Phosphate Reduction and Mitigation (PRAM)

Wetland Calculations Technical Note - Llandysul, Tregaron, and Adpar

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Version Control

Version	Date	Author	Checker	Reviewer	Approver
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1 Introduction

Under the Phosphate Reduction and Mitigation (PRAM) project, Arcadis has recently completed outline designs and supporting calculations for Cilgerran and Cenarth wetlands.

In addition, this technical note provides a summary of the estimated preliminary nutrient reductions and wetland area requirements in Llandysul, Tregaron, and Adpar if outline designs are to be undertaken at these locations under future project commissions It is envisaged that these additional wetlands could be potentially used to mitigate a significant portion of the cumulative nutrient budget in the Afon Teifi Special Area of Conservation (SAC) catchment upstream of Cilgerran and Cenarth, as a result of the new homes allocated within the current Ceredigion County Council (CeCC) and Carmarthenshire County Councils revised LDP (rLDP).

This technical note provides a summary of the estimated preliminary nutrient reductions and wetland area requirements using the following approaches:

- The P-K-C* model approach
- A plug flow model termed the k-C* model approach
- Regressions (or exponential decay) equations

P-K-C* Model

The P-K-C* model described in Kadlec and Wallace (2009)[1] is considered to be the most robust approach and is strongly recommended. This model is a 'First Order' reaction model. That is to say, the rate of reaction (the nutrient removal processes) assumed is dependent upon the concentration of the parameter in question. Such a model may be used either to derive a treatment area based upon target performance (load removal or outlet concentration), or else to derive the expected nutrient removal from a wetland with a particular treatment area.

The P-K-C* model is used to calculate the average estimated percentage of remaining contaminants (after treatment), for a given area and hydraulic loading rate (HLR). The parameters P, K and C* describe the way the contaminant of interest is processed within the wetland. C* is the 'background concentration' of a particular parameter, such as Total Phosphorus (TP). The background concentration is a parameter that represents an irreducible concentration that will exist in the water of a wetland that results from internal biogeochemical processes i.e. the contaminant would be present without the addition of the influent. It represents a concentration below which further removal of contaminant is impossible. K is the reaction rate, which describes the speed with which contaminants at any particular concentration (above C*) are removed from incoming water by the wetland. P is a parameter that describes both the hydraulic efficiency of the wetland, and the way in which contaminants 'weather' or breakdown as they pass through the wetland. Note that if contaminants are a mix of chemicals (e.g. TP), some of the chemicals that make up TP will break down more readily than others[2].

k-C* Model

The k-C* model has been widely applied to the design of treatment wetlands. As with the P-k-C* model, the k-C* model is a first order reaction model that similarly incorporates a background concentration value below which further nutrient removal is not possible.

Regression

There are numerous regression equations proposed in the literature to calculate the removal rates of different parameters, including TP. Different equations will have limitations on their input and output range and the

[1] Kadlec, R.H. and Wallace, S., 2009. Treatment wetlands. CRC press.
[2] Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals.

hydrological parameters used. The regression-based model is based on datasets generated from three Integrated Constructed Wetlands (ICWS): Glaslough, County Monaghan, Ireland; Northrepps, Norfolk; and Ingol, Norfolk[3]. The results of long-term monitoring have been combined to generate an exponential decay curve. The exponential decay curve equation has been used to estimate the size of the wetland required to achieve a desired outlet effluent quality for TP. A TP exponential decay curve has been carried out for a low flow scenario and a high flow scenario

2 Wastewater Treatment Works Summary

2.1.1 Phosphorus concentration

During the PRAM project, Dŵr Cymru Welsh Water (DCWW) provided Orthophosphate sampling data for the treated outflow from the Llandysul Wastewater Treatment Works (WwTWs) for the past 2 years where data exists. Figure 2-1 presents the average Orthophosphate at Llandysul WwTW. These values have been obtained to understand the fluctuations in TP concentrations and how that impacts the wetland area requirements and treatment efficiencies, compared to the 5 mg/l backstop limit, which will be imposed on both WwTWs over the DCWW Investment Programme period (ending 2032). Currently there is no TP permit limit at this WwTW location.

Orthophosphate sampling data was not provided for Adpar and Tregaron WwTW during the PRAM project. However, for Adpar WwTW, the annual average Orthophosphate performance of the final WwTW effluent over the last two years was previously provided during the ongoing Carmarthenshire Specialist Phosphate Advice project: in 2021, the phosphate performance was 4.8 mg/l and in 2022 it was 1.7 mg/l. For Tregaron, no data was provided on the phosphate performance. However, Tregaron WwTW has been designated a new TP permit limit of 2 mg/l, starting 2030 as part of the DCWW Investment Programme.

As a conservative basis, the wetland design calculations were undertaken based on the observed Orthophosphate concentration data (rather than TP observations) for the most recent 12 months period where data exists, but comparison was also made against the proposed 5 mg/l backstop limit for the WwTW outflow to check the implication on the wetland performance.

The average Orthophosphate concentration over the last year (Oct 2022 – Oct 2023) at Llandysul was 1.36 mg/l, and the year before that (Aug 2022 – July 2021) was 2.34 mg/l. As shown in Figure 2-1, there have been no record of incidents where the Orthophosphate concentrations exceed the 5 mg/l backstop limit. Therefore, it is worth considering whether the wetland would realistically receive a concentration of 5 mg/l considering the average is typically half of that. However, reaching 5 mg/l can still potentially occur with the fully permitted Dry Weather Flow (DWF) conditions as more new homes in future Local Development Plans (LDPs) are connected to the WwTW unless more process treatment is provided at the WwTW.

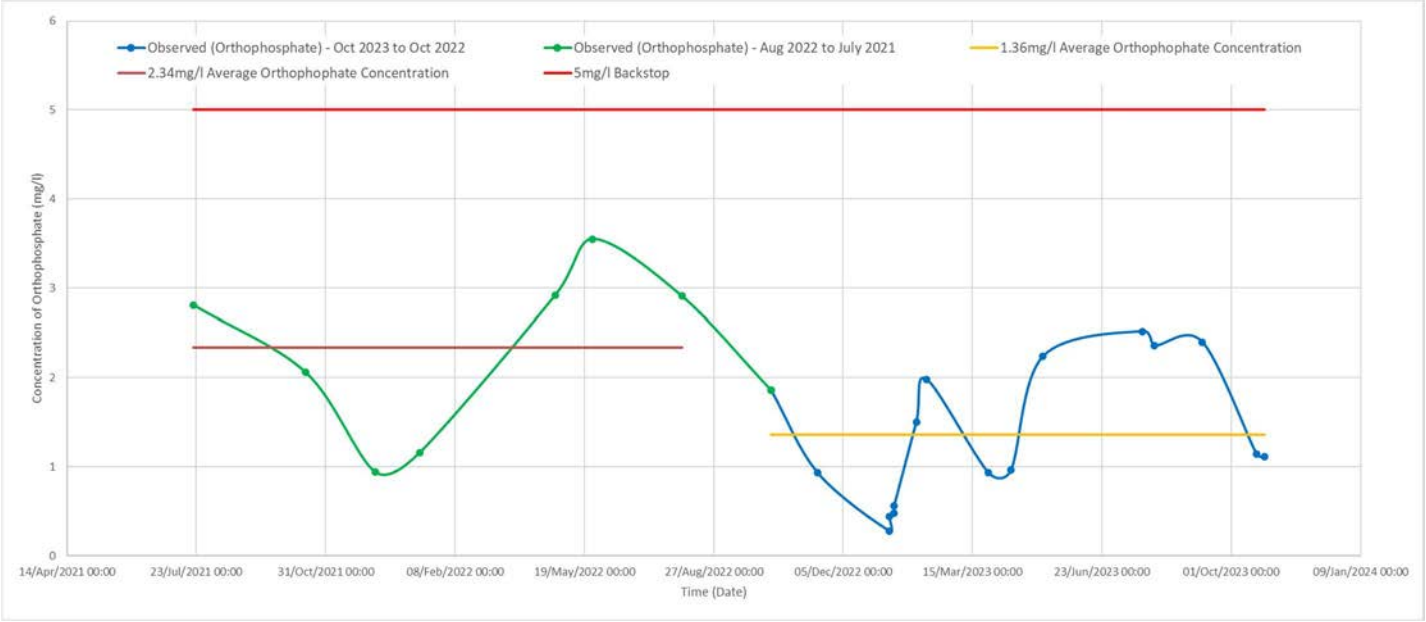

Figure 2-1: Average Orthophosphate concentration at Llandysul WwTW discharge – July 2021 to Oct 2023

Section 2.1.2 below details the DWF estimates and permitted values at Llandysul, Tregaron, and Adpar WwTWs whilst Section 2.1.3 provides a summary of key model inputs.

Section 3 and Section 4 of this technical note then show how the various Orthophosphate concentrations and other model inputs impact wetland requirements and nutrient reduction, for the different modelling approaches used.

2.1.2 Permitted Flows and Estimated Design Flows

Table 2-1 summarises the projected Dry Weather Flow (DWF) from Llandysul, Tregaron, and Adpar WwTW respectively when the proposed site allocations in the Local Development Plan (LDP) accounted for.

