ADVICE ON ACHIEVING NUTRIENT NEUTRALITY FOR NEW DEVELOPMENT IN THE SOLENT REGION

for
Local Planning Authorities

SECTION 1 INTRODUCTION

1.1 The water environment within the Solent region is one of the most important for wildlife in the United Kingdom. The Solent water environment is internationally important for its wildlife and is protected under the Water Environment Regulations[1] and the Conservation of Habitats and Species Regulations[2] as well as national protection for many parts of the coastline and their sea.[3] There are high levels of nitrogen and phosphorus input to this water environment with sound evidence that these nutrients are causing eutrophication at these designated sites. These nutrient inputs are currently caused mostly by wastewater from existing housing and agricultural sources. The resulting dense mats of green algae are impacting on the Solent's protected habitats and bird species.

1.2 There is uncertainty as to whether new growth will further deteriorate designated sites. This issue has been subject to detailed work commissioned by local planning authorities (LPAs) in association with Natural England, Environment Agency and water companies. This strategic work, which updates early studies, is on-going. Until this work is complete, the uncertainty remains and the potential for future housing developments across the Solent region to exacerbate these impacts creates a risk to their potential future conservation status.

1.3 One way to address this uncertainty is for new development to achieve nutrient neutrality. Nutrient neutrality is a means of ensuring that development does not add to existing nutrient burdens and this provides certainty that the whole of the scheme is deliverable in line with the requirements of the Conservation of Habitats and Species Regulations 2017 (as amended).

1.4 This report sets out the planning and environmental context for this nutrient neutral approach as well as a practical methodology to calculating how nutrient neutrality can be achieved. This methodology is based on best available scientific knowledge, and will be subject to revision as further evidence is obtained.

1.5 It is Natural England's advice to local planning authorities and applicants to be as precautionary as possible when addressing uncertainty and calculating nutrient budgets. Using a precautionary approach to the calculations and solutions gives the local planning authority and applicants the certainty needed for their assessments.

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[1] The Water Environment (Water Framework Directive) (England and Wales) Regulations 2017
[2] Conservation of Habitats and Species Regulations (England and Wales) Regulations 2017 (as amended)
[3] Including Wildlife and countryside Act 1981 as amended, Countryside and Rights of Way Act 200, Marine and Coastal Access Act 2009, Natural Environment and Rural Communities Act 2006

SECTION 2 PLANNING CONTEXT

Integrated Water Management Studies

2.1 In 2016, an Integrated Water Management Study (IWMS) for South Hampshire was commissioned by the Partnership for Urban South Hampshire (PUSH) Authorities, with the Environment Agency and Natural England. This examined the delivery of development growth in relation to legislative and government policy requirements for designated sites and wider biodiversity. It updated an earlier study in 2008. Similar studies have also been undertaken for Chichester Harbour and growth in Sussex (2018) though this study was largely for Water Framework Directive assessments.

2.2 The IWMS for South Hampshire was completed in March 2018 and identified that there is currently uncertainty as to whether new housing growth can be accommodated without having a detrimental effect upon the water environment.

2.3 The updated IWMS report in March 2018 concluded that there is uncertainty about the impact of local plan growth on the designated sites, especially after 2020. There was uncertainty about the efficacy of catchment measures to deliver the required reductions in nitrogen levels, and/or whether the upgrades to wastewater treatment works will be sufficient to accommodate the quantity of new housing proposed.

2.4 To examine this issue further, local planning authorities set up a Water Quality Working Group in South Hampshire to add to the one already in existence for Chichester with the Environment Agency, Natural England and water companies. The objectives of these groups include identifying and analysing the existing evidence gaps and evaluating the need for strategic mitigation measures. The primary focus of this work is to address the uncertainty associated with strategic local plan growth.

Natural England's position

2.5 Following completion of the IWMS in March 2018, Natural England has been advising that larger development (in excess of 200-300 houses), including all EIA development, should calculate a nutrient budget and achieve nutrient neutrality. As larger schemes are phased over many years, there was a risk that mitigation would be required in the later stages of the project after 2020. Early consideration of the issues ensures that any potential risks are addressed at the outset and provides the applicant with confidence that the development is deliverable.

2.6 During the summer of 2018, a detailed review of the condition of designated sites in the Solent harbours was undertaken (see next section). The best available up-to-date evidence has identified that some designated sites are in unfavourable condition due to existing levels of nutrients and unfavourable conservation status. These sites are therefore at risk from additional nutrient inputs.

2.7 It is Natural England's view that there is a likely significant effect on the internationally designated sites (Special Protection Areas, Special Areas of Conservation, potential Special Protection Areas) due to the increase in wastewater from the new developments coming forward.

2.8 The uncertainty about the impact of new development on designated sites needs to be recognised for all development proposals that are subject to new planning permissions and have inevitable wastewater implications. These implications, and all other matters capable of having a significant effect on designated sites in the Solent, must be addressed in the ways required by Regulation 63 of the Conservation of Habitats and Species Regulations 2017.

2.9 Where there is a likelihood of significant effects (excluding any measures intended to avoid or reduce harmful effects on the European site), or there are uncertainties, a competent authority should fully assess (by way of an "appropriate assessment") the implications of the proposal in view of the conservation objectives for the European site(s) in question. Appropriate assessments cannot have lacunae and must contain complete, precise and definitive findings and conclusions capable of removing all reasonable scientific doubt as to the effects of the works proposed on the protected site concerned. Complete information is required to ensure that the proposal will not affect the integrity of the international sites.

2.10 Natural England advises that the wastewater issue is examined within appropriate assessments and that the existing nutrient and conservation status of the receiving waters be taken into account.

2.11 LPAs and applicants will be aware of recent CJEU decisions regarding the assessment of elements of a proposal aimed toward mitigating adverse effects on designated sites and the need for certainty that mitigating measures will achieve their aims. The achievement of nutrient neutrality, if scientifically and practically effective, is a means of ensuring that development does not add to existing nutrient burdens.

Joint working

2.12 The Water Quality Working Groups draw together expertise from local planning authorities, Environment Agency, Natural England and the water companies to examine this uncertainty further and progress an approach that ensures that development can progress in a timely manner whilst ensuring the requirements of the Habitats Regulations are met.

2.13 The Habitats Regulations require any uncertainty to be appropriately recognised and addressed. It is the Local Planning Authority, as competent authority under the provisions of the Habitats Regulations, which requires the evidence and certainty to undertake the appropriate assessment in order to fully assess the implications of the proposal in view of the conservation objectives for the international site in question.

2.14 Natural England is working closely with local planning authorities to progress options that achieve nutrient neutrality. It is appreciated that this may be difficult for smaller developments, developments on brownfield land or developments that are well-progressed in the planning system.

2.15 Natural England has advised affected local planning authorities to set up Borough-wide or strategic approaches that developments can contribute to thereby ensuring that this uncertainty is fully addressed by all applications and is working closely with affected local planning authorities to help address this issue.

SECTION 3 ENVIRONMENTAL CONTEXT

Designated sites review

3.1 During 2018, Natural England assessed designated site condition in the Solent harbours to evaluate the levels of nitrogen within the water environment and the associated impact on designated sites. Detailed assessments are available on Defra's Magic Map. An updated review is complete for designated sites in Hampshire and Chichester Harbour. The review of the estuaries on the Isle of Wight is on-going.

3.2 This assessment revised and updated the condition assessment for estuarine water quality in relation to the interest features of the designated sites. It examined the recorded levels of nitrogen in the harbours and compared this with evidence of phytoplankton and macroalgae, specifically the percentage cover of dense opportunistic green macroalgae. A brief summary of the condition classes follows.

