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PART A *To be completed by the student*

STUDENT'S NAME Salehin Sajid

STUDENT NUMBER 16817612 COURSE Civil Engineering BEng

MODULE CODE AND TITLE CN301 Individual Project

TITLE OF ASSIGNMENT Dissertation - Design of a new Wetland

ASSIGNMENT TUTOR Heidi Burgess

DATE ASSIGNMENT DUE 01/05/2019

NEW SUBMISSION DATE REQUESTED 01/06/2019

REASONS FOR REQUEST

Note: this form is <u>not confidential</u> and you should use only a general description of your circumstances below (e.g. "medical problems"). Please submit a supporting statement with the documentary evidence as an attachment which will be treated as confidential.

Fallen behind schedule due to family medical issues and dissertation lecturer being on co

PART B *To be completed by the Course Leader or equivalent*

COURSE LEADER'S REPLY

Agreed : Yes ☑ No ☐

Comments

NEW SUBMISSION DATE APPROVED 31/5/19

NAME A LAMPROPOULOS DATE 8/4/19

University of Brighton

Faculty of Science & Engineering
School of Environment & Technology

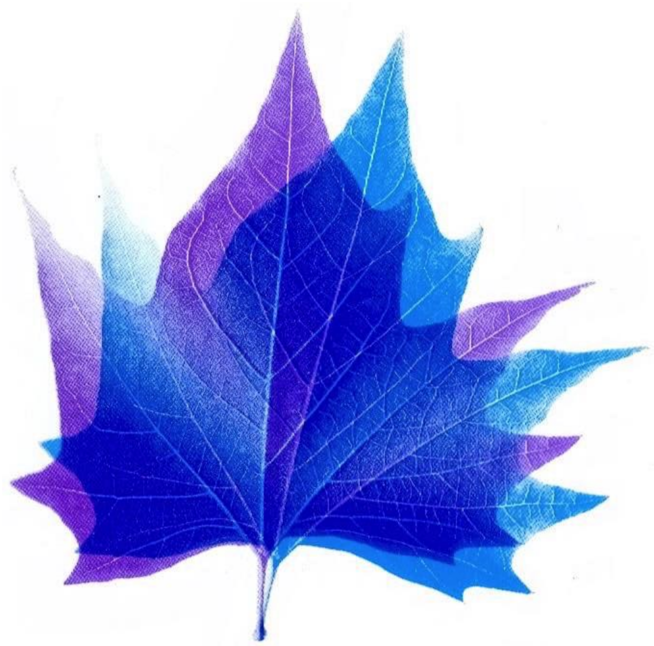
Final Year Individual Project
in part fulfilment of requirements for the degree of
BEng (Hons) in Civil Engineering

Design of a Wetland

By: Salehin Sajid

Supervised by: Heidi Burgess

31/05/2019



DECLARATION

I ………Salehin Sajid………, confirm that this work submitted for assessment is my own and is expressed in my own words. Any uses made within it of the works of other authors in any form (e.g. ideas, equations, figures, text, tables, programmes) are properly acknowledged at the point of their use.

I also confirm that I have fully acknowledged by name all of those individuals and organisations that have contributed to the research for this dissertation.

I also confirm that this work or parts of it have not been submitted previously for assessment of another module or at another institution.

A full list of the references used in this project has been included.

Signed: ……………………………….

Date: ………31/05/2019……….

Acknowledgements

Through this project I have attained an incredible amount of knowledge in a relatively new but utterly important field of hydrological and engineering science: Wetlands. This would not have been achieved without my supervisor Dr Heidi Burgess, who has helped me through this project with her extensive knowledge of hydraulics, all the while keeping it all light hearted at times of stress.

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Also, a big thanks to David Stansbury for aiding me with the DGPS and further correcting my readings.

Last but not least I would like to thank Fran Southgate of the Sussex Wildlife Trust and Penny Green of Knepp Castle Estate Office.

Abstract

A nationwide wetland creation initiative has been created by the Million Ponds Project. Its aim is to restore the network of wetlands that once resided in the UK, with the critical element of clean water being at the centre of the initiative. Knepp Estate, situated in Horsham, is taking part of the initiative. Which in turn will also correspond with their own ‘rewilding project’ to help restore the quality of freshwater environments for biodiversity. This project entails the design research, methods, and final proposal for Knepp Estates wetland, which will sit at the heart of the 3,500-acre estate. Through the project a summary of wetlands is covered along with analysis of rainfall and evotranspiration, which later leads to further exploration of climate change as it directly effects wetland design considerations. Alongside this, in depth data for flora and fauna of West Sussex is covered and collated from multiple sources, for which the wetland is designed for. While the wetland will not be germinated by hand, but rather left to its own accord to see what wildlife arrives naturally. The sole aim of the wetland is to promote biodiversity and provide a safe habitat for wildlife.

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1.0 Introduction

The world is home to an estimated "8.7 million species" (Mora et al., 2011) of animals, fungi, plants etc. all of which require rich and diverse environments and conditions. With the urbanisation taking place at accelerated rates, species may struggle to find a locality to call home. A wetland is one of earth's richest biodiverse ecosystem with each one possessing the ability to host over 100,000 species. Primarily being inundated by water (both permanently and temporarily), wetlands provide several different water configurations on a singular plot which allows numerous species to reside in them.

Wetlands can be present in any areas where there is a ground baring body of water or storm water runoffs, and areas such as national parks and other species rich regions thrive from functioning wetlands. Many nature rebuilding projects recognise the need for variations of wetlands to preserve wildlife, such as Knepp Estates 'Rewilding' initiative. Based on a 3500-acre estate which was "once intensively farmed – has been devoted to a pioneering rewilding project." (Knepp Wildland, 2018), the end goal for the estate "is to establish a functioning ecosystem where nature is given as much freedom as possible." (Knepp Wildland, 2018), and a proposed new wetland is to lie at the heart of the estate.

This report will highlight details of the design procedure of a functioning wetland for Knepp Estate, consisting of: aims and objectives; literature Review; methodology; results and the final design proposal.

2.0 Aims and Objectives

2.1 Aims

The restoration works at Knepp Estate cover a large expanse of land of which the desired wetland lies right at the heart to encourage a new habitat to wildlife. The owners of the estate would like to adhere to their commitment to the Millon Ponds Project and envisage that the pond would be formed at a variety of depths. It would lie on a land the size of 11000m2 and would also involve the removal of circa 7000m^3 of material.

The aim of this project is coherent with that of Knepp Estate's: designing a functioning wetland of varying depths but with a water table no deeper than a maximum of 1 meter at any given time.

2.2 Objectives

For this project, three main objectives have been outlined:

1. Research wetland construction
   Information regarding design considerations; construction and maintenance; safety implications; and environmental impacts for wetlands need to be researched and collated before design stages. Much of the research will come from text books on wetlands and hydraulics, while much of the design considerations research is expected to come from online texts.

2. Undertake tests on site
   Factors of the site will need to be taken into consideration for the design stages. Sediment core tests are needed to better understand the soil and a DGPS will also be done to gain site elevation information.

3. Design Wetland
   Once all relevant information has been gathered, the design process can begin.

Figure 2.1 Site map of Knepp (red box highlights proposed wetland area)

3.0 Literature Review

3.1 What Is a Wetland?

Wetlands are varying sizes of land infilled with water to most people's knowledge. However, wetlands are considered to be one of the most important ecosystems on earth. While their importance of preserving wildlife has been known for a century, wetlands have benefitted the populace of earth from the Carboniferous period by producing and preserving fossil fuels on which our society now depends on according to Mitsch and Gosselink (2015).

Mitsch and Gosselink (2015) go on to paraphrase wetlands as "kidneys of the landscape" due to their natural functions of cleaning wastewater and mitigating droughts and floods by acting like sponges and collecting, storing and filtering excess water. However, their water treatment properties are not desired by Knepp Estate.

Going back to the previous statement of "their importance of preserving wildlife", wetlands provide conditions for rich biodiversity's. They offer habitats unique only to them, which protects and provides for a sizeable selection of flora and fauna. According to Kandasamy and Vigneswaran (2009), wetlands provide a range of nutriment and fibre products (mainly aquaculture) as well as wood products and stock feed. This highlights the many benefits of wetlands alongside Knepp Estates main desire, wildlife preservation.

3.2 Functions of a Wetland

While all wetlands bare similar characteristics, their functions which regulate their ecosystems differ and they can be collated to either hydrological, biogeochemical or ecological functions (Turner et al., 2005).

Hydrological functions refer to the wetland's ability to store floodwaters, the interactions between ground and surface waters and the storage of sediments:

- Flood water detention: the short- and long-term detention and storage of waters from overbank flooding and/or slope runoff.

- Ground water recharge: the recharge of groundwater by infiltration and percolation of detained floodwater into an aquifer.
- Ground water discharge: the upward seepage of groundwater to the wetland surface.
- Sediment retention: the net retention of sediments carried in suspension by waters inundating the wetland from river overbank flooding and runoff from a contributory area.

Biogeochemical functions of a wetland refer to the export and storage of naturally occurring chemical compounds that can have significant effects on the quality of the environment:

- Nutrient retention: the storage of excess nutrients (nitrogen and phosphorus) via biological, biochemical and geochemical processes in biomass (living and dead) and soil mineral compounds of a wetland.
- Nutrient export: the removal of excess nutrients (nitrogen and phosphorus) from a wetland via biological, biochemical, physical and land management process.
- In situ carbon retention: the retention of carbon in the form of partially decomposed organic matter or peat in the soil profile due to environmental conditions that reduce rates of decomposition.
- Trace element storage and export: the storage and removal of trace elements from a wetland via biological, biochemical and physical processes in the mineral compounds of wetland soils.

Ecological functions relate primarily to the maintenance of habitats within which organisms live:

- Ecosystem maintenance: the provision of habitat for animals and plants through the interaction of physical, chemical and biological wetland processes (including habitat and biological diversity). Nursery for plants, animals, micro-organisms.
- Food web support: the support of food webs within and outside a wetland through the production of biomass and its subsequent accumulation and export.

3.3 Project Wetland

All wetlands act as a wildlife habitat alongside their other functions and most constructed wetlands are built to provide stormwater treatment, pollutant removal or groundwater tracers. Conversely, Knepp estate have stated their core reason is to provide for and preserve wildlife and this allows one to disregard many constructed wetland rules guidelines. This is because much of the relative equations and research focus on BOD levels, which goes on to providing several design criteria such as retention times, wetland sizing and water depths. Although many constructed wetlands have inlet and outlets which directly control water flow for pollutant removal and such, Knepp have also stated that the wetland can only be fed water by direct precipitation, differentiating the design stages further.

3.4 Wetland Hydrology

Hydrology is the single most important determinant of for both the formation and maintenance of wetlands and its processes state Mitsch and Gosselink (2015). The hydrological cycle is in constant motion, powered by solar energy, in which wetlands act as storage points (Aber, Pavri and Aber, 2012). Ideally the relationship between the gain, loss and storage of water, which is known as the water budget, should equal zero for a wetland:

$$Gains - Losses - Storage = Zero$$

For each component in the equation above, wetlands have many ways in which they may attain them. Wetlands may gain water through surface inflow, direct precipitation, and ground water discharge; while losing water by evaporation, transpiration, surface outflow and ground water recharge according to Aber, Pavri and Aber (2012). The methods of water inundation and loss will vary depending on the climate, location and classification of the wetland.

3.5 Hydroperiod

A hydroperiod determines the stability of wetlands, it describes the seasonal shift in surface and subsurface water levels (Scholz, 2007) and does this by integrating all of the inflows and outflows (Mitsch and Gosselink, 2015). Characteristics which describe a wetlands hydroperiod focus on flooding. For a wetland in an area such as Knepp Estate could be described as *temporarily flooded*, and the amount of time the wetland is in inundated is called *flood duration*. Factors which directly affect the hydroperiod of a wetland are the contours of the land, balance between outflow and inflow (water budget), and the geology and groundwater conditions of the subsurface.

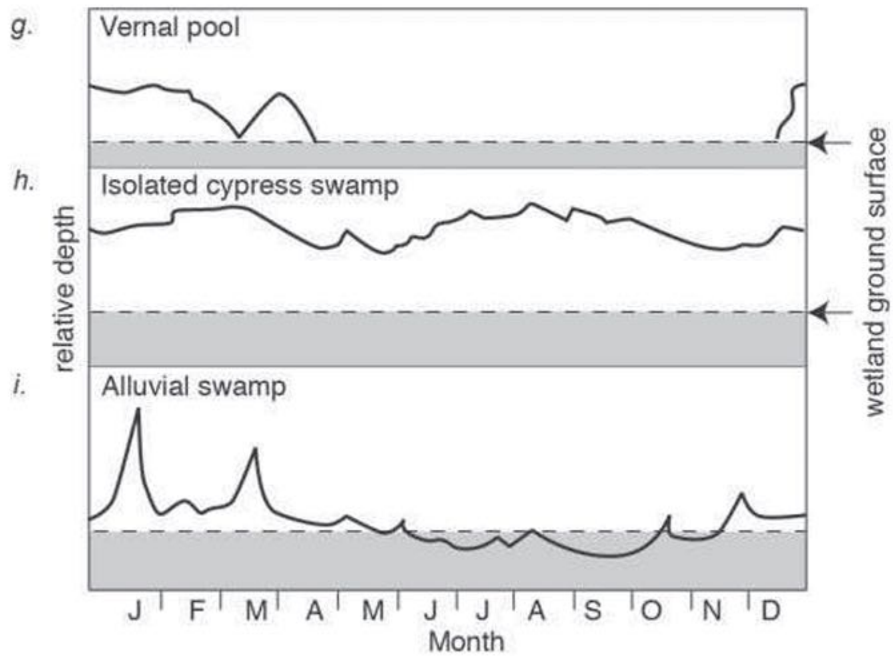

Figure 3.1 Hydroperiods for different wetlands Figure 3.1 Hydroperiods for different wetlands (Mitsch and Gosselink, 2015)

The hydroperiod for Knepp Estates' proposed wetland may look like the Vernal Pools in figure 3.1, showing that the water depth only ever goes above the wetland ground surface a few months a year. However, Knepp Estate does not want the water table to be above one meter at any given point, so this is unacceptable and must be considered in the design process.

3.6 Pulsing Water Levels

While it may seem unintuitive to deprive a wetland of its water, it may be unavoidable in many cases. Certain climates will produce inescapable droughts unless said wetland has an alternative inlet of water, again, which is not desired by Knepp. Yet, Mitsch and Gosselink (2015) states that periods of flooding "pulses" will nourish wetlands with fresh nutrients and wash away detritus and waste products. While pulses usually occur to riparian wetlands, direct precipitation wetlands could also experience such an occurrence.

3.7 Wetland Water Budget

The water budget of a wetland is defined by the balance between the inflow and outflow. This budget is summarised by the equation 3.1.

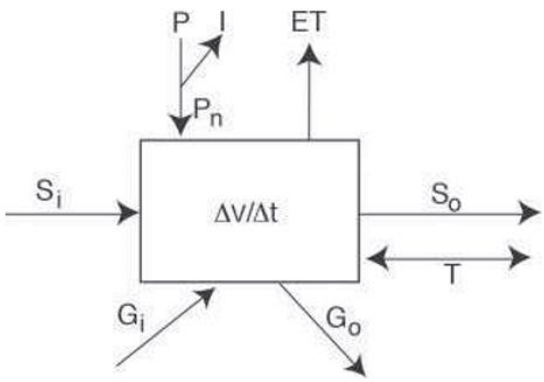

Figure 3.2 Generalised water budget for a wetland diagram (Mitsch and Gosselink 2015)

$$\Delta V/\Delta t = Pn + Si + Gi - ET - So - Go \quad (3\text{-}1)$$

where,

$V = volume\ of\ water\ storage\ within\ a\ wetland$;

$\Delta V/\Delta t =$ $change\ in\ volume\ of\ water\ storage\ in\ a\ wetland\ per\ unit\ time\ (t)$;

$Pn = net\ precipitation$;

$Si = surface\ inflows\ including\ flooded\ streams$;

$Gi = groundwater\ inflows$;

$ET = evapotranspiration$;

$So = surface\ outflows$;

$Go = groundwater\ outflows;\ and$

$T = tidal\ inflow\ (+)\ or\ outflow\ (-)$.

Average water depth, d, of a wetland at any given time can be expressed as

$$d = \frac{V}{A} \quad (3\text{-}2)$$

where

$A = wetland\ surface\ area$

The terms of equation 3-1 can be expressed as both depth per unit time (cm/yr) or volume per unit time (m^3/yr). When designing wetlands, it is easy to forget that not all wetlands will have to factor in every variable of equation 3-1, as all wetlands are affected by precipitation and evapotranspiration (evaporation + transpiration) but not all wetlands are directly affected by surface flows, ground water and tides. Another important determinant for a wetlands water budget is residence time which describes the renewal rate of water in an area:

$$t^{-1} = \frac{Q_t}{V} \tag{3-3}$$

where

$t^{-1} = renewal\ rate\ (time)$

$Q_t = total\ inflow\ rate\ (volume/time)$

$V = average\ volume\ of\ water\ storage\ in\ wetland$

The reciprocal of the renewal rate provides the residence time, which states the average time water remains in a wetland. However, this value should be used with caution according to Mitsch and Gosselink (2015), as it is usually much larger than the actual residence time because of nonuniform mixing.

3.8 Inland Wetland

Characteristics for coastal wetlands differ to inland ones. A wetland situated on Knepp estate would be classes as an inland wetland, meaning it would display seasonal hydroperiods due to precipitation, evotranspiration, spring thaw, and storm events. In such areas, wetlands respond quickest to storms in areas with silty or clayey soils (relatively impermeable) paired along with steep slopes which generate fast run offs. Conditions which alleviate storm water situations consist of sandy soils and gentler slopes which allow for more infiltration leading to slower runoff according Aber, Pavri and Aber (2012).

3.9 Precipitation

The usual ingredients needed for a wetland are in regions where precipitation prevails as a surplus over methods which lose water such as evapotranspiration and surface runoff. However, it would be inaccurate to state wetlands attain all precipitation for their own ecosystems, as much of it is intercepted. The precipitation which falls onto wetlands with vegetation in or around the vicinity is partitioned into interception, throughfall, and stem flow. When precipitation falls much of it can be intercepted by vegetation cover, and the quantity which falls through the vegetation to the wetland below is called throughfall. Kozlowski and Pallardy, (2008) state that precipitation which passes through tree crowns (throughfall) and water moving down the stems of plants (stemflow) carry an arrangement of nutrients which originate outside the wetland system. Stem flow is usually a minor factor of the water budget of a wetland.

To calculate the total precipitation in a given situation, the following equation should be used:

$$P = I + TF + SF \tag{3-4}$$

where

$P = total\ precipitation$

$I = interception$

$TF = throughfall$

$SF = stemflow$

However, the amount of precipitation which will reach the water surface of a wetland, described as the net precipitation (P_n), is given by

$$P_n = P - I \tag{3-5}$$

3.10 Surface Runoff

Runoff is the term used to describe both surface runoff and groundwater flow, both of which are direct products of precipitation but one of which flows over the land surface and the other which journeys under the surface. Surface runoff has been described by Lee (2008) as ‘a function of intensity, duration, and distribution of rain precipitation; permeability of ground surface; surface coverage; geometry of stream channel; depth of water table; and slope of the land surface.’ Ideally runoff which is not under control is avoided, as this could cause erosion on slopes as well as flooding and silting. Areas in which the climate is considered humid, where excess rainfall may be existent, measures may be needed to ensure the safe routing and conveyance of the runoff, and such methods are termed ‘surface drainage’ according to Hillel and Hatfield (2005).

There are many approaches of surface drainage, such as shaping the land and constructing it direct the runoff via curated channels while avoiding desirable areas i.e. wetlands. While there is no direct guideline for surface drainage works as each situation will differ, this will have to be taken into consideration for the project at Knepp as there are several pesticides which reside on the polo pitch north of the proposed wetland site (surface runoff map can be found in section 5.1).

3.11 Groundwater

Any water which lies below the saturated zone of a soil is termed as groundwater. Its composition consists of any surface water and rainfall which have permeated through the soil layers and into rocks. Groundwater infiltration (%) is an indication of the ratio of water within a wetland which has come from groundwater sources according to Scholz (2016). Groundwater inflow (or groundwater infiltration) takes place ‘when the surface water (or groundwater) level of a wetland is lower hydrologically than the water table of the surrounding land’ state Mitsch and Gosselink (2015). Wetlands which display this can be referred to as discharge wetland.

However, when the water level of a wetland lies above the water table of its surrounding land, groundwater will discharge out of the wetland and into the groundwater (termed groundwater recharge). For any wetland which is situated largely above the water table of its catchment is referred to as being perched (also a recharge wetland) according to Mitsch and Gosselink (2015) and will lose water only to infiltration to the ground and evotranspiration.

The proposed wetland at Knepp Estate is likely to be one of the following (depending on the permeability of the site soil strata):

1. Surface water depression wetland (figure 3.3) – inflow of water is mainly surface runoff and precipitation with minimal groundwater outflow due to largely impermeable soils.
2. Groundwater depression wetland (figure 3.4) – these wetlands are similar to that of surface water depression wetlands but differ in the condition of having

near impermeable underlying soils leading to interception of local groundwater.

