is that pollutants can be easily transferred into the groundwater resources by human activities, although there is a policy in place to protect groundwater from pollutants. Therefore SuDS can be marginally part of the solution to recharge groundwater resources and protect to some extent the environmental issues within the environmental policy.

## 10.9 Groundwater recharge and estimation

Groundwater recharge and estimations carried out in chapter 9 through the soil water balance method. Figure 9.2 presented a calculation model during a month of rainfall data and the total recharge calculated 9.1mm and indicates that 5.17% of total rainfall can be recharged back to the ground via the soil water balance method. SuDS application can recharge fully the stored surface water (Chapter 7) and is considered to be very effective. In response to the research question (6), WinDes and GIS together provide suitable tools regarding data capturing, analysis and graphic reports. WinDes (Section 7.4) currently is used as a SuDS approval tool with SuDS approval authorities.

SuDS definitely provides economies compared to conventional piped or standard drainage systems, as reviewed through case studies (chapter 5) .This is likely to be found elsewhere as there are a few, if any, site specific factors that would invalidate wider applications of the methods in the indicative design.

The urbanisation or suburbanisation of formally rural areas is largely controlled by planning considerations, and is less due to technical factors such as infiltration and aquifer management. Indeed, the location of boreholes and their associated controlled areas is commonly (if Leighton Buzzard is a good example) distant from sites for development, and in or close to areas where development was completed a long time ago. It might therefore be more germane to consider the redevelopment of existing areas as of equal or greater significance, in particular "stirring up" existing contaminants in brownfield sites. Over-abstraction turns out to be more of a problem than the loss of infiltration areas.

In a field where the likelihood of contamination by very nasty pollutants is small anyway, the SuDS contribution to control is likely to be small, and difficult to assess. However, in the specific case of Pratt's Quarry, the use of a SuDS pond does make the potential recharge more closely approximate to pre-development conditions, and thus is, in fact, more sustainable.

The contribution from the SMA development in the Pratt's Quarry site to groundwater supply in Leighton Buzzard would, in any case, be small, even if the quarry had never been dug. The SuDS contribution is therefore beneficial, but in a small way.

SuDS are the solution to the groundwater recharge challenge. They also provide the ideal opportunity to bring urban wetlands and other wildlife-friendly green spaces in our towns and cities. These link with existing habitats creating blue and green corridors. Well-designed SuDS should also be an amenity and education resources for the community, providing high-quality public green space in which to relax, play and enjoy wildlife. However, whilst there are many good examples of this already, there is still a long way to go before SuDS fulfil their potential to integrate surface water management and water quality improvements with people and wildlife benefits. In response to research question (7) SuDS provides the ideal opportunity for local authorities to deliver multiple benefits and for little or no extra cost and this is the prime objective for the local authority. In fact these sustainable solutions are very often cheaper to build and maintain than conventional drainage solutions.

SuDS is a sequence of management practices, control structures and strategic designed to efficiently and sustainably drain surface water while minimising pollution and impacts of water quality of local water bodies. Some local authorities have given the role as SuDS approving body (SAB) and SAB is responsible for approval of the proposed drainage to meet a national standard for sustainable drainage system in new development or redevelopment subject to exemptions and thresholds.

A proposed drainage system has to meet new national standards for sustainable drainage. Where planning permission is required applications for drainage approval and planning permission can be lodged jointly with the planning authority but the Approving Body will determine the drainage application.

The SuDS Approving Body (SAB) would also be responsible for adopting and maintaining SuDS which serve more than one property, where they have been approved. Highways authorities will be responsible for maintaining SuDS in public roads, to National Standards. The SAB to arrange for SuDS on private property, whether they are adopted or not. The SAB will also be required to arrange for all approved SuDS to be included on the register of structures and features.

The Financial comparison between conventional and SuDS was not carried out on the indicative design model although as part of this research however cases are studied. The cost of building SuDS, comparing like for like in terms of storage, are nearly always 10-30% cheaper than conventional drainage. Similarly the maintenance of SuDS is simple using landscape management techniques integrated with general site care. Costs of management can be difficult to confirm due to difficulty in allocating maintenance to a specific SuDS function but it is again nearly always cheaper than for piped systems and may provide additional savings in reducing the need for artificial irrigation.

## 10.10 Contribution to knowledge, and suggestions for further research

1. Impacts of impermeabilisation due to rural urbanisation and groundwater resources abstraction by water companies should be considered as potential environmental risks whether climate change projection realisation can be acknowledged or not.

2. Sustainability of groundwater resource should be considered as a primary objective for the authorities, using SuDS to recharge groundwater resources and provide an ease adoption process to encourage communities and developers to support and accept future environmental benefits.

3. The use of WinDes (Drainage software) and GIS (Geographical information system) to assess SuDS application and the change of the impermeability of the surface in developed or urbanised areas are recommended. There would be considerable benefits in extending this

work to other areas and towns, and to doing more correlation with, inter alia, economic and political factors, the rise and decline of local industries, house prices, changes in transport opportunities, costs and social preferences, etc. (All within the realms of human geography rather than of engineering or hydrogeology). The software's used proved to be suitable and viable tools to provide graphical and analytical assessments for research purposes and the analysed data could easily be further enhanced by new researchers.

4. SuDS can reduce pollutants in a variety of ways depending on the type and form of pollutants, therefore wet SuDS structures are recommended as a more efficient process at removing pollutants than dry SuDS structures.

5. SuDS is considered as a surface water management process in practice, has been recommended as a natural recharge mechanism to minimise future environmental risks and all the Local Authorities (LA) will be acting as a SuDS approval body to meet the drainage standards and sustainable levels.

6. SuDS applications for new development reduce the cost of upgrading the existing drainage network around Leighton Buzzard and provides a safety control to the locality in terms of Flood management and environmental biodiversity.

Groundwater sustainability goes in parallel with conservation; the more conservative the proposed or adopted policy, the more sustainable it will be. Sustainable return is seen to be a moving target, subject to adaptive management. Thus recharge of groundwater resource through SuDS achieves the sustainability objective of the environment.

# REFERENCES

Allen, D.J., Brewerton, L. M., Gibbs, B. R., McDonald, A. M., Wgstaff, S. & Williams, A.T., (1997) The physical properties of major aquifer in England and Wales. British Geology Survey Technical Report WD/97/34.312pp, Environment Agency R&D publication 8.

Anglian Water, (2011) Sustainable drainage system adoption manual, LED053/06/2011 & LED029/03/11, UK: Anglian Water Service Ltd.

Barnes, G., (2010) Soil Mechanics, Principle and practice, Eurocode compliant, 3rd edition, UK: Palgrave and Macmillan.

Barrett, M., Luntin, A. and Austrheim-Smith, S. (2004) Storm water pollutant removal in road side vegetated buffer strips, USA: Centre for Research in Water Resource.

Bedfordshire County Council, (2011), Public Information, received Ward population Jan 2012.

Bideaux R A., Bladh, K.W., Nichols, M.C. and John W. Anthony , J.A, (1995) Handbook of Mineralogy: Silica, Silicates, USA: Mineral Data publishing

Binnie, C .J. A. (1991) Water supplies in the UK in the 1990s and beyond, UK: Institute of Civil Engineering (ICE) ISBN: 0-11-310145 7.

Boggs, S.J (2010) Principles of sedimentology and stratigraphy, 5th edition, UK: Pearson.

Boxall, A.B.A., Forrow, D.M., Maltby, L.L., Callow, P. and Betten, C. (1993) Toxicity of road runoff contaminated sediments to Grammars Pulex. Poster presented at SETAC World Congress March 1993, Lisbon, Portugal.

Bristow, C. R. (1963) The stratigraphy and structure of the upper Jurassic and Lower Cretaceous rock in the area between Aylesbury and Leighton Buzzard. University of London: PhD thesis (Unpublished).

British Geological Survey (1994) Geology of the country around Leighton Buzzard 1994, 1st ed, London: British Geology Survey.

British Geological Survey (2013), available at: http://www.British Geology Survey.ac.uk/geoindex/ (Accessed 01Jan 2013).

British Geological Survey, (1994) Geology of the country around Leighton Buzzard. 1st ed. London: British Geological Survey, ISBN-0-11-884503-9.

British Geological Survey, (2012) Digital data map for rock units.

British Research Establishment (2003), Soakaway Design Digest 365, London: BRE publication.

British Standard 1377-2 (1990) Methods of test for soils for civil engineering purposes. Classification tests, UK: BSI.

Bulter, D. & Davies, J. W. (2011) Urban Drainage, 3rd edition, Oxon: Spon Press.

Callomon, J.H. (1968) The Kellaways Beds and the Oxford Clay: 264-290 in the Geology of the East Midlands. Leicester: Leicester University press.

Canter, L. W. & Knox, R. C. (1985) Groundwater pollution control, USA: Lewis Publisher.INC, ISBN: 0-87371-014-2.

Casey, R. (1963) The Stratigraphical palaeontology of the Lower Greensand. Palaeontology, Vol.3, 487-621.

Catchment Abstraction Management Strategy, (2005) The Upper Ouse and Bedford Ouse Catchment Abstraction Management Strategy, UK: Environment agency.

Catt, J. A. (1981) Quaternary history of the Hertfordshire area, Transaction of the Hertfordshire natural history society, Vol28, 27-53

Charbeneau R.J, (2006) Groundwater Hydraulics and Pollutant Transport, 1st edition, USA: Waveland Press Inc.

CIRIA "Construction Industry Research & Information Association" (1999): Hydraulic measures for the control and treatment of ground water pollution. Report-142. ISBN-13: 978-0860174998

CIRIA"Construction Industry Research and Information Association" (1996), Infiltration Drainage Manual for good practice, Report 156, London: CIRIA Publication.

CIRIA"Construction Industry Research and Information Association" (2007), The SuDS Manual, CIRIA C697, London: CIRIA Publication.

Clark, L. & Sims, P.A. (1993) Jet fuel clean up at an international airport: in proceeding of groundwater pollution conference, 16-17 March 1993 IBC, London.

Codd, J.W. (2007) Analysis of the distribution and characteristics of landslips in the Weald of East Sussex. MSc dissertation, University of Brighton.

Colwill, D.M., Peters, C.J., Perry, R.( 1984) Water quality of motorway runoff, Research Report 823, Transport and Road Research Laboratory, Crowthrone.

Craig, R.F (1997) Soil Mechanics, 6th edition, UK: Spon Press

Crux, J.A. (1991) Albian Calcareous nannofossils from the Gault Clay of Munday`s Hill (Bedfordshire, England): Journal of Micropalaeontology, Vol.10,203-222

Deborah, M. F., Canter, L. W. and Knox, R.C. (1987) Groundwater Quality Protection, UK: CRC Press.