In order to calculate the existing and future developments DWF, the following equation has been used:

$$DWF = PG + I$$

Where:

P = population

G = water consumption

I = Infiltration rate

	G – Water Consumption	I = Infiltration
Existing Population	50%	144**
New Dwellings	30%*	108***

* *irrespective of good construction of infrastructure*

** *(assuming 90% returned back into sewer) - assumed 160 l/p/d current consumption*

*** *120 l/p/d for PCC - 90% returned to sewer*

Table 2-1 Dry Weather Flow Estimation

	Existing				Proposed LDP Addition			Predicted Total	
WwTW	Population Equivalent	Consented DWF (m^3/day)	Measured Q90 DWF - 2021 (m^3/day)	Estimated Existing DWF (m^3/day)	New Homes	New Population	Extra DWF (m^3/day)	Total Population	Total DWF (m^3/day)
Llandysul	1534.3	689	326	-	131**	301	42	1836	369
Adpar	1799.3	535	465	-	72***	166	23	1965	488
Tregaron	900	520.4	-	194	74	170	24	1070	218****

**Assumed average household occupancy rate as 2.3*

*** 5 units in CCC and 126 units in CeCC*

**** 37 units in CCC and 35 units in CeCC*

***** Measured Q90 DWF is currently not available at Tregaron and therefore the estimated DWF value was used for the baseline.*

2.1.3 Summary of WwTW Model Inputs

Table 2-2 summarises the input data into the P-K-C* Model, k-C* and regression models.

Table 2-2 Influent Concentration and Design Flow Values

WwTW	Ci, Influent Concentration (mg/l)*	Q, Design Flow (m^3/day)
Llandysul	1.36 (Oct 2023 to Oct 2022)	689**
		369***
	2.34 (Aug 2022 to July 2021)	689**
		369***
	5 (backstop TP limit concentration)	689**
		369***
Adpar	1.7 (P performance – 2022)	535**
		488***
	4.8 (P performance – 2021)	535**
		488***

WwTW	Ci, Influent Concentration (mg/l)*	Q, Design Flow (m^3/day)
Tregaron	2 (New TP AMP8 permit limit)	520**
		218***
	5 (backstop TP limit concentration)	520**
		218***

**Influent concentration of Total Phosphorus*

*** Permitted Flow*

**** Estimated Flow*

For all three WwTWs, the estimated flow is lower than the permitted value. Therefore, the wetland design for this is primarily based on the estimated flow, but the permitted flow was also used for sensitivity testing purpose.

3 Initial Wetland Model Analysis

The following sections present the outcomes of the initial model development for nutrient removal at the proposed wetlands for Llandysul, Tregaron, and Adpar. A summary and interpretation of results is presented in Sections 4 and 5.

3.1 Llandysul

3.1.1 k-C* Model

The plug-flow k-C* model is based on the below equation; with the inputs and results summarised in Table 3-1 and Table 3-2, in which the input values are shaded in grey for clarity.

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m^3/d), k: apparent rate coefficient (m/year), Ci: inlet TP concentration (gP/m^3 or mg/l); C: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)*

The model was run with the following values:

C_o: The target TP concentration for the wetland is 1mg/l.

C: The wetland background concentration is estimated at 0.05mg/l.*

k: The apparent rate coefficient used was 12 m/year.

The analysis is undertaken for three different Ci values (1.36 mg/l, 2.34 mg/l and 5 mg/l) using the fully permitted DWF value of 689 m^3/d at the WwTW, as well as the estimated DWF, which could increase the flow entering the wetlands as a result of the proposed allocations under the LDP.

Once the wetland area is calculated, the Hydraulic Retention Time (HRT) was determined using the following equation:

$$HRT = V/Q$$

Where HRT (days), V= Wetland Volume (m^3), Q=design flow (m^3/d)

Table 3-1 Llandysul K-C Permitted Design Flow Results*

Parameter	Design Scenario 1 – See Note 2	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Values	Values	Values		
Q	689	689	689	m^3/d	Design flow (Permitted Flow) – see Table 2.2 and Note 4
Ci	1.36	2.34	5	gP/m^3 or mg/l	Inlet TP concentration – see Table 2.2
Ce	1	1	1	mg/l	Target effluent concentration

Parameter	Design Scenario 1 – See Note 2	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Values	Values	Values		
C*	0.05	0.05	0.05	mg/l	Wetland background concentration (estimated value) – see Note 5
k	12	12	12	m/year	Apparent rate coefficient - see Note 6
Water depth	0.2	0.2	0.2	m	Treatment water depth – see Note 7
Total wetland area	0.60	1.83	3.53	ha	Estimated wetland area (ha) for the specified Ci and Ce
	5,957	18,278	35,283	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	1,191.4	3,655.6	7,056.5	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	1.73	5.31	10.24	days	The average time taken for water to pass through a wetland - see Note 8

Notes

1. Design Scenario 1 is based on Ci value of 1.36 mg/l from the observed Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2-2
2. Design Scenario 2 is based on Ci value of 2.34 mg/l from the observed Orthophosphate values (Aug 2022 - July 2021), as per Table 2-2
3. Design Scenario 3 is based on Ci value of 5.0 mg/l from the backstop TP limit, as per Table 2-2 – this is a hypothetical scenario mainly for sensitivity testing.
4. Design flow for both Design Scenario 1, 2 and 3 is based on the fully permitted DWF of 689 m^3/d, as per Table 2-2
5. C* value of 0.05 mg/l is assumed, as per Wetland Feasibility, Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation
6. Apparent rate coefficient is assumed as 12 m/year, as per Wetland Feasibility, Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation

7. Treatment depth is taken as 0.2 m, as per Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals
8. Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation sates to achieve <1 mg/l TP a minimum HRT of 6.5 days is required. Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals states HRT is scheme dependent and typically 12-24hrs may be needed.

Table 3-2 Llandysul K-C Estimated Design Flow Results*

Parameter	Design Scenario 1 – See Note 2	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Values	Values	Values		
Q	369	369	369	m^3/d	Design flow (Permitted Flow) – see Table 2.2 and Note 4
Ci	1.36	2.34	5	gP/m^3 or mg/l	Inlet TP concentration - see Table 2.2
Ce	1	1	1	mg/l	Target effluent concentration
C*	0.05	0.05	0.05	mg/l	Wetland background concentration (estimated value) – see Note 5
k	12	12	12	m/year	Apparent rate coefficient - see Note 6
Water depth	0.2	0.2	0.2	m	Treatment water depth – see Note 7
Total wetland area	0.32	0.98	1.89	ha	Estimated wetland area (ha) for the specified Ci and Ce
	3,190	9,789	18,896	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	638.1	1,957.8	3,779.2	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	1.73	5.31	10.24	days	The average time taken for water to pass through a wetland - see Note 8

Notes

1. Design Scenario 1 is based on Ci value of 1.36 mg/l from the observed Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2-2
2. Design Scenario 2 is based on Ci value of 2.34 mg/l from the observed Orthophosphate values (Aug 2022 - July 2021), as per Table 2-2
3. Design Scenario 3 is based on Ci value of 5.0 mg/l from the backstop TP limit, as per Table 2-2 – this is a hypothetical scenario mainly for sensitivity testing.
4. Design flow for both Design Scenario 1, 2 and 3 is based on the estimated DWF of 369 m^3/d, as per Table 2-2
5. C* value of 0.05 mg/l is assumed, as per Wetland Feasibility, Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation
6. Apparent rate coefficient is assumed as 12 m/year, as per Wetland Feasibility, Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation
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3.1.2 P-K-C* Model

The P-K-C* Model builds on the results of the k-C* model results shown in Table 3-1 and Table 3-2, specifically the total wetland area, which is used the derive the hydraulic loading rate (q) (m/yr).

The P-K-C model is defined as[1]:

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

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)

Table 3-3 summarises the P-K-C* inputs and outputs for the permitted Q(Orthophosphate Oct 2023 – Oct 2022 scenario), and the permitted Q (Orthophosphate August 2022 – July 2021) and the permitted Q (5 mg/l backstop limit). Table 3-4 summarises the inputs and outputs for estimated Q with the same three scenarios. The input values are shaded in grey for clarity and Italic text in italics are information related calculating hydraulic loading rate (q).

