Appendix D

Interventions Measures Matrix

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Reduction of Agricultural Phosphorus at source	Category 2	This solution focusses on changing farming practices. **Advantages:** Removes P at source, thus reducing pressure on traditional WwTW and nature-based solutions. Increases sustainability of soil. Associated pre-treated sludge biosolid spreading by DCWW as a single accredited stakeholder. **Disadvantages:** Multiple stakeholders required to change long standing practices. Difficult to manage / monitor. Legacy P requires consideration i.e., 20years of continued P export needs to be considered in the land use change. **Delivery Partners:** Landowners, WG, The Council, NRW, NFU Cymru, DCWW, Env. NGOs	Increased biodiversity from a reduction in nutrient enrichment and in soil Aesthetic value Carbon sequestration	Low	Medium	High	Dairy Project Wales Land Management Forum Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Farming Source Control	Category 2	Farm improvement works to prevent Phosphorus from entering watercourses, which can include fencing. **Advantages:** A simple scheme that increases farm value and there is already an existing grant scheme, which can last a long time (50+ years) **Disadvantages:** Multiple stakeholders which may create long term management difficulties and requires seasonal vegetation management. **Delivery Partners:** DCWW, NRW, NFU Cymru, Landowners/land managers, The Council, WG: WG Spending Commitments, Basic Payment Scheme, SFS, Glastir Advanced, Commons and Organic contracts scheme, National Forest for Wales, Food accreditation scheme, Farm Business Grant Scheme post 2024	Increased biodiversity in watercourse habitats from a reduction in nutrient enrichment and in soil Aesthetic value	High	Medium	High	Dairy Project Wales Land Management Forum Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Surface Water Separation	Category 1 & Category 2	This solution focuses on separating wastewater flows from new and existing developments to capture stormwater. **Advantages:** Already normal practice for new developments, leads to reduced CSO discharges into the watercourse and reduced sewage treatment costs. Similar compensatory surface water removal approach already in place for Carmarthen Bay and Estuaries European Marine site. **Disadvantages:** Costly to retrofit in urban areas, limited reduction in Phosphorus unless effective SuDS are incorporated, long term effectiveness depends on operating practices at WwTWs. **Delivery Partners:** Developers, The Council, DCWW, Wales Green Infrastructure Forum	Increased Capacity and efficiencies at WwTW	High	Low	Low	Wales Land Management Forum Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Enhanced Wastewater Treatment Works	Category 1	Increasing the ability of WwTWs to remove Phosphate. **Advantages:** Increase headroom for new development, clear delivery mechanisms within DCWW. Opportunity to explore developer contributions. **Disadvantages**: Requires long term investment and long lead times. May transfer issues to biosolid spreading which would require extra controls. **Delivery Partners:** DCWW: Existing and new WWTW funding, Spending commitments. Developers, NRW, Ofwat, NFU Cymru, WG Spending Commitments.	Improved Water Efficiency and water quality	Medium	High	High	Wales Land Management Forum Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
SuDS Source Control	Category 1	**Permeable paving** **Advantages:** Reduces peak flows and enhance water quality treatment. Dual use of the landscape, prevents ponding, can be used in high density developments **Disadvantages:** Not compatible with large sediment loads, only suitable for low traffic volume areas, maintenance to minimise silt clogging. **Delivery Partners:** Developers, The Council.	Natural Flood mitigations Temperature Regulation	Medium	Low	High	Rainscape National Surface Water Management and SuDS Group Members Teifi SAC Catchment Phosphate Reduction and Mitigation Project Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
	Category 1	**Green roofs** **Advantages:** Reduced peak waste water flows and enhanced water quality treatment along with reduced storm water overloading and CSO discharges, Mimics predevelopment state of water flows, can be retrofitted (site dependant), no additional land, can provide a return on investment from energy savings. **Disadvantages:** High cost compared to conventional roof, not appropriate for all sites and limited retrofitting abilities, requires high maintenance as any damage to roof membrane is more critical as water is encouraged to remain on the roof, limited impact of phosphate removal. **Delivery Partners:** Developers, The Council, DCWW, Business Improvements Districts for retrofits.	Increased Biodiversity Aesthetic value Thermal attenuation Climate resilience Water efficiency Noise Attenuation Air Quality improvements Health and wellbeing if accessible Increased longevity of roofs	Medium	Medium	Medium	Rainscape National Surface Water Management and SuDS Group Members Teifi SAC Catchment Phosphate Reduction and Mitigation Project Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Swales	Category 1	Shallow broad and vegetated channels designs to store and convey runoff to remove pollutants. **Advantages:** Easy to incorporate into landscaping, good removal of urban pollutants, reduces runoff rates and volumes and low capital cost. Maintenance can be incorporated into general landscape management, pollution and blockages are visible and easily dealt with. **Disadvantages:** Not suitable for steep areas with roadside parking, limits the opportunities to use trees for landscaping, risks of blockages in existing pipework. **Delivery Partners:** Developers, The Council, Local Highways Agencies, WG, National Surface Water Management and SuDS Group, Ofwat, Innovation Fund, Water Breakthrough Challenge, Water Discovery Challenge, NRW, Four Rivers for Life, Sustainable Drainage Feasibility Grant, DCWW: Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, Wales Green Infrastructure Forum, Living Streets Cymru, Active Travel and Safe Routes in Communities (SRiC) schemes, Heritage Lottery Fund, Esmee Fairburn Foundation	Biodiversity Amenity Aesthetic value Passive cooling	Medium	Low	Medium	Rainscape National Surface Water Management and SuDS Group Members Teifi SAC Catchment Phosphate Reduction and Mitigation Project Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Conveyance Chanels	Category 1	Channels and rills are open surface water channels with hard edges that can be planted with vegetation. **Advantages:** Effective water and pollution treatment can act as pre-treatment to remove silt before water is conveyed into further SuDS features, easy to construct. **Disadvantages:** Incorrect planting can cause silt build up, Need to give careful consideration to crossings, routine maintenance to remove litter/debris, large maintenance required every 5 years. **Delivery Partners**: Same as Swales	Biodiversity Increase Amenity Aesthetic value Passive cooling	Medium	Medium	Medium	Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Filtration Strips	Category 1	Filter strips of gently sloping grass and street trees **Advantages**: Well suited to implementation in areas with heavy traffic, encourages evaporation, infiltration and interception. Easy to construct and low construction cost, effective pre-treatment option **Disadvantages:** Not suitable for all locations. No significant attenuation or reduction of extreme flows. **Delivery Partners**: Same as Swales	Biodiversity Amenity Aesthetic value Health and wellbeing Can encourage active transport	Medium	Medium	Medium	Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
	Category 1	Filter drains are stone filled trenched with underdrains alongside roads, paths or rail lines. **Advantages:** They can capture specific pollutants if there is a layer of treatment media included (the amount removed will depend on the treatment media used). Large ability for treatment since they are often created to be in parallel to the length of roads and paths. **Disadvantages:** It does not capture pollutants directly if treatment media is not added, No vegetation, Depending on the soil conditions and/or pollutant loads, there is risk of filter drains enabling phosphate pollution migration into the underlying ground water, Flow exceedance could lead to temporary flooding. **Delivery Partners**: Same as Swales	Biodiversity (microorganisms, insects and amphibians) Amenity Can filter out fine sediments, metals and hydrocarbons (depending on filter media used) Encourage adsorption and biodegradation process	Medium	Low	Medium	Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
	Category 1	Shallow landscaped areas with engineered soils, enhanced vegetation and filtration, which can also include trees. **Advantages:** Very effective in removing urban pollutants which can also reduce volume and runoff rates. Flexible layout to fit into landscape. Well-suited for installation in highly impervious areas, Good retrofit capability and when lined, can be used to manage surface water runoff from areas with high groundwater pollution risks. **Disadvantages:** Requires landscaping and management. Susceptible to clogging if surrounding landscape is not managed. Not suitable for areas with steep slope. Should be used in conjunction with other SuDS components **Delivery Partners**: Same as Swales	Biodiversity Amenity / Aesthetic value	Medium	Low	High	Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Infiltration Basins	Category 1	A solution based around, rain gardens, infiltration trenches and basins, soakaways, tree pits. **Advantages:** Rain gardens – Small and easy to retrofit, minimal land take, easy to maintain, flexible layout to fit into landscape and can be installed in impervious areas if designed correctly. Soakaways – Particulate P removal through sedimentation of solids upstream of soakaway and infiltration in the soakaway. Can reduce rate of run off and some volume reduction Tree pits – Can enhance the performance of other green infrastructure technologies. **Disadvantages:** Rain gardens – As they are often small, their impact can be limited, requires landscaping and management, susceptible to clogging if surrounding landscape is not managed. Not suitable for areas with steep slopes or impermeable soils. Soakaways – Phosphorus removal highly dependent on infiltration rate and if there is an overflow. Tree pits – Nutrients can be cascaded downstream in extreme events. **Delivery Partners**: Same as Swales	Biodiversity Amenity / Aesthetic value Natural flood mitigation Can reduce the risk of waterborne diseases	Medium	Medium	Medium	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Retention Ponds	Category 1	Building of ponds to retain water (retention ponds) **Advantages:** Can cater for all storms and has good removal capability of urban pollutants. Can be used where groundwater is vulnerable, if lined. **Disadvantages:** No reduction in runoff volume. Anaerobic conditions can occur without regular inflow. Land take may limit use in high density sites. May not be suitable for steep sites, due to requirement for high embankments. Colonisation by invasive species could increase maintenance. Perceived health & safety risks may result in fencing and isolation of the pond. **Delivery Partners**: Same as Swales	Biodiversity Thermal attenuation Climate resilience Amenity Aesthetic value Recreation Natural flood mitigation	Medum	Medium	High	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Detention Basins	Category 1	Detention basins are shallow vegetated areas which retain water at times. **Advantages:** Can cater for a wide range of rainfall events and can be used where groundwater is vulnerable, if lined. Simple to design and construct with a potential for dual land use. Easy to maintain. Safe and visible capture of accidental spillages. **Disadvantages:** Little reduction in runoff volume. Detention depths may be constrained by system inlet and outlet levels **Delivery Partners**: Same as Swales	Biodiversity Amenity Aesthetic value Health and wellbeing can double up as play and recreation areas Natural flood mitigation	High	Low	Medium	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo’r Tywi Initiative
Ponds	Category 1	Larger bodies of standing water. Water is moved in out of the pond through runoff and flow. Can be surrounded by vegetation, grass, hard landscapes, and other surroundings **Advantages:** Uptake of phosphate by plants and aquatic flora. Phosphate can also sediment out onto the base of the pond **Disadvantages:** Good practice for construction must be followed as badly designed ponds can act as exporters of dissolved phosphate. Minimal direct infiltration potential. Cannot manage large inputs of water or exceedance flows **Development Partners:** Developers, The Council, Local Highways Agencies, WG, WG Spending Commitments, Besic Payment Scheme, SFS, National Surface Water Management and SuDS Group, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, Wales Green Infrastructure Forum	Biodiversity Amenity Aesthetic value Recreation Thermal attenuation	Medium	Medium	Medium	Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo’r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Constructed Wetlands	Category 1	Wetland creation designed and maintained specifically for maximising P reduction from both storm and foul water discharges. Plant roots can absorb nutrients and incorporate them into the plant structure. Can provide for tertiary treatment after effective primary and secondary foul treatment processes. **Advantages:** Good removal capability for pollutants and can trap large volumes of sediments. If lined, can be used where groundwater is vulnerable. Large wider environmental benefits and high longevity for functioning effectively (50+ years), Reed bed systems can be incorporated into wetlands which can further enhance biodiversity. **Disadvantages:** Land take is high. Requires maintaining sufficient baseflows in dry periods and there is limited depth range for flow attenuation. May release nutrients during non-growing season, which must be mitigated by good design and maintenance. Little reduction in runoff volume and less effective for steep sites and will require significant earthworks. Colonisation by invasive species could increase maintenance. Performance vulnerable to high sediment inflows. P will be bound in sludge which may require disposal and will require extra pre-treatment with solar drying and well managed biosolid spreading to satisfy crop need. Desludging could be every 10 years but depends on the wetland design. May need to replace bed material if it is saturated with nutrients if artificial bed material is used. Seasonal vegetation removal and management. Potential mosquito habitat. **Development Partners:** Developers, The Council, Welsh Rivers Trust, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, NFU Cymru, Local Nature Partnership for North East Wales, United Utilities, DCWW, WG, WG Spending Commitments, Besic Payment Scheme, SFS, Heritage Lottery Fund, Esmee Fairburn Foundation Ofwat Innovation Fund, Water Breakthrough Challenge, Water Discovery Challenge.	Biodiversity Amenity Aesthetic value Recreation Thermal attenuation/temperature regulation Climate resilience Carbon sequestration Natural flood mitigation Potential for water reuse	Medium	Medium	High	Upper Tywi Restoration Project The Wetlands Project The Pontbren Project Four Rivers for LIFE National Surface Water Management and SuDS Group Members Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative Teifi SAC Catchment Phosphate Reduction and Mitigation Project
Integrated Buffer Zones	Category 2	A solution involving increasing grassland, floodplain grassland, beetle banks, woodland and hedgerows. **Advantages:** Good capability for capture of pollutants and wider environmental benefits. **Disadvantages:** Reduced productive area under agriculture may release nutrients during non-growing season. Risk of increasing emissions of nitrous oxide and methane (greenhouse gases) **Development Partners:** Developers, The Council, Welsh Rivers Trust, DCWW, Rivers in Wales Environmental Investment, DCWW Community Fund, NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, NFU Cymru, Cities for Trees, Local Nature Partnership Carmarthenshire , United Utilities, Salmon and Trout Conservation', WG, WG Spending Commitments, Besic Payment Scheme, SFS, Glastir Small Grant Scheme, Heritage Lottery Fund, Woodlands for Wales	Biodiversity Climate resilience Air quality Health and Wellbeing Educational Pest control Noise attenuation Amenity Aesthetic value	Medium	Medium	High	The Pontbren Project Four Rivers for LIFE National Surface Water Management and SuDS Group Members Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative Teifi SAC Catchment Phosphate Reduction and Mitigation Project