Defra & the Environment Agency (2005) Preliminary rainfall runoff management for development, R&D technical report W5-074/A/TR?1 revision D, September 2005, Bristol: Environment Agency

De Silva, R.P., (1998) A review of the method of estimating groundwater recharge in relation to the dry zone of Sri Lanka. The open University review of Engineering Technology Journal, Vol: 4 (2):3-12, Open University Sri Lanka.

Downing, R.A. (1998) Groundwater our hidden asset. UK Groundwater Forum, Wallingford, 60pp.

Eagleson, P.S. (1978) Climate, soil, and vegetation, 1. Introduction to water balance dynamics, Vol.14, issue 5, page 705-712: Water Resources Research.

ECL- Christian Ecology Link, (2012), available at http://www.christian-ecology.org.uk (Accessed 2 July 2012).

Ellis, J.B. (1979) The nature and source of urban sediments and their relation to water quality: A case study from N W London, in: Man`s impact on the hydrological cycle in the UK, Cambridge.

Environment Agency (1998) Policy and practice for the protection of ground water, UK: HM Stationary Office.

Environment Agency (2006) The state of groundwater in England and Wales, GEHO0906BLDB-E-P, UK: Environment Agency.

Environment Agency (2007) Groundwater protection: Policy and practice, Part-1: Overview, Part-2: Technical Framework, Part-3: Tools and part-4: Legislation, UK: HM Stationary Office.

Environment Agency (2008), Groundwater protection: Policy and Practice- (GP3), part-1, overview, part-2, Technical framework, part-3, Tolls and part -4, Legislation and policies, UK: Environment Agency.

Environment Agency (2008), Water resources in England and Wales, Current state and future pressures, December 23008.

Environment Agency (2013), available at: www.environment-agency.gov.uk/business/topics/water/38597.aspx (Accessed 2nd Jan 2013).

Environment Agency, (2011), Environmental Permitting Charging Scheme & Advice 2011-12, Bristol: Environment Agency

Environment Agency, (2012) The Environmental Permitting (England and Wales) Regulations 2010, No.675, UK: The HM Stationery Office Limited.

Environmental Protection Agency, (2000) Low Impact Development (LID). A review of literature, October 2000, Washington, DC: Office of Water

EURGIS (2013) Portal for soil and water management in the Europe, available at , www.eugris.info (Accessed 20 Oct 2013)

Eyers J. (1991) The influence of tectonics on early Cretaceous sedimentation in Bedfordshire. England: Journal of the Geological society of London Vol 149, 405-414.

Fellingham, L. R., Atyeo, P.Y. & Jefferies, N.L. (1993) The investigation of the groundwater pollution at Harwell laboratory: Proceeding of groundwater pollution conference, 16-17 March, 1993, IBC, London.

Frampton, T. A. (2000) Private Well Owners Pay Price as MTBE Contamination Exposes the Lack of Groundwater Protection in Federal and New York Law 18 PACE ENVTL. L. REV. 135, 141.

Fried, J.J (1975) Groundwater: Theory, Methodology, Modelling and practical rules, Netherland: Elsevier.

Fried, J.J (1975) Groundwater: Theory, Methodology, Modelling and practical rules, Netherland: Elsevier.

Gallois, R.W. and Morter, A.A. (1982). The stratigraphy of the Gault of East Anglia. Proceeding of the geologist?s Association, Vol.93, 351-368.

Groundwater Daughter Directive, (2006) Directive 2006/118/EC of the European Parliament and of the Council of 12 December 2006 on the protection of groundwater against pollution and deterioration (Daughter to 2000/60/EC), EU: European Parliament & Council.

Groundwater Forum (1995): Groundwater in the UK, A strategic study issues and research needs, Groundwater Forum by (David Grey, David Kinniburgh, John Barker & John Bloomfield) ISBN: 0-9521712 28.

Halcrow & Sir William Partners, (1988) Assessment of ground water in England and Wales, UK Department of Environment, London: HMSO.

Hallsworth, G.R. (1986) Grain size profile through two BRITISH GEOLOGY SURVEY boreholes in the Lower Woburn Sands and the Mineralogy on the clay horizons, British Geology Survey, Stratigraphy and Sedimentology Research Group Report, No. SRG/86/19.

Harris R.C. (1994) Implementation of the NRA groundwater protection policy in Groundwater Pollution, Liabilities and Engineering Implications; ed. Jones R.H. et al; East Mids Geotech Group.

Harris, B. (1993) Groundwater pollution risks from underground storage tanks, Land contamination and reclamation, Vol. 1, No-4, 197-200.

Head, K.H., (2011) Soil Laboratory Testing, Vol.2, Permeability, shear strength and compressibility test, 3dr edition, UK: Whittles Publishing.

Headworth, H.G., PURI, S. & Rampling, B.H. (1980) Contamination of the chalk aquifer by mine drainage at Tilmanstone, East Kent, UK: quarterly journal of engineering geology Vol.13, 105-117.

Hill, M.K. (1997) Understanding Environmental Pollution, UK: Cambridge University press.

Horton, A. (1995) Geology of the Country around Thame: Memoir for 1:50 000 Geological Sheet 237 (England and Wales), 1st ed. London: British Geology Survey ISBN-13: 978-0118845151.

Horton, A., Shephard-Thorn, E.R, and Thurrell, R.G. (1974). The Geology of new town of Milton Keynes. Report of the Institute of Geology Science, No74/16.

Howard, K.W.F. & Beck, P.J. (1993) Hydro-geochemical implications of groundwater contamination by road de-icing chemicals. Journal of contaminant Hydrology (No.12), 248-268.

Hulme, M. and Jenkins, G.J.(1998) Climate Changes Scenarios for the UK, UKCIP technical Report No.1, Climatic research, Norwich, UK, 80PP.

Hulme, M. Jenkins, G.J., Lu, X., Turnpenny, J.R., Mitchel, T.D, Jones, R.J, Lowe, J., Murphy, J. M., Hassell, D., Boorman,P., McDonald, R. and Hill, S.(2002) Climate Change Scenarios for the UK, The UKCIP02 scientific Report, UK: Tyndall centre for climate changes research , School of Environment Science, University of East Anglia , 120PP.

Institute of Hydrology (1995), Report No. 126, Hydrology of soil types, a hydrologically based classification of the soils of the United Kingdom, London: Institute of Hydrology Publication.

Irving, W.M. (1982) Chloride ion concentrations as an aid to estimating recharge to the Woburn Sands, Quarterly Journal of Engineering Geology and Hydrogeology, v. 15, p. 47-54.

JSCWSC, (2009) Evaluating Options for Water Sensitive Urban Design – A National Guide by Joint Steering Committee for Water Sensitive Cities, Australia

Johnston, G. (2011) UNSW Faculties of Science and Engineering, (Accessed 2 June 2012).

Jones, R.H., Rogers, C.D.F. & Holden, J.M.W.(1994) Groundwater pollution: Liabilities and Engineering implications, East Midland Geotechnical group ISBN: 0-9525210-08.

Karamouz, M., Ahmadi, A. & Akhbari, M. (2011) Groundwater Hydrology, Engineering, planning and Management, CRC Press.

Kassim,T.A. & Williamson,K.J (2005) Environmental Impact assessment of recycled water on surface and groundwater, Volume 1, Concept; methodology and chemical analysis, The Handbook of environmental chemistry, Germany: Verlag Berlin Heidelberg.

Kirkaldy J.F (1974) The Provenance of the Pebbles in the Lower Cretaceous rocks. Proceeding of the Geologist?s Association, Vol 58, 223-241.

Kumar, C. P. (1977), Estimation of Natural Ground Water Recharge, ISH Journal of Hydraulic Engineering, Vol.3, No.1, pp 61-74.

Lener D. N. (2003), Urban Groundwater Pollution, IAH International Contribution to Hydrology 24, London: Taylor & Francis.

Lerner, D.N, Issar, A.S. & Simmers, I. (1990) Groundwater recharge: A guide to understanding and estimating natural recharge. International Contributions to Hydrogeology, 8, Heise, Germany.

Longstaff, S.L., Aldous, P.J. Clark, L., Flavin, R.J. & Partington, J. (1992) Contamination of the chalk aquifer by chlorinated solvents: a case study of the Luton and Dunstable area Journal of institution of water and environment management Vol.6, No.5, 541-600.

Lorenzoni, I., Leiserowitz, A., Doria, M.D., Poortinga, W., & Pidgeon, N. F.(2006), Cross-National Comparisons of Image Associations with “Global Warming” and “Climate Change” Among Laypeople in the United States of America and Great Britain, Journal of Risk Research 9(3), pp265281

Lorenzoni, I., Nicholson-Cole, S., & Whitmarsh, L.(2007) Barriers Perceived to Engaging with Climate Change among the UK Public and their Policy Implications, Global Environmental Change, 17(3-4),pp445-459

Lorenzoni, I., & Pidgeon, N.F.(2006) Public Views on Climate Change: European and USA Perspectives, Climatic Change 77(1-2), pp73-95

Mather, J.E. (1998) Groundwater contaminants and their migration, UK: Geological society special publication.

McGraw-Hill, (2003) Dictionary of Scientific and Technical Terms, 6th edition, USA: The McGraw-Hill Companies, Inc.

Micro-Drainage (2012), Micro Drainage supplies industry standard sustainable drainage and flood hazard software for the civil engineering and environmental sectors.

Monkhouse, R. A. (1974) An assessment of the groundwater resources of the Lower Greensand in the Cambridge- Bedford region. Water Resources Board, Reading.

MORCES, (2002) The Meteorological Office Rainfall and Evaporation Calculation System: MORECS Version 2.0. An update to Hydrological Memo. No. 45, Met Office

Morrison, G.M.P. (1988) Transport mechanism and processes for metal pieces in a gully pot system, Water Research Vol.22 (No.11), 1417-1427.

Nazari, M.M, Burston, M.W, Bishop, P.K & Leaner, D.N. (1993) Urban groundwater pollution: a case study from Coventry, UK ground water; Vol.31, No.3, 417-424.

Nonner, J.C. ( 2009) Introduction to hydrogeology, Textbook in IHE Lecture Notes Series, Taylor and Francis Publishers, Leiden, The Netherlands, 258 pages.

Pidgeon, N.F., Lorenzoni, I., & Poortinga, W. (2008) Climate Change or Nuclear Power-No Thanks! AQuantitative Study of Public Perceptions and Risk Framing in Britain, Global Environmental Change18 (1), pp69-85

Pitt, R.E., Clark S. M., Parmer, K and Field, R. (1996) Groundwater Contamination from Storm water Infiltration, USA: CRC Press.

Planning Policy Statement 25 Supplement (2010), Development and coastal change Practice Guide, March 2010, UK: Department Communities and Local Government.

Raskin, I., Smith, R. D.and Salt, D. E. (1997) Phytoremediation uses plants to remove pollutants from the environment, USA: Rutgers University publication.

Rao, S. V. N., Gron, C. and Gupta, A., (2011) Groundwater Protection: Policy and practice in the EU and India, India: Euroconsult Mott MacDonald.