Unfavourable no change

3.3 This work identified that there are sections of the designated sites in the Solent that are unfavourable for the interest features on the weight of evidence of elevated levels of inorganic nitrogen and biological indication of eutrophication shown by the abundance of macroalgae. Where sites are recorded as unfavourable, the percentage cover of opportunistic green macroalgae is greater than 75%. There is also poor evidence of a reducing nutrient status that would be adequate to substantially prevent the growth of dense macroalgae mats.

3.4 There are unfavourable (no change) units within the following harbours: Solent and Southampton Water, Portsmouth Harbour, Chichester Harbour. In addition there is a more detailed, follow-on assessment, to review trends in the interest features of Chichester Harbour that is ongoing. This study is determining if there is evidence of improving trends, of no change or if the Harbour condition is declining.

Unfavourable recovering

3.5 The review identified that there are parts of Langstone Harbour where the water environment of the unit is assessed as unfavourable for the interest features on the weight of evidence on inorganic nitrogen and biological indication of eutrophication shown by the abundance of macroalgae (>75% cover density), but recovering on the basis of a large reduction in nutrient inputs through diversion of wastewater. The unit is considered 'at risk' of not recovering to a favourable situation on the water environment as it is unclear whether the nutrient status will become adequate to substantially prevent the growth of dense macroalgae mats in parts of the harbour.

3.6 There are unfavourable (recovering) units within the following harbours: Langstone Harbour.

Favourable – high risk

3.7 Some sections of the designated sites in the Solent are in favourable condition but this is borderline and these areas are at high risk. At these sites, there is not generally a dense cover of opportunistic green macroalgae (>75% cover density) but dense mats occur elsewhere and the harbour overall fails to achieve WFD Good status on macroalgae. There is elevated levels of inorganic nitrogen at these locations and there is a future risk of failing a favourable situation on the water environment. This is because it is unclear whether the nutrient status is adequate to substantially prevent the growth of dense macroalgae mats in parts of these harbours if there is change in environmental conditions.

3.8 There are favourable (high risk) units within the following harbours: Solent and Southampton Water, Portsmouth Harbour, Chichester Harbour, Langstone Harbour.

Catchment work

3.9 The high levels of nitrogen and phosphorus input to the water environment is currently caused by wastewater from existing housing and agricultural sources. There are a number of mechanisms already in place to reduce the amount of nutrient inputs within our rivers and coastal waterbodies.

3.10 Within the river catchments; Defra's Catchment Sensitive Farming (CSF) programme works with agriculture to reduce diffuse sources of pollution such as fertiliser and slurry run-off. One of the aims of this work is to deliver environmental benefits from reducing diffuse water pollution. To achieve these goals CSF delivers practical solutions and targeted support which should enable farmers and land managers to take voluntary action to reduce diffuse water pollution from agriculture to protect water bodies and the environment.

3.11 In addition, Southern Water is upgrading their wastewater treatment works to reduce the amount of phosphorus inputs from human sewage. There are agreed improvements to phosphorus permits on four Southern Water Services on the River Test and phosphorus upgrades at two wastewater treatment works on the River Itchen.

3.12 Work is currently on-going to evaluate the effectiveness of this catchment work in reducing existing inputs into the Solent's water environment.

Type of nutrient inputs to designated sites

3.13 There is evidence that inputs of both phosphorus and nitrogen influence eutrophication of the water environment. However, the principal nutrient that tends to drive eutrophication in the marine environment is nitrogen and this is supported by modelling and evidence.

3.14 Research has been undertaken by the Environment Agency to understand the relative importance of nitrogen and phosphorus in causing the growth of macroalgae and phytoplankton within estuaries in the Solent. This work used the Combined Phytoplankton and Macroalgae model developed by Cefas. The results of the assessment which was undertaken at a water body level identified that strong phosphorus limitation was only found in relation to the Medina estuary (e.g. Rees-Jones *et al* 2014 and Udal *et al* 2014[4]).

3.15 The best available evidence is for focus in the Solent harbours to be on nitrogen reduction, and reduction in both nitrogen and phosphorus in the Medina catchment. However, this approach may be refined if greater understanding of the eutrophication issue is gained such as thorough new research or updated modelling.

3.16 The nutrient budget in this report calculates levels of Nitrogen (N) from development. However, N comes in different forms and measured N concentrations vary as to exactly what is measured. These differences need to be recognised when calculating nutrient budgets. The key measurement is Total Nitrogen (TN), ie both organic and inorganic forms of nitrogen, because this is what is available for plant growth. TN is the sum of the inorganic forms - nitrate-nitrogen (NO3-N), nitrite-nitrogen (NO2-N), ammonia - and organically bonded nitrogen.

3.17 Total Nitrogen is measured by WwTW where there is a permit with a TN limit consent. However, for WwTWs without permits, measurements could be inorganic nitrogen (nitrate + nitrite + ammoniacal N) or TN or a mix. Most river quality monitoring by EA only records the inorganic N forms. The Farmscoper report measures nitrate-nitrogen <u>not</u> TN. Nitrate is normally the largest component of TN but quantities of organic N are significant. In the Test catchment dissolved organic nitrogen has been found to comprise 7% of the potential biologically available nitrogen in the river and 13% of that in the estuary (Purdie, 2005[5]). Thus, the land use change element of this methodology will underestimate TN leaching. We therefore advise that this uncertainty is recognised and the recommended precautionary buffer approach is adopted.

[4] Udal I., Rees-Jones S. and Robinson K., (2014) Chichester Harbour Water Framework Directive DIN and Ecological Impact Investigations 2007 to 2012. Environment Agency.
Rees-Jones S., Robinson K. and Udal I. (2014) Medina Water Framework Directive DIN and Ecological Impact Investigations 2007 to 2012. Environment Agency

[5] Purdie, D., Shaw, P., Gooday, A. and Homewood, J. (2005) Dissolved Organic Nitrogen in the River Test and Estuary, University of Southampton

3.18 For developments on the Isle of Wight that are impacting on the Medina estuary, both a phosphorus and nitrogen budget may be required. Natural England will work closely with the Isle of Wight Council and applicants to provide advice on a bespoke case-by-case basis.

3.19 This approach is also supported by scientific literature which confirms that whilst both nitrogen and phosphorus should be reduced to tackle estuarine eutrophication, primarily the focus should be on nitrogen[6]. Phosphorus reduction alone does not address the mechanisms caused by elevated nitrogen that affect sea-grass health and the structural stability, extent and plant species diversity of saltmarsh. In addition, most land use measures to reduce nitrogen are also likely to reduce phosphorus concurrently.

SECTION 4 NUTRIENT NEUTRALITY APPROACH FOR NEW DEVELOPMENT

Introduction

4.1 Achieving nutrient neutrality is one way to address the existing uncertainty surrounding the impact of new development on designated sites. Natural England advises that a nitrogen budget is calculated for new developments. This will show that development either avoids harm to protected sites or provides the level of mitigation required to ensure that there is no adverse effect. Natural England recommends that the proposals achieve nitrogen neutrality by securing the required mitigation in compliance with the Habitats Regulations.

4.2 The nutrient neutrality calculation includes key inputs and assumptions that are based on the best-available scientific evidence and research. It has been developed as a pragmatic tool. However, for each input there is a degree of uncertainty. For example, there is uncertainty associated with predicting occupancy levels and water use for each household in perpetuity. Also, identifying current land / farm types and the associated nutrient inputs is based on best-available evidence, research and professional judgement and is subject to a degree of uncertainty.

4.3 It is our advice to local planning authorities to be as precautionary as possible when addressing uncertainty and calculating nutrient budgets. This is achieved by choosing the most precautionary option in all cases and building in an appropriate precautionary delivery buffer. Further details of this approach are included in the following stages of the calculation. Using this precautionary approach to the

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[6] E.g. Jones B.L and Unsworth R..F. (2016) The perilous state of seagrass in the British Isles. *R. Soc. open sci.* **3**: 150596.
Turner R.E. Beneath the saltmarsh canopy: Loss of soil strength with increasing nutrient loads. Estuaries and Coasts (2011) 34:1084
Cole S., Codling I.D., Parr W. and Zabel T. 1999 Guidelines for managing water quality impacts within UK European marine sites. UK Marine SAC Project
Scott C.R, K. L. Hemingway, Elliot. M, de Honge V.N, Penthick J.S., Malcolm S. and Wilkinson M. Impact of Nutrients in Estuaries – Phase 2 Environment Agency 1999

calculations and solutions gives the local planning authority and applicants the certainty needed for their assessments.