Intervention	Mitigation Category	Discussion	Benefits		Feasibility	Maintenance	Effectiveness	Case Studies
Private Sewerage Drainage Fields	Category 2	Network of discharge pipes from septic tank or Package Treatment Plant (PTP) laid in trenches under the ground surface so that effluent can be discharged to the ground. Effluent percolates through soil. Sediment bound P is immobilised and soluble P is bound to soils and sediments. **Advantages:** Likely to be less costly than a wetland system with less maintenance for same P removal performance. Can be delivered up to medium spatial scale (<100 units / <2.0 ha) **Disadvantages:** Longevity of scheme anticipated to be low (10-20 years). Increased usage of the drainage field with time can result in the soils or filter materials sorption capacity being reached. Fields where ground water flood risk is high or water table is within 2.0 m of ground surface are unsuitable. Provides no additional environmental benefits. **Development Partners:** Developers, DCWW Spending Commitments, NFU Cymru, The Council.		Efficiency and increased capacity at WwTW	Medium	Low	High	National Surface Water Management and SuDS Group Members Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
River Channel Re-naturalisation	Category 2	Works to return rivers to a more 'natural state' including: re-meandering, creating berms, pool-riffle systems, riparian planting and reconnecting channel to floodplain. **Advantages:** Good capability for capture of pollutants and wider environmental benefits. Can have high longevity for functioning effectively (50+ years). Minimal maintenance required during the establishment phase of the river channel. **Disadvantages:** Currently no industry standard regarding the design of larger scale river and floodplain re-naturalisation schemes to support the achievement of nutrient removal. Baseline and longer-term monitoring will be required prior to and following the implementation of a scheme in order to determine how much P the scheme is removing. P absorption to sediments is primary process of nutrient removal, however, the process is reversible with desorption occurring if P concentration of water drops below a threshold. Threshold is dynamic as the sorption capacity of sediments changes over time. Management regime may depend on the local context and degree of re-naturalisation. Potentially will be over a year until additional benefits are realised. **Development Partners:** The Council, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, Welsh Rivers Trust , Salmon and Trout Conservation', Land owners / land managers, NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, WG, WG Spending Commitments, Besic Payment Scheme, SFS, Heritage Lottery Fund, Ofwat, Innovation Fund, Water Breakthrough Challenge, Water Discovery Challenge		Natural flood mitigation Biodiversity Amenity Aesthetic value Carbon sequestration Additional pollutant removal Health and well being Air quality Climate resilience	High	Low	Medium	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Drainage Ditch Blocking	Category 2	Placing of barriers across ditches to slow the flow, increase residence times and prevent downstream transport of sediments. **Advantages:** Easy to construct, low construction cost and low maintenance (mainly visual inspections needed). **Disadvantages:** Low predictability / certainty of success, and low removal performance. Lack of UK based evidence for effectiveness; baseline and long-term monitoring is recommended pre-and post-implementation and may result in localised flooding during heavy rainfall events. Dam failure would have implications for P removal efficiency. Limited research currently available on the effectiveness of this method for nutrient removal. **Development Partners:** Land owners / land managers, DCWW, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, The Council, NFU Cymru, Environmental NGOs, NRW, Sustainable Drainage Feasibility Grant, WG.	Natural flood mitigation Biodiversity Additional pollutant removal Carbon sequestration	Medium	Low	Low	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Engineered log Jams	Category 2	Leaky dams made of woody debris constructed to mimic beaver dams and slow flows and re-naturalise river reaches. **Advantages:** P removal achieved through sedimentation, chemicals sorption and biomass assimilation. Well-designed schemes will require little maintenance and could serve up to 100 units. **Disadvantages:** Risk being washed away in flood events – best suited to small watercourses < 2m wide. Lack of research for engineered log jams / beaver dams to confirm potential nutrient removal estimates; monitoring will be required pre/post scheme introduction to determine effectiveness. Potential for increased localised flooding. Adaptive management needed in case repairs are needed. Possibility that P removal may be short-term and that nutrients could be remobilised during floods. **Development Partners:** The Council, NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, DCWW, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, Welsh Rivers Trust , Salmon and Trout Conservation', Landowners / land managers, WG, WG Spending Commitments, Besic Payment Scheme, SFS, Heritage Lottery Fund, Esmee Fairburn Foundation, Ofwat, Innovation Fund, Water Breakthrough Challenge, Water Discovery Challenge	Natural flood mitigation Biodiversity Carbon sequestration Additional pollutant removal	Medium	Low	Low	Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Granular Treatment Media	Category 2	Granular treatment media that has been designed to treat various pollutants. There are phosphorus specific granular treatment media. **Advantages:** Up to 100% TP removal (if infiltration possible and depending on the manufacturer) **Disadvantaged:** P removal highly dependent on manufacturer and how well assets are maintained. Filter media will need to be changed periodically. **Development Partners:** Landowners / land managers, The Council, NRW, Sustainable Drainage Feasibility Grant, Developers, Local Highways Agencies, National Surface Water Management and SuDS Group, Living Streets Cymru.	Potential for grey water recycling May reduce unpleasant odours	Medium	Medium	Medium	Wales Water Management Forum National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative.

