# Post-processing the carbon footprint for rural and urban actions in Fresh Water Management Tool (FWMT) Stage 1

## Auckland Council

Report prepared by
**Perrin Ag Consultants Ltd and Koru Environmental Consultants Ltd**

## Prepared by Perrin Ag Consultants Ltd

**Registered Farm Management Consultants**
1330 Eruera Street, PO Box 596
Rotorua 3010
New Zealand

Phone: +64 7 349 1212
Email: consult@perrinag.net.nz
www.perrinag.net.nz


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## Document Quality Assurance

| | | |
|---|---|---|
| **Written by:** | Courtney Stone BSc, MNZIPIM, ISNM<br>Consultant, Perrin Ag<br><br>Sue Ira MSc<br>Director, Koru Environmental Consultants<br><br>Carla Muller BApplEcon, MEnvMgmt (Hons), MNZIPIM (Reg.). ASNM<br>Principal Consultant, Perrin Ag | |
| **Reviewed by:** | Tom Stephens<br>Principal – Integrated Catchment Modelling (Healthy Waters)<br>Cheilo Manalo<br>Senior Healthy Waters Specialist<br>Sustainable Outcomes (Healthy Waters) | |
| **Approved for release:** | Lee Matheson BApplSc (Hons), FNZIPIM (Reg.) ASNM<br>Managing Director<br>Perrin Ag | |
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## Executive summary

This study seeks to assess the indicative life cycle (50 year) carbon impacts of the Auckland Council Freshwater Management Tool (FWMT) interventions in a quantitative and consistent manner to ensure alignment with international greenhouse gas accounting practices for stormwater.

As part of the ongoing development of their FWMT, Auckland Council's (AC) Healthy Waters Department has requested an assessment of the likely carbon impacts (in terms of carbon dioxide equivalents; $CO_2e$) associated with rural and urban FWMT management actions ("interventions") in the FWMT Stage 1. Understanding the impacts of intervention choices on greenhouse gas profiles will help to inform AC's decision-making, specifically that operational decisions to improve water quality consider their contribution to the carbon footprint of AC.

This FWMT report is an extension to Muller et al. (2020), Ira et al. (2021) and Ira (2021) which detail rural and urban mitigations for the FWMT programme. It seeks to detail the carbon estimates for existing mitigation options (in Stage 1 of the FWMT) into the Life Cycle Cost (LCC) model for consideration alongside cost, action and water quality impact outputs from the FWMT Stage 1. This report utilises the latter library of rural and urban interventions identified for FWMT Stage 1. Readers should note the FWMT is an ongoing programme of work and as such new interventions might be added that are out of scope for this report (contact fwmt@aucklandcouncil.govt.nz for further information).

This report is structured as follows; Section 1 provides an introduction and background to this piece of work. Part A covers Sections 2 and 3, and provides details on the methodology for each of the rural sector mitigations and their corresponding carbon impact estimate. Part B covers Sections 4 and 5 detailing the equivalent methodology and carbon impact estimates for the urban sector mitigations in FWMT.. Key assumptions used and outputs from estimations are provided in the appendices.

FWMT Stage 1 water quality interventions include both devices and source controls (practice-based, surface-based) and changes in rural and urban land uses. To assign $CO_2e$ to devices and source controls, a combination of literature review and configuration of interventions within a bespoke greenhouse gas accounting platform (MOATA Carbon Portal) have been utilised.

The literature for both rural and urban interventions was sparse and widely varying in quantitative estimates for most FWMT interventions. Notably, the literature was dominated by studies that do not estimate full life cycle impact on $CO_2e$. Whilst challenging, this finding emphasises the need for advancing this analysis and producing $CO_2e$ life cycle assessments which cover operational, maintenance, and renewal carbon impacts as well as embodied carbon over often varying lifespans (e.g., decadal to centennial for urban devices). In such cases, variations in the $CO_2e$ profiles related to maintenance and renewal can significantly influence the prioritisation of interventions beyond the initial construction (acquisition) phase. Considering the life cycle $CO_2e$ of interventions provides a more holistic view in prioritising interventions.

Using literature, modelling tools and best professional judgement, estimates of the carbon impact of all FWMT Stage 1 mitigations were estimated. However, the estimates are of varying confidence; some estimates are based on more robust modelling tools or literature and have been assigned a high confidence level, while others are very uncertain based on the lack of research and analysis. Estimates should be used cautiously (e.g., alongside other measures and evidence in decision-making).

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## Definitions

**Table 1:** Summary of abbreviations and definitions of key terms used in this report

| Term | Abbreviation | Definition |
|---|---|---|
| Corrective maintenance | CM | These are activities associated with large scale maintenance of the treatment device. They tend to occur infrequently over the life of a device. |
| Edge of field | EOF | The EOF mitigations typically reduce diffuse contaminant loss from localised areas and/or intercepting diffuse contaminant losses from large areas of hydrological response units albeit on a localised area. |
| Embodied carbon | EC | The emissions from the materials. manufacturing, transportation, installation and construction of a stormwater intervention. |
| Establishment maintenance | EM | Establishment maintenance relates to additional maintenance needed to support healthy plant growth for green infrastructure practices in the first two – three years. It is over and above that needed for ongoing routine maintenance. |
| Good management practices | GMP | Practices that help manage farm resources while minimising environmental risk. |
| Green infrastructure | GI | Green infrastructure refers to stormwater assets which use soils and vegetation to restore some of the natural process used to manage stormwater and provide for healthier urban receiving water systems. |
| Life cycle cost | LCC | The life cycle cost is the sum of the acquisition and ownership costs of an asset over its life cycle from design, planning, construction, usage, and maintenance and renewals through to disposal costs. |
| Life cycle costing | | The process of assessing the cost of a product over its life cycle or portion thereof, as defined in the Australian/New Zealand Standard 4536:1999. |
| Life span | LS | The functional life of the treatment device in years. Whilst some components within a particular intervention may have different life spans, the life span used within the assessment relates to the stormwater device itself. |
| Life cycle analysis period | LCAP | This is the period of time (in years) over which the life cycle analysis is conducted, in this case, 50 years. |
| Operational carbon | OC | The emissions resulting from the long term and ongoing operation of a stormwater device, including travel, maintenance activities and replacement of parts. |
| Renewal | | Activities associated with renewing the device back to its original design state at the end of its life span. |
| Routine maintenance | RMC | These are annual activities which relate to routine maintenance events such as mowing grass, weeding, general inspections, etc. |

# 1 Introduction

Auckland Council's (AC) Healthy Waters Department, as part of their ongoing development of their Fresh Water Management Tool (FWMT), has requested an assessment of the likely carbon impacts (in terms of carbon dioxide equivalents; $CO_2e$) for each of the existing FWMT actions (across both the rural and urban mitigation libraries). Understanding the potential carbon impacts of water quality mitigation actions enables AC to better understand the co-benefits and additional (carbon) costs of actions in the FWMT when prioritising actions to improve water quality across the Auckland region. This will help improve the outcomes from AC's decision-making and make sure operational decisions to improve water quality consider their contribution to the carbon footprint of AC.

The carbon estimates will not be integrated into the FWMT at this stage, (i.e., they will not influence the optimisation in the FWMT which is targeted at water quality). Instead, they will enable AC to undertake post-processing optimisation or scenario intervention information across all life cycle carbon changes.

This project includes carbon emissions over the full 50 year life cycle utilised by the FWMT for intervention costing. This includes carbon emissions from product stage (e.g., raw materials), construction stage (e.g., transport and construction) and use stage (including maintenance and replacement). It excludes the end of life stage for the rural interventions and beyond this (e.g., disposal, recycling etc.) as it is unlikely that urban green infrastructure would be decommissioned, but rather renewed to allow for ongoing operation. For the urban interventions, an end of life renewal is included in the assessment instead. In addition, the rural options account for the change in biogenic emissions (i.e., methane and nitrous oxide from livestock and fertiliser use in farm systems) and both rural and urban options consider sequestration when appropriate. The carbon emission estimates are designed to match with the assumptions made for the water quality mitigations in the FWMT library.

This report is an extension to Muller et al. (2020), Ira et al. (2021) and Ira (2021), which detail rural and urban mitigations in the FWMT (Stage 1). It seeks to detail the carbon estimates for existing mitigation options into the Life Cycle Cost (LCC) model for considering alongside the outputs from the FWMT. This report does not consider changing FWMT mitigation designs or choices nor any additional interventions. The FWMT is an ongoing programme of work and as such mitigations will be added and existing mitigations will be improved across time, this report only considers initial FWMT mitigations in their current state in the Stage 1 build of the FWMT.

This project consists of two phases, consistent across the rural and urban sectors. The first phase includes a scan of rural and urban literature to identify existing carbon estimates for the mitigation options which exist in the FWMT library. It also identifies where estimates are not readily available or appropriate for use and attempts to fill these gaps with the best available information, where possible.

The second stage of this project estimates the carbon impacts of each mitigation in the FWMT mitigation library and employs a variety of methods. This includes aligning with existing literature and using tools to estimate carbon impact. These tools include ones that estimate the change in biogenic emissions from the rural mitigations (see Section 2.2.1) and the Moata Carbon Portal (Moata) [1] developed by Mott MacDonald. Moata consists of a series of carbon emission factor databases based on national and international research, with libraries focussing specifically on the water sector (i.e. stormwater, wastewater and water supply). Moata also has libraries for transport and energy sectors. With respect to stormwater management, Moata includes embodied carbon emissions of various types

[1] Mott MacDonald. (n.d.) *Moata Carbon Portal.* Retrieved from https://www.mottmac.com/digital/moata-carbon-portal

of stormwater assets (carbon emissions that included manufacture of material to site and construction actions).

The libraries and assets within Moata were searched for projects and emission factors which could be representative of the FWMT mitigations throughout their life cycle (i.e., including maintenance and renewals). Figure 1 below shows the Moata carbon activities that make up the embodied carbon[2] by multiplying the activity by an emissions factor to get the estimated carbon footprint. The Moata Carbon Portal assumptions are detailed in the specific assets (e.g., for mitigation devices such as detainment bunds), however the overarching assumptions are:

- New Zealand construction materials are similar to the construction materials in the UK (the carbon models were originally developed for the UK market).
- For all carbon models it was assumed that the travel distances are 30 km based on the assumption the distance travelled would be within Auckland.
- Carbon emissions for asset models cover “cradle to built asset”, i.e., not to the end of life phase.
- Where multiple sources of emission factor data have been used, emission factors from New Zealand and Australian sources have been prioritised (Mott MacDonald, 2023).

Emission factor data contained within Moata data libraries has also been used to generate long term emissions from maintenance activities for a range of rural and urban interventions.

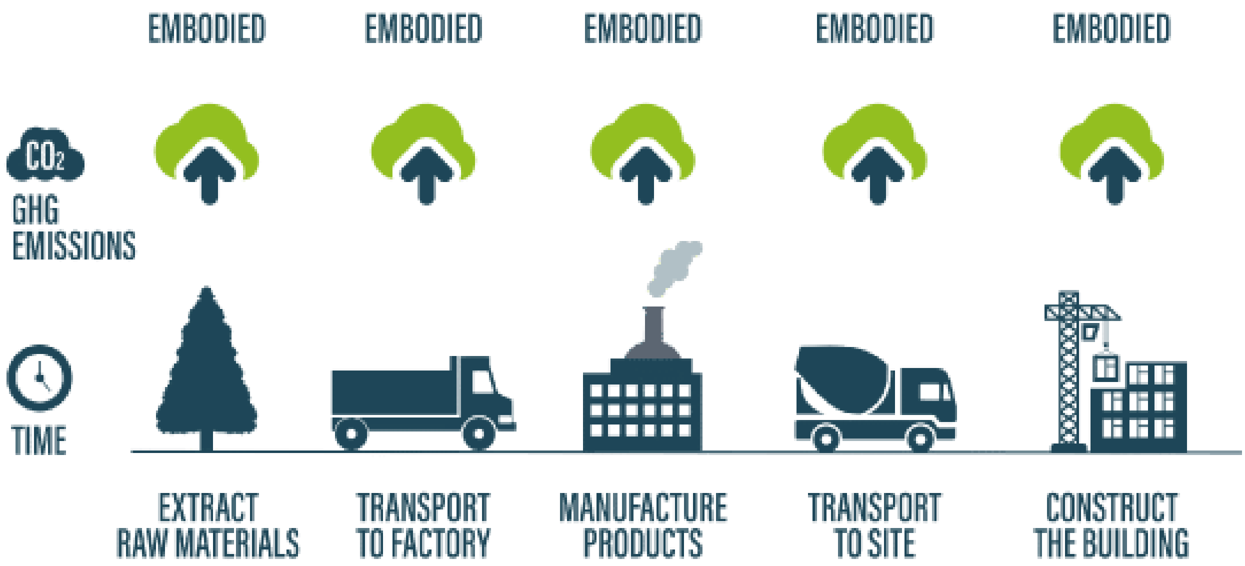


**Figure 1:** Moata carbon portal embodied carbon activities

There is a range of certainty in the carbon estimates for the existing mitigation library reflecting both the quality of information available and use of a variety of methods to generate $CO_2e$ estimates. Estimates may have been measured using existing sources, while others have been modelled using the Moata carbon portal.

Assumptions have been required in deriving FWMT intervention $CO_2e$, such as the transport distance between the source of the raw materials and the intervention sites, which will inevitably vary on a

[2] Embodied carbon emissions are emissions released into the atmosphere as a consequence of activities associated with a particular material or product and include emissions generated from the extraction of raw materials, manufacturing, transportation, construction, use, and disposal or end-of-life treatment.

project-by-project basis. Importantly, FWMT designs are readily modifiable in the Moata Carbon Portal and should be expected to vary on a project-by-project basis. For the purposes of regionalised modelling in the FWMT, standardised intervention life cycle designs are preferable.

The lifecycle $CO_2e$ results in this report provide critical information on the likely direction of carbon emissions (e.g., increase or decrease) and the likely magnitude of change in emissions from adopting FWMT strategic action plans. For aiding use in FWMT reporting and broader AC adoption, all $CO_2e$ estimates are provided with a corresponding 'confidence level' described in Table 2 below. All FWMT lifecycle carbon designs included in this report are available directly in the Moata Carbon Portal – contact the authors or Healthy Waters reviewers for more information on utilising or accessing any designs described herein).

**Table 2:** Description of confidence levels used to support carbon estimate values

| Carbon estimate confidence levels | |
|---|---|
| **Confidence level** | **Description** |
| Low | No quantifiable information |
| Medium | *May be one of the following:*<br>Some quantifiable information but limited availability or robustness.<br>Some data available to utilise in greenhouse gas calculators<br>Components of data to calculate total carbon impacts |
| High | *May be one of the following:*<br>Quantifiable information consistent across reliable and robust literature<br>Sufficient data to generate accurate greenhouse gas calculator estimates<br>Components of data to calculate total carbon impacts from a device |

## Part A – Rural Sector

As discussed in Section 1, the LCA of carbon emissions for this project is based on the production of materials, construction, use and end of life/ renewal phase. The ‘beyond life-cycle stage’ is not included in this analysis as this is outside the analysis timeframe for the FWMT stormwater interventions.

For the farm system bundled mitigations where there has been a change from a particular land use, we have assumed the carbon emissions impact from this change. The interventions that have been modelled using Moata tend to focus on the net carbon footprint of the device itself.

The LCA period used in this study is 50 years. This timeframe was chosen to ensure consistency with the FWMT LCC models which estimate the costs of implementation of urban and rural interventions over a 50 year timeframe.

Rural interventions that have been allocated a lifecycle $CO_2e$ in this project are:

- Wetlands (<1 ha, >1ha) – all rural land uses
- Detainment bunds – all pastoral land uses
- Sediment retention pond – all horticultural land uses
- Riparian planting (1 m, 2.5 m, 5 m, 10 m) – all rural land uses
- Riparian grass (1 m, 2.5 m, 5 m, 10 m) – all rural land uses
- Space planted trees – all rural land uses
- Farm systems bundled mitigation M1 – all rural land uses
- Farm systems bundled mitigation M2 – all rural land uses
- Farm systems bundled mitigation M3 – all rural land uses

Rural interventions and their applicability across different land uses are summarised in more detail in Table 3.

In 2020, methane and nitrous oxide from the agricultural sector totalled approximately 39,450 kilotonnes of carbon dioxide equivalent (kt $CO_2e$), representing 50% of New Zealand’s greenhouse gas (GHG) emissions in 2020 (MfE, 2022). Farm level biogenic emissions include methane (mainly produced from livestock digestive systems), nitrous oxide (mainly derived from livestock urine patches, with some contribution from nitrogen fertiliser) and carbon dioxide. In addition to these biogenic emissions, there are emissions such as electricity and fuel which are typically considered embodied carbon. There is also sequestered carbon associated with woody vegetation.

A range of farm system practice and edge of field mitigations span across each of the pastoral and horticultural land use typologies in the FWMT rural mitigation library. Most rural sector emissions are from enteric fermentation (methane), therefore reducing livestock stocking rates will have an impact on $CO_2e$ (bundled mitigations). Planting of vegetation (space planting and riparian planting) will sequester carbon[3] and areas retired from production will reduce relative biogenic emissions from the land retired. For the edge of field (EOF) mitigations[4], the carbon impacts have largely considered the biological emissions (methane and nitrous oxide) and sequestration. The devices calculated in Moata (detainment bunds and sediment retention ponds) have considered the embodied carbon in transportation and implementation of these mitigations.

Calculating the greenhouse gases of a farm system is not a new concept, however the quantification of some water quality mitigation actions on greenhouses gases and carbon emissions is an emerging area

[3] Noting that gross emissions is the sum of net emissions plus applicable sequestration.

[4] See definition of EOF in section 3.1 below

that requires further research to parameterise or validate estimates. Currently, when accounting for greenhouse gases, both the agricultural carbon emissions and the embodied carbon are uncertain given the available greenhouse gas accounting tools do not consider either the whole life cycle, total carbon impact or cannot consider all possible mitigation options at the farm scale (Dodd et al., 2021). It is important to note that the methodology used here is not comparable to the calculation of agricultural emissions for the purposes of reporting and/or pricing as this piece of work is not related to policy development. This work is instead focussed on making operational decisions with the best possible information principally, determining the impact of cost-optimal water quality management plans for associated lifecycle $CO_2e$ change.

The methodology adopted here is purposely designed to help resolve comparative differences in direct and lifecycle $CO_2e$ for FWMT interventions (associated with operational outlay, maintenance and renewal only). Use of the methodology is possible but more uncertain for quantifying absolute $CO_2e$ footprints from FWMT outputs and should be approached more cautiously.

Figure 2 summarises the elements of carbon that are considered in this work. Embodied carbon refers to the carbon emitted in constructing mitigations. This is largely for EOF mitigations and includes, for example, the production of the materials themselves and the transport of materials to site to construct a detainment bund. Sequestration is the carbon stored as a result of planting. For example, riparian areas in woody vegetation or space planting poplar trees. This is not constrained to what is considered eligible in the Emissions Trading Scheme (ETS), but best estimates of carbon stored as a result of the water quality mitigations. Biogenic emissions refer to the carbon equivalent emissions as a result of the farm system. This includes methane and nitrous oxide and is likely to change with farm system mitigations. These values are converted to a carbon equivalent[5]. For horticulture land uses there is very little methane emissions, but biogenic emissions are still applicable due to nitrous oxide emissions from the growing system. Examples of operational carbon[6] emissions on farms include emissions associated with electricity in the shearing shed and milking parlour. These have been excluded from the carbon impact estimates due to their likely insignificant change as a result of water quality mitigations.

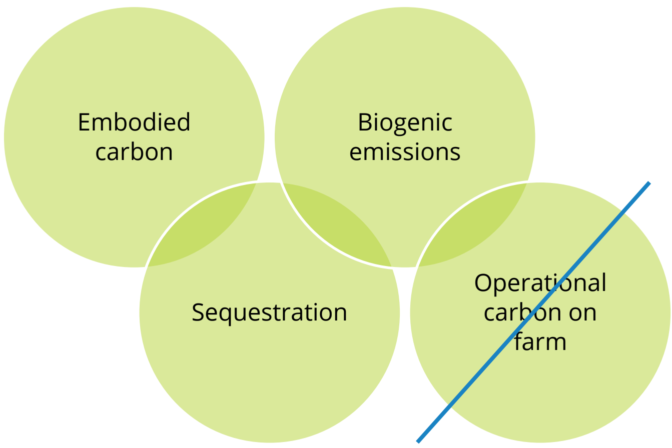


**Figure 2:** Types of carbon that have been considered in the carbon impact estimates for the rural FWMT mitigations

[5] 1 t C is equivalent to 3.67 t $CO_2$

[6] Operational carbon refers to the ongoing greenhouse gas emissions from day to day operations, which has been excluded from this report. Embodied carbon refers to the total greenhouse gas emissions associated with the production, processing, transport and disposal of goods and services.

# 2 Methodology for rural sector mitigations

## 2.1 Existing rural sector mitigation library

The existing FWMT mitigation library for the rural sector is summarised in Table 3 and Table 4 for pastoral and horticulture land uses respectively. These are separated by practice-based mitigations (altering farm systems) and devices (EOF mitigations) for hydrological response units (HRU – basis of land typology). More detail on each of these mitigations can be found in Muller et al. (2020; 2022).

**Table 3:** Existing rural sector mitigations for pastoral land uses (HRU's represented by stocking unit per hectare – SU/ha)

| Land use typology (HRU) | Farm system practice mitigations | Edge of field mitigations |
|---|---|---|
| More than 10 SU/ha[1] dairy | M1 | Wetlands small (<1 ha) |
| | M2 Nitrogen | Wetlands large (>1 ha) |
| | M2 Phosphorus | Detainment bunds |
| | M2 Nitrogen and Phosphorus combined | Space planted trees |
| | M3 Nitrogen | Riparian planting (1 m, 2.5 m, 5 m 10 m) |
| | M3 P | Riparian rank grass (1 m, 2.5 m, 5 m 10 m) |
| | M3 Nitrogen and Phosphorus combined | |
| Less than 10 SU/ha sheep and beef | M1 | Wetlands small (<1 ha) |
| | M2 | Wetlands large (>1 ha) |
| | M3 | Detainment bunds |
| | | Space planted trees |
| | | Riparian planting (1 m, 2.5 m, 5 m 10 m) |
| | | Riparian rank grass (1 m, 2.5 m, 5 m 10 m) |
| More than 10 SU/ha sheep and beef | M1 | Wetlands small (<1 ha) |
| | M2 | Wetlands large (>1 ha) |
| | M3 | Detainment bunds |
| | | Space planted trees |
| | | Riparian planting (1 m, 2.5 m, 5 m 10 m) |
| | | Riparian rank grass (1 m, 2.5 m, 5 m 10 m) |

[1] SU/ha signifies the number of stock units per hectare

**Table 4:** Existing rural sector mitigations for horticultural land uses (refer to Muller et al., 2022 for M1 – M3 definitions)

| Land use typology (HRU) | Farm system practice mitigations | Edge of field mitigations |
|---|---|---|
| **Low and Medium Impact Horticulture –** Medium: Arable, citrus, fodder, nuts & viticulture Low: Orchards, idle & fallow. Based on an arable farm model | M1 | Wetlands small (<1 ha) |
| | M2 | Wetlands large (>1 ha) |
| | M3 | Detainment bunds/Sediment retention ponds |
| | | Riparian planting (1 m, 2.5 m, 5 m, 10 m) |
| | | Riparian rank grass (1 m, 2.5 m, 5 m 10 m) |
| **High Impact Horticulture –** Berryfruit, flowers, stonefruit, kiwifruit, nursery, pipfruit, fruit, vegetables & greenhouses. Based on a vegetable farm model | M1 | Wetlands small (<1 ha) |
| | M2 | Wetlands large (>1 ha) |
| | M3 | Detainment bunds/ Sediment retention ponds |
| | | Riparian planting (1 m, 2.5 m, 5 m 10 m) |
| | | Riparian rank grass (1 m, 2.5 m, 5 m 10 m) |

## 2.2 Method for estimating $CO_2$e impacts for mitigation actions

To quantify the $CO_2$e impacts from the FWMT rural mitigation library, a variety of methods were used, depending on data availability. The process and associated methods were:

- Utilising the $CO_2$e impact estimates from the same literature that was used to estimate the water quality impacts where appropriate and where the estimates were considered robust.
- If the existing literature did not quantify the impact on $CO_2$e emissions for the water quality mitigations but contained enough data that these estimates could be estimated, the likely change in biogenic emissions were calculated using an existing greenhouse gas calculator. This was applicable for mitigations that were largely system or practice-based rather than devices which are not the focus of the existing greenhouse gas calculators.
- If neither of the above methods were appropriate the alternative literature was searched and utilised where there were appropriate estimates that aligned with how the existing mitigation had been described.
- The final alternative was to utilise the Moata Carbon Portal (Moata) to 'build' the mitigation from its component parts to estimate the $CO_2$e impact, this was the preferred method for device-based mitigations which had some kind of construction component associated with them.

The rural mitigations lend themselves to different methods. For example, devices which have embodied carbon emissions during construction, but low to no emissions over their life cycle lend themselves to being built in Moata. Conversely, the farm system mitigations with enough data which largely impact biogenic emissions are best estimated through one of the 'approved' greenhouse gas calculators (i.e., reflecting greater and differing sources of uncertainty).

### 2.2.1 Assessment of greenhouse gas calculators

For the farm system mitigations 'approved' greenhouse gas calculators were used to calculate the likely change in biogenic emissions for rural mitigations in the FWMT. To date, there are 12 greenhouse gas emissions calculator tools that have been made available publicly for use and are approved from the He Waka Eke Noa programme (Journeaux et al., 2021; 2022). A summary of the gases the tool accounts for, and the complexity and farm type it applies to can be found in

The He Waka Eke Noa calculators listed in Table 5 were assessed for fit for purpose (e.g., to FWMT translating relativistic changes across interventions in direct lifecycle $CO_2$e), input data required and the data available for FWMT interventions. From this, the Ministry for the Environment (MfE) Calculator was consistently adopted in this project where a calculator was required for an FWMT intervention lifecycle $CO_2$e estimate. The MfE Calculator was chosen as it required the least amount of farm specific data to calculate an estimate, farm data is generalised in the FWMT, and additional assumptions needed were therefore minimised.

The MfE Calculator was used across all pastoral and horticultural land uses to ensure consistency across these estimates. Whilst it provides a simple approach to estimating biogenic emissions from animals, manure management and nitrogen use on farm, it also enabled consistent assumptions to be made across interventions. For instance, in using the MfE Calculator it was assumed that all other sources of carbon (embodied carbon on farm and sequestration) were held constant and only the biological greenhouse gas emissions changed (Figure 2).

**Table 5:** Greenhouse gas calculators in Journeaux et al. (2021; 2022) and assessed for FWMT intervention use. MfE agriculture greenhouse gas (**bold**) selected for use.

| Creator/ Owner | Tool Name |
|---|---|
| Beef + Lamb New Zealand (B+LNZ) | B+LNZ GHG Calculator |
| Foundation for Arable Research (FAR) | ProductionWise |
| Toitū | Toitū farm emanage |
| MyImprint | MyImprint Farm |
| New Zealand Merino (NZM) | Made for Good RX |
| **Ministry for the Environment** | **Agriculture Greenhouse Gas Calculator** |
| Overseer | OverseerFM |
| Alltech | Alltech E-$CO_2$ |
| Grazing Systems Limited | Grazing Systems Limited |
| Farmax | FARMAX Pro |
| Ministry for Primary Industries | Fonterra Agricultural Inventory Model (AIM) |
| Ministry for Primary Industries | Horticulture NZ Calculator |

### 2.2.2 Base $CO_2$e footprints by rural land use

Many FWMT interventions remove land from production. Corresponding lifecycle $CO_2$e estimates will be a combination of both the intervention associated emissions/sequestration and also, the corresponding change in land-based emissions from the change in production. Some mitigation estimates are provided in the literature as a percentage change to farm emissions, which also requires the use of an appropriate base carbon footprints by land use. Hence, the identification of a suitable base carbon footprint for the rural land use options is necessary for assigning rural FWMT interventions their lifecycle $CO_2$e estimate.