Table 3-3 Llandysul Permitted Design Flow P-K-C Results*

Parameter	Design Scenario – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Value	Value	Value		
C_{i-}	1.36	2.34	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
C*	0.022	0.022	0.022	mg/l	Background concentration of Total Phosphorus (estimated value) – see Note 4
P	2	2	2	-	Apparent no. of tanks in series
k	10	10	10	m/yr	Rate coefficient for reduction of Total Phosphorus – see Note 5
Design Flow	*689*	*689*	*689*	*m^3/d*	*Design flow (Permitted Flow) – see Table 2.2 and Note 6*
***Total** annual hydraulic throughput*	*251,485*	*251,485*	*251,485*	*m^3/yr*	*Design Flow (m^3/d) X 365*
***Total** wetland area*	*5,957*	*18,278*	*35,283*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control structures) – directly taken from Table 3-1 (from **k-C* Model**) for each Design Scenario*
q	42.217	13.759	7.128	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.07	1.25	1.41	mg/l	NB. treated discharge from the wetland cannot be less than the background
	79.94	53.80	28.34	%	

Parameter	Design Scenario – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Value	Value	Value		
					concentrations, as it is not possible to achieve i.e. background concentration will always be present
Treatment efficiency of wetland	20.06	46.20	71.66	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of 1.36 mg/l from the observed Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2.2
2. Design Scenario 2 is based on Ci value of 2.34 mg/l from the observed Orthophosphate values (Aug 2022 - July 2021), as per Table 2.2
3. Design Scenario 3 is based on Ci value of 5.0 mg/l from the backstop TP limit, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
4. C* value of 0.022 mg/l is assumed, based on Kadlec & Wallace report (2009) for the median flow-weighted TP concentration in 85 relatively undeveloped basins of the United States. It also states levels are very low in Florida Everglades, often in the range of 0.006-0.010. Free Water Surface (FWS) wetlands receiving low strength wastewater. Kadlec & Wallace report (2009) also advises C* typical values of 0.010 – 0.040 mg/l for rainfall driven FWS systems.
5. For total phosphorus (TP) reduction, Kadlec & Wallace report (2009) advises that adjustment of the rate constant using a temperature coefficient ,Θ, is not a good model with the equation $k_T = k_{20}\theta^{(T-20)}$ where T is the operating temperature. Studies of FWS wetlands in cold climates gave a median 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 median rate constant for 282 studied wetlands was 10.0 m/yr.
6. Design flow for the Design Scenarios 1, 2 and 3 are based on the fully permitted DWF of 689 m^3/d, as per Table 2.2

Table 3-4 Llandysul Estimated Design Flow P-K-C Results*

Parameter	Design Scenario – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Value	Value	Value		
C_{i-}	1.36	2.34	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
C*	0.022	0.022	0.022	mg/l	Background concentration of Total Phosphorus (estimated value) – see Note 4
P	2	2	2	-	Apparent no. of tanks in series
k	10	10	10	m/yr	Rate coefficient for reduction of Total Phosphorus – see Note 5
Design Flow	*369*	*369*	*369*	*m^3/d*	*Design flow (Permitted Flow) – see Table 2.2 and Note 6*
***Total** annual hydraulic throughput*	*134,685*	*134,685*	*134,685*	*m^3/yr*	*Design Flow (m^3/d) X 365*
***Total** wetland area*	*3,190*	*9,789*	*18,896*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control structures) – directly taken from Table 3-1 (from **k-C* Model**) for each Design Scenario*
q	42.218	13.759	7.128	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.07	1.25	1.72	mg/l	NB. treated discharge from the wetland cannot be less than the background
	79.94	53.80	34.54	%	

Parameter	Design Scenario – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Value	Value	Value		
					concentrations, as it is not possible to achieve i.e. background concentration will always be present
Treatment efficiency of wetland	20.06	46.20	65.46	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of 1.36 mg/l from the observed Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2.2
2. Design Scenario 2 is based on Ci value of 2.34 mg/l from the observed Orthophosphate values (Aug 2022 - July 2021), as per Table 2.2
3. Design Scenario 3 is based on Ci value of 5.0 mg/l from the backstop TP, as per Table 2.2 - – this is a hypothetical scenario mainly for sensitivity testing.
4. C* value of 0.022 mg/l is assumed, based on Kadlec & Wallace report (2009) for the median flow-weighted TP concentration in 85 relatively undeveloped basins of the United States. It also states levels are very low in Florida Everglades, often in the range of 0.006-0.010. FWS wetlands receiving low strength wastewater. Kadlec & Wallace report (2009) also advises C* typical values of 0.010 – 0.040 mg/l for rainfall driven FWS systems.
5. For total phosphorus (TP) reduction, Kadlec & Wallace report (2009) advises that adjustment of the rate constant using a temperature coefficient ,Θ, is not a good model with the equation $k_T = k_{20}\theta^{(T-20)}$ where T is the operating temperature. Studies of Free Water Surface (FWS) wetlands in cold climates gave a median 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 median rate constant for 282 studied wetlands was 10.0 m/yr.
6. Design flow for Design Scenarios 1, 2 and 3 are based on the estimated DWF of 369 m^3/d, as per Table 2.2

3.1.3 Regression

The regression results below are based on the phosphorus exponential curves shown in The Wye & Usk Foundation (July 2022) Wetland Feasibility, Design and Offsetting[3]. The results below are therefore an interpretation of those results rather than based on a published equation. Further research undertaken to date could not find a regression equation specific for wetland P removal. Therefore, there is low confidence in the results below and these should not be used for design purposes.

The inputs into the Regression model are based on the Orthophosphate values shown in Section 2.1.1 for the period between Oct 2023 - July 2021. Figure 3-1 and Figure 3-2 show derived TP exponential decay curve for a wetland under a low flow scenario and a high flow scenario for the average Orthophosphate concentration between Oct 2023 – Oct 2023. Figure 3-3 and Figure 3-4 show the derived TP exponential decay curve for a wetland under a low flow scenario and a high flow scenario for the average Orthophosphate concentration between August 2022 – July 2021.

However, one of the main limitations of this exercise is that the regression equation used in the analysis is based on a DWF of much lower value of circa 15 m^3/day and TP level 5.6 mg/l for the low flow scenario and 79.83 m^3/day and TP of 2.82 mg/l for the high flow scenario.

Therefore, the initial estimated wetland area was then normalised with the fully permitted design flow (689 m^3/day) and estimated design flow (369 m3/day) to recalculate the wetland areas for low flow and high flow scenarios, as shown in Table 3-5. Table 3-6 summarises the wetland area requirements for the Estimated Design Flow, based on the Orthophosphate data set being used.

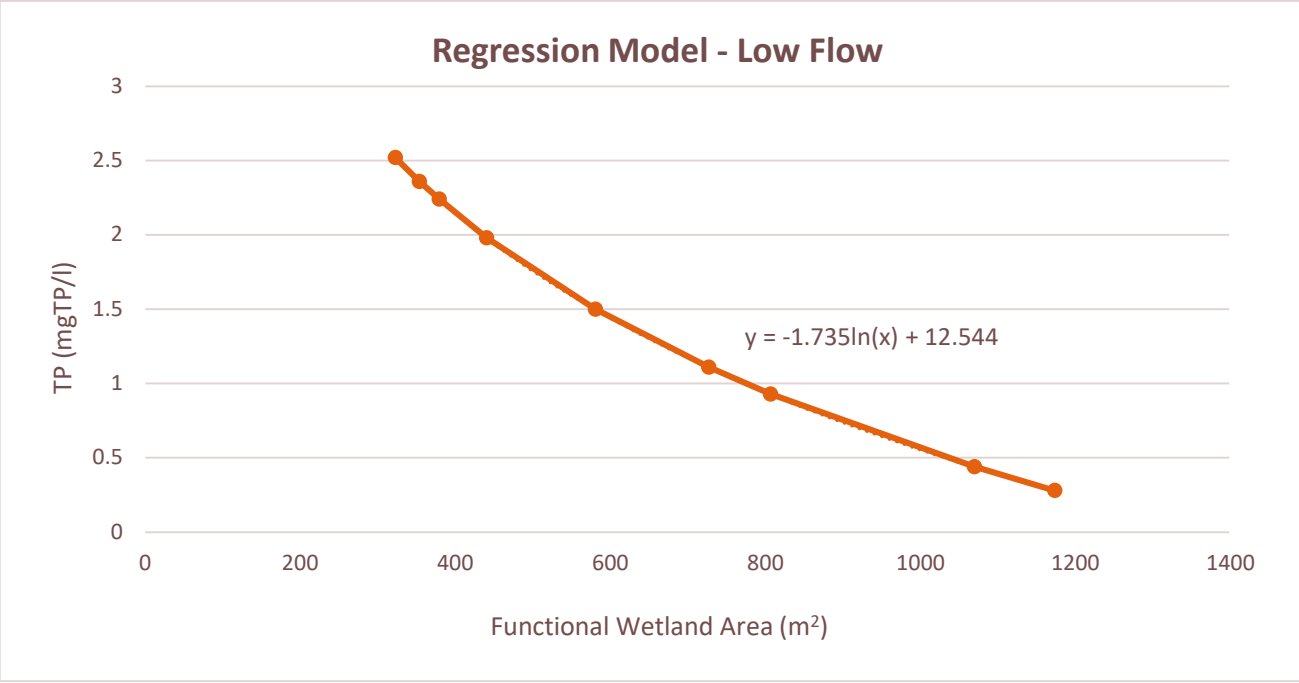

Figure 3-1 TP Regression Curve for Low flow scenario (with DWF of 15.41 m^3/day) using Orthophosphate values (Oct 2023 -Oct 2022)