Intervention	Mitigation Category	Discussion	Benefits	Feasibility	Maintenance	Effectiveness	Case Studies
Willow Beds	Category 2	Willow beds can be designed to treat stormwater from low/medium risk surfaces of small catchments. They allow capturing, attenuation, and evapotranspiration of captured flows. **Advantages:** Capture, attenuation and evapotranspiration of all flows so no discharge occurs. Uptake of P by the willow. Harvesting willow can be a valuable resource. If built as part of a closed systems, it is effective immediately. **Disadvantages:** Not commonly used in the UK, and where they are, they tend to be for private sewage treatment installations. To have optimal TP removal performance harvesting of willow will be required. Harvesting of willow is a valuable resource but the process is of harvesting it is onerous. Some sediment removal is required at the inlet and any suspended sediment may have to be removed periodically. Little information available currently regarding regulations on their implementation of water treatment. Effective only during the willow growing season. **Development Partners:** Landowners / land managers, The Council , NRW, Sustainable Drainage Feasibility Grant, Four Rivers for Life, DCWW, DCWW Spending Commitments, Rivers in Wales Environmental Investment, DCWW Community Fund, Developers: Could help to deliver Net Benefit for Biodiversity, DCWW, WG, WG Spending Commitments, Besic Payment Scheme, SFS, Heritage Lottery Fund, Ofwat, Innovation Fund, Water Breakthrough Challenge, Water Discovery Challenge.	Biodiversity Natural flood mitigation Aesthetic value Amenity value Carbon sequestration Can harvest the willow which could then be sold (offsets some of the maintenance costs)	Medium	Low	High	The Pontbren Project Natural Flood management plus in the Cadoxton catchment Four Rivers for LIFE National Surface Water Management and SuDS Group Members Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative
Attenuation storage tanks (lined)	Category 2	Lined cellular/crated or other storage below ground (no infiltration). **Advantages:** Particulate P removal through sedimentation of solids upstream of attenuation tank. **Disadvantages:** Attenuation tank is not designed to provide any P removal on its own. P removal highly dependent on upstream features and how well assets are maintained. Filters need changing every few years. **Development Partners:** Landowners / land managers, The Council, NRW, DCWW, DCWW Spending Commitments, Developers: Could help to deliver Net Benefit for Biodiversity, DCWW, WG, WG Spending Commitments, Besic Payment Scheme	Natural flood mitigation	Medium	High	High	Natural Flood management plus in the Cadoxton catchment Wales Water Management Forum Rivers Trust of Wales (Welsh Rivers Trust) Afonydd Cymru The West Wales Rivers Trust Taclo'r Tywi Initiative

Appendix E

Wetland Calculations Technical Notes

30192602-ARC-XX-XX-CA-CE-0001-P1 – Cenarth and Cilgerran
30192602-ARC-XX-XX-CA-CE-0002-P1 – Llandysul, Tregaron and Adpar

Phosphate Reduction and Mitigation (PRAM)

Wetland Calculations Technical Note

Doc Ref: 30192602-ARC-XX-XX-CA-CE-0001-P2

DECEMBER 2023

Version Control (optional)

Version	Date	Author	Checker	Reviewer	Approver
P1	08/12/2023	Elliot Blount-Powell	Matt Brown	Luis Vergara Romero	Renuka Gunasekara
P2	20/12/2023	Elliot Blount-Powell	Matt Brown	Luis Vergara Romero	Renuka Gunasekara

Contents

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Appendices

1 Introduction

To support the outline design of the Cenarth and Cilgerran wetlands being progressed under the Phosphate Reduction and Mitigation (PRAM) project, this technical note provides a summary of the estimated 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 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.

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[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.

[3] The Wye & Usk Foundation (July 2022) Wetland Feasibility, Design and Offsetting. Wetland Development on the River Wye SAC – Titley.

2 Wastewater Treatment Works Summary

2.1.1 Phosphorus concentration

Dŵr Cymru Welsh Water (DCWW) have provided Orthophosphate sampling data for outflow from the Cenarth and Cilgerran Wastewater Treatment Works (WwTWs) for the past 2 years where data exists. Figure 2-1 and Figure 2-2 present the average Orthophosphate at Cenarth WwTW and Cilgerran WwTW respectively. 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 either of these WwTW locations.

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

The average Orthophosphate concentration over the last year (Sep 2022 – Sep 2023) at Cenarth were 4.33mg/l, which is slightly below the 5mg/l backstop limit. However, as shown in Figure 2-1, there have been fluctuations in the Orthophosphate concentrations above the proposed backstop limit of 5mg/l.

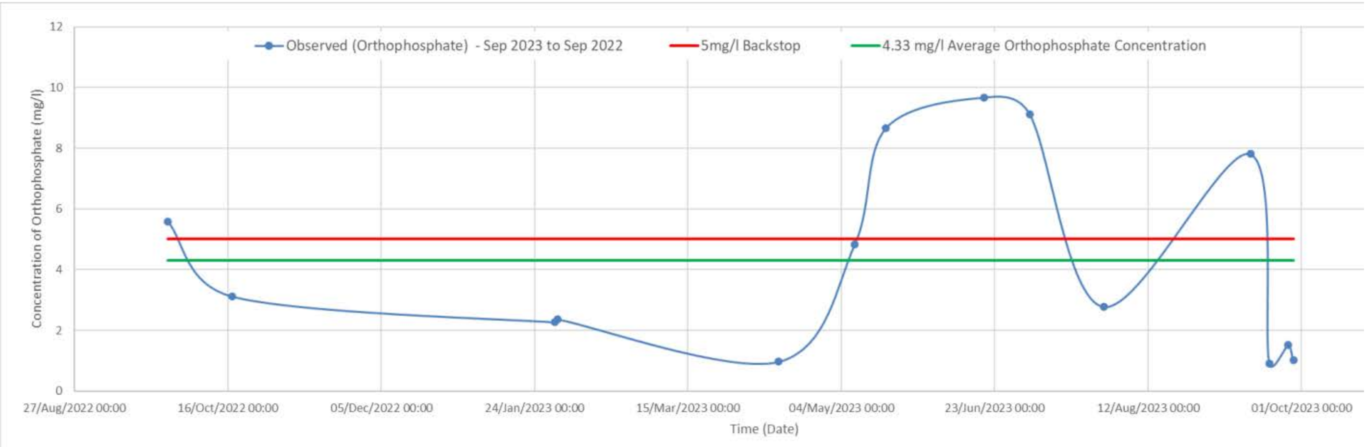

Figure 2-1: Average (Orthophosphate) at Cenarth WwTW - Sep 2023 to Sep 2022

For Cilgerran, the average Orthophosphate concentrations over the last year (Oct 2022 – Oct 2023) were 2.37mg/l, and the year before that (Sep 2021 – Sep 2022) they were 2.48mg/l. As shown in Figure 2-2, there have been no record incidents where the Orthophosphate concentrations exceed the 5mg/l backstop limit. Therefore, it is worth considering whether the wetland would realistically receive a concentration of 5mg/l considering the average is typically half of that. However, reaching 5mg/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.

Section 2.1.2 below details the DWF estimates and permitted values at the two WwTW locations and 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.