Reed, D. W., Faulkner, D., Robson, A. and Houghton-Carr, H, (2002) Flood Estimation Handbook, UK: Institute of Hydrology.

Rivett, M. O., Learner, D.N. & Lloyd, J.W.( 1990) Chlorinated solvents in UK aquifers, Journal of Institute of water and environmental management; Vol.4, No.3, 242-250.

Sanders, C.H. (2004), Safety and Health in Building, Advanced calculation of moisture movement in structure, Project report 164187, London: BRE.

Sarter, J.D. & Boyd, G.B. (1972) Water pollution aspects of street surface contaminants. EPA Report, EPA-R2-72-081, USA.

Seiler, K. P, and Gat, J. R. (2007) Groundwater recharge from runoff, infiltration and percolation, Netherlands: Springer.

Shah, E.M., Beven, K.J., Chappel, N.A and Lamb, R. (2011) Hydrology in Practice, 4th edition, UK: Spon Press.

Shaw, M. A., Beven, K. J., Chappell, N. A. and Lamb, R. (2011) Hydrology in Practice, 4th edition 2011, UK: Spon Press.

Sophocleous, M. A. (1991) Combining the soil water balance and water-level fluctuation methods to estimate natural ground water recharge - practical aspects, Journal of hydrology, Vol.124, pp 229-241.

South Beds District Council (2009), Planning Application BC/CM/2008/41, Pratt?s Quarry, Billington Road, Leighton Buzzard, planning permission 2/2009.

Sparks, D.L., (2003) Environmental Soil Chemistry, 2nd edition, USA: Elsevier Science.

Stefano, L. D. and Llamas, M. R. (2012) Water Agriculture and the Environment in Spain: Can we square the circle?, London: Taylor & Francis Group

Sumbler, (1996) An atlas of Stratigraphy Structure and Engineering Geology, London: British Geology Survey.

Sustainable Urban Drainage System (2004), Interim Code of Practice for Sustainable Drainage Systems, UK: National SuDS Working Group.

Tebbutt, T.H.Y (1992) Principles of water quality control, 5th edition, UK: Elsevier Ltd, ISBN: 0750636580.

The council of the European communities (1980), Council Directive on the protection of groundwater against pollution caused by certain dangerous substance of 17th December 1979, 80/68/EEC, Official Journal of European Communities 26.1.1980 (No.L20/43).

Thomas, R., (2009) the European Directive on the Protection of Groundwater, A Model for the United States, 26 Pace Envtl. L. Rev. 259

Thornthwaite C.W. (1948) An approach towards a rational classification of climate. Geogr. Rev.; Vol.38, No.1, pp 55-94.

Town and Country Planning (1999) Local Government Act 1999: Part 1 regulations 1999, UK: HM Stationary Office and Queen`s printer of act of Parliament.

UK Climate Change Projections (2009) UK Climate Projection Science Report, climate change projections. Met office Hadley Centre, Exeter, UK.

UK Climate Impact Program (2002) Climate change scenarios for the UK, the UK CIP02 Briefing Report April 2002, UK: Tyndall centre for climate change research.

United Nations Environmental Programmes (1998), Environmental Data Report 1989/90, pp547, Oxford: Blackwell.

Walton, W. C. (1989), Numerical Groundwater Modelling, Flow and Contaminant Migration, 2nd edition, USA: CRC Press.

Water Framework Directive, (2000) Directive 2000/60/EC of European parliament and of the council of 23 October 2000, establishing a framework for Community action in the field of water policy, Official Journal of the European Communities L327/3.

Water UK (2007), available at: www.water.org.uk/home/our-members/list-of-companies/supply (Accessed 2nd June 2012).

Water UK (2009), available at: www.water.org.uk/home/our-members/list-of-companies/water-and-sewerage (Accessed 2nd June 2012).

Water UK (2012), available at: www.water.org.uk/home/our-members (Accessed 2nd June 2012).

WBB Minerals (2003), Extension and Restoration of Pratt's Quarry, New information and formal public open space and associated lake, None technical summary.

Whitmarsh, L. (2009), Behavioural Responses to Climate Change: Asymmetry of Intentions and Impacts, Journal of Environmental Psychology, 29(1), pp13-23

Woods-Ballards, B., Kellagher, P., Martin, P., Jefferies, C., Bray, R. and Shaffer, P. (2007) The SuDS Manual, C697, UK: CIRIA.

William, A. (2006) Tracking U.U. Groundwater: Reserve for the future, Environment, April 2006, p10-15.

WSRA - Water Service Regulatory Authority (2012) available at http://www.ofwat.gov.uk (accessed 2nd July 2012).

Wyatt, R.J. and Ambrose, K. (1988) Geological notes and local details for 1:10000 sheets SP51NW and SP51SW: Weston on the Green and slip. British Geological Survey technical report WA/88/27

# APPENDIX- A

## A1 Shear Box test

### *A1.1: Application of direct shear test and its parameter (BS1377: Part 7:1990:4, and ASTMD3080)*

The measurement of the shear strength of soil in the laboratory by using the direct shear box method which involves the sliding of one portion of soil on another. The shear box test in which the relative movement of two halves of the square block of soil takes place along a horizontal surface. The Vane shear test which a relative rotational movement takes place between a cylindrical volume of soil and surrounding material.

Some theoretical background knowledge is necessary for a proper understanding of the basic test principle such as force, stress and strain. The shear box test is the simplest, the oldest and the most straightforward procedure for measuring the immediate or short term shear strength of soil in terms of total stresses, it's also easier to understand, but it has a number of shortcomings which must be considered.

The test is carried out on Leighton Buzzard sands; the shear strength of dry sand depends upon several factors such as the mineralogical composition of the grain, size, shape, surface texture, grading, the soil structure and moisture content.

A Dry shear box test was carried out for the particular Leighton Buzzard sand at Kingston Laboratory, experience has shown that shear strength result obtained on saturated sands are very similar to those for dry sand, provided that the sand remains saturated and that drainage takes place freely during shear.

There is some uncertainty in the interpretation of result obtained from shear test for providing a failure reason for the soil. The methods outlines the research have been generally used for obtaining a sand failure principle in BS 1377. The main limitation and disadvantage of the shear box test are summarized below:

## *A1.2: Limitation*

- The soil specimen is constrained to fail along a predetermined plan of shear.
- The distribution of stresses on the sand shear box in not very uniform.
- The actual stress pattern is complex and the distribution of the plan of principle stresses rotate as the shear strain is increased.
- The deformation which can be applied to the soil is limited by the maximum length of travel of the apparatus.
- The area of contact between the soil in the halves of the shear box decrease as the test proceeds, a correction procedure, but its effect is very small, it affects the shear stress and normal stress in equal portion and the effect on the Coulomb envelop is usually negligible, so it is generally ignored.

## *A1.3: Advantage*

- The test is relatively simple to carry out.
- The basics principle is easily understood.
- Preparation or recomputed test specimens are not difficult and consolidation is relatively rapid due to small thickness of the test specimen.

## *A1.4: Apparatus and test procedure*

The apparatus described here is typical Figure A1 of which commercially available in UK for routine testing and the procedure follows the British Standards.
The most common apparatus accommodates a 60mm square specimen, 20 or 25mm high, for detail refer to BS1377:Part 7 :1990:4

*Fig – A1a: BS 1377; EN DD ENV 1997-2; ASTM D3080*
*Fig – A1b:EL26-2181 Shear box Assembly and Accessories*

Figure A2: The shear box machines comprises of a drive unit and accessories

The procedure depends upon the type of soil and the condition in which it is to be tested; the maximum size of particles present in the significant quantity should not exceed 1/3rd of the specimen height.

As we understand the Leighton Buzzard sand is classified according to sieve analysis as medium-coarse sand and the sand sample doesn't have significant quantity of fine particle passing a 63µm sieve.

### *A1.5: Critical Features of the Direct Shear Test*

The Direct Shear test is carried out to determine a key piece of information regarding a soil sample:

- The Shearing Angle (ϕ)

Three identical samples were tested in the preparation of this report and each was tested under a different Normal stress. The three tests results were used to derive three sets of Shear stress data. Three separate graphs were then plotted based upon all the gathered and calculated data. Table A1 to Table A4 represent a sand sample, test reading data under direct shear box for different loads.

| | | | |
|---|---|---|---|
| **Table A1: Shear Box Test** | | **SAND SAMPLE-1, NORMAL LOAD = 100N** | |
| **Name: Nasser Hashemi- 04-11-2008** | | | **Nominal size: M** |
| **Soil Description: Leighton Buzzard dry sand** | | | |
| Initial Measure-ments | Depth of base plate 44 mm | Depth to op grid 9 mm | Specific Gravity: Gs<br>**(Assumed)** |
| | Mean thickness of base grid 3 mm | Mean thickness of top grid 3mm | |
| | Length, L = 60.03 mm | Area, $A = 3.5969\times10^{-3}$ mm$^2$ | |
| | Breath, B = 59.92 mm | Volume, Vo= 29× A | |
| | Height, Ho = 41 mm | Bulk Density, $\rho_o$ | |
| | Mass, m = 300-103=197 kg | Dry Density, $\rho_d$ | |
| | Moisture, w = dry | Void Ratio, $e_o$ | |

| | |
|---|---|
| **Shearing** | **After consolidations** |
| Load Ring number | |
| Mean calibration, $C_r$ 2.116 N/Div | |
| Stress factor, $C_T$ | |
| Rate of displacement | |
| Normal force ratio 10:1 100 N | |
| Normal stress, $\sigma_n = 27.8$ kN/mm$^2$ | |

