



WATER DESIGN ENGINEERS

————— Pioneering —————

CONSTRUCTED WETLAND DESIGN & SPECIFICATION

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1 Introduction

The client Gladman Estates (GE) intends to construct a nutrient mitigation wetland to treat the water from the Aberderfyn stream on land off Bangor Road, Johnstown, Wrexham, Wales. Water Design Engineers (WDE) has been appointed by the client to undertake the design and specification of the wetland, as required to support the necessary planning application.

The purpose of the off-line constructed wetland is to reduce a prescribed load of phosphorus (TP), in terms of kg/yr, from the River Dee catchment in order to offset the nutrient impact of the new development at Johnstown.

Whilst there is no specific requirement for the development to be nutrient neutral, English nutrient neutrality guidelines (as issued by Natural England) will be utilised as a means of ensuring that the new development will not cause harm to the River Dee.

1.1 Purpose

The purpose of the wetland design and specification is to confirm the sizing, configuration, efficacy, construction, operation and maintenance of the wetlands to ensure that the prescribed nutrient loads are sufficiently reduced 'in perpetuity', and to support the necessary planning application.

1.2 Scope & Limitations

The design and specification is based upon information available at the time of preparation, which includes correspondence between WDE, Water Environment Ltd (WEL) and GE to date, as well as publicly available records from the National River Flow Archive and Natural Resources Wales. It is also based upon current best practice guidance, set out in Kadlec & Wallace 'Treatment Wetlands', 2009, and covers the criteria laid out in Natural England's 'Framework Approach for Responding to Wetland Mitigation Proposals'.

This document should be read with reference to the following accompanying drawings / documents:

- 23010_WDE_ZX_DR-1001 General Arrangement of Proposed Wetland (Appendix D)

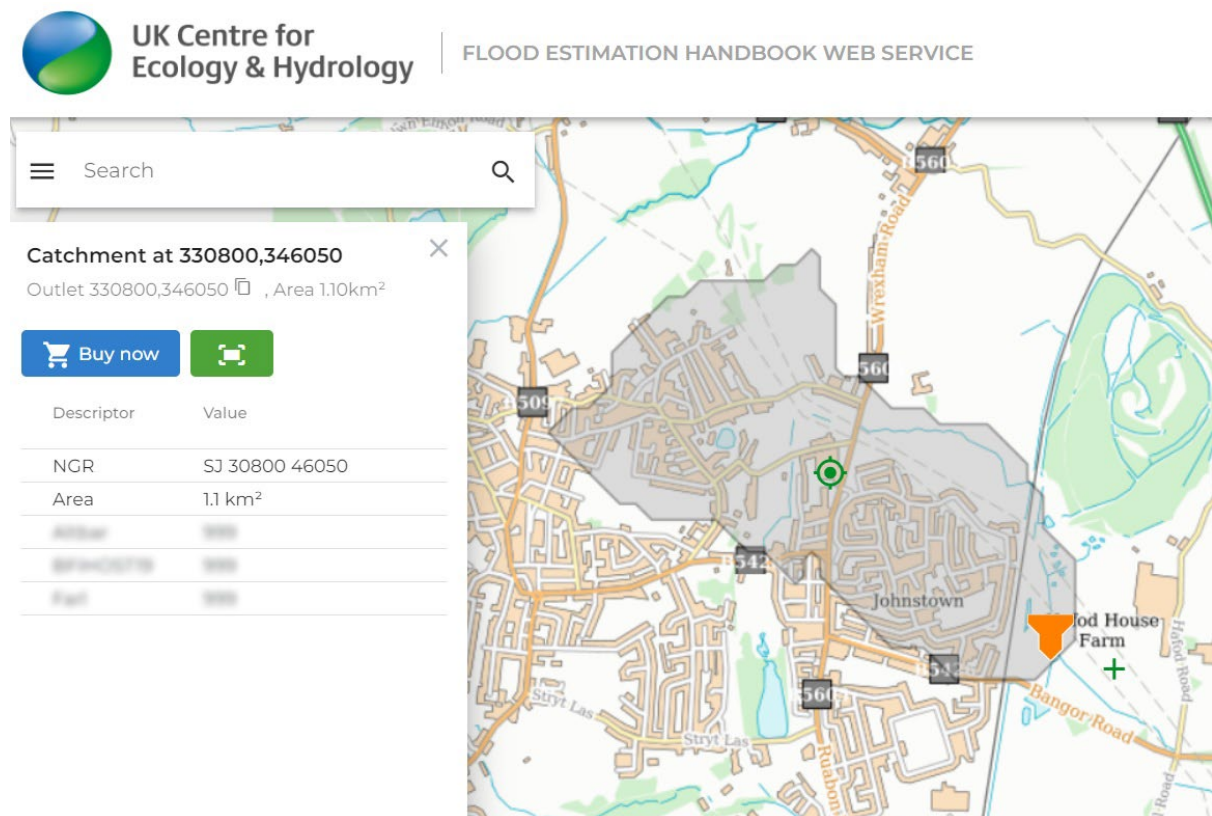
2 Basis of Design

2.1 Nutrient Availability

The availability of nutrients from the Aberderfyn stream should ideally be established from long-term records of flow and water quality monitoring at the proposed point of abstraction. However, such records do not exist and alternative methodology is necessary.

2.1.1 Estimation of Flow

In the absence of flow monitoring data, standard hydrological modelling is required with robust supporting narrative.



The catchment area of the Aberderfyn stream upstream of the proposed point of abstraction is shown in the map above, reproduced from the UKCEH Flood Estimation Handbook (FEH) Web Service. The total catchment area is 1.1 km². The following catchment descriptors are applicable, as obtained from UKCEH:

Standard Percentage Runoff Coefficient (SPR)	0.33
Standard Annual Average Rainfall (SAAR)	840mm

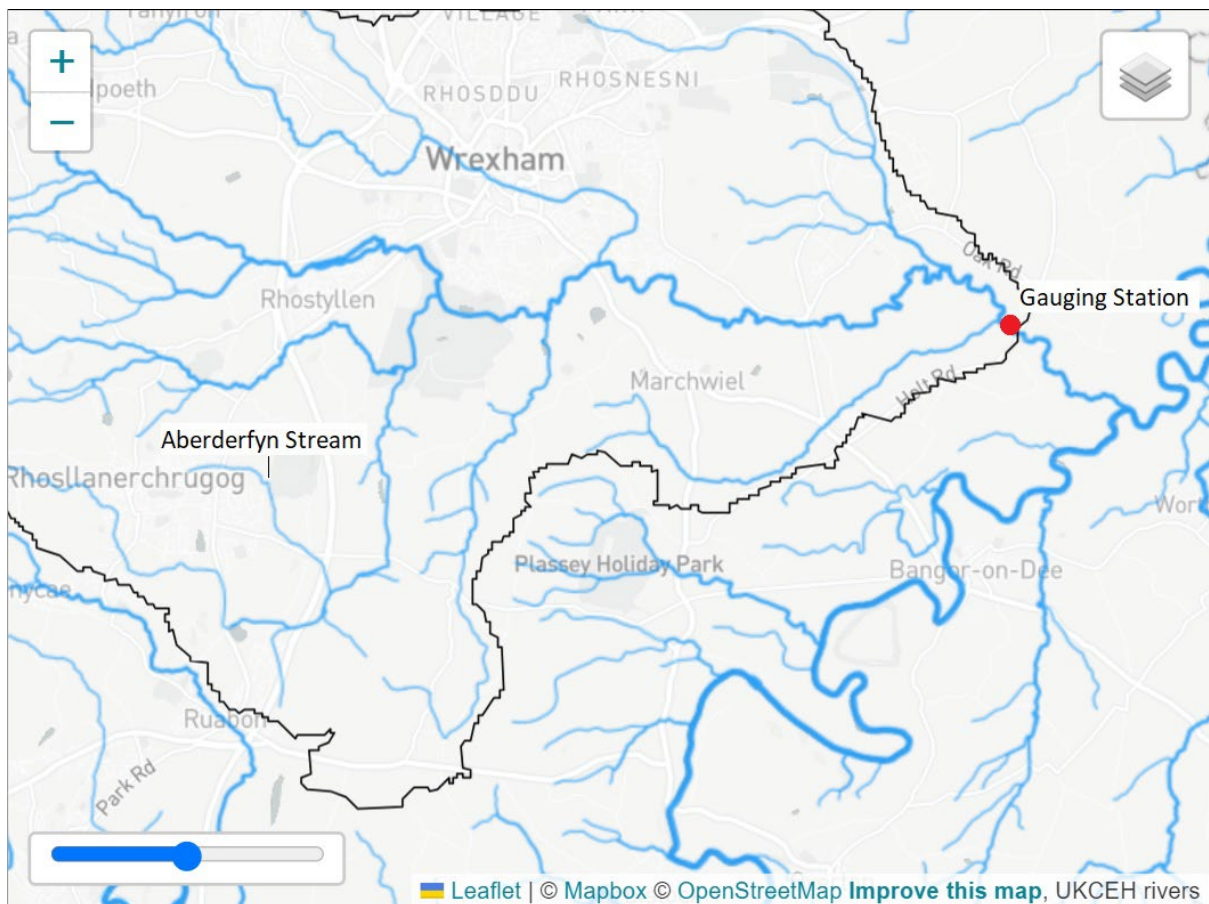
The average annual flow from the catchment can be estimated by the following calculation:

SAAR (m /yr) x Catchment Area (m²) x SPR (dimensionless)

$$0.84 \times 1,100,000 \times 0.33 = 304,920 \text{ m}^3$$

The average daily flow from the catchment is therefore $304,920 / 365 = \mathbf{835.4 \text{ m}^3/\text{d}}$

The Aberderfyn stream is a tributary to the River Clywedog, which is itself a tributary of the River Dee. Whilst there is no flow monitoring of the Aberderfyn stream, there is flow monitoring at a gauging station on the River Clywedog at Bowling Bank (Natural Resources Wales local station number 067025). The map below shows the stream in relation to the gauging station (reproduced from National River Flow Archive, UKCEH).