The literature was assessed to calculate an appropriate base carbon footprint for each rural land use (HRU group) in the FWMT with base footprints adopted here summarised in Table 6 below.

**Table 6:** Base $CO_2$e footprints for rural mitigation options

| Land Use | Base $CO_2$e Footprint | Source |
|---|---|---|
| Dairy | 9.2 t $CO_2$e ha/yr | DairyNZ Economics Group (2014) data entered into the MfE Calculator |
| Sheep & Beef (<10 SU) | 3.4 t $CO_2$e ha/yr | Matheson et al. (2018) data entered into the MfE Calculator |
| Sheep & Beef (>10 SU) | 3.8 t $CO_2$e ha/yr | |
| Horticultural (low and medium impact) | 1.5 t $CO_2$e ha/yr | |
| Horticultural (high impact) | 1.2 t $CO_2$e ha/yr | The Agribusiness Group (2014) data entered into the MfE Calculator |

For dairy land the base footprint used was 9.2 t $CO_2$e ha/yr based on entering information from the DairyNZ Economics Group (2014) into the MfE Calculator. The corresponding $CO_2$e estimate is similar to Ag Matters[7] estimates for an average dairy farm (9.6 t GHG/ha/yr [Ag Matters, 2022]) and to Matheson et al. (2018) estimates for a Bay of Plenty case study data (8.1 t $CO_2$e ha/yr using Overseer 6.3.0 and MfE Calculator). It is important to note that the Matheson et al. (2018) and DairyNZ Economics Group (2014) farm data use different case studies. Matheson et al. (2018) used a Bay of Plenty dairy farm that was milking 304 cows per hectare with 131 kg N fertiliser and 13% imported feed. The DairyNZ Economics Group (2014) was for a dairy farm in the Waikato-Waipa River catchment that was milking 366 cows per hectare with 116 kg N fertiliser and 17% imported feed. The DairyNZ Economics Group (2014) base was chosen as this aligned with the source to estimate the water quality and profitability impacts of the FWMT good farming practice bundled interventions (e.g., mitigation bundles 2 and 3 for nitrogen).

Sheep and beef land uses were attributed a different base for less than 10 SU/ha and more than 10 SU/ha as both define differing HRU groups for pastoral land in the FWMT. In the FWMT, Matheson et al. (2018) informed design of good farming practice bundled interventions. The latter farm data were entered into the MfE Calculator to provide a base footprint of 3.8 t $CO_2$e /ha/yr for the more than 10 SU/ha farm and 3.4 t $CO_2$e /ha/yr for the less than 10 SU/ha. The 3.4 and 3.8 t $CO_2$e ha/yr estimates are also supported by Ag Matters (2022) which provides a nationwide base $CO_2$e footprint estimate of 3.6 t $CO_2$e /ha/yr (not differentiated by stocking rates) for drystock farming across all regions.

The base carbon footprint for the low and medium impact horticulture were estimated for a maize silage farm system from Matheson et al. (2018), utilised in the MfE Calculator. The latter 40 ha maize silage farm system used 630 kg urea per hectare (or 290 kg N/ha/yr) and grazed 300

[7] Ag Matters is a website that draws together latest scientific knowledge, background information, resources and case studies to help New Zealand's primary producers and rural professionals understand what they can do to help reduce on-farm emissions of greenhouse gases and achieve other environmental goals. Ag Matters is funded by the Ministry for Primary Industries' Sustainable Land Management and Climate Change programme and managed by the New Zealand Agricultural Greenhouse Gas Research Centre.

dairy cows on annual for 8 weeks over the winter, which for the MfE Calculator was adjusted to an equivalent number of cows across the whole year (namely 46 cows). The base $CO_2$e footprint was 1.5 t $CO_2$e ha/yr. Notably, the MfE Calculator estimate is lower than the Matheson et al. (2018) estimate of 3.1 t $CO_2$e ha/yr. Differences in estimates may be a result of Matheson et al. (2018) using an older version of Overseer that has now been improved to better represent technical information. Given the relative calculations in Overseer and the MfE Calculator, it might be that that these changes are driven by the high winter stocking rate and the relative increases in nitrous oxide losses from urine patches, a temporal variation the MfE calculator can't accommodate. The use of the MfE Calculator does allow for consistency across the two studies used for the high impact horticulture mitigations.

The high impact horticulture land use FWMT mitigations were based on Agribusiness Group (2014) data for the Lower Waikato catchment, which aligns with the source of information used for estimating impact and cost of good farming practice bundled interventions. A weighted average of 50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden were used in the MfE Calculator. To calculate the carbon impact and base footprint for these mitigations the total fertiliser applied on each rotation (across each 4-year rotations) was annualised. This was done because the fertiliser applied in each year varied across the 4-year rotation and the MfE Calculator is based on an annual estimate. This was then weighted as above across the three rotations. This meant that in the base model there was 237 kg N/ha/yr applied through 516 kg urea (without urease inhibitor) fertiliser. There was limited comparable data to validate this estimate of carbon emissions from this farm system. The base $CO_2$e footprint was 1.2 t $CO_2$e ha/yr.

# 3 Carbon impact of rural mitigation actions

This section details the rural mitigation options and their estimated $CO_2$e impact. As discussed in the Part A introduction, these can include the embodied carbon in constructing a mitigation ("acquisitional" or "operational"), the change in biological emissions from the change in farm systems and any additional sequestration from the mitigation. Changes in embodied carbon in a farm system (e.g., replacement of infrastructure) are excluded at this stage as the impact of the mitigations on these is expected to be insignificant.

Rural mitigations in the FWMT include both source controls (changing diffuse contaminant losses from large areas of HRU, also known as farm system changes and practice-based mitigations) and EOF mitigations (reducing diffuse contaminant loss from localised areas and/or intercepting diffuse contaminant losses from large areas of HRU albeit on a localised area).

Table 7 and Table 8 summarise the impact of each mitigation on $CO_2$e emissions. Each section below details one rural sector mitigation in the FWMT library. Each section gives a brief overview of the mitigation, an estimated $CO_2$e impact alongside a confidence level and a brief discussion. Detailed discussion on the broader literature behind each mitigation option is included in Muller et al. (2020) and Muller and Stephens (2020) and is not repeated here.

**Table 7:** Summary of the $CO_2$e impact of farm system rural sector mitigation

| Land use typology (HRU) | Farm system mitigations | $CO_2$e impact (change in biological emissions) | Description |
|---|---|---|---|
| Dairy | M2 N | -0.88 t $CO_2$e/ha/yr | Change of -0.88 t $CO_2$e/ha/yr from a base of 9.79 t $CO_2$e/ha/yr |
| | M3 N | -1.34 t $CO_2$e/ha/yr | Change of -1.34 t $CO_2$e/ha/yr from a base of 9.79 t $CO_2$e/ha/yr |
| Sheep and beef (<10 SU/ha) | M1 | 0 t $CO_2$e/ha/yr | No change from a base of 3.4 t $CO_2$e/ha/yr |
| | M2 | -0.1 t $CO_2$e/ha/yr | Change of -0.1 t $CO_2$e/ha/yr from a base of 3.4 t $CO_2$e/ha/yr |
| | M3 | -0.2 t $CO_2$e/ha/yr | Change of -0.2 t $CO_2$e/ha/yr from a base of 3.4 t $CO_2$e/ha/yr |
| Sheep and beef (>10 SU/ha) | M1 | 0 t $CO_2$e/ha/yr | No change from a base of 4.3 t $CO_2$e/ha/yr |
| | M2 | -0.3 t $CO_2$e/ha/yr | Change of -0.3 t $CO_2$e/ha/yr from a base of 4.3 t $CO_2$e/ha/yr |
| | M3 | -0.4 t $CO_2$e/ha/yr | Change of -0.4 t $CO_2$e/ha/yr from a base of 4.3 t $CO_2$e/ha/yr |
| Hort (low & medium impact) | M1 | -0.2 t $CO_2$e/ha/yr | Change of -0.2 t $CO_2$e/ha/yr from a base of 1.5 t $CO_2$e/ha/yr |
| | M2 | -0.8 t $CO_2$e/ha/yr | Change of -0.8 t $CO_2$e/ha/yr from a base of 1.5 t $CO_2$e/ha/yr |
| | M3 | -1 t $CO_2$e/ha/yr | Change of -1 t $CO_2$e/ha/yr from a base of 1.5 t $CO_2$e/ha/yr |
| Hort (high impact) | M1 | 0 t $CO_2$e/ha/yr | No change from a base of 1.2 t $CO_2$e/ha/yr |
| | M2 | -0.1 t $CO_2$e/ha/yr | Change of -0.1 t $CO_2$e/ha/yr from a base of 1.2 t $CO_2$e/ha/yr |
| | M3 | -0.2 t $CO_2$e/ha/yr | Change of -0.2 t $CO_2$e/ha/yr from a base of 1.2 t $CO_2$e/ha/yr |

**Table 8:** Summary of the $CO_2e$ impact of the EOF rural sector mitigations

| Land use typology (HRU) | EOF mitigations | $CO_2e$ impact | Description |
|---|---|---|---|
| All | Space planting | -7 t $CO_2e$/ha/yr | An additional 7 t $CO_2e$/ha/yr is sequestered in the trees in years 1-25 then all is released during felling at year 26 (167 $CO_2e$/ha/yr) and then an additional 7 t $CO_2e$/ha/yr is sequestered in the trees in years 27-50, before all being released again. |
| All pasture | Detainment bund | +12.7 t $CO_2e$ | An additional 12.7 t $CO_2e$ is emitted across the 50 years. This includes 3.1 t $CO_2e$ in years 1 and 26 for construction and then 0.14 t $CO_2e$ in every other year for maintenance. |
| All horticulture | Sediment retention pond | +7.9 t $CO_2e$ | An additional 7.9 t $CO_2e$ is emitted across the 50 years. This includes 0.5 t $CO_2e$ in years 1 and 26 for construction and then 0.15 t $CO_2e$ in every other year for maintenance. |
| Dairy | Small wetlands (5,000m$^2$) | +50.37 t $CO_2e$<br>+1.26 t $CO_2e$<br>+0.15 t $CO_2e$/yr<br>-0.23 t $CO_2e$/yr | An additional 50.37 t $CO_2e$ is emitted in construction, another 1.26 t $CO_2e$ emitted during renewal in year 26 and an additional 0.15 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.23 t $CO_2e$/yr. |
| Sheep & beef (<10SU/ha) | | +50.37 t $CO_2e$<br>+1.26 t $CO_2e$<br>+0.15 t $CO_2e$/yr<br>-0.09 t $CO_2e$/yr | An additional 50.37 t $CO_2e$ is emitted in construction, another 1.26 t $CO_2e$ emitted during renewal in year 26 and an additional 0.15 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.09 t $CO_2e$/yr. |
| Sheep & beef (>10SU/ha) | | +50.37 t $CO_2e$<br>+1.26 t $CO_2e$<br>+0.15 t $CO_2e$/yr<br>-0.10 t $CO_2e$/yr | An additional 50.37 t $CO_2e$ is emitted in construction, another 1.26 t $CO_2e$ emitted during renewal in year 26 and an additional 0.15 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.10 t $CO_2e$/yr. |
| Hort (low & medium impact) | | +50.37 t $CO_2e$<br>+1.26 t $CO_2e$<br>+0.15 t $CO_2e$/yr<br>-0.04 t $CO_2e$/yr | An additional 50.37 t $CO_2e$ is emitted in construction, another 1.26 t $CO_2e$ emitted during renewal in year 26 and an additional 0.15 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.04 t $CO_2e$/yr. |
| Hort (high impact) | | +50.37 t $CO_2e$<br>+1.26 t $CO_2e$<br>+0.15 t $CO_2e$/yr<br>-0.03 t $CO_2e$/yr | An additional 50.37 t $CO_2e$ is emitted in construction, another 1.26 t $CO_2e$ emitted during renewal in year 26 and an additional 0.15 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.03 t $CO_2e$/yr. |

| Land use typology (HRU) | EOF mitigations | $CO_2e$ impact | Description |
|---|---|---|---|
| Dairy | Large wetlands (15,000$m^2$) | +114.65 t $CO_2e$<br>+1.95 t $CO_2e$/yr<br>+0.43 t $CO_2e$/yr<br>-0.69 t $CO_2e$/yr | An additional 114.6 t $CO_2e$ is emitted in construction, another 1.95 t $CO_2e$ emitted during renewal in year 26 and an additional 0.43 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.69 t $CO_2e$/yr. |
| Sheep & beef (<10SU/ha) | | +114.65 t $CO_2e$<br>+1.95 t $CO_2e$/yr<br>+0.43 t $CO_2e$/yr<br>-0.26 t $CO_2e$/yr | An additional 114.6 t $CO_2e$ is emitted in construction, another 1.95 t $CO_2e$ emitted during renewal in year 26 and an additional 0.43 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.26 t $CO_2e$/yr. |
| Sheep & beef (>10SU/ha) | | +114.65 t $CO_2e$<br>+1.95 t $CO_2e$/yr<br>+0.43 t $CO_2e$/yr<br>-0.29 t $CO_2e$/yr | An additional 114.6 t $CO_2e$ is emitted in construction, another 1.95 t $CO_2e$ emitted during renewal in year 26 and an additional 0.43 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.29 t $CO_2e$/yr. |
| Hort (low & medium impact) | | +114.65 t $CO_2e$<br>+1.95 t $CO_2e$/yr<br>+0.43 t $CO_2e$/yr<br>-0.11 t $CO_2e$/yr | An additional 114.6 t $CO_2e$ is emitted in construction, another 1.95 t $CO_2e$ emitted during renewal in year 26 and an additional 0.43 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.11 t $CO_2e$/yr. |
| Hort (high impact) | | +114.65 t $CO_2e$<br>+1.95 t $CO_2e$/yr<br>+0.43 t $CO_2e$/yr<br>-0.09 t $CO_2e$/yr | An additional 114.6 t $CO_2e$ is emitted in construction, another 1.95 t $CO_2e$ emitted during renewal in year 26 and an additional 0.43 t $CO_2e$/yr for maintenance (years 2-50). There is a change in biological emissions of -0.09 t $CO_2e$/yr. |
| Dairy | Riparian 1 m | Planted -57.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -40.37 kg $CO_2e$ /buffer width $m^2$ | Embodied carbon (fencing) +5.63 kg $CO_2e$ /m fence /50 yrs, with +2.815 kg $CO_2e$ occurring in yr 1 and another +2.815 kg $CO_2e$ in yr 26.<br>Change in biological emissions for both planted & grass, varies by HRU and buffer width.<br>Additional sequestration 0.34 kg $CO_2e$ /buffer width $m^2$/yr for planted. |
| | Riparian 2.5 m | Planted -151.87 kg $CO_2e$ /buffer width $m^2$<br>Grass -109.37 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 5 m | Planted -309.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -224.37 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 10 m | Planted -624.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -454.37 kg $CO_2e$ /buffer width $m^2$ | |

| Land use typology (HRU) | EOF mitigations | $CO_2e$ impact | Description |
|---|---|---|---|
| Sheep & beef (<10SU/ha) | Riparian 1 m | Planted -28.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -11.37 kg $CO_2e$ /buffer width $m^2$ | Embodied carbon (fencing) +5.63 kg $CO_2e$ /m fence /50 yrs, with +2.815 kg $CO_2e$ occurring in yr 1 and another +2.815 kg $CO_2e$ in yr 26.<br>Annual change in biological emissions for both planted & grass, varies by HRU and buffer width.<br>Additional sequestration 0.34 kg $CO_2e$ /buffer width $m^2$/yr for planted. |
| | Riparian 2.5 m | Planted -79.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -36.87 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 5 m | Planted -164.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -79.37 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 10 m | Planted -334.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -164.37 kg $CO_2e$ /buffer width $m^2$ | |
| Sheep & beef (>10SU/ha) | Riparian 1 m | Planted -30.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -13.37 kg $CO_2e$ /buffer width $m^2$ | Embodied carbon (fencing) +5.63 kg $CO_2e$ /m fence /50 yrs, with +2.815 kg $CO_2e$ occurring in yr 1 and another +2.815 kg $CO_2e$ in yr 26.<br>Change in biological emissions for both planted & grass, varies by HRU and buffer width.<br>Additional sequestration 0.34 kg $CO_2e$ /buffer width $m^2$/yr for planted. |
| | Riparian 2.5 m | Planted -84.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -41.87 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 5 m | Planted -174.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -89.37 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 10 m | Planted -354.37 kg $CO_2e$ /buffer width $m^2$<br>Grass -184.37 kg $CO_2e$ /buffer width $m^2$ | |
| Hort (low & medium impact) | Riparian 1 m | Planted -24.50 kg $CO_2e$ /buffer width $m^2$<br>Grass -7.50 kg $CO_2e$ /buffer width $m^2$ | Embodied carbon (fencing) +5.63 kg $CO_2e$ /m fence /50 yrs, with +2.815 kg $CO_2e$ occurring in yr 1 and another +2.815 kg $CO_2e$ in yr 26.<br>Change in biological emissions for both planted & grass, varies by HRU and buffer width.<br>Additional sequestration 0.34 kg $CO_2e$ /buffer width $m^2$/yr for planted. |
| | Riparian 2.5 m | Planted -61.50 kg $CO_2e$ /buffer width $m^2$<br>Grass -19 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 5 m | Planted -122.50 kg $CO_2e$ /buffer width $m^2$<br>Grass -37.50 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 10 m | Planted -245 kg $CO_2e$ /buffer width $m^2$<br>Grass -75 kg $CO_2e$ /buffer width $m^2$ | |

| Land use typology (HRU) | EOF mitigations | $CO_2e$ impact | Description |
|---|---|---|---|
| Hort (high impact) | Riparian 1 m | Planted -23 kg $CO_2e$ /buffer width $m^2$<br>Grass -6 kg $CO_2e$ /buffer width $m^2$ | Embodied carbon (fencing) +5.63 kg $CO_2e$ /m fence /50 yrs, with +2.815 kg $CO_2e$ occurring in yr 1 and another +2.815 kg $CO_2e$ in yr 26.<br>Change in biological emissions for both planted & grass, varies by HRU and buffer width.<br>Additional sequestration 0.34 kg $CO_2e$ /buffer width $m^2$/yr for planted. |
| | Riparian 2.5 m | Planted -57.50 kg $CO_2e$ /buffer width $m^2$<br>Grass -15 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 5 m | Planted -115 kg $CO_2e$ /buffer width $m^2$<br>Grass -30 kg $CO_2e$ /buffer width $m^2$ | |
| | Riparian 10 m | Planted -230 kg $CO_2e$ /buffer width $m^2$<br>Grass -60 kg $CO_2e$ /buffer width $m^2$ | |

## 3.1 Edge of field (EOF) mitigations

The EOF mitigations include mitigations that intercept contaminant lost from land. These typically require limited system changes and may not be land use specific. Common examples include wetlands (creation or restoration), riparian buffers (grassed or planted), detainment bunds and sedimentation retention ponds (Muller et al., 2020).

### 3.1.1 EOF – Space planting of erosion control trees

Space planting, where poplars or willows (typically) are planted on highly erodible land, is intended to reduce erosion from slopes. The current mitigation in the FWMT (based on Muller et al., 2020) assumes that:

- The trees are planted in year 1 and 25 (i.e., they have a 25 year life span).
- They are only applicable for pastoral land, not horticulture land.
- The results are not differentiated by soil type or slope due to a lack of information on the literature estimates, although one can assume they have the most benefit where they stop erosion from happening which is more likely to happen on highly erodible land.
- There is no quantifiable data set to understand the base adoption, and therefore opportunity for this mitigation.
- It was assumed that the shading impact of trees as they mature had limited impact on pasture production when balanced with the reduction in soil loss and positive impacts that shading will have on animal welfare.
- The benefit for water quality for space planted trees in Muller et al. (2020) was based on Daigneault and Elliott (2017) while the costs were based on Parminter et al. (2001) for approximately 70 stems/ha and at this rate of planting there was no change in production.

Trees planted on slopes support the retention of soil, thereby preventing erosion. As well as preventing shallow landslides, space planted poplars will sequester carbon. Where planted trees meet the minimum criteria under the ETS, space planted poplar forests are eligible to enter the ETS and accumulate NZUs. To be eligible, stands must be 1 ha or more with an average minimum width of 30 m, have a potential height of more than 5 m and be capable of achieving 30% canopy cover. For narrow-crowned non-fastigiate type cultivars, this is assumed to occur at between 80-100 stems/ha (Matheson and Muller, 2020), approximately twice the density required to achieve soil stabilisation. For ETS registrations less than 100 ha, NZUs are accumulated based on the Exotic Hardwood look-up tables published by Te Uru Rākau (MPI, 2017). However, because the assumption was made in Muller et al. (2020) that 70 stems/ha were planted it is unlikely that this mitigation would qualify for registration in the ETS and therefore we cannot use the look-up tables to estimate a feasible carbon sequestration. If more stems were planted to achieve this registration in the ETS then it is likely that the assumptions around cost in Muller et al. (2020) would no longer hold due to the increase in shading and therefore loss in pasture production.

The method for calculating the $CO_2e$ impact of space planting erosion control trees across pastoral land uses was to utilise estimates of the carbon sequestered from space planted poplars from Matheson and Muller (2020) can be found in Table 9 below. Because this $CO_2e$

impact is only assumed to impact sequestration there is no differentiation across land use types (noting the land use was assumed to be unaffected at 70 stems/ha).

Space planting of erosion control trees on pastoral land uses will have a positive impact on $CO_2e$ as trees sequester carbon dioxide in their roots, leaves, branches and roots. It is likely that the $CO_2e$ impacts will vary over the 50 year LCC because of the amount of sequestration a tree will have over its lifetime. However, to simplify the LCC model each tree will be assumed to have the same sequestration annually for 25 years. When a tree is removed the sequestered carbon is released. Over time the replacement tree begins sequestering.

Matheson and Muller (2020) analysed the carbon sequestration potential of space planted poplars in New Zealand based on a range of literature. A plantation of 25 year space planted poplar planted at 156 stems/ha was estimated to sequester approximately 101.4 t C/ha or 371.4 t $CO_2$ /ha[8]. Based on this estimate, it is assumed a single space planted poplar sequesters 0.65 t C/ha per tree over 25 years, therefore for 70 stems/ha (the assumed planting rate for the FWMT mitigation) this equates to 45.5 t C/ha, or 167 t $CO_2$/ha.

By comparison, Cannell (1999) reported that poplar trees planted at 156 stems/ha sequestered approximately 26 kg C per tree per annum (over a 25 year growing period), and 1,820 kg C/ha [45,500 t C/ha/yr] over 25 years. Using the per tree rates in Matheson and Muller (2020) and Cannell (1999) 70 stems/ha is estimated to sequester 167 t $CO_2e$/ha across 25 years. This equates to 7 t $CO_2e$/ha/yr. This occurs in years 1 to 25, all carbon is then released when the trees are assumed to be replaced and then the same sequestration occurs in years 27 to 50. A summary is provided in Table 9.

**Table 9:** Summary of carbon sequestration calculations in space planting

| Source | Stems (/ha) | Sequestration (t C/ha) | Sequestration (t C/stem/ha) | Sequestration (t $CO_2e$/ha over 25 years) | Sequestration (t $CO_2e$/ha/yr growing) |
|---|---|---|---|---|---|
| Matheson and Muller (2020) | 156 | -101.4 | -0.65 | -371 | -14.9 |
| FWMT | 70 | -45.5 | -0.65 | -167 | -7 |

Matheson and Muller (2020) undertook their assessment of the $CO_2e$ impact of space planted trees for a farm in the Upper Turakina catchment. They took the annual biological greenhouse gas emissions (in $CO_2e$) and deducted the $CO_2e$ accumulated in a space planted tree over a 28 year period post planting. The net greenhouse gas emissions from the 29.7 ha broad-crowned space planted poplars before planting was approximated to be 48,652 t $CO_2e$, equivalent to 1,638 t $CO_2e$/ha over the 28 year period. The change from unplanted to planted emissions saw a change of -9% in the net quanta of greenhouse gases (in $CO_2$ and $CO_2e$) from 48,652t $CO_2e$ to 44,051 t $CO_2e$ (1,483 t $CO_2e$) during this period. This was a combined impact from a change in production (due to shading effects from 156 stems/ha) as well as sequestration. This percentage reduction is not directly comparable to this report as the FWMT mitigation does not reduce the farm production and stock numbers.

Daigneault and Elliott (2017) have estimated a percentage change of greenhouse gases, with a change of -5% for dairy and -6% for sheep and beef land uses (they have not assumed stocking rate changes). There was no clear reason provided for the minor difference in the impact of

[8] Assuming 1 t C is equivalent to 3.663 t of $CO_2$.

space planting on dairy and sheep and beef land. Estimates were derived from the national GHG inventory methodology, however Daigneault and Elliott (2017) do not provide their assumptions used.

Based on the available data, reasonable alignment with literature and the expectation that planting trees will sequester carbon and therefore reduce greenhouse gas emissions, the Matheson and Muller (2020) and aligned Cannell (1999) estimates have been used to quantify the $CO_2e$ impact of space planted trees, with a **medium confidence level**. The estimates can be found in Table 10 below.

**Table 10:** Estimated $CO_2e$ impacts of space planted trees

| | Total $CO_2e$ impact (t $CO2_e$/ha/yr) | | | | Confidence level |
|---|---|---|---|---|---|
| **HRU** | **Years 1 -25 (sequestered)** | **Year 26 (emitted)** | **Year 27-50 (sequestered)** | **Year 51 (emitted)** | Medium |
| **All pasture** | -7 | 167 | -7 | 167 | |
| *Applies to area with space planted trees and for 25 years and then is released before being re-sequestered.* | | | | | |

This mitigation accounts for continuous annual sequestration for each year the trees are growing. When they die (assumed after 25 yrs) they release all this stored carbon, replacement tree plantings then start storing carbon again.

### 3.1.2 EOF – Wetlands [<1 ha and >1 ha]

Understanding the carbon fluxes and therefore true $CO_2e$ impact of a wetland has long been considered a challenge to determine with real certainty. A wetland is defined as permanently or intermittently wet areas, shallow water, or land/water margins that support a natural community of plants and animals adapted to living in wet conditions (Manaaki Whenua, 2018). Wetlands are complex when it comes to $CO_2e$ emissions and sequestration, acting as both a source and sink of carbon both across time and across wetland characteristics (Whiting and Chanton, 2001). Globally, wetlands are the dominant natural source of methane ($CH_4$) emissions, however their anaerobic conditions prevent decomposition of matter.

The benefit of wetlands to water quality is well understood, particularly with the ability to markedly attenuate nutrient and sediment loads to waterways (Rutherford et al., 2004, 2009; Rutherford, 2017). According to Whiting and Chanton (2001), the $CO_2e$ impact of wetlands as a mitigation option tends to counter-balance, meaning what can be good for water quality may not lead to positive carbon impacts. The balance of different forms of carbon emission pathways is pivotal in understanding the likely $CO_2e$ impact of wetlands. Figure 3 provides a stylised example of a carbon cycle in a wetland. Key carbon emission pathways include:

- Carbon sequestration through vegetation.
- Methane emissions through microbial processes in waterlogged soils.
- Storage of long term carbon in wetland soil (due to slow diffusion of oxygen).
- Emission of carbon dioxide through respiration and decomposition processes (and emission of nitrous oxides through incomplete denitrification – unshown).