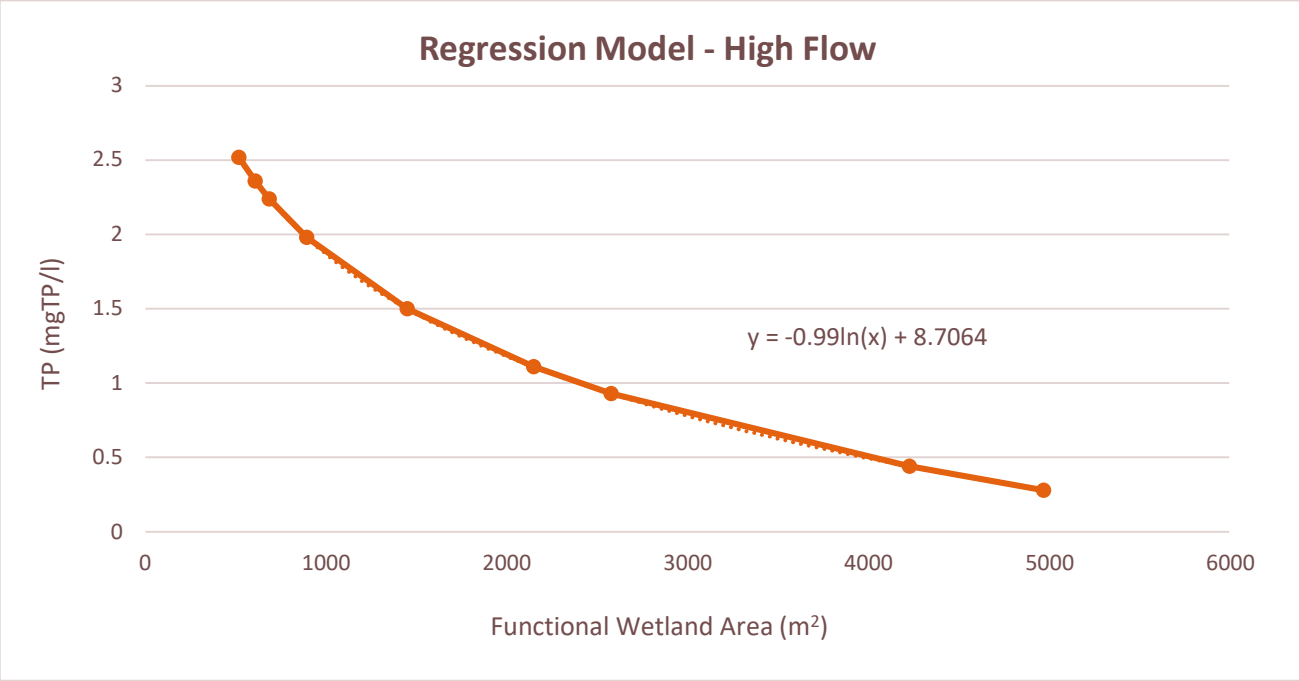

Figure 3-2 TP Regression Curve for High flow scenario (with DWF of 79.83 m^3/day) using Orthophosphate values (Oct 2023 -Oct 2022)

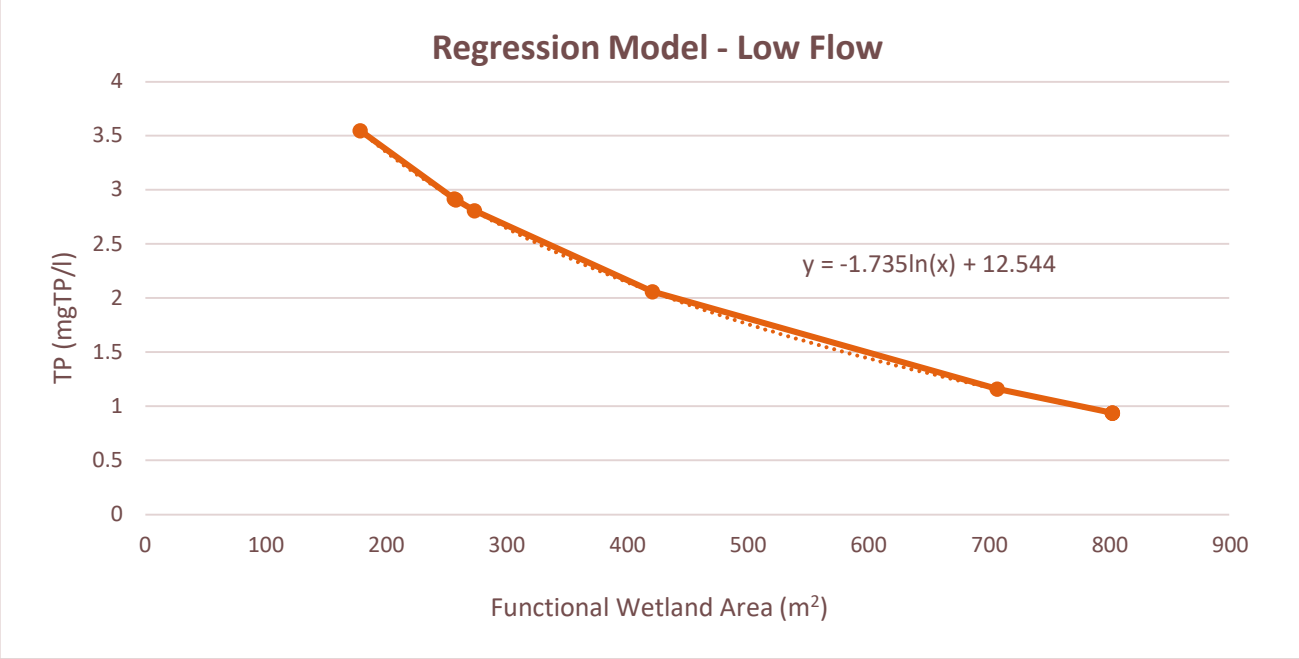

Figure 3-3 TP Regression Curve for Low flow scenario (with DWF of 15.41 m^3/day) using Orthophosphate values (Aug 2022 – July 2021)

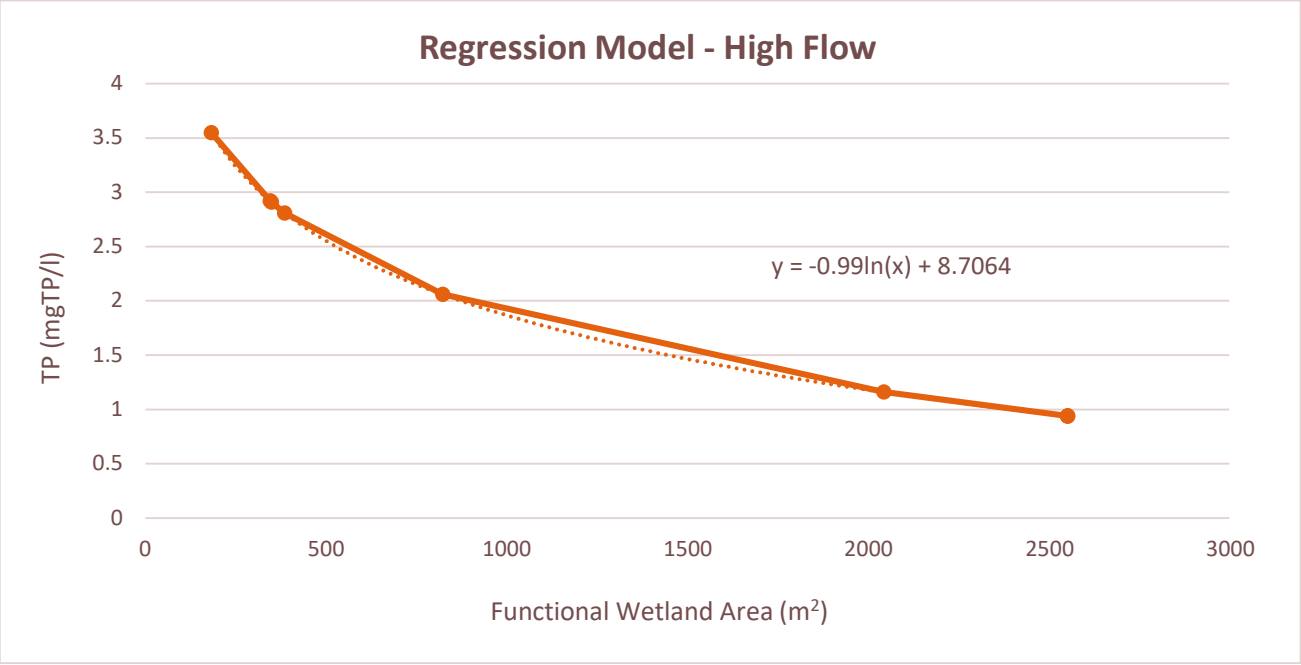

Figure 3-4 TP Regression Curve for High flow scenario (with DWF of 79.83 m^3/day) using Orthophosphate values (Aug 2022 -July 2021)

Table 3-5 Summary of Regression Model Outputs for Llandysul for Permitted Q

Regression	Permitted Q , Orthophosphate data (Oct 2023 - Oct 2022)		Permitted Q , Orthophosphate data (Aug 2022 - July 2021)	
	Low Flow Scenario	High Flow Scenario	Low Flow Scenario	High Flow Scenario
Desired TP value (mg TP/l)	1	1	1	1
Initially Estimated Wetland Area (m^2)	830.9	2,918.1	764.5	2,340.9
Normalised Wetland Area (m^2)*	37,148	130,471	34,180	104,662

* The Normalised Wetland Area (m^2) is calculated by multiplying the Estimated Wetland Area with the ratio of Permitted Flow (689 m^3/d) and mean flow used in the Titley Regression curve (15.41 m^3/d).

Table 3-6 Summary of Regression Model Outputs for Llandysul for Estimated Q

Regression	Estimated Q , Orthophosphate data (Oct 2023 - Oct 2022)		Estimated Q , Orthophosphate data (Aug 2022 - July 2021)	
	Low Flow Scenario	High Flow Scenario	Low Flow Scenario	High Flow Scenario
Desired TP value (mg TP/l)	1	1	1	1
Initially Estimated Wetland Area (m^2)	830.9	2,918.1	764.5	2,340.9
Normalised Wetland Area (m^2)*	19,895.5	69,875	18,306	56,053

* The Normalised Wetland Area (m^2) is calculated by multiplying the Estimated Wetland Area with the ratio of Estimated Flow (369 m^3/d) and mean flow used in the Titley Regression curve (15.41 m^3/d).