| **Reading** | | | | | | **V- Movement** | | **Remarks** |
|---|---|---|---|---|---|---|---|---|
| Date | Time | Horizontal displacement (mm) | Load Dial reading (Divs) | Horizontal load (N) | Shear Stress (kN/m$^2$) | Dial reading (mm) | Expansion.(+) Settlement.(-) (mm) | |
| 4.11.08 | 10:30 | 0 | 0 | 0 | 0 | 0.000 | | |
| | | 0.2 | 10 | 21.16 | 5.88 | 0.010 | | |
| | | 0.4 | 22 | 46.55 | 12.94 | 0.020 | | |
| | | 0.6 | 30 | 63.48 | 17.65 | 0.050 | | |
| | | 0.8 | 37 | 78.29 | 21.77 | 0.075 | | |
| | | 1 | 42 | 88.87 | 24.71 | 0.121 | | |
| | | 1.2 | 46 | 97.34 | 27.06 | 0.147 | | |
| | | 1.4 | 48 | 101.57 | 28.24 | 0.185 | | |
| | | 1.6 | 49 | 103.68 | 28.83 | 0.235 | Failure:<br>$\sigma_n$ =27.80 kN/mm$^2$<br>$\tau$ =30.00 kN/mm$^2$ | |
| | | 1.8 | 50 | 105.80 | 29.41 | 0.279 | | |
| | | 2 | 51 | 107.92 | 30.00 | 0.312 | | |
| | | 2.2 | 51 | 107.92 | 30.00 | 0.412 | | |
| | | 2.4 | 51 | 107.92 | 30.00 | 0.444 | | |
| | | 2.6 | 50 | 105.80 | 29.41 | 0.480 | | |
| | | 2.8 | 49 | 103.68 | 28.83 | 0.514 | | |
| | | 3 | 47 | 99.45 | 27.65 | 0.545 | | |
| | | 3.2 | 47 | 99.45 | 27.65 | 0.567 | | |
| | | 3.4 | 46 | 97.34 | 27.06 | 0.591 | | |
| | | 3.6 | 45 | 95.22 | 26.47 | 0.611 | | |
| | | 3.8 | 45 | 95.22 | 26.47 | 0.630 | | |
| | | 4 | 44 | 93.10 | 25.88 | 0.668 | | |
| | | 4.5 | 43 | 90.99 | 25.30 | 0.680 | | |
| | | 5 | 42 | 88.87 | 24.71 | 0.690 | | |
| | | 5.5 | 42 | 88.87 | 24.71 | 0.695 | | |
| | | 6 | 41 | 86.76 | 24.12 | 0.695 | | |
| | | 6.5 | 40 | 84.64 | 23.53 | 0.698 | | |
| | | 7 | 40 | 84.64 | 23.53 | 0.690 | | |
| | | 7.5 | 40 | 84.64 | 23.53 | 0.692 | | |
| | | 8 | 39 | 82.52 | 22.94 | 0.672 | | |

| | |
|---|---|
| **Table A2: Shear Box Test** | **SAND SAMPLE-1, NORMAL LOAD = 200N** |
| **Name: Nasser Hashemi- 04-11-2008** | **Nominal size: M** |
| **Soil Description: Leighton Buzzard dry sand** | |

| | | | |
|---|---|---|---|
| Initial Measure-ments | Depth of base plate 44 mm | Depth to op grid 6 mm | Specific Gravity: Gs |
| | Mean thickness of base grid 3 mm | Mean thickness of top grid 3mm | |
| | Length, L = 60.03 mm | Area, A = $3.5969 \times 10^{-3}$ mm$^2$ | (Assumed) |
| | Breath, B = 59.92 mm | Volume, Vo= 29× A | |
| | Height, Ho = 41 mm | Bulk Density, $\rho_o$ | |
| | Mass, m = 315-111 =204 grs | Dry Density, $\rho_d$ | |
| | Moisture, w = dry | Void Ratio, $e_o$ | |

| | |
|---|---|
| **Shearing** | **After consolidations** |
| Load Ring number | |
| Mean calibration, $C_r$ 2.116 N/Div | |
| Stress factor, $C_T$ | |
| Rate of displacement | |
| Normal force ratio 10:1 200 N | |
| Normal stress, $\sigma_n = 55.6$ kN/mm$^2$ | |

| **Reading** | | | | | | V- Movement | | Remarks |
|---|---|---|---|---|---|---|---|---|
| Date | Time | Horizontal displacement (mm) | Load Dial reading (Divs) | Horizontal load (N) | Shear Stress (kN/m$^2$) | Dial reading (mm) | Expansion.(+) Settlement.(-) (mm) | |
| 4.11.08 | 11:30 | 0 | 0 | 0 | 0 | 0.000 | | |
| | | 0.2 | 20 | 42.32 | 11.77 | 0.000 | | |
| | | 0.4 | 44 | 93.10 | 25.88 | -0.003 | | |
| | | 0.6 | 66 | 139.66 | 38.83 | -0.006 | | |
| | | 0.8 | 80 | 169.28 | 47.06 | -0.027 | | |
| | | 1 | 87 | 184.09 | 51.18 | -0.065 | | |
| | | 1.2 | 92 | 194.67 | 54.12 | -0.107 | | |
| | | 1.4 | 95 | 201.02 | 55.89 | -0.156 | | |
| | | 1.6 | 96 | 203.14 | 56.47 | -0.212 | Failure:<br>$\sigma_n = 55.60$ kN/mm$^2$<br>$\tau = 55.89$ kN/mm$^2$ | |
| | | 1.8 | 96 | 203.14 | 56.47 | -0.260 | | |
| | | 2 | 95 | 201.02 | 55.89 | -0.310 | | |
| | | 2.2 | 95 | 201.02 | 55.89 | -0.360 | | |
| | | 2.4 | 92 | 194.67 | 54.12 | -0.395 | | |
| | | 2.6 | 90 | 190.44 | 52.94 | -0.440 | | |
| | | 2.8 | 89 | 188.32 | 52.36 | -0.471 | | |
| | | 3 | 86 | 181.98 | 50.59 | -0.520 | | |
| | | 3.2 | 84 | 177.74 | 49.41 | -0.544 | | |
| | | 3.4 | 83 | 175.63 | 48.83 | -0.567 | | |
| | | 3.6 | 81 | 171.40 | 47.65 | -0.581 | | |
| | | 3.8 | 80 | 169.28 | 47.06 | -0.595 | | |
| | | 4 | 78 | 165.05 | 45.88 | -0.605 | | |
| | | 4.5 | 73 | 154.47 | 42.94 | -0.628 | | |
| | | 5 | 72 | 152.35 | 42.36 | -0.634 | | |
| | | 5.5 | 71 | 150.24 | 41.77 | -0.535 | | |
| | | 6 | 70 | 148.12 | 41.18 | -0.635 | | |
| | | 6.5 | 71 | 150.24 | 41.77 | -0.625 | | |
| | | 7 | 70 | 148.12 | 41.18 | -0.610 | | |
| | | 7.5 | 70 | 148.12 | 41.18 | -0.600 | | |
| | | 8 | 70 | 148.12 | 41.18 | -0.591 | | |

| | | | |
|---|---|---|---|
| **Table A3: Shear Box Test** | | **SAND SAMPLE-1, NORMAL LOAD = 400N** | |
| **Name: Nasser Hashemi- 04-11-2008** | | | **Nominal size: M** |
| **Soil Description: Leighton Buzzard dry sand** | | | |
| Initial Measure-ments | Depth of base plate 44 mm | Depth to op grid 5.5 mm | Specific Gravity: Gs<br>(Assumed) |
| | Mean thickness of base grid 3 mm | Mean thickness of top grid 3mm | |
| | Length, L = 60.03 mm | Area, A = $3.5969\times10^{-3}$ mm$^2$ | |
| | Breath, B = 59.92 mm | Volume, Vo= 29× A | |
| | Height, Ho = 41 mm | Bulk Density, $\rho_o$ | |
| | Mass, m = 300-88.3=211.7gr | Dry Density, $\rho_d$ | |
| | Moisture, w = dry | Void Ratio, $e_o$ | |

| | |
|---|---|
| **Shearing** | **After consolidations** |
| Load Ring number | |
| Mean calibration, $C_r$ 2.116 N/Div | |
| Stress factor, $C_T$ | |
| Rate of displacement | |
| Normal force ratio 10:1 400 N | |
| Normal stress, $\sigma_n$=111.2 kN/mm$^2$ | |

| **Reading** | | | | | | V- Movement | | Remarks |
|---|---|---|---|---|---|---|---|---|
| Date | Time | Horizontal displacement (mm) | Load Dial reading (Divs) | Horizontal load (N) | Shear Stress (kN/m$^2$) | Dial reading (mm) | Expansion.(+) Settlement.(-) (mm) | |
| 4.11.08 | 12:30 | 0 | 0 | 0 | 0 | 0.000 | | |
| | | 0.2 | 40 | 84.64 | 23.53 | -0.020 | | |
| | | 0.4 | 75 | 158.70 | 44.12 | -0.015 | | |
| | | 0.6 | 100 | 211.60 | 58.83 | -0.010 | | |
| | | 0.8 | 129 | 272.96 | 75.89 | 0.000 | | |
| | | 1 | 141 | 298.36 | 82.95 | 0.031 | | |
| | | 1.2 | 149 | 315.28 | 87.65 | 0.066 | | |
| | | 1.4 | 154 | 325.86 | 90.59 | 0.103 | | |
| | | 1.6 | 158 | 334.33 | 92.95 | 0.147 | Failure:<br>$\sigma_n$=111.20 kN/mm$^2$<br>$\tau$= 93.53 kN/mm$^2$ | |
| | | 1.8 | 159 | 336.44 | 93.53 | 0.202 | | |
| | | 2 | 159 | 336.44 | 93.53 | 0.242 | | |
| | | 2.2 | 159 | 336.44 | 93.53 | 0.290 | | |
| | | 2.4 | 158 | 334.33 | 92.95 | 0.328 | | |
| | | 2.6 | 157 | 332.21 | 92.36 | 0.364 | | |
| | | 2.8 | 155 | 327.98 | 91.18 | 0.392 | | |
| | | 3 | 154 | 325.86 | 90.59 | 0.420 | | |
| | | 3.2 | 148 | 313.17 | 87.06 | 0.453 | | |
| | | 3.4 | 144 | 304.70 | 84.71 | 0.480 | | |
| | | 3.6 | 141 | 298.36 | 82.95 | 0.499 | | |
| | | 3.8 | 137 | 289.89 | 80.59 | 0.515 | | |
| | | 4 | 133 | 281.43 | 78.24 | 0.515 | | |
| | | 4.5 | 124 | 262.38 | 72.95 | 0.540 | | |
| | | 5 | 118 | 249.69 | 69.42 | 0.575 | | |
| | | 5.5 | 112 | 236.99 | 65.89 | 0.586 | | |
| | | 6 | 111 | 234.88 | 65.30 | 0.583 | | |
| | | 6.5 | 110 | 232.76 | 64.71 | 0.575 | | |
| | | 7 | 110 | 232.76 | 64.71 | 0.570 | | |
| | | 8 | 110 | 232.76 | 64.71 | 0.568 | | |

| | | | |
|---|---|---|---|
| **Table A4: Shear Box Test** | | **SAND SAMPLE-1, NORMAL LOAD = 600N** | |
| **Name: Nasser Hashemi- 04-11-2008** | | | **Nominal size: M** |
| **Soil Description: Leighton Buzzard dry sand** | | | |
| Initial Measurements | Depth of base plate 44 mm | Depth to op grid 6 mm | Specific Gravity: Gs |
| | Mean thickness of base grid 3 mm | Mean thickness of top grid 3mm | |
| | Length, L = 60.03 mm | Area, A = $3.5969\times10^{-3}$ $mm^2$ | (Assumed) |
| | Breath, B = 59.92 mm | Volume, Vo= 29×A | |
| | Height, Ho = 41 mm | Bulk Density, $\rho_o$ | |
| | Mass, m = 299-105=194 gr | Dry Density, $\rho_d$ | |
| | Moisture, w = dry | Void Ratio, $e_o$ | |