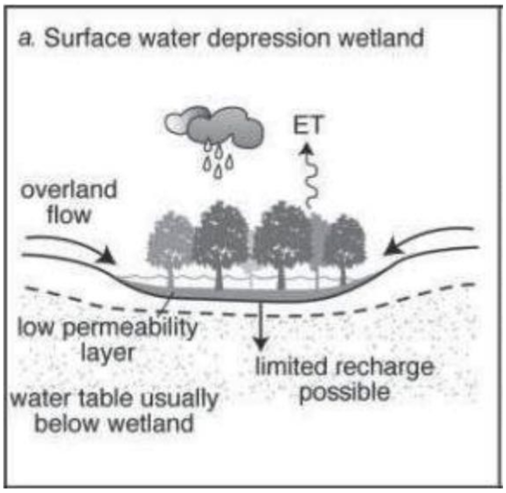

Figure 3.4 Surface water depression wetland (Mitsch and Gosselink, 2015)

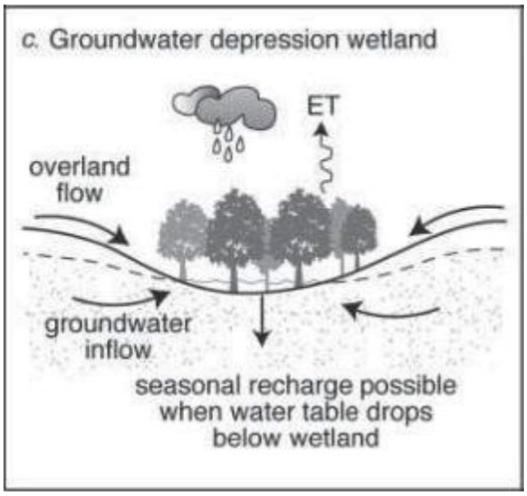

Figure 3.3 Groundwater depression wetland (Mitsch and Gosselink, 2015)

3.11.1 Darcey's Law

Darcey's law can procure the flow of groundwater in and out of a wetland. The law states that flow of groundwater is proportional to the slope of the piezometric surface and the hydraulic conductivity, or permeability. The equation states:

$$G = kA_x s \tag{3-6}$$

Where

$G = flow\ rate\ of\ groundwater\ (volume\ per\ unit\ time)$

$k = hydraulic\ conductivity\ or\ permeability\ (length\ per\ unit\ time)$

$A_x =$ $groundwater\ cross\ sectional\ area\ perpendicular\ to\ the\ direction\ of\ flow$

$s =$ $hydraulic\ gradient\ (slope\ of\ water\ table\ or\ piezometric\ surface)$

3.12 Evapotranspiration

The means of evapotranspiration is a dual component process which combines evaporation of water from water or soil, with transpiration of moisture which passes through vascular plants to the atmosphere. The rate of evaporation is proportional to the difference between the vapour pressure at the water surface and vapour pressure in overlaying air (Mitsch and Gosselink, 2015). To measure actual evapotranspiration differs from measuring the potential evapotranspiration as to say the actual is a measurement of the quantity of water which evaporates and transpires from the surface, whereas the potential is a measure of the ability of the atmosphere to remove water through said processes (Pidwirny, 2006).

One of the most common methods to measure evapotranspiration (potential) is by the use of a lysimeter, which measures the change in weight of an isolated soil sample with overlaying vegetation while measuring precipitation to and drainage from the sample (Shuttleworth, 2008).

However, there are methods which allow the estimation of evapotranspiration through empirical equations which use easily measured meteorological variables (Mitsch and Gosselink, 2015), Thornwaite's equation (potential evotranspiration) being one of them:

$$ET_i = 16(10T_i/I)^a \tag{3-7}$$

Where

$$ET_i = potential\ evotranspration\ for\ month\ i\ (mm/month)$$
$$T_i = mean\ monthly\ temperature\ (C)$$
$$I = local\ heat\ index\ \textstyle\sum_{i=1}^{12}(T_i/5)^{1.514}$$
$$a = (0.675 * I^3 - 77.1 * I^2 + 17920 * I + 492390) * 10^{-6}$$

Due to the several meteorological and biological factors, none of the empirical equations available fully appease the estimation of evotranspiration. Comparisons for the several methods have been attempted (Rosenberry et al., 2004) and the findings have concluded that most empirical provided judicious approximations of evotranspiration. Final figures need to be adjusted according to the latitude of the site due to variation of daily sunshine hours (adjustment table found in appendix 4). The Thornwaite equation, the simplest of all methods, (due to the only measurement requirement being air temperature) provided the most accurate measurement per instrument cost and remains a commonly used empirical equation for estimating wetland evapotranspiration according to Mitsch and Gosselink (2015). Although, it only gives estimates for monthly intervals rather than daily or hourly.

3.13 Flora

Wetlands are mostly oxygen deprived, nutrient deficient, high in salinity, low pH, bodies of water. Along with other characteristics, that of which would be usually considered destitute, wetlands are not the ideal place for normal vegetation. Aquatic plants, termed hydrophytes, must be able to cope with such conditions and have done so with adaptations while having gone on to survive as well as thrive.

Vegetation which emerges from the bottom of water bodies can range from scarce mudflats to heavily vegetated swamps. The inclusion of rice, the world's most important crop, shows that the wetland may be cultural as well as natural features. (Aber et al., 2012). Hydrophytes have adapted specifically to manage with low oxygen levels and underwater submergence.

Some wetland plants can tolerate substantial variations in soil moisture and water level, but others have strict water requirements for survival. On this basis, wetland vegetation is grouped into four general ecological categories, depending mainly on growth position in relation to water level (Whitley et al., 1999):

A. Shoreline - Plants that grow in wet soil on raised hummocks or along the shorelines of streams, ponds, bogs, marshes, and lakes. These plants are situated at or above the level of standing water; some may be rooted in shallow water.
B. Emergent - Plants that are rooted in soil that is underwater most of the time. These plants grow up through the water, so that the stems, leaves and flowers emerge in the air above water level.
C. Floating - Plants whose leaves mainly float on the water surface. Much of the plant body is underwater and may or may not be rooted in the substrate. Only small portions, namely flowers, rise above water level.
D. Submerged - Plants that are largely underwater with a few floating or emergent leaves. Flowers may emerge briefly in some cases for pollination.

Any plant in a wetland area must be tolerant to pollutants and hypertrophic water-logged conditions along with the ability to readily remove a high concentration of pollutants. Wetland vegetation can manage this through either "direct assimilation or storage, or indirectly by enhancement of microbial transformations. (Kandasamy and Vigneswaran, 2009).

Not all wetland vegetation can survive in any wetland. For a plant to sustain itself in a wetland many design considerations come into play such as its “mode of operation, loading rate, and waste water characteristics (Kandasamy and Vigneswaran, 2009). In usual practise, constructed wetlands will next to always prefer native species that grow within the wetland catchment and in many cases floating water plants are used to enhance aesthetics or are avoided due to light blockage.

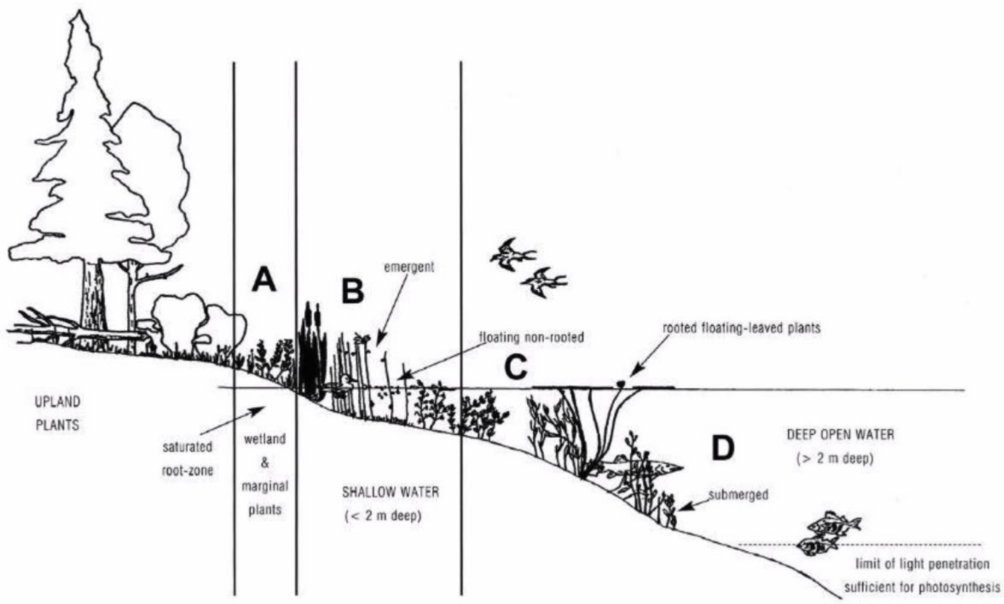

Figure 3.5 General ecological zones for wetland plants (Aber et al., 2012).

3.13.1 Sussex Flora

Research conducted by Southgate (2012) has concluded that due to progressive land engineering which leads to the neglect of natural habitats, eutrophication, and competition from alien species, has greatly resulted in the decline of wetland flora. Southgate (2012) has curated a list of rare and threatened wetland plant species in Sussex, many of which are now considered a national importance (found in appendix 1). Plant life which is endangered should be greatly considered for any wetland construction to preserve biodiversity.

Sussex wildlife trust have provided a list of more common plants for pond use (see appendix 2). The following list offers a core list of plants which will deliver structure and diversity to the wetland, which in turn will attract different wildlife to hide and live in (SWT, 2015).

3.13.2 Supply Mechanisms

While wetland conservation has gained much needed attention in recent years, it may still be regarded as uncharted waters in terms of gathered research. Species and communities which reside in wetlands have individual and vital ecohydrological requirements – coined supply mechanism. However, due to the insufficient research, these conditional requirements are not readily accessible, and plants will not flourish unless given the requirements they demand. Research conducted by the Environment Agency (2004) assess' several wetland plant species habitat requirements and collates the findings into one comprehensive guide.

The collated results highlight that many emergent, floating, and submerged plant species share the same supply mechanisms, while shoreline plants rely on entirely different supply mechanisms. Presented below are all the supply mechanisms for the native target flora species:

A. **Shoreline Plants**
   - *Mentha aquatica*
   - *Lythrum salicaria*

According to the Environment Agency (B.D. Wheeler et al., 2004) 'Common reed is found throughout Britain (to 500 m AOD) but true reedbeds occur mainly below 150m levels with minimal topographic variation (flat or slopes <20°) e.g. in the Broads and Suffolk River Valleys Environmentally Sensitive Areas (ESAs) and the Fen basin. Some reedbeds may be very extensive (e.g. Walberswick - 300 ha), but the community also occurs in drainage channels where it is most typical in arable ditches only 1–2.5 m wide'.

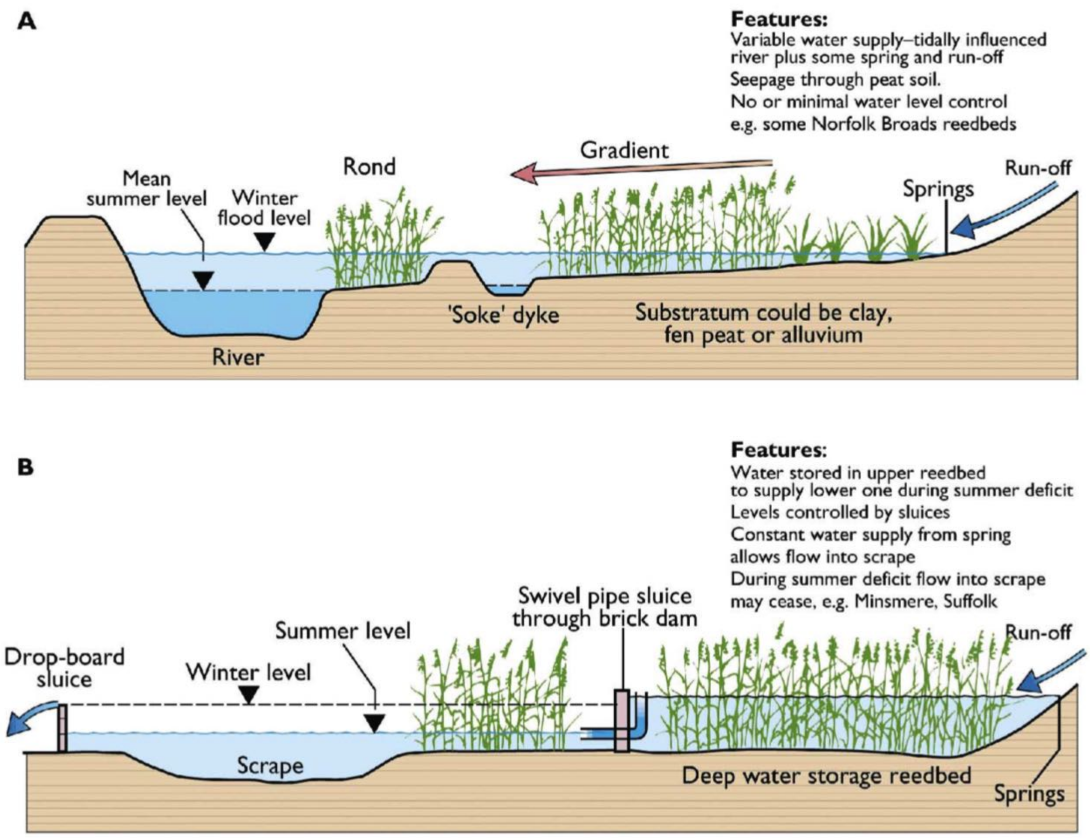

Figure 3.6 Example shoreline hydrological arrangement for Mentha aquatica & Lythrum salicaria (Environment Agency, 2004).

- *Caltha palustris (MG8)*
- *Lychnis flos-cuculi (MG8)*

This community of plant requires sufficient water to supply the soil throughout summer. However, prolonged waterlogging and soil dryness are both dangers to the community, hence it is found soils which have a water table of 0.5 m from the surface and shows relatively little seasonal fluctuation. The mechanism shown in figure 3.7 are equipped with dense ditch networks which maintains a constant water level.

- Oenanthe fistulosa *(MG13)*

This specific plant, which is classified as 'vulnerable', has one major supply mechanism in which they occur in shallow depressions where water is captured from surface run off or storm/flood events.

B. Emergent Plants

- *Sparganium erectum*
- *Glyceria fluitans*

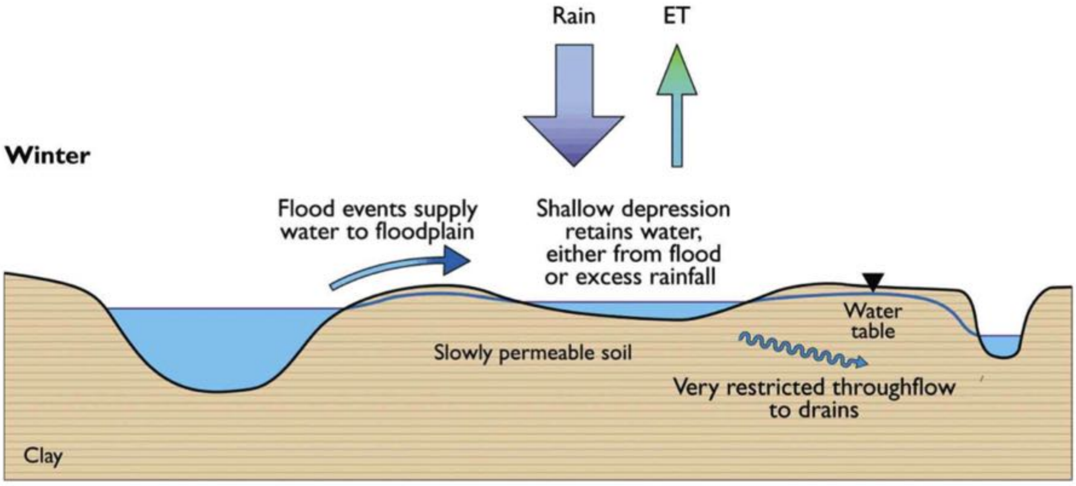

Figure 3.8 Example shoreline hydrological arrangement for Caltha palustris & Lychnis flos-cuculi (Environment Agency, 2004).

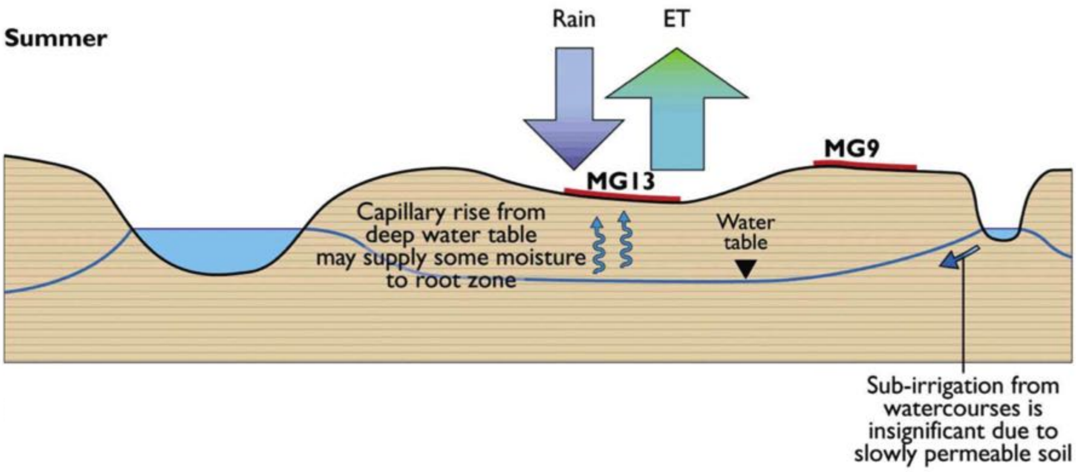

Figure 3.7 Example shoreline hydrological arrangement for Oenanthe fistulosa (Environment Agency, 2004).

C. Floating Plants

- *Hydrocharis morsus-ranae*
- *Potamogeton natans*

D. Submerged Plants

- *Ceratophyllum demersum*

The plants from the list above all share a common supply mechanism. The water supply is from a combination of runoff and rainfall.

The million ponds project have also curated a list of plants in East Sussex for wetland use and have furthermore drawn out the supply mechanisms required.

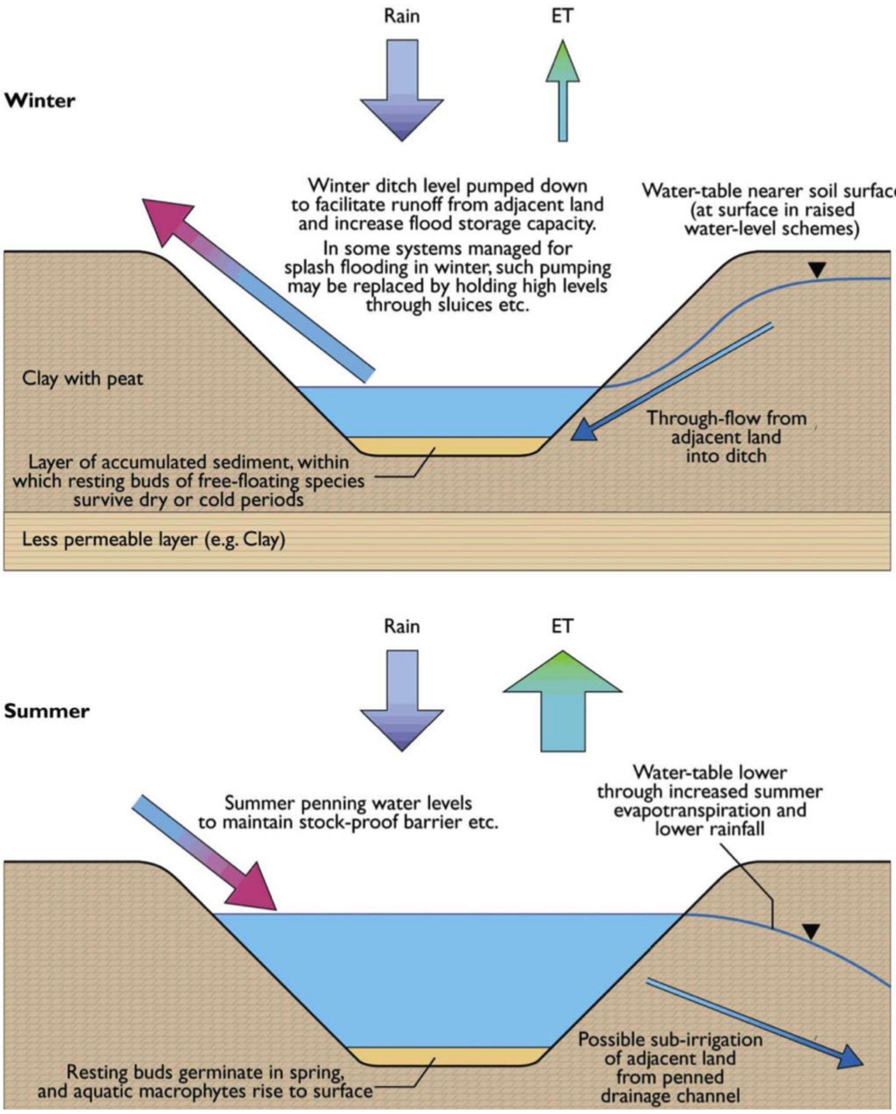

Figure 3.9 Example emergent, floating & submerged hydrological arrangement (Environment Agency, 2004)

- *Pilularia globulifera (Pillwort)*
- *Baldellia ranunculoides (Lesser Water-plantain)*

The Lesser Water-plantain, while once scattered throughout the country, is now considered nationally ‘near threatened’. It requires seasonal fluctuations in water levels with low natural nutrient levels and resides in the drawdown zone (see section 3.13.3).

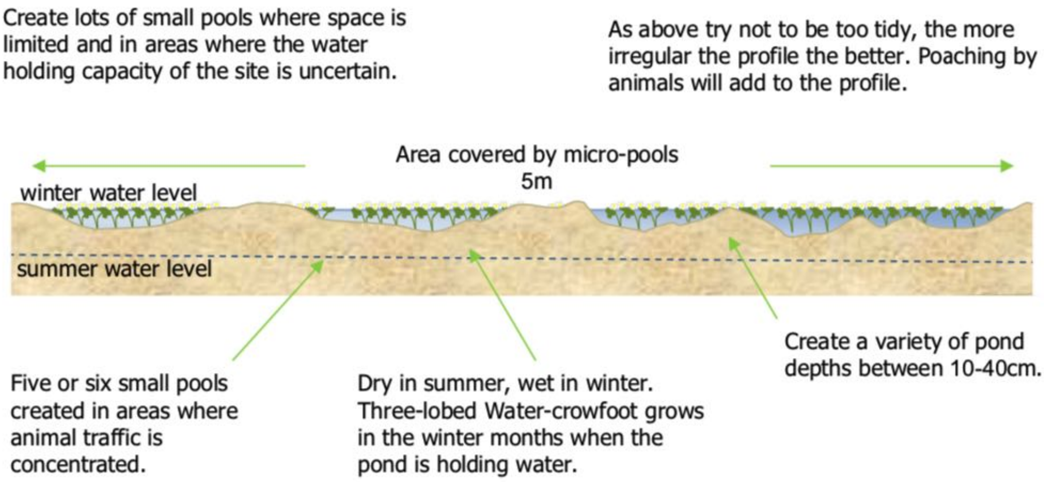

Figure 3.10 Supply Mechanism for Lesser Water-plantain (Freshwaterhabitats.org, 2019)

- *Ranuncluus tripartitus (Three-lobed Water-crowfoot)*
  The Three-lobed Water-crowfoot require shallow pools which are dry in the summer and flooded in the winter and will be successive with fluctuating water levels.