Type of development

4.4 This methodology is for all types of development that would result in a net increase in population served by a wastewater system, including new homes, student accommodation, tourism attractions and tourist accommodation. This development will have inevitable wastewater implications.

4.5 Other commercial development not involving overnight accommodation will generally not be included. It is assumed that anyone living in the catchment also works and uses facilities in the catchment, and therefore wastewater generated by that person can be calculated using the population increase from new homes and other accommodation. This removes the potential for double counting of human wastewater arising from different planning uses.

4.6 Tourism attractions and tourism accommodation are exceptions as these land uses as they attract people into the catchment and generate additional wastewater and consequential nitrogen loading on the Solent. This includes self-service and serviced tourist accommodation such as hotels, guest houses, bed and breakfasts and self-catering holiday chalets and static caravan sites. Other applications will be considered on their individual merits, for example new cruise ship facilities etc.

4.7 There may be cases where planning applications for new commercial or industrial development or changes in agricultural practices could result in the release of additional nitrogen into the system. In these situations, a case-by-case approach will be adopted. Early discussions with Natural England via our chargeable services (DAS) are recommended.

Methodology

Stage 1 Calculate Total Nitrogen (TN) in kilograms per annum derived from the development that would exit the Wastewater Treatment Works (WwTW) after treatment

Stage1 Step 1 Calculate additional population

4.8 To determine the additional population that would use the proposed development, it is recommended that well evidenced occupancy rates are used. Natural England recommends that an occupancy rate of 2.4 is used in the calculation. This is based on the latest Office for National Statistics figure that can be applied across all affected local authority areas.

4.9 In order to be appropriately precautionary, the calculation needs to be based on values that take account of long term trends to address the impacts of the development in perpetuity rather than just over a local plan period.

4.10 All types of new housing (market and affordable) and overnight accommodation will increase the housing stock within the catchment, which will result in an associated increase in population levels, leading to inevitable wastewater implications.

4.11 It is Natural England’s view that using the latest Office for National Statistics figure is suitably precautionary and based on best available evidence. Local planning authorities, as competent authorities, may choose to use alternative occupancy rates in their assessments, when these are supported by evidence.

4.12 Competent authorities may also choose to adopt bespoke calculations for detailed planning applications. For example, it may be possible to evidence alternative figures for flats or in relation to the number of bedrooms of each household.

4.13 These are matters for each competent authority. Natural England’s advice is to take a precautionary approach that recognises the uncertainty.

Stage 1 Step 2 Confirm water use

4.14 Determine the water use / efficiency standard for the proposed development to be defined in the planning application and, where relevant, the Environmental Statement. The nitrogen load is calculated from the scale of water use and thus the highest water efficiency standards under the building regulations will minimise the increase in nitrogen from the development.

4.15 It is recommended that each Local Planning Authority impose a planning condition on all planning permissions for one or more net additional new dwellings requiring construction to the optional requirement[7] under G2 of the Building Regulations 2010.

4.16 A model condition is set out below:

“*The dwellings shall not be occupied until the Building Regulations Optional requirement of a maximum water use of 110 litres per person per day has been complied with.”*

4.17 The water use figure is a proxy for the amount of wastewater that is generated by a household. New residential development may be able to achieve tighter water use figures, with or without grey water recycling systems, and this approach is supported from a water resource perspective (for example in support of Southern Water’s Target 100 litres per person per day). However, the key measurement is the amount of wastewater generated by the development that flows to the wastewater treatment works.

4.18 If tighter water use restrictions are used in the nutrient calculation – with or without grey water recycling systems – these restrictions must reflect the wastewater

[7] The optional requirement referred to in G2 requires installation and fittings and fixed appliances for the consumption of water at 110 litres per person per day.

generated for the lifetime of the development. There is a risk that when kitchen and bathroom fittings are changed by occupants over the years, less water-efficient models could be installed. It is Natural England's view that it would be difficult to evidence and secure delivery of tighter restrictions at this time, to provide certainty for the lifetime of the development. However, if sound evidence can be provided, this will be considered on a case-by-case basis.

4.19 It is Natural England's view that it is reasonable for the authorities to assume that households will achieve the 110 litres per person per day target in perpetuity and this precautionary approach should be adopted in the calculation.

Stage 1 Step 3 Confirm WwTW and permit level

4.20 Identify the Wastewater treatment works (WwTW) that the development will use and identify the permit concentration limit for Total Nitrogen at the WwTW. If the WwTW will have a tightened permit concentration limit for Total Nitrogen under the company's Water Industry Asset Management Plan by 2024 then use this tightened value. If a new WwTW is proposed, obtain a determination from the Environment Agency on the permit limit for Total Nitrogen that would apply to the works and when they are likely to be built. Where the WwTW has no consent limit on Total Nitrogen derive a value for nitrogen in the wastewater stream based on the type of wastewater treatment at the works.

4.21 Where there is a permit limit for Total Nitrogen, the load calculation will use a worst case scenario that the WwTW operates at 90% of its permitted limit. A water company has the option of operating the works as close to the consent limit as practicable without breaching the consent limit. Natural England and the Environment Agency have agreed to take 90% of the consent value as the closest the water company can reasonably operate works without breaching the consent limit.

4.22 For most planning applications, the WwTW provider is not confirmed until after planning permission is granted. The nutrient calculation should be based on the permit levels of the most likely WwTW. In any cases where the WwTW changes, a reassessment of the nutrient calculation will be required to ensure the development is nutrient neutral.

4.23 For developments that discharge to WwTWs with no Total Nitrogen permit level, best available evidence must be used for the calculation. In the first instance, Southern Water or other wastewater provider should be contacted for details of the nitrogen effluent levels for the specific WwTW.

4.24 However, if this data is not available, an average figure of 27 mg/l can be used. This figure has been derived by Southern Water from nitrogen effluent levels at two WwTWs in the Solent area. Please note this average figure may change if new evidence becomes available.

Stage 1 Step 4 Calculate Total Nitrogen (TN) in Kg per annum that would exit the WwTW after treatment derived from the proposed development

4.25 The Total Nitrogen load is calculated by multiplying the water use of the proposed development by the appropriate concentration of Total Nitrogen after treatment at the WwTW.

4.26 The following worked example calculates the Total Nitrogen load of a development of 1000 dwellings based on a WwTW with a consent limit for Total Nitrogen of 9 mg/l.

4.27 Where residential developments also include other overnight accommodation such as tourist accommodation and attractions, the associated water use from these additional land uses will need to be included in the calculation. This should be based on the water use associated with these facilities.

STAGE 1 - WORKED EXAMPLE TO CALCULATE TOTAL NITROGEN (TN) LOAD FROM DEVELOPMENT WASTEWATER				
Step	**Measurement**	**Value**	**Unit**	**Explanation**
Development proposal	Development types that would increase the population served by a wastewater system	1000	Residential dwellings	
Step 1	Additional population	2400	Persons	Uses an average household size of 2.4 x 1000 dwgs (greenfield site).
Step 2	Wastewater volume generated by development	264,000	litres/day	2400 persons x 110 litres Where relevant, deduct wastewater volume of population displaced by the proposed development
Step 3	Receiving WwTW environmental permit limit for TN	9.0	mg/l TN	

Step 4	TN discharged after WwTW treatment	2,138,400	mg/TN/day	90% of the consent limit = 8.1 mg/l TN. 264000 x 8.1
	Convert mg/TN to kg/TN per day	2.1384	Kg/TN/day	Divide by 1,000,000
	Convert kg/TN per day to kg/TN per year	781	Kg/TN/yr	X 365 days
Wastewater total nitrogen load	**781 kg/TN/yr**			

Table 1 – Calculating wastewater Total Nitrogen load from proposed development

Stage 2 Adjust Nitrogen load to offset existing nitrogen from current land use

4.28 This next stage is to calculate the existing nitrogen losses from the current land use. The nitrogen loss from the current land use will be removed and replaced by that from the proposed development land use. The net change in land use will need to be subtracted from or added to the wastewater Total Nitrogen load.