As an alternative means of assessing the flow in the Aberderfyn Stream, the flow recorded at the gauging station can be 'apportioned' to the stream. The catchment area of the River Clywedog upstream of the gauging station is 98.6 km² and therefore the catchment area of the Aberderfyn stream (1.1 km²) is 1.12% of the wider catchment area. It is reasonable to assume that the flows in the stream are proportionate to those recorded at the gauging station, estimated by multiplying them by 1.12%.

The following table summarises the recorded flows and the apportioned flows:

Flow Percentile	Gauging Station (measured) l/s	Aberderfyn Stream (apportioned) l/s
Q95	321	3.59
Q70	584	6.54
Q50	838	9.39
Q10	2,747	30.77
Q5	3,876	43.41

The Q50 is the median flow, exceeded 50% of the time. Whilst it is not the same as the average flow, it is more reliable as it is not skewed by the higher flows.

Using the apportioned Q50 flow, the daily flow from the catchment can be estimated by the following calculation:

$$9.39 \times 3.6 \times 24 = \mathbf{811.3 \text{ m}^3/\text{d}}$$

This apportioned estimate is similar to the earlier estimate made using the rainfall and runoff data and verifies that the methodology is robust. In order to remain conservative, the lower of the two estimates shall be used (811.3 m³/d).

It is not desirable to intercept and divert 100% of the available stream flow, as this could cause detriment to the ecology within the stream channel downstream of the diversion. Therefore a leaky dam will be used in the stream channel to divert 30 – 40% of the stream flow into the wetland (243.4 – 324.5 m³/d) and retain 60 – 70% of the flow within the existing stream.

2.1.2 Estimation of Phosphorus Concentration

Whilst there is no water quality data available for the Aberderfyn stream, there is available data from the following EA sampling points, on similar watercourses within 15km of the site:

- MD-30000380 on River Perry at Gobowen
- MD-30234380 on Newnes Brook, Ellesmere A495 Bridge

The EA water quality monitoring for these locations provides records for Orthophosphate-P (mg PO₄-P/l). PO₄-P is not the same as Total Phosphorus (TP), as it is only one constituent of TP. TP is a measure of all of the forms of phosphorus, dissolved or particulate, organic or inorganic that are found in the water column. The ratio of PO₄-P : TP in the water environment is typically found to be in the range 0.4 – 0.8 : 1 and it is therefore conservative to assume a ratio of 0.8 : 1.

The average concentration of PO₄-P in the surface water between the two sampling points is 0.315 mg/l. Assuming a ratio of PO₄-P : TP of 0.8 : 1, the average concentration of TP in the Great Stour between the two sampling points is 0.393 mg/l.

Please see Appendix A for a summary sheet of the EA water quality data used to derive the average concentrations of TP.

2.2 Wetland Design Model

Wetland design models are based upon 'reaction rates' for the reduction of specific contaminants such as biochemical oxygen demand (BOD), suspended solids and nutrients (TP and TN).

The most simplistic quantitative model for contaminant reduction considers a constant rate of removal, which is known as 'zero-order' removal as it does not depend on how much of the contaminant is present at a given location. The only parameter of interest in the zero-order model is area, and the local load removal is given by J , which is the constant removal per unit area ($\text{g/m}^2/\text{yr}$). The zero-order model does not allow for variations in the influent concentration of the contaminants, the hydraulic loading rate, or the reduction of the contaminant concentration over time. (Kadlec & Wallace 2009).

A more advanced model for contaminant reduction is the first order 'plug flow dispersion' (PFD) model, which considers the concentration of the contaminant (C), the rate of reduction of the contaminant over time (rate coefficient ' k ', m/d), the length of the wetland (L), the average water velocity (u) and the dispersion coefficient (D , m^2/d). The model also considers a background concentration of the contaminant (C^*) which is continuously present in the water column of the wetland, based upon the interactions between the water column and the wetland substrate (soil and plants) which acts as both a source and sink for the contaminant. However, whilst the PFD model is more accurate than the basic zero order model, the dispersion coefficient assumes a uniform, eddying flow over the whole wetland which is not appropriate for free water surface (FWS) wetlands as the flow is predominantly laminar. (Kadlec & Wallace 2009)

The 'Tanks In Series' (TIS) model assumes that the wetland behaves like a treatment plant with a number of completely mixed tanks connected in series, whereby the contaminant is reduced in each tank. This model considers the concentration of the contaminant (C), the background concentration (C^*), the rate of reduction of the contaminant over time (rate coefficient ' k ', m/d) and the hydraulic parameter (N = no. of tanks in series). It is an improvement on the PFD model, as N is considered to be a finite number (for plug flow, $N = \infty$ which is not achievable). However, the TIS model assumes the reduction of a single compound through a treatment wetland, whereas many contaminants such as TN and TP are mixtures of contaminants that break down at different rates. The mixture becomes *weathered*, which is a term used to describe the selective stripping of light volatile materials upon exposure to outdoor environments. Observed weathering behaviour in real wetland situations may be represented by the TIS model, wherein the parameter values are relaxed to become fitting parameters. This 'relaxed' TIS model is known as the P-k- C^* model and is defined to be as follows (Kadlec & Wallace 2009):

$$\frac{C_e - C^*}{C_i - C^*} = \left[1 + \frac{k}{Pq} \right]^{-P}$$

C_i = Influent concentration of contaminant (mg/l)

C_e = Effluent concentration of contaminant (mg/l)

C^* = Background concentration of contaminant (in the wetland water column) (mg/l)

k = Rate coefficient for reduction of contaminant (m/yr)

P = Apparent no. of tanks in series (PTIS – dimensionless)

q = Hydraulic loading rate (m/yr)

2.3 Wetland Performance Calculations

The P-k-C* model is used to calculate the average estimated percentage of remaining contaminant (after treatment), for a given area and hydraulic loading rate. The treatment efficiency (in terms of percentage of contaminant removed) is then calculated as $1 - \% \text{ remaining contaminant}$.

The annual rate constant k (m/yr) is specific for each contaminant and is selected according to the type of wetland and the climate.

For total phosphorus (TP) reduction, Kadlec & Wallace report that adjustment of the rate constant using a temperature coefficient is not a good model. Studies of Free Water Surface (FWS) wetlands in cold climates gave a median θ value of 0.986, meaning that the rate constant decreased with increasing temperature. It is therefore more appropriate to look at actual rate constants from existing FWS wetlands. Kadlec & Wallace report that the average rate constant for 17 select cold climate wetlands is 18 m/yr. They also report that the 60%ile of 282 studied wetlands (in warm and cold climates) was 13.1m/yr (60%ile is taken on the basis that cold climate wetlands tend to perform better than warm climate wetlands). Therefore, for the purposes of design we shall select the more conservative of these rate constants:

$$k_{TP} = 13.1 \text{ m/yr}$$

The apparent number of tanks in series, $PTIS$, depends upon the hydraulic efficiency of the wetland, which in turn is affected by the length (L) to width (W) aspect ratio and the uniformity of distribution of flow across the wetland. Wetlands with cells arranged to accommodate two or more parallel flow paths, and/or more than one stage (i.e. two or more cells in series) will have higher values of P , as the hydraulic efficiency will be greater. According to Kadlec & Wallace, wetlands consisting of one stage (one cell per flow path) with a W:L aspect ratio of at least 1:3 will have a P value of 2 to 3. Wetlands consisting of three stages will have a P value of 6 to 9. Therefore, the modelling for a wetland with at least three stages assumes $P = 6$.

Regarding background concentrations, Kadlec & Wallace report that the following levels can be assumed for FWS wetlands receiving low strength wastewater:

$$C^*_{TN} = 1.5 \text{ mg/l}$$

$$C^*_{TP} = 0.022 \text{ mg/l}$$

It should be noted that the treated discharge from the wetland cannot be less than these background concentrations, as it is not possible to achieve.