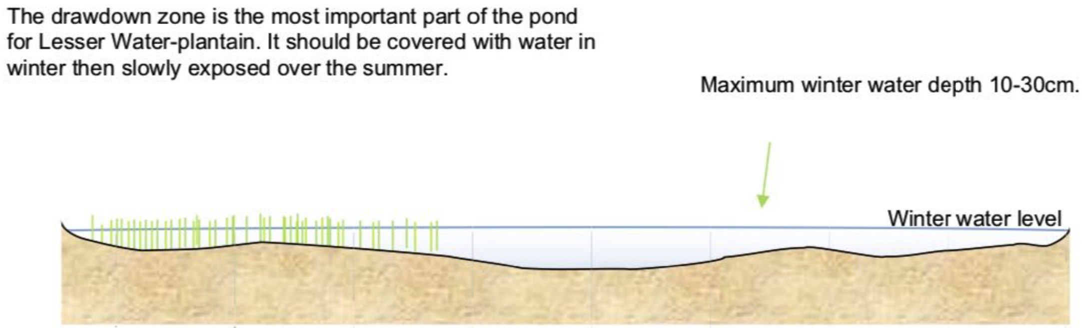

Figure 3.11 Supply mechanism for Three-lobed Water-crowfoot (Freshwaterhabitats.org, 2019)

- *Stonewart*
  Stonewarts are now labelled as nationally scarce. Being a a very old group of aquatic plant, they have become rare due to water pollution. (Freshwaterhabitats.org.uk, 2019).

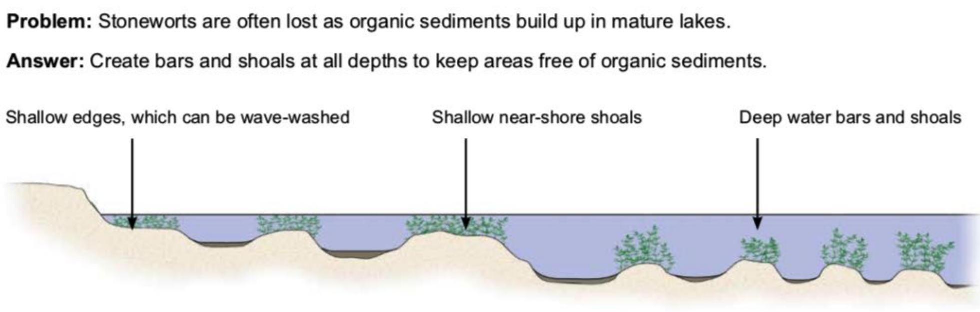

Figure 3.12 Stonewart supply mechanism (Freshwaterhabitats.org.uk, 2019)

3.14 Fauna

Wetlands are home to an array of animals ranging in sizes due to their productive ecosystems, hosting animals such as the Bengal tiger. Wetland animals may reside in, on or around vegetation. The type of wildlife in a wetland depends on the vegetation chemistry, habit and form, and its structure and species. Another characteristic which effect the diversity in wetland animals is water, where some species may require water for either part or all of their time on this planet. **"If the vegetation is right, and the disturbance low enough, the animals will be right"** (Haslam, 2003).

Protecting wildlife and biodiversity is the sole motivation for preserving and reinstating wetlands around Knepp estate. Although, the estate would like to see which fauna will naturally colonises in the wetland rather than trying to target specific species.

3.15 Wetland Design Considerations and Guidelines

The design constraints for this wetland will differ from traditional wetland design processes as explained in section 3.2.1. While some area and design criteria's have been set by Knepp estate, much of the design guidelines have been collated from national trusts and wildlife preservation research conducted by the million ponds project.

3.15.1 Pond Complexity

To preserve biodiversity, ponds of varying sizes and shapes are preferred, as singular ponds do not provide enough complexity for wildlife to flourish. A collection of ponds with varying maximum depths will promote site richness, however this is not to say all pools should to be inundated at all times. Due to seasonal changes, many of the pools are expected to become dry, while some may remain permanently inundated (Freshwaterhabitats.org.uk, 2019).

3.15.2 Pond Areas

For a wetland to be rich in wildlife, different habitats must be available within the wetland. Figure 3.10 describes in which parts of the wetland will host the richest areas and which parts will harbour the most animals.

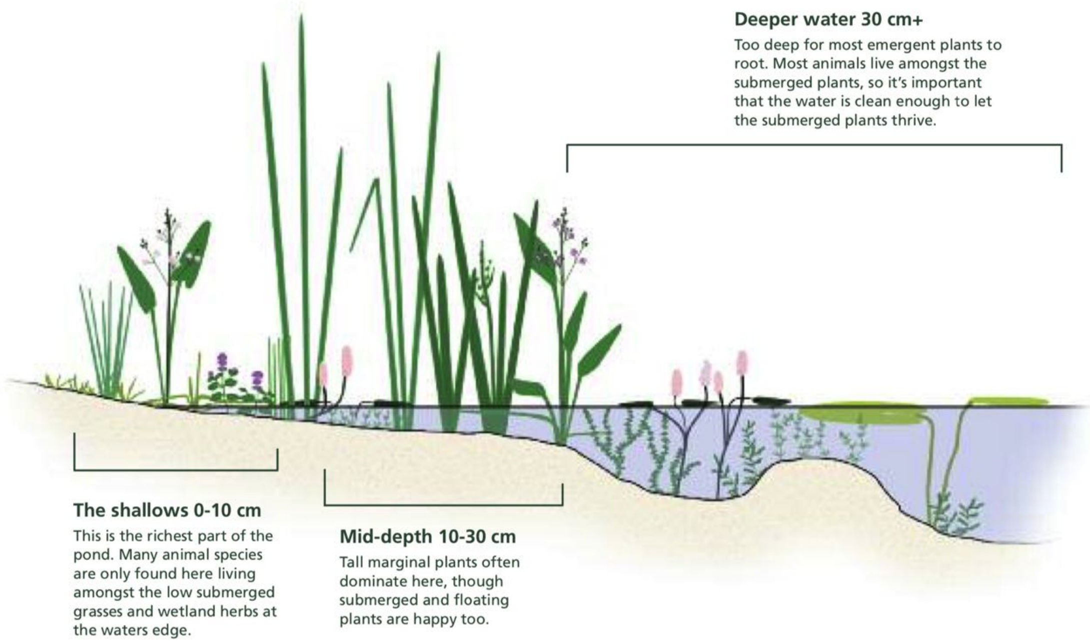

Figure 3.13 Different areas of a wetland (Freshwaterhabitats.org.uk, 2019).

3.15.3 Drawdown Zone

Wetlands are not expected to be fully inundated at all times, but rather fluctuation in water levels is preferred over stable water levels. Fresh Water Habitats (2019) state that water levels will usually drop by 0.5 m during summer months, which exposes a seasonal 'drawdown zone' that can be described as an area of vegetation and mud which will experience flooding during winter and spring months, while gradually dries as water levels fall during the summer. The drawdown zone is considered a vastly rich environment for both flora and fauna and is often may be used by birds and mammals as a feeding area (Freshwaterhabitats.org.uk, 2019). Constructing banks with very low angles will create extended drawdown zones.

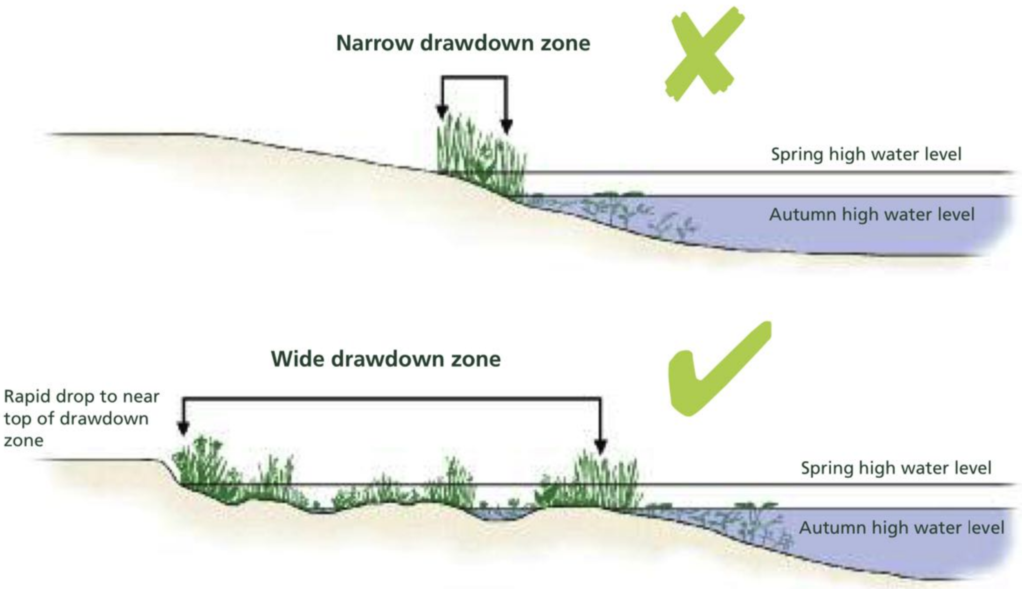

Figure 3.14 Good drawdown zone example (Freshwaterhabitats.org, 2019)

3.15.4 Water Depths

To assure optimum habitats for wildlife, shallow water serves best. Depths of 1-10 cm deep will usually provide the richest areas of wildlife and can be designed using appropriate slopes. Slopes need to be gentle at the edge at less than 1:5 (12˚) and preferably less than 1:20 (3˚). If normal pond margins of 20° to 30° are used, then the vital wildlife rich area would only amount to a band of 35 cm wide. (Freshwaterhabitats.org.uk, 2019).

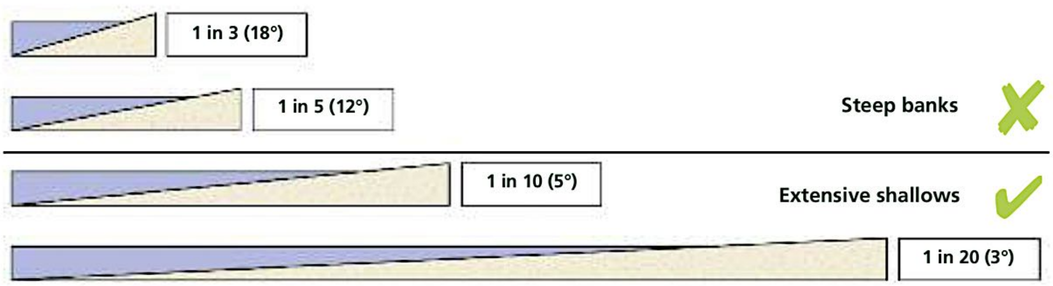

Figure 3.15 Design for shallow bank angles (Freshwaterhabitats.org.uk, 2019)

To create deeper ponds (with depth over 0.5 m) and broad areas of shallow water – you need larger ponds. For a small pond (less than 10 m x 10 m) with an average summer drawdown of 0.5 m in height, even with quite a steep 10° (roughly 1:6)

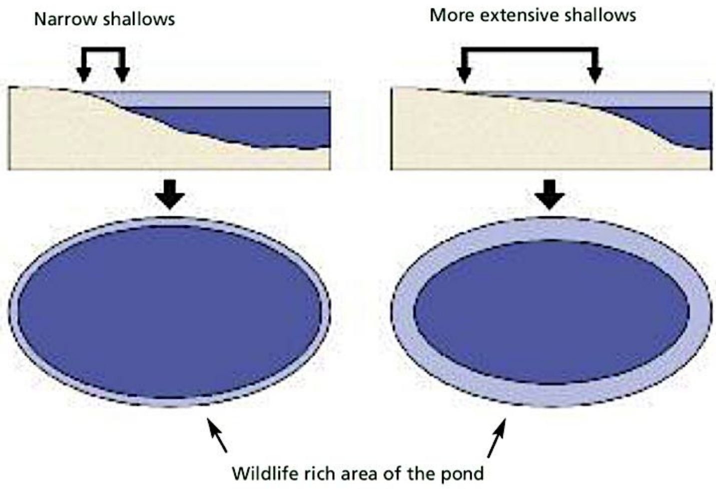

Figure 3.16 Highlighting extensive shallows where wildlife is rich (Freshwaterhabitats.org.uk, 2019)

slope, the maximum summer water depth in the middle would be 50 cm, and the average depth 25 cm. (Freshwaterhabitats.org.uk, 2019)

3.15.5 Wind, fetch and bank erosion

Wetlands in any situation will experience strong winds which can lead to erosion of its banks. In effect, this will cause erosion on small sharp-edged cliffs when the prevailing wind drives waves towards the far bank. In Britain, the prevailing wind direction is largely from the south-west, meaning any north-east bank will face the most erosion. The size of waves constructed by any wind is determined by both wind speed and the length of water across which the wind blows.

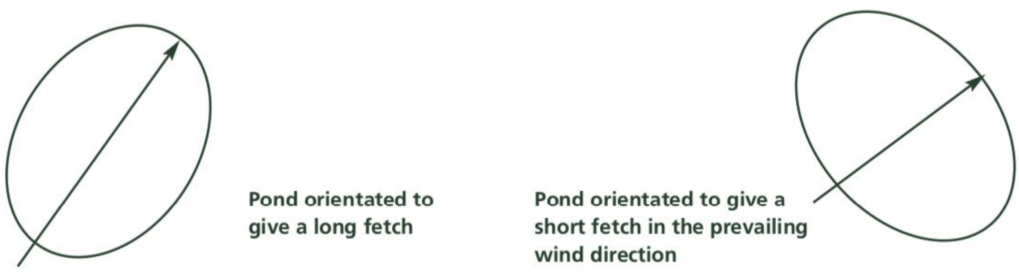

Figure 3.17 Wetland orientation settings to counteract wind energy

While wave wash could be deemed as an undermining feature for a wetland, it can also provide benefits for flora and fauna. Submerged plants such as stonewarts, which grow on bare sand or clays, benefit from the erosion of sand and clay bank materials which are deposited in the water. Furthermore, wave wash also has the capability to free the base of a wetland of organic silt by washing deposits into deeper water areas. Winds will also transport seeds, spores, eggs and other fragments along the wind margin and if the wind and wave energy is slackened, the banks upon which the fragments are delivered can develop into a rich habitat. This can be done by creating islands or deep embankments along eastern margins (Freshwaterhabitats.org.uk, 2019).

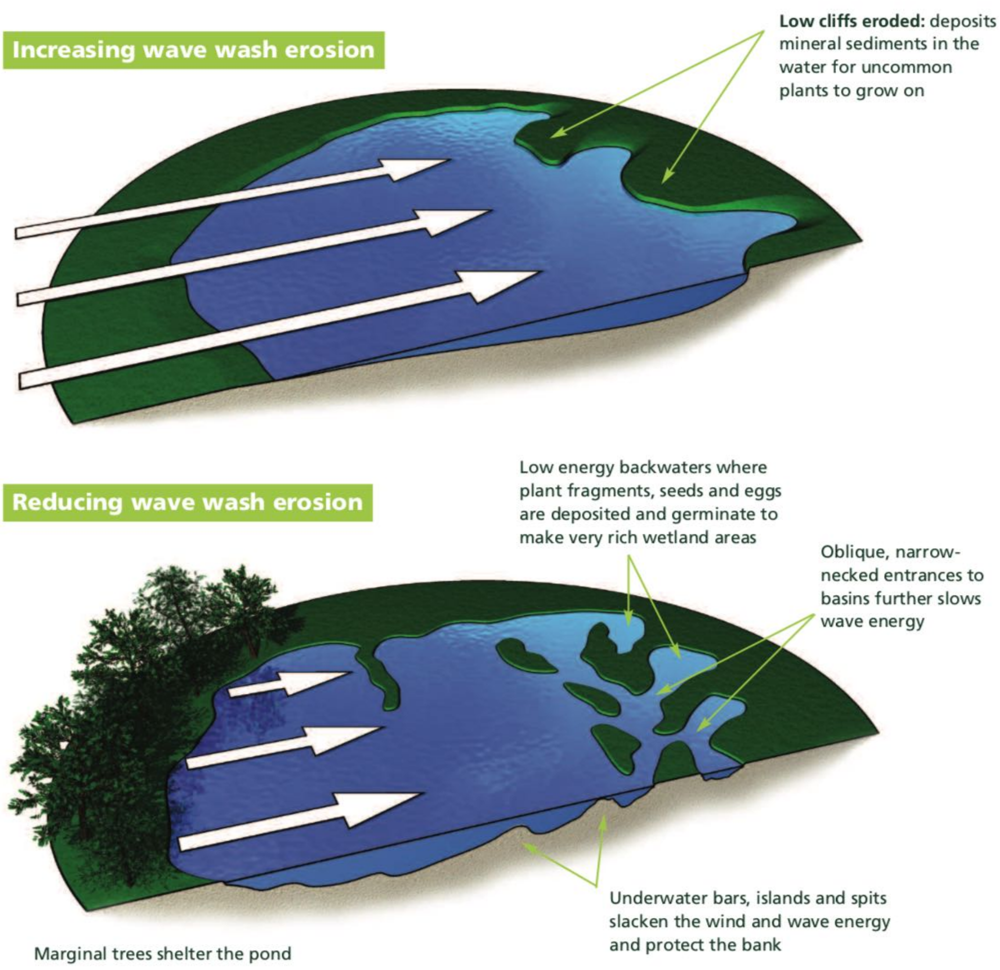

Figure 3.18 Wave energy slacking methods (Freshwaterhabitats.org.uk, 2019)

3.15.6 Islands

Following the ethos of variety creates diversity, islands provide different environments for species to reside on. Wading birds regard islands as a safe area to feed, roost and nest on. However, if a large number of birds congregate due to a higher number of islands, it may result in vegetation and water deterioration. The height of islands is an important factor in wetland design. Islands which are too high will produce a wooded area which can block views and provide perching spaces for crows. Although, if an island is too low, then it will become a submerged bar which proves useful for aquatic plants to root in according to Fresh Water Habitats (2019). Knepp Estate have also requested for islands to be included in the proposed design to encourage habitat variety.

4.0 Methodology

4.1 Introduction

Knepp estate have requested for the design of a wetland in Knepp Park to promote the conservation of wildlife and threatened species. The requirements for the wetland consist of a depth of no deeper than 1 m at any point along with no constructed input or output of water, only allowing water flow from precipitation and groundwater flow. The design is not to be planted with seeds or filled with fauna, but rather left to its own accord to see what wildlife naturally colonises. The design will not follow traditional methods as wetland science is a relatively new discipline which does not have vast expanses of information readily available when comparing to other ecological subjects. While the instruments to measure design factors exist, design procedures are still developing slowly. Much of the data used to design the wetland has been collated from online public sources.

Wetland science can be considered relatively new in comparison to other hydrological subjects. Due to this, it proved difficult to grasp an understanding to complete a design, especially when regarding a natural scrape wetland instead of the more traditionally researched storm water wetland designed for pollutant removal. From the beginning it was understood that the basic hydrological principles upon which many, if not all, water related designs must adhere to would be easily gathered. Background information for basic factors such as the water budget, precipitation influx, and water tables were known to be readily available in books and online alike. However, for more niche considerations such as scrape design guidelines or flora supply mechanisms, the task to gather relative information to procure a design was more arduous. Given the difficulty of attaining said factors, both quantitative and qualitative methods were adopted, as mixed methods allow for a combination of numerical measurement and in-depth exploration. While research into the field was required to ensure the collection of sufficient information, geospatial surveys of the proposed site were conducted as such information would not be available in books or on the web.

4.2 Methods of Data Collection

A range of methods were employed in the procurement of the design, ranging from direct help from an expert in the field to on site testing for sediment stratum. Quantitative methods such as geospatial surveys of the site and precipitation records gave numerical insights. While qualitative methods such as analysing existing data and expert help aided in the design process.

4.2.1 Site Tests and Data

DGPS

To distinguish depths for soil removal, elevation of the proposed site needed to be recorded and was gauged using a Differential Global Positioning System (DGPS). A total of over 250 elevation points (see appendix 3) were recorded in relation to above ordnance datum which measures the height of said points relative to the average sea level at Newlyn, Cornwall UK. Fran Southgate, a wetland researcher for Sussex Wildlife Trust, recommended using LIDAR data to coincide with the DGPS measured points to confirm the precision of the DGPS data.

Sediment Strata

An understanding of the soil stratum for the proposed wetland site is required to analyse groundwater effects on the wetland. Sediment core samples with a depth of 1 m were taken at three locations on the proposed site. Taking multiple samples from different locations on site will help differentiate any inconsistencies in the soil stratum. Results of all the data can be found in appendix 4.

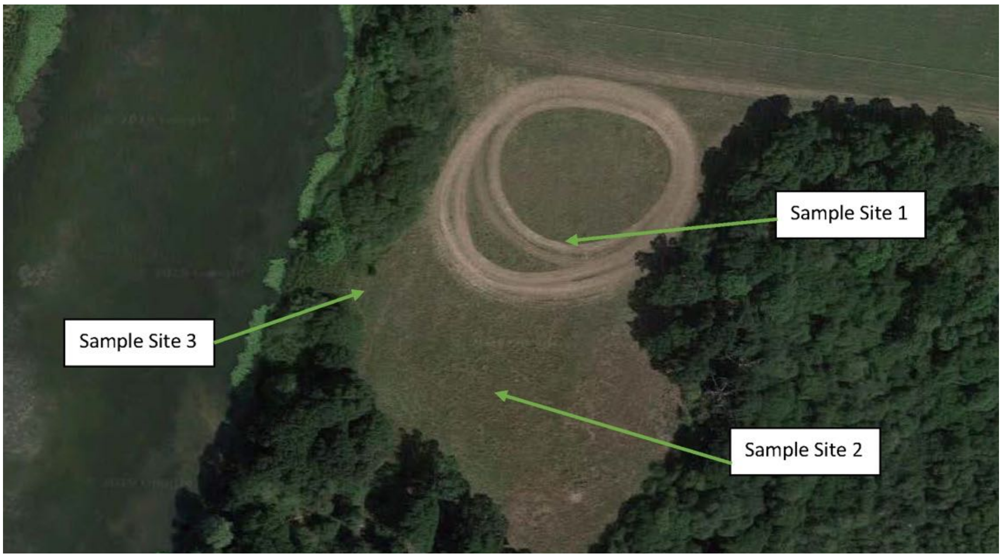

Figure 4.1 Sediment core sample site locations.