4.29 Nitrogen–nitrate loss from agricultural land can be modelled using the Farmscoper model. A study commissioned by Natural England from ADAS modelled this loss for different farm types across the river catchments that drain to the Solent (ADAS UK Ltd. 2015. Solent Harbours Nitrogen Management Investigation).

4.30 If the development area covers agricultural land that clearly falls within a particular farm type used by the Farmscoper model then the modelled average nitrate-nitrogen loss from this farm type should be used. The farm types used in the ADAS model are set out in Table 2, with the nitrate-nitrogen loss. Further details on farm classification are included in Appendix 1.

AVERAGE NITRATE-NITROGEN LOSS PER FARM TYPE IN THE SOLENT CATCHMENT AREA (kg/ha)	
Cereals	31.2
Dairy	36.2
General Cropping	25.4
Horticulture	29.2
Pig	70.4
Lowland Grazing	13.0
Mixed	28.3
Poultry	70.7
Average for catchment area	**26.9**

Table 2 Farm types and average nitrogen-nitrate loss

4.31 If the proposed development area covers several or indeterminate farm types then the average nitrate-nitrogen loss across all farmland may be more appropriate to use. The average figure is also included in Table 2.

4.32 The figures in the ADAS report are based on 2010 land use data and may be updated from time-to-time as land use and agricultural practice to control nitrate loss changes.

4.33 For sites that are in use as allotments, it is recommended that the most appropriate farm type for allotments is the average rate of 26.9 kg/ha/yr. If evidence can be provided to support an alternative figure, then this information will be reviewed by the local planning authority and Natural England.

4.34 For sites that are currently in use as horse paddocks, it is recommended that the lowland grazing figure should be used in the calculation. If evidence can be provided to support an alternative figure, then this information will be reviewed by the local planning authority and Natural England.

4.35 It is important that farm type classification is appropriately precautionary. It is recommended that evidence is provided of the farm type for the last 10 years and professional judgement is used as to what the land would revert to in the absence of a planning application. In many cases, the local planning authority, as competent authority, will have appropriate knowledge of existing land uses to help inform this process.

4.36 There may be areas of a greenfield development site that are not currently in agricultural use and have not been used as such for the last 10 years. There is no agricultural nitrogen input onto this land and these areas should not be included in Stage 2 of the calculation.

4.37 Where development sites include wildlife areas, woodlands, hedgerows, ponds and lakes, these areas should also be excluded from the calculation as there is no existing agricultural nitrogen input onto this land.

4.38 For sites, where existing land use is not confirmed, it is Natural England's advice to local planning authorities and applicants to be as precautionary as possible. A worked example to calculate the nitrogen load from existing land use is set out in Table 3.

STAGE 2 - WORKED EXAMPLE TO CALCULATE NITROGEN LOAD FROM CURRENT LAND USE

Step	Measurement	Value	Unit	Explanation
1	Total area of existing agricultural land	40	Hectares	This is the area of agricultural land that will be lost due to development

2	Identify farm type and confirm nitrate loss.	26.9	Kg/ha/yr	The developable area covers several farm types therefore an average has been used. Reference Appendix 1 and Table 2
3	Multiply area by nitrate loss	1,076	Kg/N/yr	40 ha x 26.9 kg/N/yr
Nitrogen load - current land use	1,076 Kg/N/yr			

Table 3 Calculating nitrogen load from current land use

Stage 3 Adjust nitrogen load to account for land uses with the proposed development

4.39 The last stage is to add in the nitrogen load that will result from the new development that is not received by a WWTW. This includes the nitrogen load from the new urban development and from the new open space including any Suitable Alternative Natural Greenspace (SANG), Nature Reserves or Bird Refuge Areas.

4.40 The calculation only includes the areas of the site where there will be a change in land use, for example from agricultural land to new urban development or agricultural land to Suitable Alternative Natural Greenspace (SANG) / open space. Where there is no proposed change to land use, this land should be excluded from the nitrogen budget as there will be no change to the nitrogen load from this area.

Urban development

4.41 The nitrogen load from the new urban development results from sewer overflows and from drainage that picks up nitrogen sources on the urban land. Urban development includes the built form, gardens, road verges and small areas of open space within the urban fabric. These nitrogen sources include atmospheric deposition, pet waste, fertilisation of lawns and gardens and inputs to surface water sewers. The nitrogen leaching from urban land equates to 14.3 kg/ha/yr[8]. Appendix 2 sets out the scientific research and literature in relation to this figure.

Open Space and Green Infrastructure

4.42 Nitrogen loss draining from new designated open space or Suitable Alternative Natural Greenspace (SANG) should also be included. The nitrogen leaching from this land is likely to equate to 5 kg/ha/yr. Appendix 3 sets out the scientific research and

[8] Supplementary Planning Document – Achieving Nitrogen Neutrality in Poole Harbour

literature in relation to this figure. This figure can also be used where new nature reserves or bird refuge areas are created.

4.43 The competent authority will need to be assured for perpetuity that this open space will be managed as such and there will be no additional inputs of nutrients or fertilisers onto this land. Appropriate planning and legal measures will be necessary to ensure it will not revert back to agricultural use, or change to alternative uses that affect nutrient inputs on the long term. It is therefore recommended that the 5 kg/ha/yr rate applies to areas of designated open space on-site of around 0.5 hectares and above. These sites will also need long term management to ensure the provision of dog bins and that these are regularly emptied.

4.44 Small areas of open space within the urban fabric, such as road verges, gardens, children's play areas and other small amenity areas, should not be included within this category. The urban development figure is appropriate for these land uses.

Community food growing provision

4.45 For any areas of the site that are proposed for community food growing provision, it is recommended that the average farm type rate is used (26.9 kg/ha/yr).

4.46 A worked example is shown in the table below. This is based on a developable area of 30 hectares covering land in a mix of farm types with the removal of 10 hectares of agricultural land to create SANG.

STAGE 3 - WORKED EXAMPLE TO CALCULATE NITROGEN LOAD FROM FUTURE LAND USES				
Step	**Measurement**	**Value**	**Unit**	**Explanation**
1	New urban area	30	Hectares	Area of development that will change from agricultural land to urban land use
2	Nitrogen Load from future urban area	429	Kg/N/yr	30 ha x 14.3 Kg/N/yr
3	New SANG / open space	10	Hectares	Area of development that will change from agricultural land to SANG / open space
4	Nitrogen load from SANG / open space	50	Kg/N/yr	10 ha x 5.0 Kg/N/yr
5	Combine Nitrogen load from future land uses	479	Kg/N/yr	429 Kg/N/yr + 50 Kg/N/yr
Nitrogen Load - future land uses	479 Kg/TN/yr			

Table 4 – Adjust Nitrogen Load to account for future land uses

Stage 4 Calculate the net change in the Total Nitrogen load that would result from the development

4.47 The last stage is to calculate the net change in the Total Nitrogen load to the Solent catchment with the proposed development. This is derived by calculating the difference between the Total Nitrogen load calculated for the proposed development (wastewater, urban area, open space etc) and that for the existing land uses.