| | |
|---|---|
| **Shearing** | **After consolidations** |
| Load Ring number | |
| Mean calibration, $C_r$ 2.116 N/Div | |
| Stress factor, $C_T$ | |
| Rate of displacement | |
| Normal force ratio 10:1 600 N | |
| Normal stress, $\sigma_n$=166.8 $kN/mm^2$ | |

| **Reading** | | | | | | V- Movement | | Remarks |
|---|---|---|---|---|---|---|---|---|
| Date | Time | Horizontal displacement (mm) | Load Dial reading (Divs) | Horizontal load (N) | Shear Stress ($kN/m^2$) | Dial reading (mm) | Expansion.(+) Settlement.(-) (mm) | |
| 4.11.08 | 13:30 | 0 | 0 | 0 | 0 | 0.000 | | |
| | | 0.2 | 55 | 116.38 | 32.35 | 0.009 | | |
| | | 0.4 | 90 | 190.44 | 52.94 | 0.012 | | |
| | | 0.6 | 125 | 264.50 | 73.53 | 0.022 | | |
| | | 0.8 | 150 | 317.40 | 88.24 | 0.027 | | |
| | | 1 | 165 | 349.14 | 97.06 | 0.028 | | |
| | | 1.2 | 180 | 380.88 | 105.89 | 0.020 | | |
| | | 1.4 | 192 | 406.27 | 112.95 | 0.010 | | |
| | | 1.6 | 202 | 427.43 | 118.83 | 0.000 | Failure:<br>$\sigma_n$=166.80 $kN/mm^2$<br>$\tau$= 129.42 $kN/mm^2$ | |
| | | 1.8 | 210 | 444.36 | 123.54 | -0.054 | | |
| | | 2 | 218 | 461.29 | 128.24 | -0.060 | | |
| | | 2.2 | 219 | 463.40 | 128.83 | -0.084 | | |
| | | 2.4 | 220 | 465.52 | 129.42 | -0.096 | | |
| | | 2.6 | 220 | 465.52 | 129.42 | -0.124 | | |
| | | 2.8 | 218 | 461.29 | 128.24 | -0.172 | | |
| | | 3 | 217 | 459.17 | 127.65 | -0.193 | | |
| | | 3.2 | 214 | 452.82 | 125.89 | -0.223 | | |
| | | 3.4 | 211 | 446.48 | 124.12 | -0.259 | | |
| | | 3.6 | 205 | 433.78 | 120.60 | -0.295 | | |
| | | 3.8 | 198 | 418.97 | 116.48 | -0.308 | | |
| | | 4 | 191 | 404.16 | 112.36 | -0.335 | | |
| | | 4.5 | 182 | 385.11 | 107.06 | -0.353 | | |
| | | 5 | 178 | 376.65 | 104.71 | -0.378 | | |
| | | 5.5 | 174 | 368.18 | 102.36 | -0.371 | | |
| | | 6 | 173 | 366.07 | 101.77 | -0.361 | | |
| | | 6.5 | 173 | 366.07 | 101.77 | -0.357 | | |
| | | 7 | 172 | 363.95 | 101.18 | -0.348 | | |
| | | 7.5 | 172 | 363.95 | 101.18 | -0.329 | | |
| | | 8 | 170 | 359.72 | 100.01 | -0.306 | | |

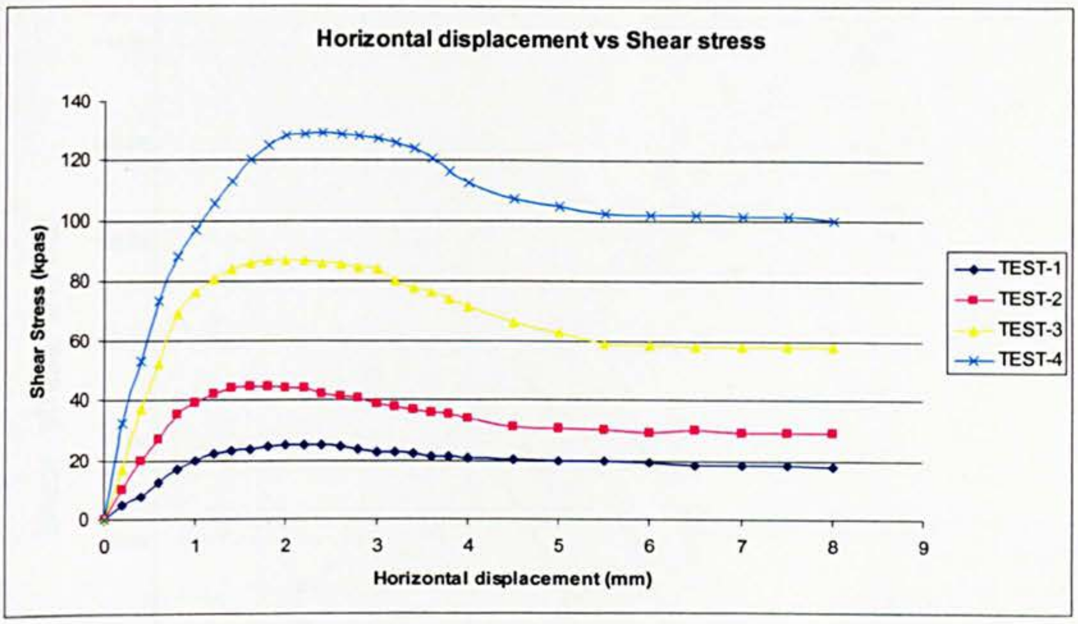


Figure A2: Horizontal displacement and shear stress

From four different loading we have found shear stresses failures value as tabulated below. Figure A3 represents the shear and normal stresses to obtain average ϕ.

| Test no. | Normal load (kN) | Normal stress, σn(kN/m2) | Shear stress, τ (kN/m2) |
|---|---|---|---|
| 1 | 100 | 27.80 | 30.00 |
| 2 | 200 | 55.60 | 55.89 |
| 3 | 400 | 111.20 | 93.53 |
| 4 | 600 | 166.80 | 129.42 |

Result from the shear test:
c= 0 cohesion less soil (sand)
ϕ = 42.5 degree (average)

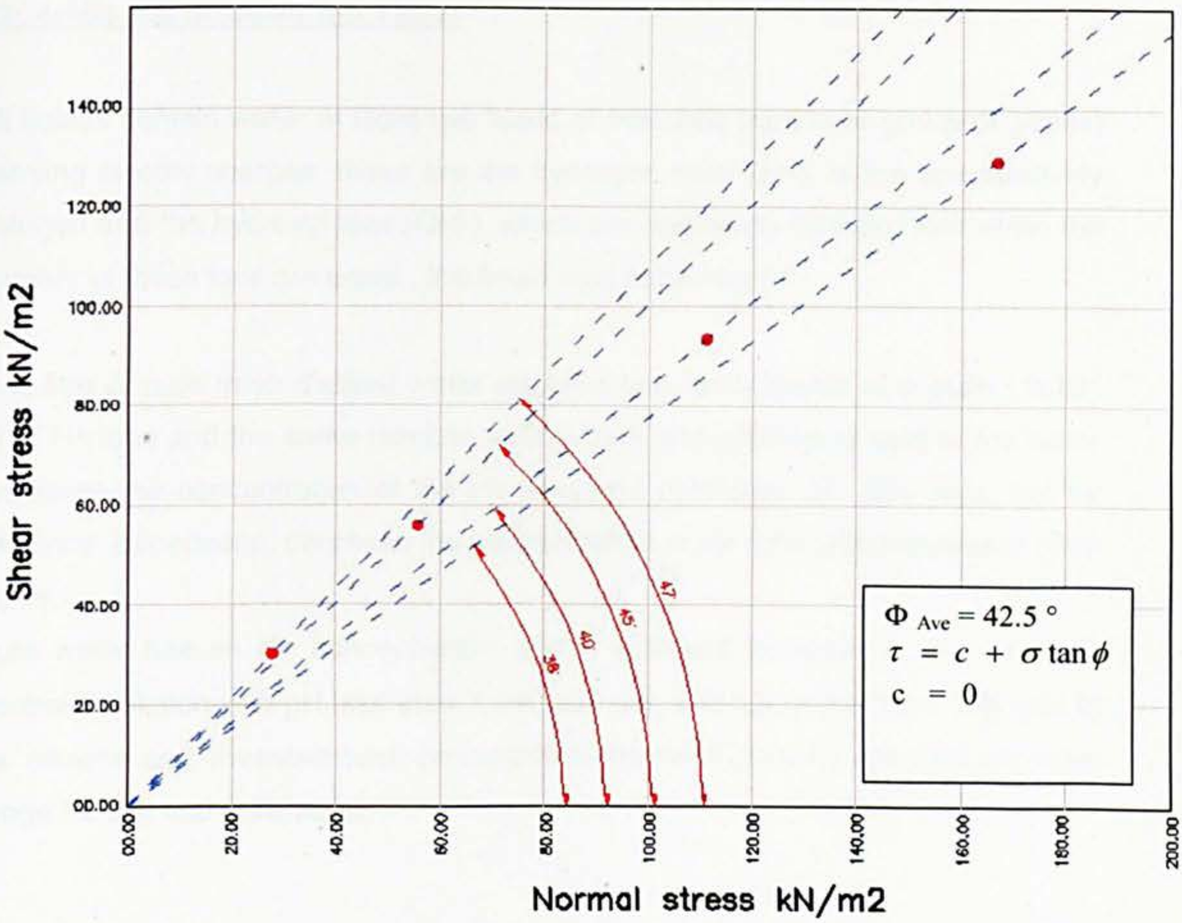


Figure A3: Shear stress and Normal stress

For the dry sand the values of c and ϕ are the effective stress parameters c' and ϕ', since the effective stresses are equal to the applied stresses as there are no pore water pressures developed. Shear strength for sand is $\tau = \sigma \tan \phi$ because c=0, and if the normal stress is given at a depth of aquifer, shear strength can be calculated. Shear strength of soil can be increased by reducing void ratio and reducing water pressure, therefore reduction in permeability in soil increase of shear strength. The result of this test can be used in SuDS application and soil slope stability.

## *A2: Acidity and Alkalinity (pH Value)*

All liquids contain water at least two kinds of free ions (atoms or group of atoms) carrying electric charges, these are the hydrogen ions (H+), which are positively charged and the hydroxyl ions (OH-), which are negatively charged and when the number of these ions are equal , the liquid said to be neutral.

One litre of pure fresh distilled water contains one ten-millionth of a gram ($1x10^{-7}$ g) of H+ ions and the same number of OH- ions, the addition of acid to the water increases the concentration of the H+ ions and decrease of OH- ions, but for alkalinity its opposite, decrease the concentration of H+ ions and increase of (OH-) ions.

Pure water has an H+ concentration of $10^{-7}$ g/lit and its value is 7 , which is neutral a solution with pH less than 7 are acid and with pH more than 7 is said to be alkaline and measure base on logarithmic scale. Figure A4 specifies pH valve range for soil and pure water.