4.2.2 Rainfall Data

Rainfall data for the UK is available to find online from several sources. The MET office has public records of rainfall data ranging from 1910-2010, but this data only provides an average monthly figure of rainfall for the South East and Central South of England rather than specific locations. Conversely, to calculate daily mean flows 24-hour readings are required. Also, the average rainfall over large catchments would vary significantly when compared to smaller regions in the same catchment. Futhermore, the data is nearly a decade old and does not show the effects of the current climate issues of rising temperatures and heavier rainfall. However, the environmental agency has a tipping rain bucket gauge set up at Cowfold, situated roughly 5.5 km away from the proposed wetland site, which has been collecting rainfall data from 1998-2018. This data would better represent the catchment in which the wetland is to reside. Further data was attained via the MET office library of average monthly and daily rainfall data, during 1998-2018, from their weather station at Wiggonolt which is situated 11.3 km from the proposed wetland site. This was due to insufficient readings in the EA data from Cowfold, meaning any analysis would not have been an accurate representation of the hydrology of the area. While the data from Wiggonholt is further away, which may lead to greater inaccuracies due to location, in comparison it provides a more complete analysis outcome.

4.2.3 Evapotranspiration Data

Estimating evapotranspiration accurately, for most methods and equations, requires solar radiation and vapour pressure data, none of which can be easily measured without the correct instruments which are not readily available. Thornwaite's equation to estimate potential evapotranspiration only requires mean monthly air temperature, assuming there are 12 theoretical sunshine hours per day, for which sunshine hours are later corrected by using latitude for the location of interest. Mean monthly temperatures for several stations located across the UK have been recorded by the MET office from 1981-2010 and can be publicly accessed online. Once again, to keep the data sets in the same range of years for precision reasons, further data for the years 1998-2018 were sent from the MET office library. The new data also needed to be attained in favour of the 1981-2010 readings due to climate change. Using old data which does not take into account the accelerating rise in temperature due to the global issue would not be an accurate representation of the present or years to come.

4.2.4 Groundwater

Groundwater measurements are difficult to attain without the correct instruments needed to asses water tables and there is no publicly available data for Knepp Estate. It was decided that groundwater would be considered negligible when regarding the sediment core sample results (refer to section 5.1).

4.2.5 Sussex Flora

Knepp have requested that they would like to see what fauna will colonise the wetland of their own accord, although, in terms of flora, the wetland would need to be designed so to their requirements to encourage natural colonisation. Flora requirements are still being studied and research is difficult to attain. Much of the gathered research has come from national trust databases and the environment agency, both of which have produced documents listing native plants in Sussex and their supply mechanisms (hydrological requirements). Southgate (2012) has also curated a list form near threatened up to critically endangered flora species in Sussex.

4.2.6 Design Guidelines

Guidelines for wildlife wetlands are scarce and much of the material found in textbooks or online only regard water treatment wetlands. Basic principles of wetland design have been incorporated along with wildlife wetland design guidelines from the Million Ponds Project which outline several requirements to ensure rich biodiversity in a wetland.

4.3 Methods of Analysis

4.3.1 Site Data

DGPS

The DGPS data had to be corrected for positional errors which was done by David Stansbury, a principal technician. The corrected elevation points where imported into ArcMap on top of LIDAR data for the area from Defra to assess the precision. The DGPS data lined up with the LIDAR data accurately but was later not used due to having a cell size

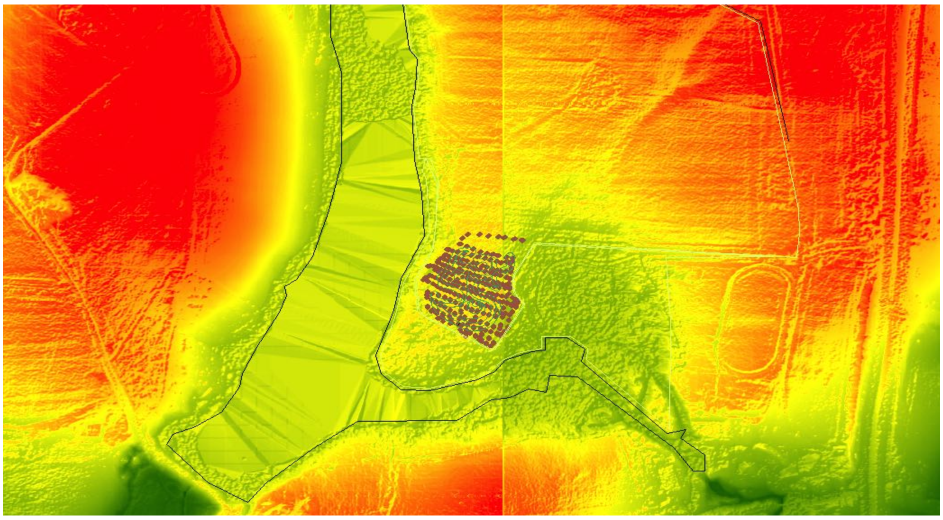

Figure 4.4 DGPS survey points overlaying LIDAR data.

of 10 x 5 m in comparison to the 1 m resolution LIDAR data. Having a resolution any greater than 1 m would compromise the precision of the construction as the proposed site is a relatively small catchment.

Sediment Stratum

The collected sediment core samples were run through a laser particle size analyser (LPSA) to measure the sediment sizes in the sample. Results from the LPSA (Appendix 4) were matched with the Wentworth (1922) grain size classification table (Appendix 5) to identify which sediment particles were present in the site soil stratum. In doing so led to the classification of the unified soil sample by using the USAD soil classification chart (Appendix 6). This was done by assessing the percentage of silt, sand and clay in the soil sample and plotting the results onto the chart until each point had unified. Knowing the unified soil category allows the estimation of infiltration rates of the soil which can aid in groundwater influence assessments.

4.3.2 Rainfall Data

Many factors which may affect the wetlands ability to retain water were calculated from the rainfall data. Using excel, daily mean flow graphs (DMF) were generated by using data ranges and cumulative frequencies along with logarithmic values to highlight the frequency of several singular rainfall events. Return periods were also calculated to estimate the depth of rainfall for the largest rainfall event in a number of years to come and was done so by utilising Weibull's quantity equations.

Using the EA, Cowfold data, analysis which was required from the rainfall data was achievable, but, was not a fully accurate representation of the rainfall events of the catchment. This is because some data from the years 1998, 1999, 2005, and 2015 were missing due to redevelopment periods. An anomaly in 2011 (249.8mm of rainfall on 25/02) which bore the largest rainfall recorded in the whole data set from 1998-2018 was also noticed and calculations were done with and without it to compare and gain a more accurate rainfall representation. This was done by excluding the singular anomaly and replacing it by the third largest rainfall event in 2011 (51.2mm – 10/02), as the second largest was only a day before the largest with a value of 160.8mm, which embodied the expected trend in rainfall when collated with the other years.

However, once the more recent MET office data (1998-2018) was attained, all analysis was redone using their figures. This was not to say that the EA data was immaculate in terms of readings available, as there were also significant gaps in the monthly averages for 1999 and occasional gaps in the daily readings during the month of January from 2001-2003. Due to this, the years 2002-2018 were used for the water budget analysis, while all years were used for the daily mean flow and return periods analysis.

4.3.3 Evotranspiration

There were substantial gaps in the MET office readings for 1998-2001, and so the years 2002-2018 were used for water budget calculations as they were fully recorded while matching with the data range for rainfall. The mean monthly temperature for all months ranging from 2002-2018 were totalled and averaged to for all years. This was then inputted into equation 3-7 and calculated accordingly. The figures below are not exact to real calculations due to rounding.

<u>*Example of calculations:*</u>

Mean monthly temperature ***January 2001-2018****:* 5.5°

$$ET_i = 16(10T_i/I)^a$$

Where

$$ET_i = 16.18\frac{mm}{month}$$

$T_i = 5.5\ (C)$

$I = local\ heat\ index\ \sum_{i=1}^{12}(T_i/5)^{1.514} = 1.14831$

$a = (0.675 * I^3 - 77.1 * I^2 + 17920 * I + 492390) * 10^{-6} = 1.159$

$I = (5.5/5)^{1.514} = 1.14831$

'I' calculated for all months and summated: 41.998

$a = (0.675 * 1.14831^3 - 77.1 * 1.14831^2 + 17920 * 1.14831 + 492390) * 10^{-6}$

$ET_i = 16((10 * 5.5)/41.998)^{1.159} = 21.87\ mm$

Adjustment factor for January (based on latitude of Knepp: 50°): 0.74

ET adjusted value: $21.87 * 0.74 = 16.18\ mm$

4.3.4 Water Budget

The water budget displays the balance of water influx during selected time periods. Monthly averages for the years 2002-2018 were calculated and summated for both rainfall and evotranspiration. From this, both the yearly and monthly average water budget can be calculated by calculating the difference between rainfall and evapotranspiration as shown in equation 3-1.

Example of calculations (monthly):

Mean monthly rainfall for January: 110.32 mm

Mean monthly evapotranspiration for January: 16.11

Water Budget: $110.32 - 16.11 = 94.21\ mm$

Summer and winter month water budgets were also calculated by summating the number of months considered to be summer (June, July and August) and winter (December, January, February) then again calculating the difference. Other variables such as groundwater inflow/outflow, *Gi/Go,* surface inflow/outflow, *Si/So* and tidal inflow (+)/outflow (-), *T,* were not accounted for as they can be counted as negligible. Surface run-off should not affect the proposed wetland site according to figure 5.3. As for tidal influence, Knepp estate is not tidally influenced by any body of water and the wetland is not directly connected any body of water.

4.3.5 Flora

Flora data gathered from Southgate (2012) and Sussex Wildlife Trust (SWT) have been cross-referenced with the Environment Agency's Ecohydrological Guidelines Report (2004). This allows the identification of hydrological supply mechanisms for said species, which leads the design considerations for the final proposal, and allows the tailoring of the wetland for said species.

4.4 Design Tools

To visually model the wetland requires specific field related software. Drawings of the proposal aid in understanding the basics of the design but not the specifics, nor will it allow 3D visualisation. Hydrological spatial design is usually conducted on GIS systems such as ArcGIS, a platform to create, manage, share and analyse spatial data. With the use of ArcMap (an ArcGIS system software), designs can be moulded into its surrounding environments and layered with maps to give a broader view of the design. ArcMap is the industry standard software, which is utilised worldwide, which is why it has been used to further the design proposal from the initial drawings.

Along with ArcGIS, AutoCAD will also be used to draw 2D plots of the design. AutoCAD allows intricate details to be drawn on a 2D surface and can later be imported into ArcMap to act as a base layer for 3D visualisation.

4.4.1 AutoCAD

A base drawing of the site and its surroundings found online from public ordinance databases, along with an aerial image of the site was imported into AutoCAD to act as a guideline for the initial wetland design. Using AutoCAD allowed the development of first draft by producing a 2D aerial drawing which was later annotated to illustrate depths and design considerations. By importing the DGPS points and using the aerial image of the site allowed the design to be accurate in terms of scaling.

4.4.2 ArcMap

AutoCAD file formats are integrated into the ArcGIS tools. Importing the AutoCAD file into ArcMap allowed accurate alignment of the design and landscape, and once the original AutoCAD data was georeferenced to the British National Grid on top of

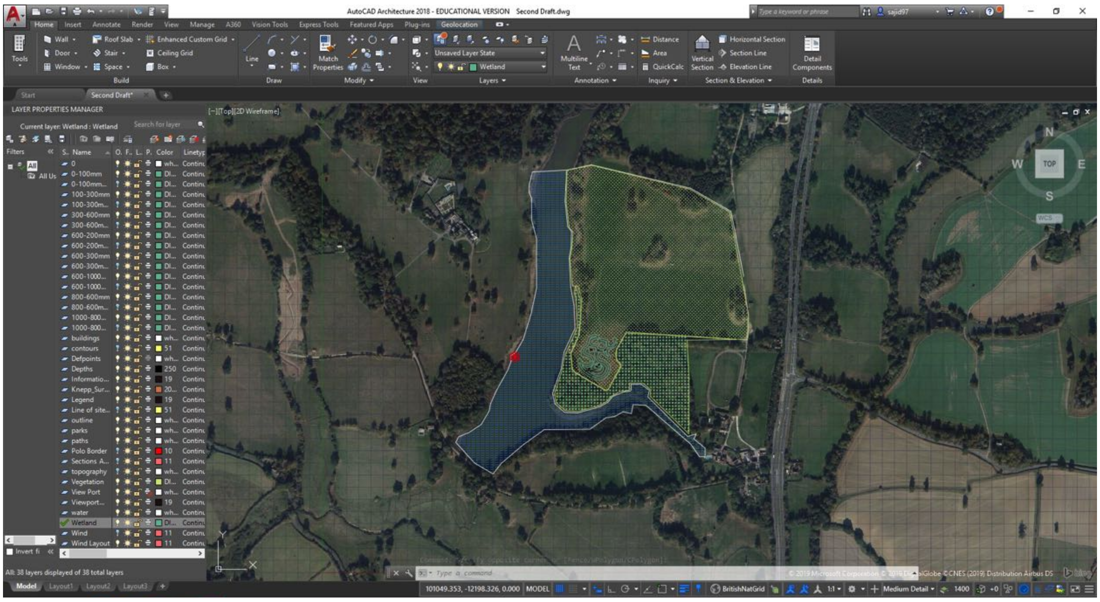

Figure 4.5 AutoCAD design with all data layers active

LIDAR data, designing to a high precision became straightforward. Using the trace facility of ArcMap, the wetland contour lines can be drawn and converted from vector (data consisting lines) to raster file type (pixel-based data).

Once design shapes are drawn, heights of contours can be entered to created desired depths and slopes. '3D Analyst Tools' were used to create 'TIN' models which allows the evaluation of geometric properties and relationships between three dimensional features and most importantly elevation modelling. (Pro.arcgis.com, 2019). After elevation and depths have been created and analysed, a final raster

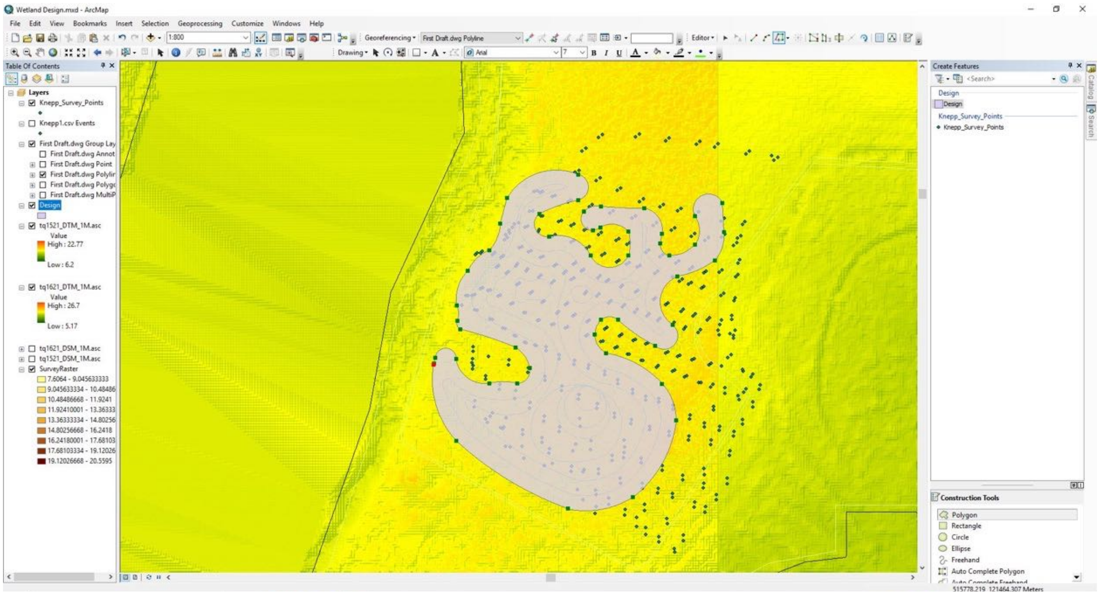

Figure 4.7 ArcMap wetland tracing with DGPS points & LIDAR data

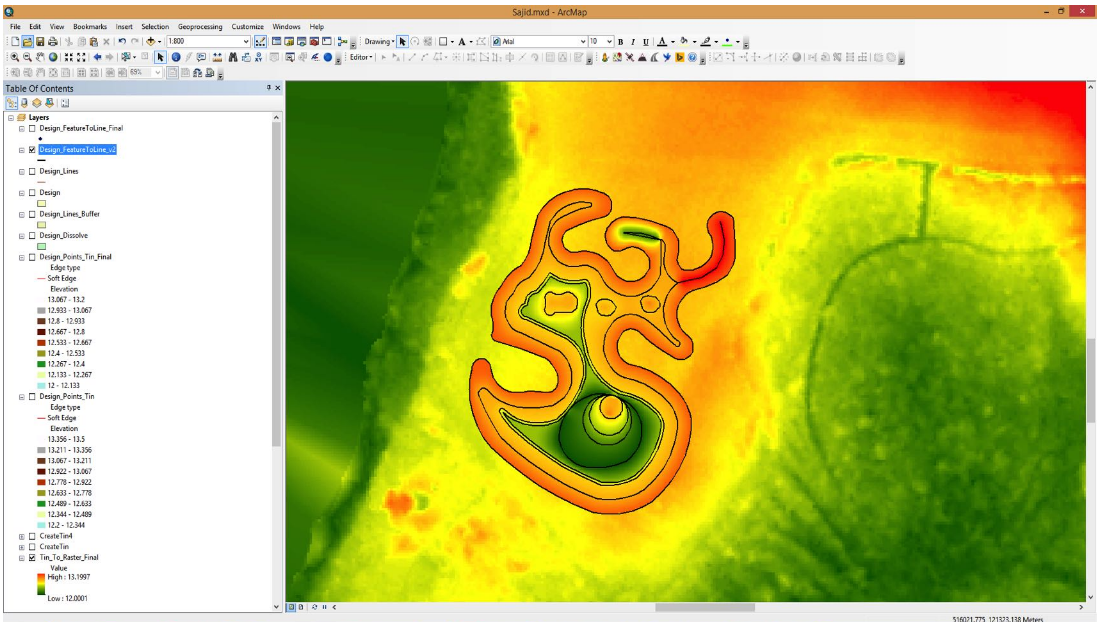

Figure 4.6 Final TIN to Raster ArcMap

conversion is needed to allow the model to be enveloped into the LIDAR data of the surrounding landscape.

4.4.3 ArcScene

ArcScene is another extension of the ArcGIS tools system. It allows data from ArcMap to be imported and analysed in 3D. ArcScene was used only to obtain 3D images of the final proposal.

Versions of tools:

- *AutoCAD 2018*
- *ArcMap/ArcScene 10.6.1*

5.0 Results Analysis

5.1 Site Analysis

After comparing the results of the sediment core samples, from sites 1, 2 and 3 (Figure 4.1), it was determined that much of the soil is a combination of silt loam and silty clay loam. The proposed site has essentially the same soil stratum across its catchment, and the depth variations seen are most likely due to elevation differences

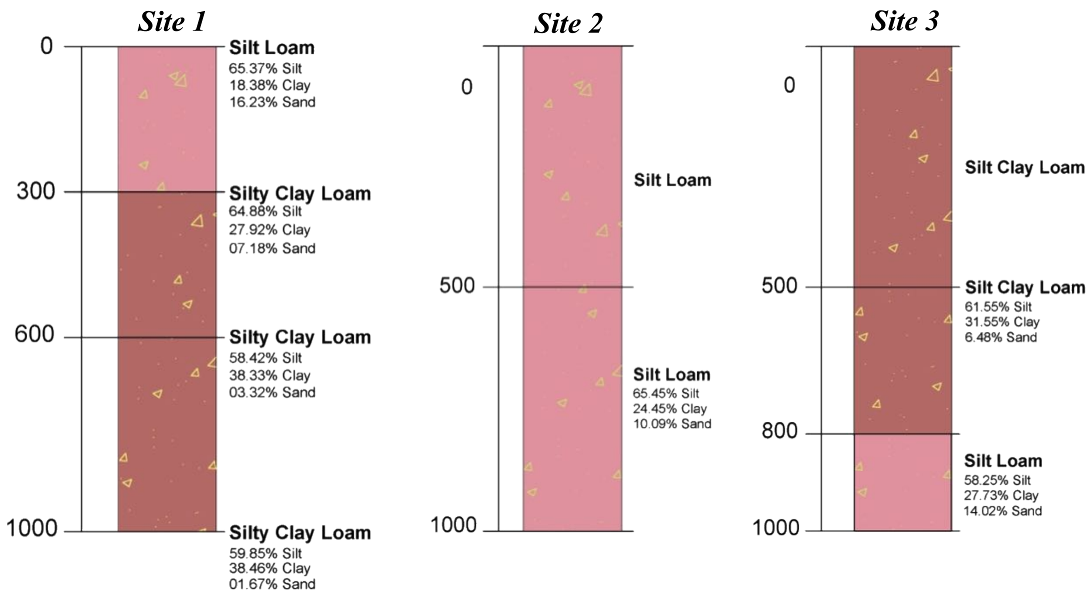

Figure 5.1 Sediment core sample results shown in cross section of soil (AutoCAD).