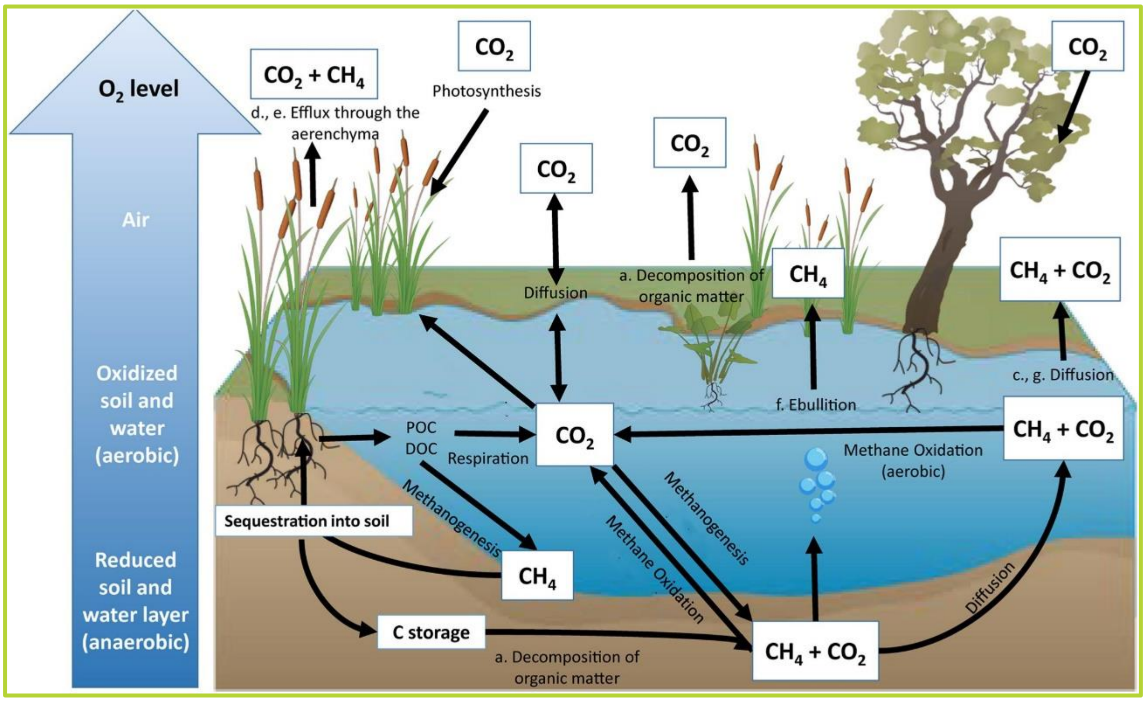


**Figure 3:** Example of inland wetland cycle and carbon sequestration and emission pathways (Limpert et al., 2021).

In the FWMT rural mitigation library there are multiple wetland mitigations. Initially, in Muller et al. (2020) the wetlands recommended were considered facilitated or naturalised wetlands (i.e., distinguished from highly engineered and constructed variants). Naturalised wetlands are differentiated by size in the FWMT, to equal to/less than or more than 1 ha, due to differing associated lifecycle cost. (An addendum in Muller et al. (2022) also costs an additional wetland type, a large rural constructed wetland greater than 5 ha in footprint – that is not considered here).

Limited quantifiable information on the greenhouse gas profiles of rural wetlands meant a single $CO_2$e estimate is recommended here (e.g., "defensible simplicity" – a principle underpinning continuous improvement within the FWMT programme).

Facilitated rural wetlands in the FWMT are costed for 50% loss in productivity (see below), reflecting a midpoint of literature estimates (Muller et al., 2020). This is important as any change in stocking rates will need to be considered in terms of reducing biological greenhouse gas emissions. The wetland mitigations in the FWMT assume that wetlands only occur in flat and rolling areas with no variation in cost or efficacy across soil types (Muller et al., 2020). In Muller et al. (2020) the benefit of wetlands on water quality were based on Daigneault and Elliott (2017) while the costs were based on Muller (2019) and NIWA (2007).

A review of existing literature found that the carbon impact of a wetland will vary depending on environmental conditions. Daigneault and Elliott (2017) estimated that the carbon impact of wetlands across pastoral and horticultural HRU's to be neutral. A study in the Waikato showed that a wetland converted into pasture emitted 3.7 t C /ha/yr in the first 40 years (Schipper & McLeod, 2002), slowing to about 1 t C/ha/yr more recently (Nieveen et al., 2005). Limpert et al. (2021) discusses that the carbon before and after a watering event will vary based on the carbon and methane interactions. Ausseil et al. (2015) conducted a study on the estimate of carbon stocks of freshwater wetlands across New Zealand, estimating organic wetlands to have a carbon density mean of 1,348 t C/ha, comparable to estimates from wetlands overseas.

The New Zealand GHG Inventory provides long term carbon stock estimates for wetlands, across all land uses. It is noted there is a lack of current data available on biomass carbon stock[9] changes to estimate the complete carbon impact of a wetland. Carbon stock estimates are the only available information as there is currently no practicable method for measuring non-$CO_2$ emissions. From 1990-2020, vegetated wetlands in New Zealand emitted 68.6kt $CO_2$. (68,600 t $CO_2$). The estimate equates to approximately 0.009 t $CO_2$ /ha, annualised over ten years (MfE, 2022).

On reviewing the New Zealand literature there appears a dearth of studies and little consensus in the $CO_2$e equivalent emissions from a wetland – clearly, more research is needed to better understand the impact of wetlands on carbon emissions if this is important to water quality management strategies. Hence, an approximation is reported here from both the change in biological emissions due to the construction of a wetland (i.e., reduction of 50% production on land turned into a wetland) and the embodied carbon emissions in the construction and maintenance of a wetland.

Using the Moata Carbon Portal, the schedule of quantities for construction of an urban wetland was used to form the basis of the assets that are assumed to make up a rural wetland. These construction schedules were provided by AR Associates (pers. Comm. 20 April, 2023) for the use in this project. The wetland dimensions assume a 6:1 ratio for the 5,000 $m^2$ wetland with a perimeter of 450 m, and a 8:1 ratio for the 15,000 $m^2$ wetland with a perimeter of 700 m. These dimensions comply with the minimum ratio recommended by the Auckland Council (Auckland Council, 2017).

A 5,000 $m^2$ wetland was constructed to represent a facilitated wetland of <1 ha, and a 15,000 $m^2$ wetland was constructed to represent a constructed wetland >1 ha, in line with the rural wetland mitigations in the FWMT. Large rural wetlands (those more than 5 ha in size) were not included. The size and assumptions around construction requirements varied between facilitated and construction wetlands. It is assumed that embodied $CO_2$e in wetlands construction would not differ across pastoral and horticultural land uses. There are several assumptions that have been made for different phases of construction. The assumptions relating to quantities for the 15,000 $m^2$ wetland, representative of wetlands greater than a hectare have been quantified as a proportion of the 5,000 $m^2$ wetland quantities that have been provided. The embodied carbon accounts for the components related to construction (year 1), maintenance (years 2-50) and renewal (year 25). It has been assumed that only fencing is renewed and therefore the renewal impact accounts for fencing and the related transport emissions only, there is no fencing maintenance. Detailed assumptions of the wetland assets can be found in Table 34, however the differences in a facilitated and constructed wetland are summarised in Table 11.

[9] A carbon stock, or carbon pool, is a system that has the capacity to store or release carbon.

**Table 11:** Facilitated and constructed wetlands assets used in models in Moata carbon portal

| Asset | Description | Facilitated | Constructed |
|---|---|---|---|
| Earthworks | Assume that the clearing of topsoil and bulk excavation will be stockpiled/spread/utilised on site. This accounts for the use of earth working (e.g., excavators) machinery for soil from trimming and shaping of wetland bays and embankments. | None | 29,480 $m^3$ |
| Site Clearing | Assume that there will be removal of existing pasture and vegetation. | 5,000 $m^2$ | 15,000 $m^2$ |
| Roading | Assume that gravel will be transported and laid on site to provide access for diggers and compactor machinery during construction. This is one of the key differences to the urban interventions which will require transport of excavation off site. | None | 120 $m^3$ |
| Compaction | Accounts for travel to and from site and diesel used to operate compactor. | None | 600 kg compactor travelling 30 km both ways |
| Construction components | Assume a plastic underdrain pipe, silt fence for erosion control during construction and hydroseed is required to stabilise outside berm areas and exposed areas. | None | HDPE pipe, 700 $m^2$ hydroseed, 300 m silt fence 1 m high |
| Outlet structures | It has been assumed that geotextile lining, riprap, a scruffy dome, a stormwater pipe, a manhole and an inlet/outlet concrete wingwall is required. | None | |
| Planting | Assume 6 litres of diesel per trip for transportation of planting/trees. The number of trips depends on size of wetland and amount of planting required. | Three trips | Nine trips |
| Fencing | Treated wooden batten posts at 5 m centres, height 1.40 m (8 wires) with 4 mm wire. | 450 m | 700 m |
| Sequestration | Due to challenges and a likelihood of a minor contribution, sequestration from wetland planting has been excluded in the carbon impact estimate. | | |

In addition to the embodied $CO_2e$ there is a change of $CO_2e$ emissions produced for land where the wetland was constructed. This varies by land use based on the relative base $CO_2e$ footprints (biological emissions) and was assumed to reduce by 50% based on the assumptions in the FWMT. This means the land was assumed to be only operating at 50% of typology production potential due to being a wetter boggier area and therefore suited to creating a facilitated wetland. The differences in the facilitated and constructed wetland are representative of the increased construction required for the constructed wetland.

**Table 12:** Estimated $CO_2$e impacts of facilitated and constructed wetlands in FWMT (derived from Moata Carbon Portal)

<table>
<tr><th rowspan="3">Size</th><th rowspan="3">HRU</th><th colspan="4">Total $CO_2$e impact (t $CO_2$e/wetland)</th><th rowspan="3">Confidence level</th></tr>
<tr><th rowspan="2">Change in base $CO_2$e footprint (change in biological emissions)[1]</th><th colspan="3">Embodied $CO_2$e emissions[2]</th></tr>
<tr><th>Construction (yr 1)</th><th>Maintenance (yrs 2-50)</th><th>Renewal (yr 25)</th></tr>
<tr><td rowspan="5">Facilitated wetland <1 ha (5,000m$^2$)</td><td>Dairy</td><td>-0.23</td><td rowspan="5">+50.37</td><td rowspan="5">+0.15 (per year)</td><td rowspan="5">+1.26</td><td rowspan="5">Low</td></tr>
<tr><td>Sheep and beef (<10SU/ha)</td><td>-0.085</td></tr>
<tr><td>Sheep and beef (>10SU/ha)</td><td>-0.095</td></tr>
<tr><td>Horticulture (low & medium impact)</td><td>-0.0375</td></tr>
<tr><td>Horticulture (high impact)</td><td>-0.03</td></tr>
<tr><td rowspan="5">Constructed wetland >1 ha (15,000m$^2$)</td><td>Dairy</td><td>-0.69</td><td rowspan="5">+114.65</td><td rowspan="5">+0.43 (per year)</td><td rowspan="5">+1.95</td><td rowspan="5">Low</td></tr>
<tr><td>Sheep and beef (<10SU/ha)</td><td>-0.255</td></tr>
<tr><td>Sheep and beef (>10SU/ha)</td><td>-0.285</td></tr>
<tr><td>Horticulture (low & medium impact)</td><td>-0.1125</td></tr>
<tr><td>Horticulture (high impact)</td><td>-0.09</td></tr>
</table>

[1] Based on 50% of base footprint on a m$^2$ basis, multiplied by area of wetland.

[2] Based on Moata estimates and assumptions above and in Table 34.

The $CO_2$e impact of a rural facilitated wetland device is marked as a **low confidence level** (e.g., considerable assumptions regarding design and excluding estimates of $CO_2$e emissions/sequestration of the wetland itself). It is prudent these estimates are used with caution given the uncertainty and lack of literature to support the estimates (Table 12).

### 3.1.3 EOF – Riparian areas, both planted and rank grass

The $CO_2$e impact of riparian planting and riparian grass is difficult to estimate given the limited literature available. Muller et al. (2020) had a range of mitigation options for riparian planting and riparian grass with a range of buffer widths (1 m, 2.5 m, 5 m, 10 m). Scenarios varied land use and slope (for pastoral land uses) and the 1-metre scenario was only considered for rank grass not planting. Stock water reticulation was only considered for sheep and beef pastoral land uses under the stock exclusion (1 metre buffer width) scenario, but this was excluded from the estimates of $CO_2$e emissions.

The $Co_2$e impact for riparian management included sequestration of riparian planting but not for rank grass due to a lack of information (and the fact that ungrazed pasture ultimately reaches a steady state of growth and senescence). The embodied carbon of transporting plant and fencing materials and related maintenance requirements was estimated using Moata. These assumptions can be viewed in more detail in Table 37. It has been assumed that there is minimal disturbance to planting in riparian areas to avoid disturbance of any carbon sequestered in soil. In addition, any land retired from production for riparian area also means there is a loss of biological emissions from that area of land. To calculate this the base $CO_2$e footprint for each land use was adjusted to a square metre basis and then can be applied for the require length of riparian areas.

Burrows et al. (2018) estimates sequestration from planted riparian areas at 3.4 t $CO_2$/ha/yr or 0.34 kg $CO_2$ /buffer width $m^2$/yr. The latter is recommended for use in FWMT riparian devices but only to planted riparian areas, not rank grass that lacks additional sequestration. The estimate of sequestration in planted riparian areas of 3.4 t $CO_2$/ha/yr from Burrows et al. (2018) has been used in He Waka Eke Noa modelling for reducing emissions on farms.

Planting in the FWMT rural riparian areas is generalised to be at 1 metre spacing and a mix of sedges, native trees and/or shrubs. While planting varies site by site, a generalised planting sequestration estimate is used (noting the ETS would exclude latter estimates from qualifying). Also, minimal (no) release of greenhouse gas is assumed for the planting period. The estimates of sequestration in riparian planting are in $CO_2$ values based on the literature. These are not recorded in $CO_2$e, as these estimates are related to carbon sequestration only it is assumed in this case that $CO_2$ is equivalent to $CO_2$e.

Embodied carbon for fencing materials and transport of these and plants to fencing sites was estimated in the Moata Carbon Portal, regardless of the buffer width, 1 m of riparian area requires 1 m of fencing. It has been assumed that there are no maintenance requirements, and that wooden fencing and planting is renewed after 25 years in the LCC in line with the renewal period for other mitigations in the FWMT. It is likely that transport of fencing materials is highly variable, however we have assumed a petrol 'ute' newer than 2015 would be used for regular inspections, with diesel vehicles only used to transport larger materials or machinery to site. Fencing has an impact on the $CO_2$e emissions from riparian planting. Across each of the buffer widths for riparian and rank grass, the carbon footprint from fencing (wooden fence 1.5 m with 8 wires, 4 mm), inclusive of the transport of plantings and sequestration of the plantings themselves, a $CO_2$e impact has been estimated. It is important to note that only one fencing type has been used to represent the maximum emissions across all HRUs. The transport emissions were based on the transport for fencing in wetlands on a per meter basis (averaged across the two fencing lengths for the different wetland types). This impact was included in year 1 and when the fence was replaced in year 26. No fencing was not included for horticulture as they typically do not require fencing.

In addition to the sequestration, productive land retired for riparian management will reduce a proportion of biological emissions. The FWMT rural riparian device costs are based on Muller and Stephens (2020) where retired land was assumed of equivalent productivity to broader farm effective area. To estimate the impact on different land uses the base biological emissions described in Section 2.2.2 were used and adjusted to a metre squared basis which allows the change in biological emissions to be calculated for 1 m of riparian area of varying widths.

Planted riparian sequestration estimates whilst based on research are considered of **low confidence level.**

There is no robust estimate of carbon sequestration from rank grass. According to the New Zealand's Greenhouse Gas Inventory 1990-2019 (Ministry for the Environment, 2021), the annual carbon accumulation in the above ground biomass of low producing grassland is 0.752 t C/ha, equivalent to 2.75 t $CO_2$/ha (1 t C is equivalent to 3.663 t of $CO_2$). It is important to note that New Zealand uses IPCC default values for biomass accumulation with uncertainty of ±75 percent (Intergovernmental Panel Climate Change, 2006). In addition, according to Zhang et al. (2011), studies have also suggested that grasslands carbon flux often shift between carbon sources in drought years and carbon sinks in other years, reflecting different management and climate conditions. In the absence of robust literature, it has been assumed that rank grass has zero sequestration. This assumption considers that sequestration, soil carbon changes and storage of carbon in pasture, as well a release of methane as pasture decays. Fencing has been considered for rank grass which has an estimate of 22.4 kg $CO_2$e/$m^2$ for all buffer widths.

Overall rural riparian device CO2e estimates for the FWMT are detailed in Table 13 below, which vary between planted and rank grass, setback and land use but not by soil or slope type.

**Table 13:** Estimate carbon impact of riparian and grass planting at different buffers for all land uses

| HRU | Planted | Grass | Carbon component | Carbon impact estimate (kg $CO_{2e}$ /buffer width $m^2$/50yr LCA)[3] 1 m | 2.5 m | 5 m | 10 m | Confidence level planted | Confidence level grass |
|---|---|---|---|---|---|---|---|---|---|
| Dairy | × | | Additional sequestration | -0.34 | -0.85 | -1.70 | -3.40 | Medium | Low |
| | × | × | Removed biological emissions | -0.92 | -2.30 | -4.60 | -9.20 | | |
| | | | Change in carbon footprint | -1.26 | -3.15 | -6.30 | -12.60 | | |
| | | | Change in carbon footprint (over 50 yrs) | -63.00 | -157.50 | -315.00 | -630.00 | | |
| | × | × | Embodied carbon impact (per 50 yr inclusive of yr 26 and 50) | +5.63 | | | | | |
| | | | **Total $CO_2$e emissions riparian (over 50 years)** | **-57.37** | **-151.87** | **-309.37** | **-624.37** | | |
| | | | **Total $CO_2$e emissions grass (over 50 years)** | **-40.37** | **-109.37** | **-224.37** | **-454.37** | | |
| Sheep and beef (< 10 SU/ha) | × | | Additional sequestration | -0.34 | -0.85 | -1.70 | -3.40 | Medium | Low |
| | × | × | Removed biological emissions | -0.34 | -0.85 | -1.70 | -3.40 | | |
| | | | Change in carbon footprint | -0.68 | -1.70 | -3.40 | -6.80 | | |
| | | | Change in carbon footprint (over 50 yrs) | -34.00 | -85.00 | -170.00 | -340.00 | | |
| | × | × | Embodied carbon impact (per 50 yr inclusive of yr 26 and 50) | +5.63 | | | | | |
| | | | **Total $CO_2$e emissions riparian (over 50 years)** | **-28.37** | **-79.37** | **-164.37** | **-334.37** | | |
| | | | **Total $CO_2$e emissions grass (over 50 years)** | **-11.37** | **-36.87** | **-79.37** | **-164.37** | | |
| Sheep and beef (> 10 SU/ha) | × | | Additional sequestration | -0.34 | -0.85 | -1.70 | -3.40 | Medium | Low |
| | × | × | Removed biological emissions | -0.38 | -0.95 | -1.90 | -3.80 | | |
| | | | Change in carbon footprint | -0.72 | -1.80 | -3.60 | -7.20 | | |
| | | | Change in carbon footprint (over 50 yrs) | -36.00 | -90.00 | -180.00 | -360.00 | | |
| | × | × | Embodied carbon impact (per 50 yr inclusive of yr 26 and 50) | +5.63 | | | | | |
| | | | **Total $CO_2$e emissions riparian (over 50 years)** | **-30.37** | **-84.37** | **-174.37** | **-354.37** | | |
| | | | **Total $CO_2$e emissions grass (over 50 years)** | **-13.37** | **-41.87** | **-89.37** | **-184.37** | | |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Horticulture (low and medium) | × | | Additional sequestration | -0.34 | -0.85 | -1.70 | -3.40 | Medium | Low |
| | × | × | Removed biological emissions | -0.15 | -0.38 | -0.75 | -1.50 | | |
| | | | Change in carbon footprint | -0.49 | -1.23 | -2.45 | -4.90 | | |
| | | | Change in carbon footprint (over 50 yrs) | -24.50 | -61.50 | -122.50 | -245.00 | | |
| | × | × | Embodied carbon impact (per 50 yr inclusive of yr 26 and 50) | +0.00 | | | | | |
| | | | **Total $CO_2$e emissions riparian (over 50 years)** | **-24.50** | **-61.50** | **-122.50** | **-245.00** | | |
| | | | **Total $CO_2$e emissions grass (over 50 years)** | **-7.50** | **-19.00** | **-37.50** | **-75.00** | | |
| Horticulture (high) | × | | Additional sequestration | -0.34 | -0.85 | -1.70 | -3.40 | Medium | Low |
| | × | × | Removed biological emissions | -0.12 | -0.30 | -0.60 | -1.20 | | |
| | | | Change in carbon footprint | -0.46 | -1.15 | -2.30 | -4.60 | | |
| | | | Change in carbon footprint (over 50 yrs) | -23.00 | -57.50 | -115.00 | -230.00 | | |
| | × | × | Embodied carbon impact (per 50 yr inclusive of yr 26 and 50) | +0.00 | | | | | |
| | | | **Total $CO_2$e emissions riparian (over 50 years)** | **-23.00** | **-57.50** | **-115.00** | **-230.00** | | |
| | | | **Total $CO_2$e emissions grass (over 50 years)** | **-6.00** | **-15.00** | **-30.00** | **-60.00** | | |

### 3.1.4 EOF – Detainment bunds and sediment retention ponds

In Muller et al. (2020) there was no explicit differentiation between detainment bunds and sediment retention ponds. Detainment bunds were assumed to be applied to pastoral land and the benefits of these to water quality in pastoral land were based on Daigneault and Elliott (2017) while sediment retention ponds were assumed to apply to horticultural land and the benefit of these in horticultural land was based on Doole (2015).

Detainment bunds are a mitigation tool designed to specifically remove phosphorus and sediment from large volumes of surface runoff, typically in pastoral contexts. Detainment bunds enable water to temporarily pond behind the bunding following a heavy rainfall event. A detainment bund is typically constructed on pasture across the flow path of low-order ephemeral streams (Levine, 2020).

Sediment retention ponds are defined as a "stock pond or earth reservoir constructed at natural outlet of zero-order catchment" (Daigneault and Elliott, 2017, pp. 27), in this case analogous with the detainment bund mitigation in the FWMT. Daigneault and Elliott (2017) estimated that detainment bunds had no effect on carbon emissions albeit with no reported assessment or basis. Here, given their constructed nature and ease of representation, a pastoral detainment bund and a horticultural sediment retention pond were designed and assessed in the Moata Carbon Portal (separately).

#### 3.1.4.1 Pastoral Detainment bund

Figure 4 below represents the detainment bund mitigation structure used to guide the Moata Carbon portal design build.

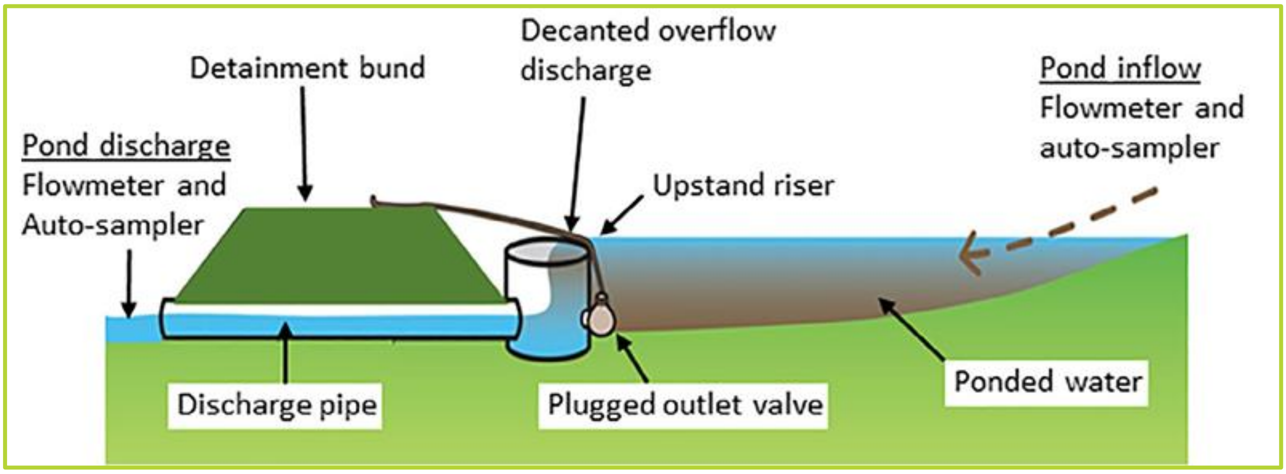


**Figure 4:** Cross-section of the detainment bund structure on pastural land (Levine et al., 2021).

Several asset types are available to build "carbon projects" within the Moata Carbon Portal (note: projects define activities or materials, which combine into a design for a device). All detailed assumptions on pastoral detainment bund design structure are listed in Appendix 1. To ensure consistency with the LCC detailed in Muller et al., (2020) it is assumed that the detainment bund will generate a pulse of $CO_2e$ emissions in year 1 and year 25 based on construction and replacement, with no carbon sequestration or emissions in other years. The maintenance activities include an annual inspection (for 48 years, excluding year of establishment and last year of life) based on the assumptions made in Muller et al., (2020). Given that excavation of material will depend on deposition rate (of which we cannot provide a valid estimate of), it was assumed that the annual excavation of material is approximately 30% of the total bund capacity, excluding year 1 and year 50. It is accepted that different lifespan assumption may be made based on different stakeholders (e.g., asset management). The assumptions around lifespan cycles made in Moata for this project are based on assumptions that align with the FWMT.

**Table 14:** Summary of pastoral detainment bund assumptions for Moata configuration

| Assets | Type of asset | Assumptions |
|---|---|---|
| Plastic HDPE Pipe | Physical | Based on 30 m plastic pipe (Levine et al., 2021). Full replacement at 25 years. |
| Scruffy dome (for the upstand riser) | Physical | 1,000 mm diameter & 1.5 m height (based on Levine et al., 2021). Full replacement at 25 years. |
| Rock around pipe (to prevent erosion) | Physical | Full replacement at 25 years. |
| Geotextile material (to prevent erosion of the 5 m wide spillway) | Physical | Full replacement at 25 years. |
| 130 $m^2$ planting material | Physical | Full replacement at 25 years. |
| Excavation of inflow and outflow area | Process | Re-excavation at 25 years. |
| Disposal of excavation on site | Process | It is assumed some of this is used to build the bund mound. Only assumed to impact the initial build not replacement. |
| Annual inspection | Maintenance | Excluding year 1 and 25 (build and replacement years). |

Table 14 summarises the estimated $CO_2e$ impacts of pastoral detainment bunds for FWMT. These estimates are based on the device footprint, however given the factors included in estimating $CO_2e$ it is not expected to vary based on device footprint or treatment area. The $CO_2e$ impact of a detainment bund is of **low confidence level** as there are no other studies to validate the lifecycle carbon impact of these interventions and there are considerable assumptions made in configuring Moata. However, the emissions profile of each asset component in Moata is robust. The carbon impact of a detainment bund is estimated to be 3.1 t $CO_2e$ in year 1 and this same impact in year 25 with an annual carbon impact of 0.14 t $CO_2e$ for maintenance, over a 50 year lifecycle period. This estimate should be used with caution given the uncertainty and lack of literature to support the estimate (Table 15).