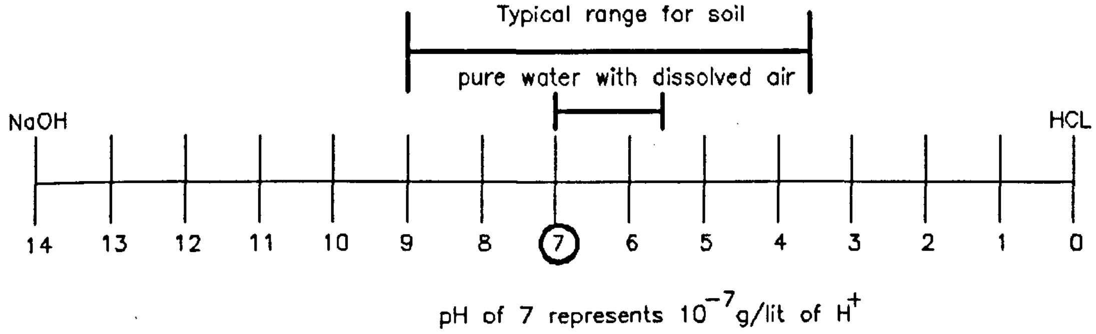
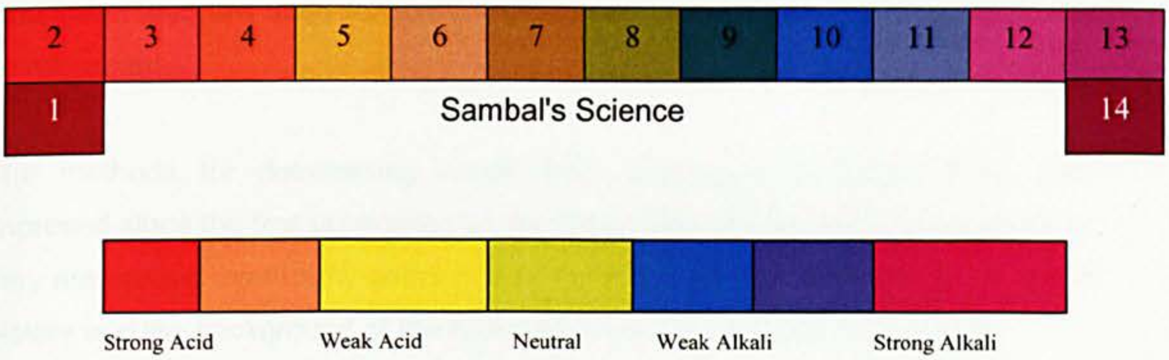


Figure A4: pH value

Certain dyes, known as indicators, change colour in a definite manner, according to the acidity or alkalinity of the solution in which they are mixed. Indicator is Litmus which is red in an acid and blue in an alkaline solution. Indicator products by Sambal's Science and Johnson Test Papers Figure A5, as they always to support research programs. The test was carried out on samples according BS1377 Part: 3 1990. 100mg quality of sand is placed in test tube, adding distilled water and shacked, dipping the test paper in the water, and quantity water about twice of the sand quantity.



Johnson Test Papers

Figure A5: Sambal`s Science and Johnson test paper indicator colour code

There is also an electric device to carry out the test; the operation of an electrical pH meter is based on the principle that the solution to be tested can be considered as an electrolyte of a voltaic cell. Here we have not discussed the feature of the meter, but the most reliable tester for pH value.

Table A5: pH vale test for Leighton Buzzard sand

| sample | Quantity | Colour code | Estimated pH value Litmus | Estimated pH value Electrometer | Comments |
|---|---|---|---|---|---|
| sand-1 | 50gr sand + 100gr pure water | yellow | 4.0 | 4.0 | Weak acidic |
| sand-2 | 100gr sand + 200gr pure water | yellow | 4.0 | 4.1 | Weak acidic |

# APPENDIX- B: Greenfield runoff volume and peak ruler discharge

Techniques for the derivation of peak flow from undeveloped and partly urbanised catchment also are used for the determination of allowable discharge from new development.

The methods for determining runoff from ungauged catchment have been improved since the first publication of the ***Flood Studied Report*** (FSR). However, they are spread over many years and several references. The following is a brief history and the background of the methods currently used by professionals.

The Flood Studied Report Volume-1 chapter - 4 and 6 details approaches for determining runoff from ungauged catchment, these have been modified in subsequent Flood Studied Supplementary Report Nos 5.14 and 16. Ciria Book 14, 1993 takes these modification into account and provides clear worked examples of the methodologies, these may be used also on partly urbanised catchment.

On small catchment less than 25km$^2$, the IH124 equation for QBAR (and the equation for the instantaneous time to peak for the unit hydrograph approaches) may be used in lieu of those suggested in Ciria book 14 but otherwise the detailed approach is unchanged.

Comparison between the FSR and FEH (*Flood Estimation Handbook*) methods are contained in FEH volume 3 and 4, 1999. The difficulty in obtaining digitally derived data for small catchments and the relative complexity of developing growth curves using FEH methodology are reasons for the continuing use for FSR approach in appropriate circumstances on small catchment.

There is ADAS method as it is widely used. In summary therefore the calculation to determine discharge from ungauged catchments may be done using ADAS345 *(Agricultural Development and Advisory Service **Report 345**)* or IH124 *(Institute of Hydrology Report no 124)*. A third method is also available based on FEH data, but it is usually used on catchment larger than 20km$^2$.

IH124: The IH124 method is based on the FSR approach and developed for use on catchments less than 25km$^2$. It yields the Mean Annual maximum flood (QBAR). The reference also recommends the use of Ciria Book 14 to generate Growth Factors, these are used to convert QBAR to different return periods for different regions in the UK.

ADAS: The ADAS document doesn't refer to any return period, but yield a "Peak Flood Flow". However, ADAS has confirmed that the Gross as the main crop type the return period of the flow is 1 year. For other crop types different return periods have been used but if we assume "green field " runoff means grassland then ADAS yield a 1 year return period (or 100% annual probability).

A 1 year peak runoff maybe converted to a Mean Annual Flood using table 1 of FSSR No 2, 1977. The Mean Annual Flood may then be converted to other return period using the method described for IH124 above. The table of the return period's flows is only available for "Grass" as dominant or main crop type.

FEH: The Flood Estimation Handbook method yield the Median Annual Maximum Flood (QMED), the FEH approach is intended for larger sites and the method cannot be applied to catchment areas smaller than 50ha (0.5km$^2$).

The statutory authority will advise on the approved method. The national SuDS working group, interim code of practice for sustainable drainage, published July 2004, recommends the use of IH124 for all catchments up to 200ha, above this the engineer must decide whether the IH124 or FEH method is more applicable to the site. For the catchment smaller than 50ha the equivalent runoff from a 50ha site must be calculated using IH124, it is then possible to pro-rata this value to give the peak runoff for the smaller site.

The Highway Agency document HA106/04 requires the ADAS method to be used for sites of 40ha or less and IH124 for sites larger than 40ha. These methods are statically based and yield the peak value of the flood. If the full flow hydrograph is required this must be generated using the rainfall runoff unit hydrographs *(Micro-Drainage, 2012)*.

## B1: Comparison of the different methods of adjustment for return period

The FEH manual recommends that growth curves and hence the growth factors associated with a return period be derived from gauged catchments. Where the catchment is not gauged or if the gauged data is limited the growth curve is derived from a "pooling group". "Catchments are grouped according to their perceived hydrological similarity rather than their geographical position".

The FRS approach grouped catchments into 10 geographical locations in Britain. This enabled the publication of tables to drive growth curves quickly and easily. It does not however group together catchments of different sizes and soils but with similar average annual rainfall. It also results in relatively large groups, which reduces accuracy. The FEH approach is fundamentally different. Hydrologically similar catchments have to be identified and may be scattered throughout the country. However it requires first principle analysis to be conducted in every case which is more accurate but is also very difficult *(FEH Vol.3, 16.7.4)*, it does provide for permeable catchment areas to be considered as a special case *(FEH, 1999-Vol.3, Chapter 19)*.

The FEH model may also be unnecessary difficult when an estimate of flow on small site is needed only to specify a reasonable allowable discharge from a proposed development. Other factors such as the capacity of the downstream drainage system may play a larger role in determining on allowable discharge. The biggest variation for the 100 years return period storm is between region 10 (2.08 x QBAR) and region 5 (3.56 x QBAR). when data was collected for the whole of great Britain the growth factor for 100 return period was 2.61*(FSR Vol.1,table 2.38)*.

## B2: Error and Safety Factors

Both FSR *(Vol.1,2.6.8)* and FEH *(Vol.3,17.5)* attempted to quantify standard errors for the growth curve determination. Both suggested that a direct derivation was not possible but gave the following indications. FSR growth factors have a standard deviation of approximately 14%, 27%, 32% and 50% for 10, 50, 100 and 1000 year return periods respectively expressed as a percentage of regional growth curve ordinate. FEH derived an approximation from PUM analysis that yielded factorial standard error of more than 1.15 and 1.23 for 20 and 50 year return period respectively. Both methods are compared in FEH documents using other measurement of accuracy and the FEH methodology was found to be more homogeneous with lower pooled uncertainly measure PUMs *(FEH Vol 3, 16.7.4)*.

It should be noted that there is greater scope for error in determining QBAR and QMED from catchment characteristics alone. The standard factorial error for the SFR method is 1.46 (the 6 variable equation, an error for IH124 is not given) and for the FEH method it is 1.55 *(FEH Vol.3, 13.9.2)*. if the distribution is normal it implies that 68% of sites would have an actual QMED in the range:

*QMED actual > (QMED estimated/1.55) and*

*QMED actual < (1.55QMED estimated)*

If a 50 year return period is required then the factorial standard error for both the index flood and the growth curve should be combined. If the determination of an allowable discharge on a small site were critical then a safety factor could reasonably be employed with the use of FSR method. Inspection of the above standard errors would yield a safety factor of 1.5 for a 2 year return period increasing to a factor of 2 for a 100 year return period. The portion of the error associated with the growth curve and hence the safety factor could be allowed to increase linearly with Ln(T) as described in FSR *( Vol 1,2.6.8)*

Safety factor for return period T

$SF_T= (Lnt - Ln2) \times (SF_{100} - FS_2)/ (Ln100 - Ln2) + SF_2$

This would equate to a confidence interval of 68% *(FEH Vol.3,12.5)*. However, approximately 84% ( 68% + 32%/2) of sites could be assumed to have a discharge greater the flood flow after the safety factor was applied. If the objective is to protect a river catchment with dozens of these structures it can be seen that the few cases of overestimate (16%) will be far outweighed by the cases of underestimate (84%) and an overall improvement will be achieved. If gauged records were available on the subject on the subject site or on Hydrologically similar sites then a reduced safety factor could be justified. The above method provides for a reasonable first estimate.