The value of q is simply a function of the total annual hydraulic throughput (m^3/yr) divided by the total treatment area of the wetland (m^2). This provides a loading rate given in m/yr . The treatment area of the wetland is defined as the active cell area, i.e the total wetland area net of the area taken up by diving berms, spreader channels and level control structures.

The total active treatment area for the wetland will be selected according to the maximum possible size within the restrictions on the site.

Area m^2 (ha)	Minimum Flow m^3/d	Maximum Flow m^3/d	Minimum q (m/yr)	Maximum q (m/yr)
13,000 (1.30)	243.4	324.5	6.8	9.1

The corresponding treatment efficiency for the minimum and maximum flows can be calculated using the P-k-C* model given in section 2.2, with rate constants, background concentrations and PTIS value given earlier in this section.

As the P-k-C* model gives the percentage of remaining concentration, the treatment efficiency (percentage of concentration removed) = $1 - \% \text{ remaining}$.

Performance	
Minimum q (m/yr)	6.8
TP treatment efficiency	81%
Maximum q (m/yr)	9.1
TP treatment efficiency	72%

Using the influent water quality for TP provided in section 2.1.2, the influent load of nutrients to the wetland can be calculated as follows:

$$\text{Daily flow (m}^3/\text{d)} \times \text{influent concentration (mg/l)} / 1000 = \text{Influent load (kg/d)}$$

Please see appendix B for a summary of the basis of design, loading and corresponding treatment efficiency for the treatment wetland. The summary sheet also provides the total annual mitigated nutrient load, in terms of kgTP/yr .

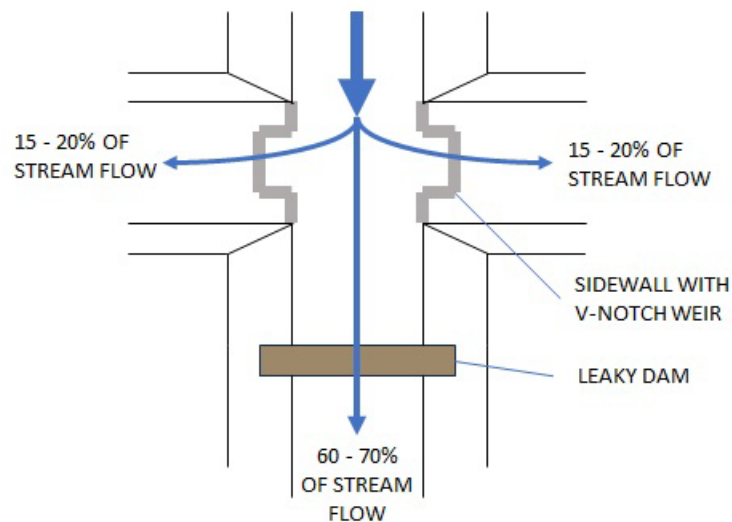
3 Operation

The wetland is off-line, meaning it is constructed outside of the stream channel, with water diverted to the wetland from the channel.

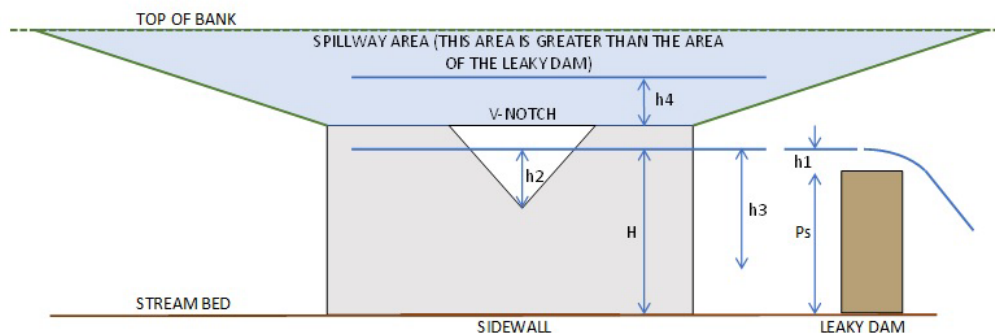
3.1 Abstraction

Abstraction of water from the stream channel will be passive, using a leaky dam and two diversion channels with v-notch weirs to divert water into the wetland cells north and south of the stream as shown in the following diagrams.

PLAN VIEW OF STREAM CHANNEL AT POINT OF INTERCEPTION



In order to reduce flood risk, the 'spillway' areas over each of the sidewalls are greater than the area of the leaky dam so that there is more cross sectional area to conduct the higher flows.

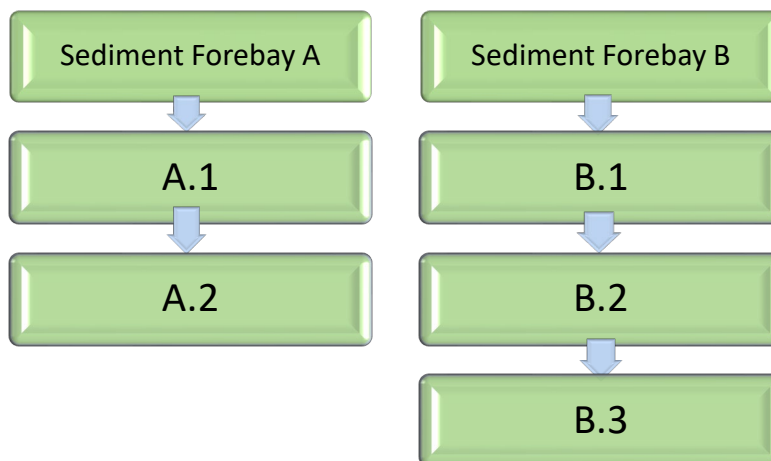


VIEW OF LONGITUDINAL SECTION THROUGH STREAM CHANNEL

3.2 Cell Layout & Flow Paths

The proposed cell layout within the wetland consists of an array, made up of a parallel paths x sequential stages. It is important for continuous flow wetlands to have more than one stage and more than one flow path, for better treatment efficiency and so that operation can continue during times of maintenance. The size of the array is optimised according to the shape and size of the site. Hydraulic efficiency increases with increasing size of array, but a greater number of cells means less overall active area due to the increased number of berms and level control structures.

The cells are labelled alphanumerically according to their location within the array. The numeral relates to the stage in series, whilst the letter relates to the flow path. The diagram below shows the cell layout of the wetland, with the flow paths A and B split south and north of the stream channel, respectively. Whilst sediment forebays are active cells, they have different characteristics and maintenance requirements to the other cells and are therefore labelled separately.



The annual flow regime allows for one flow path to be routinely isolated and drained for maintenance for one month per year (allowing for cutting of reeds and removal of leaf litter).

3.3 Sediment Accumulation

The sediment forebays are intended to trap the majority of incoming sediments from the Aberderfyn Stream catchment. This is important in preventing sediment build-up in subsequent cells downstream, as large 'pulses' of sediment can arrive in individual storm events. The design of the forebays has been made using current best practice, as laid out in the CIRIA SuDS Manual (C753):

The volume of the forebay is determined using the following equation:

$$V_s = A_c R L_o F_c$$

where:

V_s = volume of forebay sediment storage required (m³)

A_c = contributing catchment area (ha)

R = capture efficiency (0.8 recommended)

L_o = sediment loading rate (m³/ha/year) (for example guidance see Wilson *et al*, 2004)

F_c = desired clean-out frequency (years)

The area of the forebay is determined using the following equation which is modified from Fair and Gayer (1954):

where:

$$R = 1 - \left[1 + \frac{v_s A_f}{n Q} \right]^{-n}$$

R = fraction of target sediment removed (0.8 recommended)

v_s = settling velocity of target sediment (0.1 m/s for 1 mm particle)

Q = 1:1 year, critical duration flow rate (m³/s)

A_f = minimum forebay area for sediment capture (m²)

n = turbulence or short-circuiting parameter (0.5 recommended)

The following key design inputs have been used to size the forebay:

Parameter	Value	Justification
A_c	110 ha	Contributing catchment area as provided in section 4.4.1
L_o	0.5 m ³ /ha/yr	Maximum rate for geographical area according to section 6.3 of R&D Technical Report No P2-209 <i>Prediction of Sediment Delivery to Watercourses from Land Phase II</i> (National Soils Resources Institute on behalf of Environment Agency, 2002)
V_s	0.023 m/s	This is the settling velocity for coarse silt (62 µ particle). Source: Maryland Dept. of Environment 1987 in Engineers Australia 2006. This is more conservative than designing for 1 mm particle size.
Q	360 l/s	Flow for the 1 in 1 year 6 hour event from the catchment (UKCEH)
F_c	10 years	It is desirable that the desilting of the forebay is as infrequent as possible, due to the relative scale of the task
dp	0.9m	Depth of permanent pool. This allows sediment to build up as much as 0.5m on the bed between cleaning-out activities without risk of carry-over downstream.