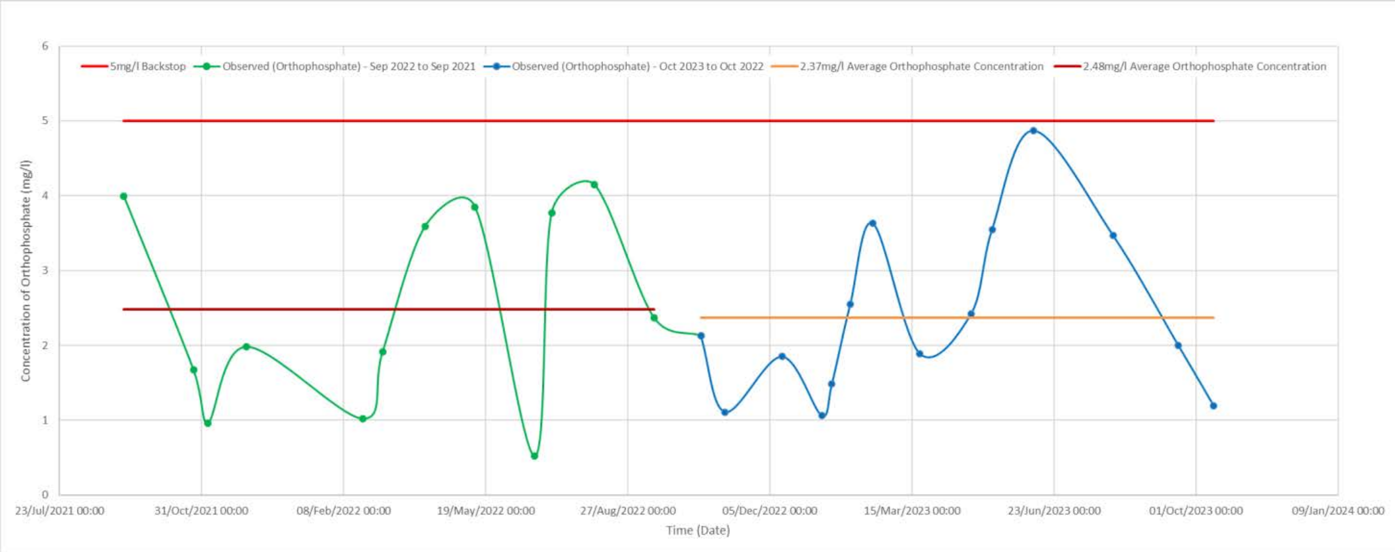

Figure 2-2 Average (Orthophosphate) at Cilgerran WwTW - Oct 2023 to Sep 2021

2.1.2 Permitted Flows and Estimated Design Flows

Table 2-1 summarises the projected Dry Weather Flow (DWF) from Cenarth and Cilgerran 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)	Estimated Existing DWF (m^3/day)	New Homes	New Population	Extra DWF (m^3/day)	Total Population	Total DWF (m^3/day)
Cenarth	680	152	147	38	87	12	767	159
Cilgerran	1,033	408	223	50	115	16	1,148	239

**Assumed average household occupancy rate as 2.3*

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 (m3/day)
Cenarth	4.33 (Sep 2023 - Sep 2022)	152
	5 (backstop TP limit concentration)	152
Cilgerran	2.37 (Oct 2023 to Oct 2022)	408**
		239***
	2.48 (Sep 2022 to Sep 2021)	408**
		239***
	5 (backstop TP limit concentration)	408**
		239***

**Influent concentration of Total Phosphorus*

*** Permitted Flow*

**** Estimated Flow*

Based on Table 2-1, the estimated flow (159m^3/day) for Cenarth WwTW was very similar to the permitted flow (152m^3/day). Therefore, the permitted flow value was used for the wetland design purpose.

For Cilgerran WwTW, the estimated flow (239m^3/day) is substantially lower than the permitted value (408m^3/day). 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 Cenarth and Cilgerran. A summary and interpretation of results is presented in Sections 4 and 5.

3.1 Cenarth

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, 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 two different Ci values (4.33mg/l and 5mg/l) using the fully permitted DWF value of 152m^3/d at the WwTW. 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 Cenarth K-C Inputs and Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
Q	152	152	m^3/d	Design flow (Permitted Flow) – see Table 2.2 and Note 3
Ci	4.33	5	gP/m^3 or mg/l	Inlet TP concentration - see Table 2.2
Ce	1	1	mg/l	Target effluent concentration
C*	0.05	0.05	mg/l	Wetland background concentration (estimated value) – see Note 4

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Values	Values		
k	12	12	m/year	Apparent rate coefficient - see Note 5
Water depth	0.2	0.2	m	Treatment water depth – see Note 6
Total wetland area	0.71	0.78	ha	Estimated wetland area (ha) for the specified Ci and Ce
	7,075	7,783	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	1,415	1,557	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	9.31	10.24	days	The average time taken for water to pass through a wetland - see Note 7

Notes

1. Design Scenario 1 is based on Ci value of 4.33mg/l from the observed Orthophosphate values (Sep 2023 - Sep 2022), as per Table 2.2.
2. Design Scenario 2 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2 – this is a hypothetical scenario mainly for sensitivity testing.
3. Design flow for both Design Scenario 1 and 2 is based on the fully permitted DWF of 152m³/d, as per Table 2.2
4. C* value of 0.05mg/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
5. Apparent rate coefficient is assumed as 12m/year, as per Wetland Feasibility, Design and Offsetting: Wetland Development on the River Wye SAC – Titley Report (July 2022) by The Wye & Usk Foundation
6. Treatment depth is taken as 0.2m, as per Natural England (June 2022) Framework Approach for Responding to Wetland Mitigation Proposals
7. 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.

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

Table 3-2 summarises the P-K-C* inputs and outputs for both the permitted Q (Orthophosphate Sep 2023 – Sep 2022) and the permitted Q (5 mg/l backstop limit) scenarios. The input values are shaded in grey for clarity and Italic text in italics are information related calculating hydraulic loading rate (q).

Table 3-2 Cenarth P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Value	Value		
C_{i-}	4.33	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
C*	0.022	0.022	mg/l	Background concentration of Total Phosphorus (estimated value) – see Note 3
P	6	6	-	Apparent no. of tanks in series
k	10	10	m/yr	Rate coefficient for reduction of Total Phosphorus – see Note 4
Design Flow	*152*	*152*	*m³/d*	*Design flow (Permitted Flow) – see Table 2.2 and Note 5*
***Total** annual hydraulic throughput*	*55,480*	*55,480*	*m³/yr*	*Design Flow (m³/d) X 365*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Unit	Comment
	Value	Value		
***Total** wetland area*	*7,076*	*7,784*	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	7.841	7.127	m/yr	Hydraulic loading rate = Total annual hydraulic throughput (m^3/yr) / Total wetland area (m^2)
Amount of remaining contaminant, Ce - C*	1.36	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
	31.46	28.34	%	
Treatment efficiency of wetland	68.54	71.66	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of 4.33mg/l from the observed Orthophosphate values (Sep 2023 - Sep 2022), as per Table 2.2.
2. Design Scenario 2 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2 – this is undertaken for mainly sensitivity testing purpose should the average inlet concentration is reached the backstop TP limit of 5mg/l for the WwTW effluent.
3. C* value of 0.022mg/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 Water Surface (FWS) systems.
4. 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 10.0m/yr.

5. Design flow for both Design Scenario 1 and 2 is based on the fully permitted DWF of 152m^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 Sep 2023 and Sep 2022. 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. 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 15m^3/day and TP level 5.6mg/l for the low flow scenario and 79.83m^3/day and TP of 2.82mg/l for the high flow scenario.

Therefore, the initial estimated wetland area was then normalised with the fully permitted design flow of 152 m^3/day to recalculate the wetland areas for low flow and high flow scenarios, as shown in Table 3-3.