## B3: What is a reasonable allowable discharge?

While the standard errors of the methods are large the variation in specified allowable discharge across the country has varied from 1 to 80lit/s/h (a factor of 80). The method proposed under the interim code of practice for SUDS, July 2004, does take the above criteria into account and suggests an approach based on the area of the site under consideration. On larger sites the latest and most complex method (FEH is suggested while IH124 with the FSR based growth curves is acceptable for sites less than 200ha and above 200ha when FEH cannot be applied.

Summary based on chapter 6:*ICP SUDS, 2004*:

Where the site is less than 50ha then the 50ha result for the discharge is calculated a pro-rata discharge linearly interpolated e.g. if 20l/s is the calculated for 50ha then use 12l/s for 30ha.

| | |
|---|---|
| Area <50ha | IH124 and prorate 50ha result |
| 50<=Area <200ha | IH124 |
| Area>=200ha | FEH, Unit Hydrographs, IH124 |

Summary based on HA106/4, February 2004

| | |
|---|---|
| Area<=40ha | ADAS |
| Area>40ha | IH124 |

Methods are statically based and yield the peak value of the flood. If the full flow hydrograph is required this must be generated using rainfall runoff unit hydrographs. However,the IH124 and FEH statistical methods of predicting peak flow may be used to adjust the parameters of the unit hydrographs.

For more clarity of the methods, the methods are briefly explained and tested by computer software "WinDes" for Leighton Buzzard.

## B3.1: Method-1: IH124

Based on IH124 with growth curves from FSR and Ciria Book 14, my research results, it to be suitable for catchments <25km2(2500ha): Interim Code of Practice for SUDS, July 2004 recommends <200ha. HA106/04, February 2004, recommend use >40ha.

Calculation method:
The mean annual flood QBAR for catchment under 25km$^2$

$$QBAR_{Rural} = 0.00108 AREA^{0.89} SAAR^{1.17} SOIL^{2.17}$$

AREA: Catchment area in Km
SAAR: Average annual rainfall (1941-1970 in mm
SOIL: The soil index (the five SOIL classes have values of 0.15, 0.3, 0.4, 0.45, and 0.5)

Adjustment for urbanisation from IH report 124 equation 7.2 to 7.4 Ciria Book 14,3.2.2:

$$CIND = 102.4\, SOIL + 0.28(cwi - 125)$$

$$NC = 0.92 - 0.00024\, SAAR\ (for\ 500 \le SAAR \le 1100mm$$

$$NC = 0.74 - 0.00082\, SAAR\ (for 1100 \le SAAR \le 3000mm$$

$$\frac{QBAR_{urban}}{QBAR_{Rular}} = (1 + URBAN)^{2NC}\left(1 + URBAN\left(\left(\frac{21}{CIND}\right) - 0.3\right)\right)$$

CWI: Catchment wetness index is a function of the average annual rainfall and is described in FSR Fig1.6.62

CIND: The catchment index

NC: Rainfall continentally factor which is a function of SAAR

URBAN: The fraction of the catchment area

Urbanised Catchment growth factors for return periods not exceeding 50 years, calculate equivalent reduced variant y from the following table based on Ciria Book14 table 3.

| *URBAN* | *Return Period (Years)* | | | | | |
|---|---|---|---|---|---|---|
| | *2* | *5* | *10* | *20* | *25* | *50* |
| *0.00* | *0.37* | *1.5* | *2.25* | *2.97* | *3.20* | *3.90* |
| *0.25* | *0.52* | *1.5* | *2.20* | *2.76* | *2.93* | *3.35* |
| *0.50* | *0.65* | *1.6* | *2.12* | *2.55* | *2.67* | *3.00* |

Using the y value from the above table obtain the growth factor from the following table based on Ciria Book 14 table 3.2.

| *Region* | *Value of y* | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | *0.0* | *0.5* | *1.0* | *1.5* | *2.0* | *2.5* | *3.0* | *3.5* | *4.0* |
| *1* | *0.82* | *0.94* | *1.06* | *1.20* | *1.36* | *1.53* | *1.72* | *1.94* | *2.17* |
| *2* | *0.84* | *0.94* | *1.05* | *1.18* | *1.33* | *1.51* | *1.72* | *1.95* | *2.23* |
| *3* | *0.84* | *0.98* | *1.11* | *1.25* | *1.38* | *1.52* | *1.65* | *1.79* | *1.92* |
| *4* | *0.80* | *0.93* | *1.07* | *1.23* | *1.40* | *1.58* | *1.79* | *2.01* | *2.25* |
| *5* | *0.79* | *0.93* | *1.10* | *1.29* | *1.52* | *1.79* | *2.11* | *2.49* | *2.93* |
| *6-7* | *0.77* | *0.92* | *1.09* | *1.28* | *1.50* | *1.74* | *2.02* | *2.34* | *2.69* |
| *8* | *0.78* | *0.92* | *1.07* | *1.23* | *1.40* | *1.58* | *1.76* | *1.95* | *2.16* |
| *9* | *0.84* | *0.96* | *1.08* | *1.21* | *1.35* | *1.49* | *1.64* | *1.80* | *1.97* |
| *10* | *0.85* | *0.96* | *1.07* | *1.19* | *1.31* | *1.45* | *1.58* | *1.73* | *1.88* |

Britain is grouped into 10 regions for the determination of growth factors FSR fig 1.2.4 and Ciria Book14 Fig 3.7

On urbanised catchment growth factor for return periods exceeding 50 years, Ciria Book14 table 3.3.

| *Region* | *Return Period (years)* | | | | |
|---|---|---|---|---|---|
| | *100* | *200* | *250* | *500* | *1000* |
| *1* | *2.48* | *2.81* | *2.92* | *3.25* | *3.63* |
| *2* | *2.63* | *2.98* | *3.10* | *3.45* | *3.85* |
| *3* | *2.08* | *2.36* | *2.45* | *2.73* | *3.04* |
| *4* | *2.57* | *3.02* | *3.17* | *3.62* | *4.16* |
| *5* | *3.56* | *4.19* | *4.39* | *5.02* | *5.76* |
| *6-7* | *3.19* | *3.75* | *3.93* | *4.49* | *5.16* |
| *8* | *2.42* | *2.85* | *2.98* | *3.41* | *3.91* |
| *9* | *2.18* | *2.47* | *2.57* | *2.86* | *3.19* |
| *10* | *2.08* | *2.36* | *2.45* | *2.73* | *3.04* |

Soil table:

| *Soil Class* | *Soil Index* (Peak)- IH124 | *SPR* UH) | *St* *(ADAS)* | *Permeability Class* |
|---|---|---|---|---|
| *1* | *0.15* | *10* | *0.1* | *Very rapid* |
| *2* | *0.3* | *30* | *0.5* | *Moderate* |
| *3* | *0.4* | *37* | *0.8* | *Slow to Moderate* |
| *4* | *0.45* | *47* | *1* | *Very slow* |
| *5* | *0.50* | *53* | *1.3* | |

## B3.2: Method 2 – FEH

This method is suitable for large areas. QMED is used as the index flood in the Flood estimation Handbook, QMED is formally defined as the middle ranking value in the series of annual maximum floods where the annual maximum series comprises the largest flow observe in each year. This method is applicable for the area no smaller than 50ha.

$$QMED_{Rural} = 1.172 AREA^{AE} \left(\frac{SAAR}{1000}\right)^{1.560} FARL^{2.642} \left(\frac{SPRHOST}{100}\right)^{1.211} 0.0198^{RESSHOT}$$

$$AE = 1 - 0.015 Ln\left(\frac{AREA}{0.5}\right)$$

$$RESHOST = BHIHOST + 1.3\left(\frac{SPRHOST}{100}\right) - 0.987$$

AE: Area Exponent

RESHOST: Residual soils term obtained from HOST data

SPRHOST: Standard percentage runoff derived from HOST soil data

BFIHOST: Base flow index derived from HOST soil data

FARL: Index of flood attenuation to reservoir and lakes

URBEXT: Extent of urban and suburban cover

UAF: Urban adjustment factor

PRUAF: % runoff urban adjustment factor inferred from the rainfall runoff method

QMED: Median annual flood ($m^3/s$) 2 year returns period

$$QMED = UAF\ QMED_{Rural}$$

$$PRUAF = 1 + 0.615\ URBEXT\left(\left(\frac{70}{SPRHOST}\right) - 1\right)$$

$$URBAN = 2.05(URBEXT)$$

## B3.3: Method 3 – ADAS 345

This method is intended for land drainage purpose, for peak flow Q0 for catchment under 30ha. ADAS has confirmed that the "Grass" as the dominant crop type the return period of the flow is 1 year.

$$Q_0 = St\, F\, A$$

St: Soil type factor

F: number derived from site length, slope, crop type and average annual rainfall

A: Area in hectares- (paved area percentage but not exceeding 10%)

AAR: The average rainfall in mm from FSR

Q0: Peak flood flow (l/s)

| ***Determine the soil type factor St*** | |
|---|---|
| ***Permeability class*** | ***St*** |
| ***Very slow*** | ***1*** |
| ***Slow to Mod*** | ***0.8*** |
| ***Moderate*** | ***0.5*** |
| ***Very rapid*** | ***0.1*** |

## B3.4: Method 4 – ICP SUDS

ICP SUDS- Interim Code of Practice Sustainable Drainage System for the sites smaller than 50ha the IH124 method is applied to a 50ha site and the result multiplied by scale factor equal to the site area in hectares divided by 50.

| | |
|---|---|
| Sites>200ha: | FEH statistical and Unit Hydrograph method should be applied. |
| 50-200ha: | IH124 method applied directly as described in method 1 |
| 0-50ha: | IH124 method applied with 50ha in the formula, results are linearly interpolated using the ratio of the development size to 50ha. |

Leighton Buzzard catchment area is estimated 178km$^2$ (17800ha) from the FEH Software and table below, shows the catchment area parameters.

| ***FEH CD Rom-2 catchment descriptor*** | | | |
|---|---|---|---|
| *Subject site location: 491500, 227150* | | *Catchment centroid: 494410, 223066* | |
| ***Catchment descriptor*** | | | |
| *Area* | *178.22km2* | *RMED-1H* | *10.1mm* |
| *ALTBAR* | *150m* | *RMED-1D* | *30.9mm* |
| *ASPBAR* | *307 degree* | *RMED-2D* | *38.5mm* |
| *ASPVAR* | *0.05* | *SAAR* | *641mm* |
| *BFIHOST* | *0.482* | *SAAR4170* | *662mm* |
| *DPLBAR* | *13.28km* | *SPRHOST* | *40.5* |
| *DPSBAR* | *33.3m/km* | *URBCONC1990* | *0.663* |
| *FARL* | *0.987* | *URBEXT1990* | *0.0272* |
| *LDP* | *22.39km* | *URBLOC1990* | *0.725* |
| *PROPWET* | *0.31* | *URBCONC2000* | *0.829* |

| | | | |
|---|---|---|---|
| | | *URBEXT2000* | *0.0425* |
| | | *URBLOC2000* | *0.735* |
| ***Catchment area DDF value*** | | | |
| *C* | *-0.026* | *D3* | *0.281* |
| *D1* | *0.327* | *E* | *0.371* |
| *D2* | *0.272* | *F* | *2.425* |
| ***1km point DDF value for 492000,227000*** | | | |
| *C (1km)* | *-0.027* | *D3(1km)* | *0.262* |
| *D1(1km)* | *0.331* | *E(1km)* | *0.316* |
| *D2(1km)* | *0.280* | *F(1km)* | *2.422* |