The following key design outputs have been calculated:

Parameter	Value	Explanation
A _f	997 m ²	This is total area of the two sediment forebays shown on drawing 23010_ENV_ZX_DR-1001
R	0.791	This is the capture efficiency for coarse silt, which is approximately 0.8 as recommended. The capture efficiency for 1mm particles is >0.9

Sediment load and accumulation within the cells downstream of the sediment forebays will be a function of the biological activity within the wetland rather than the level of incoming solids from the feedwater. Biochemical floc can accumulate as much as 20 mm per year within the cells, which is typically associated with FWS wetlands performing secondary treatment of municipal effluent, meaning that there could be up to 80 mm of accumulation between maintenance cycles. However, in reality the majority of the floc is assimilated into plant tissue and new microbes, and some is volatilised as CO₂ as part of a natural wetland process. A small residual portion of the floc is buried into the soil profile. It is understood that there are FWS wetlands that have been operating for 15-20 years without the need to remove sediment in the active cell area. In any case, the provision of 300mm freeboard from the operating water level to the top of the surrounding berm will contain the effects of any rise in the bed level.

3.4 Outfalls

The final treated water from each wetland flow path will flow back to the stream channel via outfall headwalls set within the stream bank, at separate locations downstream of the leaky dam.

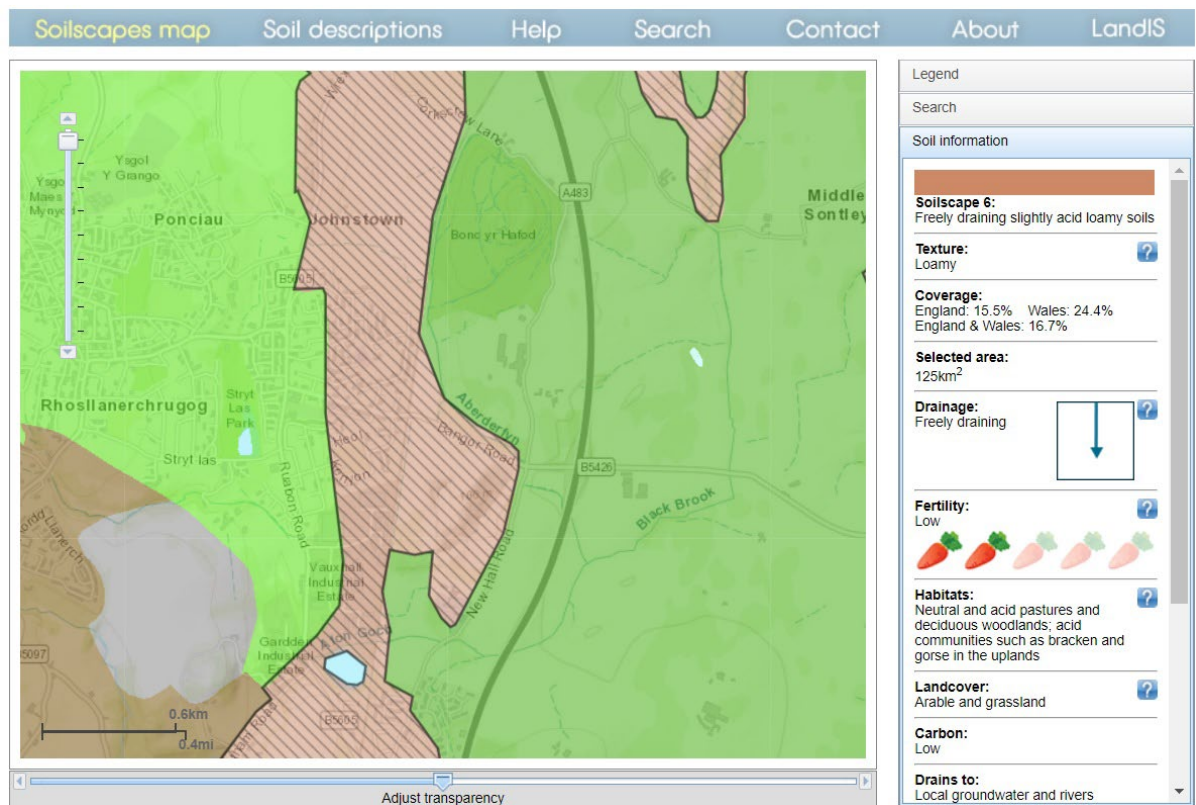
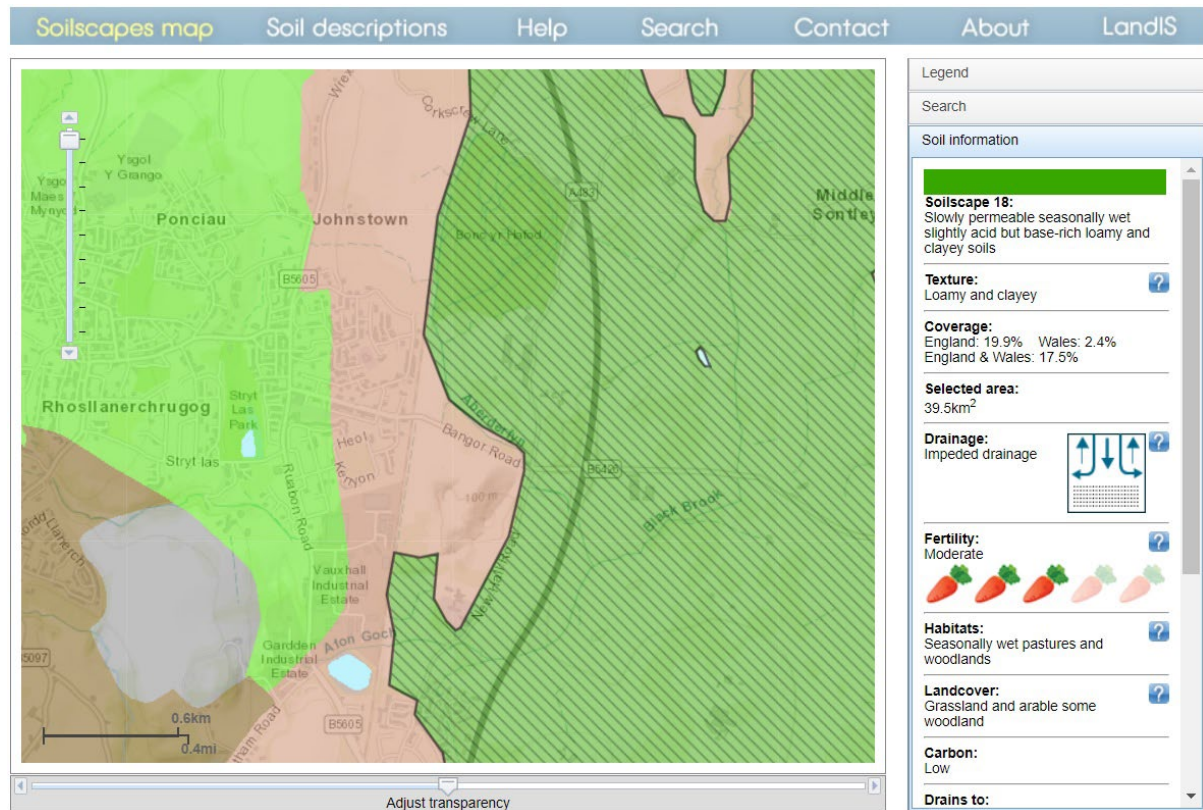
3.5 Water Balance

The amount of flow returned to the river will not equal the amount of flow extracted from it, due to losses through evapotranspiration and infiltration and gains through precipitation.

- The permeability of the wetland cells will be limited to less than 1×10^{-9} m/s by installing a GCL liner¹
- The annual rainfall on the site (SAAR value according to UKCEH) is 840mm
- The evapotranspiration rate for the site is assumed to be 0.018 – 0.125m / month²

The projected wetland 'water budget' for each wetland is illustrated and summarised in appendix C. This shows how much water, in terms of m³/d, is expected to flow out of the wetland after allowing for the losses and gains described above.

¹Limiting the infiltration loss is preferable as it maximises the amount of water returned to the stream channel, as well as preventing 'short circuiting' of the wetland treatment. Unless an intrusive ground investigation using falling head soakage tests can demonstrate that the natural permeability of the soil is 1×10^{-8} m/s or less, lining of the cells will be required. The data available from the Soilsmap map (Cranfield, Defra) as shown in the following screenshots describes the soil as loamy / loamy and clayey with varying drainage. This means that the natural permeability of the soil on site is likely to be too high.



Geosynthetic clay liners (GCLs) have a sodium bentonite core which is activated when hydrated by the water within the soil. GCL's provide the same performance as a thick layer of clay, keeping permeability low whilst still allowing natural gases to escape from the subsoil, and allowing the roots of macrophytes to penetrate. Permeability of at least 1×10^{-9} m/s is typical when using a GCL.