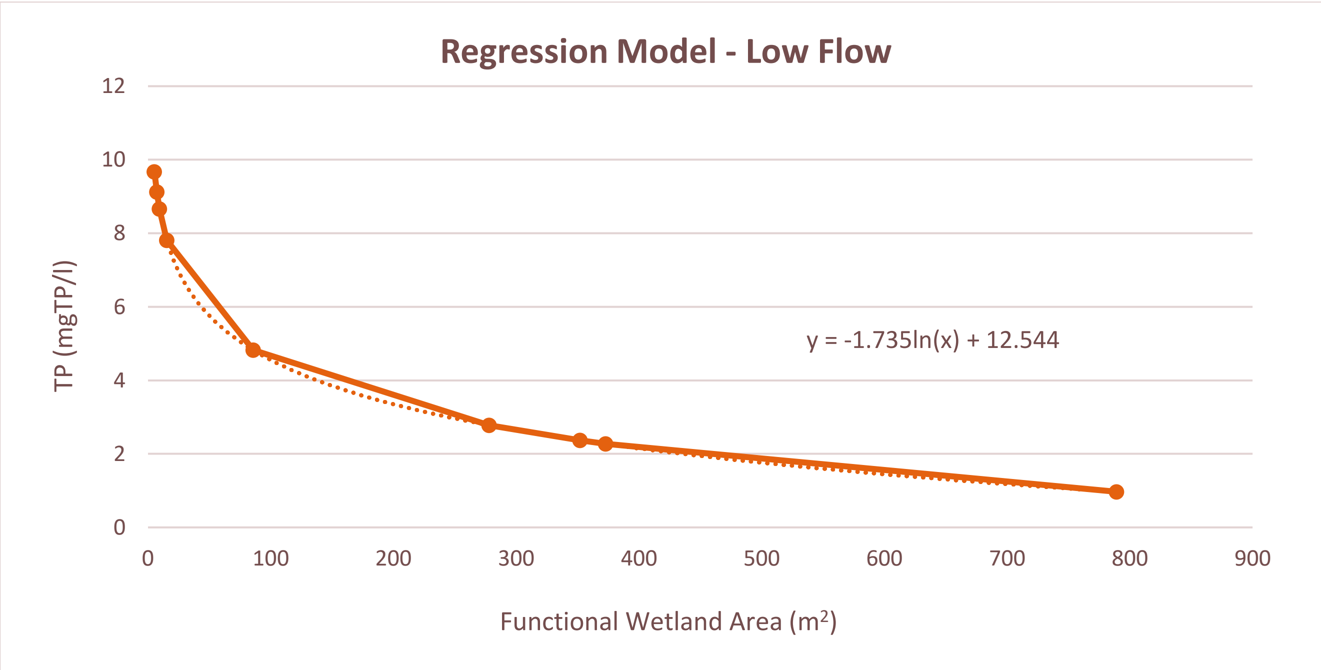

Figure 3-1 TP Regression Curve for Low flow scenario (with DWF of 15.41m^3/day)

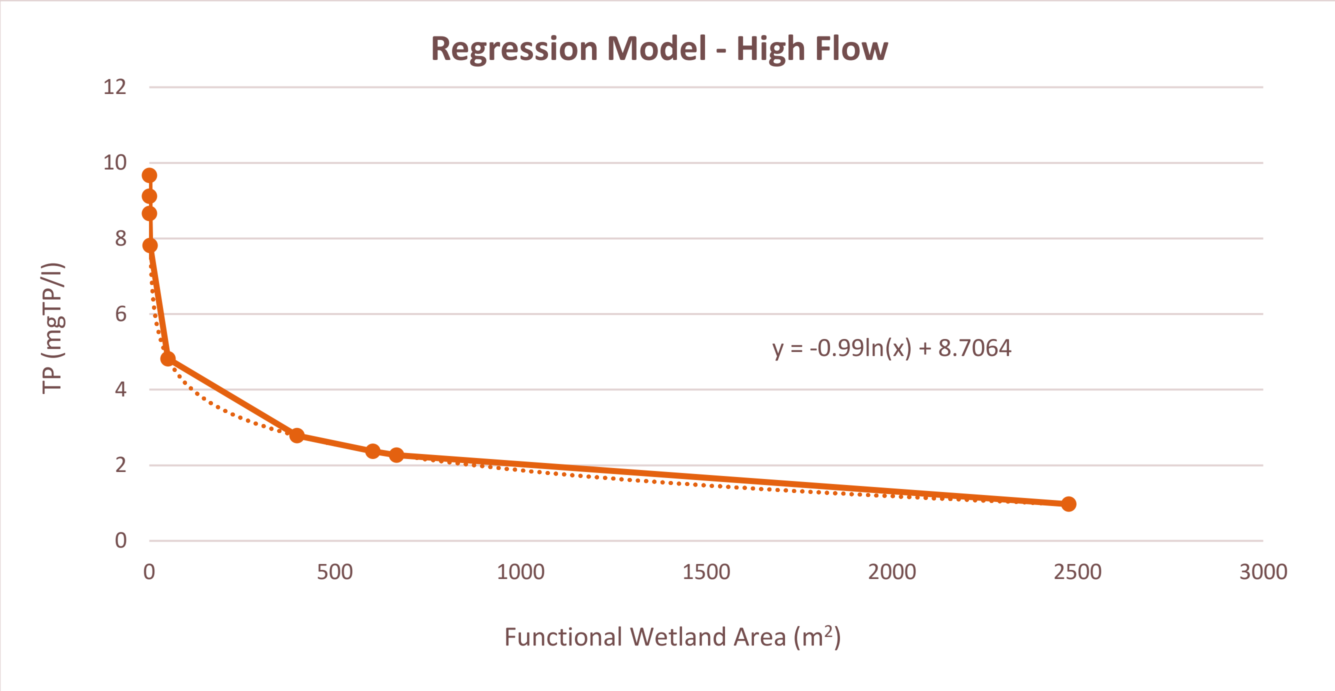

Figure 3-2 TP Regression Curve for High flow scenario (with DWF of 79.83 m3/day)

Table 3-3 Summary of Regression Model Outputs for Cenarth

Regression	Permitted Q , Orthophosphate data (Sep 2023 - Sep 2022)	
	Low Flow Scenario	High Flow Scenario
Desired TP value (mg TP/l)	1	1
Initially Estimated Wetland Area (m^2)	508.7	1,205
Normalised Wetland Area (m^2)*	5,018	11,883

* The Normalised Wetland Area (m^2) is calculated by multiplying the Estimated Wetland Area with the ratio of Permitted Flow (152 m^3/d) and mean flow used in the Titley Regression curve (15.41 m^3/d).

3.2 Cilgerran

As discussed in Section 2.1.1, Orthophosphate concentrations data for Cilgerran showed an average of 2.37mg/l in the period of Oct 2022 – Oct 2023 and 2.48mg/l in the period of Sep 2021 – Sep 2022. 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.

As explained in Section 2.1.3, the estimated flow (239m^3/day) is substantially lower than the permitted value (408m^3/day) for Cilgerran WwTW. Therefore, the wetland design for this is primarily based on the estimated flow, but the permitted flow was also used for sensitivity testing purpose.

3.2.1 k-C* Model

As discussed in Section 3.1.1, the following are the same across all the models and therefore, Table 3-4 and Table 3-5 only present the other specific parameters and outputs related to the Cilgerran WwTW:

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

Table 3-4 Cilgerran k-C Permitted Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3– See Note 3	Unit	Comment
	Values	Values	Values		
Q	408	408	408	m^3/d	Design flow (Permitted Flow) - see Table 2.2 and Note 4
Ci	2.37	2.48	5	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	1	mg/l	Target effluent concentration
Total wetland area	1.10	1.16	2.09	ha	Estimated wetland area (ha) for the specified Ci and Ce
	10,994	11,599	20,893	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	2,199	2,320	4,179	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce
Hydraulic Retention Time (HRT)	5.39	5.69	10.24	days	The average time taken for water to pass through a wetland - see Note 5

Notes:

1. Design Scenario 1 is based on Ci value of 2.37 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 2.48 mg/l from the observed Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2.
3. Design Scenario 3 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2.
4. Design flow for all three scenarios is based on the fully permitted DWF of 408 m^3/d, as per Table 2.2 - this is undertaken for mainly sensitivity testing purpose should the full permitted flow to be treated in the future.
5. 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 3-5 Cilgerran k-C Estimated Design Flow Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3– See Note 3	Unit	Comment
	Values	Values	Values		
Q	239	239	239	m^3/d	Design flow (Estimated Flow) - see Table 2.2 and Note 4
Ci	2.37	2.48	5	gP/m^3	Inlet TP concentration – see Table 2.2
Ce	1	1	1	mg/l	Target effluent concentration
Total wetland area	0.64	0.68	1.22	ha	Estimated wetland area (ha) for the specified Ci and Ce
	6,440	6,794	12,239	m^2	Estimated wetland area (m^2) for the specified Ci and Ce
Wetland volume	1,288	1,359	2,448	m^3	Estimated wetland volume (m^3) for the specified Ci and Ce

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3– See Note 3	Unit	Comment
	Values	Values	Values		
Hydraulic Retention Time (HRT)	5.39	5.69	10.24	days	The average time taken for water to pass through a wetland - see Note 5

Notes:

1. Design Scenario 1 is based on Ci value of 2.37 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 2.48 mg/l from the observed Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2.
3. Design Scenario 3 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2 - this is undertaken for mainly sensitivity testing purpose should the average inlet concentration is reached the backstop TP limit of 5mg/l for the WwTW effluent.
4. Design flow for all three Scenarios is based on the estimated DWF of 239 m^3/d, as per Table 2.2.
5. 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.

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 3-6 and Table 3-7 below:

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

Table 3-6 Cilgerran Permitted Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3– See Note 3	Unit	Comment
	Values	Values	Values		
C_{i-}	2.37	2.48	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	6	6	6	-	Apparent no. of tanks in series
Design Flow	408	408	408	m^3/d	Design flow (Permitted Flow) – see Table 2.2 and Note 4
Total annual hydraulic throughput	148,920	148,920	148,920	m^3/yr	Design Flow (m3/d) X 365
Total wetland area	10,994	11,599	20,893	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	13.5	12.8	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*	1.17	1.18	1.41	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
	49.85	48.08	28.34	%	
Treatment efficiency of wetland	50.15	51.92	71.66	%	% of contaminant removed

Notes

1. Design Scenario 1 is based on Ci value of 2.37 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 2.48 mg/l from the observed Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2.
3. Design Scenario 3 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2.
4. Design flow for all three scenarios is based on the fully permitted DWF of 408 m^3/d, as per Table 2.2 – this is undertaken for mainly sensitivity testing purpose should the full permitted flow to be treated in the future.