**Table 15:** Estimated carbon impacts of pastoral detainment bunds (Moata Carbon Portal)

| | Total carbon impact (t $CO2_e$/detainment bund) | | | | Confidence level |
|---|---|---|---|---|---|
| **HRU** | **Year 1 (emissions)** | **Year 2-25** | **Year 26 (emissions)** | **Year 27-50** | Low |
| **All pasture** | +3.1 | +0.14 (per year) | +3.1 | +0.14 (per year) | |
| **Total** | +12.7 t $CO_2e$ | | | | |
| *Based on Moata estimates and assumptions in Table 14* | | | | | |

### 3.1.4.2 Horticultural Sediment Retention Pond

Horticultural sediment retention pond devices assume a 130 $m^3$ bund capacity, similar to the detention bund capacity used to represent pastoral land uses (Horticulture New Zealand, n.d.). The assets that comprise the sediment retention pond include the HDPE pipe, geotextile material liner, rock to prevent erosion of the pipe outlet and bulk excavation to a stockpile on site. It is assumed that the sediment will be utilised on another part of the farm. Figure 5 below represents the mitigation structure.

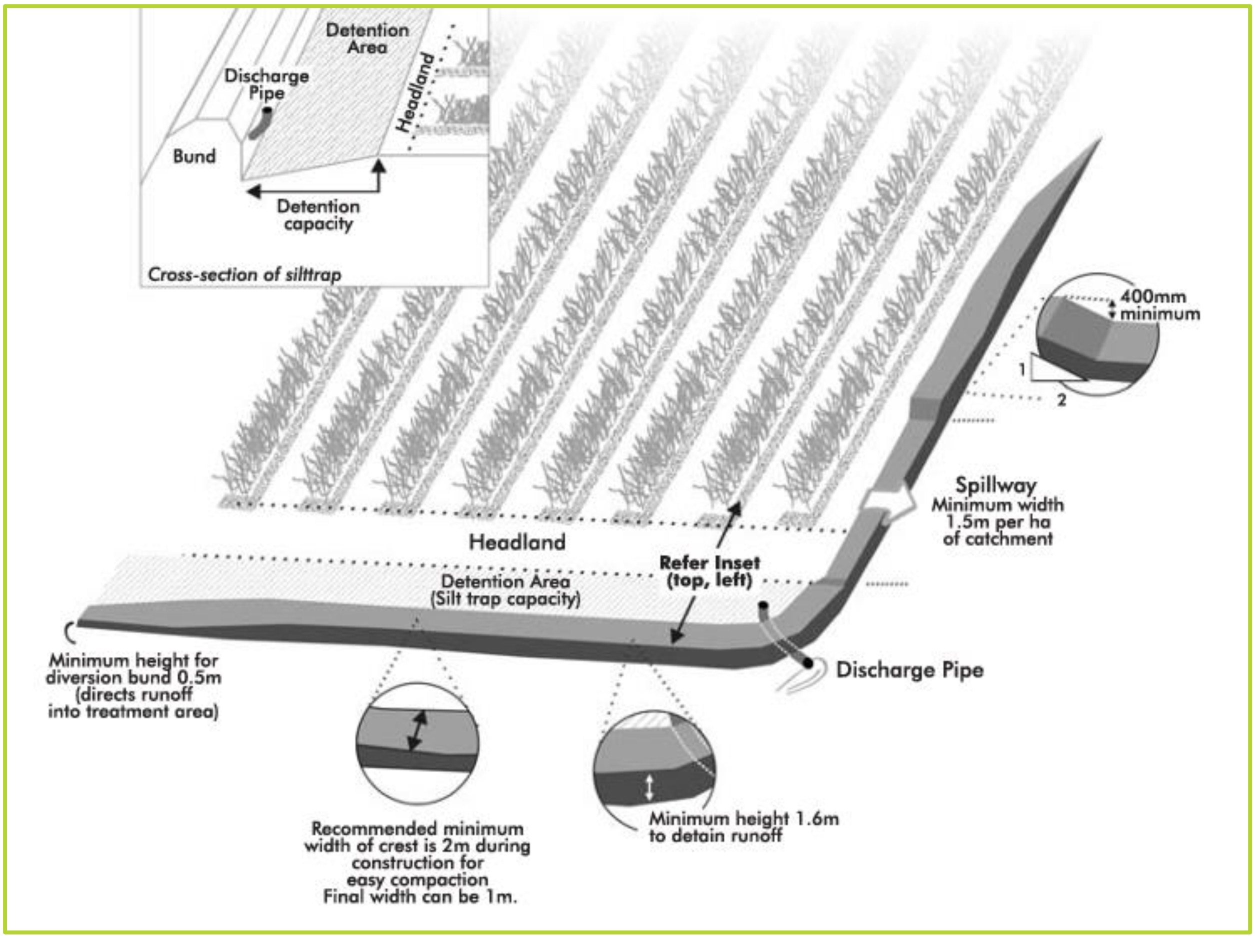


**Figure 5:** Visual representation of sediment retention pond construction components (Horticulture New Zealand, n.d.)

The sediment retention pond is assumed to incur a full replacement of the discharge pipe, replacement of the geotextile material liner and rock around the pipe outflow preventing erosion at 25 years. The maintenance requirements are estimated to be the same as the detainment bund. Consistent with the LCC detailed in Muller et al., (2020) it is assumed that the sediment retention pond will express a $CO_2e$ impact in year 1 and year 25, predicted on a 25 year life span for this mitigation. It was assumed that the annual excavation of material is approximately 30% of the total bund capacity, excluding year 1 and year 50.

The Moata Carbon Portal estimates a FWMT horticultural sediment retention pond to have a carbon impact of 0.5 t $CO_2e$ at year 1 and year 26, with an annual maintenance carbon impact of 0.15 t $CO_2e$.

The embodied carbon impact of the sediment retention pond is less than a pastoral detainment bund reflecting lesser construction materials required in the build. The carbon impact of a horticultural sediment retention pond is marked as a **low confidence level** as there is no literature to compare the carbon impact of a sediment retention pond on horticultural land (Table 16). This carbon impact should be used with caution.

**Table 16:** Estimated carbon impact of sediment retention pond (Moata Carbon Portal)

| | Total carbon impact (t $CO2_e$/sediment retention pond) | | | | Confidence level |
|---|---|---|---|---|---|
| HRU | Year 1 (emissions) | Year 2-25 | Year 26 (emissions) | Year 27-50 | Low |
| All horticultural land uses | +0.5 | +0.15 (per year) | +0.5 | +0.15 (per year) | |
| Total | +7.9 t $CO_2e$ | | | | |
| *Based on Moata estimates and assumptions in Table 14* | | | | | |

## 3.2 Farm system bundled mitigations (good farming practices)

The FWMT represents pastoral and horticultural sectoral good farming practices uniquely, by sector and via levels of effort (e.g., M1, M2 and M3 across three pastoral and two horticultural types). Latter bundles represent a mix of mitigation actions applied to farm management and systems to minimise contaminant losses, specifically nitrogen (N) and phosphorus (P) and act as source controls in the FWMT.

At a broad level, the three mitigation bundles explored in Stage 1 for rural land uses are:

- M1 – essentially the practice change[10] and minor system change that might be considered to represent good management practices (that could be expected to be identified by and implemented as a result of a farm environment planning process). These will vary across farm types (dairy, horticulture & sheep and beef) and align with the generally accepted position of M1 being low cost and [relatively] easy for adoption on farm.
- M2 – this will represent a combination of less costly bundled system changes and de-intensification[11] and be cumulative of the M1 options – i.e., M2 is applied in addition to, not instead of M1.
- M3 – same as M2 but more expensive or challenging system changes[12], and/or further de-intensification, cumulative of the mitigations in M1 and M2.

FWMT good farming mitigation bundles are cumulative, requiring changes whether in contaminant or carbon impacts to be read from a pre-mitigation base. Notably, latter lifecycle costs and contaminant values used in FWMT Stage 1 utilised numerous differing studies (i.e., for dairy, M1 is from a different base study to M2 and M3 – undergoing revision for use of Auckland regional data as of writing). This provides a challenge to $CO_2e$ estimation and increases uncertainty.

FWMT good farming mitigation bundles involve changes to the farm system that largely exclude new infrastructure or devices. As such, it was considered appropriate for this report to only consider the impact of the bundled mitigations on biological emissions, rather than the associated embodied carbon on farm.

[10] Practice change is defined as modification to existing practices (how we do things) that do not change farm/orchard system parameters (what we are doing).
[11] De-intensification is defined as modifications to an existing farm system (what we are doing) that reduces farm intensity (how much we produce with what we are using).
[12] System change is defined as modifications to an existing farm system (what we are doing) that do not alter farm intensity (how much we produce with what we are using).

Given study-based differences (and Overseer versioning) across bundles, it was determined that the best approach to estimate the changes in lifecycle $CO_2$e was to consistently represent all good farming practice bundled source controls in the MfE Calculator. (Noting due to the changes introduced differing overall and requiring harmonisation between M1, M2 and M3 within each pastoral and horticultural sectoral type, any prior carbon impacts from contributing studies were not directly used – e.g., those in Daigneault et al., 2017).

All detailed model assumptions and raw results for the estimated carbon impact of M1, M2 and M3 can be found in Appendix 2 (dairy), Appendix 3 (sheep and beef >10 SU and <10 SU) and Appendix 4 (horticulture).

### 3.2.1 Dairy mitigation bundles

The dairy mitigation bundles that a $CO_2$ estimate was generated for (M2 and M3) were sourced from DairyNZ Economics Group (2014) and therefore the base was derived from the 118 ha Waipa-Franklin farm model. The base biological emissions from the dairy land use is 9.2 t $CO_2$e ha/yr. A base file was set up based on the base Waipa-Franklin file of 366 cows (at 3.1 stocking rate) and N fertiliser 116 kg N per effective area from DairyNZ Economics Group (2014). This is shown as the base in Table 17.

The $CO_2$e estimates for M2 and M3 dairy have both been allocated a medium confidence level. The MfE Calculator is simple but robust and the farm data used to drive the MfE Calculator aligns with the data used to estimate the economic and water quality impacts of the mitigations in the FWMT. However, the simplified MfE Calculator was run using data from Waikato and so may be different to the farm systems in the Auckland region.

#### 3.2.1.1 Mitigation bundle M1 dairy

Mitigation bundle M1 for dairy is a bundled mitigation that includes full stock exclusion from minor streams, reducing soil Olsen P levels from 38 to 32, enlarging effluent areas to appropriate effluent potassium loading rates and adjusting effluent pond storage to have an additional month of storage and utilise a low application depth. The contributing study (NIWA, 2010) does not include sufficient detail to enable representation in the MfE Calculator (e.g., stocking rates or feed inputs) and the recommendation is to instead assign the bundle no net change in $CO_2$e.

#### 3.2.1.2 Mitigation bundle M2 dairy

Mitigation bundle M2 for dairy was based on two different studies, DairyNZ Economics Group (2014) was utilised for N and Newman and Muller (2017) was utilised for P, both were cumulative to NIWA (2010).

Neither Newman and Muller (2017) or DairyNZ Economics Group (2014) consider the relative greenhouse gas emissions from different mitigations. To estimate the carbon impact of these mitigations they need to be assessed in one of the greenhouse gas emissions calculators. However, Newman and Muller (2017) do not provide the required detail (e.g., stocking rates and fertiliser use) to estimate the greenhouse gas emissions in any of the given calculators. As such the carbon estimates are only able to be estimated for the N mitigation bundles for dairy. P mitigations used in Newman and Muller (2017) would likely have some impacts on $CO_2$e emissions, however this study did not provide the required information to estimate these in the MfE Calculator.

The N mitigation bundle for dairy M2 was based on the Waipa-Franklin farm of 118 effective hectares (DairyNZ Economics Group, 2014). The N mitigation bundle M2 for dairy is based on reducing N inputs (feed and fertiliser) and stocking rates: Stocking rate reduced from 3.1 to 2.9 cows per effective hectare; N fertiliser reduced from 116 to 60 kg N/ effective hectare; and bought feed (as % of total offered) reduced from 17% to 16%. The Waipa-Franklin farm would typically use urea (without urease inhibitor) fertiliser with an N content of 46%, which has been used to estimate the carbon impact of the mitigations.

The MfE Calculator estimates that the carbon impact after the dairy M2 mitigation was applied changes from 9.79 t $CO_2e$ /yr to 8.91 t $CO_2e$ /yr as seen in Table 17 below.

#### 3.2.1.3 Mitigation bundle M3 dairy

For mitigation bundle M3, as with M2 dairy, there are two estimates included for dairy. One estimate relates to N targeted mitigations (M3 N), and one to P targeted mitigations (M3 P). The M3 N mitigation option is considered more robust for the Auckland region. As with the M2 dairy bundles, there is only enough information available to estimate the greenhouse gas emissions from the M3 N bundles not the P or combined bundles.

The N mitigation bundle M3 for dairy reduces N inputs (feed and fertiliser) and stocking rates. Stocking rate reduced from 3.1 to 2.8 cows/effective ha (slightly lower stocking rate than M2). Urea without urease inhibitor is applied and N fertiliser reduced from 116 to 29 kg N/ effective ha (significantly reduced N from M2). Bought feed (as % of total offered) reduced from 17 to 15%.

The MfE Calculator estimates that the $CO_2e$ impact after the dairy M3 mitigation was applied changes from 8.91 t $CO_2e$ /yr at M2 to 8.45 t $CO_2e$ /yr as seen in

Table **17** below.

**Table 17**: Carbon impact estimate for dairy mitigation bundles on a per ha basis (all sourced from MfE Calculator)

| Mitigation bundle | Methane (t $CO_2e$) | Nitrous Oxide (t $CO_2e$) | Carbon dioxide (t) | Total (t CO2e ha/yr) | Confidence level |
|---|---|---|---|---|---|
| Base | 7.71 | 1.90 | 0.18 | 9.79 | Medium |
| M1 | Not enough data to calculate in MfE Calculator | | | | NA |
| M2 (N only) | 7.20 | 1.60 | 0.09 | 8.91 | Medium |
| M3 (N only) | 6.95 | 1.45 | 0.04 | 8.45 | Medium |

*There is not enough information to run the P or therefore the combined mitigation bundles through the MfE Calculator.*

### 3.2.2 Sheep and beef bundles

For less than 10 SU/ha these estimates (M1, M2 and M3) were based on the Rangitāiki sheep and beef farm in Matheson et al. (2018). For greater than 10 SU/ha, these estimates (M1, M2 and M3) were based on the Kaituna-Pongakawa-Waitahanui (KPW) sheep and beef farm in Matheson et al. (2018). It is assumed that both of these case studies apply a urea without urease inhibitor with an N content of 46%, which has been used to estimate the $CO_2e$ impact of the mitigations.

An average stock unit ratio of 1.2 for sheep and 5 for cattle (based on a dry mixed age cow) has been applied to convert the case study data into livestock numbers that align with the MfE Calculator input options. These ratios were determined to be representative of different cattle and sheep types for consistency across base files and mitigations. It is recognised that this is a simplification of the complex livestock data in the Overseer models. However, the challenge with using the Overseer figures is that these are based on an old version (6.3.0) and the greenhouse gas model has changed in Overseer since then.

A base file was set up based on the Rangitāiki case study for sheep and beef (<10 SU/ha) based on a 584 effective ha system with 1786 sheep (2,143 SU at 1.2 SU ratio accounting for the different classes of sheep from lambs to ewes) and 693 cattle (3,465 SU at 5 SU ratio based on a dry mixed age cow) (Matheson et al., 2018) applying 59 kg urea/ha. Likewise, a base file was set up based on the KPW case study for sheep and beef (>10 SU/ha) based on a 324 ha farm with 1,250 mixed age ewes, 540 ewe hogget replacements, 50 breeding cows and 300 dairy heifer replacements which are contract grazed from 4 to 21 months of age (Matheson et al., 2018). It has been assumed that mixed age ewes are 1 SU and ewe hoggets are 0.8 SU. Dairy heifers were which are grazed for 17 out of 24 months were adjusted to an annual equivalent number of dairy cows (namely 213). The KPW sheep and beef farm is a 324 ha farm that applies N fertiliser at 30 kg N/ha to 94 ha of the flat and rolling country in the autumn. To represent the application to only some of the farm, 9 kg N is applied to the whole farm, which we have assumed to be 20 kg urea/ha.

Both base $CO_2$e estimates for sheep and beef land uses are in Table 18 below. They are 3.4 t $CO_2$e/ha/yr for <10 SU and 4.3 t $CO_2$e/ha/yr for >10 SU based on the MfE Calculator. Detailed information on the breakdown of the $CO_2$e impact outputs for both small and large sheep and beef systems from the MfE Calculator can be found in Appendix 3. This compares to 3.8 t $CO_2$e ha/yr in the base model in Matheson et al. (2018) for < 10 SU sheep and beef, and 4.3 t $CO_2$e ha/yr for the > 10 SU sheep and beef model.

As with the dairy estimates, the $CO_2$e estimates for the **sheep and beef mitigation bundles have been allocated a medium confidence level**. The MfE Calculator is simple and robust but employed using data from Bay of Plenty (i.e., very likely different farm systems to the Auckland region). In addition, the sheep and beef farm systems require greater generalisation that other pastoral sectors for use in the MfE Calculator.

Matheson et al. (2018) did calculate the biological greenhouse gas emissions from the farm systems they modelled (using Overseer Version 6.3.0). In recognising the significant change in Overseer versions between 2018 and now, and the desire to align methods for estimating $CO_2$e footprints across the farm system bundles in the FWMT, we used the MfE Calculator rather than the Overseer estimates. However, the Overseer estimates (as a percentage change) are useful to compare the quantum of change seen by using the MfE Calculator. The estimates were found to be similar which supports the confidence in these estimates.

#### 3.2.2.1 Mitigation bundle M1 sheep and beef [<10 SU/ha]

M1 for sheep and beef land uses with less than 10 SU/ha was sourced from Matheson et al. (2018) and utilised the Rangitāiki sheep and beef farm. The mitigation included improved nutrient budgeting and maintenance of Olsen P, efficient fertiliser use technology, stock class management within landscape, improve winter cropping practices, laneway run-off diversion, relocation of troughs, appropriate gate, track and race placement, targeted space planting of poles, slow release Reactive Phosphate Rock (RPR) fertiliser, adoption of low N leaching forages, full stock exclusion from all water bodies greater than 1 m wide at any point adjacent to farm (including drains) and wetlands (2 m average vegetated and managed buffer around rivers, streams, lakes and wetlands; 1 m around drains; 3 m average buffer on slopes greater than 8 degrees; 5 m average buffer on slopes greater than 16 degrees). None of these mitigations affected the number of SU/ha or fertiliser volumes used and as such there was no change in biological emissions in the MfE Calculator. This aligns with Matheson et al. (2018) which provides a biological greenhouse gas estimate for M1 of 3.762 t $CO_2$e ha/yr for the M1 bundle, a change of -1% from the base of 3.8 t $CO_2$e ha/yr.

#### 3.2.2.2 Mitigation bundle M2 sheep and beef [<10 SU/ha]

M2 for sheep and beef land with less than 10 SU/ha was sourced from Matheson et al. (2018) and utilised the Rangitāiki sheep and beef farm. The mitigation was (in addition to the M1 actions) elimination of N fertiliser applied to accelerate liveweight gain, develop a detention bund, complete protection of gully heads, management of gorse, whole paddock space planting of poles, full stock exclusion from minor, permanently flowing waterbodies (less than 1 m wide) and 1 m average vegetated and managed buffer (2 m average buffer on slopes greater than 8 degrees, 3 m average buffer on slopes greater than 16 degrees [with associated stock water reticulation, if any]), afforestation of erosion prone land and changing stock ratios to reflect lower N leaching potential.

This mitigation changed the N fertiliser from 59 kg urea/ ha to 27 kg urea/ha. The stock ratios were adjusted by 10%. This was from a base of 62:38 cattle to sheep in the base (based on SU). This meant cattle decreased from 693 to 580 and sheep increased from 1,786 to 2,253. The farm changes in fertiliser and stocking rate meant this farm system had an estimated $CO_2$e footprint of 3.3 t $CO_2$e ha/yr from the MfE Calculator. This is a minor decrease from 3.4 t $CO_2$e ha/yr in M1 and the base.

Matheson et al. (2018) provided a biological greenhouse gas estimate of M2 sheep and beef land uses of 3.572 t $CO_2$e ha/yr (a -6% change) from the base using Overseer. This compares to a change of approximately -3% calculated through the MfE Calculator.

#### 3.2.2.3 Mitigation bundle M3 sheep and beef [<10 SU/ha]

M2 for sheep and beef land with less than 10 SU/ha was sourced from Matheson et al. (2018) and utilised the Rangitāiki sheep and beef farm. The mitigation was (in addition to M1 and M2 <SU/ha mitigations) full stock exclusion from REC Order 1 watercourses less than 1 m wide and 1 m wide average vegetated buffer, creation of new wetlands, elimination of N applications to support capital livestock. The stock ratio remained the same as M2. The only piece of the mitigation that impacts the MfE Calculator is the reduction in N fertiliser. The farm application of urea in autumn was removed from the $CO_2$e impact calculation in the MfE Calculator, this was a reduction from 27 kg urea/ha to 11 kg urea/ha.

The MfE Calculator estimated that the $CO_2$e impact of M3 sheep and beef land with less than 10 SU/ha is 3.2 t $CO_2$e ha/yr. Matheson et al. (2018) provided a biological greenhouse gas estimate of M3 sheep and beef land uses of 3.458 t $CO_2$e ha/yr (-9%) from the base.

The biological emissions (greenhouse gases) estimates for all sheep and beef land uses with less than 10 SU/ha are shown in Table 18 below. Because these are on a per ha basis the full MfE Calculator results (for the 584 ha farm) are in Appendix 3.

#### 3.2.2.4 Mitigation bundle M1 sheep and beef [>10 SU/ha]

M1 for sheep and beef land with more than 10 SU/ha was sourced from Matheson et al. (2018) and utilised the KPW sheep and beef farm. The M1 bundle for >10 SU/ha utilised the same actions as the M1 bundle for the less than 10 SU/ha sheep and beef farm. None of these affected the number of SU/ha or fertiliser volumes used and as such there was no change in biological emissions in the MfE Calculator (remains as 4.3 t $CO_2$e ha/yr) this is detailed in Table 18. The latter aligns with Matheson et al. (2018) which provides a biological greenhouse gas estimate for M1 of 4.257 t $CO_2$e ha/yr for the M1 bundle, a change of -1%, from the base of 4.3 t $CO_2$e ha/yr.

#### 3.2.2.5 Mitigation bundle M2 sheep and beef [>10 SU/ha]

M2 for sheep and beef land with more than 10 SU/ha was sourced from Matheson et al. (2018) and utilised the KPW sheep and beef farm. The mitigation was (in addition to the M1 actions) elimination of N fertiliser applied to accelerate liveweight gain, develop a detention bund, complete protection of gully heads, management of gorse, whole paddock space planting of poles, full stock exclusion from permanently flowing waterbodies less than 1 m wide (REC Order 2 and above) and 1 m average vegetated and managed buffer (2 m average buffer on slopes greater than 8 degrees, 3 m average buffer on slopes greater than 16 degrees [with associated stock water reticulation, if any]), afforestation of erosion prone land, and changing stock ratios to reflect lower N leaching potential.

The amount of fertiliser applied was assumed to remain constant, i.e., 20 kg urea/ha. The stock ratios were adjusted by 10% from a 55:45 ratio to what we have assumed to be a 65:35 ratio of sheep to cattle. This changed the sheep numbers from 1,790 to 1,986, beef cattle from 50 to 39 and dairy replacements from 213 (annual equivalents to the 300 dairy cows for 17 months) to 165. These changes led to an estimated $CO_2$e impact of 4.0 t $CO_2$e ha/yr from the MfE Calculator (reduced from 4.3 t $CO_2$e ha/yr in the base and M1). Comparatively, Matheson et al. (2018) provided a biological greenhouse gas estimate of M2 sheep and beef land uses of 4.21 t $CO_2$e ha/yr (a -2% change) from the base.

#### 3.2.2.6 Mitigation bundle M3 sheep and beef [>10 SU/ha]

The M3 bundled mitigation actions included improved nutrient budgeting and maintenance of Olsen P, efficient fertiliser use technology, stock class management within landscape, improve winter cropping practices, laneway run-off diversion, relocation of troughs, appropriate gate, track and race placement, targeted space planting of poles, slow release RPR fertiliser, adoption of low N leaching forages, elimination of N fertiliser applied to accelerate liveweight gain, develop a detention bund, complete protection of gully heads, management of gorse, whole paddock space planting of poles, afforestation of erosion prone land, changing stock ratios to reflect lower N leaching potential, full stock exclusion from REC Order 1 watercourses less than 1 m wide and 1 m wide average vegetated buffer, creation of new wetlands, elimination of N applications to support capital livestock.

The only action of those in M3 with an impact on the MfE Calculator was reducing the N fertiliser applied to accelerate liveweight gain. The ratio of N fertiliser applied in spring and autumn was not detailed, therefore it was assumed that the ratio of N applied in the spring and autumn is the same ratio as was applied on the small sheep and beef land uses (40% in spring and 60% in autumn) and all autumn fertiliser was removed. The $CO_2$e impact estimate for M3 sheep and beef land uses with more than 10 SU/ha is 3.9 t $CO_2$e ha/yr (or -7% from the base) this compares to the estimate in Matheson et al. (2018) of 3.96 t $CO_2$e ha/yr (a -8% change) from the base (Table 18).

**Table 18:** Carbon impact estimate for sheep and beef mitigation bundles per ha (all sourced from MfE Calculator)

| Land use | Mitigation bundle | Methane (t $CO_2$e) | Nitrous Oxide (t $CO_2$e) | Carbon dioxide (t) | Total (t $CO_2$e ha/yr) | Confidence level |
|---|---|---|---|---|---|---|
| | Base | 3.8 t $CO_2$e ha/yr (Matheson et al., 2018) | | | | |
| Sheep and beef <10SU/ha | Base | 2.8 | 0.5 | 0.0 | 3.4 | Medium |
| | M1 | 2.8 | 0.5 | 0.0 | 3.4 | Medium |
| | M2 | 2.8 | 0.5 | 0.0 | 3.3 | Medium |
| | M3 | 2.8 | 0.4 | 0.0 | 3.2 | Medium |
| | Base | 4.3 t CO2e ha/yr (Matheson et al., 2018) | | | | |
| Sheep and beef >10SU/h | Base | 3.7 | 0.6 | 0.0 | 4.3 | Medium |
| | M1 | 3.7 | 0.6 | 0.0 | 4.3 | Medium |
| | M2 | 3.4 | 0.5 | 0.0 | 4.0 | Medium |
| | M3 | 3.4 | 0.5 | 0.0 | 3.9 | Medium |

### 3.2.3 Horticulture and arable bundles

The mitigation bundle estimates for horticultural land uses (M1, M2, M3) have all been derived using the MfE Calculator. Mitigations have been represented for low and medium impact horticulture combined and for high impact horticulture.