3.2 Adpar

As discussed in Section 2.1.1, no data was provided on the Orthophosphate concentrations or phosphate performance at Adpar WwTW. However, the average P performance over the last two years at Adpar WwTW were provided. Also, as discussed in 2.1.2, the projected DWF, as a result of the proposed allocations under the LDP could increase the flow entering the wetlands. Therefore, a number of calculations have been undertaken to understand the impact of the design and estimated flow, against the different Orthophosphate concentrations.

3.2.1 k-C* Model

As discussed in Section 3.1.1, the following are the same across all the models and therefore, Table 3-7 and Table 3-8 only present the other specific parameters and outputs related to the Adpar WwTW:

- K = 12 m/year
- C* = 0.05 mg/l
- Water depth = 0.20 m

Table 3-7 Adpar k-C Permitted Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Q	535	535	m^3/d	Design flow (Permitted Flow) - see Table 2.2 and Note 3
Ci	1.7	4.8	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	mg/l	Target effluent concentration
Total wetland area	0.86	2.67	ha	Estimated wetland area (ha) for the specified Ci and Ce
	8,578	26,690	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	1,715.6	5,338.0	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	3.21	9.98	days	The average time taken for water to pass through a wetland - see Note 3

Notes:

1. Design Scenario 1 is based on Ci value of the average P performance (2022) of 1.7 mg/l, as per Table 2.2
2. Design Scenario 2 is based on Ci value of the average P performance (2021) of 4.8 mg/l, as per Table 2.2. The 5mg/l backstop limit scenario was not specifically analysed considering that 4.8 mg/l already gives a very clear indication of this. Furthermore, in 2022 P performance of the WwTW outflow has significantly improved, therefore 5 mg/l (median value) is unlikely to be exceeded in any case.
3. Design flow for both scenarios is based on the fully permitted DWF of 535 m^3/d, as per Table 2.2 – this is undertaken mainly for sensitivity purposes, should the full permitted flow be treated in the future.
4. Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation sates to achieve <1 mg/l TP a minimum HRT of 6.5 days is required. Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals states HRT is scheme dependent and typically 12-24 hrs may be needed.

Table 3-8 Adpar k-C Estimated Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Q	488	488	m^3/d	Design flow (Estimated Flow) - see Table 2.2 and Note 3
Ci	1.7	4.8	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	mg/l	Target effluent concentration
Total wetland area	0.78	2.43	ha	Estimated wetland area (ha) for the specified Ci and Ce
	7,824	24,345	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	1,564.9	4,869.1	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	3.21	9.98	days	The average time taken for water to pass through a wetland - see Note 4

Notes:

1. Design Scenario 1 is based on Ci value of the average P performance (2022) of 1.7 mg/l, as per Table 2.2
2. Design Scenario 1 is based on Ci value of the average P performance (2021) of 4.8 mg/l, as per Table 2.2. The 5mg/l backstop limit scenario was not specifically analysed considering that 4.8 mg/l already gives a very clear indication of this. Furthermore, in 2022 P performance of the WwTW outflow has significantly improved, therefore 5 mg/l (median value) is unlikely to be exceeded in any case.
3. Design flow for both scenarios is based on the estimated DWF of 488 m^3/d, as per Table 2.2
4. Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation sates to achieve <1 mg/l TP a minimum HRT of 6.5 days is required. Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals states HRT is scheme dependent and typically 12-24 hrs may be needed.

3.2.2 P-K-C* Model

As discussed in Section 3, the following parameters are standard across all the P-K-C models and therefore are not presented in Table 3-9 and Table 3-10 below:

- C* = 0.022
- k = 10
- θ- = 0.986
- Water depth = 0.20 m

Table 3-9 Adpar Permitted Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
C_{i-}	1.7	4.8	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	2	2	-	Apparent no. of tanks in series
Design Flow	*535*	*535*	*m^3/d*	*Design flow (Permitted Flow) – see Table 2.2 and Note 3*
***Total** annual hydraulic throughput*	*195,275*	*195,275*	*m^3/yr*	*Design Flow (m3/d) X 365*
***Total** wetland area*	*26,690*	*8,578*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
				*structures) – directly taken from Table 3-4 (from **k-C* Model)** for each Design Scenario*
q	7.31	22.76	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.13	1.69	mg/l	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background concentration will always be present
	67.223	35.29	%	
Treatment efficiency of wetland	32.77	64.71	%	% of contaminant removed

Notes

1. Design Scenario 1 is based on Ci value of the average P performance (2022) of 1.7 mg/l, as per Table 2.2.
2. Design Scenario 1 is based on Ci value of the average P performance (2021) of 4.8 mg/l, as per Table 2.2. The 5mg/l backstop limit scenario was not specifically analysed considering that 4.8 mg/l already gives a very clear indication of this. Furthermore, in 2022 P performance of the WwTW outflow has significantly improved, therefore 5 mg/l (median value) is unlikely to be exceeded in any case.
3. Design flow for both scenarios is based on the fully permitted DWF of 535 m^3/d, as per Table 2.2

Table 3-10 Adpar Estimated Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
C_i	1.7	4.8	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	2	2	-	Apparent no. of tanks in series
Design Flow	*488*	*488*	*m^3/d*	*Design flow (Estimated Flow) – see Table 2.2 and Note 4*
***Total** annual hydraulic throughput*	*178,120*	*178,120*	*m^3/yr*	*Design Flow (m^3/d) X 365*
***Total** wetland area*	*7,824*	*24,345*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control structures) – directly taken from Table 3-4 (from **k-C* Model**) for each Design Scenario*
q	22.77	7.32	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.13	1.69	mg/l	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background concentration will always be present
	67.23	35.29	%	
Treatment efficiency of wetland	32.77	64.71	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of the average P performance (2022) of 1.7 mg/l, as per Table 2.2
2. Design Scenario 1 is based on Ci value of the average P performance (2021) of 4.8 mg/l, as per Table 2.2. The 5mg/l backstop limit scenario was not specifically analysed considering that 4.8 mg/l already gives a very clear indication of this. Furthermore, in 2022 P performance of the WwTW outflow has significantly improved, therefore 5 mg/l (median value) is unlikely to be exceeded in any case.
3. Design flow for both scenarios is based on the estimated DWF of 535 m^3/d, as per Table 2.2

3.2.3 Regression

As discussed in Section 2, there is no Orthophosphate data for Adpar WwTW. Therefore, the Regression model cannot be undertaken.

3.3 Tregaron

As discussed in Section 2.1.1, no data was provided on the Orthophosphate concentrations or phosphate performance at Tregaron WwTW. However, Tregaron WwTW has been designated a new TP permit limit of 2mg/l, starting 2030 as part of the DCWW Investment Programme. Also, as discussed in 2.1.2, the projected DWF, as a result of the proposed allocations under the LDP could increase the flow entering the wetlands. Therefore, a number of calculations have been undertaken to understand the impact of the design and estimated flow, against the different Orthophosphate concentrations.

3.3.1 k-C* Model

As discussed in Section 3.1.1, the following are the same across all the models and therefore, Table 3-11 and Table 3-12 only present the other specific parameters and outputs related to the Tregaron WwTW:

- K = 12 m/year
- C* = 0.05 mg/l
- Water depth = 0.20 m

Table 3-11 Tregaron k-C Permitted Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Q	520	520	m^3/d	Design flow (Permitted Flow) - see Table 2.2 and Note 3
Ci	2	5	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	mg/l	Target effluent concentration
Total wetland area	1.11	2.66	ha	Estimated wetland area (ha) for the specified Ci and Ce
	11,119	26,628	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	2,223.8	5,325.7	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	4.28	10.24	days	The average time taken for water to pass through a wetland - see Note 4

Notes:

1. Design Scenario 1 is based on Ci value of new TP permit limit of 2.0 mg/l, as per Table 2.2
2. Design Scenario 2 is based on Ci value of 5.0 mg/l from the backstop TP, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
3. Design flow for both scenarios is based on the fully permitted DWF of 520 m^3/d, as per Table 2.2
4. Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation sates to achieve <1 mg/l TP a minimum HRT of 6.5 days is required. Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals states HRT is scheme dependent and typically 12-24 hrs may be needed.

Table 3-12 Tregaron k-C Estimated Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Q	218	218	m^3/d	Design flow (Estimated Flow) - see Table 2.2 and Note 3
Ci	2	5	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	mg/l	Target effluent concentration
Total wetland area	0.47	1.12	ha	Estimated wetland area (ha) for the specified Ci and Ce
	4,661	11,163	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	932.3	2,232.7	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	4.28	10.24	days	The average time taken for water to pass through a wetland - see Note 4

Notes:

1. Design Scenario 1 is based on Ci value of new TP permit limit of 2.0 mg/l, as per Table 2.2
2. Design Scenario 2 is based on Ci value of 5.0 mg/l from the backstop TP, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
3. Design flow for both scenarios is based on the estimated DWF of 218 m^3/d, as per Table 2.2
4. Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation sates to achieve <1 mg/l TP a minimum HRT of 6.5 days is required. Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals states HRT is scheme dependent and typically 12-24 hrs may be needed.