Table 3-7 Cilgerran Estimated Design Flow P-K-C Results*

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Values	Values	Values		
C_i	2.37	2.48	5	mg/l	Influent concentration of Total Phosphorus - see Table 2.2
P	6	6	6	-	Apparent no. of tanks in series
Design Flow	239	239	239	m^3/d	Design flow (Estimated Flow) – see Table 2.2 and Note 4
Total annual hydraulic throughput	87,235	87,235	87,235	m^3/yr	Design Flow (m^3/d) X 365
Total wetland area	6,440	6,794	12,239	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

Parameter	Design Scenario 1 – See Note 1	Design Scenario 2 – See Note 2	Design Scenario 3 – See Note 3	Unit	Comment
	Values	Values	Values		
q	13.546	12.840	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*	1.17	1.18	1.41	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
	49.85	48.08	28.34	%	
Treatment efficiency of wetland	50.15	51.92	71.66	%	% of contaminant removed

Notes:

1. Design Scenario 1 is based on Ci value of 2.37 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 2.48 mg/l from the observed Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2.
3. Design Scenario 3 is based on Ci value of 5.0mg/l from the backstop TP limit, as per Table 2.2 - 2 – this is undertaken for mainly sensitivity testing purpose should the average inlet concentration is reached the backstop TP limit of 5mg/l for the WwTW effluent.
4. Design flow for all three Scenarios is based on the estimated DWF of 239 m^3/d, as per Table 2.2

3.2.3 Regression

As discussed in Section *3*, the Regression model has been undertaken to compare the wetland area requirements against the k-C* and P-K-C* model results. However, there is limited confidence in the results as they are based on the phosphorus exponential decay curve of a much smaller WwTW (Titley) rather than an equation. The main limitation of this exercise is that the regression equation used in the analysis is based on a DWF of much lower value of circa 15m3/day and TP level 5.6mg/l for the low flow scenario and 79.83m3/day and TP of 2.82mg/l for the high flow scenario. Table 3-8 below summarises the wetland area requirements for Permitted Design Flow and Estimated Design Flow, based on the Orthophosphate data set being used.

Table 3-8 Summary of Regression Model Outputs for Cilgerran for Permitted Q

Regression	**Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2.2**		**Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2**	
	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)	650	1,666	764	2,414
Normalised Wetland Area (m^2)*	17,203	44,118	20,217	63,908

* The Normalised Wetland Area (m2) is calculated by multiplying the Estimated Wetland Area with the ratio of Permitted Flow (408 m^3/d) and mean flow used in the Titley Regression curve (15.41 m^3/d)

Table 3-9 Summary of Regression Model Outputs for Cilgerran for Estimated Q

Regression	**Orthophosphate values (Oct 2023 - Oct 2022), as per Table 2.2**		**Orthophosphate values (Sep 2022 – Sep 2021), as per Table 2.2**	
	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)	650	1,666	764	2,414
Normalised Wetland Area (m^2)*	10,077	25,843	11,843	37,437

* The Normalised Wetland Area (m2) is calculated by multiplying the Estimated Wetland Area with the ratio of Estimated flow (239m^3/d) and mean flow used in the Titley Regression curve (15.41 m^3/d)

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 include the findings for the wetland sizes shown in current design drawings for the PRAM project as well as a potential larger wetland scheme that may form under a future phase.

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 and **Error! Reference source not found.** present a summary of the P-K-C* model results for the Cilgerran and Cenarth wetlands respectively and the complete results can also be found in Appendix A and Appendix B.

These calculations are performed on the basis of having a minimum of six wetland cells at each location for Cilgerran and Cenarth. The outline design drawings currently show that at Cenarth there are four main wetland areas, which can be further subdivided to potentially create up to eight wetland cells in total. Similarly, the outline design drawings currently show that at Cilgerran there are four main wetland areas, which can be further subdivided to potentially create up to eight wetland cells in total. Therefore, the design calculations currently adopt a sufficient precautionary approach.

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:

- At Cilgerran – 1.25 to 1.5 mg/l
- At Cenarth – 1.25 to 1.5 mg/l

Potentially Expanded Wetland Scheme:

- At Cilgerran – 0.5 to 1.5 mg/l
- At Cenarth – 1.0 mg/l

Also note that the above outlet effluent quality values are based on the estimated DWF and observed Orthophosphate inlet concentration values (i.e. rather than the fully permitted DWF and backstop TP limit values, which were mainly used for sensitivity scenario testing purposes only).

4.1 Cilgerran

						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 (m3/day)	Wetland (ha)	Volume (m3)	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))
Cilgerran - 1.5 ha (potential expanded scheme)	2.37	408**	1.500	3000	7.35	60.59	213.85	38.34	33.37	193.75		0.93	1.46
	2.37	239***	1.500	3000	12.55	77.95	161.16	55.22	28.15	149.02		0.52	1.06
	2.48	408**	1.500	3000	7.35	60.59	223.77	38.34	34.91	202.74		0.98	1.53
	2.48	239***	1.500	3000	12.55	77.95	168.64	55.22	29.46	155.94		0.55	1.11
	5*	408**	1.500	3000	7.35	60.59	451.15	38.34	70.39	408.76		1.97	3.08
	5*	239***	1.500	3000	12.55	77.95	340.00	55.22	59.39	314.39		1.10	2.24
Cilgerran - 0.6ha (**current design**)	2.37	408**	0.600	1200	2.94	32.29	113.96	17.97	15.64	101.11		1.60	1.94
	2.37	239***	0.600	1200	5.02	47.86	98.95	28.42	14.49	88.70		1.24	1.70
	2.48	408**	0.600	1200	2.94	32.29	119.25	17.97	16.36	105.80		1.68	2.03
	2.48	239***	0.600	1200	5.02	47.86	103.54	28.42	15.16	92.82		1.29	1.78
	5*	408**	0.600	1200	2.94	32.29	240.43	17.97	32.99	213.32		3.39	4.10
	5*	239***	0.600	1200	5.02	47.86	208.75	28.42	30.57	187.13		2.61	3.58

* Backstop TP Limit ** Permitted DWF *** Estimated DWF

4.2 Cenarth

						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 (m3/ day)	Wetland (ha)	Volume (m3)	HRT (days)	Removal efficiency, P = 6 (%)	Annual Tp removal, P = 6 (Kg/year)	Removal efficiency, P = 6 (%)	Annual Tp removal, P = 6 (Kg/year)	P = 6 (kg/yr)	Final Effluent TP (mg/l), P = 6	Final Effluent TP (mg/l), P = 6)
Cenarth 1.0ha (potential expanded scheme)	4.33	152*	1.000	2000	13.16	79.32	190.55	56.81	33.65	176.56	0.90	1.87
	5*	152*	1.000	2000	13.16	79.32	220.03	56.81	38.86	203.88	1.03	2.16
Cenarth - 0.7ha **(current design)**	4.33	152*	0.700	1400	9.21	68.18	163.79	45.11	26.72	149.56	1.38	2.38
	5*	152*	0.700	1400	9.21	68.18	189.13	45.11	30.86	172.70	1.59	2.74

* Backstop TP Limit   ** Permitted DWF/ Estimated DWF

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 designs for Cenarth and Cilgerran under the PRAM project.

Table 5-1 below summarises the wetland area requirements and effective removal of TP for Cenarth and Cilgerran wetlands. The results show that the current design wetland areas, 0.7 ha for Cenarth and 0.6 ha for Cilgerran, the wetlands would provide in excess of the treatment performance to mitigate for the proposed developments under the current LDPs of Ceredigion and Pembrokeshire to achieve nutrient neutrality requirement. The results also show that future growth in Ceredigion and Pembrokeshire could be potentially mitigated for by expanding these wetland areas. If additional houses are not to come forward at these WwTW locations then both the current wetland designs and future expanded schemes would help to achieve favourable ecological conditions of the Afon Teifi SAC.

Key advantages of the wetland scheme at Cenarth over Cilgerran wetland scheme include:

- It can also offset the increased phosphorus discharges from the downstream Abercych and Cilgerran WwTW locations
- It has a higher phosphorus inlet concentration than Cilgerran, allowing a larger TP annual budget to be removed with a smaller wetland area

As mentioned before, these calculations are performed on the basis of having a minimum of six wetland cells at each location for Cilgerran and Cenarth. The outline design drawings currently show that at Cenarth there are four main wetland areas, which can be further subdivided to potentially create up to eight wetland cells in total to maximise the treatment performance. Similarly, the outline design drawings currently show that at Cilgerran there are four main wetland areas, which can be further subdivided to potentially create up to eight wetland cells in total. Therefore, the design calculations currently adopt a sufficient precautionary approach.