(depth below surface) rather than hydrogeological differences. Identifying the unified soil samples allows estimation of infiltration rates which can aid in groundwater influx estimations. Both categories of soil found in the core samples display poor to very poor infiltration rates which that indicates groundwater discharge and recharge could be considered as negligible. Considering the 1 m depth of the wetland it will most likely experience flooding, which will lead to surface run-off to its surroundings and mainly the lake due to the low permeability soils. In

Soil type/texture	ISO 14688-1 description (after Blake, 2010)	Typical infiltration coefficients (m/s)
Poor infiltration media		
• loam	Very silty clayey SAND	$1 \times 10^{-7} - 5 \times 10^{-6}$
• silt loam	Very sandy clayey SILT	$1 \times 10^{-7} - 1 \times 10^{-5}$
• chalk (structureless)	N/A	$3 \times 10^{-8} - 3 \times 10^{-6}$
• sandy clay loam	Very clayey silty SAND	$3 \times 10^{-10} - 3 \times 10^{-7}$
Very poor infiltration media	–	
• silty clay loam	–	$1 \times 10^{-8} - 1 \times 10^{-6}$
• clay	Can be any texture of soil	$< 3 \times 10^{-8}$
• till	described above	$3 \times 10^{-9} - 3 \times 10^{-6}$

Figure 5.2 Average soil infiltration rates (Woods Ballard et al., 2015)

addition, while the groundwater table was not measured it can be assumed that it will sit lower than 1 m below the surface, as during the site core sample testing no visible water was found, and the soils were only slightly moist rather than ‘saturated’. The

Knepp Millpond wetland

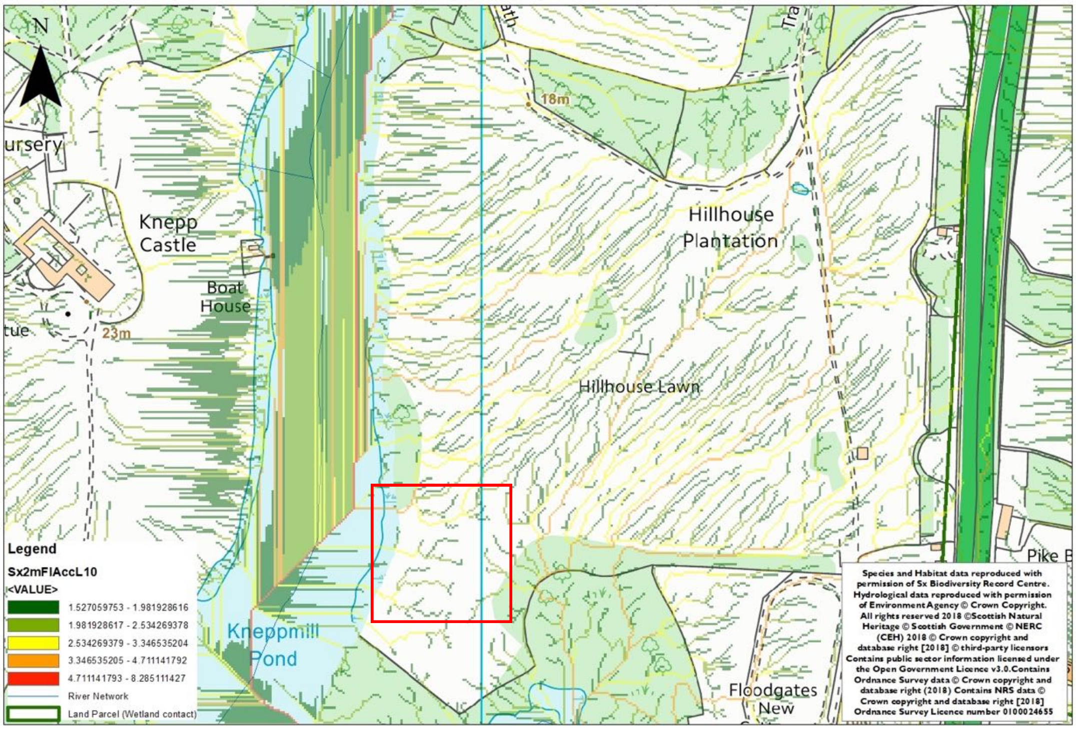

Figure 5.3 Knepp millpond surface flow map, red box shows site of wetland.

moisture in the soil present would most likely come from the lake.

During flood periods, the wetland will overflow, and water will run-off in the surroundings. A polo pitch is situated north of the proposed site. Any surface run off from the pitch will lead to an influx of pesticides into the wetland which are sprayed on the pitch, which could lead to wildlife dying due to changes in water conditions and pH levels. Figure 5.3 highlights surface flow lines of the catchment which indicates no surface water run-off will gather on the proposed wetland site, but rather its surrounding vegetation and the lake. A polo pitch is situated north of the proposed site. Any surface run off from the pitch will lead to an influx of pesticides into the wetland which are sprayed on the pitch, which could lead to wildlife dying due to changes in water conditions and pH levels. This analysis will be taken as an assumption with the final design.

5.2 Rainfall

From the MET office rainfall data, using all years, average daily mean rainfall and return periods were calculated. Table 5.1 and 5.2 collates the data from figures 5.4 and 5.5 into tabulated figures. The results of the daily mean rainfall highlight that 10% of all rain events in a year will amount to 10 mm or more. When assessing this to the scale of the wetland, 10 mm of rainfall will not cause flooding unless during winter months. 95% of all rain events will amount to a total of 1.5 mm, which again will not influence the wetlands water table much unless during heavy rainfall periods throughout winter months when the ground saturation level is higher and there are fewer sunshine hours in the day.

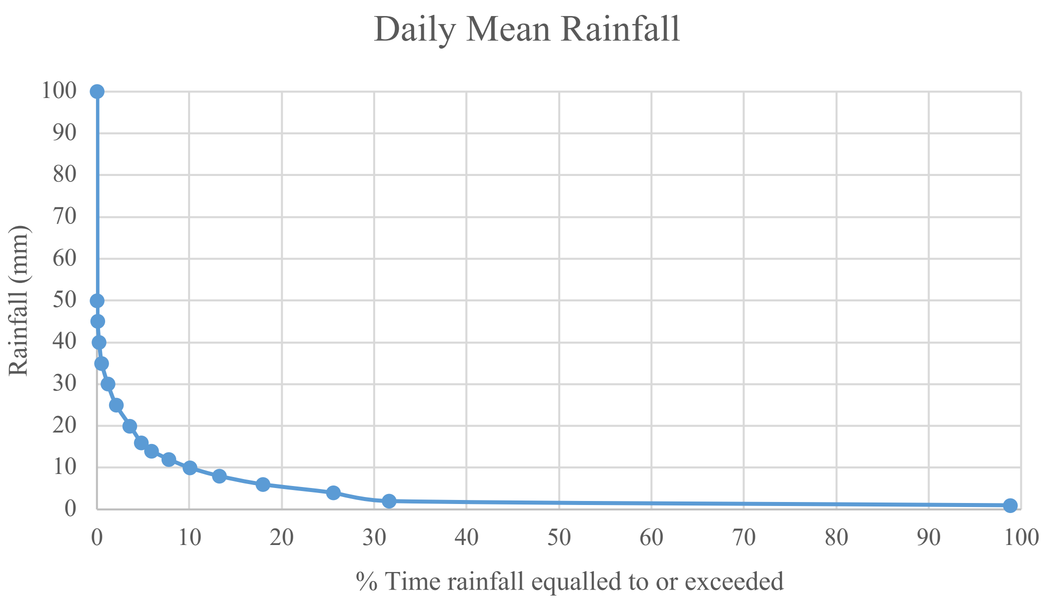

Figure 5.4 Daily mean rainfall graph

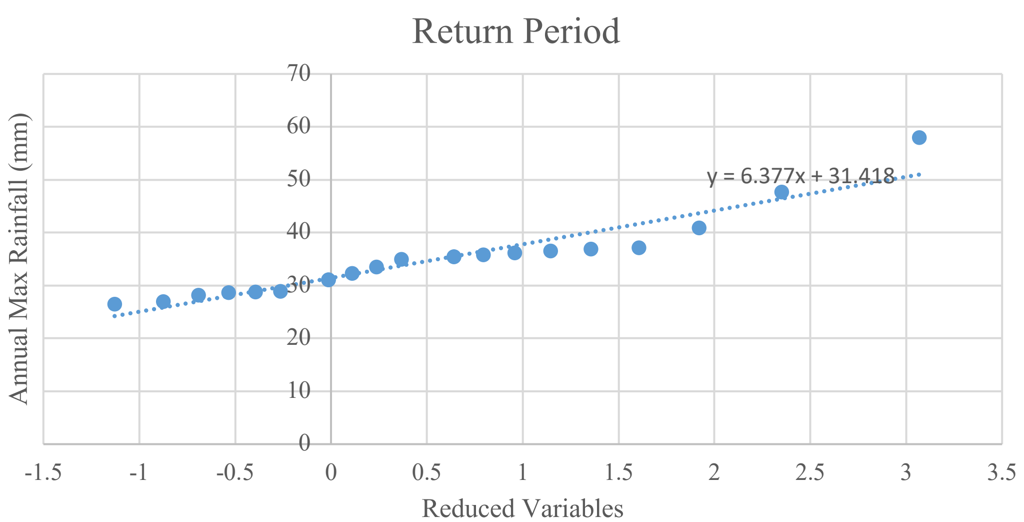

Figure 5.5 Return period graph

Table 5.1 Statistical analysis of figure 5.4, low, median & high rainfall

Time equalled or exceeded (%)	Rainfall (mm)
10 (high rainfall and flooding)	10
50 (median rainfall)	2
95 (low rainfall)	1.5

Table 5.2 Return period analysis of figure 5.5

Return Period (T)	Y	Rainfall (mm)
2	0.366513	33.75525289
3	0.90272	37.17464835
5	1.49994	40.9831173
10	2.250367	45.76859245
15	2.673752	48.46851709
20	2.970195	50.3589351
25	3.198534	51.81505299
50	3.901939	56.30066282
100	4.600149	60.75315162

The return periods display similar trends as the daily mean rainfall data in terms of flooding. A 1 in 100-year flood will result in 60 mm of rainfall, which, during winter months, will cause intense flooding of the wetland due to its 1 m depth and already saturated soils. In comparison, a 1 in 2-year flood is over half of that of a 1 in 100 year. This indicates in a greater range of years; flood events will not go over the depth of 1 m by very much. In such cases where it may, the water from the flooded wetland will run-off to the adjacent lake and also into the ancient woodland by its perimeters.

However, when this data is compared to that of the EA's Cowfold data (table 5.3), the difference in the amount of rainfall after a 1 in 2-year return period increases greatly. The difference in a 1 in 100-year flood between the MET office, Wiggonholt, and EA, Cowfold, data is over 117mm. While this could be related to the difference in location, much of it will be largely due to the anomaly in the EA data during 2011 in which 502.4mm of rainfall occurred in 3 days, with 250mm of the total occurring in 1 day. This is one of the reasons the

EA data was not used for the final design considerations. In terms of daily mean rainfall, data from both stations gave similar results. Rainfall has also greatly increased in terms of amount in single rain events as well as the number of days it does rain due to climate change.

Table 5.3 EA data return period

Return Period (T)	Y	Rainfall (mm)
2	0.366513	40.78901005
3	0.90272	58.07580477
5	1.49994	77.32956523
10	2.250367	101.5225923
15	2.673752	115.1720937
20	2.970195	124.7291246
25	3.198534	132.0905461
50	3.901939	154.7676004
100	4.600149	177.2772109

However, when this data is compared to that of the EA's Cowfold data, the difference in the amount of rainfall after a 1 in 2-year return period increases greatly. The difference in a 1 in 100-year flood between the MET office, Wiggonholt, and EA, Cowfold, data is over 117mm. While this could be related to the difference in location, much of it will be largely due to the anomaly in the EA data during 2011 in which 502.4mm of rainfall occurred in 3 days, with 250mm of the total occurring in 1 day. This is one of the reasons the EA data was not used for the final design considerations. In terms of daily mean rainfall, data from both stations gave similar results. Rainfall has also greatly increased in terms of amount in single rain events as well as the number of days it does rain due to climate change.

5.3 Evapotranspiration

Analysis of the evapotranspiration results illustrate seasonal fluctuations as expected. Rates of evapotranspiration are largest during summer periods and lowest during winter periods, this is due to greater sunshine hours during summer and thus resulting in greater evaporation rates. The wetland will experience droughts during most of the summer months, as the soils will be less saturated if not dry and groundwater tables being lower.

Table 5.5 Monthly mean evapotranspiration values

Months	MET (1981-2010) - PET (adjusted) in mm/month	MET (1998-2010) - PET (adjusted) in mm/month
Jan	14.6046055	16.11038429
Feb	16.01336784	16.25643742
Mar	34.02581135	30.43777108
Apr	55.11509172	49.52489237
May	90.77964211	76.51285824
Jun	119.3093924	100.0880532
Jul	146.2616528	114.8337383
Aug	131.5562561	102.1398177
Sep	86.37087391	73.39301451
Oct	52.02662182	48.94129062
Nov	25.35256532	27.27281155
Dec	14.93526689	16.37356694
Annual	**786.3511478**	**671.8846362**

When comparing the data from different range sets, it can be seen that evotranspiration rates are increasing during winter periods and vice versa during summer periods. This is mainly due to climate change, as during winter months, temperatures have risen, while during summer months transpiration is less as plants will be more likely to hold on to water. Although it might seem contradictory, as an increase in evaporation will lead to an increased amount of water vapour in the air, which in turn should result in more rainfall. According to the Clausius-Clapeyron equation, for every 1C rise in temperature, water vapour in the air increases by 7% (Carbon Brief, 2019). This is explained by the forever shifting weather patterns and several other dynamics, meaning the increased moisture will not fall uniformly throughout the plant. When the results are displayed with average monthly temperatures from both data sets, a clear trend is seen regarding to an increase in mean monthly temperature.

5.4 Water Budget

From the rainfall and evapotranspiration data a water budget can be calculated for the wetland. Both yearly and monthly mean water budgets were calculated, one of which shows the surplus of water annually and the other displaying summer and winter water levels. The annual water budget (table 5.5) shows a surplus of 18.3 mm, this is not to say that there will be a constant depth of 18.3 mm in the wetland, but rather gives an indication of how annual average rainfall is greater than the annual average evapotranspiration. This can be further broken down into monthly segments which give a clearer indication of what type of conditions the wetland will have to face throughout the year.

The monthly water budgets (table 5.6) indicate that the wetland will be near full capacity during winter periods and most likely experience flooding for most of the season. During this time is when wildlife will flourish to its full extent as water will be readily available for flora to grow and fauna to reproduce in.

Table 5.7 Mean monthly water budget.

Data	Amount (mm)
Annual Average Rainfall	74.292831
Annual Average Evotranspiration	55.990386
Difference	**18.302445**

Table 5.9 Mean annual water budget (mm)

Monthly Water budget	
January	94.21315
February	57.40239
March	25.24458
April	0.851578
May	-11.9893
June	-48.741
July	-51.3337
August	-33.9575
September	-22.9636
October	41.79621
November	85.60954
December	83.49702

When a wetland starts to dry up during summer months, the water temperature increases, and dissolved oxygen starts to drop, leading to most fauna evacuating the wetland to survive the dry period. While this may leave the wetland barren, it will also lead to the enrichment of its soils as many plants and animals die and decompose. During this time, it can be seen that there is a shortage of water, this does not mean there will be no water throughout the entire summer period but rather on average. Rainfall will still occur and temporarily and saturate the wetland area for short periods of time.

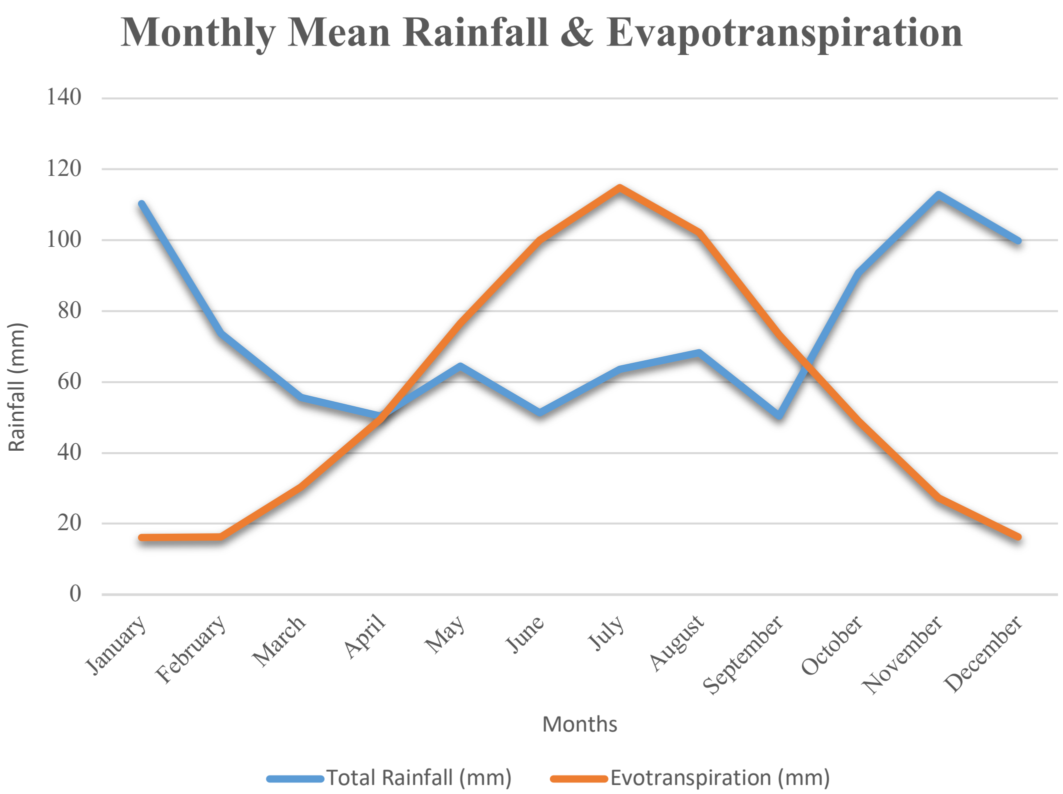

Figure 5.6 Monthly mean rainfall and evotranspiration (2002-2018)

5.5 Flora

The flora hydrological data gathered provides visual insights into their specific requirements. Essentially this data would dictate the design of the wetland in comparison to other factors, as it is the flora which attracts the diverse range of wetland fauna – **"If the vegetation is right, and the disturbance low enough, the animals will be right"** (Haslam, 2003).

Upon cross analysing the native wetland plants of Sussex with the Environment Agency's hydrological data, supply mechanisms were found for several flora species. The data covers a range of requirements such as soil pH, max/min water levels and nutrient necessities. However much of this data, while useful, cannot be fully utilised. This is due to restrictions in the design criteria set by Knepp Estate. Many mechanisms require sluices and other unnatural interventions through pumps and even dams. This again is not in line with Knepp estates needs of the wetland being as natural as possible. Knepp Estate does not want to plant for flora but rather design for a variety and let nature run its own course.

No changes in the soil characteristics can be made, and with half of the requirements being soil based, it proved to be difficult to design accordingly for flora. The greatest differences between flora requirements for each species were soil-based needs, although many of them shared the same hydrological requirements.

Shoreline species all preferred shallow slopes (<20°) and saturated soil or a low water depth. Emergent species prefer fluctuations in water depth and groundwater capillary rise when above the wetland water table. Floating and submerged species all have similar requirements which consist of relatively high wetland water tables and layers of accumulated sediment, in which resting buds of free-floating species can survive dry or cold periods to later germinate in spring.

5.6 Design

Much of the design considerations come from section 3.15, all of which greatly encourages the attraction of different species by designing safe areas for both flora and fauna to reside in. Creating a variety of spaces, which increases the wetland complexity, results in a greater chance of species diversity; which is Knepp estates foremost ambition.

6.0 Proposed Design

The final design proposal has been drawn up and visualised through the use of AutoCAD and ArcGIS tools. Full AutoCAD and ArcGIS drawings and images can be found in the appendix.

6.1 Pond Complexity

6.1.1 Shape

Shifting away from standard shapes produces larger surface areas for wildlife to inhabit and thus increasing the number of species which can migrate to the wetland. Introducing variations in the wetland shape also creates a greater drawdown area, which generates further site richness for wildlife.

Any seeds, spores, eggs and other valuable fragments, which can be transported by winds, will end up in the narrow basins unharmed due to the combination of islands

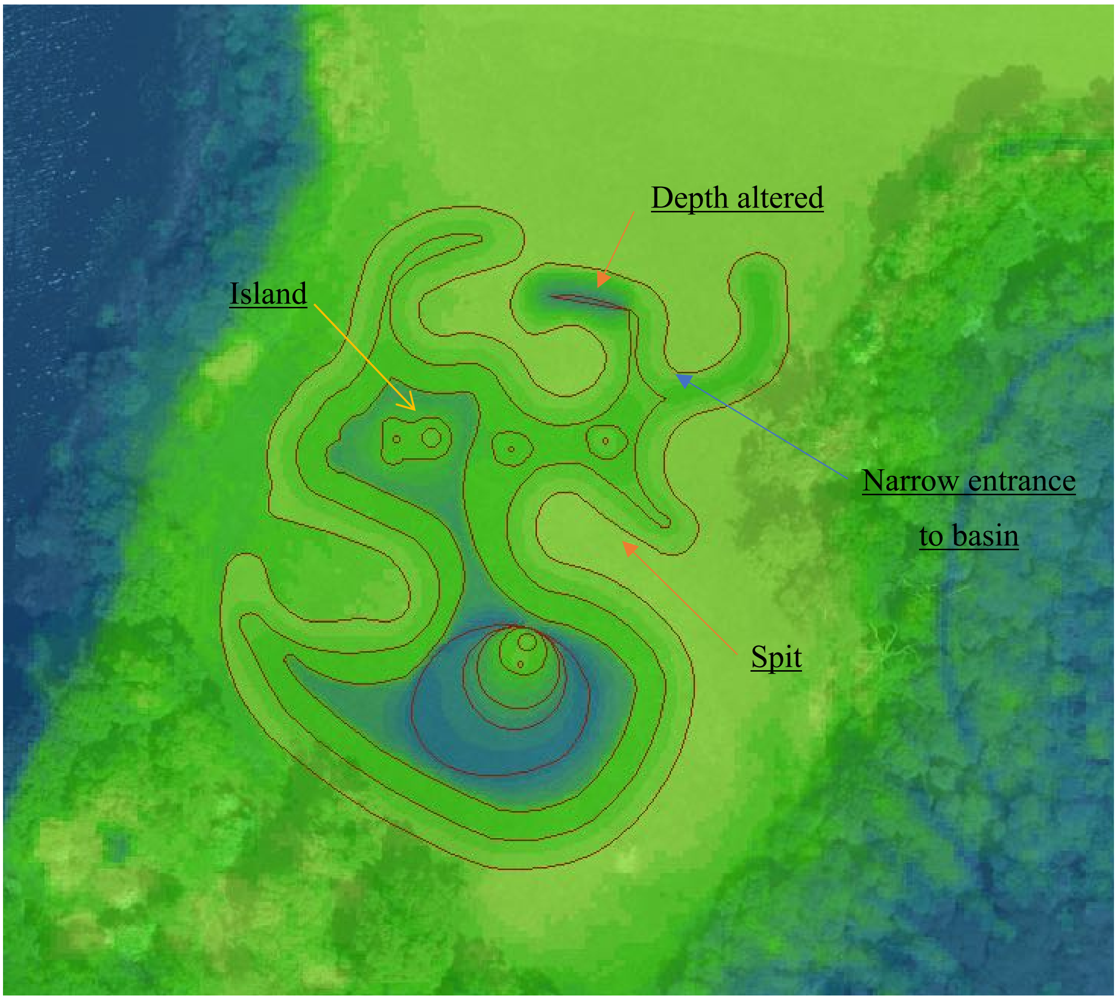

Figure 6.1 Wetland shape and contours

and spits which will slacken wave energy from strong winds. These features will also ensure smooth edged cliffs as high energy waves will erode the banks.