3.3.2 P-K-C* Model

As discussed in Section 3, the following parameters are standard across all the P-K-C* models and therefore are not presented in Table 3-13 and Table 3-14 below:

- C* = 0.022
- k = 10
- θ- = 0.986
- Water depth = 0.20 m

Table 3-13 Tregaron Permitted Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
C_{i-}	2	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	2	2	-	Apparent no. of tanks in series
Design Flow	*520*	*520*	*m^3/d*	*Design flow (Permitted Flow) – see Table 2.2 and Note 3*
***Total** annual hydraulic throughput*	*189,800*	*189,800*	*m^3/yr*	*Design Flow (m^3/d) X 365*
***Total** wetland area*	*11,119*	*26,628*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control structures) – directly taken from Table 3-4 (from **k-C* Model**) for each Design Scenario*
q	17.07	7.13	m/yr	Hydraulic loading rate = Total annual hydraulic throughput

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
				(m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.18	1.72	mg/l	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background concentration will always be present
	59.82	34.54	%	
Treatment efficiency of wetland	40.18	65.46	%	% of contaminant removed

Notes

1. Design Scenario 1 is based on Ci value of new TP permit limit of 2.0 mg/l, as per Table 2.2
2. Design Scenario 2 is based on Ci value of 5.0mg/l from the backstop TP, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
3. Design flow for both scenarios is based on the fully permitted DWF of 520 m^3/d, as per Table 2.2

Table 3-14 Tregaron Estimated Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
C_i	2	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	2	2	-	Apparent no. of tanks in series

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Design Flow	*218*	*218*	*m^3/d*	*Design flow (Estimated Flow) – see Table 2.2 and Note 4*
***Total** annual hydraulic throughput*	*79,570*	*79,570*	*m^3/yr*	*Design Flow (m^3/d) X 365*
***Total** wetland area*	*4,661*	*11,163*	*m^2*	***Active** cell area (i.e. excluding diving berms, spreader channels and level control structures) – directly taken from Table 3-4 (from **k-C* Model**) for each Design Scenario*
q	17.07	7.13	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.18	1.72	mg/l	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background concentration will always be present
	59.82	34.54	%	
Treatment efficiency of wetland	40.18	65.46	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of new TP permit limit of 2.0 mg/l, as per Table 2.2
2. Design Scenario 2 is based on Ci value of 5.0 mg/l from the backstop TP, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
3. Design flow for both scenarios is based on the estimated DWF of 218 m^3/d, as per Table 2.2

3.3.3 Regression

As discussed in 2, there is no Orthophosphate data for Tregaron WwTW. Therefore, the Regression model cannot be undertaken.

4 Refined Wetland Model Analysis

Section 4 presents the further results from the P-K-C* model, which was deemed to provide the most robust approach. The results are based on larger wetland sizes currently being identified for the ongoing Carmarthenshire Action Plan (as part of the Carmarthenshire Specialist phosphate Advice project).

Wetland areas used in this final P-K-C* modelling exercise to estimate the wetland removal % efficiencies have been informed by the initial values obtained (in Section 3) from the K-C* model to achieve the intended 1 mg/l effluent outlet concentration.

Section 4.1, 4.2 and 4.3 present a summary of the P-K-C* model results for the Llandysul, Adpar and Tregaron wetlands respectively and the complete results can be found in Appendix A, Appendix B and Appendix C respectively.

These refined calculations in Section 4 are performed on the basis of having a minimum of six wetland cells at each WwTW location. On the other hand, the preliminary calculations in Section 3 are done on the basis of just two wetland cells at each WwTW location.

During the period of January to March, it was assumed that winter maintenance activities may be performed, which may reduce the available wetland treatment area by up to 50%, causing a lowered wetland performance. Therefore, effective annual TP removal quantities were also presented to reflect this possibility alongside the normal annual TP removal quantities for comparison. They show that the predicted outlet effluent quality following the wetland treatment is broadly as shown below when they are operating at an optimum level (without any winter wetland maintenance activities).

Current Wetland Scheme performance (see note below):

- At Llandysul – 0.5 to 1.0 mg/l
- At Tregaron – 0.5 to 1.0 mg/l
- At Adpar – 1.0 mg/l

Also note that the above wetland outlet effluent quality values are based on the estimated WwTW DWF and the most recent observed inlet concentration values from the WwTW treated effluent (i.e. rather than the fully permitted DWF and backstop TP limit values, which were mainly used for sensitivity scenario testing purposes only). However, since observed concentration values are not available at Tregaron the 2mg/l AMP8 permit level was provisionally used for the wetland inlet concentration at this stage, but the observed values should be used to refine the current estimates.

4.1 Llandysul

	Ci (mg/l)	Q (m3/day)	Wetland (ha)	Volume (m3)	HRT (days)	**P-K-C* model - 100% performance** Removal efficiency (%)	**P-K-C* model - 100% performance** Annual Tp removal (Kg/year)	**P-K-C* model – 50% performance (Jan – March)** Removal efficiency (%)	**P-K-C* model – 50% performance (Jan – March)** Annual Tp removal (Kg/year)	**Effective Annual TP removal** Annual TP removal (kg/yr)	**P-K-C* model - 100% performance** Final Effluent TP (mg/l)	**P-K-C*model - 50% performance (Jan - March)** Final Effluent TP (mg/l)
Llandysul	1.36	689	2.000	4000	5.81	52.61	179.94	31.96	26.95	161.91	0.64	0.93
	1.36	369	2.000	4000	10.84	73.47	134.58	50.34	22.74	123.67	0.36	0.66
	2.34	689	2.000	4000	5.81	52.61	309.60	31.96	46.38	278.57	1.11	1.59
	2.34	369	2.000	4000	10.84	73.47	231.55	50.34	39.12	212.78	0.62	1.15
	5	689	2.000	4000	5.81	52.61	661.53	31.96	99.09	595.24	2.37	3.40
	5	369	2.000	4000	10.84	73.47	494.77	50.34	83.59	454.66	1.32	2.47

4.2 Adpar

						P-K-C* model - 100% performance		P-K-C* model – 50% performance (Jan – March)		Effective Annual TP removal	P-K-C* model - 100% performance	P-K-C*model - 50% performance (Jan - March)
	Ci (mg/l)	Q (m^3/day)	Wetland (ha)	Volume (m^3)	HRT (days)	Removal efficiency (%)	Annual Tp removal (Kg/year)	Removal efficiency (%)	Annual Tp removal (Kg/year)	Annual TP removal (kg/yr)	Final Effluent TP (mg/l)	Final Effluent TP (mg/l)
Adpar	1.7	535	1.0	2,000	3.74	38.82	128.87	22.18	18.16	114.81	1.04	1.32
	1.7	488	1.0	2,000	4.10	41.53	125.75	23.99	17.91	112.23	0.99	1.29
	4.8	535	1.0	2,000	3.74	38.82	363.87	22.18	51.26	324.16	2.94	3.74
	4.8	488	1.0	2,000	4.10	41.53	355.07	23.99	50.57	316.88	2.81	3.65

4.3 Tregaron

						P-K-C* model - 100% performance		P-K-C* model – 50% performance (Jan – March)		Effective Annual TP removal	P-K-C* model - 100% performance	P-K-C*model - 50% performance (Jan - March)
	Ci (mg/l)	Q (m^3/day)	Wetland (ha)	Volume (m^3)	HRT (days)	Removal efficiency (%)	Annual Tp removal (Kg/year)	Removal efficiency (%)	Annual Tp removal (Kg/year)	Annual TP removal (kg/yr)	Final Effluent TP (mg/l)	Final Effluent TP (mg/l)
Tregaron	2	520	1.5	3,000	5.77	52.40	198.91	31.80	29.76	178.95	0.95	1.36
	2	218	1.5	3,000	13.76	80.59	128.25	58.33	22.89	119.08	0.39	0.83
	5	520	1.5	3,000	5.77	52.40	497.28	31.80	74.41	447.37	2.38	3.41
	5	218	1.5	3,000	13.76	80.59	320.63	58.33	57.22	297.69	0.97	2.08

5 Summary

This technical note provides a summary of the nutrient reductions and estimated wetland area requirements using the following approaches:

- The P-K-C* approach
- A plug flow model termed the k-C* approach
- Regressions (or exponential decay) equations

Using the approaches above, a number of scenarios have been run to understand the impact of the design and estimated flow, against the different Orthophosphate concentrations on the wetland area requirements and effectiveness.

The P-K-C* model is considered to be the most robust approach based on industry guidance. Therefore, this approach has been used in the final design analysis to understand the effectiveness of the current wetland proposals for Llandysul, Tregaron and Adpar.

Table 5-1 below summarises the wetland area requirements and effective removal of TP Llandysul, Tregaron and Adpar wetlands. The results show that the wetland areas of 2 ha for Llandysul, 1.5 ha for Tregaron and 1 ha for Adpar would provide sufficient treatment to mitigate for the proposed developments under the current CeCC LDP and CCC rLDP to deliver nutrient neutrality.

As mentioned before, the refined calculations performed in Section 4 are done on the basis of having a minimum of six wetland cells at each WwTW location although the preliminary calculations in Section 3 are done on the basis of just two wetland cells at each WwTW location.

Finally, it is important to build suitable additional contingency in the design approach to account for potential reduced wetland performance during the early wetland plant establishment period, winter maintenance months etc. Therefore, the current assessment approach would account for this, but ongoing monitoring of the wetland treatment performance is strongly recommended to inform future designs.