The low and medium impact horticulture bundle estimates were based on two different literature sources. A maize silage production system in Matheson et al. (2018) for the base and the M1 bundle and Southland feed wheat, milling wheat and barley crops in Mathers (2017) for M2 and M3 bundle. One key difference between the two studies is that the base and M1 used from Matheson et al. (2018) includes 300 dairy cows on farm for 8 weeks while Mathers (2017) has no cattle. The base $CO_2$e footprint of the low and medium impact horticulture of 1.5 t $CO_2$e ha/yr was defined based on Matheson et al. (2018), as discussed in Section 2.2.2. There is **a medium confidence level assigned to the base and M1 models** (given the use of the simplified MfE Calculator) but there is a **low confidence level for M2 and M3** (that originate from a different study to the base and M1).

The high impact horticulture bundles estimates were based on Agribusiness Group (2014) from work in the Lower Waikato catchment. Weighted average of their results is based on 50% of extensive horticulture rotation, 45% intensive rotation and 5% market garden. The Agribusiness Group (2014) used Overseer 6.1 modelling but no greenhouse gas estimations were included. To calculate the $CO_2$e impact and base footprint for these mitigations the total fertiliser applied on each rotation (across each 4-year rotation) was annualised to align with MfE Calculator requirements. Latter $CO_2$e estimates were weighted as above across the three rotations. This meant that in the base model there was 237 kg N/ha/yr applied, equivalent to 516 kg urea/ha/yr urea without urease inhibitor fertiliser. There is a **medium confidence level assigned to the high impact horticulture estimates**. It is important to note that the variation in studies used and related regions will impact the estimates. The limitations of the model do not allow us to interrogate the data to identify the true source of variation.

#### 3.2.3.1 Mitigation bundle M1 horticultural land uses (low and medium impact)

M1 for low and medium impact horticulture was sourced from Matheson et al. (2018) and utilised the maize silage production system. The 40 ha maize silage production system in Matheson et al. (2018) receives 290 kg N/ha/yr at the base, assumed in the form of a urea without urease inhibitor fertiliser and equating to 630 kg urea/ha. M1 for low and medium impact horticulture has assumed a change of -12% in fertiliser application and therefore assumes 255 kg N/ha, equivalent to 555 kg urea without urease inhibitor/ha. M1 also included other mitigations such as grass or planted buffer strips, maintain optimal Olsen P and appropriate P fertiliser use, efficient fertiliser use technology, cover crops between cultivation cycles, manage risk from contouring and reduced tillage practices, but none of this impacts the MfE Calculator, only the N fertiliser.

The MfE Calculator estimates a greenhouse gas emissions of 1.5 t $CO_2$e ha/yr for the base scenario, which reduces to 1.3 t $CO_2$e ha/yr following M1. Meanwhile, Matheson et al. (2018) estimates greenhouse gas emissions in Overseer (Version 6.3.0) at the base as 3.1 t $CO_2$e ha/yr, reducing to 2.79 t $CO_2$e ha/yr with M1. Using the MfE Calculator has a change of -13% in greenhouse gas emissions between base and M1, while the Overseer estimates showed a change of -10%. Each of these sources provide viable estimates but, the MfE Calculator carbon impacts are used here for consistency and comparability across sectors. This change has been assigned a **medium confidence level**.

#### 3.2.3.2 Mitigation bundle M2 horticultural land uses (low and medium impact)

The M2 bundle for low and medium horticulture HRU is based on Southland feed wheat, milling wheat and barley crops in Mathers (2017). This mitigation includes reducing N fertiliser use from 216 kg N/ha/yr across feed wheat, milling wheat and barley to 140 kg N/ha/yr. The reduction in fertiliser yield is modelled to reduce yield from 12 t/ha (wheat) and 10 t/ha (barley) to 8 t/ha (both wheat and barley). This equates to a $CO_2$e footprint of 0.7 t $CO_2$e ha/yr.

It is important to reiterate that this is a different study from Matheson et al. (2018) and as such the effect of the dairy cattle in Matheson et al. (2018) has been removed and fertiliser has changed from the 255 kg N/ha/yr in M1 Matheson et al. (2018) to 140 kg/ha/yr in Mathers (2017). As discussed above, there is a **low confidence level** assigned to this mitigation (integrated two studies).

#### 3.2.3.3 Mitigation bundle M3 horticultural land uses (low and medium)

Following the M2 bundle for low and medium impact horticulture, the M3 bundle was also based on Mathers (2017). Specifically, reducing fertiliser usage from 140 kg N/ha/yr to 100 kg N/ha/yr, or to 217 kg urea/ha/yr. When using the MfE Calculator this equates to a $CO_2$e footprint of 0.5 t $CO_2$e ha/yr. As with the M2 bundle this has a **low confidence level.**

#### 3.2.3.4 Mitigation bundle M1 horticultural land uses (high impact)

Muller et al. (2020) included a M1 bundle for high impact horticulture based on The Agribusiness Group (2014). The M1 bundle for the high impact horticulture from The Agribusiness Group (2014) limits the application of N to 80 kg N/ha per month (i.e., any month receiving more than 80 kg N/ha per month was reduced to this limit). No reduction in total fertiliser used was associated, instead altering the timings of application. The MfE Calculator generated a corresponding $CO_2$e footprint of 1.2 t $CO_2$e ha/yr, which did not vary from the base estimate. The fact that there was no change from the base was expected as the total volume of fertiliser used did not change.

There is therefore no $CO_2$e impact from adopting M1 on high impact horticulture in the FWMT, which has a **high confidence level**.

#### 3.2.3.5 Mitigation bundle M2 horticultural land uses (high impact)

The high impact horticulture M2 bundle was based on Agribusiness Group (2014) from work in the Lower Waikato catchment where fertiliser was reduced by 10% relative to the base and M1 (which had the same volume of fertiliser). It was assumed that the weighted average annual fertiliser applied in this mitigation was 214 kg N/ha/yr, relative to 237 kg N/ha/yr in the base (and M1). When run through the MfE Calculator there was an associated carbon footprint arising of 1.1 t $CO_2$e ha/yr compared to the base of 1.2 t $CO_2$e ha/yr, a change of -0.1 t $CO_2$e ha/yr. This has been assigned a **medium confidence level** because it is simply a reduction in fertiliser use which is captured in the MfE Calculator. However, it is not high confidence as the fertiliser is a simple annual average and doesn't capture how this varies across the five-year crop rotation.

#### 3.2.3.6 Mitigation bundle M3 horticultural land uses (high impact)

The high impact horticulture M3 bundle was also based on the Agribusiness Group (2014) where N fertiliser was reduced by 20% with a reduction in yield of 20% (summer potatoes, onions & carrots), 25% (squash, broccoli, lettuce), 30% (cabbage, spinach & cauliflower) and 35% (winter potatoes & barley). It was assumed that the weighted average annual fertiliser applied in this mitigation was 190 kg N/ha/yr, relative to 237 kg N/ha/yr in the base (and M1) and 214 kg N/ha/yr in the first M2 bundle. The associated MfE Calculator outcome was a carbon footprint of 1 t $CO_2$e ha/ya compared to the base of 1.2 t $CO_2$e ha/ya, a change of -0.2 t $CO_2$e ha/yr. As with the M2 high impact horticulture, this has been assigned a **medium confidence level**.

**Table 19:** Carbon impact estimate for horticultural bundles on a per ha basis (all sourced from MfE Calculator)

| Land use | Mitigation bundle | Methane (t $CO_2$e/ha/yr) | Nitrous Oxide (t $CO_2$e/ha/yr) | Carbon dioxide (t $CO_2$/ha/yr) | Total (t $CO_2$e/ha/yr) | Confidence level |
|---|---|---|---|---|---|---|
| Low and medium impact horticulture | Base | 0 | 1 | 0.5 | 1.5 | Medium |
| | M1 | 0 | 0.9 | 0.4 | 1.3 | Medium |
| | M2 | 0 | 0.5 | 0.2 | 0.7 | Low |
| | M3 | 0 | 0.3 | 0.2 | 0.5 | Low |
| High impact horticulture | Base | 0 | 0.8 | 0.4 | 1.2 | Medium |
| | M1 | 0 | 0.8 | 0.4 | 1.2 | Medium |
| | M2 | 0 | 0.7 | 0.3 | 1.1 | Medium |
| | M3 | 0 | 0.7 | 0.3 | 1 | Medium |

## Part B – Urban Sector

As discussed in Section 1, the LCA of carbon emissions for this project is based on the production of materials, construction, use and end of life/ renewal phase. The 'beyond life-cycle stage' is not included in this analysis as this is outside the analysis timeframe for the FWMT stormwater interventions.

Unlike the rural life cycle carbon assessment in Part A, no changes in carbon emissions from particular urban land uses are assumed as there is no robust method available to predict such changes. Rather, the analysis focusses on the net carbon footprint of the device itself.

The LCA period used in this study is 50 years. This timeframe was chosen to ensure consistency with the FWMT LCC models which estimate the costs of implementation of urban and rural interventions over a 50 year timeframe.

Existing carbon emissions data for urban stormwater infrastructure were obtained via a literature review, as well as a review of the design templates and emission factor data within the Moata Carbon Portal.

Unique designs, fully consistent with the FWMT LCC models, were developed for FWMT urban interventions within the Moata Carbon Portal for:

- Wetlands
- Rain gardens
- Swales
- Permeable paving
- Underground filters
- Rain tanks
- Green roofs
- Inert roofs (coloursteel)
- Street sweeping

# 4 Investigation of urban carbon impact emissions

## 4.1 Literature review

A comprehensive, systematic review of national and international literature, focusing on carbon and greenhouse gas (GHG) emissions from green infrastructure and urban stormwater interventions was undertaken. The literature review was scoped on the basis of investigating the following key research objectives:

1. Embodied GHGs of construction materials;
2. GHGs from the construction, maintenance and 'end of life' phase;
3. Carbon sequestration potential of green infrastructure.

A desktop review of the literature was undertaken based on a number of key "search terms" used in internet searches within a number of scholarly databases such as Google Scholar, EVRI, jstor.org and Science Direct. These terms included words such as: green infrastructure, life cycle analysis carbon emissions, $CO_2$ emissions, greenhouse gas emissions, stormwater infrastructure, carbon sequestration, maintenance phase carbon emissions.

Eighteen papers or research articles were found relating to this topic (these have been included in the reference list), and of these about 10 papers contributed useful information for this study.

Kavehei et al (2018) undertook a comprehensive literature review which investigated the net carbon footprints of various stormwater green infrastructure (GI) interventions. The analysis took a life cycle approach to investigate $CO_2$ equivalent (CO2e) footprint and net $CO_2e$ footprint of bioretention basins, green roofs, vegetated swales and stormwater ponds. Their selection criteria and review procedure was applied to 1057 primary studies which were then filtered down to 40 relevant research studies, on which their analysis was based. Of this, 28 papers were related to the LCA approach to quantify the global warming potential impact and 12 studies discussed the carbon sequestration of GI. Rain tanks, sand filters and porous pavements were not included in the study. Additionally, constructed wetlands and ponds which were mostly used for purposes other than stormwater management were excluded from the pool of papers.

The system boundary used for the analysis was taken from that developed by Moore and Hunt (2013) and is shown in Figure 6.

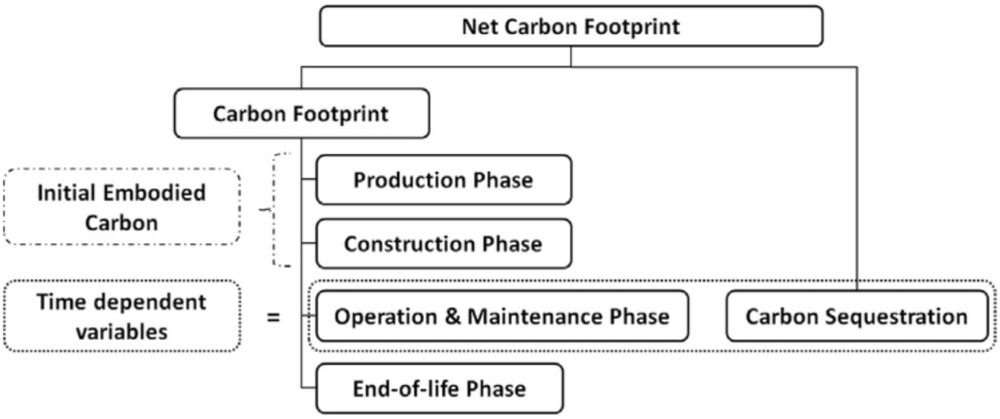


**Figure 6:** Stages included in the estimation of the net $CO_2$e footprint of green infrastructure (Kavehei et al, 2018 p. 1181)

The functional units of the studies analysed were generally either area or volume based, and the LCA life span was standardised to 40 years for green roofs and 30 years for the remaining GI devices investigated. Data were converted to kilograms of $CO_2$ equivalent per square metre (kg CO2e / $m^2$).

Table 20 summarises the $CO_2$e footprint and net $CO_2$e footprint results from Kavehei et al. (2018). The authors state that the results presented can be used to estimate the net carbon footprint for any of the applicable GI interventions where the surface area has been estimated based on its capacity to treat stormwater.

**Table 20:** Summary of the $CO_2e$ footprint and sequestration potential of applicable GI interventions (results obtained and summarised from Kavehei et al., 2018)

| GI Intervention | Low Estimate kg $CO_2e/m^2$ | High Estimate kg $CO_2e/m^2$ | Life Span - years | Mean Estimate kg $CO_2e/m^2$ | Error Margin kg $CO_2e/m^2$ | Mean Sequestration kg $CO_2e/m^2$ | Error Margin kg $CO_2e/m^2$ | Net footprint kg $CO_2e/m^2$ | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Bioretention Basins** | 68.1 | 153.3 | 30 | 98.4 | ± 19 | -69.7 | | 28.7 | This system requires a large amount of material such as concrete, pipes and filter media, which can account for approximately 50% of the carbon footprint. The initial embodied carbon was estimated to be 76.6, 43.9 and 25.3 kg $CO_2e/m^2$, respectively. This represents 53% of the $CO_2e$ footprint for bioretention basins. Their ability to sequester carbon is poorly understood as no field measurements have been undertaken. |
| **Rain Gardens**[13] | 13.9 | 138.9 | 30 | 62.9 | ± 21.2 | -75.5 | ± 68.4 | -12.6 | Rain gardens are non-engineered, shallow, planted garden beds with compost-amended soils, which receive stormwater from nearby impervious catchments. Rain gardens have been shown to have 40% and 60% lower GHG emissions than sand filters respectively. The initial embodied $CO_2e$ of rain gardens accounts for 41% of its carbon footprint. |

[13] Note: In the United States, rain gardens are a depressed area in the landscape that collects rain water from a roof, driveway or street and allows it to soak into the ground. They are non-engineered devices and do not include an imported filtration media. https://www.epa.gov/soakuptherain/soak-rain-rain-gardens#:~:text=A%20rain%20garden%20is%20a,reduce%20runoff%20from%20your%20property.

| GI Intervention | Low Estimate kg $CO_2$e/ m$^2$ | High Estimate kg $CO_2$e/ m$^2$ | Life Span - years | Mean Estimate kg $CO_2$e/ m$^2$ | Error Margin kg $CO_2$e/ m$^2$ | Mean Sequestration kg $CO_2$e/ m$^2$ | Error Margin kg $CO_2$e/ m$^2$ | Net footprint kg $CO_2$e/ m$^2$ | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | Transportation has a dominant share of the initial embodied carbon. |
| **Stormwater Ponds** | | | 30 | 119.3 | ± 78.5 | -10.4 | ± 1.2 | 108.9 | Only based on 2 studies. Carbon sequestration rates of around −0.3 kg $CO_2$e/ m$^2$ /yr were reported for shallow water zones of stormwater ponds in the USA and temporary inundation areas in Sweden. Comparatively, carbon sequestration rates in a humid tropical climate of Singapore were almost double with −0.5 kg $CO_2$e /m$^2$ /yr. These differences indicate that carbon accumulation rates of ponds are highly dependent on climate conditions and vegetation cover. |
| **Vegetated Swales** | | | 30 | 19.1 | | -8.57 | ± 2.3 | 10.53 | $CO_2$e footprint based on one study by Moore and Hunt (2013). |

| GI Intervention | Low Estimate kg $CO_2e$/ $m^2$ | High Estimate kg $CO_2e$/ $m^2$ | Life Span - years | Mean Estimate kg $CO_2e$/ $m^2$ | Error Margin kg $CO_2e$/ $m^2$ | Mean Sequestration kg $CO_2e$/ $m^2$ | Error Margin kg $CO_2e$/ $m^2$ | Net footprint kg $CO_2e$/ $m^2$ | Comments |
|---|---|---|---|---|---|---|---|---|---|
| **Green Roofs** | 6.4 | 155.8 | 40 | 85 | ± 16.7 | -58.4 | ± 24.7 | 27.2 | The initial embodied carbon is defined as the combination of the $CO_2e$ embodied in the material production, transportation and construction phases. Its value for green roofs is consequently identified as being within the range of 36.7, 37.6 and 57 kg $CO_2e$/ $m^2$ by three independent studies (but could be 4-5 times higher). The current analysis shows that the initial embodied $CO_2e$ represents 71% of the $CO_2e$ footprint while operation and maintenance, and end-of-life phases represent 19% and 10% respectively. However, the complete consideration of these phases is often disregarded in many of the reviewed papers. Re sequestration: The positive correlation between carbon sequestration and substrate depth may explain the high variance between the maximum and minimum carbon sequestration values (−23.7 and −0.69 kg $CO_2e$/ $m^2$/ yr) for 30 and 6 cm depth green roofs. |

Kavehei et al. (2018) also reported the proportion of $CO_2e$ emitted from the various life cycle phases for green roofs, rain gardens and bioretention basins[14] (Figure 7).


**Figure 7:** The contribution of different life cycle phases to $CO_2e$ footprint (adapted from Kavehei et al., 2018)

Kavehei et al. (2018) found that carbon sequestration of bioretention basins, green roofs, vegetated swales and stormwater ponds can mitigate approximately 70%, 68%, 45% and 8% of their $CO_2e$ footprint respectively (Figure 8). None of the devices were found to have a net sink of their life cycle greenhouse gases and are therefore likely net $CO_2e$ emitters over their life span.

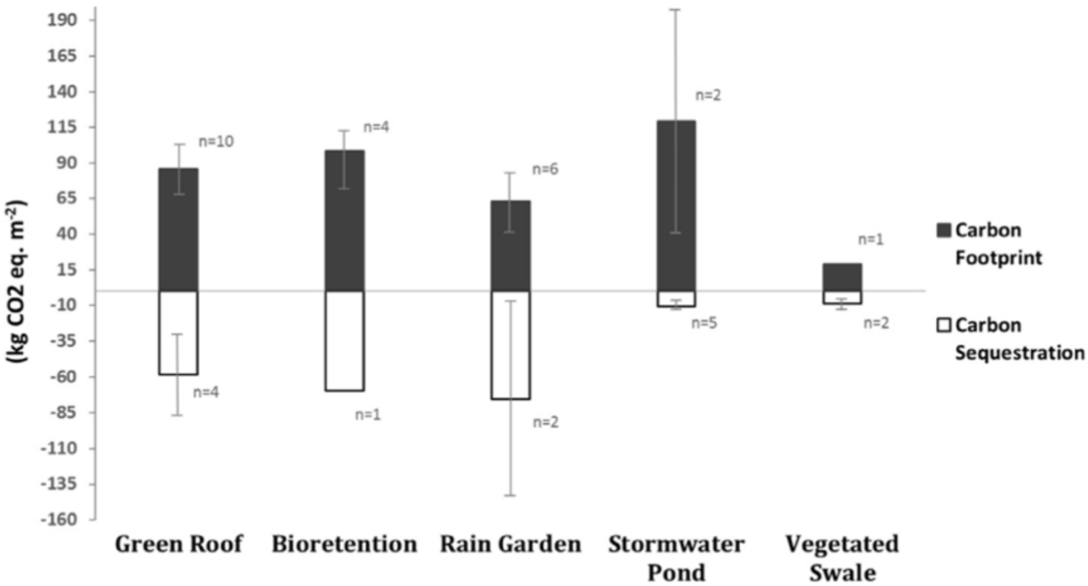


**Figure 8:** Mean $CO_2e$ footprint and mean sequestration of GI interventions (40 year life time for green roofs and 30 years for the other GI interventions) (Kavehei et al., 2018 p. 1189)

Moore and Hunt (2013) undertook a detailed analysis of the carbon footprint associated with constructed wetlands, wet ponds, level spreader filter strips, bioretention cells, permeable pavement, green roofs, rainwater tanks (for reuse) and sand filters. The functional unit used for

[14] Note: rain gardens in the US are different from rain gardens (as described from GD01) in New Zealand and have therefore been disregarded. Bioretention basins in the US are more in-line with GD01 rain gardens and are considered comparable.

the analysis is based on the surface area/ volume of each intervention needed to treat the first 25 mm of rainfall from a 100% impervious 1 ha catchment. Permeable pavement and green roofs were set to 1 ha areas.  It is noted that the maintenance tasks and frequencies for each intervention were mainly focussed on routine inspections. Mowing and pruning frequencies were less than those set through the FWMT LCC maintenance tables and no allowance was made for replacement of parts (except for media replacement for sand filters and bioretention cells, and a pump replacement for rain tanks), minor repairs or council related inspections (Table 21).

**Table 21:** Maintenance tasks and frequencies as outlined in Moore and Hunt (2013, p. 47)

| SCM | Maintenance task | Frequency |
|---|---|---|
| Sand filter | Routine inspection | 4 times per year |
| | Sand removal and replacement | 1 time every 4 years |
| Wetland and pond | Routine inspection | 12 times per year |
| | Forebay cleanout | 1 time every 7 years |
| | Mowing banks | 4 times per year |
| Bioretention cell | Routine inspection | 12 times per year |
| | Mulch removal and replacement | 1 time every 3 years |
| | Pruning | 1 time per year |
| | Mowing (for grass systems) | 10 times per year |
| Level spreader-vegetated filter strip | Routine inspection | 1 time per year |
| | Mowing | 4 times per year |
| | Forebay/diversion box cleanout | 1 time per year |
| Green roof | Routine inspection | 2 times per year |
| Permeable pavement | Routine inspection | 4 times per year |
| | Street sweeping | 4 times per year |
| Rainwater harvesting | Routine inspection | 12 times per year |
| | Pump replacement | 1 time every 10 years |

The analysis focussed solely on carbon emissions (not $CH_4$ or other greenhouse gases) and also did not include indirect reduction in carbon emissions (e.g., decreased energy demands from buildings with green roofs). Table 22 summarises the carbon emissions for various stages within the life cycle. The study highlighted that for ponds and constructed wetlands, both of which require relatively few material inputs, a large portion of the initial footprint related to construction works. For all other interventions, carbon dioxide emitted during material extraction and production and transport to the construction site dominated the initial carbon footprint. Material construction and production represented 99% of the initial carbon footprint of green roofs, the principal materials of which are the product of carbon intense processes (Moore and Hunt, 2013).

The study highlighted that whilst the production of materials which comprise bioretention systems (sands, soils and gravels) have relatively low associated carbon emissions, transport of materials is costly in terms of carbon emissions and can influence the analysis (accounting for about 50% of the bioretention device's initial carbon footprint). Similar transport emissions were also associated with sand filters, highlighting the importance of transportation emissions for stormwater interventions with large quantities of high-density materials.

**Table 22:** Summary of carbon emissions (initial, maintenance and life cycle) for various stormwater interventions as presented in Moore and Hunt (2013).

| GI Intervention | Initial carbon (tons $CO_2$ /ha area treated) | kg $CO_2$ /year (maintenance) | Life Cycle Carbon (30 years) kg $CO_2$ /m2 | Comments |
|---|---|---|---|---|
| Wetland | 1 | 52 | 2.9 | Maintenance emissions were considered on an annual basis and can be multiplied by time (in years) to calculate the net carbon footprint for a desired time period. |
| Pond | 0.6 | 52 - 78 | 11 | |
| Bioretention | 5.1 | 52 - 78 | 21.5 | |
| Sand Filter | 18 | 78 | 240 | |
| Permeable Paving | 86 | | 9.1 | |
| Rain tanks | 4.2 | | 80 | |
| Green Roofs | 100 | 8 | 10 | |
| Filter strips | 0.5 | 10 | 5.2 | |

Andrew and Veseley (2008), which was the only local study related to carbon emissions of green infrastructure, found that $CO_2$ emissions for rain gardens were 30% less than those of sand filters over their life cycle. As with Moore and Hunt (2013), their analysis highlighted the significant contribution of transport of materials and staff needed for the initial construction and ongoing maintenance of the devices. Their life cycle assessment (LCA) was undertaken over 50 years and included a hypothetical sand filter design as well as a reduced rain garden design (smaller surface area with higher infiltration rates as the Paul Matthew Raingarden which was analysed – reduced surface area from 200 $m^2$ to 40 $m^2$). Maintenance activities and frequencies were not defined. Table 23 highlights that, without disposal, the rain garden $CO_2$ life cycle emissions equated to 16.5 tons $CO_2$ /$m^2$ and the sand filter 23.4 tonnes $CO_2$ /$m^2$. The 'small' rain garden had a $CO_2$ emission of 8 tonnes. It is noted that the 'end of life' disposal increased the emissions by approximately 21% across the devices.

**Table 23:** Rain garden and sand filter life cycle $CO_2$ emissions from Auckland, New Zealand (Andrew and Veseley, 2008).

| | Raingarden (as constructed) | | Raingarden (smaller design) | | Sand filter (hypothetical) | |
|---|---|---|---|---|---|---|
| | Energy (GJ) | $CO_2$ (tonnes) | Energy (GJ) | $CO_2$ (tonnes) | Energy (GJ) | $CO_2$ (tonnes) |
| Total (without disposal) | 237 | 16.5 | 112 | 8.0 | 290 | 23.4 |
| Total (with disposal) | 286 | 19.9 | 123 | 8.7 | 299 | 24.0 |
| Transportation | 173 | 12.0 | 88 | 6.1 | 199 | 13.8 |
| Transportation disposal | 49 | 3.4 | 11 | 0.7 | 9 | 0.6 |
| Others | 12 | 0.8 | 2 | 0.2 | 2 | 0.1 |

Note: Totals may not add due to rounding. The figures for transportation associated with disposal are based on one possible scenario.

With respect to green roofs, Mithraratne (n.d.) found that construction $CO_2e$ emissions for green roofs in Singapore generally equated to 70% of the total emissions for continuous roof installation and up to 90% for modular constructed green roofs, with a total life cycle $CO_2e$ emissions of 58 and 192 t $CO_2e/1000\ m^2$ respectively over a 20 year LCA period.

O'Sullivan et al. (2015) found that a concrete vortex pre-fabricated stormwater treatment unit contributed a total of 3,507 kg $CO_2e$ over a 30 year life cycle, with materials alone contributing 1,469 kg $CO_2e$. The authors also investigated two different types of sand filter systems, differing only in the production of the recycled or new plastic (polypropylene, PP) for the detention chambers, with the recycled one emitting 3,226 kg $CO_2e$ and the new plastic version emitting 3,400 kg $CO_2e$. Their modelled rain garden emitted just over 2,000 kg $CO_2e$, with a smaller surface area rain garden (similar to the Andrew and Veseley 2008 study) emitting 1,400 kg $CO_2e$ (Figure 9).