6.1.2 Depths

The use of varying depths creates rich habitats for wildlife. The design has been split into two segments in which one denotes a deeper body of water while the other provides shallow habitats for wildlife. Figure 6.2 shows an east elevation view of the wetland and its varying depths (depths exaggerated for viewing purposes).

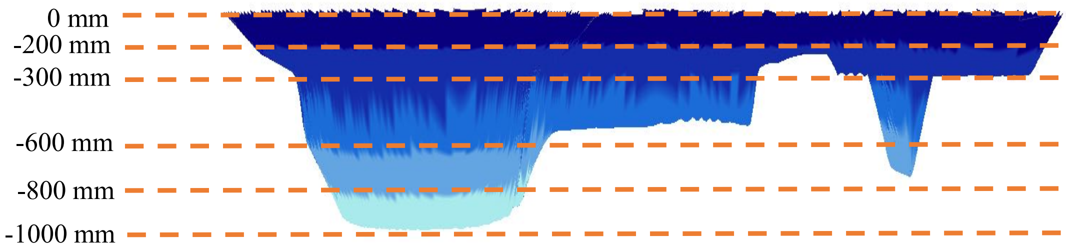

Figure 6.2 Wetland east elevation depths

The different depths will allow distinctive hydrological conditions to exist in the same ecosystem. Not all areas will be inundated at the same or at all times, this offers diverse habitats for both flora and fauna. The depths of the design changed throughout the design process to satisfy deeper habitat areas. Depth of the middle norther basin was altered from 200 mm to 600 mm to increase the diversity in available habitats as the other two basins are only 200 mm deep.

6.1.3 Islands

A total of 4 islands have been placed in the wetland, all of which vary in depth, shape, and size. These islands will provide a safe area for wading birds to feed, roost and nest on. The islands are all have a diameter of less than 1 m to ensure that birds will not congregate in large numbers which could lead to vegetation and water deterioration. Island depths have been chosen carefully as islands which are too high will offer spots for unwanted predators such as crows to feed off small wildlife easily. During winter months, some islands will become inundated and act as a submerged bar which will prove useful for aquatic plants to root in.

The construction process has also been kept in mind when designing the islands by keeping diameters large enough for diggers to be precise while excavating.

6.1.4 Drawdown Zones

The outer rim of the wetland was taken carefully into consideration as it would act as the drawdown zones. Depths decrease a total of 500 mm over lengths of 5 m or more which creates slopes of less than 3° and very extensive shallows.

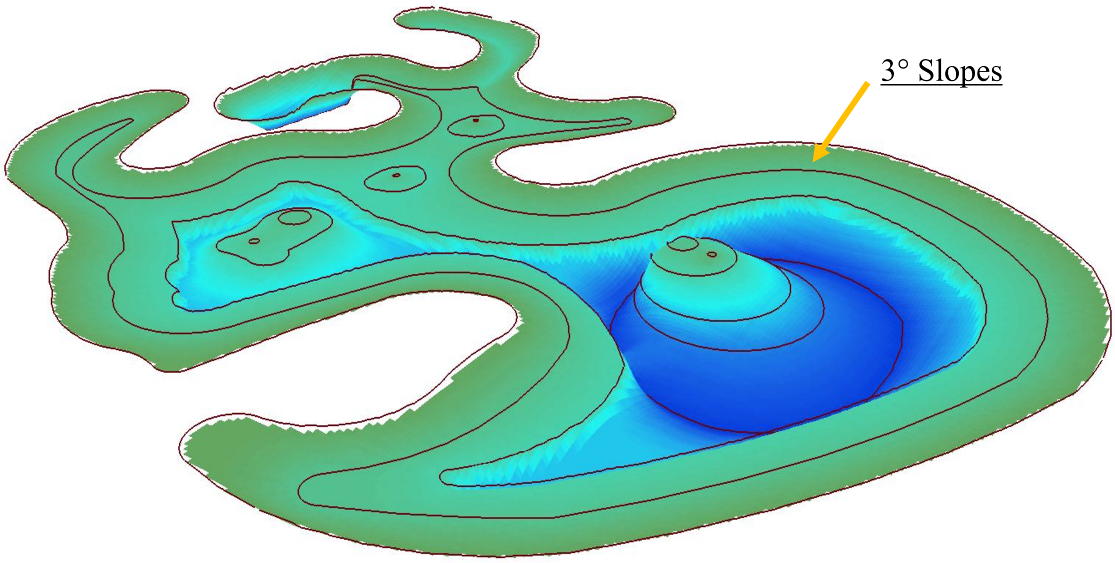

Figure 6.3 3D View of wetland (ArcScene, 2019)

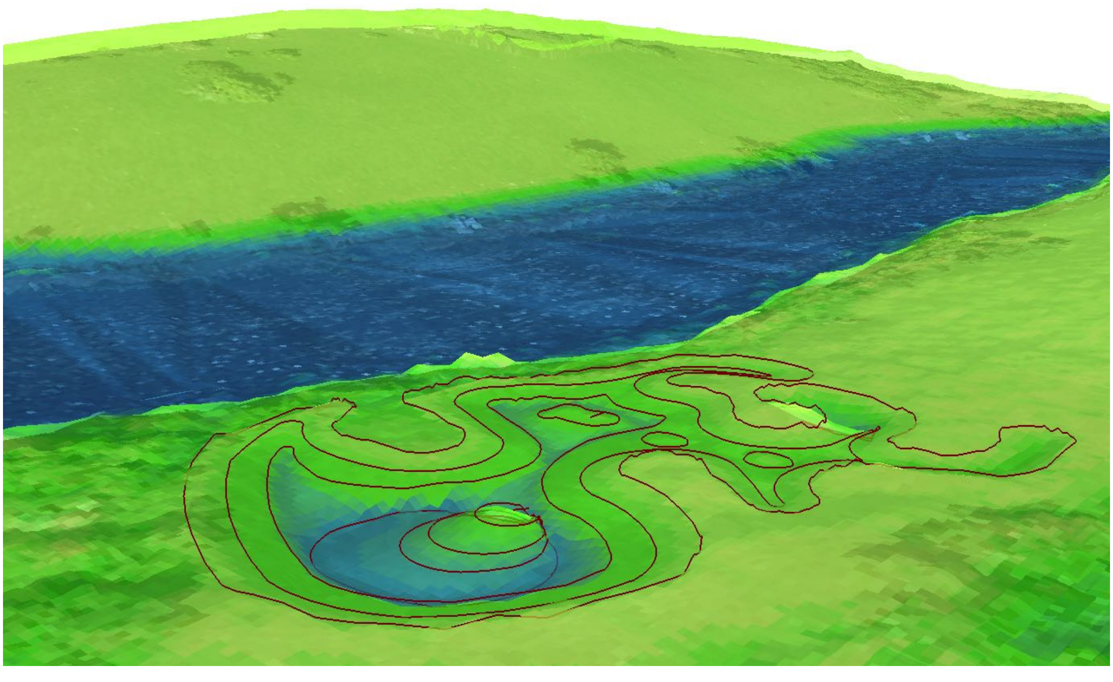

Figure 6.4 3D View of wetland on proposed site (ArcScene, 2019)

6.1.5 Neighbourhood Considerations

The wetlands surrounding were taken into consideration through the design process, distances of 6 -14 m were left around the wetland for people and animals alike on Knepp estate to walk around if desired. This will give the deer on the estate freedom to make use of the wetland just as much as native wetland species.

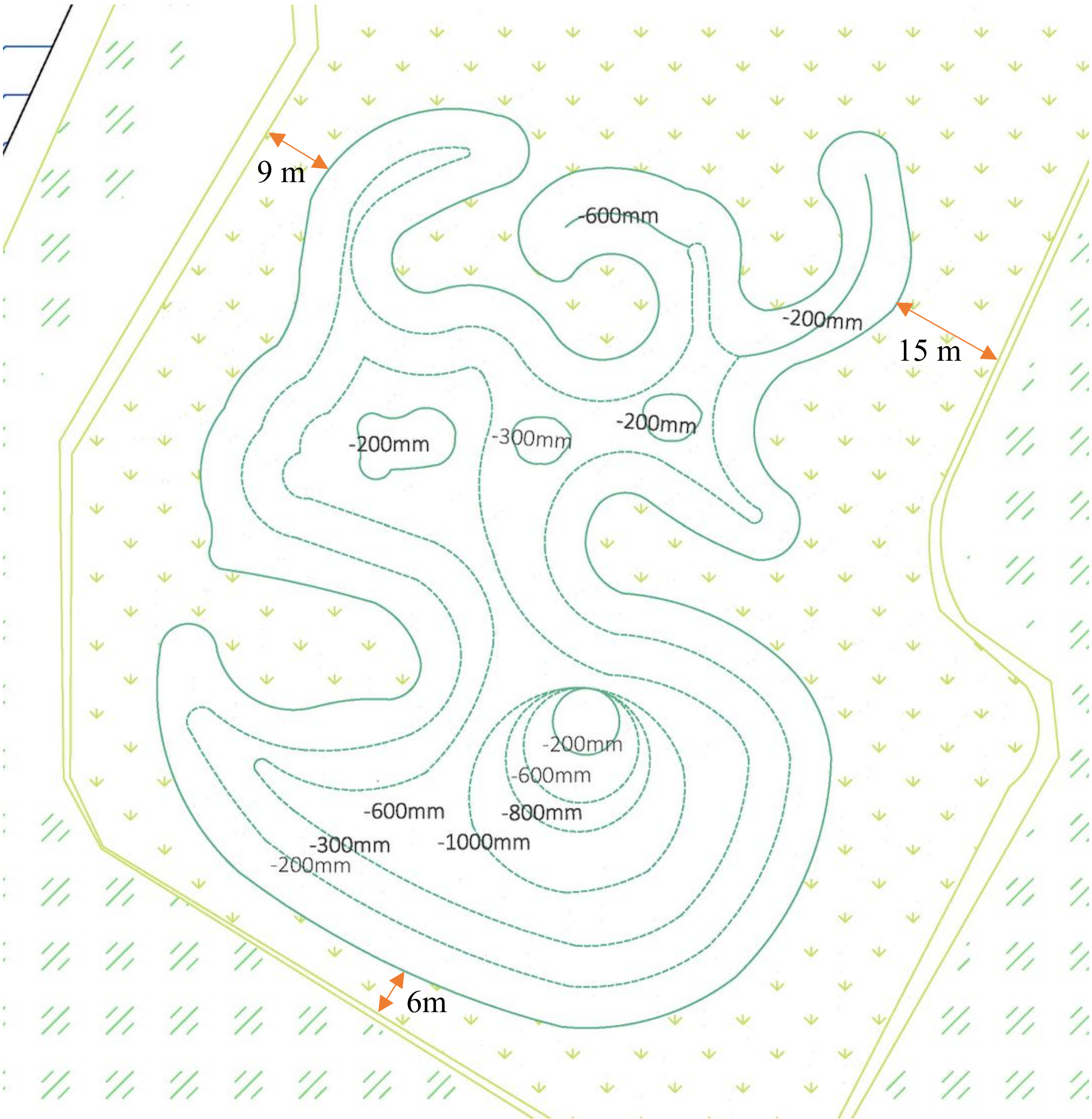

Figure 6.5 Drawing of wetland highlighting edge to neighbouring perimeter distance

More drawings and model render's in Appendix 7.

6.2 Construction

The basics of the construction process have been researched and will be outlined in this section.

6.2.1 Starting Construction

The site should be surveyed for any environmental concerns which may be disrupted by the construction of the wetland. The safety of people and wildlife alike is of utmost paramount as it would be for any construction process. Markings of where to cut and fill should be put in place before any construction takes place as this will lead to fewer errors in the final result. Working on the estate will differ from the usual construction worksite and thus there are many considerations to be taken such as laminating the site plans to protect from mud and water.

6.2.2 Excavation Techniques

While excavation can be carried out both manually and electronically, it is recommended to use tracked excavator. Tracked excavators can lift over a few tonnes and have a range of changeable arm lengths, which will prove useful over the 100 m width site. The tracks also provide stability on slopes and saturated soils and will also cause less damage to surrounding landscapes due to having rubber tracks. Using heavy machinery will provide a much quicker completion without chancing precision errors. Excavation should usually start from the middle of the wetland and work outwards.

Cut and fill data can be found in Appendix 9

6.2.3 Spoil Removal

While spoil disposal should be kept at a minimum, there is not much to do when a large portion of the works consist of cutting rather than filling. The excess spoil could be used to create an embankment at the north head of the wetland to guarantee no pesticide contaminated surface run off will flow into the wetland.

7.0 Discussion

7.1 Findings and Limitations

At the beginning of the project the gravity of the assignment was not fully understood. Wetlands are complex and dynamic ecosystems in which thousands of species regard as home. Several factors come into play when considering the design of a wetland, many of which have not been researched in depth. Research for constructed wetlands which are created for pollutant removal is readily available with relevant equations and considerations. Wetland science itself is relatively young. For wetlands similar to a proposal such as this, research data is scarce. This may be due to the limiting factors which apply when comparing such a wetland to the usual constructed wetland such as flora supply mechanisms. Factors which do apply, such as rainfall, evapotranspiration and groundwater, were constricted in terms of design aid due to requirements set by Knepp estate (no inlet/outlet and 1 m depth). Due to this the interim report differs greatly from the final report.

While the analysis of rainfall helped understand situations the wetland may face, it did not assist in much else. Water budgets and other hydrological analysis should aid in sizing a wetland. Yet once again due to strict requirements not much could have been done from the data which was analysed. There were several methods to analyse rainfall and estimate evapotranspiration, but no methods or equations to easily estimate or analyse groundwater levels without having the required instruments to measure groundwater data through site tests.

Furthermore, it has illustrated the impacts of climate change directly through analysis of weather and temperature data, and how it affects hydrogeological systems. In a world with growing concern towards the issue, there is still much to be done in resolving the matter. A majority of the world recognises the change but cannot grasp the extent of its effects. Upon analysing rainfall and evapotranspiration, clear trends show the dynamic effects of global warming on rainfall duration, depth and average temperature readings. With rainfall depth increasing during single rainfall events, along with the small increase in number of events, the threats to wildlife posed are greater than ever. In the instance of the proposed wetland, annual rainfall increases such as the ones mentioned above, will eventually result in the ancient woodland becoming overly saturated and possibly leading to the destruction of several wildlife habitats. Moreover, if flows are high enough, the surface flow of run-offs may change and direct elsewhere, leading to pesticide infiltration from the polo pitch in unwanted areas.

7.2 Similar Work

Once again, when comparing to pollutant removal wetlands, wetlands such as this have limited reports and guidelines. The million ponds project is the only available resource from which an extensive guide can be attained to aid in the design of this wetland. No other research papers or information exist in depth, or are not publicly available, in this field of wetland science. If this report is made public, then it may belong to a miniscule category of already available reports, if not the first.

7.3 Recommendations

The design process, which was investigated throughout this project, has allowed the development of a much greater understanding of wetland hydrology and sciences. From both an engineering and GIS point of view.

While there are several ways to further this research, attention towards the instant enhancement of this project should be addressed first given the additional time and resources. Basic improvements such as further site analysis to better understand the hydrology of the catchment is of utmost priority. Such tests will give a better insight towards groundwater tables and soil permeability.

Due to the insufficient flora data publicly available, scouting Knepp Estate and curating a catalogue of flora and their environments would lead to a better understanding of what their hydrological requirements are, and how to design accordingly. This would also result in gaining an understanding of fauna and which native flora they tend to reside by or are attracted to. Such data does exist, but not for specific sites but rather on regional or national scales.

8.0 Conclusion

Wetlands are ancient hydrogeological systems which host dynamic conditions and should be considered as prized national assets. Their biological and monetary significance are extraordinarily compromised by both human action and environmental influences. Combatting their degradation and promoting their authority on ecological improvement should be of utmost importance to the world. With wetland science being relatively young when compared to other fields, it serves as an exciting prospect to further develop, recreate and construct new and existing wetlands.

In terms of the project, the initial timeline did not go as planned due to obstacles during the research and difficulties with resources. To evaluate the aims of the project they are as follows:

1. Conduct extensive research behind wetland hydrology and science.
2. Undertake site tests to evaluate site conditions.
3. Complete a design proposal.

Of the three project aims, all were completed to their full extent and further. The research stage obtained results which were not expected at the beginning of the project, but instead offered a different insight overall. Understanding the different types of wetland at first seemed a hindrance, but later became a constructive challenge. Site tests were completed and returned practical results which could be analysed for the design. While some data that was required was incomplete, it did not result in the incompletion of the project and goes to show that for any venture all the data required will never be available. However, data can only grow, meaning when a similar project to this is picked up again it can only develop further. The final design proposal is considered to be the best possible solution to Knepp estates requirements, as not only is it designed to reach a high level of biodiversity, it also offers atheistic value to the site.

While this project started with the sole aim to deliver a design for a wetland, it ended with the hope of curating an in depth contemporary natural wetland design guideline to promote wetland restoration globally.

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10.0 Appendicies

1. Appendix 1 – Sussex Flora (Southgate, 2012)
2. Appendix 2 – Sussex Flora from Sussex Wildlife Trust
3. Appendix 3 – DGPS Survey Points
4. Appendix 4 – Laser Particle Analyser Results
5. Appendix 5 – Wentworth Classification (Planetary.org, 2019)
6. Appendix 6 – Soil Texture Triangle
7. Appendix 7 – CAD Drawing
8. Appendix 8 – Final Renders
9. Appendix 9 – Cut and Fill data

10.1 Sussex Flora (Southgate, 2012)

Scientific name	Common name	Status
Baldellia ranunculoides	Lesser Water-plantain	Near Threatened
Blysmus compressus	Flat-sedge	Vulnerable
Carex vulpina	True Fox-sedge	Vulnerable
Cyperus longus	Galingale	Near Threatened
Dactylorhiza incarnata ssp. incarnata	Early Marsh-orchid	Waiting list
Dactylorhiza incarnata ssp. pulchella	Early Marsh-orchid	Waiting list
Groenlandia densa	Opposite-leaved Pondweed	Vulnerable
Gymnadenia densiflora	Marsh Fragrant-orchid	Data Deficient
Hydrocharis morsus-ranae	Frogbit	UK Vulnerable but common in Sussex
Leersia oryzoides	Cut-grass	Endangered, Schedule 8
Myriophyllum verticillatum	Whorled Water-milfoil	Vulnerable
Oenanthe fistulosa	Tubular Water-dropwort	Vulnerable
Oenanthe silaifolia	Narrow-leaved Water-dropwort	Near Threatened
Persicaria minor	Small Water-pepper	Vulnerable
Potamogeton acutifolius	Sharp-leaved Pondweed	Critically Endangered
Ranunculus tripartitus	Three-lobed Crowfoot	Endangered
Ruppia cirrhosa	Spiral Tasselweed	Near Threatened
Schoenoplectus x kuekenthalianus	A hybrid Club-rush	Vulnerable
Sium latifolium	Greater Water-parsnip	Endangered
Stellaria palustris	Marsh Stitchwort	Vulnerable
Wolffia arrhiza	Rootless Duckweed	Vulnerable

10.2 Sussex Flora from Sussex Wildlife Trust

A. **Shoreline Plants** – Split into two categories:

Shoreline (Marginal)	**Marsh or bog plants**
Water forget-me-not (*Myositis scorpioides*)	Purple loosestrife (*Lythrum salicaria*)
Water mint (*Mentha aquatica*)	Ragged robin (*Lychnis flos-cuculi*)
Water speedwell (*Veronica anagallis-aquatica*)	Pendulous sedge (*Carex pendula*)
Marsh marigold (*Caltha palustris*)	Marsh woundwort (*Stachys palustris*)
Water forget-me-not (*Myositis scorpioides*)	Cuckooflower (*Cardamine pratensis*)

B. **Emergent Plants**

- Branched bur-reed (*Sparganium erectum*)
- Bogbean (*Menyanthes trifoliata*)
- Greater spearwort (*Ranunculus lingua*)
- Greater pond sedge (*Carex riparia*)
- Small sweet grass (*Glyceria fluitans*)

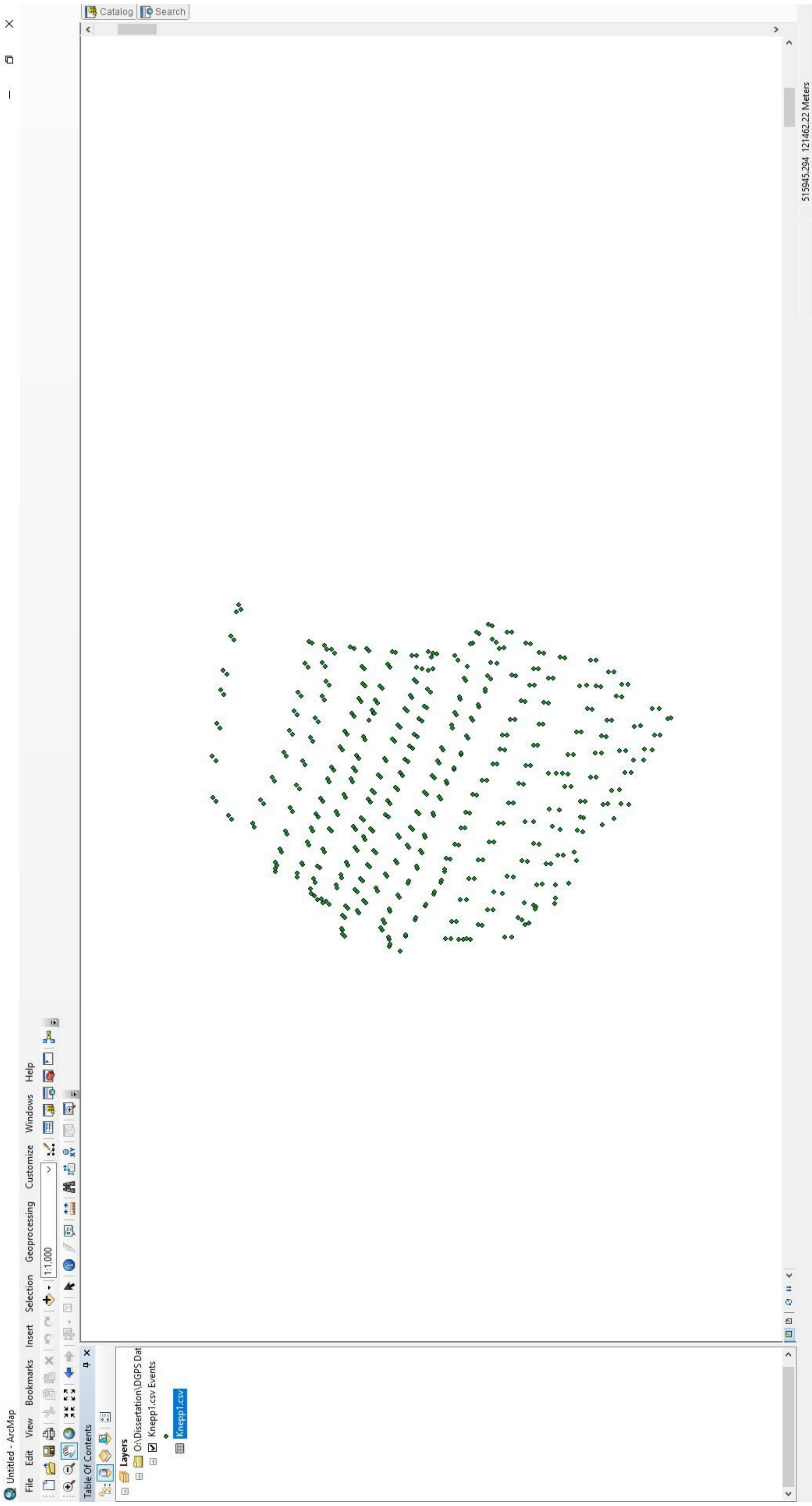
C. **Floating Plants**

- Amphibious bistort (*Polyginum amphibium*)
- Frogbit (*Hydrocharis morsus-ranae*)
- Broad-leaved pondweed (*Potamogeton natans*)

D. **Submerged Plants**

- Curled pondweed (*Potamogeton crispus*)
- Rigid hornwort (*Ceratophyllum demersum*)
- Water crowfoot (*Ranunculus aquatilis*)
- Common water starwort (*Callitriche stagnalis*)
- Spiked water milfoil (*Myriophyllum spicatum*) - Do not accidentally use *M. aquaricum,* known as Parrot's feather, which is non-native and extremely invasive.