²The evapotranspiration rate is based upon the most recent 12 months of data from Crondall weather station in Surrey.

3.6 Flood Risk

A Flood Risk Assessment (FRA) has been conducted for the whole site, including the area where the proposed wetland will be located (ref MB616-65-ACJ/HB RevA, JPB, 10th June 2023). The FRA reports that the proposed wetland area has the following risks:

- Low risk of flooding from rivers or sea (Flood Zone 1)
- Some risk of pluvial flooding for 1 in 75 and 1 in 100 year rainfall events
- No historic records of any forms of flooding
- High susceptibility to groundwater flooding

The partial blocking of the Aberderfyn stream using the leaky dam shall not increase flood risk due to the compensatory nature of the diversion channels into the wetland, which provide a greater total cross sectional area than that of the dam (thus providing an increase in capacity to conduct flows).

The freeboard within the wetland cells provide some attenuation storage for higher flows, reducing downstream flood risk. If surcharged, the overflow from the wetland cells shall be directed into the existing stream channel. The wetland is designed to withstand seasonal flooding, either from pluvial or groundwater sources. The cells can be fully submerged temporarily (for a number of days) without compromising the integrity of the berms, reeds or rooting soil.

3.7 Drought Risk

The wetland cells are designed to operate with varying water levels from 100mm – 600mm above the bed level. This provides resilience during prolonged periods of drought in the summer months, when losses through evapotranspiration may not be replenished by abstracted stream water. Kadlec & Wallace report that the presence of vegetation retards evaporation in FWS wetlands, on the order of 50%. However, this reduction is offset by the transpiration from the plants.

The wetland plants shall be common reeds (*Phragmites Australis*) and although they thrive in waterlogged conditions, they are able to withstand dry periods. Even if the entire water column was lost through evapotranspiration, the soil and rhizomes would remain waterlogged and it would take another month of high evapotranspiration for the soil to dry out.

As reported by Kadlec & Wallace, the gains in water temperature during periods of low flows are offset by evapotranspiration, which can be thought of as the cooling system for a treatment wetland. Therefore there will be negligible effect on the temperature of the water returned to the stream.

3.8 Carbon Sequestration

Carbon sequestration is the capture and storage of carbon from the atmosphere. Wetlands have the ability to sequester significant amounts of carbon (C), and could therefore provide an effective approach to mitigate the accumulation of greenhouse gases (GHG's) in the atmosphere (Bernal and Mitsch, 2016). However, in contrast the anaerobic processes within wetland soils *produce* GHG emissions (mostly methane, CH₄, and to a lesser extent, nitrous oxide). It is therefore necessary to take account of both the C sequestration rate *and* the CH₄ emission rate to determine whether a constructed wetland serves as a sink or source of C to the atmosphere.

As reported by Bernal and Mitsch (2016), Mitsch et al (2013) compared C sequestration rates of 21 freshwater wetlands from around the world to their rate of CH₄ emission and found that, even after accounting for the high global warming potential of CH₄, all of these wetlands become a net sink of C and radiative forcing, given that CH₄ oxidises to CO₂ over time.

Badiou et al. (2011) studied C accumulation in the soil of newly restored and long-term restored wetlands in the prairie pothole region of North America and estimated that, after accounting for the GHG's emitted from these wetlands, their net soil C sequestration was 90 gC m⁻² yr⁻¹. This equates to 900 kgC ha⁻¹ yr⁻¹.

Bernal and Mitsch (2016) report that soil organic matter content in created wetland sites increases with time (i.e. with wetland age) and that the successful soil C accretion requires successful establishment of hydrology, vegetation, and microbial communities – with macrophyte productivity appearing to be one of the main factors. Mander et al (2014) report that support for the development of aquatic macrophyte cover and controlled harvesting in FWS constructed wetlands can help minimise GHG emissions.

Altor and Mitsch (2008), Nahlik and Mitsch (2010), and Sha et al. (2011) indicate that although CH₄ emissions are difficult to predict, open water sites had consistently higher emission rates than the other sections of the wetlands.

Having reviewed the available literature, it is reasonable to assume that FWS constructed wetlands provide sustainable sinks of C subject to the following design considerations:

- Minimal proportion of open water areas
- Establishment of emergent vegetation such as reeds (aquatic macrophyte cover)
- Controlled harvesting of emergent vegetation

There is insufficient evidence to predict exactly how much C may be sequestered by FWS constructed wetlands, but even if they performed at one third of the rate of the wetlands reported by Badiou et al. this would equate to a sequestration rate of 300 kgC ha⁻¹ yr⁻¹.

4 Construction

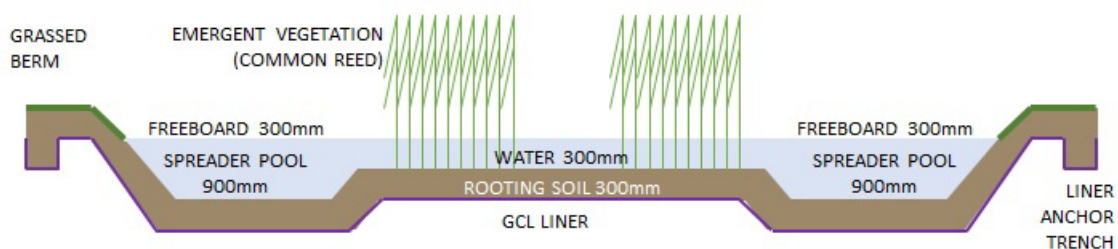
4.1 Earthworks

The wetland cells need to be low-lying and level, with respect to existing ground levels. Their creation will therefore necessitate a significant amount of excavation. Cut and fill analysis will be necessary to establish the likely volume of spoil produced.

4.2 Inlet & Outlet of Cells

In order to maximise the hydraulic efficiency of the wetland, the inlet and outlet of all cells consist of 'spreader pools' which run the full width of the cell and are set deeper than the cell bed (where the emergent vegetation is planted) – as shown in the following diagram:

LONGITUDINAL SECTION THROUGH FWS WETLAND CELL



The connections to all cells consist of submerged headwalls set within the spreader pools with invert levels below the cell bed, but above the bottom of the spreader pool. There are two, parallel headwalls per spreader pool. Polyethylene (PE) Twinwall pipe (225mm dia) connects the headwalls to the weir wall chambers.

The bottom of the spreader pools and the areas in front of the headwalls are protected with overlying rock mattress for scour protection, as well as to prevent mechanical damage to the GCL liner during desilting and other maintenance activities.

4.3 Dividing Berms

The dividing berms shall be formed from excavated soil with sloping sides no steeper than 1 in 3 (18°). Where the berm has to be made above existing ground level, it shall be built up layer by layer with each one being compacted / rolled before the next is added. Allowance must be made for the GCL liner edge detail, where a 300 x 300 trench is required to anchor the material at the top of the slope. The top of the berms shall be a minimum width (in cross section) of 3.0m in order to provide accessways for maintenance (4 x 4 vehicles and small excavators).

The GCL liner material requires a uniform 300mm deep backfill of site won soil to ensure that the material is protected and the bentonite core is under sufficient pressure.

For the cells adjacent to the stream bank, the top of the berms (nearest edge of accessways) must be a minimum distance of 3.0m from the top of the stream bank to prevent any potential weakening.

Level control structures between cells shall be located centrally to the berm (in cross section) with the cover of the access chamber set flush with the top of the berm.

4.4 Hydraulic Profile & Level Control

The hydraulic profile of the wetland is determined by the bed levels of the cells and the level control structures.

The water level of each cell is controlled by the downstream weir wall chamber. The height of the fixed weir wall is 0.30m above the bed level, creating the 300mm water column in the cell in normal operation. The top of the weir wall features a 300mm wide x 350mm deep opening with a manually adjustable penstock weir that allows the water level of the cell to be adjusted from 0mm – 300mm above the bed level for commissioning and maintenance purposes. The upward closing penstock weir consists of a self-contained frame with non-rising spindle which is operated manually using a T-key. The frame and spindle are fabricated from 304 grade stainless steel and the penstock gate is fabricated from HDPE for durability.

The penstock weirs within all weir wall chambers are fully closed during normal operation (maintaining the 300mm water column), which provides a freeboard of 300mm to the top of the surrounding berm. The freeboard is sufficient to contain rising water levels attributed to periods of heavy rainfall and the gradual accretion of solids (leaf litter and biological floc) between maintenance activities.

The levels of the cells are tabulated on drawing 23010_ENV_ZX_DR-1001 (Appendix D)

4.5 Soil & Vegetation

The soil which constitutes the bed of the wetland cells is critical to the successful establishment of the emergent vegetation. A 300mm layer of excavated topsoil should be backfilled and spread over the GCL liner to provide soil for the plant roots to establish themselves (the 'rooting soil'). It is then vitally important to maintain a high soil moisture level, without flooding the cells, throughout the period the vegetation becomes established. This is achieved by lowering the penstock weirs to the lowest setting.