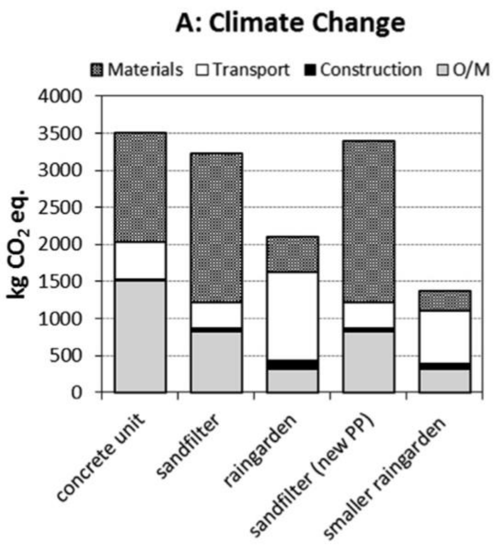


**Figure 9:** $CO_2e$ emissions (kg) for 5 different types of stormwater interventions with a 30 year LCA period and 'end-of-life' disposal omitted (O'Sullivan, 2015)

Fathollahi and Coupe (2021) carried out a LCA for 10 different types of drainage systems, including swales, permeable paving, wetlands and ponds. They reported that for life cycle stages A1 – A4[15], $CO_2$ emissions equated to:

- Wetlands: 220 kg $CO_2e/\ m^2$
- Ponds: 43 kg $CO_2e/\ m^2$
- Permeable paving: 176 kg $CO_2e/\ m^2$
- Swales: 13 kg $CO_2e/\ m^2$

No results were provided for the maintenance phase, nor for the full life cycle process for any of the devices.

[15] The four life cycle stages discussed in the study include extraction of virgin materials and fuels, manufacturing blocks (A1), transport of materials and equipment (A2), construction of drainage systems (A3), using maintenance and end-of-life of the drainage systems (A4)

## 4.2 Moata Carbon Portal

The libraries and asset models within the Moata Carbon Portal were searched for projects and emission factors which could be representative of the urban FWMT interventions throughout their life cycle (i.e. including maintenance and renewals). However, no full $CO_2e$ LCA existed prior to this project. With respect to initial embodied $CO_2e$ (material production, transport and construction stage emissions), Table 24 summarises the FWMT urban interventions which are included within the Moata emissions libraries.

**Table 24:** Device emissions sourced from Moata

| Device | Size Limitations | Moata Library Source | Comments |
|---|---|---|---|
| Rain tanks | 3.5 – 30 $m^3$ | NZ_Stormwater | Above ground residential PE rain tank. Includes excavation for foundation, sand foundation plus 500 mm clearance and PE rain tank. Size and installation method are of rain tank from Devan Tanks. Pipework is excluded. Transport distance is 30 km. |
| Rain gardens | Approx. 5 $m^2$ | NZ_Stormwater | Model is of a single raingarden cell. Model includes 3x1.5 m precast concrete raingarden surround, excavation, backfill, raingarden soil mix backfill, planting, lining, and rock and sand layer. Assumed transport distance of 30 km. The installation of underdrain and overflow structure are excluded from the model. |
| Tree pit | Approx. 15 $m^3$ | NZ_Stormwater | Tree pit is in road. Includes the excavation and reinstatement of the road, ponding area, the excavation of road surface, kerb block and channel, and ductile iron gate and frame. Assumed fixed tree pit volume of 15 $m^3$, the soil volume for a medium/large size of a tree in-built structure. Model includes waterproof lining and a root barrier lining. Transport distance 30 km. Underdrain excluded from the model. |
| Swales | 10 – 1,000 m | NZ_Stormwater | Inclusions - Excavation, backfill and replanting of vegetation on slopes. Exclusions - Any other works not within cradle to built asset boundary. |
| Pervious paving | 10 – 10,000 $m^2$ | NZ_Stormwater | Inclusions - Excavation, geotextile layers and labour required to lay permeable paving. Exclusions - Any other works not within cradle to built asset boundary.<br>*Type of permeable paving is not defined.* |

The following interventions were not previously included in any of the existing databases in Moata:

- Wetlands (and ponds)
- Stormwater filtration devices
- Green roofs
- Inert roofs
- Street sweeping

As before, for interventions above and in Table 20, no maintenance, renewal or end of life $CO_2e$ estimates were available in Moata prior to this project.

# 5 Carbon impact of urban interventions

## 5.1 Development of net carbon footprints for Auckland

### 5.1.1 Methodology for modelling emissions

Based on the literature reviewed and information contained within Moata, the following approach to developing $CO_2$e life cycle emissions was undertaken:

**For rain gardens, swales, rain tanks, permeable paving:**

1. The Moata NZ_Stormwater design templates were used for embodied $CO_2$e emissions, except for the bioretention rain garden (500$m^2$ surface area) where a bespoke design was created within Moata;
2. Based on the maintenance tasks, units and frequencies in the FWMT LCC models, individual emission factors within Moata and external MfE libraries were used to develop a $CO_2$e maintenance emissions model for routine and corrective maintenance;
3. Moata NZ_Stormwater and UK_Stormwater design templates were used for the end of life renewal.

**For filtration devices, wetlands, inert roofs and green roofs:**

<u>Construction Phase (A1 – A5)</u>

1. A generic filtration system was used as a surrogate device for the generic filtration device modelled in the LCC analysis and a bespoke design was created for the construction of a filter system within Moata.
2. AR Associates prepared a design, sizing and schedule of quantities for a GD01 compliant wetland. This wetland was used as the basis for creating a bespoke wetland design within Moata for the construction phase.
3. A bespoke inert roof (based on the use of colorsteel) design was created within Moata for the construction materials and construction phase.
4. For green roofs, the mean value for a continuous green roof from Kavehei et al. (2018) was used for the embodied $CO_2$e estimate.

<u>Maintenance and Renewal Phases (B1 – B7, C1 – C4):</u>

5. Based on the maintenance tasks, units and frequencies in the FWMT LCC models, individual emission factors within Moata and external MfE libraries were used to develop $CO_2$e emissions for each of the above identified urban interventions.
6. The initial embodied $CO_2$e estimates (construction estimates) were used for the end of life renewal.

**For street sweeping:**

Street sweeping is a source control intervention and relates solely to ongoing maintenance activities. Based on the number of kilometres swept in one day and the average volume of sediment disposed after a day of sweeping, Moata and the external MfE libraries were used to assess $CO_2$e emissions.

The LCA $CO_2$e models were built with the assistance of Pattle Delamore Partners and peer reviewed by Mott MacDonald. The 50 year LCA models were exported into excel so that they could be analysed and graphed in a manner consistent with the urban intervention LCC models.

The device sizes chosen and used in the Moata carbon LCA models, along with the catchment area treated, is consistent with the FWMT devices sizes provided within the SUSTAIN workbook.

Assumptions used in each of the models are tabulated in **Appendix 5: Urban intervention carbon model assumptions**.

### 5.1.2 Defining the sequestration potential of green infrastructure

The carbon sequestration potential of each green infrastructure urban intervention was taken from the recommended values provided by PDP (2021), for those localities with similar climatic conditions to New Zealand, and are summarised in Table 25.

**Table 25:** Recommended average carbon sequestration rates from localities with similar climatic conditions to New Zealand, based on an international literature review undertaken by PDP for Auckland Council (adapted from PDP, 2021)

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| ***Green roof (living roof)*** | 0.69 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | Michigan, USA (temperate climate) | Experiment conducted at research institution | 4 years | Typical green roof substrate (6 cm) | *Sedum* species | **2.36** | Getter et al. (2007) | The sequestration potential is for both above and below-ground biomass of the 6 cm substrate green roof. The main objective of this study was to research how green roof slope affects runoff retention quantities. Sequestration rates measured in this study are reported in later publications. |
| | 0.375 kg C $m^{-2}$ over 2 years (ranges between 0.073 to 0.276 kg C $m^{-2}$ for 12 green roofs) (1.38 kg $CO_2$e. $m^{-2}$) | Michigan and Maryland, USA (temperate climate) | Experiment conducted at research institutions | 2 years | Typical green roof substrate (2.5 to 12.7 cm) | *Sedum* species | | Getter et al. (2009) | In total, the extensive roof system sequestered 375 g C $m^{-2}$ comprising of 168 g C $m^{-2}$ in above ground plant biomass, 107 g C $m^{-2}$ in below-ground plant biomass and 100 g C $m^{-2}$ in substrate carbon. The authors reported that the materials needed to install the type of green roof used in the study had an embodied energy of 6.5 kg C $m^{-2}$ with a payback |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | period due to energy savings of about 0.70 kg C $m^{-2}$ of 9 years. When the carbon sequestered by the green roof vegetation was included it reduced that payback period by 2 years. |
| | 1.9 kg $CO_2e$. $m^{-2}$ $yr^{-1}$ | Michigan, USA (temperate climate) | Experiment conducted at research institution | 3 years | Typical green roof substrate (10.5cm) | *Sedum* species | | Whittinghill et al. (2014) | The study concludes that green roofs have good potential for carbon sequestration but management practices can affect their net carbon sequestration and the permanence of the carbon sequestered. The use of green roofs may reduce the payback period of carbon embodied in the green roof materials from 15 years to less than 3 years. |
| | 3.1 kg $CO_2e$. $m^{-2}$ $yr^{-1}$ | | | | | Native *prairie* | | | |
| | 9.4 kg $CO_2e$. $m^{-2}$ $yr^{-1}$ | Hong Kong (humid sub-tropical climate) | Experimental and modelling study | 40 year life cycle modelled | n/a | n/a | | Peng and Jim (2015) | This study evaluated the benefits of two hypothetical roof-greening scenarios: 60% coverage of extensive green roofs vegetated with |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | 20 cm grasses and 60% coverage of intensive green roofs planted with 6 m trees on all the roofs and podiums within a district of Hong Kong. Extensive green roofs were modelled more economically attractive than the intensive green roof. |
| | 2.5 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | Japan (humid sub-tropical climate) | Experiment conducted at research institution | 1 year | Seedling propagation substrate (5 cm) | *Z. matrella* | | Kuronuma and Watanabe (2017) | The study used wet, dry and non-irrigation treatments. The sequestration results are for the plants and substrate materials. The results indicate that soil media depth and composition are significant factors that influence carbon storage in green roofs. The results also suggest that in countries with high rainfall, a high frequency of irrigation has an insignificant effect on the physiological and morphological characteristics, and carbon |
| | 1 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *O. japonicus* | | | |
| | 1.2 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *S. mexicanum* | | | |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | sequestration in the *Sedum* green roofs. |
| | 0.16 kg C $m^{-2}$ $yr^{-1}$ (average) (0.59 kg $CO_2$e. $m^{-2}$ $yr^{-1}$) | Hong Kong (humid sub-tropical climate) | Experimental and modelling study | n/a | n/a | *P. claviformis, R. discolor, C. blumei, S. octophylla, S. octophyllax, D. repens, F. elastic* | | Pan (2016) | PhD thesis. The study also measured $CO_2$ fluxes from all seven plant species and determined the carbon emissions over their life-cycle. |
| | 2.53 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | Japan (humid sub-tropical climate) | Experiment conducted at research institution | 1 year | Perlite, compost and zeolite (6.5 cm deep) | *C. dactylon (with irrigation)* | | Kuronuma et al. (2018) | Plant and substrate materials were sampled to measure the sequestration rates. Irrigation practices have substantial effect on the carbon uptake. This experiment supports the carbon sequestration capacity of several green roof plants. |
| | 2.754 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *F. arundinacea (with irrigation)* | | | |
| | 2.459 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *Z. matrella (with irrigation)* | | | |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 1.684 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *S. aizoon (with irrigation)* | | | |
| | 1.232 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ | | | | | *S. aizoon (non-irrigation)* | | | |
| ***Vegetated swale / filter strip*** | 0.62 kg $CO_2$ e. $m^{-2}$ $yr^{-1}$ | USA | Modelling study | n/a | n/a | Grasses, woody vegetation and shrubs | **0.49** | FHWA (2010) | Bouchard et al. (2013) examined this analysis and concluded that the model overestimates the carbon sequestration rate by a factor of 1.7 (FHWA 0.17 kg C $m^{-2}$ $yr^{-1}$ versus Bouchard 0.099 kg C $m^{-2}$ $yr^{-1}$), and the sequestration rate was not restrained to a timeframe (assumed indefinite). |
| | 0.36 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ (21.5 year period) 0.19 kg $CO_2$e. $m^{-2}$ $yr^{-1}$ (37 year period) | North Carolina, USA (sub-humid, sub-tropical climate) | Experimental and modelling study | 21.5 years and 37 years | Felsic and crystalline soils and lower coastal plain | Mostly grass (depth sampled 0.2 m) | | Bouchard et al. (2013) | The study also investigated wetland swales but did not provide sequestration rates (carbon stocks only). Based on the comparison of carbon stocks to date at the vegetated swales vs wetland swales, the authors |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | | conclude that to promote carbon sequestration, wetland swales appear to be preferable to dry swales. |
| ***Rain garden*** | 144 kg $CO_2$e. $m^{-2}$ over 30 years | Pennsylvania, USA (humid continental climate) | Modelling study (life-cycle assessment) | 30 years | n/a | See survey details in publication | **2.98** | Flynn and Traver (2013) | A detailed vegetation survey was undertaken at the rain garden to collect input data for the urban forest model (i-Tree Eco model). However, the model does not calculate sequestration rates for shrub, herbaceous vegetation and turf areas, and the estimate is likely conservative. |
| | 0.31 kg C $m^{-2}$ $yr^{-1}$ (1.15 kg $CO_2$e. $m^{-2}$ $yr^{-1}$) | Gold Coast, Australia (sub-tropical climate) | Experimental study | 2 - 13 years | 25 bioretention basins with varying substrate designs (see publication for more details) (depth | *Carex appress a, Ficinia nodosa and Lo mandra longifolia.* | | Kavahei et al. (2019) | The study found that bioretention basins can store carbon over the whole ponding area and that age is the most influencing factor on soil carbon accumulation. The results show that bioretention systems could be designed for the enhancement of their carbon sequestration |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | | | | | sampled 0.2 m) | | | | potential, and amendments in their design, such as addition of a carbon source layer (e.g. activated carbon or biochar), are important for better managing carbon availability in the basins. For a comparison with natural ecosystems, the authors note that a large scale survey of more than 100 south-east Australian wetlands displayed the C sequestration rates of 0.25 kg C $m^{-2}$ $yr^{-1}$ for permanent open freshwater sites and 0.08 kg C $m^{-2}$ $yr^{-1}$ for shallow freshwater marshes. |
| ***Constructed stormwater wetland*** | 0.08 kg C $m^{-2}$ $yr^{-1}$ (0.3 kg $CO_2$e. $m^{-2}$ $yr^{-1}$) | North Carolina, USA (sub-humid, sub-tropical climate) | Experimental study | 1 - 15 years | 4 estuarine marshes (see publication for details) | Various (see publication for details) | **0.79** | Craft (1996) | Note that even though these marshes were not constructed for stormwater management purposes, the sequestration numbers have been used in early modelling studies. |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 0.084 kg C $m^{-2}$ $yr^{-1}$ (0.311 kg $CO_2$e. $m^{-2}$ $yr^{-1}$) (shallow water zone) | North Carolina, USA (sub-humid, sub-tropical climate) | Experimental study | Various | 20 wetlands (see publication for substrate details), 40% of surface area comprised emergent macrophytes (depth sampled 0 - 0.1 m) | Grasses, sedges and emergent macrophytes (see publication for details) | | Moore and Hunt (2012) | The study concludes that constructed stormwater wetlands have greater potential to provide carbon sequestration (as well as vegetative diversity and cultural ecosystem services). |
| | 0.219 - 0.267 kg C $m^{-2}$ $yr^{-1}$ (0.810 - 0.988 kg $CO_2$e. m-2 yr-1) | Ohio, USA (continental climate) | Experiment conducted at research institution | 15 years | 2 created riverine wetlands created on former agricultural soils | Various (see publication for details) | | Mitsch et al. (2014) and Bernal and Mitsch (2013) | The authors conclude that the wetlands were effective carbon sinks and had sequestration rates higher than those measured at a reference natural wetland (0.14 ± 0.016 kg C $m^{-2}$ $yr^{-1}$) after 15 years. The authors also note that the sequestration was higher at a wetland that was naturally colonised compared to the wetland with planned planting. |

| Green infrastructure | Carbon sequestration* | Location | Method | Lifetime | Substrate parameters | Vegetation | Average value kg $CO_2$ eq. m-2 yr-1 | Reference | Comments |
|---|---|---|---|---|---|---|---|---|---|
| | 0.42 kg C $m^{-2}$ $yr^{-1}$ (1.55 kg $CO_2$e. $m^{-2}$ $yr^{-1}$) | California, USA (Mediterranean-like climate) | Experimental study | 10 years | Sandy loam | Dominated by *Iva heyesian, Juncus acutus, and Leymus condensatus* | | Maziarz et al. (2019) | Soil and vegetation carbon stocks of the constructed wetland increased rapidly but plateaued after 6 years, and were higher than, or comparable to, local natural wetlands. |

**The sequestration rates reported in kg C m-2 yr-1 are often converted to an aerial amount of CO2 equivalents using a conversion factor of 3.7 for C to CO2 (IPCC, 2007)*

## 5.2 Results

### 5.2.1 $CO_2$ emissions

Average total kilogram $CO_2$e life cycle emissions have been generated for a wide range of urban interventions using Moata and are summarised in Table 26 based on surface area size and the corresponding catchment area treated.

With respect to the stormwater treatment devices, wetlands incur the lowest $CO_2$e emissions, followed by filtration devices, the large bioretention rain garden (500 $m^2$ surface area) and swales (Figure 10) based on catchment area treated. On a device surface area basis, vegetated swales have the lowest $CO_2$e emissions over 50 years, followed by wetlands, green roofs and the large bioretention rain garden. Generally, results demonstrate that those devices which have a smaller surface area to catchment area ratio (e.g. wetlands and underground filtration devices), tend to have lower emissions on a catchment-treated basis. This relationship is likely caused by the predominating effect of long term maintenance activities on the total emissions. Much of the maintenance is device specific and incorporates the need for transport to and from the site (e.g., inspections). This type of maintenance needs to be undertaken irrespective of device size, therefore leading to reduced emissions per $m^2$ .[16] This result is consistent with the finding of the FWMT Stage 1 LCC models (Ira et al., 2021). Further modelling of various devices sizes for each intervention is needed to confirm this relationship.

Figure 11– Figure 17 illustrate the proportion of carbon emitted during the construction and maintenance phases for a selection of devices. Again, those devices which are less reliant on regular inspections and routine maintenance activities (such as regular mowing, inspections, pruning, etc.) have a higher proportion of initial embodied $CO_2$e emissions during the production and construction phase of the life cycle. The proportion of initial embodied $CO_2$e emissions for green roofs (Figure 11) is relatively well aligned with that found by Kavehei et al. (2018) (Figure 6).

Rain tanks only emit 0.08 - 0.1 kg $CO_2$e/ $m^3$ / year of water stored over a 50 year LCA period. Street sweeping was found to emit approximately 85.7 kg $CO_2$e /day. This equates to approximately 2.45 kg $CO_2$e/ km kerb swept.

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[16] It is noted that potentially economies of scale could be realised through reduced maintenance activities for a larger number of smaller devices in close proximity to each other but this has not been investigated through this study.

**Table 26:** $CO_2e$ emissions for various urban stormwater interventions (including renewals)

| Intervention Type | Device Size | Catchment Area Treated | Unit | Total kg $CO_2e$ LCA | kg $CO_2e$/ unit device size | kg $CO_2e$/ unit device size / yr | kg $CO_2e$/ $m^2$ catchment area treated/ yr |
|---|---|---|---|---|---|---|---|
| Living roof | 200 $m^2$ | 200 $m^2$ | $m^2$ | 23,836.30 | 119.18 | 2.38 | 2.38 |
| Inert roof | 200 $m^2$ | 200 $m^2$ | $m^2$ | 11,173.94 | 55.87 | 1.12 | 1.12 |
| Vegetated swale (30m length) | 150 $m^2$ | 600 $m^2$ | $m^2$ | 6,074.01 | 40.49 | 0.81 | 0.20 |
| Grassed (mown) swale (30m length) | 150 $m^2$ | 600 $m^2$ | $m^2$ | 14,521.82 | 96.81 | 1.94 | 0.48 |
| Concrete box rain garden | 5 $m^2$ | 100 $m^2$ | $m^2$ | 7,385.83 | 1,477.17 | 29.54 | 1.48 |
| Bioretention rain garden | 500 $m^2$ | 10,000 $m^2$ | $m^2$ | 95,116.58 | 190.23 | 3.8 | 0.19 |
| Wetland | 5,000 $m^2$ | 19 ha (70% impervious) | $m^2$ | 402,530.56 | 80.51 | 1.61 | 0.04 |
| Rain tank (5,000L) | 5 $m^3$ | - | $m^3$ | 3,799.61 | 0.76 | 0.02 | |
| Rain tank (10,000L) | 10 $m^3$ | - | $m^3$ | 4,943.49 | 0.49 | 0.01 | |
| Filtration device | 20 $m^2$ | 6,300 $m^2$ | $m^2$ | 36,602.19 | 1,830.11 | 36.60 | 0.12 |
| Permeable paving | 75 $m^2$ | 75 $m^2$ | $m^2$ | 55,605.58 | 741.41 | 14.83 | 14.83 |