4.48 It is necessary to recognise that all the figures used in the calculation are based on scientific research, evidence and modelled catchments. These figures are the best available evidence but it is important that a precautionary buffer is used that recognises the uncertainty with these figures and ensures the approach is precautionary. Natural England therefore recommends that a 20% precautionary buffer is built into the calculation.

4.49 There may be instances where it is the view of the competent authority that an alternative precautionary buffer should be used based on a site-specific basis.

4.50 Table 5 sets out a worked example.

STAGE 4 - WORKED EXAMPLE TO CALCUATE THE NET CHANGE IN NITROGEN LOAD FROM THE DEVELOPMENT				
Step	**Measurement**	**Value**	**Unit**	**Explanation**
1	Identify Nitrogen load from wastewater (stage 1)	781	Kg/N/yr	See Table 1
2	Calculate the net change in Nitrogen from land use change - subtract existing land uses Nitrogen load (stage 2) from future land uses Nitrogen load (stage 3)	-597	Kg/N/yr	479 Kg/N/yr - 1076 Kg/N/yr
3	Determine Nitrogen Budget – the Total Nitrogen wastewater load for the proposed development plus the change in Nitrogen load from land use change (the latter figure may be positive ie the change in land	184	Kg/N/yr	781 Kg/N/yr (step 1) + -597 Kg/N/yr (step 2)

	use will generate more nitrogen, or negative ie the change in land use will generate less Nitrogen)			
4	Nitrogen Budget without buffer	184	Kg/N /yr	184 Kg/N /yr x 1.5
5	Divide Nitrogen Budget without buffer by 5.	36.8	Kg/N /yr	184 Kg/N /yr divide by 5 = 36.8.
6	Identify Nitrogen Buffer with 20% buffer	220.8	Kg/N /yr	Add 36.8 to the stage 4 figure
Nitrogen Budget with 20% buffer	221 Kg/N /yr			

Table 5 Nitrogen Load Budget

Need for mitigation

4.51 If there is a Nitrogen surplus (a positive figure), then mitigation is required to achieve nitrogen neutrality. If the calculation identifies a deficit (a negative figure), no mitigation is required.

4.52 In the worked example above, the Nitrogen Budget with 20% buffer is 221 Kg/TN/yr. Natural England recommends that mitigation is achieved for 221 Kg/TN/yr. Mitigation can be ‘direct’ through upgrading sewage treatment works and through alternative measures, e.g. interceptor wetlands or ‘indirect’ by offsetting the nitrogen generated from new development by taking land out of nitrogen intensive uses, e.g. where fertiliser is applied to crops. Mitigation measures will need to be secured for the duration over which the development is causing the effects, generally 80-125 years.

4.53 The options for mitigation include a combination of the following:

(i) Agreement with the wastewater treatment provider that will maintain an increase in nitrogen removal at the WwTW.
(ii) Agreement with the wastewater treatment provider or others to provide and maintain an increase in nitrogen offsetting from catchment management measures (this may include mini-farm interceptor wetlands).
(iii) Provide measures that will remove nitrogen draining from the development site or discharged by the WwTW (such as wetland or reedbed) (Appendix 4).
(iv) Increase the size of the SANGs and Open Space provision for the development on agricultural land that removes more nitrogen loss from this source.
(v) Establish changes to agricultural land in the wider landholding in perpetuity that removes more nitrogen loss from this source.
(vi) Acquire, or support others in acquiring, agricultural land elsewhere within the river catchment area containing the development site, changing the

land use in perpetuity (e.g. to woodland, heathland, saltmarsh, wetland or conservation grassland) to remove more nitrogen loss from this source and/or, if conditions are suitable, provide measures that will remove nitrogen on drainage pathways from land higher up the catchment (e.g. interception wetland).

4.54 Further information on the potential for nitrogen mitigation using wetlands is included in Appendix 4. Detailed information has been provided on stormwater wetlands, constructed wetlands taking discharges from STW and wetlands associated with streams and rivers.

4.55 Detailed consideration will need to be given to the location and catchment of the proposed mitigation measures in relation to the impact of the development on the designated sites. We advise that this issue is examined on a case by case basis in consultation with the relevant local planning authority or authorities and Natural England.

4.56 Natural England can provide further advice on the methodology and mitigation options through our chargeable services (DAS).

4.57 It is appreciated that achieving nutrient neutrality may be difficult for smaller developments, developments on brownfield land or developments that are well-progressed in the planning system. Natural England is working closely with local planning authorities to progress Borough /District/ City wider and more strategic options that achieve nutrient neutrality and enable this scale of development to come forward.

4.58 This work is currently on-going and it is recommended that discussions are held with the relevant local planning authorities with regard to these options.

Appendix 1 – Farm Types

The UK system is based on weighting the contributions of each enterprise in terms of their associated outputs. The weights used (known as 'Standard Outputs' or SOs) are calculated per hectare of crops and per head of livestock and used to calculate the total standard output associated with each part of the Farm Business.

Cereals
Holdings on which cereals, combinable crops and set-aside account for more than two thirds of the total SO and (pre-2007) where set-aside alone did not account for more than two thirds of the total SO. (Holdings where set-aside accounted for more than two thirds of total SO were classified as specialist set aside and were included in "other" below.)

General cropping
Holdings on which arable crops (including field scale vegetables) account for more than two thirds of the total SO, excluding holdings classified as *cereals;* holdings on which a mixture of arable and horticultural crops account for more than two thirds of their total SO excluding holdings classified as *horticulture* and holdings on which arable crops account for more than one third of their total SO and no other grouping accounts for more than one third.

Horticulture
Holdings on which fruit (including vineyards), hardy nursery stock, glasshouse flowers and vegetables, market garden scale vegetables, outdoor bulbs and flowers, and mushrooms account for more than two thirds of their total SO.

Specialist Pigs
Holdings on which pigs account for more than two thirds of their total SO.

Specialist Poultry
Holdings on which Poultry account for more than two thirds of their total SO.

Dairy
Holdings on which dairy cows account for more than two thirds of their total SO.

Lowland Grazing Livestock
Holdings on which cattle, sheep and other grazing livestock account for more than two thirds of their total SO except holdings classified as *dairy.* A holding is classified as lowland if less than 50 per cent of its total area is in the Less Favoured Area (LFA).

Mixed
Holdings for which none of the above categories accounts for more than 2/3 of total SO. This category includes mixed pigs and poultry farms as well as farms with a mixture of crops and livestock (where neither accounts for more than 2/3 of SOs).
http://farmbusinesssurvey.co.uk/DataBuilder/UK_Farm_Classification_2014_Final.pdf

Appendix 2 – Leaching of nitrogen from urban areas

The average total nitrogen leaching rate from an urban area (14.3kg/ha/yr) comes from values for hydrologically effective rainfall (478mm - precipitation minus losses from evapo-transpiration) and the nitrogen concentration of leachate (3mg/l) given in Bryan et al (2013) the latter figure derived from an AMEC report. The value for nitrogen concentration is similar to one quoted in House et al (1993) who give a mean event concentration of 3.2mg/l for total nitrogen (with this value derived from other sources) with a range of 0.4-20mg/l. Thus although it is not specified by Bryan et al (2013), it is probably reasonable to take the 3mg/l to be total nitrogen especially since the organic component of N from urban areas is likely to be relatively small.

Mitchell (2001) gives the following event mean concentrations in mg/l total N from urban areas; Urban Open 1.68; Ind/Comm 1.52; Residential 2.85; Main roads 2.37.
It is recognised that the datasets that produced these figures are not large (n = 14 in this case), a good deal of uncertainty remains and that further sampling is needed to validate models of pollutant effects from urban runoff (Leverett et al 2013).