10.3 DGPS Survey Points



10.4 Laser Particle Analyser Results

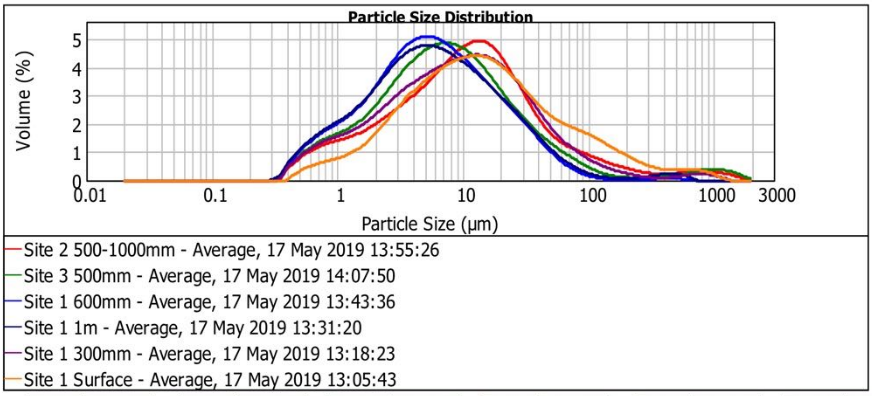
MALVERN INSTRUMENTS

MASTERSIZER 2000

Result Analysis Report

Sample Name: Site 1 Surface - Average	**SOP Name:** Basic Ultrasonics	**Measured:** 17 May 2019 13:05:43	
Sample Source & type:	**Measured by:** jc670	**Analysed:** 17 May 2019 13:05:45	
Sample bulk lot ref:	**Result Source:** Averaged		
Particle Name: Silica 0.1	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.544	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 15.48 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 0.852 %	**Result Emulation:** Off
Concentration: 0.0134 %Vol	**Span :** 7.901	**Uniformity:** 3.17	**Result units:** Volume
Specific Surface Area: 1.05 m²/g	**Surface Weighted Mean D[3,2]:** 5.726 um	**Vol. Weighted Mean D[4,3]:** 47.908 um	

d(0.1): 2.366 um **d(0.5): 13.276 um** **d(0.9): 107.254 um**



Size (µm)	Volume In %
0.020	
	0.00
0.060	
	18.39
3.900	
	16.60
7.800	
	19.64
15.600	
	17.39
31.000	
	11.75
63.000	
	7.73
125.000	
	4.66
250.000	
	2.09
500.000	
	1.58
1000.000	
	0.18
2000.000	

MASTERSIZER 2000

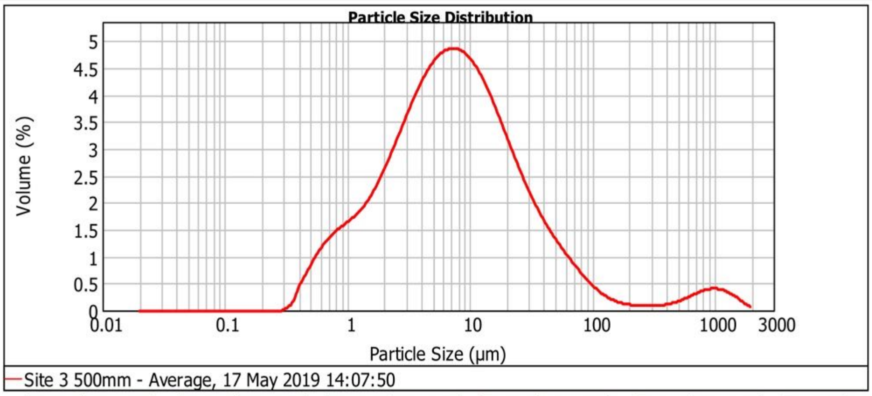
Result Analysis Report

Sample Name: Site 3 500mm - Average	**SOP Name:** Basic Ultrasonics	**Measured:** 17 May 2019 14:07:50
Sample Source & type:	**Measured by:** jc670	**Analysed:** 17 May 2019 14:07:52
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Silica 0.1	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.544	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 14.70 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.262 %	**Result Emulation:** Off

Concentration: 0.0080 %Vol	**Span :** 5.627	**Uniformity:** 5.4	**Result units:** Volume
Specific Surface Area: 1.79 m²/g	**Surface Weighted Mean D[3,2]:** 3.349 um	**Vol. Weighted Mean D[4,3]:** 41.965 um	

d(0.1): 1.269 um **d(0.5): 7.165 um** **d(0.9): 41.588 um**



Size (μm)	Volume In %
0.020	
	0.00
0.060	
	31.56
3.900	

Size (μm)	Volume In %
3.900	
	21.15
7.800	
	20.31
15.600	

Size (μm)	Volume In %
15.600	
	13.39
31.000	
	7.12
63.000	

Size (μm)	Volume In %
63.000	
	2.72
125.000	
	0.68
250.000	

Size (μm)	Volume In %
250.000	
	0.47
500.000	
	1.40
1000.000	

Size (μm)	Volume In %
1000.000	
	1.22
2000.000	

Operator notes:

Malvern Instruments Ltd. Malvern, UK Tel := +[44] (0) 1684-892456 Fax +[44] (0) 1684-892789	Mastersizer 2000 Ver. 5.60 Serial Number : MAL100857	File name: SAJID Record Number: 24 17/05/2019 14:35:32

MASTERSIZER 2000

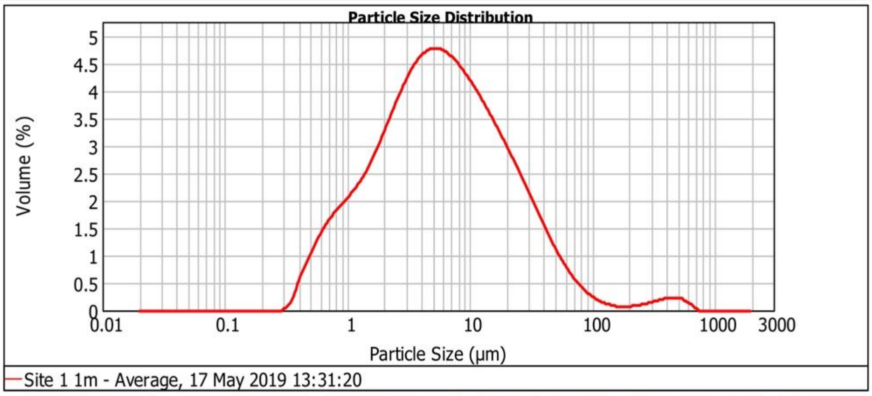
Result Analysis Report

Sample Name: Site 1 1m - Average	**SOP Name:** Basic Ultrasonics	**Measured:** 17 May 2019 13:31:20
Sample Source & type:	**Measured by:** jc670	**Analysed:** 17 May 2019 13:31:22
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Silica 0.1	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.544	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 14.12 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.377 %	**Result Emulation:** Off

Concentration: 0.0065 %Vol	**Span :** 5.114	**Uniformity:** 2.46	**Result units:** Volume
Specific Surface Area: 2.11 m²/g	**Surface Weighted Mean D[3,2]:** 2.850 um	**Vol. Weighted Mean D[4,3]:** 16.592 um	

d(0.1): 1.074 um **d(0.5): 5.682 um** **d(0.9): 30.133 um**



Size (µm)	Volume In %
0.020	0.00
0.060	38.34
3.900	

Size (µm)	Volume In %
3.900	21.31
7.800	18.22
15.600	

Size (µm)	Volume In %
15.600	12.51
31.000	6.38
63.000	

Size (µm)	Volume In %
63.000	1.66
125.000	0.39
250.000	

Size (µm)	Volume In %
250.000	0.83
500.000	0.35
1000.000	

Size (µm)	Volume In %
1000.000	0.00
2000.000	

Operator notes:

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Malvern, UK
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Mastersizer 2000 Ver. 5.60
Serial Number : MAL100857

File name: SAJID
Record Number: 12
17/05/2019 14:35:32

MASTERSIZER 2000

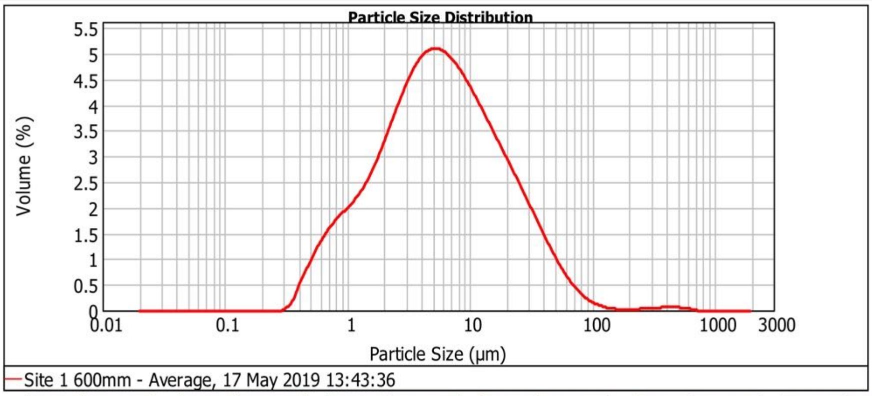
Result Analysis Report

Sample Name: Site 1 600mm - Average	**SOP Name:** Basic Ultrasonics	**Measured:** 17 May 2019 13:43:36
Sample Source & type:	**Measured by:** jc670	**Analysed:** 17 May 2019 13:43:38
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Silica 0.1	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.544	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 14.85 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.351 %	**Result Emulation:** Off

Concentration: 0.0069 %Vol	**Span :** 4.566	**Uniformity:** 1.68	**Result units:** Volume
Specific Surface Area: 2.09 m²/g	**Surface Weighted Mean D[3,2]:** 2.878 um	**Vol. Weighted Mean D[4,3]:** 11.898 um	

d(0.1): 1.109 um **d(0.5): 5.529 um** **d(0.9): 26.358 um**



Size (μm)	Volume In %
0.020	
0.060	0.00
3.900	38.47

Size (μm)	Volume In %
3.900	
7.800	22.71
15.600	18.80

Size (μm)	Volume In %
15.600	
31.000	12.36
63.000	5.99

Size (μm)	Volume In %
63.000	
125.000	1.24
250.000	0.13

Size (μm)	Volume In %
250.000	
500.000	0.23
1000.000	0.08

Size (μm)	Volume In %
1000.000	
2000.000	0.00

Operator notes:

MASTERSIZER 2000

Result Analysis Report

Sample Name:
Site 2 500-1000mm - Average

SOP Name:
Basic Ultrasonics

Measured:
17 May 2019 13:55:26

Sample Source & type:

Measured by:
jc670

Analysed:
17 May 2019 13:55:28

Sample bulk lot ref:

Result Source:
Averaged

Particle Name:
Silica 0.1

Accessory Name:
Hydro 2000G (A)

Analysis model:
General purpose

Sensitivity:
Enhanced

Particle RI:
1.544

Absorption:
0.1

Size range:
0.020 to 2000.000 um

Obscuration:
15.00 %

Dispersant Name:
Water

Dispersant RI:
1.330

Weighted Residual:
1.048 %

Result Emulation:
Off

Concentration:
0.0098 %Vol

Span :
5.842

Uniformity:
3.71

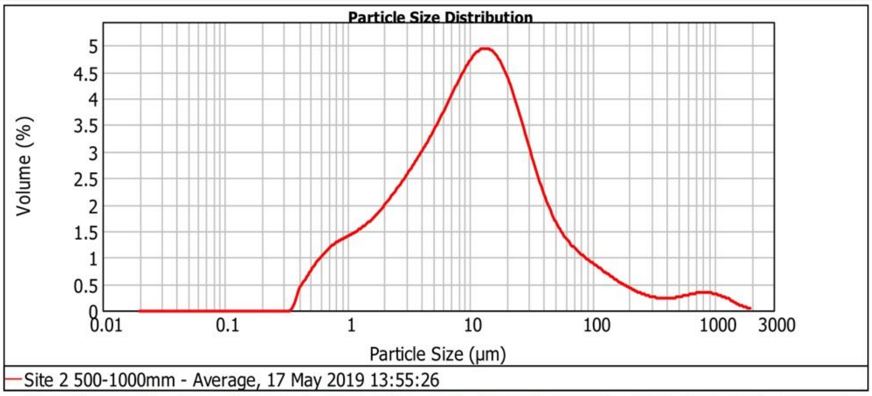
Result units:
Volume

Specific Surface Area:
1.49 m^2/g

Surface Weighted Mean D[3,2]:
4.015 um

Vol. Weighted Mean D[4,3]:
44.047 um

d(0.1): 1.458 um **d(0.5): 10.655 um** **d(0.9): 63.696 um**



Size (μm)	Volume In %
0.020	
0.060	0.00
3.900	24.45

Size (μm)	Volume In %
3.900	
7.800	16.25
15.600	21.54

Size (μm)	Volume In %
15.600	
31.000	18.33
63.000	9.34

Size (μm)	Volume In %
63.000	
125.000	4.46
250.000	2.31

Size (μm)	Volume In %
250.000	
500.000	1.14
1000.000	1.41

Size (μm)	Volume In %
1000.000	
2000.000	0.77

Operator notes:

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Mastersizer 2000 Ver. 5.60
Serial Number : MAL100857

File name: SAJID
Record Number: 20
17/05/2019 14:35:32

MASTERSIZER 2000

Result Analysis Report

Sample Name:
Site 3 500mm - Average

SOP Name:
Basic Ultrasonics

Measured:
17 May 2019 14:07:50

Sample Source & type:

Measured by:
jc670

Analysed:
17 May 2019 14:07:52

Sample bulk lot ref:

Result Source:
Averaged

Particle Name:
Silica 0.1

Accessory Name:
Hydro 2000G (A)

Analysis model:
General purpose

Sensitivity:
Enhanced

Particle RI:
1.544

Absorption:
0.1

Size range:
0.020 to 2000.000 um

Obscuration:
14.70 %

Dispersant Name:
Water

Dispersant RI:
1.330

Weighted Residual:
1.262 %

Result Emulation:
Off

Concentration:
0.0080 %Vol

Span :
5.627

Uniformity:
5.4

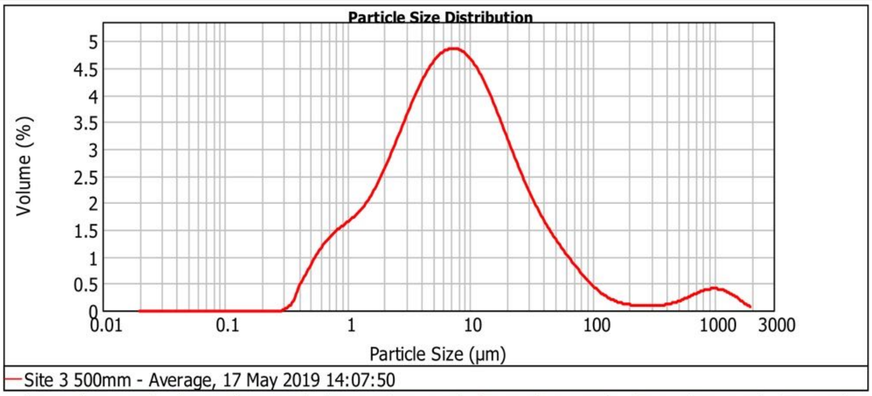
Result units:
Volume

Specific Surface Area:
1.79 m²/g

Surface Weighted Mean D[3,2]:
3.349 um

Vol. Weighted Mean D[4,3]:
41.965 um

d(0.1): 1.269 um **d(0.5): 7.165 um** **d(0.9): 41.588 um**



Size (μm)	Volume In %
0.020	
0.060	0.00
3.900	31.56

Size (μm)	Volume In %
3.900	
7.800	21.15
15.600	20.31

Size (μm)	Volume In %
15.600	
31.000	13.39
63.000	7.12

Size (μm)	Volume In %
63.000	
125.000	2.72
250.000	0.68

Size (μm)	Volume In %
250.000	
500.000	0.47
1000.000	1.40

Size (μm)	Volume In %
1000.000	
2000.000	1.22

Operator notes:

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Malvern, UK
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Mastersizer 2000 Ver. 5.60
Serial Number : MAL100857

File name: SAJID
Record Number: 24
17/05/2019 14:35:32

MASTERSIZER 2000

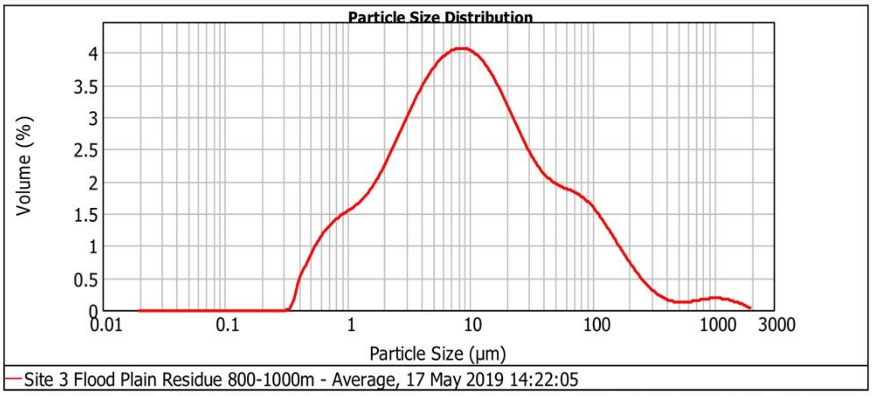
Result Analysis Report

Sample Name: Site 3 Flood Plain Residue 800-1000m	**SOP Name:** Basic Ultrasonics	**Measured:** 17 May 2019 14:22:05
Sample Source & type:	**Measured by:** jc670	**Analysed:** 17 May 2019 14:22:07
Sample bulk lot ref:	**Result Source:** Averaged	

Particle Name: Silica 0.1	**Accessory Name:** Hydro 2000G (A)	**Analysis model:** General purpose	**Sensitivity:** Enhanced
Particle RI: 1.544	**Absorption:** 0.1	**Size range:** 0.020 to 2000.000 um	**Obscuration:** 14.80 %
Dispersant Name: Water	**Dispersant RI:** 1.330	**Weighted Residual:** 1.142 %	**Result Emulation:** Off

Concentration: 0.0090 %Vol	**Span :** 9.283	**Uniformity:** 3.95	**Result units:** Volume
Specific Surface Area: 1.63 m²/g	**Surface Weighted Mean D[3,2]:** 3.688 um	**Vol. Weighted Mean D[4,3]:** 41.037 um	

d(0.1): 1.320 um **d(0.5): 9.404 um** **d(0.9): 88.612 um**



Size (µm)	Volume In %
0.020	
	0.00
0.060	
	27.73
3.900	

Size (µm)	Volume In %
3.900	
	17.31
7.800	
	17.80
15.600	

Size (µm)	Volume In %
15.600	
	13.53
31.000	
	9.61
63.000	

Size (µm)	Volume In %
63.000	
	7.50
125.000	
	4.12
250.000	

Size (µm)	Volume In %
250.000	
	1.14
500.000	
	0.67
1000.000	

Size (µm)	Volume In %
1000.000	
	0.58
2000.000	

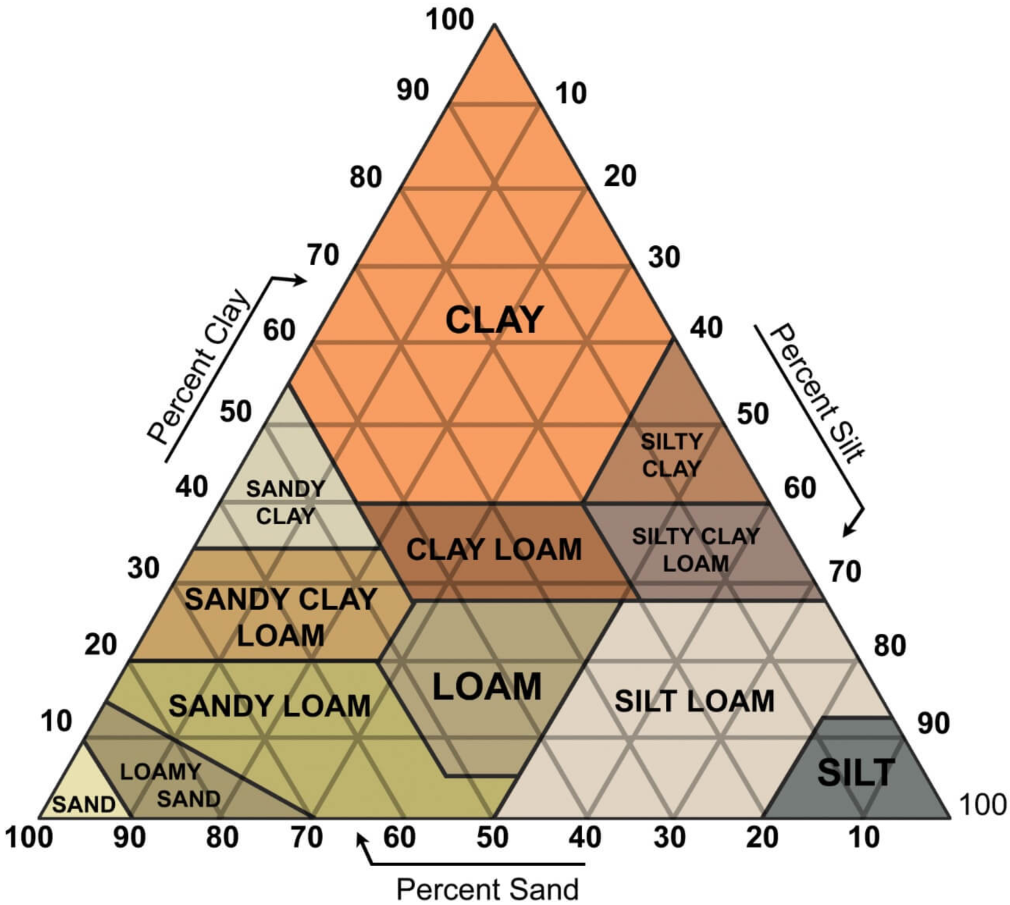
Operator notes:

10.5 Wentworth Classification (Planetary.org, 2019)

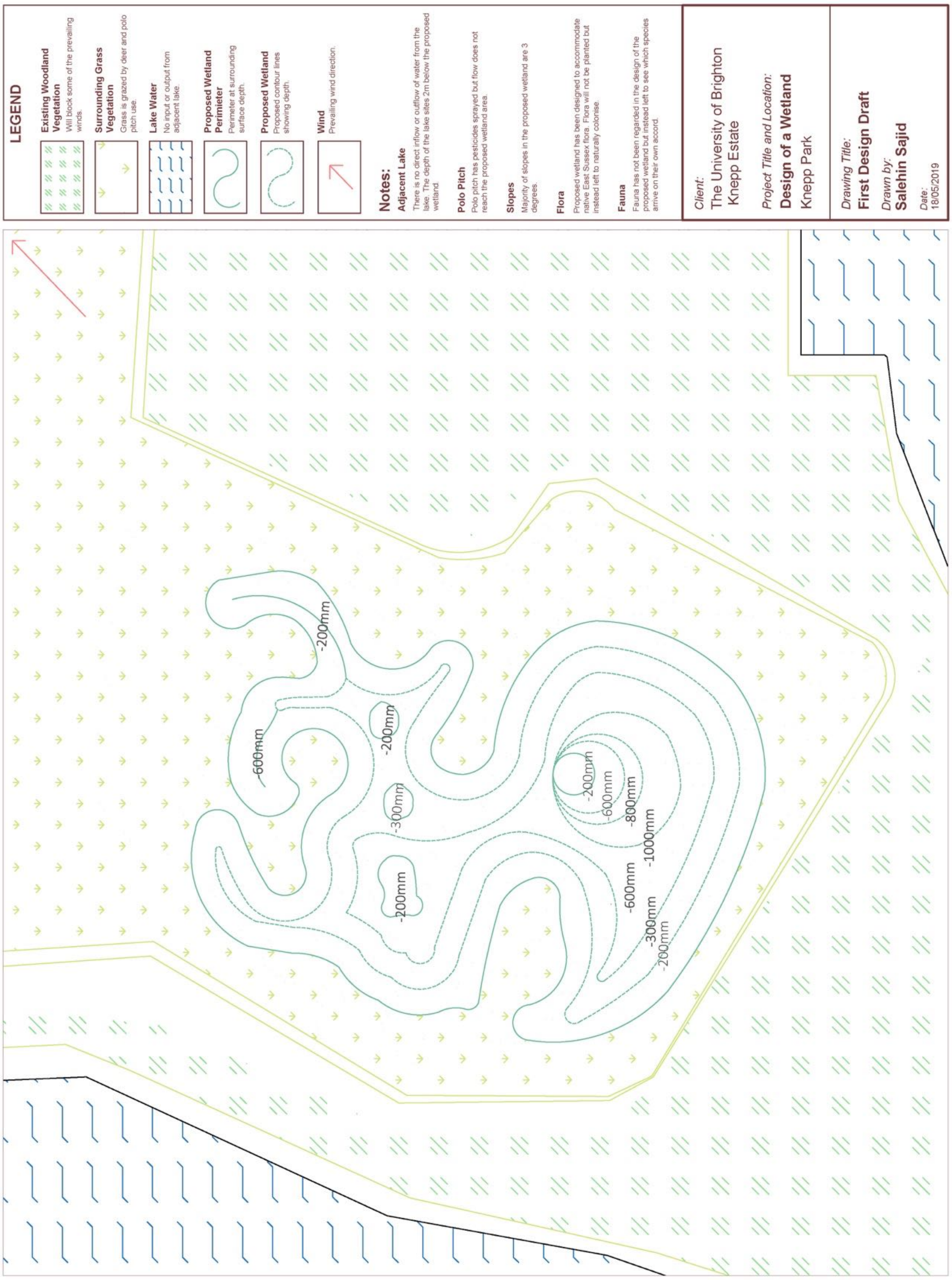
Millimeters (mm)		Micrometers (µm)	Phi (ϕ)	Wentworth size class	
	4096		-12.0	Boulder	Gravel
	256		-8.0	Cobble	Gravel
	64		-6.0	Pebble	Gravel
	4		-2.0	Granule	Gravel
	2.00		-1.0	Very coarse sand	Sand
	1.00		0.0	Coarse sand	Sand
1/2	0.50	500	1.0	Medium sand	Sand
1/4	0.25	250	2.0	Fine sand	Sand
1/8	0.125	125	3.0	Very fine sand	Sand
1/16	0.0625	63	4.0	Coarse silt	Silt
1/32	0.031	31	5.0	Medium silt	Silt
1/64	0.0156	15.6	6.0	Fine silt	Silt
1/128	0.0078	7.8	7.0	Very fine silt	Silt
1/256	0.0039	3.9	8.0	Clay	Mud
	0.00006	0.06	14.0		

10.6 Soil Texture Triangle

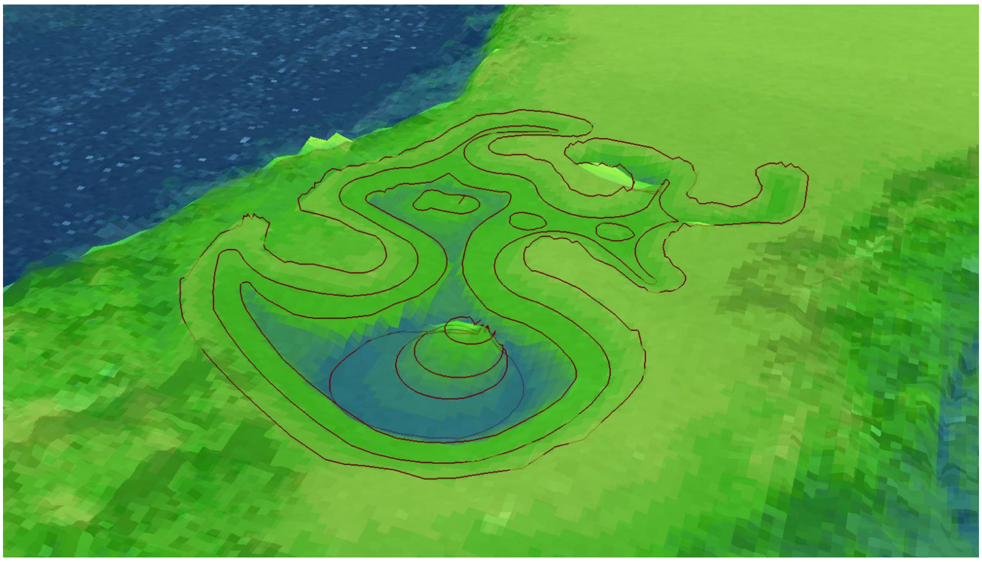
https://soilsensor.com/articles/soil-textures/

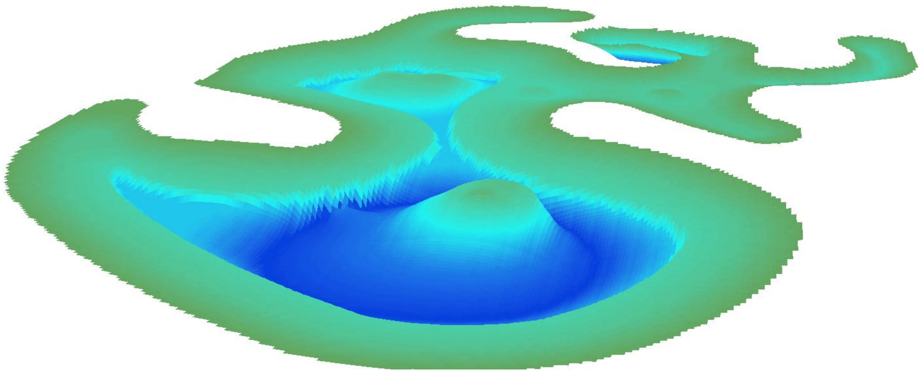


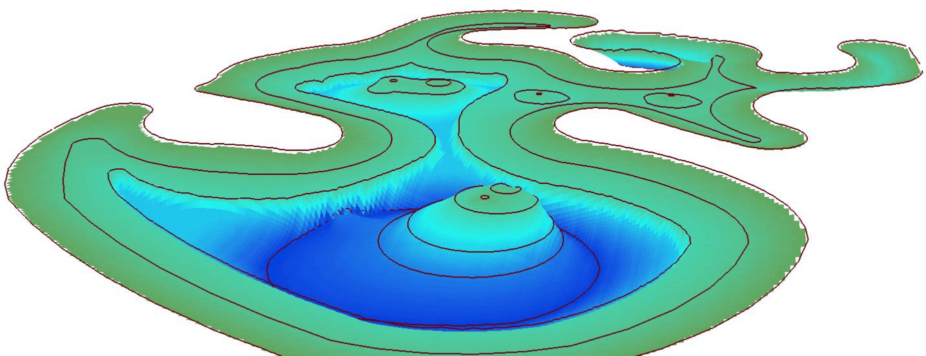
10.7 CAD Drawing

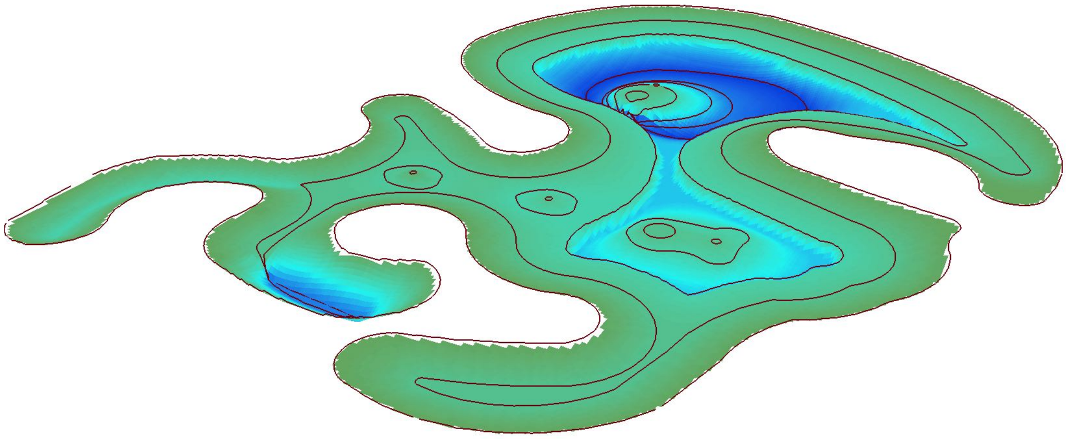


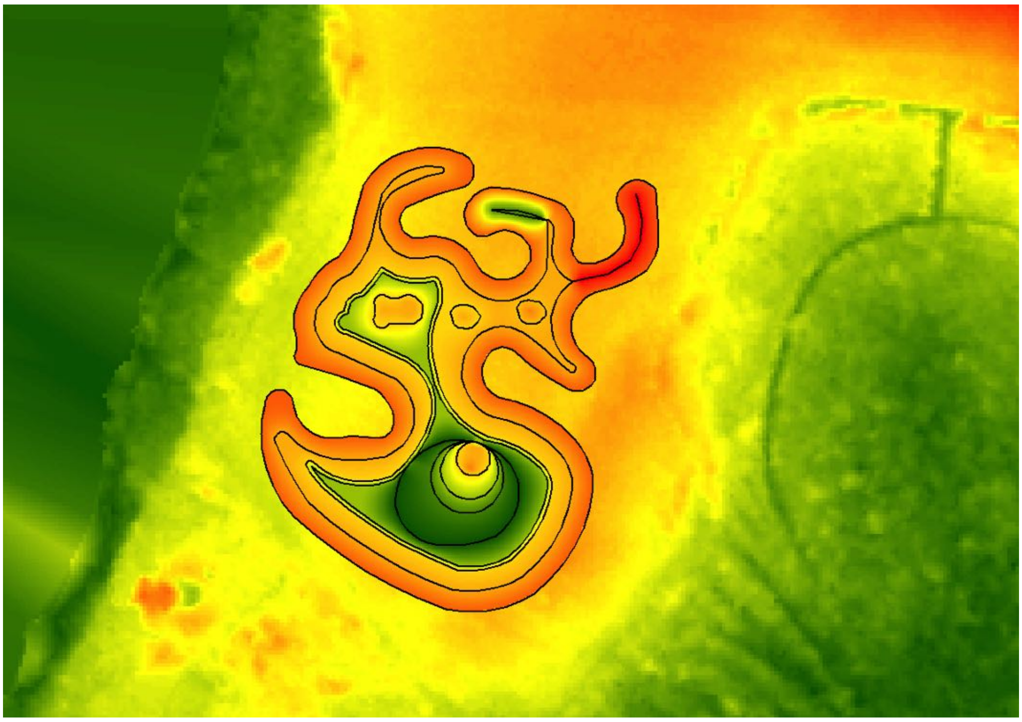
10.8 Final Renders of Proposed Design

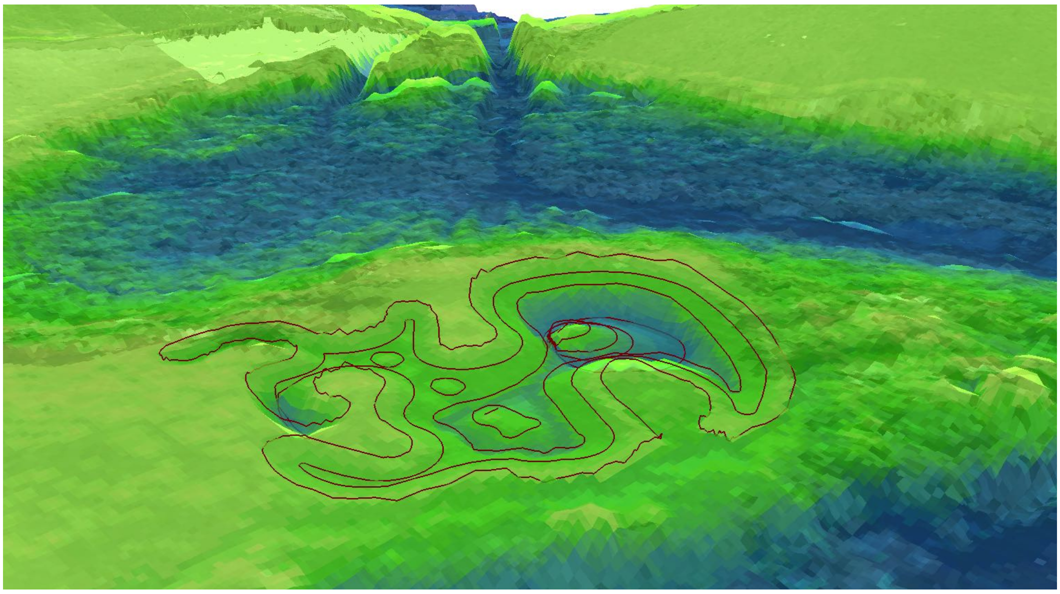


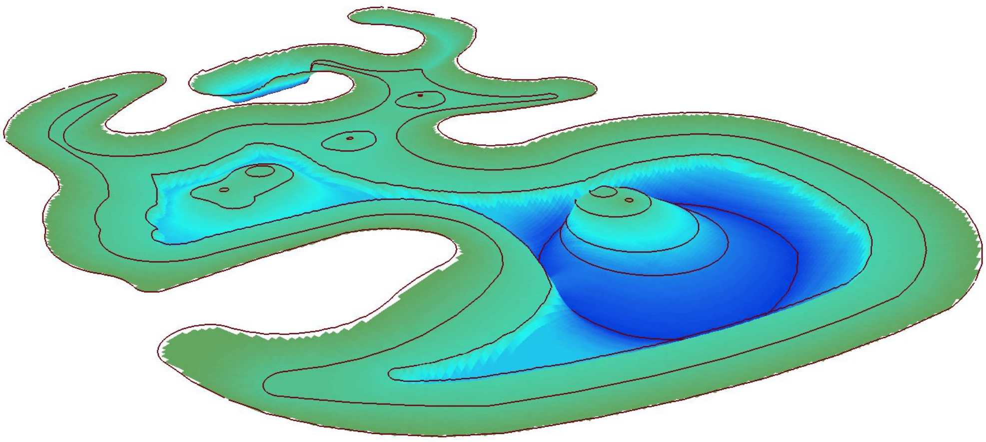












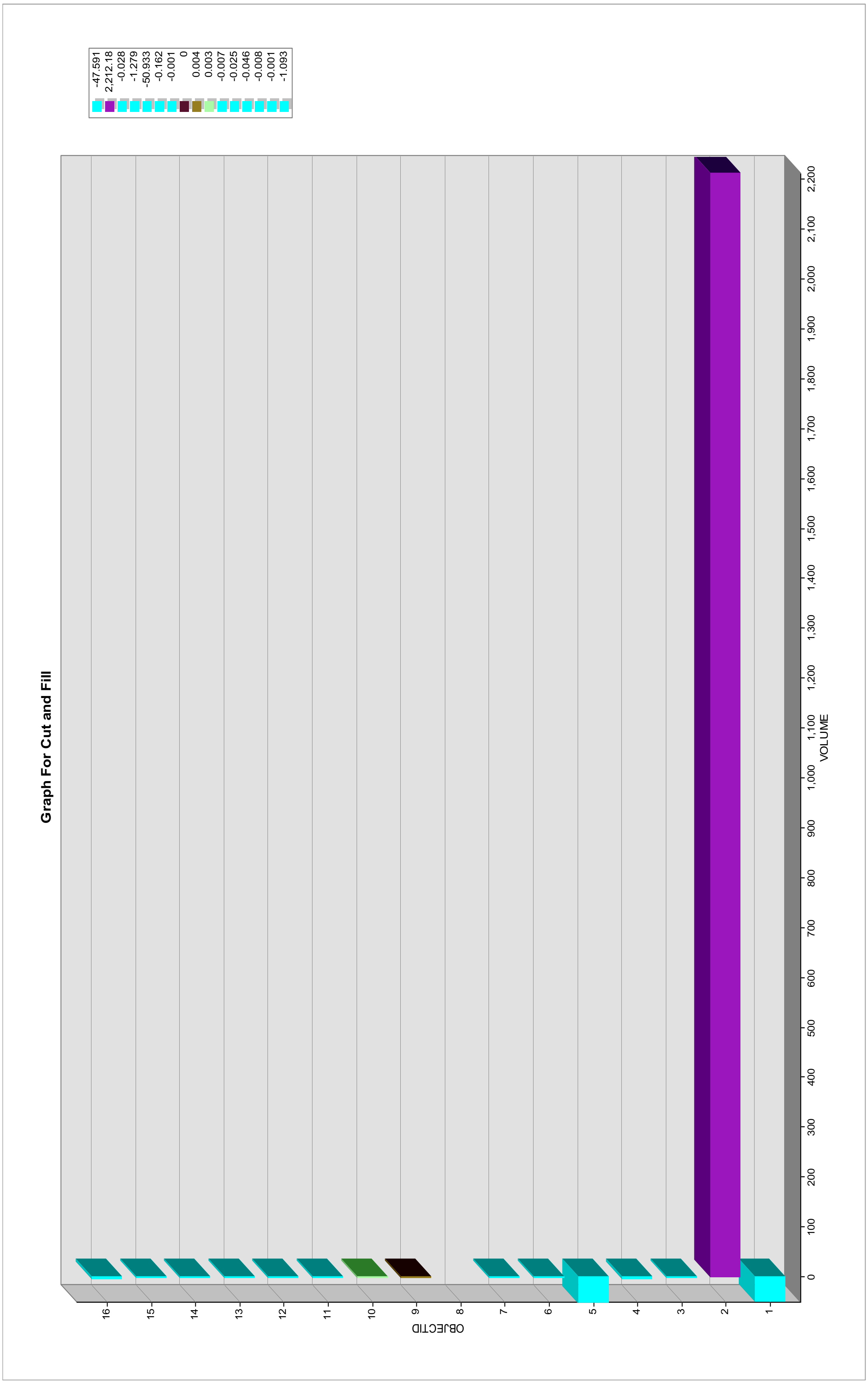
10.9 Cut and Fill

Purple areas cut.

Blue areas fill.

Total cut: 2212.18 m^2

Total fill: 101.174 m^2



Graph For Cut and Fill
-47.591
2,212.18
-0.028
-1.279
-50.933
-0.162
-0.001
0
0.004
0.003
-0.007
-0.025
-0.046
-0.008
-0.001
-1.093
OBJECTID
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
VOLUME
0
100
200
300
400
500
600
700
800
900
1,000
1,100
1,200
1,300
1,400
1,500
1,600
1,700
1,800
1,900
2,000
2,100
2,200