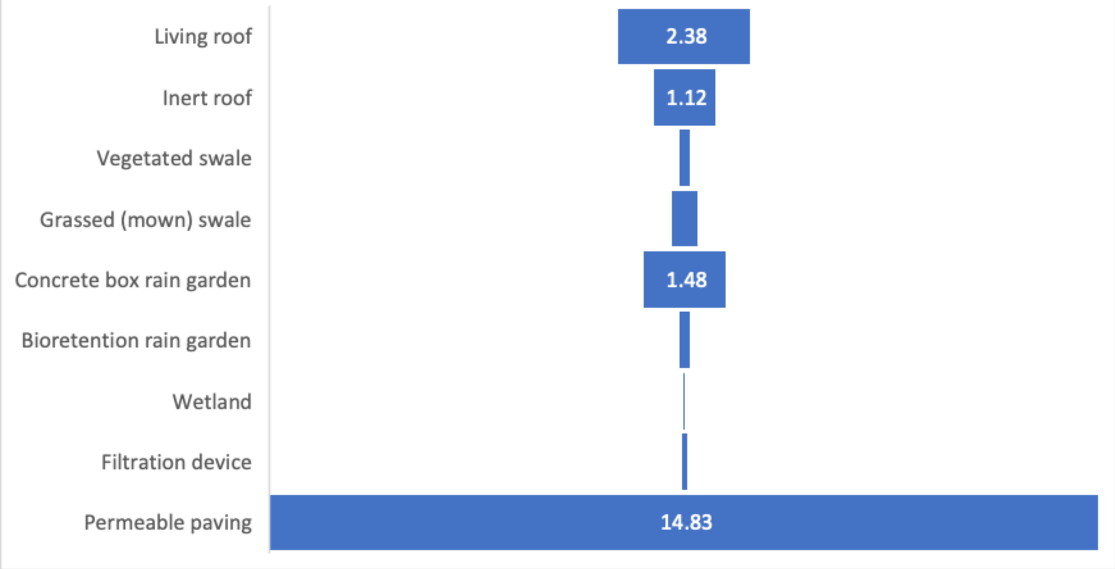


**Figure 10:** kg $CO_2e$/ $m^2$ catchment area treated/ year for various urban stormwater interventions

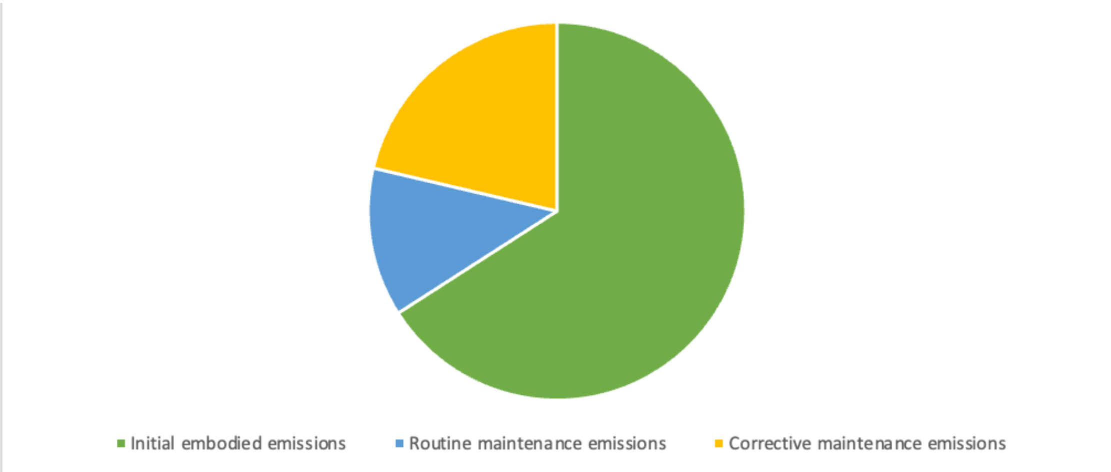


**Figure 11:** Proportion of $CO_2e$ emissions for green roofs over a 50 year LCA

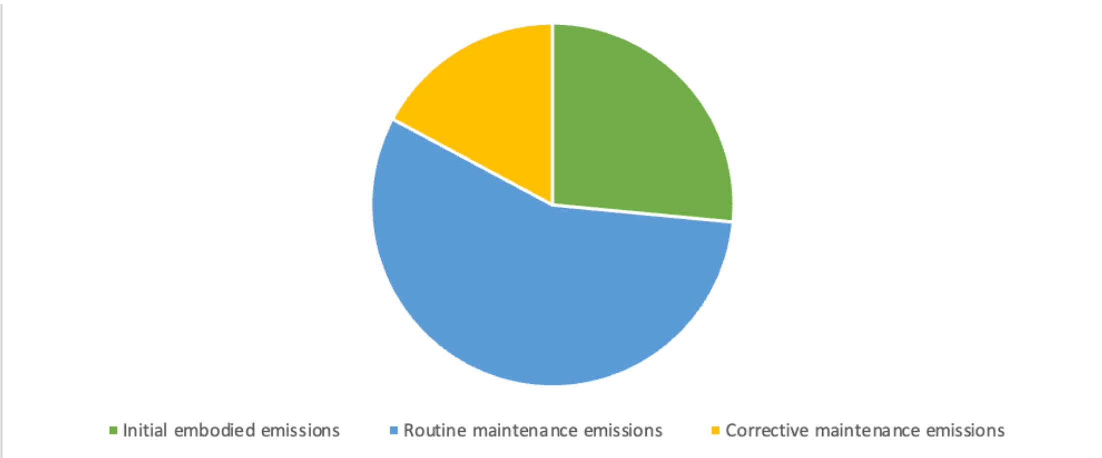


**Figure 12:** Proportion of $CO_2e$ emissions for swales over a 50 year LCA

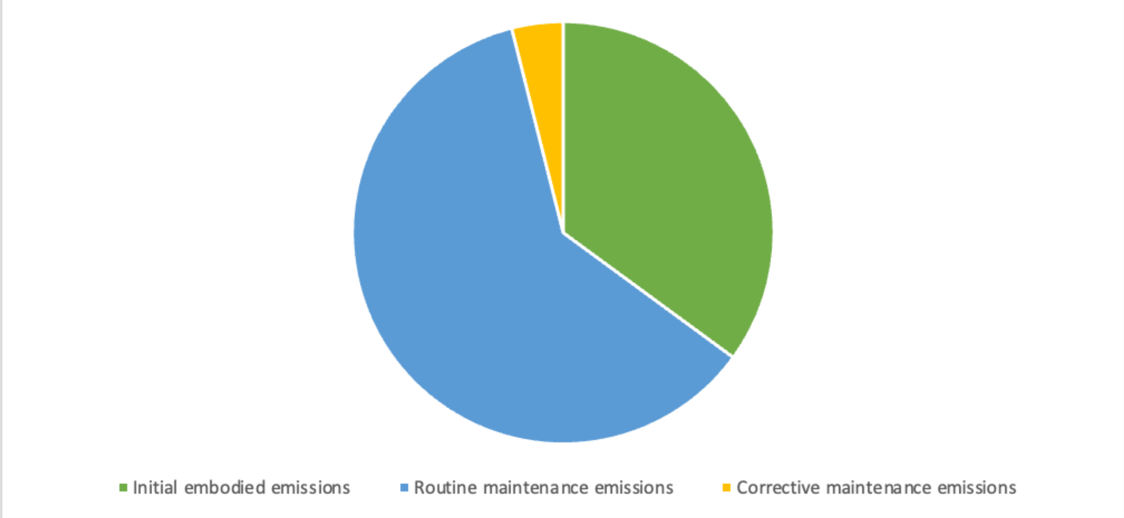


**Figure 13:** Proportion of $CO_2e$ emissions for a concrete box rain garden over a 50 year LCA

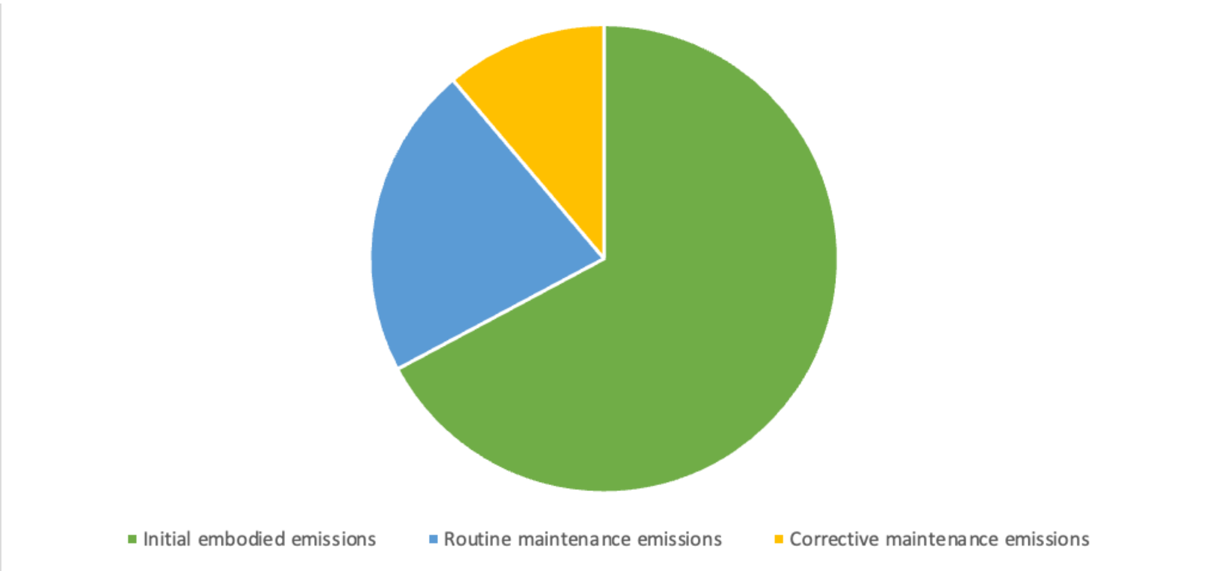


**Figure 14:** Proportion of $CO_2e$ emissions for a constructed wetland over a 50 year LCA

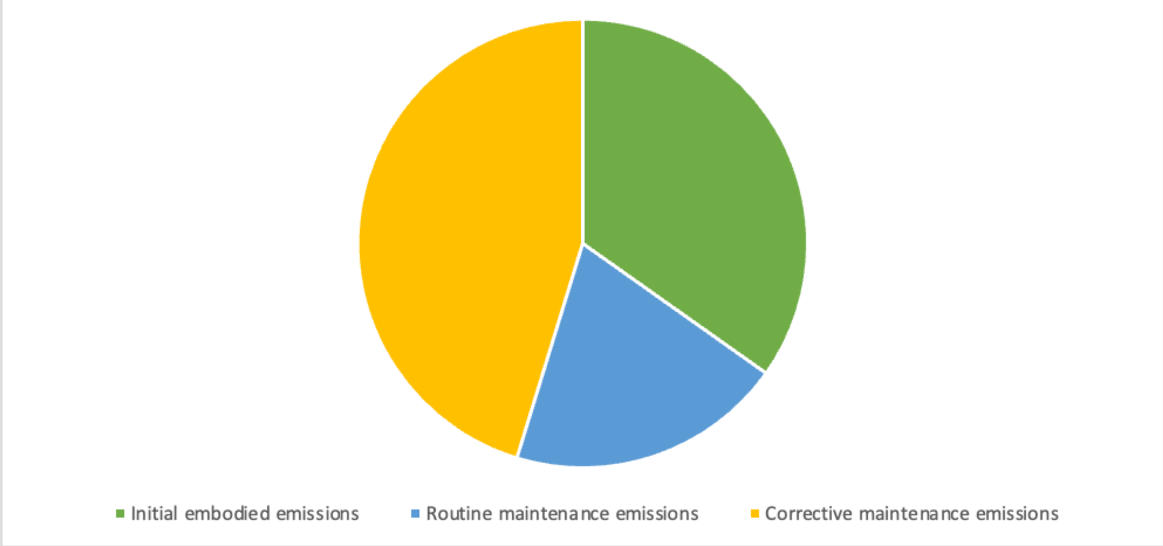


**Figure 15:** Proportion of $CO_2e$ emissions for a rain tank over a 50 year LCA

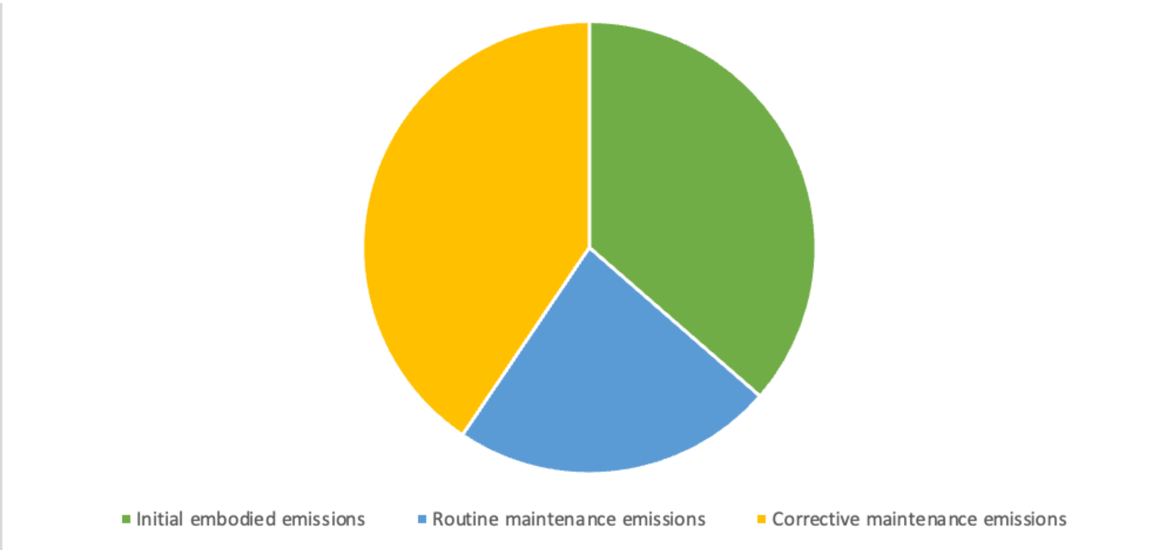


**Figure 16:** Proportion of $CO_2e$ emissions for permeable paving over a 50 year LCA

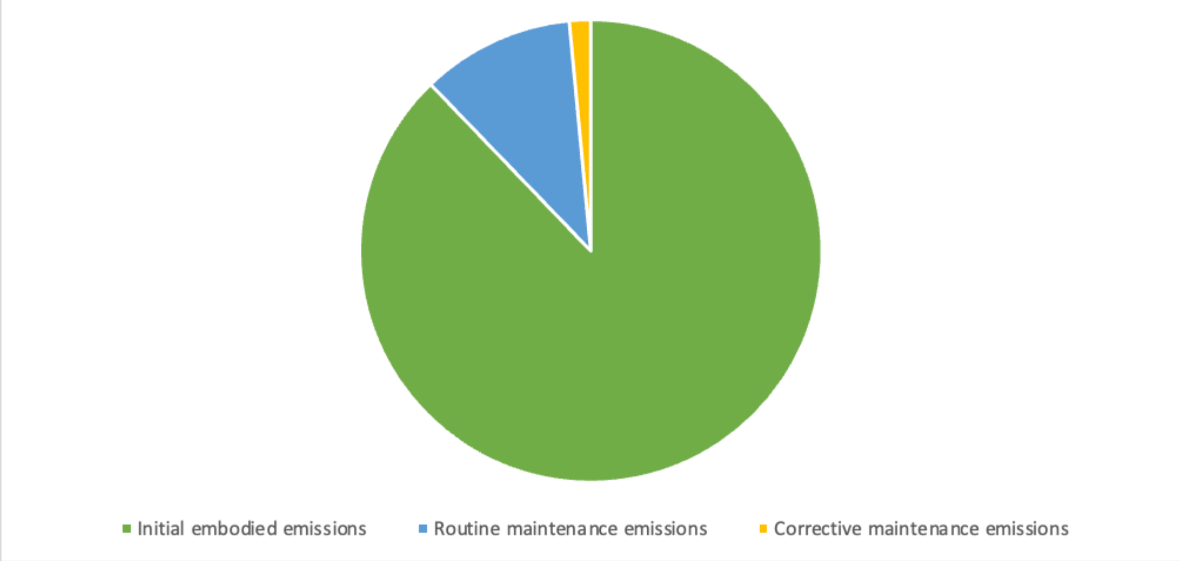


**Figure 17:** Proportion of $CO_2$e emissions for a generic underground filtration device over a 50 year LCA

When interrogating the data based on surface area, those devices which comprise substantial concrete components (concrete box rain gardens, filtration devices, permeable paving) have significantly higher $CO_2$e kg/m$^2$/ yr emission rates. Reducing concrete components within stormwater management devices could lead to a significant reduction in overall $CO_2$e emissions.

With respect to maintenance, travel to and from a device is a key consideration. For all devices, travel was assumed to be 30 km. This estimate was chosen as it is consistent with NZ_Stormwater templates that were used for the construction phase. Additionally, whether diesel, petrol or electric vehicles are used for ongoing inspections and travel to the site can negatively or positively impact the overall emission estimates. The models used for this report all assumed a petrol 'ute' newer than 2015 would be used for regular inspections, with diesel vehicles only used to transport larger materials or machinery to site. Life cycle emissions can be reduced if hybrid or electric vehicles are used during maintenance operations.

The model build phase and associated outputs have led to the following interesting observations and learnings:

- Vegetated swales (using oioi plants or similar) have lower LCA $CO_2$e emissions than grassed swales. This difference is solely due to mowing of grassed swales using diesel tractors, although the vegetated swale model included some minor routine maintenance components associated with plant trimmings, etc.
- Almost 50% of the construction emissions for the wetland model are a result of constructing the concrete accessway for maintenance.
- Almost 70% of the green roof routine maintenance emissions relate to vehicle emissions from routine inspections. If electric vehicles were used for the inspections, this would be reduced by approximately 900%.
- Providing pre-treatment of rain gardens and underground filtration devices (e.g., via vegetated swales) could possibly decrease sediment cleanout frequencies, leading to a reduction in corrective maintenance emissions.
- Permeable paving emissions are high as a result of the pavers themselves as well as sand which is used to bed and fill between pavers. Ongoing replacement of these pavers and 'top-up' of fines means that their life cycle $CO_2$e emissions are particularly high.

- Reducing concrete components within stormwater management devices and reducing travel distances for the transport of high density materials (such as sand or bioengineered media) could lead to a significant reduction in overall $CO_2e$ emissions.
- The models do not include an assessment of economies of scale resulting from the maintenance processes for numerous individual devices which are all in close proximity to each other, as might be the case for small concrete box rain gardens. Potentially the 500 $m^2$ bioretention device emissions could be used as a surrogate for multiple concrete box rain gardens where inspection and maintenance activities could be undertaken as part of one trip.
- It is likely that significant $CO_2e$ emission reductions could be realised for all interventions if electric vehicles were used for maintenance inspections and works.

#### 5.2.1.1 Renewals

Due to the uncertainties around developing a schedule of works for a 50 year renewal for each of the interventions, it was assumed (see Section 4) that the 50 year renewal equated to a rebuild of the device and the construction emissions were therefore applied again at this life cycle stage (this approach is consistent with that taken for the FWMT LCC models).

A 'renewal at end of life' approach is a conservative approach as some elements (e.g., inlet and outlet structures in wetlands) may not require complete replacement after 50 years. To better understand the sensitivity of the models to this renewal component, the models were rerun excluding renewals. Table 27 indicates that the relative difference in emissions between the different types of interventions is unchanged when the renewal component is removed. It is noted that Andrew and Veseley (2008) found that the 'end of life' disposal increased the emissions by approximately 21% for rain gardens and sand filters. The Moata models indicate an average increase in emissions as a result of 'end of life' renewal of 22% for rain gardens and 47% for the underground filtration device. This difference in sand filter renewal could be due to Andrew and Veseley (2008) using a prefabricated Hynds sand filter in their model versus the bespoke design and constructed filtration system used within the Moata model.

**Table 27** Comparison of $CO_2e$ emissions for various urban stormwater interventions with and without renewals

| Intervention Type | Device Size | Unit | Total kg $CO_2e$ LCA (without renewals) | Total kg $CO_2e$ LCA (with renewals) | kg $CO_2e$/ unit device size/ yr (without Renewals | kg $CO_2e$/ unit device size/ yr (with renewals) |
|---|---|---|---|---|---|---|
| Living roof | 200 $m^2$ | $m^2$ | 14,366.30 | 23,836.30 | 1.44 | 2.38 |
| Inert roof | 200 $m^2$ | $m^2$ | 3,845.70 | 11,173.94 | 0.38 | 1.12 |
| Vegetated swale [30m length] | 150 $m^2$ | $m^2$ | 4,801.59 | 6,074.01 | 0.64 | 0.81 |
| Grassed (mown) swale [30m length] | 150 $m^2$ | $m^2$ | 13,249.40 | 14,521.82 | 1.77 | 1.94 |
| Concrete box rain garden | 5 $m^2$ | $m^2$ | 5,468.66 | 7,385.83 | 21.87 | 29.54 |

| Intervention Type | Device Size | Unit | Total kg $CO_2e$ LCA (without renewals) | Total kg $CO_2e$ LCA (with renewals) | kg $CO_2e$/ unit device size/ yr (without Renewals | kg $CO_2e$/ unit device size/ yr (with renewals) |
|---|---|---|---|---|---|---|
| Bioretention rain garden | 500 $m^2$ | $m^2$ | 82,803.01 | 95,116.58 | 3.31 | 3.8 |
| Wetland | 5,000 $m^2$ | $m^2$ | 240,777.36 | 402,530.56 | 0.96 | 1.61 |
| Rain tank (5,000L) | 5 $m^3$ | $m^3$ | 2,239.89 | 3,799.61 | 0.01 | 0.02 |
| Rain tank (10,000L) | 10 $m^3$ | $m^3$ | 2,714.31 | 4,943.49 | 0.01 | 0.01 |
| Filtration device | 20 $m^2$ | $m^2$ | 19,489.32 | 36,602.19 | 19.49 | 36.60 |
| Permeable paving | 75 $m^2$ | $m^2$ | 40,762.19 | 55,605.58 | 10.87 | 14.83 |

#### 5.2.1.2 Comparison with the literature and data confidence

The LCA $CO_2e$ emissions generated through Moata for this study have been compared against those found within the international literature (Table 20). With the exception of wetlands and green roofs, Moata generated LCA emissions were higher than those documented in the literature, and significantly so for filtration systems and permeable paving. Swale, filtration, biofiltration and permeable paving emissions are reported to be lower in Moore and Hunt (2013) since the functional unit used for that study relates to treatment of a 100% impervious 1ha catchment and the LCA period was only 30 years. The devices modelled within Moata treat significantly smaller catchment areas (see Table 28). Inspections needed for maintenance purposes are undertaken irrespective of device size leading to a resultant inverse relationship between device size and $CO_2e$ emissions (i.e. smaller stormwater interventions are likely to have higher $CO_2e$ emissions on a per metre squared surface area basis). Additionally, for permeable paving, Moore and Hunt (2013) did not allow for any replacement or repair of pavers, and this item contributed approximately 28% of the LCA $CO_2e$ emissions in the Moata model. Initial embodied $CO_2$ in the Moata model for permeable paving was only 21 kg $CO_2e$/ $m^2$ higher in Moata than in Fathollahi and Coupe (2021). The Moata bioretention emissions are higher than Moore and Hunt (2013) as the Moata models also accounted for replacement of bioretention media and replacement of parts, as well as erosion repair and associated rip rap replacement over a period of 50 (rather than 30) years.

No literature or data was available on $CO_2e$ emissions resulting from street sweeping, and no $CO_2e$ emission factor was found for street sweeper trucks, thus leading to a low level of confidence in the carbon emissions generated. Data confidence for inert roofs is also low due to the large variability in roof materials and no literature or data was available on $CO_2e$ emissions from inert roofs. The filtration device and permeable paving emissions are also considered to have a low level of confidence due to:

- the underground filtration device being a generic 'hybrid' of various types of filtration devices; and
- the unknowns with respect to frequency and quantity of replacement of permeable pavers over the life cycle.

Based on the available data and reasonable alignment with literature, swales and rain gardens are considered to have medium confidence level. Green roofs and wetlands have been assigned a medium to high level of confidence as they fall within the emission ranges provided within the international literature.

**Table 28:** Comparison of Moata Carbon Portal FWMT model results (with and without renewals) against LCA emissions outlined in the international literature summarised in Section 4.1.

| Intervention Type | Moata Carbon Portal FWMT Models (50 year LCA) | | | | | International Literature (30 – 40 year LCA, standardised to 1ha device size) | Data Confidence |
|---|---|---|---|---|---|---|---|
| | Device Size | Catchment Area Treated | Unit | kg $CO_2e$/ m² device size (with renewals) | kg $CO_2e$/ m² device size (without renewals) | kg $CO_2e$/ m² device size | |
| Living roof | 200 m² | 200 m² | m² | 119.18 | 71.83 | 6.4 - 155.8 | Medium-High |
| Vegetated swale | 150 m² | 600 m² | m² | 40.49 | 32.01 | 13 - 19.1 | Medium |
| Grassed (mown) swale | 150 m² | 600 m² | m² | 96.81 | 88.33 | | Medium |
| Concrete box rain garden | 5 m² | 100 m² | m² | 1,477.17 | 1093.73 | | Medium |
| Bioretention rain garden | 500 m² | 10,000 m² | m² | 190.23 | 165.61 | 68.1 - 153.3 | Medium |
| Wetland | 5,000 m² | 19 ha (70% impervious) | m² | 80.51 | 48.16 | 119.3± 78.5 | Medium-High |
| Filtration device | 20 m² | 6,300 m² | m² | 1,830.11 | 974.47 | 240 | Low |
| Permeable paving | 75 m² | 75 m² | m² | 741.41 | 543.50 | 176 | Low |

### 5.2.2 Net carbon footprints

Based on the average sequestration rates in Table 25, net carbon footprints have been calculated for all devices **(**Table 29 and Table 30**)**. It is assumed that inert roofs, underground filtration, permeable paving, street sweeping and rain tanks do not sequester carbon. Additionally, it is assumed that no carbon is sequestered during the construction and renewal periods. Figure 18 and Figure 19 highlight that green roofs, wetlands, vegetated swales and larger bioretention devices have the most potential for offsetting their carbon footprint. When renewals are excluded from the $CO_2e$ emissions LCA, then green roofs are able to completely offset their carbon footprint and sequester carbon over a 50 year period, subject to suitable management practices in place as these can affect the mitigation device's net carbon sequestration and the permanence of the carbon sequestered. In Figure 19**,** the size of the circle is representative of the net carbon footprint over 50 years.

The analysis here clearly demonstrates that permeable paving and inert roofs along with small, concrete encased rain gardens, have high net carbon footprints when compared to other types of stormwater management devices over 50 year life cycles.

**Table 29:** Net carbon footprints (including renewals and sequestration potential) over a 50 year LCA

| Intervention Type | Unit | kg $CO_2e$ / unit (over 50 years) | LCA Sequestration /$m^2$ over 50 years [17] | Net Carbon Footprint / unit (over 50 years) | Net Carbon Footprint (TOTAL) | Percentage Emissions offset | Net Carbon Footprint / catchment area treated (over 50 years) |
|---|---|---|---|---|---|---|---|
| Living roof (200$m^2$) | $m^2$ | 119.18 | 113.42 | 5.76 | 1,151.50 | 95% | 5.76 |
| Inert roof (200$m^2$) | $m^2$ | 55.87 | 0 | 55.87 | 11,173.94 | 0% | 55.87 |
| Vegetated swale (150$m^2$) | $m^2$ | 40.49 | 23.52 | 16.97 | 2,546.01 | 58% | 4.24 |
| Concrete box rain garden (5$m^2$) | $m^2$ | 1,477.17 | 143.0 | 1,334.13 | 6,670.63 | 10% | 66.71 |
| Bioretention rain garden (500$m^2$) | $m^2$ | 190.23 | 143.0 | 47.19 | 23,595 | 75% | 2.36 |
| Wetlands (5000$m^2$) | $m^2$ | 80.51 | 38.01 | 42.50 | 212,498.56 | 47% | 1.12 |
| Rain tank (5,000L) | $m^3$ | 0.76 | 0 | 0.76 | 3,799.61 | 0% | |
| Rain tank (10,000L) | $m^3$ | 0.49 | 0 | 0.49 | 4,943.49 | 0% | |
| Filtration device (20$m^2$) | $m^2$ | 1,830.11 | 0 | 1,830.11 | 36,602.19 | 0% | 5.81 |
| Permeable paving (75$m^2$) | $m^2$ | 741.41 | 0 | 741.41 | 55,605.58 | 0% | 741.41 |

[17] As per Table 25: Recommended average carbon sequestration rates from localities with similar climatic conditions to New Zealand, based on an international literature review undertaken by PDP for Auckland Council (adapted from PDP, 2021) care must be taken when accounting for the sequestration potential of mitigation devices, as management practices can affect their net carbon sequestration and the permanence of the carbon sequestered. This applies to devices where planting does not result in woody mass and/or the planting media gets disturbed/ renewed, thereby causing a release of stored carbon emissions.

**Table 30:** Net carbon footprints (without renewals) over a 50 year LCA

| Intervention Type | Unit | kg $CO_2$e/ unit (over 50 years) | LCA Sequestration | Net Carbon Footprint / unit (over 50 years) | Net Carbon Footprint (TOTAL) | Percentage Emissions offset | Net Carbon Footprint/ catchment area treated (over 50 years) |
|---|---|---|---|---|---|---|---|
| Living roof (200m$^2$) | m$^2$ | 71.83 | 113.42 | (41.59) | (8,318.50) | 158% | (41.59) |
| Inert roof (200m$^2$) | m$^2$ | 19.23 | 0 | 19.23 | 3,845.70 | 0% | 19.23 |
| Vegetated swale (150m$^2$) | m$^2$ | 32.01 | 23.52 | 8.49 | 1,273.59 | 73% | 2.12 |
| Concrete box rain garden (5m$^2$) | m$^2$ | 1,093.73 | 143.0 | 950.69 | 4,753.46 | 13% | 47.53 |
| Bioretention rain garden (500m$^2$) | m$^2$ | 165.61 | 143.0 | 22.57 | 11,285 | 86% | 1.13 |
| Wetlands (5000m$^2$) | m$^2$ | 48.16 | 38.01 | 10.15 | 50,745.36 | 79% | 0.27 |
| Rain tank (5,000L) | m$^3$ | 0.45 | 0 | 0.45 | 447.98 | 0% | |
| Rain tank (10,000L) | m$^3$ | 0.27 | 0 | 0.27 | 271.43 | 0% | |
| Filtration device (20m$^2$) | m$^2$ | 974.47 | 0 | 974.47 | 19,489.32 | 0% | 3.09 |
| Permeable paving (75m$^2$) | m$^2$ | 543.50 | 0 | 543.50 | 40,762.19 | 0% | 543.50 |

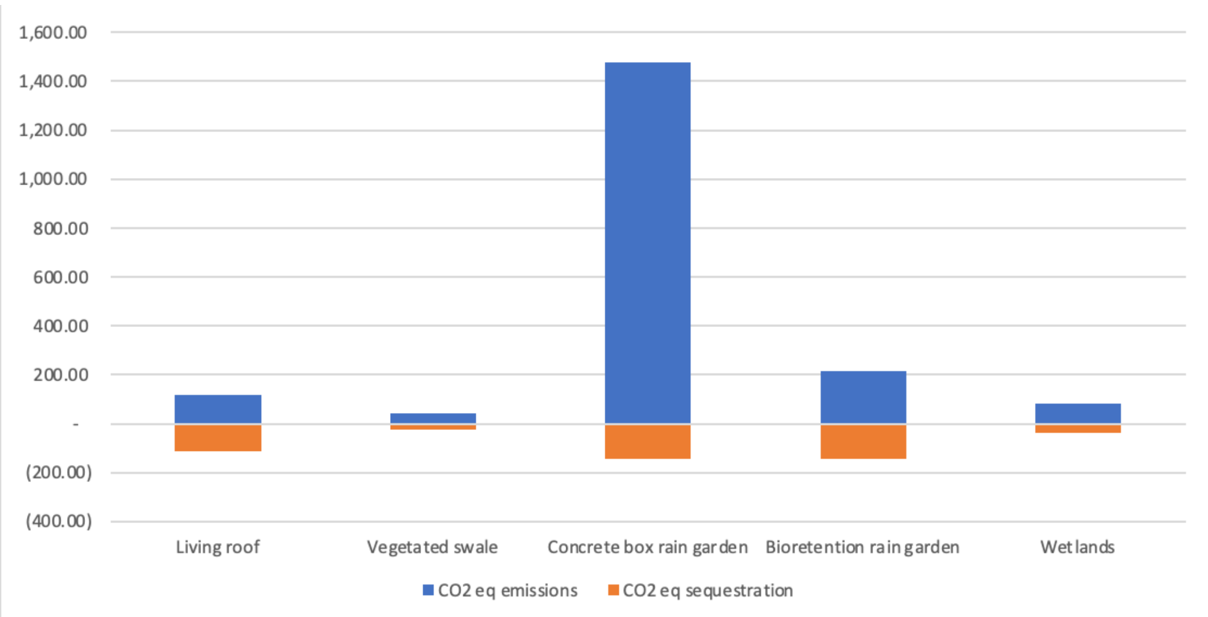


**Figure 18:** kg $CO_2$e emissions vs kg $CO_2$ equivalent sequestration per metre squared device surface area over 50 years (including renewals)

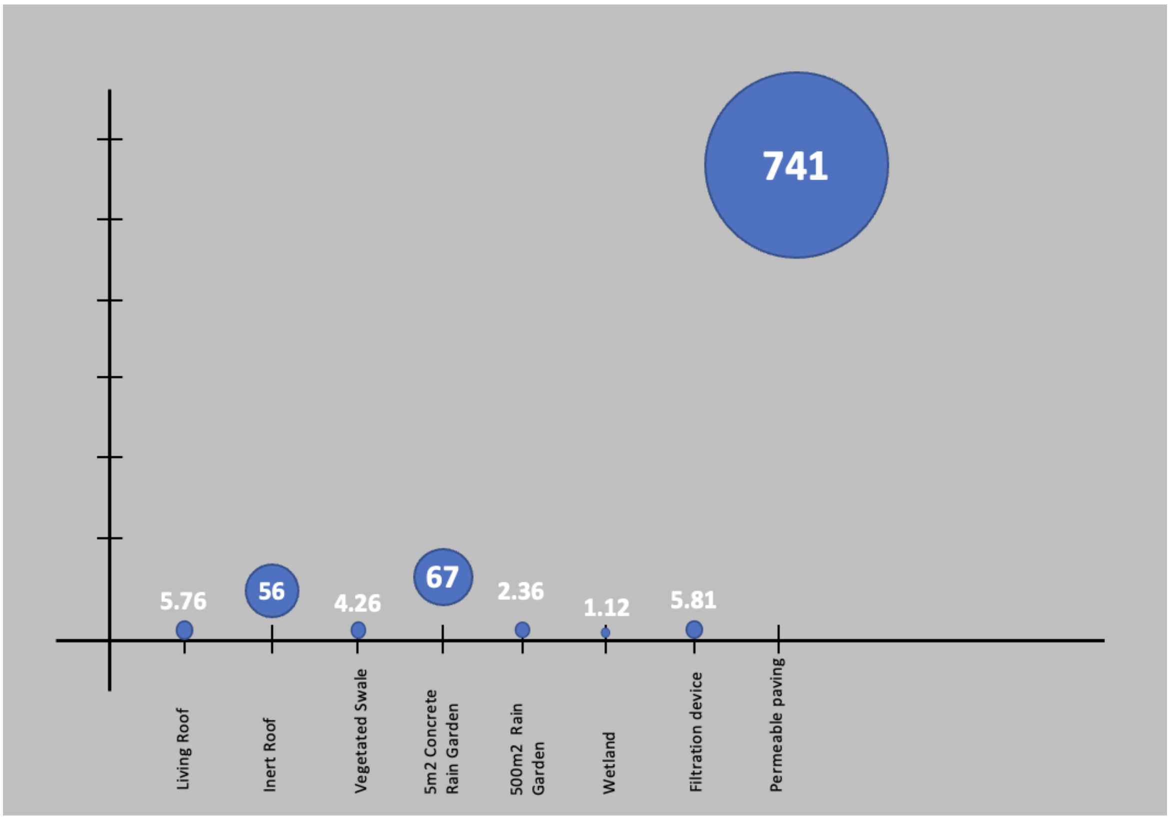


**Figure 19:** Net carbon footprints per metre square treatment device surface area over 50 years

# 6 Conclusion and recommendations

This report documents an assessment of a first-of-its-kind lifecycle analysis (LCA) of 50 year standardised emissions and sequestering of carbon for rural and urban water management interventions, in terms of $CO_2$e, purposely for the FWMT framework.