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 design 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 Cenarth and Cilgerran 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)				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**	
Cenarth	Cenarth Abercych	65.51 (see Note 1)	99 (see Note 1)	0.662	10,000 (Including Future Expansion)	190.550	176.550	**288**	**267**	220.030	203.880	**333**	**308**	0.450
	Cilgerran				**7,000 (Current Scheme)**	163.790	149.56	**248**	**226**	189.130	172.700	**286**	**261**	**0.315**
Cilgerran	Cilgerran	32.45 (see Note 2)	50	0.649	15,000 (Including Future Expansion)	161.160	**149.020**	**248**	**230**	451.150	408.760	**695**	**630**	0.675
					6,000 (Current Scheme)	98.95	88.7	**152**	**137**	240.43	213.32	**370**	**329**	**0.270**

Note 1 - Cenarth Wetland

Ceredigion County Council (CeCC) LDP Total Houses to mitigate = 38 (all 38 houses at Cenarth WwTW)
CeCC LDP Total Annual Phosphorus Budget = 25.38 Kg TP/Year

Pembrokeshire County Council (PCC) LDP Total Houses to mitigate = 61 (50 houses at Cilgerran WwTW and 11 houses at Abercych WwTW)
PCC LDP Total Annual Phosphorus Budget = 40.13 Kg TP/Year

Combined CeCC and PCC LDP houses to mitigate = 99
Combined CeCC and PCC Total Annual Phosphorus Budget to mitigate = 65.51 Kg TP/year

Note 2- Cilgerran Wetland

PCC LDP Total Houses to mitigate = 50 (all 50 houses at Cilgerran WwTW)
PCC LDP Total Annual Phosphorus Budget to mitigate = 32.45 Kg TP/Year

Appendix A

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

Current Design

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 - Cenarth Permitted Q, Orthophosphate Sep 2023 - Sep 2022	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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
		GBA:	Resilience - Water
KEY	CLIENT: Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
Input values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP
Calculated values		APPROVER:	0
Linked values	SUBJECT: Process Design Calculations - Cenarth	DATE:	30/11/2023
Assumed values		DOC. No:	0
Iterated values	SECTION: P-k-c	SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	4.33	Influent concentration of Total Phosphorus (Sep 2022 - Sep 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	7,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	7.925714286	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	1.37	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
contaminant, Ce - C*	%	31.82	
Treatment efficiency of wetland	%	68.18	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
KEY	CLIENT: Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
Input values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP
Calculated values		APPROVER:	0
Linked values	SUBJECT: Process Design Calculations - Cenarth	DATE:	30/11/2023
Assumed values		DOC. No:	0
Iterated values	SECTION: P-k-c	SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	4.33	Influent concentration of Total Phosphorus (Sep 2022 - Sep 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	3,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	15.85142857	

Total Phosphorus

Parameter	Unit	Value	References/Comments
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
	%	54.89	
Treatment efficiency of wetland	%	45.11	% 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 - Cenarth	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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:	Resillience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.7ha (current design)	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cenarth Permitted Q, Assumed Backstop/ Current TP	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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
		GBA:	Resillience - Water
KEY	CLIENT: Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
Input values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.7ha (current design)	CHECKER:	EBP
Calculated values		APPROVER:	0
Linked values	SUBJECT: Process Design Calculations - Cenarth	DATE:	30/11/2023
Assumed values		DOC. No:	0
Iterated values	SECTION: P-k-c	SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	7,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	7.925714286	

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
	%	31.82	
Treatment efficiency of wetland	%	68.18	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
KEY		GBA:	Resillience - Water
Input values	CLIENT: Ceredigion County Council	REVISION:	P01
Calculated values		AUTHOR:	RG
Linked values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.7ha (current design)	CHECKER:	EBP
Assumed values		APPROVER:	0
Iterated values	SUBJECT: Process Design Calculations - Cenarth	DATE:	30/11/2023
		DOC. No:	0
	SECTION: P-k-c	SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	3,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	15.85142857	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining contaminant, Ce - C*	-	2.73	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
	%	54.89	
Treatment efficiency of wetland	%	45.11	% 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.

Future Expansion

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 - Cenarth Permitted Q, Orthophosphate Sep 2023 - Sep 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**		**LV**	**12/01/23**	

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

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	4.33	Influent concentration of Total Phosphorus (Sep 2022 - Sep 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.548	

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	0.89	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
	%	20.68	
Treatment efficiency of wetland	%	79.32	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	4.33	Influent concentration of Total Phosphorus (Sep 2022 - Sep 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	11.096	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining contaminant, Ce - C*	-	1.86	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
	%	43.19	
Treatment efficiency of wetland	%	56.81	% 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:	Resillience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cenarth 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:	Resillience - Water		
Input values	PROJECT: Wetland Sites - Teifi Wetlands	REVISION:	P01		
Calculated values		AUTHOR:	RG		
Linked values	SUBJECT: Process Design Calculations - Cenarth	CHECKER:	EBP		
Assumed values		APPROVER:	0		
Iterated values		DATE:	24/11/2023		
		DOC. No:	0		
	SECTION: P-k-c	SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	10,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.548	

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
	%	20.68	
Treatment efficiency of wetland	%	79.32	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	152	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	55480	
Total wetland area	m^2	5,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	11.096	

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.15	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
	%	43.19	
Treatment efficiency of wetland	%	56.81	% of contaminant removed

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

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.

Appendix B

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

Current Design

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Estimated Q, Orthophosphate Oct 2022 - Oct 2023	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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
			GBA:	Resilience - Water
KEY	CLIENT:	Ceredigion County Council	REVISION:	P01
			AUTHOR:	RG
Input values	PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha	CHECKER:	EBP
Calculated values			APPROVER:	0
Linked values	SUBJECT:	Process Design Calculations - Cilgerran	DATE:	30/11/2023
Assumed values			DOC. No:	0
Iterated values	SECTION:	P-k-c	SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	14.53917	

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.22	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
	%	52.14	
Treatment efficiency of wetland	%	47.86	% of contaminant removed

ARCADIS	CALCULATIONS		PROJECT No:	30192602		
KEY	CLIENT:	Ceredigion County Council	GBA:	Resilience - Water		
Input values	PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha	REVISION:	P01		
Calculated values			AUTHOR:	RG		
Linked values	SUBJECT:	Process Design Calculations - Cilgerran	CHECKER:	EBP		
Assumed values			APPROVER:	0		
Iterated values	SECTION:	P-k-c	DATE:	30/11/2023		
			DOC. No:	0		
			SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	29.07833333	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	1.68	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
contaminant, Ce - C*	%	71.58	
Treatment efficiency of wetland	%	28.42	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Cilgerran	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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 - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Estimated Flow, Orthophosphate Sep 2021 - Sep 2022	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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		GBA:	Resilience - Water
	CLIENT: Ceredigion County Council	REVISION:	P01
Input values		AUTHOR:	RG
Calculated values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
Linked values		APPROVER:	0
Assumed values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	30/11/2023
Iterated values		DOC. No:	0
	SECTION: P-k-c	SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	14.53916667	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	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
contaminant, Ce - C*	%	52.14	
Treatment efficiency of wetland	%	47.86	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
KEY	CLIENT: Ceredigion County Council	GBA:	Resilience - Water
Input values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	REVISION:	P01
Calculated values		AUTHOR:	RG
Linked values	SUBJECT: Process Design Calculations - Cilgerran	CHECKER:	EBP
Assumed values		APPROVER:	0
Iterated values	SECTION: P-k-c	DATE:	30/11/2023
		DOC. No:	0
		SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	29.07833333	

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	1.76	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
	%	71.58	
Treatment efficiency of wetland	%	28.42	% of contaminant removed