Typical nutrient concentrations in urban stormwater runoff in the U.S. are 2.0 mg/l for total N (TN) (Schueler 2003). Population densities seem to be less in the most studied urban catchments (eg Groffman et al 2004 in Baltimore, Hobbie et all 2017 in Minnesota) than those in the UK but this does not necessarily lead to an increase in the rate of nitrogen leaching from the catchment for the factors affecting this value are complex. Thus although there will clearly be variation between different urban areas, there is insufficient knowledge to be able to predict N leaching from the different characteristics of these areas. And for practical purposes an overall N leaching figure is needed; nothing found in the literature indicates that another value would be more representative than 3mg/l.

An N leaching figure can also be derived by using the relationship between mean stream and river flow rate and catchment area. The ratio for the gauging station on the River Meon at Mislingford is $0.014m^3/sec/km^2$ and, with a TN concentration of 3mg/l, this equates to a TN leaching rate of 13.2mg/l, similar to the value obtained when hydrologically effective rainfall is used.

Comparison can also be made with direct measurements of TN urban outputs from studies in the USA (Hobbie et al 2017, Groffman 2004). The values in the Hobbie paper for urban catchments in Minnesota varied from 12.5-27.2 kg/ha/yr with a mean of 17.3 kg/ha/yr. The outputs measured by Groffman (2004) were smaller (between 5.5 and 8.6kg/ha/yr) but these were less urbanised catchments, several including areas of old growth forest where nitrogen retention was very high. Thus these values are broadly of the same order as the 14.3 kg/ha/yr leaching figure initially calculated.

Nitrogen inputs in these studies come predominantly from three sources - atmospheric deposition, pet waste and lawn fertilisation. N deposition was slightly lower in both Baltimore and Minnesota than values from APIS in the around the Solent (23.8kg/ha/yr for hedgerows or woodland, 14.7kg/ha/yr for grassland). No UK studies have been found to compare with the US ones for N inputs in urban areas from pet waste or from lawn fertilisation.

References

Bryan, G, Kite, D, Money, R, Jonas, P and Barden R. 2013. Strategy for managing nitrogen in the Poole Harbour catchment to 2035. Environment Agency report.

Ellis JB and Mitchell G. 2006 Urban diffuse pollution: key data information approaches for the Water Framework Directive. Water and Environment Journal **20** (2006) 19–26.

Groffman, P.M., Law, N.L., Belt, K.T., Band, L.E., Fisher, G.T., 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7, 393e403.

Hobbie Sarah E, Jacques C. Finlay, Benjamin D. Janke, Daniel A. Nidzgorski, Dylan B. Millet, and Lawrence A. Baker (2017). Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution PNAS April 18, 2017 114 (16) 4177-4182.

House, M.A., Ellis, J.B., Herricks, E.E., Hvitved-Jacobsen, T.,Seager, J., Lijklema, L., Aalderink, H. and Clifforde, I.T. (1993) Urban Drainage: Impacts on Receiving Water Quality. Water Sci. Techol., 27 (12), 117–158.

Leverett Dean, John Batty, Dawn Maycock (2013) Assessing the scale and impact of urban run-off on water quality. Report to DEFRA from WCA Environment Ltd.

Mitchell G. 2001. The Quality of urban stormwater in Britain & Europe: Database & recommended values for strategic planning models. School of Geography, University of Leeds.

Schueler, T., 2003. Impacts of Impervious Cover on Aquatic Systems. Watershed Protection Research Monograph No 1. Center for Watershed Protection, Ellicot City, MD.

Appendix 3 - Estimating the leaching of total nitrogen (TN) from natural greenspace (SANG).

A number of assumptions must be made about the management of the SANG to allow an estimate of TN leaching to be made. These are as follows:

- The vegetation of the SANG would be predominantly permanent grassland but with an element of tree and scrub cover (this will of course vary for different SANGS but a 20% average figure is used here). The degree of tree and scrub cover will not greatly affect the result as both permanent grassland and woodland/scrub exhibit a high degree of N retention. It matters most because of the differences in the rate of atmospheric N deposition between the two habitats.
- The grassland would be permanent (ploughing will release large amounts of N) and is not fertilised either with artificial fertiliser or manures. It may be ungrazed or grazed very lightly (<0.1LU/ha/yr) with no supplementary feeding (even without supplementary feeding, grazing can increase N leaching because N retention is lower when N is delivered in the form of cattle urine and dung [Wachendorf et al 2005]).
- The grassland may be cut with the cutting regime dependent on other factors. Cuttings may be left or removed from site as the case may be but should not gathered and composted in heaps on site. Any gorse within the scrub should be controlled so it is no more than rare across the mitigation area since a significant amount of nitrogen fixation occurs within gorse stands.

A generic leaching value for N concentration from AMEC for ‘rough grazing’, quoted in Bryan et al (2013), is 2mg/l. Using this concentration together with a value of 478mm for the hydrologically effective rainfall (HER) gives a leaching value for N of 9.6 kg/ha/yr. A similar value (8.8kg/ha/yr) is obtained if the relationship between mean stream flow and catchment area (0.014 cumecs/km^2 which is the ratio for the gauging station on the nearby River Meon at Mislingford) is used instead, keeping the same N concentration of 2mg/l. It is not clear whether these AMEC concentrations are for total nitrogen or for inorganic nitrogen.

The particular grassland management regime for which the 2mg/l N concentration applied is not known. However, even though studies of N leaching from natural unfertilised grasslands are rare in the literature (most are of agricultural grasslands with fertiliser inputs of some sort) it seems likely that this value is higher than might be expected from a natural grassland with no fertiliser inputs such as a SANG. Thus for example TN leachate concentrations were between 0.44 and 0.67 mg/l in an extensively managed montane grassland (that still had one slurry application per year) and the equivalent mean TN loss was 1.0, 2.6 and 3.1 kg/ha/yr for three different areas (Fu et al 2017).

Adjusting for a SANG with 20% woodland/scrub, using the AMEC woodland generic leaching value of 0.5mg/l (Bryan et al 2013) for the woodland/scrub component, results in an N output of 8.1 kg/ha/yr.

The 0.5mg/l value is also much higher than the very low nitrate concentrations in streams from purely forested catchments (Groffman 2004) and from those reported by for a large sample of forested streams by Mulholland et al 2008 where the mean nitrate-N concentrations were <0.1mg/l. All but a few of the samples from an unfertilised suburban lawn had nitrate-N concentrations below the detectable limit of 0.2mg/l (Gold et al 1990). The same was true for a forest plot and the average nitrate-N losses from both home lawn and the forest plots averaged 1.35 kg/ha/yr over 2 years. These studies of both grassland and woodland nutrient cycling suggest that the AMEC generic leachate concentration of 3mg/l, resulting in an N output of 9.6kg/ha/yr, is too high when applied to a SANG.

Despite there being no direct N fertiliser inputs on a SANG, N inputs will still occur from three main sources. These are atmospheric deposition, pet waste and N fixation from legumes and estimating the contribution of each of these sources, together with the proportion of N retained, is an alternative method of working out the N contribution from a SANG.

N deposition

The following are typical values taken from APIS for TN deposition in the Solent area. .

Improved grassland 14.7 kgN/ha/yr; Arable horticultural 14.7 kgN/ha/yr; Neutral grassland 14.7 kgN/ha/yr

Hedgerows 23.8 Kg N/ha/year; Broadleaved, Mixed and Yew Woodland 23.8 Kg N/ha/year

Using the value for hedgerows and woodland for the 20% scrub component of the hypothetical SANG and the neutral grassland value for the rest results in a deposition rate of 11.76 + 4.76 = 16.5 kg/ha/yr.

Pet waste

SANGs are specifically designed to attract increased levels of public access particularly dog walkers so the potential inputs of N from dog waste are likely to be significant.

Hobbie et al (2017) give a figures for TN inputs from this source for entire urban areas and these vary between 3.56 and 21.2kg/ha/yr for 7 urban catchments with a median of 6.9kg/ha/yr. A figure of 17kg/ha/yr can be gleaned from Baker 2001 which was worked out using information on pet numbers, nutritional needs, pet weights etc; 76% of this was from dogs.