A ground investigation will need to assess the antecedent load of nutrients in the soil profile (in terms of g/kg), in order to determine whether there is 'treatment liability' that needs to be accommodated before the incoming water can be treated. If the wetland start-up is rushed, i.e. the hydraulic load is increased to normal operating levels before the wetland is stabilised, then the wetland can become a net *exporter* of nutrients – i.e. increasing the nutrient load on the catchment rather than reducing it.

The assessed loads will need to be checked against the Biofiltration Filter Media Guidelines (Version 3.01), prepared by the Facility for Advancing Water Biofiltration (FAWB), 2009. These guidelines are recommended within the CIRIA SuDS Manual for the specification of soils for biofiltration systems. The guidelines specify the following limits:

Total Nitrogen (TN) Content: <1000 mg/kg

Orthophosphate (PO_4^{3-}) Content : <80 mg/kg. Soils with total phosphorus >100 mg/kg should be tested for potential leaching.



Vegetation shall consist of emergent wetland species that are suited to the 300mm water column. As leaving the wetland to colonise naturally would take more time for the vegetation to establish, the cells shall be planted with common reed (*Phragmites Australis* pictured above). For the treatment wetland to work as modelled, it is vitally important that the vegetation is established over the entire treatment area of each cell. Reed is preferable over Bulrush (*Typha Latifolia*) as the stems remain upright and intact over the winter months (maintaining essential substrate for biofilm and creating less litter), it supports a greater variety of wildlife and is less sensitive to fluctuations in water level.

The industry standard planting density for constructed wetlands is 4 plants per m² (40,000 plants per ha). The density of the established plant stems is important in creating sites for active biofilms to be established, whilst the annual cycle of leaf litter deposition helps to maintain soil production (for sequestration of P) and the provision of a carbon source required for denitrification.

It should be noted that the common reed is an invasive species, which means that the plant will establish coverage quickly but may also impact upon existing nearby wetland habitats. The dividing berms around each cell provide a means of preventing the spread of rhizomes, however they do not provide any mitigation from seed dispersal by the wind and feeding birds.

Vegetation on this scale will need to be provided on a grow to order basis, whereby the plant supplier is contracted to grow, deliver and plant the vegetation. Whilst this is more expensive than leaving the wetland to vegetate naturally, the key difference is the time taken for the vegetation to become established enough for the wetland to become operational.

A planted wetland can become fully operational after 1-2 growing seasons, whereas natural vegetation can take 3 – 5 growing seasons.



*Reeds grown from seeds in a nursery, producing plants which can be delivered to site and planted.
Photos courtesy of Reeds from Seeds (MWH Treatment).*

5 Monitoring & Maintenance

Monitoring and maintenance should ideally be carried out by separate organisations, for reasons of transparency and avoiding a conflict of interest.

The purpose of monitoring is to assess the performance of the wetland and inform the priorities for the management and maintenance for continued optimal performance. The most important indicators of the wetland's nutrient mitigation performance are the differences in water quality between the inlet (point of extraction) and outlet (point of final discharge), as well as the flow in and out of the wetland. However, there are other important indicators that should be monitored in parallel to help inform reasons for changes in performance, and to help inform the priorities for the management and maintenance.

The purpose of maintenance is to enable the wetland to continue operating and performing as designed, in perpetuity. The wetland is a 'living' biological treatment system and its nutrient mitigation performance relies upon the functioning of a healthy ecosystem. The most critical elements to maintaining a healthy wetland involve the correct management of flows, levels and vegetation.

5.1 Monitoring Agent

The 'Monitoring Agent' is the organisation responsible for monitoring the performance of the constructed wetland. This is suited to a third party organisation that is *not connected* to the landowner or the landowners' representative, for reasons of transparency and avoiding a conflict of interest.

The Monitoring Agent could be a private consultancy, wildlife trust, university or other organisation. Key attributes of the Monitoring Agent are the competency to collect, interrogate and interpret data from varying sources in order to objectively assess the nutrient mitigation performance of the wetland, without prejudice. Other key attributes include the ability to clearly communicate written reports that are not overly scientific, providing practical guidance for the Maintenance Agent.

The Monitoring Agent is not responsible for policing the landowner with respect to upholding the terms of any permits or licenses (i.e. the monitoring agent is not an agent for the environmental regulator). The regulator will conduct their own site visits specifically to monitor adherence to any applicable permits and licenses.

5.2 Monitoring Schedule

Activity	Location	Frequency ²
Collation and analysis of recorded flow data ¹	Remote	Every two months
Water sampling and laboratory analysis ³	On site	Every two months
Visual monitoring of wetland vegetation	On site	Monthly during the first 1 or 2 growing seasons until 60 – 80% coverage established.
Aerial drone survey of wetland vegetation	On site	Twice a year (late March and late August)
Visual monitoring of wetland ecology	On site	Seasonally (including wintering bird survey)

¹Battery powered ultrasonic level devices can be used to monitor the flow over the V-notch weirs in real time, so that the total flow through the wetland can be measured remotely over 3G network.

²Please note that these timescales may be relaxed after the first three years of operation, when the wetland has matured and the data demonstrates that performance / ecology has stabilised.

³Total unfiltered phosphorus, Orthophosphate-P and turbidity should be measured.

5.3 Maintenance Agent

The Maintenance Agent is the organisation responsible for the operational management and maintenance of the constructed wetland. The responsibilities of the Maintenance Agent automatically rest with the landowner, and the role is well suited to the Management Company that will be set up for the associated Waterbrook Park development. Ongoing funding of both monitoring and maintenance activities will be paid for by the Management Company (which will be funded by contributions from the residents of the development).

Key attributes of the Maintenance Agent include the competency to conduct physical activities such as mowing, cutting and clearing of vegetation, rodding of pipework and localised excavation, adjustment of hydraulic controls and management of specialist subcontractors.

The legal obligations to adhere to any applicable licenses or permits (i.e. water abstraction or transfer license and surface water discharge permit) rest with the landowner.

5.4 Maintenance Schedule

Activity	Location	Frequency
Visual checking of V-notch weirs, intake channels and all headwalls and spreader channels (removing any debris as required)	Intake Channels, Outfall Headwalls and within wetland cells	Monthly AND following any flood event
Visual checking of berms for erosion / structural damage	Around the perimeters of the wetland cells	Monthly AND following any flood event
Mowing / strimming of berms	Around the perimeters of the wetland cells	Seasonally as required
Repair of berms	Around the perimeters of the wetland cells	As required
Cutting back of reeds and checking of cell bed level	Wetland cells – on rotational basis (25% of area at a time, with each area on a 4 yearly cycle)	Mid – Late Oct
Desilting	Sediment Forebays Weir Wall Chambers	Typically 5 – 10 years, or as required by Monitoring Agent



Appendix A

Environment Agency Water Quality Data

EA Water Quality Data for R Perry at Gobowen

09-Oct	18-Nov	09-Dec	14-Jan	09-Feb	08-Apr	27-Apr	25-May	29-Jun	25-Jul	08-Aug	21-Sep	25-Oct	28-Nov	13-Dec	10-Jan	07-Feb	10-Mar	27-Apr	25-May
2015	2015	2015	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2016	2017	2017	2017	2017	2017
0.076	0.099	0.08	0.338	0.086		0.226	0.054		0.35	0.373	0.162	0.314		0.075	0.087		0.083	0.323	0.181

AVERAGE

0.182 mg PO₄-P/l

0.227 mg TP/l

EA Water Quality Data for Newnes Brook Ellesmere A495 Bridge

27-Sep	06-Dec	10-Jan	26-Apr	06-Jul	31-Oct	01-Feb	11-May	05-Apr	17-May	19-Jun	25-Jul	28-Aug	10-Sep	24-Oct	11-Nov	06-Dec	07-Jan	21-Feb	06-Mar
2016	2016	2017	2017	2017	2017	2018	2018	2019	2019	2019	2019	2019	2019	2019	2019	2019	2020	2020	2020
0.773	0.523	0.301	0.51	0.711	0.75	0.593	0.258	0.478	0.463	0.389	0.97	0.7	0.46	0.2	0.175	0.21	0.19	0.17	0.13

AVERAGE

0.448 mg PO₄-P/l

0.560 mg TP/l

Average concentration of TP for these sites = 0.393 mg/l, using a conservative ratio of 0.8 PO₄-P : 1 TP



Appendix B

Summary of Basis of Design

Basis of Design for Nutrient Mitigation Wetland



Site:	Johnstown		
Client:	Gladman Estates		
Date:	02/11/2023	Rev	

1. Total Nutrient Loads to be Mitigated

Total Nitrogen		kgTN/yr
Total Phosphorus	30.00	kgTP/yr

*From assessment using Natural England guidance

Proposed Wetland Scheme

Free Water Surface (FWS) Interceptor Wetland (Offline)
Event Driven - Gravity flow from catchment
Interception of Aberderfyn stream
Diversion of portion of flow using leaky dam