CALCULATIONS		PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Cilgerran	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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 - Cilgerran - reduced to 0.6ha (current desi Estimated Flow, Assumed Backstop TP	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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 - Cilgerran - reduced to 0.6ha (current design)	CHECKER:	EBP		
Assumed values		APPROVER:	0		
Iterated values		DATE:	30/11/2023		
		DOC. No:	0		
	SECTION: P-k-c	SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	14.53916667	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining contaminant, Ce - C*	-	2.60	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
	%	52.14	
Treatment efficiency of wetland	%	47.86	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
KEY		GBA:	Resilience - Water
Input values	CLIENT: Ceredigion County Council	REVISION:	P01
Calculated values		AUTHOR:	RG
Linked values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP
Assumed values		APPROVER:	0
Iterated values	SUBJECT: Process Design Calculations - Cilgerran - reduced to 0.6ha (current design)	DATE:	30/11/2023
		DOC. No:	0
	SECTION: P-k-c	SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	29.07833333	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	3.56	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
contaminant, Ce - C*	%	71.58	
Treatment efficiency of wetland	%	28.42	% 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 - Cilgerran - reduced to 0.6ha (current design)	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Permitted Q, Orthophosphate Oct 2022 - Oct 2023	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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
Input values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	GBA:	Resilience - Water
Calculated values	SUBJECT: Process Design Calculations - Cilgerran	REVISION:	P01
Linked values	SECTION: P-k-c	AUTHOR:	RG
Assumed values		CHECKER:	EBP
Iterated values		APPROVER:	0
		DATE:	30/11/2023
		DOC. No:	0
		SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	24.82	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	1.59	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
contaminant, Ce - C*	%	67.71	
Treatment efficiency of wetland	%	32.29	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
KEY	CLIENT: Ceredigion County Council	GBA:	Resilience - Water
Input values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	REVISION:	P01
Calculated values		AUTHOR:	RG
Linked values	SUBJECT: Process Design Calculations - Cilgerran	CHECKER:	EBP
Assumed values		APPROVER:	0
Iterated values	SECTION: P-k-c	DATE:	30/11/2023
		DOC. No:	0
		SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	49.64	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining contaminant, Ce - C*	-	1.93	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
	%	82.03	
Treatment efficiency of wetland	%	17.97	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Cilgerran	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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 - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Permitted Q, Orthophosphate Sep 2021 - Sep 2022	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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 - reduced to 0.6ha (current design)	REVISION:	P01		
Calculated values	SUBJECT: Process Design Calculations - Cilgerran	AUTHOR:	RG		
Linked values	SECTION: P-k-c	CHECKER:	EBP		
Assumed values		APPROVER:	0		
Iterated values		DATE:	30/11/2023		
		DOC. No:	0		
		SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	24.82	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining contaminant, Ce - C*	-	1.66	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
	%	67.71	
Treatment efficiency of wetland	%	32.29	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602		
		GBA:	Resilience - Water		
KEY	CLIENT: Ceredigion County Council	REVISION:	P01		
Input values		AUTHOR:	RG		
Calculated values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP		
Linked values		APPROVER:	0		
Assumed values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	30/11/2023		
Iterated values		DOC. No:	0		
	SECTION: P-k-c	SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	49.64	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	2.02	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
contaminant, Ce - C*	%	82.03	
Treatment efficiency of wetland	%	17.97	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Cilgerran	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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.

CALCULATIONS

CLIENT:	Ceredigion County Council	PROJECT No:	30192602
		GBA:	Resilience - Water
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	REVISION:	P01
		AUTHOR:	RG
		CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Permitted Q, Backstop TP	DATE:	30/11/2023
		DOC. No:	
SECTION:	Front Sheet	SHEET:	1 OF 4

ISSUE	TOTAL SHEETS	AUTHOR	DATE	CHECKED BY	DATE	APPROVED BY	DATE	COMMENTS
P01	**4**	**RG**	**30/11/23**	**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		
			GBA:	Resilience - Water		
KEY	CLIENT:	Ceredigion County Council	REVISION:	P01		
Input values			AUTHOR:	RG		
Calculated values	PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP		
Linked values			APPROVER:	0		
Assumed values	SUBJECT:	Process Design Calculations - Cilgerran	DATE:	30/11/2023		
Iterated values			DOC. No:	0		
	SECTION:	P-k-c	SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	6,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	24.82	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	3.37	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
contaminant, Ce - C*	%	67.71	
Treatment efficiency of wetland	%	32.29	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
KEY	CLIENT: Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
Input values	PROJECT: Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
Calculated values		APPROVER:	0
Linked values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	30/11/2023
Assumed values		DOC. No:	0
Iterated values	SECTION: P-k-c	SHEET:	3 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	3,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	49.64	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	4.08	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
contaminant, Ce - C*	%	82.03	
Treatment efficiency of wetland	%	17.97	% of contaminant removed

ARCADIS	CALCULATIONS	PROJECT No:	30192602
		GBA:	Resilience - Water
CLIENT:	Ceredigion County Council	REVISION:	P01
		AUTHOR:	RG
PROJECT:	Wetland Sites - Teifi Wetlands - reduced to 0.6ha (current design)	CHECKER:	EBP
		APPROVER:	0
SUBJECT:	Process Design Calculations - Cilgerran	DATE:	45260
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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.

Future Expansion

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 - Cilgerran Estimated 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)

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.81567	
Total Phosphorus			
Amount of remaining contaminant, Ce - C*	-	0.52	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
	%	22.05	
Treatment efficiency of wetland	%	77.95	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus (Oct 2022 - Oct 2023)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	11.63133333	

Total Phosphorus

Amount of remaining	-	1.05	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
contaminant, Ce - C*	%	44.78	
Treatment efficiency of wetland	%	55.22	% 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 - Cilgerran	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 - Cilgerran Estimated Flow, Orthophosphate Sep 2021 - Sep 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

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.815666667	

Total Phosphorus

Amount of remaining	-	0.54	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
contaminant, Ce - C*	%	22.05	
Treatment efficiency of wetland	%	77.95	% 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 - Cilgerran	CHECKER:	EBP		
Assumed values		APPROVER:	0		
Iterated values		DATE:	24/11/2023		
		DOC. No:	0		
	SECTION: P-k-c	SHEET:	3	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	11.63133333	

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
	%	44.78	
Treatment efficiency of wetland	%	55.22	% 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 - Cilgerran	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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 (m3/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 - Cilgerran Estimated Flow, Assumed 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
		GBA:	Resilience - Water
KEY	CLIENT: Ceredigion County Council	REVISION:	P01
Input values		AUTHOR:	RG
Calculated values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP
Linked values		APPROVER:	0
Assumed values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	24/11/2023
Iterated values		DOC. No:	0
	SECTION: P-k-c	SHEET:	2 OF 4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	5.815666667	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	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
contaminant, Ce - C*	%	22.05	
Treatment efficiency of wetland	%	77.95	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Assumed Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	239	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	87235	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	11.63133333	

Total Phosphorus

Amount of remaining contaminant, Ce - C*	-	2.23	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
	%	44.78	
Treatment efficiency of wetland	%	55.22	% 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 - Cilgerran	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	9.928	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	0.93	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
contaminant, Ce - C*	%	39.41	
Treatment efficiency of wetland	%	60.59	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.37	Influent concentration of Total Phosphorus
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	19.856	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	1.45	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
contaminant, Ce - C*	%	61.66	
Treatment efficiency of wetland	%	38.34	% 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 - Cilgerran	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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):

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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 - Cilgerran Permitted Q, Orthophosphate Sep 2021 - Sep 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		GBA:	Resilience - Water		
Input values	CLIENT: Ceredigion County Council	REVISION:	P01		
Calculated values		AUTHOR:	RG		
Linked values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP		
Assumed values		APPROVER:	0		
Iterated values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	24/11/2023		
		DOC. No:	0		
	SECTION: P-k-c	SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	9.928	

Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	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
contaminant, Ce - C*	%	39.41	
Treatment efficiency of wetland	%	60.59	% of contaminant removed

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

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	2.48	Influent concentration of Total Phosphorus (Sep 2021 - Sep 2022)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
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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	408	Input flow rate into here
Total annual hydraulic throughput	m^3/yr	148920	
Total wetland area	m^2	7,500	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
q	m/yr	19.856	

Total Phosphorus

Amount of remaining	-	1.52	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
contaminant, Ce - C*	%	61.66	
Treatment efficiency of wetland	%	38.34	% 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 - Cilgerran	DATE:	45254
		DOC. No:	0
SECTION:	References	SHEET:	4 OF 4

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
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CLIENT:	Ceredigion County Council	REVISION:	P01
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PROJECT:	Wetland Sites - Teifi Wetlands	CHECKER:	EBP
		APPROVER:	
SUBJECT:	Process Design Calculations - Cilgerran Permitted 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**	

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ARCADIS	CALCULATIONS	PROJECT No:	30192602		
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Input values		AUTHOR:	RG		
Calculated values	PROJECT: Wetland Sites - Teifi Wetlands	CHECKER:	EBP		
Linked values		APPROVER:	0		
Assumed values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	24/11/2023		
		DOC. No:	0		
Iterated values	SECTION: P-k-c	SHEET:	2	OF	4

Process Calculations

Parameter	Unit	Value	References/Comments
$C_{i\text{-}TP}$	mg/l	5	Influent concentration of Total Phosphorus (Backstop TP)
C^*_{TP}	mg/l	0.022	Background concentration of Total Phosphorus
k_{TP}	m/yr	10	Rate coefficient for reduction of Total Phosphorus
$\theta_{\text{-}TP}$	-	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	408	Input flow rate into here
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Total wetland area	m^2	15,000	**Active** cell area (i.e. excluding diving berms, spreader channels and level control structures)
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Total Phosphorus

Parameter	Unit	Value	References/Comments
Amount of remaining	-	1.96	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
contaminant, Ce - C*	%	39.41	
Treatment efficiency of wetland	%	60.59	% of contaminant removed

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Iterated values	SUBJECT: Process Design Calculations - Cilgerran	DATE:	24/11/2023		
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q	m/yr	19.856	

Total Phosphorus

Amount of remaining	-	3.07	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
contaminant, Ce - C*	%	61.66	
Treatment efficiency of wetland	%	38.34	% of contaminant removed

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SECTION:	References	SHEET:	4 OF 4

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