The heavy use of SANGS by dogs suggests that N inputs would most likely be higher than these figures averaged over the whole urban area. Nevertheless, inputs to the SANG from this waste means that it is not deposited elsewhere in the urban area where N may anyway end up in the same receiving water.

TN retention in grasslands will also be higher than the average over other parts of the urban area but the characteristics of the inputs from dogs is likely to lower the amount of TN retained because the concentrated patchy nature of the input will reduce the proportion of TN retained compared with more evenly spread inputs, as mentioned above.

Picking up dog faeces will obviously reduce the input from but not remove inputs from urine. Dog urine has a high N content.

In these circumstances there is clearly uncertainty about the level of input from this source the highest figure from Hobbie et al (21.2kg/ha/yr) has been used but adjusted downwards because not all of this will be from dogs resulting in an overall value of 16.1 kg/ha/yr.

This has also been done on the basis that funding, together with a binding commitment, is provided for in perpetuity collection of dog waste and enforcement of pick up rather than relying on direct LA resources which could stop at any time.

TN fixation

Hobbie et al (2017) give a value for this of 17.5kg/ha/yr from direct investigation of unfertilised urban parks and this is the value used. Fixation would only be in the grassland part of the SANG which reduces the figure to 14 kg/ha/yr.

TN retention

A number of studies have shown high TN retention in urban areas (eg 80% Hobbie et al 2017) thought to be mainly attributable to TN retention in urban grasslands and lawns which may be in turn related to high carbon within organic matter in the soils. The release of large quantities of N when permanent grassland is ploughed illustrates the capacity of these grassland for N storage (eg Howden et al 2011).

Direct measurements of total N outputs from urban grasslands in the Groffman et al (2009) studies in Baltimore also show high N retention in urban grassland but there are difficulties in applying these results directly to SANGs partly because the plots were either quite heavily fertilised or may have had unmeasured N inputs from neighbouring land. Nitrate-N losses from an unfertilised home lawn averaged 1.35 kg/ha/yr over 2 years (Gold et al 1990). Generally the complex processes and uncertainties about how the management of these grasslands might affect the degree of TN retention and TN output makes estimation of the proportion retained difficult. Nevertheless a value of 90% given in Groffman et al (2009), and supported by a number of references given there, would seem reasonable considering also that overwatering and over fertilising, neither of which would happen on a SANG, seem to be factors that lead to more leaching.

Woodland and scrub. N retention measured in forest plots in Baltimore was very high (95%) Groffman (2004). N percolation losses measured by Gold et al 1990 in forest plots were low and similar to those in unfertilised lawn. However, it is probably not valid to equate a scrub/woodland part of a SANG with the forest plots measured in the Groffman studies in Baltimore for these were old growth well established forests. Nevertheless there is still likely to be high N retention in these areas even if not as much as 95%.

Given all of the above, a 90% TN retention rate over the SANG as a whole has been used in the calculation below**Inputs**

N Deposition (APIS) = 16.5 kg/ha/yr
Pet waste 16.1 kg/ha/yr
N fixation 14 kg/ha/yr

Total = 46.6 kg/yr

Watershed retention of TN 90%

Total TN output = 4.66 kgN/ha/yr

Conclusion

The question of estimating TN outputs from a SANG has been approached from different angles. These investigations all indicate that the value used so far – 13 kg/ha/yr is too high. Instead an TN output of 5 kg/ha/yr is considered to be close to the true value but still sufficiently precautionary.

References

Baker LA, Hope D, Xu Y, Edmonds J, Lauver L. 2001. Nitrogen balance for the central Arizona–Phoenix (CAP) ecosystem. Ecosystems 4:582–602.

Bryan, G, Kite, D, Money, R, Jonas, P and Barden R. 2013. Strategy for managing nitrogen in the Poole Harbour catchment to 2035. Environment Agency report.

Carey Richard O., George J. Hochmuth, Christopher J. Martinez, Treavor H. Boyer, Michael D. Dukes, Gurpal S. Toor, John L. Cisar (2012) Evaluating nutrient impacts in urban watersheds: Challenges and research opportunities. Environmental Pollution 173 (2013) 138-149.

Fu, Jin, Rainer Gasche, Na Wang, Haiyan Lu, Klaus Butterbach-Bahl, Ralf Kiese (2017) Impacts of climate and management on water balance and nitrogen leaching from montane grassland soils of S-Germany. Environmental Pollution 229 (2017) 119-13.

Gold, A.J., W.R. DeRagon, W.M. Sullivan, and J.L. LeMunyon. 1990. Nitrate nitrogen losses to groundwater from rural and suburban land uses. J. Soil Water Conserv. 45:305–310.

Groffman, P.M., Law, N.L., Belt, K.T., Band, L.E., Fisher, G.T., 2004. Nitrogen fluxes and retention in urban watershed ecosystems. Ecosystems 7, 393-403.

Groffman, P.M., Williams, C.O., Pouyat, R.V., Band, L.E., Yesilonis, I.D., 2009. Nitrate leaching and nitrous oxide flux in urban forests and grasslands. Journal of Environmental Quality 38, 1848-1860.

Hobbie Sarah E, Jacques C. Finlay, Benjamin D. Janke, Daniel A. Nidzgorski, Dylan B. Millet, and Lawrence A. Baker (2017). Contrasting nitrogen and phosphorus budgets in urban watersheds and implications for managing urban water pollution PNAS April 18, 2017 114 (16) 4177-4182.

Howden N J K, T.P. Burt, S.A. Mathias, F. Worrall, M.J. Whelan (2011) Modelling long-term diffuse nitrate pollution at the catchment-scale: Data, parameter and epistemic uncertainty. Journal of Hydrology 403 (2011) 337–351

Magesan Guna N., Hailong Wang and Peter W. Clinton 2011 Nitrogen cycling in gorse-dominated ecosystems in New Zealand. New Zealand Journal of Ecology (2012) 36(1): 21-28

Mulholland P J and 30 others (2008) Stream denitrification across biomes and its response to anthropogenic nitrate loading. Nature 452, 202-206

Wachendorf Christine, Friedhelm Taube and Michael Wachendorf (2005) Nitrogen leaching from ^{15}N labelled cow urine and dung applied to grassland on a sandy soil. Nutrient Cycling in Agroecosystems (2005) 73:89–100

Appendix 4 – Potential for N mitigation using wetlands

Where N budget calculations indicate that N outputs from proposed developments are greater than pre development conditions, the use of new constructed wetlands to retain some of the N output is one mitigation option.

There are a number of possibilities for different types of constructed wetland. Wetlands can be designed as part of a sustainable urban drainage (SUDs) system, taking urban runoff/stormwater; discharges from STWs can be routed through wetlands; or the flow, or part of the flow, of existing streams or rivers can be diverted through wetlands.

Wetlands receiving nitrogen-rich water can remove a proportion of this nitrogen through processes such as denitrification and sedimentation. This has been demonstrated in numerous studies; a recent systematic review of the effectiveness of wetlands for N (and P) removal (Land et al 2016) used data from 203 wetlands worldwide of which the majority were free water surface (FWS) wetlands (similar in appearance and function to natural marshes with areas of open water, floating vegetation and emergent plants). The median removal rate for wetlands that were included in this review was 93g/m^2/yr (or just under a tonne/ha/year). The proportion of N removed is termed the efficiency and the median efficiency of wetlands included in the Land review was 37%.

Many factors influence the rate of N removal in a wetland the most important being hydraulic loading (HLR - a function of the inlet flow rate and the wetland size), inlet N concentration and temperature. Together inlet N concentration and flow rate determine the amount of N that flows through the wetland which ultimately limits the amount of N saving that can be achieved.