Table 5-1 Summary wetland area requirements and effective removal of TP for Llandysul, Tregaron and Adpar Wetlands.

Wetland Location	**Downstream WwTWs Mitigated**	**Teifi SAC - Total Annual Phosphorus Budget/ per Wetland Location (Kg TP/Year/Wetland)**	**Teifi SAC - Total Houses/ per Wetland**	**Total Annual Phosphorus Budget/ per Wetland Location/per home** (Kg TP/Year/Wetland/home)	Wetland Area (m2)	P-K-C model, 6 wetland cells (using latest 12 months DCWW P performance data + projected estimated DWF)				P-K-C model, 6 wetland cells (using Backstop TP Permit + Full Permitted DWF)				**Wetland Area (m2)**	**Indicative Wetland Capital Cost + 50% contingency (£ -in M)**
						Wetland annual TP removal – 100% performance nutrient credits(Kg TP/year)	**Wetland annual TP removal – Effective performance nutrient credits (Kg TP/year)**	**Max Housing No Unlocked - 100% wetland performance**	**Max Housing No Unlocked - Effective wetland performance**	**Wetland annual TP removal – 100% performance nutrient credits(Kg TP/year)**	**Wetland annual TP removal – Effective performance nutrient credits (Kg TP/year)**	**Max Housing No Potentially Unlocked - 100% wetland performance**	**Max Housing No Potentially Unlocked - Effective wetland performance**		
Llandysul	Llandysul Pencader Drefach/Felindre	139.06 (see Note 1)	186 (see Note 1)	**0.748**	20,000	**135.600**	**124.540**	**181**	**167**	**661.530**	**595.240**	**885**	**796**	20,000	0.900
Adpar	Adpar Capel Iwan	60.51 (see Note 2)	78 (see Note 2)	**0.776**	10,000	**128.870**	**114.810**	**166**	**148**	**363.870**	**324.160**	**469**	**418**	10,000	0.450
Tregaron	Tregaron Lampeter PTP (SuV36/h2) PTP (SuV36/h1) Llanybydder Llanfihangel-ar-arth	177.12 ((see Note 3)	399 (see Note 3)	**0.444**	15,000	**497.280**	**447.370**	**1008**	**1008**	**198.910**	**178.950**	**448**	**403**	15,000	0.675

Note 1 – Llandysul Wetland:	**Note 2 – Adpar Wetland**
Ceredigion County Council (CeCC) LDP Total Houses to mitigate = 126 (all 126 houses at Llandysul WwTW) CeCC LDP Total Annual Phosphorus Budget = 87.78 Kg TP/Year Carmarthenshire County Council (CCC) LDP Total Houses to mitigate = 60 (5 houses at Llandysul WwTW, 44 houses at Pencader WwTW and 11 houses at Drefach/Felindre WwTW) CCC LDP Total Annual Phosphorus Budget = 51.28 Kg TP/Year Combined CeCC and CCC LDP houses to mitigate = 186 Combined CeCC and CCC Total Annual Phosphorus Budget to mitigate = 139.06 Kg TP/year	Ceredigion County Council (CeCC) LDP Total Houses to mitigate = 35 (all 35 houses at Adpar WwTW) CeCC LDP Total Annual Phosphorus Budget = 27.33 Kg TP/Year Carmarthenshire County Council (CCC) LDP Total Houses to mitigate = 43 (37 houses at Adpar WwTW and 6 houses at Capel Iwan WwTW) CCC LDP Total Annual Phosphorus Budget = 33.18 Kg TP/Year Combined CeCC and CCC LDP houses to mitigate = 78 Combined CeCC and CCC Total Annual Phosphorus Budget to mitigate = 60.51 Kg TP/year

Note 3 – Tregaron Wetland: Ceredigion County Council (CeCC) LDP Total Houses to mitigate = 330 (94 houses at Tregaron WwTW and 236 houses at Lampeter) CeCC LDP Total Annual Phosphorus Budget = 135.14 Kg TP/Year Carmarthenshire County Council (CCC) LDP Total Houses to mitigate = 69 (30 houses at Lampeter WwTW, 22 houses at Package Treatment Plants, 10 at Llanybydder WwTW and 7 houses at Llanfihangel-ar-arth WwTW) CCC LDP Total Annual Phosphorus Budget = 41.98 Kg TP/Year Combined CeCC and CCC LDP houses to mitigate = 399 Combined CeCC and CCC Total Annual Phosphorus Budget to mitigate = 117.12 Kg TP/year	

Appendix A

Refined Wetlands Analysis with P-K-C* Model – Llandysul

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul Permitted Q, Orthophosphate Oct 2022 - Oct 2023	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Llandysul	APPROVER:	0		
Iterated values			DATE:	24/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.36	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	12.57425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.26	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	43.64	
Treatment efficiency of wetland	%	56.36	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.63	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	47.39	
Treatment efficiency of wetland	%	52.61	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.36	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	25.1485	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	15.30	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	65.12	
Treatment efficiency of wetland	%	34.88	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.91	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	68.04	
Treatment efficiency of wetland	%	31.96	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Llandysul	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul Permitted Q, Othophosphate July 2021 - Aug 2022	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

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P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

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ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Llandysul	APPROVER:	0		
Iterated values			DATE:	24/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2.34	Influent concentration of Total Phosphorus (July 2021 - Aug 2022)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	12.57425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.26	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	43.64	
Treatment efficiency of wetland	%	56.36	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.10	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	47.39	
Treatment efficiency of wetland	%	52.61	% of contaminant removed

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Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
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Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2.34	Influent concentration of Total Phosphorus (July 2021 - Aug 2022)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	25.1485	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	15.30	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	65.12	
Treatment efficiency of wetland	%	34.88	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.58	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	68.04	
Treatment efficiency of wetland	%	31.96	% of contaminant removed

P-k-C* modelling

Constructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul Permitted Q, Backstop TP	DATE:	24/11/2023
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ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

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KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Llandysul	APPROVER:	0		
Iterated values			DATE:	24/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	12.57425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.26	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	43.64	
Treatment efficiency of wetland	%	56.36	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.36	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	47.39	
Treatment efficiency of wetland	%	52.61	% of contaminant removed

ARCADIS	CALCULATIONS			
KEY	CLIENT:	Ceredigion County Council	PROJECT No:	30192602
			GBA:	Resilience - Water
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01
Calculated values			AUTHOR:	RG
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP
Assumed values			APPROVER:	0
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023
			DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{I\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{I\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	689	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	251485	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	25.1485	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	15.30	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	65.12	
Treatment efficiency of wetland	%	34.88	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	3.39	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	68.04	
Treatment efficiency of wetland	%	31.96	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
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CLIENT:	Ceredigion County Council	REVISION:	P01
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PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Llandysul	DATE:	45254
		DOC. No:	0
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P-k-C* modelling

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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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul	DATE:	24/11/2023
	Estimated Q, Orthophosphate Oct 2022- Oct 2023	DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.36	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	6.73425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	5.43	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	23.09	
Treatment efficiency of wetland	%	76.91	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.36	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	26.53	
Treatment efficiency of wetland	%	73.47	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values	SUBJECT:	Process Design Calculations - Llandysul	AUTHOR:	RG		
Linked values	SECTION:	P-k-c	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values			DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{I\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{I\text{-}TP}$	mg/l	1.36	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
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k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	13.4685	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.80	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	45.95	
Treatment efficiency of wetland	%	54.05	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.66	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	49.66	
Treatment efficiency of wetland	%	50.34	% of contaminant removed

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul Estimated Q, Orthophosphate July 2021 - Aug 2022	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2.34	Influent concentration of Total Phosphorus (July 2021 - Aug 2022)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	6.73425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	5.43	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	23.09	
Treatment efficiency of wetland	%	76.91	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.62	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	26.53	
Treatment efficiency of wetland	%	73.47	% of contaminant removed

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KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Llandysul	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2.34	Influent concentration of Total Phosphorus (July 2021 - Aug 2022)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
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k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	13.4685	
Total Nitrogen			
Amount of remaining contaminant, Ce - C*	-	10.80	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	45.95	
Treatment efficiency of wetland	%	54.05	% of contaminant removed
Total Phosphorus			
Amount of remaining contaminant, Ce - C*	-	1.15	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	49.66	
Treatment efficiency of wetland	%	50.34	% of contaminant removed

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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

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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Llandysul Estimated Q, Backstop TP	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Llandysul	APPROVER:	0		
Iterated values			DATE:	24/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	20,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	6.73425	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	5.43	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	23.09	
Treatment efficiency of wetland	%	76.91	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.32	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	26.53	
Treatment efficiency of wetland	%	73.47	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Llandysul	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{I\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
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T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	369	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	134685	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	13.4685	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.80	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	45.95	
Treatment efficiency of wetland	%	54.05	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.47	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	49.66	
Treatment efficiency of wetland	%	50.34	% of contaminant removed

P-k-C* modelling

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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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

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Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