*Using WinDes software to calculate peak rural discharge for different area and compare the result:*

| | | | |
|---|---|---|---|
| **IH124 Input** | | | |
| *Return Period* | *1 year* | *Urban* | 0 |
| *Area* | *100ha* | *Region* | 5 |
| *SAAR* | *641* | *Soil* | 0.3 |
| **Result** | | | |
| QBAR(lit/sec) | 152.3 | QBA urban (lit/sec) | 152.3 |
| **Return Period Flood (lit/sec)** | | | |
| Q(1yrs) | 132.5 | Q(30yrs) | 366.0 |
| Q(2yrs) | 136.1 | Q(50yrs) | 432.9 |
| Q(5yrs) | 196.5 | Q(100yrs) | 542.3 |
| Q(10yrs) | 252.1 | Q(200yrs) | 638.3 |
| Q(20yrs) | 318.5 | Q(250yrs) | 668.8 |
| Q(25yrs) | 344.6 | Q(1000yrs) | 877.5 |
| QBAR (lit/sec) | | 152.3 | |

| | | | |
|---|---|---|---|
| **ICP SUDS (FSR Method)** | | | |
| *Return Period* | *1 year* | *Urban* | 0 |
| *Area* | *100ha* | *Region* | 5 |
| *SAAR* | *641mm* | *Soil* | 0.3 |
| **Result** | | | |
| QBAR(lit/sec) | 153.2 | QBA urban (lit/sec) | 152.3 |
| **Return Period Flood (lit/sec)** | | | |
| Q(1yrs) | 132.5 | Q(100yrs) | 542.0 |
| Q(30yrs) | 366.0 | QBAR | 152.3 |

To use ADAS 345, this method is suitable for smaller area e.g. 25ha

| | | | |
|---|---|---|---|
| **ADAS345** | | | |
| *Return Period* | *1 year* | *Urban* | 0 |
| *Area* | *25ha* | *Region* | 5 |
| *AAR* | *641mm* | *Soil* | 0.3 |
| *Length* | *1000m* | *Paved area* | 10% |
| *Average Slope(1:x)* | *1000* | *Dominant Crop* | Grass |
| **Result** | | | |
| Q0(lit/sec) | 12.5 | Q0 Total (lit/sec) | 12.5 |
| **Return Period Flood (lit/sec)** | | | |
| Q(1yrs) | 12.5 | Q(30yrs) | 34.4 |

| | | | |
|---|---|---|---|
| Q(2yrs) | 12.8 | Q(50yrs) | 40.7 |
| Q(5yrs) | 18.5 | Q(100yrs) | 51.0 |
| Q(10yrs) | 23.7 | Q(200yrs) | 60.0 |
| Q(20yrs) | 30.0 | Q(250yrs) | 62.9 |
| Q(25yrs) | 32.4 | Q(1000yrs) | 82.5 |

Figure (B1): Catchment area map for Leighton Buzzard

## B4: Volumetric Runoff

In the United Kingdom the Wallingford procedure is used to calculate rainfall and runoff, the rainfall and runoff variables required in the Modified Rational Method may need some explanation.

Rainfall is calculated using region, return period, M5-60 and ratio R or by using data directly from the flood estimation Handbook CD rom.

### B4.1: Region

The rain fall across the United Kingdom varies considerably. A different formula is used for the following regional categories.

1- FEH rainfall
2- England and Wales
3- Scotland and Ireland
4- Load rainfall file(other countries)

## B4.2: Return Period or Annual probability

There is nothing new about this concept. It denoted the frequency with which a storm may be expected to occur. Rational method design usually uses return periods between 1 and 5 years in the UK, an alternative term is annual probability. A return period of 1 has an annual probability of 100% while a 2 year return has an annual probability of around 50%.

## B4.3: M5-60 and Ratio R

These two factors may be read from the maps contained in the Wallingford procedure or the Flood Studied Report, available from the Centre for Ecology and Hydrology in Wallingford, Oxon. They enable the program to calculate the intensity/ Duration/ Frequency characteristics for any location in the United Kingdom.

M5-60 is the rainfall depth based on a 60 minute storm of 5 years return period. Ratio R is the ratio of the 60 minute storm to the 2 day storm. If, for a given location the M5-60 is 20mm and M5-2 day is 50mm then the ratio

$$R = \left(\frac{20}{50}\right) = 0.4\ or\ (40\%)$$

This indicates that in a region where only 50mm of rain fall may fall in two days 40% of that rain may fall in just one hour.

The Volumetric runoff coefficient Cv is the proportion of water that fall on the site entering the drainage system. The Wallingford Procedure states that if our design is based solely on roofed and paved areas(impermeable area), then the Cv ranges between 0.6 and 0.9 and is typically 0.75. the fact that it is not 1 for impermeable area has surprised many people but it has based on-site measurement.

Rational Method Design formula:

$$Q\left(\frac{l}{s}\right) = 2.78\ x\ I\left(\frac{mm}{h}\right) x\ A\ (ha)$$

Modified Rational Method design formula:

$$Q\left(\frac{l}{s}\right) = Cv\ x\ \ Cr\ \left(2.78\ x\ I\left(\frac{mm}{hr}\right) x\ A(ha)\right) \quad - where\ Cr = 1.3$$

However,the modified Rational Method also has a constant Routing Factor Cr, which is 1.3. If we take the typical value of Cv as 0.75 and multiply it by 1.3, we get 0.975 which is very nearly 1 and therefore it makes no difference compared to the Rational Method of design. However don not make the mistake of specifying a Cv of 1, as this result in a 30% over design. Cv may be calculated from equation 7.3 Volume1, Wallingford Procedure as:

$$PR = 0.829\ PIMP + 25SOIL + 0.078UCWI - 20.7\ and\ \ Cv = \frac{PR}{PIMP}$$

Where

| | |
|---|---|
| PIMP: | Surface intended to drain to the storm |
| SOIL: | Soil Type |
| UCWI: | Antecedent wetness condition (mm) |

# APPENDIX- C: Ground recharges model calculation- evapo-transpiration formula

Crops need water in particular quantities for their optimum growth. Excessive or deficit amounts of water could retard crop growth and ultimately lower the crop yields. Conditions influencing the rate of water use by crops include the type of the crop, stage of its growth, climatic parameters like temperature, wind velocity, humidity etc., available water supply and soil characteristics ( Praveen et al. ,2011)

**Methods used to estimate reference evapotranspiration.**

| **Method** | **Formula Applied** |
|---|---|
| Pan method<br>Pan co-efficient | $ET = K_{p} E_{pa}$<br>$K_{p} = 0.108 - 0.0286U2 + 0.0422\ln(FE)$<br>$+0.1434\ln(RH_{i}) - 0.000631[\ln(FE)^2]\ln(RH_{i})$ |
| Penman [1] | $ETr = \Delta\frac{R_{1} - G}{\Delta} + \frac{\gamma 6.43\, f(u)(ea - ed)}{\gamma}$ |
| Penman Monteith[2] | $\frac{\Delta(R_{1} - G) + \rho_a C_p (e_a - e_d)/r_{t}}{\Delta + \gamma(1 + {}^{\gamma}/_{\gamma_{t}})}$ |
| Kimberly-Penman[2] | $ET = \frac{\Delta(R_{1} - G)}{\Delta + \gamma} + \frac{\gamma}{\Delta + \gamma}\,\frac{6.43W_{j}D}{\lambda}$ |
| Priestley-Taylor[2] | $ET = 1.26\,\frac{\Delta(R_{1} - G)}{\Delta + \gamma}$ |
| Hargreaves[2] | $ET = 0.0038\,R_{t}T(\delta)^{0.5}$ |
| Samani-Hargreaves [2] | $Et = 0.00094\,S_{t}\,\delta T_f\,T_f$ |
| Blanney-Criddle[2] | $ET = a_{Bt} + b_{Bt}f$<br>$f = p(0.46T+8.13)$<br>$a_{BC} = 0.0043(RH_{mi}) - \left(\frac{n}{N}\right)$<br>$b_{Bt} = 0.82 - 0.0041(RH_{i}) + 1.07\left(\frac{n}{N}\right) + 0.066(U_{t})$ |

**Legend:** ETr is reference ET (mm/day), Kp is pan co-efficient, $U_2$ is average daily wind speed at 2 m height ($ms^{-1}$), $RH_m$ is average daily relative humidity (%), FET is fetch, $E_{pan}$ is pan evaporation (mm), Δ is gradient of saturation vapour pressure temperature function ($kPa^0C^{-1}$), $R_n$ is the net radiation ($MJm^{-2}$ day), G is soil heat flux ($MJm^{-2}day^{-1}$), $\gamma a$ is air density ($Kg\,m^{-3}$), $C_p$ is specific heat of the air at constant pressure ($KP_a$), $\gamma$ is psychrometric constant ($kPa^0C^{-1}$), f(u) is an empirical wind speed function, $\gamma a$ is aerodynamic resistance to water vapour diffusion into the atmospheric boundary layer ($Sm^{-1}$), $\gamma$ cis the vegetation canopy resistance to water vapour transfer ($Sm^{-1}$), $W_f$ is a wind function., $\lambda$ is latent heat of vapourization of water ($MJkg^{-1}$), Ra is extra terrestrial radiation expressed in equivalent evaporation ($mmday^{-1}$), T is mean air temperature (°c), δT is the difference between mean monthly maximum and mean monthly minimum temperature (°c),So is water equivalent of extra terrestrial radiation ($mmday^{-1}$), $\delta T_f$ is the difference between mean monthly maximum and mean monthly minimum temperature (°c),$T_f$ is mean temperature (°c), $a_{BC}$, $b_{BC}$ and F are functions, (n/N) is the ratio of actual to possible sunshine hours, $RH_{min}$ is minimum daily relative humidity, P is the ratio of actual daily day time hours to annual mean daily day time hours, $V_d$ is the day time wind at 2 m height ($ms^{-1}$).

Praveen, P., Sachin Kumar,M., Puttaswamy, H., Police patil, V. M. and Ravi Kumar (2011) Estimation of evapo-transpiration rate by different methods for Paddy crop in South Kodagu, Central Western Ghats, Plant Sciences Feed