SUBJECT TO NRW APPROVAL

2. Intercepted Catchment Characteristics

Total Catchment Area	110.00	ha	From UKCEH FEH web service
TN Leaching from Catchment		kgTN/yr	
TP Leaching from Catchment	124.84	kgTP/yr	Taken from WEL NN report with 50% confidence
SAAR	840.00	mm	Standard average annual rainfall (1961 - 1990) - From UKCEH
SPR	0.33		Standard percentage runoff coefficient - From UKCEH
Average annual runoff	296124.5	m ³ /yr	Calculated from apportioned Q50 flow measured at gauging station
Average TN conc of runoff		mgTN/l	
Average TP conc of runoff	0.3900	mgTP/l	Based upon Environment Agency water quality monitoring data

2a. Flow Regime for Normal Operation (Mid Feb - Mid Jan)

100% of wetland area in use

Percentage runoff treated	30%		Minimum percentage of flow diverted from stream channel
Average daily flow treated	243.4	m ³ /d	
No. of months	11		
Total influent load of TN		kgTN/yr	
Total influent load of TP	34.33	kgTP/yr	

2b. Flow Regime During Wetland Maintenance (Mid Jan - Mid Feb)

75% of wetland area in use

Percentage runoff treated	30%		Minimum percentage of flow diverted from stream channel
Average daily flow treated	243.4	m ³ /d	
No. of months	1		
Total influent load of TN		kgTN/yr	
Total influent load of TP	3.12	kgTP/yr	

3. Wetland Design Characteristics

Designed using the P-k-C* model (Kadlec & Wallace 2009)

Area of treatment wetland	1.300	ha	Drawing 22036_ENV_ZX_DR-1001
Apparent Tanks in Series (P TIS)	6.0		Applicable for FWS wetland with at least three stages and width to length ratio 1:3
Rate constant for TN (k_{TN})	11.2	m/yr	
Rate constant for TP (k_{TP})	13.1	m/yr	
Background conc TN (C^*_{TN})	1.50	mgTN/l	
Background conc TN (C^*_{TP})	0.0220	mgTP/l	

Basis of Design for Nutrient Mitigation Wetland



Site:	Johnstown		
Client:	Gladman Estates		
Date:	02/11/2023	Rev	

1. Total Nutrient Loads to be Mitigated

Total Nitrogen		kgTN/yr
Total Phosphorus	30.00	kgTP/yr

*From assessment using Natural England guidance

Proposed Wetland Scheme

Free Water Surface (FWS) Interceptor Wetland (Offline)
Event Driven - Gravity flow from catchment
Interception of Aberderfyn stream
Diversion of portion of flow using leaky dam

SUBJECT TO NRW APPROVAL

4. Wetland Performance Characteristics

4a. Performance for Normal Operation (Mid Feb - Mid Jan)

100% of wetland area in use

Hydraulic Loading Rate (HLR)	1.87	cm/d
q	6.8	m/yr
Treatment efficiency for TN	77%	
Treatment efficiency for TP	81%	
TN Load Removed		kg
TP Load Removed	27.83	kg
Nominal effluent conc of TN		mgTN/l
Nominal effluent conc of TP	0.0739	mgTP/l

Calculated from P-k-C* model (Kadlec & Wallace 2009)
Calculated from P-k-C* model (Kadlec & Wallace 2009)

4b. Performance During Wetland Maintenance (Mid Jan - Mid Feb)

75% of wetland area in use

Hydraulic Loading Rate (HLR)	2.50	cm/d
q	9.1	m/yr
Treatment efficiency for TN	67%	
Treatment efficiency for TP	72%	
TN Load Removed		kg
TP Load Removed	2.26	kg
Nominal effluent conc of TN		mgTN/l
Nominal effluent conc of TP	0.1075	mgTP/l

Calculated from P-k-C* model (Kadlec & Wallace 2009)
Calculated from P-k-C* model (Kadlec & Wallace 2009)

5. Total Annual Nutrient Mitigation

Total Nitrogen		kgTN/yr
Total Phosphorus	30.09	kgTP/yr
TN Removal Rate		kgTN/ha/yr
TP Removal Rate	23.14	kgTP/ha/yr
Treatment efficiency for TN		
Treatment efficiency for TP	80%	
Nominal effluent conc of TN		mgTN/l
Nominal effluent conc of TP	0.0767	mgTP/l

100% of requirement

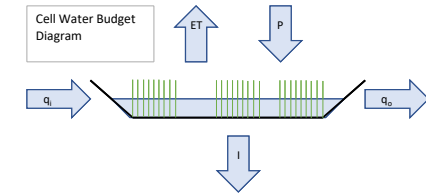


Appendix C

Wetland Water Budget

Wetland Water Budget

Johnstown Phosphate Mitigation Wetland



Water Budget Terms:

q_i = HLR input
 ET = Evapotranspiration Rate
 I = Infiltration Rate
 P = Precipitation Rate
 q_o = Net HLR (q_i for next cell)

Water Budget Equation:

$$q_o = q_i + (P - ET - I)$$

Total Annual Flows

Q_i	88,841.00 m ³ /yr	
ET	10,602.11 m ³ /yr	11.93% of Q_i
P	10,237.50 m ³ /yr	
I	384.35 m ³ /yr	0.43% of Q_i
Q_o	88,092.05 m ³ /yr	99.16% of Q_i

FOR OUTLINE DESIGN

WITH GCL LINER

Wetland Design Input Data

Total Area, A	13,000.00 m ²	Apparent Cell Area, A_c	2,166.67 m ²
Annual Precipitation, P	0.84 m/y	Average Daily Precipitation, P_d	0.00230 m/d
Infiltration Rate, I	1.00E-09 m/s	Average Daily Infiltration, I_d	0.0000864 m/d
Min Evapotranspiration, ET_{Min}	0.018 m/month	Min E'transpiration, ET_{dMIN}	0.00060 m/d
Max Evapotranspiration, ET_{Max}	0.125 m/month	Average E'transpiration, ET_{dAV}	0.00238 m/d
P TIS	6	Max E'transpiration, ET_{dMAX}	0.00417 m/d
Depth	0.3 m		
Porosity	0.95	Apparent Cell Volume, V_c	617.50 m ³

Daily Water Budget for Jan, Feb, Mar, Dec (100% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	4 mo
Q_{max} (m ³ /d)	243.4	246.90	250.40	253.90	257.40	260.90	264.39	-	
P	-	4.99	4.99	4.99	4.99	4.99	4.99	29.92	
ET (Min)	-	1.30	1.30	1.30	1.30	1.30	1.30	7.80	
I	-	0.19	0.19	0.19	0.19	0.19	0.19	1.12	
HRT (d)	15.2	2.5	2.5	2.4	2.4	2.4	2.3	14.5	
HLR (cm/d)	1.9	11.4	11.6	11.7	11.9	12.0	12.2	-	

*Cell 6 = Outflow

Daily Water Budget for Jun (100% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	1 mo
Q_{max} (m ³ /d)	243.4	239.17	234.94	230.71	226.49	222.26	218.03	-	
P	-	4.99	4.99	4.99	4.99	4.99	4.99	29.92	
ET (Max)	-	9.03	9.03	9.03	9.03	9.03	9.03	54.17	
I	-	0.19	0.19	0.19	0.19	0.19	0.19	1.12	
HRT (d)	15.2	2.6	2.6	2.7	2.7	2.8	2.8	16.2	
HLR (cm/d)	1.9	11.0	10.8	10.6	10.5	10.3	10.1	-	

*Cell 6 = Outflow

Daily Water Budget for Aug, Sep (100% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	2 mo
Q_{max} (m ³ /d)	243.4	239.17	234.94	230.71	226.49	222.26	218.03	-	
P	-	4.99	4.99	4.99	4.99	4.99	4.99	29.92	
ET (Max)	-	9.03	9.03	9.03	9.03	9.03	9.03	54.17	
I	-	0.19	0.19	0.19	0.19	0.19	0.19	1.12	
HRT (d)	15.2	2.6	2.6	2.7	2.7	2.8	2.8	16.2	
HLR (cm/d)	1.9	11.0	10.8	10.6	10.5	10.3	10.1	-	

*Cell 6 = Outflow

Daily Water Budget for Nov (75% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	1 mo
Q_{max} (m ³ /d)	243.4	243.13	242.85	242.58	242.31	242.03	241.76	-	
P	-	3.74	3.74	3.74	3.74	3.74	3.74	22.44	
ET (Av)	-	3.87	3.87	3.87	3.87	3.87	3.87	23.24	
I	-	0.14	0.14	0.14	0.14	0.14	0.14	0.84	
HRT (d)	11.4	1.9	1.9	1.9	1.9	1.9	1.9	11.5	
HLR (cm/d)	1.4	8.4	8.4	8.4	8.4	8.4	8.4	-	