Appendix B

Refined Wetlands Analysis with P-K-C* Model – Adpar

ARCADIS

CALCULATIONS

CLIENT:	Ceredigion County Council	PROJECT No:	30192602
		GBA:	Resilience - Water
PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01
		AUTHOR:	RG
		CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Adpar Permitted Q, Ci 1.7 (2022 P performance)	DATE:	29/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Adpar	APPROVER:	0
Iterated values			DATE:	29/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.7	Influent concentration of Total Phosphorus (2022 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	535	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	195275	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	19.5275	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	13.60	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	57.88	
Treatment efficiency of wetland	%	42.12	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.03	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	61.18	
Treatment efficiency of wetland	%	38.82	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Adpar	APPROVER:	0
Iterated values			DATE:	29/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.7	Influent concentration of Total Phosphorus (2022 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	535	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	195275	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	39.055	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	17.77	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	75.60	
Treatment efficiency of wetland	%	24.40	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.31	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	77.82	
Treatment efficiency of wetland	%	22.18	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Adpar	DATE:	45259
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations -Adpar	DATE:	29/11/2023
	Permitted Q, Ci 4.8 (2021 P performance)	DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations -Adpar	APPROVER:	0		
Iterated values			DATE:	29/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	4.8	Influent concentration of Total Phosphorus (2021 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	535	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	195275	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	19.5275	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	13.60	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	57.88	
Treatment efficiency of wetland	%	42.12	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.92	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	61.18	
Treatment efficiency of wetland	%	38.82	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations -Adpar	APPROVER:	0		
Iterated values			DATE:	29/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	4.8	Influent concentration of Total Phosphorus (2021 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	535	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	195275	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	39.055	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	17.77	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	75.60	
Treatment efficiency of wetland	%	24.40	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	3.72	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	77.82	
Treatment efficiency of wetland	%	22.18	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations -Adpar	DATE:	45259
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Adpar Estimated Q, Ci 1.7 (2022 P performance)	DATE:	29/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS			
KEY	CLIENT:	Ceredigion County Council	PROJECT No:	30192602
			GBA:	Resilience - Water
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01
Calculated values			AUTHOR:	RG
Linked values	SUBJECT:	Process Design Calculations - Adpar	CHECKER:	EBP
Assumed values			APPROVER:	0
Iterated values	SECTION:	P-k-c	DATE:	29/11/2023
			DOC. No:	0
			SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.7	Influent concentration of Total Phosphorus (2022 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	488	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	178120	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	17.812	
Total Nitrogen			
Amount of remaining contaminant, Ce - C*	-	12.94	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	55.05	
Treatment efficiency of wetland	%	44.95	% of contaminant removed
Total Phosphorus			
Amount of remaining contaminant, Ce - C*	-	0.98	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	58.47	
Treatment efficiency of wetland	%	41.53	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Adpar	APPROVER:	0		
Iterated values			DATE:	29/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	1.7	Influent concentration of Total Phosphorus (2022 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	488	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	178120	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	35.624	
Total Nitrogen			
Amount of remaining contaminant, Ce - C*	-	17.31	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	73.64	
Treatment efficiency of wetland	%	26.36	% of contaminant removed
Total Phosphorus			
Amount of remaining contaminant, Ce - C*	-	1.28	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	76.01	
Treatment efficiency of wetland	%	23.99	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Adpar	DATE:	45259
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C*

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Adpar Estimated Q, Ci 4.8 (2021 P performance)	DATE:	29/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Adpar	APPROVER:	0		
Iterated values			DATE:	29/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	4.8	Influent concentration of Total Phosphorus (2021 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	488	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	178120	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	17.812	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	12.94	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	55.05	
Treatment efficiency of wetland	%	44.95	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.79	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	58.47	
Treatment efficiency of wetland	%	41.53	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Adpar	APPROVER:	0
Iterated values			DATE:	29/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	4.8	Influent concentration of Total Phosphorus (2021 P performance)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	488	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	178120	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	35.624	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	17.31	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	73.64	
Treatment efficiency of wetland	%	26.36	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	3.63	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	76.01	
Treatment efficiency of wetland	%	23.99	% of contaminant removed

P-k-C* modelling

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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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

Appendix C

Refined Wetlands Analysis with P-K-C* Model – Tregaron

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Tregarron Permitted Q, Proposed Permit	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Tregarron	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2	Influent concentration of Total Phosphorus (Proposed Permit)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	520	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	189800	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	12.65333333	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.31	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	43.85	
Treatment efficiency of wetland	%	56.15	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.94	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	47.60	
Treatment efficiency of wetland	%	52.40	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Tregarron	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2	Influent concentration of Total Phosphorus (Proposed Permit)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	520	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	189800	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	25.30666667	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	15.34	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	65.29	
Treatment efficiency of wetland	%	34.71	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.35	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	68.20	
Treatment efficiency of wetland	%	31.80	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Tregarron	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Treggaron Permitted Q, Assumed Backstop/Current TP	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Treggaron	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop/Current TP)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	520	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	189800	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	12.65333333	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	10.31	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	43.85	
Treatment efficiency of wetland	%	56.15	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.37	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	47.60	
Treatment efficiency of wetland	%	52.40	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Treggaron	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop/Current Tp))
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	520	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	189800	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	25.30666667	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	15.34	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	65.29	
Treatment efficiency of wetland	%	34.71	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	3.40	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	68.20	
Treatment efficiency of wetland	%	31.80	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Treggaron	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Tregaron Estimated Q, proposed Permit	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values			REVISION:	P01		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG		
Linked values			CHECKER:	EBP		
Assumed values	SUBJECT:	Process Design Calculations - Tregaron	APPROVER:	0		
Iterated values			DATE:	24/11/2023		
	SECTION:	P-k-c	DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2	Influent concentration of Total Phosphorus (Proposed Permit)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	218	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	79570	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.304666667	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	3.86	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	16.43	
Treatment efficiency of wetland	%	83.57	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.38	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	19.41	
Treatment efficiency of wetland	%	80.59	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Tregaron	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	2	Influent concentration of Total Phosphorus (Proposed Permit)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	218	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	79570	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	10.60933333	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	8.90	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	37.87	
Treatment efficiency of wetland	%	62.13	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.82	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	41.67	
Treatment efficiency of wetland	%	58.33	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Tregaron	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

onstructed Wetland Design & Specification.pdf

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 = ∞ 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 (*P*TIS – dimensionless)
q = Hydraulic loading rate (m/yr)

k - C* modelling

*Wetland Feasibility, Design and Offsetting (1).pdf

Plug-flow k-C* Model

The plug-flow k-C* model is based on the below equation; large constructed p-control wetlands have been found to fit this description (Kadlec 2016[11]):

$$A=(0.0365*Q/k)*\ln[(Ci-C^*)/Ce-C^*)]$$

Where A= Area (ha), Q=design flow (m_3/d), k: apparent rate coefficient (m/year/1), C_i: inlet TP concentration (gP/m3); C*: background Concentration (mgP/l); Ce=Target Effluent Concentration (mg/l)

The model was run with the following values:

- (Flows and TP levels modelled are outlined in table 2).
- C_o: The target TP concentration for the wetland is 1mg/l.
- C*: The wetland background concentration is estimated at 0.05mg/l.
- k: The apparent rate coefficient used was 12 m/year.

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Tregaron Estimated Q, assumed Backstop/current TP	DATE:	24/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**29/11/23**	**EBP**	**30/11/23**	**LV**	**12/01/23**	

DESIGN BASIS STATEMENT (Inc. high level description of site/process and purpose of calculations)

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Tregaron	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	24/11/2023		
			DOC. No:	0		
			SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (assumed Backstopm/current TP)
C^*_{TN}	mg/l	1.5	Background concentration of Total Nitrogen
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
$\theta_{\text{-}TN}$	-	1.056	Median Temp coefficient for Total Nitrogen
$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	218	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	79570	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.304666667	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	3.86	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	16.43	
Treatment efficiency of wetland	%	83.57	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.97	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	19.41	
Treatment efficiency of wetland	%	80.59	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water
Input values			REVISION:	P01
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands	AUTHOR:	RG
Linked values			CHECKER:	EBP
Assumed values	SUBJECT:	Process Design Calculations - Tregaron	APPROVER:	0
Iterated values			DATE:	24/11/2023
	SECTION:	P-k-c	DOC. No:	0
			SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TN}$	mg/l	25	Influent concentration of Total Nitrogen
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop/current TP)
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C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TN}	m/yr	11.18	Rate coefficient for reduction of Total Nitrogen
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$k_{20\text{-}TN}$	m/yr	21.5	Median value rate coefficient for reduction of Total Nitrogen
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$\theta_{\text{-}TP}$	-	0.986	Median Temp coefficient for Total Phosphorus
T	°C	8	Average operating temperature
No. of treatment stages	-	3	
P	-	6	For one treatment stage i.e. 1 cell in series/three treatment stages i.e 3 cells in series - *P* is 2 or 6 respectively (conservative value)
Design Flow	m3/d	218	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	79570	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	10.60933333	

Total Nitrogen

Amount of remaining contaminant, Ce - C*	-	8.90	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	37.87	
Treatment efficiency of wetland	%	62.13	% of contaminant removed

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.07	NB. treated discharge from the wetland cannot be less than the background concentrations, as it is not possible to achieve i.e. background conc will always be present
	%	41.67	
Treatment efficiency of wetland	%	58.33	% of contaminant removed

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SUBJECT:	Process Design Calculations - Tregaron	DATE:	45254
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SECTION:	References	SHEET:	4 OF 4

P-k-C* modelling

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C_e = Effluent concentration of contaminant (mg/l)
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k - C* modelling

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- k: The apparent rate coefficient used was 12 m/year.

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