The rate of removal can also be expressed in terms of the amount of N removed per unit wetland area. This removal rate will typically increase as the inlet N concentration increases, at least within the normal range of inlet N concentrations. Thus wetlands that treat the N rich discharges, for example from STWs, or water in rivers where the N concentrations are high, will remove more N per unit area than say, wetlands treating water in a stream where water quality is very good and the N concentration is low. Thus if space is at a premium, and the goal is to remove as much N as possible, it makes sense to site wetlands where N concentrations are high.

For wetlands to work well, specialist design input based on sound environmental information will be necessary. There will be a need for consultation with relevant statutory bodies. These processes are likely to be easier where wetlands are an integral part of a larger development. Wetlands do offer additional benefits above offsetting but will also require ongoing monitoring, maintenance and adjustments beyond any particular developments completion. Consideration of the long term security of facilities and their adoption at an early stage is advisable.

There are a number of publications which advise about constructed wetlands. For example, Kadlec and Wallace (2009) is a comprehensive source of information covering all stages related to the implementation of different types of constructed wetland. The many papers relating the results from detailed monitoring over many years of the performance of two constructed wetlands in Ohio, USA are also instructive (eg Mitsch et al 2005, 2006, 2014).

Stormwater wetlands

These are what is termed event-driven precipitation wetlands with intermittent flows. There will normally be baseflow and stormwater components to the inputs.

For such wetlands Kadlec and Wallace state that:-

'*A typical configuration consists of a sedimentation basin as a forebay followed by some combination of marshes and deeper pools'*

However, ponds are usually less effective at removing N (Newman et al 2015) than shallow FWS wetlands so the emphasis here should be on the latter although a small initial sedimentation basin is desirable since is likely to reduce the maintenance requirement for sediment removal in the FWS wetland. One advantage of this type of wetland is that it can be designed as an integral part of SUDs for the development and therefore is subject to fewer constraints.

Some wetlands with intermittent flows are prone to drying out and may need provisions for a supplemental water source. In some circumstances, this may be possible through positioning the wetland bottom so that there is some connection to groundwater. However many varieties of wetland vegetation can withstand drying out although there may be a small reduction in water quality improvement (Kadlec and Wallace 2009). Nevertheless base and stormwater flows to each wetland should be worked out to ensure that it is viable.

Wetlands need to be appropriately sized taking into account the HLR and N loading rates. To give a general idea of the areas involved, a wetland 1ha in area would serve a development area of about 50ha.

Calculating the potential N retention in such wetlands involves first determining the proportion of the HER that will pass through the wetland because a percentage of the water carrying N will go directly into groundwater, bypassing storm drains and SUDs and the constructed wetlands. This percentage will depend on such factors as the proportion of hard surface within the development and the geology. Then, assuming the inlet TN concentration is 3mg/l, a proportionate reduction of 37% can be used to work out the amount of N retained.

Provision is needed to control tree and scrub invasion, for wetlands with emergent vegetation medium height such as Typha and reed had higher rates of denitrification than those dominated by trees and woody shrubs (Alldred and Baines 2016).

Other critical aspects of design are the water control structures - inflow and outflow arrangements with water level control – and the need or otherwise for a liner. This last issue is related to soil permeability. A variety of emergent wetland plants, not only reed, can be effective within wetlands. Wetlands with a number of different plant species, rather than monocultures, are desirable both for biodiversity reasons and because they are more resilient against changes in environmental conditions; different species will have different tolerances. Guidance concerning planting can be found in Kadlec and Wallace (2009); allowance should be made in planting ratios and densities for different rates of expansion of different species. Another approach is to use material containing wetland plant seeds from a nearby wetland with a species composition similar to the one preferred. However, unless the donor site is carefully monitored, this would obviously increase the risk of importing unwanted alien plants.

Sedimentation will eventually compromise some aspects of the wetland's function and rejuvenation measures will be necessary (Kadlec and Wallace 2009). The same authors indicate a sediment accretion rate in the order of 1 or 2cm/yr and give examples of rejuvenation after 15 and 18 years but other wetlands have not needed any significant restoration in similar timespans. Various different options for the management of sediment accumulation are given by Qualls and Heyvaert (2017). There of course needs to be provisions to ensure that appropriate maintenance and restoration measures, guided by monitoring, are periodically carried out.

Other sources of information about stormwater wetlands include Wong et al (1999, available on line). The papers about a stormwater wetland in the Lake Tahoe Basin in California are also useful (Heyvaert et al 2006, Qualls and Heyvaert 2017).

Constructed wetlands taking discharges from STW

Many of the considerations discussed above for stormwater wetlands apply equally here. There will obviously be constraints on the location and size of such a wetland because of land availability in the area of the STW. The flow from the STW together with the N concentration in the discharge are needed to determine the approximate size of a wetland. We would recommend a wetland area that gives an N loading of about 500 $g/m^2/yr$ or lower. Because many of the discharges from STW have a high N concentration the potential for N retention in such wetlands is also high. The concentration of N in the outflow will be variable but the purpose of such wetlands is to retain N overall rather than to provide a specific constant standard of water quality in the outflow.

Wetlands associated with streams and rivers

Diverting part of the flow of a stream or river through a wetland, with the outflow returning to the watercourse, provides another opportunity for N saving. For obvious reasons such wetlands would mostly need to be located on the river floodplain. The inlet flow rate can be controlled so it is appropriate for the size of the wetland created and so that the ecology of the watercourse is not compromised in the section affected.

There can be other concerns in relation to the potential effects on the stream or river. An abstraction licence will almost certainly be required.

References

Alldred, M and Baines, S B (2016). Effects of wetland plants on denitrification rates: a met-analysis. Ecological Applications 26(3) 2016, 676-685.

Heyvaert, Alan C., John E. Reuter, Charles R. Goldman (2006). Subalpine, Cold Climate, Stormwater Treatment with a Constructed Surface Flow Wetland. Journal American Water Resources Association 42:1 45-54

Kadlec R H, and S D Wallace (2009). *Treatment Wetlands*. 2nd ed. CRC press, Taylor & Francis Group.

Land M, Graneli W, Grimvall A, Hoffmann CC, Mitsch WJ, Tonderski KS, Verhoeven JTA (2016) How effective are created or restored freshwater wetlands for nitrogen and phosphorus removal? A systematic review. Environmental Evidence 5:9

Mitsch, William J., Li Zhang, Christopher J. Anderson, Anne E. Altor, Maria E. Hernandez (2005). Creating riverine wetlands: Ecological succession, nutrient retention, and pulsing effects. Ecological Engineering 25 (2005) 510–527.

Mitsch, William J., John W. Day Jr (2006) Restoration of wetlands in the Mississippi–Ohio–Missouri (MOM) River Basin: Experience and needed research. Ecological Engineering 26 (2006) 55–69

Mitsch, William J., Li Zhang, Evan Waletzko, Blanca Bernal (2014) Validation of the ecosystem services of created wetlands: Two decades of plant succession, nutrient retention, and carbon sequestration in experimental riverine marshes. Ecological Engineering 72 (2014) 11–24

Newman, Jonathan R., Manuel A Duenas-Lopez, Mike C. Acreman, Elizabeth J. Palmer-Felgate, Jos T. A. Verhoeven, Miklas Scholz, Edward Maltby (2015) Do on-farm natural, restored, managed and constructed wetlands mitigate agricultural pollution in Great Britain and Ireland? A Systematic Review. CEH report to DEFRA.

Qualls, Robert G. and Alan C. Heyvaert, (2017). Accretion of Nutrients and Sediment by a Constructed Stormwater Treatment Wetland in the Lake Tahoe Basin. Journal of the American Water Resources Association (JAWRA) 1-18. https://doi.org/10.1111/1752-1688.12595

Wong Tony H F, Peter F Breen, Nicholas L G Somes and Sara D Lloyd (1999*). Managing Urban Stormwater Using Constructed Wetlands*. Cooperative Research Centre (CRC) for Catchment Hydrology and Department of Civil Engineering, Monash University: Clayton, Victoria, Australia.