*Cell 6 = Outflow

Daily Water Budget for Apr, May (100% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	2 mo
Q_{max} (m ³ /d)	243.4	243.04	242.67	242.31	241.94	241.58	241.21	-	
P	-	4.99	4.99	4.99	4.99	4.99	4.99	29.92	
ET (Av)	-	5.16	5.16	5.16	5.16	5.16	5.16	30.98	
I	-	0.19	0.19	0.19	0.19	0.19	0.19	1.12	
HRT (d)	15.2	2.5	2.5	2.5	2.6	2.6	2.6	15.3	
HLR (cm/d)	1.9	11.2	11.2	11.2	11.2	11.1	11.1	-	

*Cell 6 = Outflow

Daily Water Budget for Jul (100% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	1 mo
Q_{max} (m ³ /d)	243.4	239.17	234.94	230.71	226.49	222.26	218.03	-	
P	-	4.99	4.99	4.99	4.99	4.99	4.99	29.92	
ET (Max)	-	9.03	9.03	9.03	9.03	9.03	9.03	54.17	
I	-	0.19	0.19	0.19	0.19	0.19	0.19	1.12	
HRT (d)	15.2	2.6	2.6	2.7	2.7	2.8	2.8	16.2	
HLR (cm/d)	1.9	11.0	10.8	10.6	10.5	10.3	10.1	-	

*Cell 6 = Outflow

Daily Water Budget for Oct (50% of wetland area)

	Inflow	Cell 1	Cell 2	Cell 3	Cell 4	Cell 5	Cell 6*	Total	1 mo
Q_{max} (m ³ /d)	243.4	243.22	243.04	242.85	242.67	242.49	242.31	-	
P	-	2.49	2.49	2.49	2.49	2.49	2.49	14.96	
ET (Av)	-	2.58	2.58	2.58	2.58	2.58	2.58	15.49	
I	-	0.09	0.09	0.09	0.09	0.09	0.09	0.56	
HRT (d)	7.6	1.3	1.3	1.3	1.3	1.3	1.3	7.6	
HLR (cm/d)	0.9	5.6	5.6	5.6	5.6	5.6	5.6	-	

*Cell 6 = Outflow

Appendix D

General Arrangement of Proposed Wetland

WETLAND SCHEDULE						
TAG No.	TOP OF BERM	TOP OF SPILLWAY	MARSH BED LEVEL	SPREADER POOL BED LEVEL	TOP OF WATER LEVEL	AREA OF WETLAND
A1 SEDIMENT FOREBAY	103.10	103.10	-	102.30	102.80	544.65m ²
A1	103.10	103.10	102.70	102.10	102.90	3319.83m ²
A2	102.90	102.90	102.50	101.90	102.70	3313.34m ²
B1 SEDIMENT FOREBAY	103.00	103.00	-	102.20	102.70	452.63m ²
B1	103.00	103.00	102.60	102.00	102.80	2153.66m ²
B2	102.80	102.80	102.40	101.80	102.60	2158.21m ²
B2	102.60	102.60	102.20	101.60	102.40	1067.13m ²
TOTAL						13,009.45m ²

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 2. This drawing has been produced for the purposes of supporting the planning application for the proposed works - it is NOT to be used for construction
 3. All stated materials and dimensions are nominal - to be confirmed at the detailed design and construction phase

Liability Statement:

The purpose of this general arrangement drawing is to provide details of the intended layout, configuration and operation of the proposed works. It should only be reviewed with reference to the accompanying design and specification document (23010_ENV_ZX_SP-1000) to inform the local planning authority (LPA), the statutory consultees to the planning process and other third parties employed by the client whose scope is affected by the design and specification of the proposed works.

These plans and the materials specified are subject to change at the detailed design and construction phase.

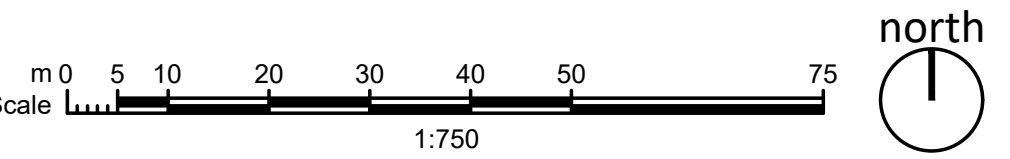
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LEGEND :	
	BERM SLOPES
	DEEP MARSH BED
	SHALLOW MARSH BED
	SPREADER POOL BED / OPEN WATER
	GRASSED ACCESSWAYS



No	Date	Reason	DRN	CHK	APR
01	25.10.2023	Revised Layout	EJ	DO	GR
00	17.10.2023	Design Concept	EJ	DO	GR
REVISIONS					



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Project

JOHNSTOWN WETLAND

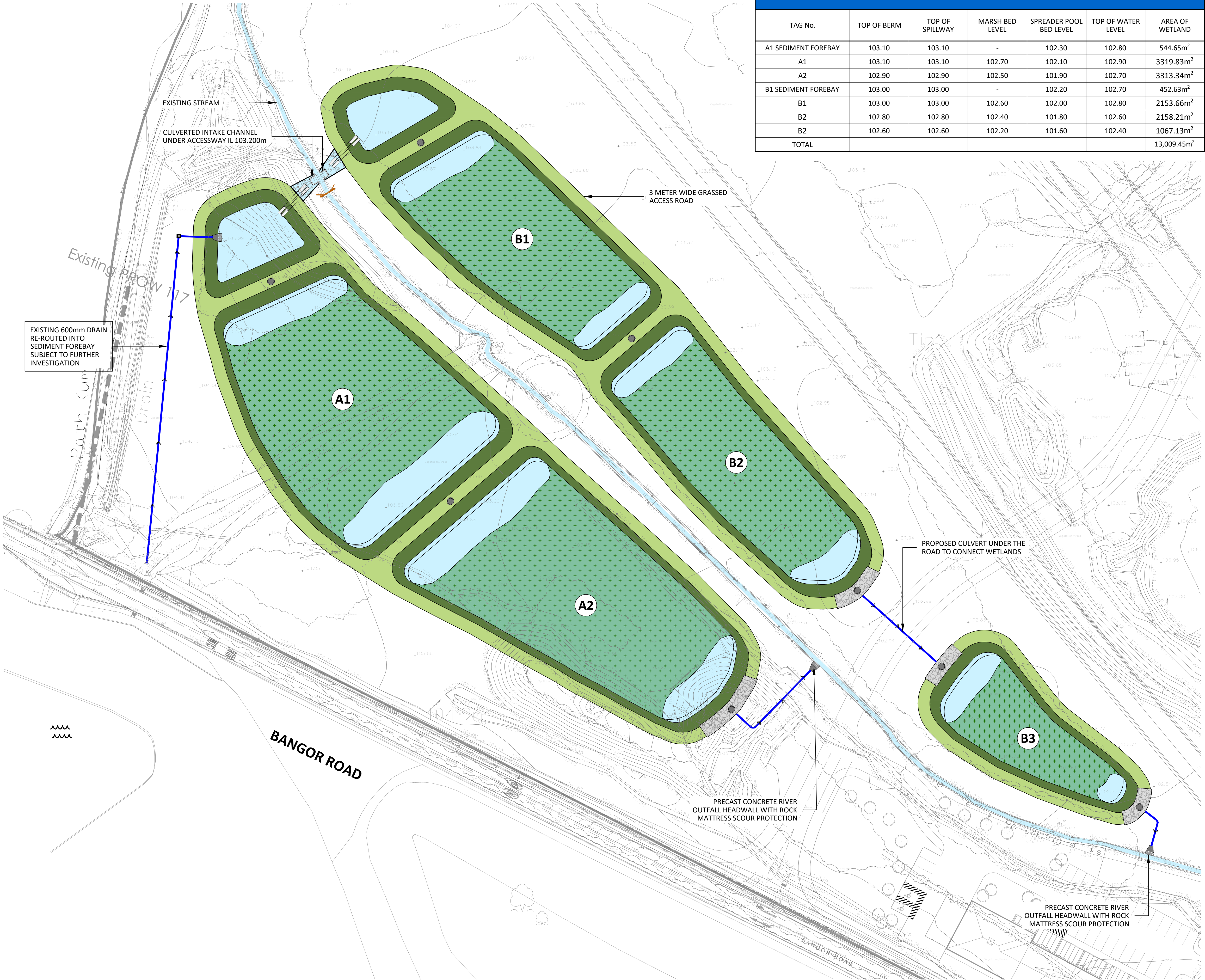
Drawing

GENERAL ARRANGEMENT OF PROPOSED WETLAND

Scale	Date	Drawn
1:500 @ A1	OCT '23	EJ
Drawing No.	Revision	
23010_ENV_ZX_DR-1001	01	

☒ Preliminary	☐ Detailed Design
☐ Issued for Planning Approval	☐ Issued for Tender
☐ Issued for Construction	☐ As Built

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GENERAL ARRANGEMENT OF PROPOSED WETLAND

SCALE 1 : 500 M