The FWMT framework is an operational water quality accounting programme developed by AC (Healthy Waters) to improve decision-making on strategic actions and investment needed to achieve freshwater and coastal water quality outcomes.

This report has been commissioned to enable FWMT Stage 1 optimised and scenario intervention information (devices, source controls – scale of required) to be translated into integrated lifecycle CO2e estimates. Understanding the potential carbon impacts of water quality mitigation actions at catchment-scale enables AC (Healthy Waters) to better understand the co-benefits/costs of actions identified by the FWMT as being least-cost for water quality objectives.

This report described the process, assumptions and models used to generate corresponding lifecycle $CO_2$ equivalent emissions for FWMT rural and urban water management interventions.

The lifecycle analysis is based on the production, construction, user and end of life (or renewal) phase over a standardised 50 year timeframe, consistent with the analysis timeframe for the FWMT stormwater interventions.

The lifecycle analysis also utilised consistent intervention designs and assumptions used in earlier reporting (Auckland Council 2021) to provide lifecycle (50 year) direct costs for FWMT interventions.

All carbon impact estimates have been allocated a confidence level based on the reliability of the data or information that has been used to estimate the carbon impact for each mitigation.

Confidence in LCA $CO_2$e estimates varies widely between interventions due to variation in: (1) confidence of intervention design; (2) available data specific to Auckland region; and (3) lack of comparative independent estimates from other studies.

The FWMT carbon impact estimates are novel. It is advisable to exercise caution when using these estimates including limiting their initial use to indicative assessment of integrated outcomes (e.g., not for use in direct costing and optimised cost modelling, only for contextualising FWMT optimised outputs).

Table 31 (rural EOF mitigations), Table 32 (rural bundled mitigations) and Table 33 (urban) summarise the results from this research. While there is significant detail and assumptions behind each mitigation, these tables summarise the total emissions across 50 years for each intervention.

## 6.1 Rural mitigations

The FWMT rural intervention $CO_2$e emissions were estimated using literature, the MfE Calculator or modelled using the Moata Carbon Portal over a 50 year life cycle based on assumptions which are consistent with the FWMT rural LCC models (Muller et al. (2020).

The rural mitigation options span bundled farm practice and system changes (M1, M2, M3 in order of increasing cost and severity of change) to EOF mitigation (wetlands [small, large], riparian management [1 m, 2.5 m, 5 m, 10 m setback; grassed, planted], detainment bunds, sediment retention ponds and space planted erosion control trees).

Carbon estimates for rural mitigations include estimating three key elements, (1) embodied carbon in constructing mitigations, (2) sequestration changes as a result of the mitigations and (3) changes in biological emissions as a result of the mitigations. Carbon estimates have been provided for each of the FWMT rural mitigations, using a range of sources depending on data availability. Estimates are provided for HRU groupings where appropriate. For each of the mitigations, the types of carbon that have been considered in the carbon impact estimates vary based on the availability of data and source of the estimate. Assumptions on the carbon form and quantification are recorded in text as well as how the estimate was derived.

The mitigations assessed in this work were limited to the mitigations that already existed in Stage 1 of the FWMT. Wherever possible all detail of the mitigations in this assessment were aligned with how the mitigations were modelled in the FWMT. In addition, the rural and urban mitigations modelling methods and assumptions were aligned where appropriate. This was most evident in mitigations that used the Moata carbon portal.

Literature-based estimates were derived for EOF mitigations of space planting of erosion control trees and riparian planting. The Moata carbon portal was used to estimate embodied carbon in wetlands, detainment bunds and sediment retention ponds. Farm system bundled mitigation estimates were based on literature and derived using the MfE Calculator which focuses on biogenic emissions as these farm system mitigations do not have embodied carbon.

To identify a suitable base carbon footprint for the rural land use, the impact of changing mitigations such as riparian areas, which remove land from productive use, was estimated. These base footprints were also calculated in the MfE Calculator which meant the base footprints were directly comparable to the farm system mitigations.

Each of these carbon impact estimates have been modelled over the full 50 year life cycle that is included in the FWMT. Confidence levels have been assigned to the carbon impact estimate of each mitigation. Because many are medium or low confidence, the key focus needs to be on the direction of travel and magnitude of change rather than the specific quantum of changes in carbon as a result of each mitigation.

## 6.2 Urban mitigations

### 6.2.1 Conclusions

The FWMT urban intervention $CO_2e$ emissions were modelled using the Moata Carbon Portal over a 50 year life cycle based on assumptions which are consistent with the FWMT urban LCC models (see Ira et al., 2021). Model results were compared to emissions sourced from the literature and carbon sequestration levels were based on an international literature review done for AC by PDP (2021). The models made no assumptions regarding ambient $CO_2e$ emissions from particular urban land uses. Rather, the life cycle analysis here focussed on the net carbon footprint of the device itself. Additionally, the models do not include any indirect reduction in $CO_2e$ emissions which could result from the interventions (e.g. decreased energy demands from buildings with green roofs).

The model results established that, with respect to the stormwater treatment devices, wetlands incur the lowest $CO_2e$ emissions, followed by filtration devices, the large bioretention rain garden and swales based on catchment area treated. On a device surface area basis, vegetated swales have the lowest $CO_2e$ emissions over 50 years, followed by wetlands, green roofs and the large bioretention rain garden.

Generally, the results demonstrate that those devices which have a smaller surface area to catchment area ratio (e.g. wetlands and underground filtration devices), tend to have lower emissions on a catchment-treated basis. This relationship is likely caused by the predominating effect of long term maintenance activities on the total emissions. This result is consistent with the finding of the FWMT

Stage 1 LCC models (Ira et al., 2021). However, further modelling of various devices sizes for each intervention is needed to reduce uncertainty and confirm this relationship. Both the Moata rain garden models and Andrew and Veseley (2008) found that the 'end of life' disposal (or renewal) increased the emissions by approximately 20%.

Whilst the results presented herein reflect that of a generalised, theoretical and predictive model, overall, they are comparable with that found in the literature. With the exception of wetlands and green roofs, the Moata Carbon Portal generated LCA emissions were higher than those documented in the literature. This is expected and is likely due to:

1. the LCA period within the literature being 30 years, as opposed to 50 years used within this study; and
2. the functional unit used in Moore and Hunt (2013) was treatment of a 100% impervious 1ha catchment, larger than that used within the Moata models.

The study has also confirmed that, of the various stormwater treatment interventions assessed, green roofs, wetlands, vegetated swales and larger bioretention devices have the most potential for offsetting their carbon footprint on a kg $CO_2$e /$m^2$ surface area basis (Figure 18 and Figure 19) (subject to suitable management practices in place as these can affect the net carbon sequestration and the permanence of the carbon sequestered). When renewals are excluded from the $CO_2$e emissions LCA, then green roofs could potentially offset their carbon footprint and sequester carbon over a 50 year period.

### 6.2.2 Moata Carbon Portal

All FWMT interventions described here and modelled in the Moata Carbon Portal have designs available for use under the "Auckland Stormwater" library.

### 6.2.3 Learnings

This study has highlighted a number of lessons with respect to the carbon footprint of various urban stormwater management interventions. These include:

**Construction phase:**

- Reducing concrete components within stormwater management devices and reducing travel distances for the transport of high-density materials (such as sand or bioengineered media) could lead to a significant reduction in overall $CO_2$e emissions.
- Almost 50% of the embodied emissions for the wetland model are a result of constructing the concrete accessway needed for maintenance.
- Amending designs of concrete encased rain gardens to use alternative, more natural solutions would reduce $CO_2$e emissions of small rain gardens.
- Refining designs which reduce the catchment area to surface area ratio (without compromising stormwater function) would reduce emissions (e.g. using types of engineered media which enhance filtration and infiltration rates without compromising treatment function).
- Promotion of a treatment train approach through the use of vegetated (not mown) swales would enable the reduction of the surface area of rain gardens or other stormwater devices, potentially lowering $CO_2$e emissions.

**Maintenance phase:**

- Vegetated swales (using oioi plants or similar) should be promoted over grassed swales as they have lower $CO_2$e emissions. This difference is solely due to mowing of grassed swales using diesel tractors.

- Almost 70% of the green roof routine maintenance emissions relate to vehicle emissions from routine inspections. If electric vehicles were used for the inspections, this would be reduced by approximately 900%.
- Providing pre-treatment of rain gardens and underground filtration devices (e.g. via vegetated swales) could decrease maintenance obligations such as sediment cleanout frequencies, leading to a reduction in corrective maintenance emissions.
- Permeable paving emissions are high as a result of the pavers themselves as well as sand which is used to bed and fill between pavers. Ongoing replacement of these pavers and 'top-up' of fines means that their life cycle $CO_2e$ emissions are particularly high.
- It is likely that significant $CO_2e$ emission reductions could be realised for all interventions if electric vehicles were used for maintenance inspections and works.
- Economies of scale could potentially be realised through coordinated maintenance activities for a number of smaller devices in close proximity to each other, to minimise travel, leading to a consequential reduction in LCA kg $CO_2e$ /$m^2$.

In general, the perceived rigidity of existing standards seems to unintentionally bias stormwater treatment/ infrastructure solutions towards higher carbon solutions. Guideline documents developed to meet consenting requirements is potentially stifling new innovative solutions which could lead to new low carbon options. Including the cost of carbon as a matter for discretion in the consenting process could assist in incentivising low carbon solutions in the future. Additionally, efficient maintenance procedures, whereby inspection and maintenance trips are combined and rationalised, will lead to a reduction in long term, ongoing $CO_2e$ emissions.

**Table 31:** Summary of carbon impact for all rural device and EOF FWMT interventions

| Rural device and EOF FWMT interventions | | | | | | |
|---|---|---|---|---|---|---|
| **Intervention Type** | **Rural intervention carbon impact estimates (50 year LCA)** | | | **Data Confidence** | **Identification in Moata** | **Comments** |
| | **Intervention Size** | **Unit** | **kg $CO_2$e/intervention** | | | |
| Small wetland | 5,000 $m^2$ | $m^2$ | 58,755.3 (inclusive of maintenance and renewals) | Low | ID: 8351 | Representative of a facilitated wetland less than one hectare. Accounts for embodied carbon only, sequestration and emissions of the wetland itself are not accounted for. Refer to Table 8 for removed biological emissions that vary by HRU. |
| Large wetland | 15,000 $m^2$ | $m^2$ | 137,169.7 (inclusive of maintenance and renewals) | Low | ID: 8355 | Representative of a constructed wetland greater than one hectare. Accounts for embodied carbon only, sequestration and emissions of the wetland itself are not accounted for. Refer to Table 8 for removed biological emissions that vary by HRU. |
| Pastoral detainment bund | 120 $m^2$ | $m^2$ | 12,679.8 (inclusive of maintenance and renewals) | Low | ID: 7483 | Assumes that the detainment bund will generate a pulse of $CO_2$e emissions in year 1 and year 25 based on construction and replacement, with no carbon sequestration or emissions in other years. The detainment bund will receive a full replacement after 25 years. |
| Horticultural sediment retention pond | 130 $m^2$ | $m^2$ | 7,861 (inclusive of maintenance and renewals) | Low | ID: 7878 | It is assumed that the sediment retention pond will express a $CO_2$e impact in year 1 and year 25 and will receive a full replacement after 25 years. |
| Space planted trees | 10,000 | $m^2$ | 7,000/year or 167,000/25 years | Medium | N/A | It has been assumed that the carbon emissions from harvested forestry have been considered negligible and therefore this estimate only accounts for cumulative sequestration. |
| Riparian (planted) | Per buffer width$^2$ | $m^2$ | The carbon impact varies by HRU and buffer width. Refer to Table 8 for estimates. | Medium | ID: 7966 | The $CO_2$e impact for riparian management included sequestration of riparian planting and embodied carbon from transporting plant and fencing materials and related maintenance requirements was estimated using Moata. It has been assumed that there is minimal disturbance to planting in riparian areas to avoid disturbance of any carbon sequestered in soil. |
| Riparian (rank grass) | Per buffer width $^2$ | $m^2$ | The carbon impact varies by HRU and buffer width. Refer to Table 8 for estimates. | Low | ID: 7966 | The $CO_2$e impact for rank grass only included embodied carbon from transporting plant and fencing materials and related maintenance requirements was estimated using Moata. It has been assumed that there is minimal disturbance to planting in riparian areas to avoid disturbance of any carbon sequestered in soil. |

**Table 32:** Summary of carbon impact for all rural farm system bundled FWMT interventions

| Rural interventions estimated from literature or tool | | | | | |
|---|---|---|---|---|---|
| | **Type** | **t $CO_2$e/year** | **t $CO_2$e/50 year LCA** | **Data Confidence** | **Comments** |
| Dairy mitigation bundles | M2 | -0.88 | -44.00 | Medium | All the farm system bundled mitigations are calculated in the MfE calculator with good farming practice source controls to ensure consistency across interventions. These estimates show the carbon impact of the mitigation from the base carbon impact. |
| | M3 | -1.34 | -67.00 | Medium | |
| Sheep and beef bundles (< 10 SU/ha) | M1 | 0.00 | 0.00 | Medium | |
| | M2 | -0.10 | -5.00 | Medium | |
| | M3 | -0.20 | -10.00 | Medium | |
| Sheep and beef bundles (> 10 SU/ha) | M1 | 0.00 | 0.00 | Medium | |
| | M2 | -0.30 | -15.00 | Medium | |
| | M3 | -0.40 | -20.00 | Medium | |
| Horticulture and arable bundles (low and medium impact) | M1 | -0.20 | -10.00 | Medium | |
| | M2 | -0.80 | -40.00 | Low | |
| | M3 | -1.00 | -50.00 | Low | |
| Horticulture and arable bundles (high impact) | M1 | 0.00 | 0.00 | Medium | |
| | M2 | -0.10 | -5.00 | Medium | |
| | M3 | -0.20 | -10.00 | Medium | |

**Table 33:** Summary of carbon impact for all urban FWMT interventions

| Intervention Type | Moata Carbon Portal FWMT Models (50 year LCA) | | | | | | Data Confidence | Comments[1] |
|---|---|---|---|---|---|---|---|---|
| | Device Size | Catchment Area Treated | Unit | kg $CO_2$e/ unit device surface area (with renewals) | kg $CO_2$e/ unit device surface area (without renewals) | Net Carbon Footprint / unit device surface area (with renewals) | | |
| Living roof | 200 $m^2$ | 200 $m^2$ | $m^2$ | 119.18 | 71.83 | 5.76 | Medium-High | kg $CO_2$e emission estimates fall within the range given in the international literature. Almost 70% of the green roof routine maintenance emissions relate to vehicle emissions from routine inspections.<br>Moata ID: 7809 |
| Inert roof | 200 $m^2$ | 200 $m^2$ | $m^2$ | 55.87 | 19.23 | 55.87 | Low | Based on a coloursteel inert roof. No literature estimates were available for LCA emissions from inert roofs.<br>Moata ID: 8061 |
| Vegetated swale | 150 $m^2$ | 600 $m^2$ | $m^2$ | 40.49 | 32.01 | 16.97 | Medium | kg $CO_2$e estimates are slightly higher than in the international literature, but not significantly so.<br>Moata ID: 7775 |
| Grassed (mown) swale | 150 $m^2$ | 600 $m^2$ | $m^2$ | 96.81 | 88.33 | - | Medium | Not enough data on sequestration of grass swales to determine a net carbon footprint. The difference in emissions between vegetated and grass swales relates to mowing of grassed swales using diesel tractors.<br>Moata ID: 7577 |
| Concrete box rain garden | 5 $m^2$ | 100 $m^2$ | $m^2$ | 1,477.17 | 1093.73 | 1,334.13 | Medium | The concrete components within the encased rain garden and maintenance inspections needed (irrespective of device size), lead to higher kg $CO_2$e estimates than for a large scale bioretention rain garden.<br>Moata ID: 7055 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Bioretention rain garden | 500 $m^2$ | 10,000 $m^2$ | $m^2$ | 190.23 | 165.61 | 47.19 | Medium | Devices which have a smaller surface area to catchment area ratio (e.g. wetlands and underground filtration devices), tend to have lower emissions on a catchment-treated basis. This relationship is likely caused by the predominating effect of long term maintenance activities on the total emissions. However, further modelling of various devices sizes for each intervention is needed to reduce uncertainty and confirm this relationship.<br>Bioretention rain garden Moata ID: 7057<br>Wetland Moata ID: 8113 |
| Wetland | 5,000 $m^2$ | 19 ha (70% impervious) | $m^2$ | 80.51 | 48.16 | 42.50 | Medium-High | |
| Rain tank | 5,000 L | 5 $m^3$ | $m^3$ | 0.76 | 0.45 | 0.76 | Medium | Based on a rainwater reuse tank. Approximately 65% of the kg $CO_2e$ emissions relate to maintenance activities.<br>Moata ID: 7592 |
| Rain tank | 10,000 L | 10 $m^3$ | $m^3$ | 0.49 | 0.27 | 0.49 | Medium | Based on a rainwater reuse tank. Approximately 60% of the kg $CO_2e$ emissions relate to maintenance activities.<br>Moata ID: 7785 |
| Filtration device | 20 $m^2$ | 6,300 $m^2$ | $m^2$ | 1,830.11 | 974.47 | 1,830.11 | Low | Based on catchment area treated, filtration devices have relatively low kg $CO_2e$ emission estimates as they have a small surface area to catchment area ratio. However, based on device surface area, their carbon footprint is the highest of all the devices modelled. Given that the underground filtration device is a generic 'hybrid' of various types of filtration devices, modelling results have a low level of confidence.<br>Moata ID: 8059 |
| Permeable paving | 75 $m^2$ | 75 $m^2$ | $m^2$ | 741.41 | 543.50 | 741.41 | Low | Due to the unknowns with respect to frequency and quantity of replacement of permeable pavers over the life cycle, the level of confidence in the Moata permeable paving model is low.<br>Moata ID: 7578 |
| Street sweeping | - | - | km | 2.45 | | 2.45 | Low | Relates to per km of kerb swept. No literature or data was available on $CO_2e$ emissions resulting from street sweeping, and no $CO_2e$ emission factor was found for street sweeper |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | | trucks, thus leading to a low level of confidence in the carbon emissions generated.<br><br>Moata ID: 7826 |

[1] See Appendix 5: Urban intervention carbon model assumptions for a full breakdown of assumptions for each of the LCA carbon models

# 7 Recommendations

This study, which has described and quantified life cycle $CO_2$e emissions for various urban and rural stormwater interventions, is the first of its kind in New Zealand. Resultantly, there are a number of areas where further research and modelling is needed to refine assumptions and reduce uncertainty.

## 7.1 Rural

For the rural $CO_2$e LCA emissions where the Moata model has been used, it is recommended that further sensitivity analysis is undertaken to better understand the models and their limitations:

- The influence of a design changes based on the productivity loss of the land converted to the mitigation type.
- The influence of design differences to increase the surface area to catchment ratio.It is recommended that further research into rural wetlands and their total carbon impact is undertaken.

The existing estimate is detailed with several assumptions particularly around their carbon sequestration potential and the emissions from the wetland (outside of the embodied carbon in the construction and maintenance phases). This research would support the refinement of the carbon impact estimate for a rural wetland which would contribute to farmers and growers understanding of their options to reduce on-farm emissions to meet our greenhouse gas reduction targets.

For rural LCA emissions that were calculated using variable studies and their relative regions, it is recommended that further study is undertaken. This research would enable greater understanding of the variables contributing to the carbon impact of these mitigations specific to the Auckland region.

## 7.2 Urban

For the urban $CO_2$e life cycle emissions, further modelling of various devices sizes for each intervention is needed in order to confirm the influence of long term maintenance activities on LCA emissions and whether an inverse relationship exists between device size and $CO_2$e emissions (as with the LCC models). Additionally, to account for uncertainty within the model predictions (relating to differences in construction methodology, materials, maintenance activities and frequencies) it is recommended that low and high emission scenarios are modelled to provide an 'envelope' of potential LCA emissions for a range of device sizes.

Further sensitivity analysis is also recommended to increase confidence in the model results and better understand the sensitivity of the models to:

- the influence of distances travelled and types of vehicles on the LCA $CO_2$e emissions (electric vs petrol vehicles or mowers);
- the influence of design changes which could reduce concrete components or increase the surface area to catchment area ratio;
- the influence of changes to routine maintenance frequencies and activities on the overall LCA $CO_2$e emissions.

Furthermore, it is recommended that further modelling of treatment trains of interventions in series be undertaken. This is needed to ascertain whether or not combinations of smaller devices would have lower emissions than single larger devices. It would also assist in understanding whether devices (such as a vegetated swale), being used for pre-treatment, could reduce emissions from downstream devices resulting from reduced maintenance requirements.

With respect to the sequestration rates used within this report, it is recommended that monitoring of the relevant stormwater interventions be undertaken to develop local sequestration values and ground-truth the international averages used here.

Finally, it is recommended that the findings of the suggested further modelling be used to inform potential changes to future design guidance for relevant stormwater management devices.

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# 9 References


Ag Matters. (2022). *Dairy.* Retrieved from https://www.agmatters.nz/farm-types/dairy/

Ag Matters. (2023). *Trees and vegetation.* Retrieved from https://www.agmatters.nz/actions/planting-trees/

Andrew, R.M. and Vesely, E.T. (2008). Life-cycle energy and CO2 analysis of stormwater treatment devices. *Water Science & Technology*—WST | 58.5 | 2008.

Auckland Council. (2017). *Stormwater management devices in the Auckland region*. Retrieved from www.aucklandcouncil.govt.nz/UnitaryPlanDocuments/mir-stormwater-management-devices-auckland-region.pdf

Ausseil, A.-G. E., Jamali, H., Clarkson, B. R. & Golubiewski, N. E., (2015). Soil carbon stocks in wetlands of New Zealand and impact of land conversion since European settlement. Wetlands Ecol Manage.

Bambic, D., Riverson, J., Stephens, T., Kpodonu, T., Brown, N., Clark, C. & Judd, H. (2020). Freshwater Management Tool" Rivers Current State. Paradigm and Morphum Client Report for Healthy Waters (Auckland Council). In prep.

Basher, L., Djanibekov, U., Soliman,T. & Walsh, P. (2019). Les Basher, Utkur Djanibekov, Tarek Soliman, Patrick Walsh. National modelling of impacts of proposed sediment attributes: literature review and feasibility study. A report prepared for the Ministry for the Environment. 68p.

Bixler, T. S., Houle, J. Ballestero, J. and Mo, W. (2019). A dynamic life cycle assessment of green infrastructures. *Science of the Total Environment* 692 (2019) 1146–1154

Burrows, L., Easdale, T., Wakelin, S., Quinn, J., Graham, E. & Mackay, A. (2018). *Carbon sequestration potential of non-ETS land on farms*. Retrieved from https://www.mpi.govt.nz/dmsdocument/32134-Carbon-sequestration-potential-of-non-ETS-land-on-farms-Sep18-FINAL

Cannell, M.G.R. (1998). Growing trees to sequester carbon in the UK. Forestry Vol. 72, No. 3. 237-247.

Casal-Campos, G. Fu, D. Butler. (2013). The whole life carbon footprint of green infrastructure: A call for integration. *Novatech 2013 - 8th International Conference on planning and technologies for sustainable management of Water in the City*, Jun 2013, Lyon, France. hal-03303470

Case, B. & Ryan, C. (2020). An analysis of carbon stocks and net carbon position for New Zealand sheep and beef farmland. https://beeflambnz.com/sites/default/files/news-docs/BL_Carbon_report_for_review_final_submit.pdf

Daigneault, A. & Elliott, S. (2017). Land-use Contaminant Loads and Mitigation Costs. https://motu-www.motu.org.nz/wpapers/17_10.pdf

Daigneault, A., Elliott, S., Greenhalgh, S., Kerr, S., Lou, E., Murphy, L., Timar, L. & Wadhwa, S. (2017). *Modelling the potential impact of New Zealand's freshwater reforms on land-based Greenhouse Gas emissions.* (2017). https://ageconsearch.umn.edu/record/290516/

DairyNZ Economics Group. (2014). *Waikato Dairy Farm Nitrogen Mitigation Impacts: Analysis of Waipa-Franklin and Upper Waikato Dairy Farms.* Retrieved from http://waikatocivildefence.govt.nz/assets/WRC/Council/Policy-and-Plans/HR/S32/C/3231728.pdf

Dodd, M., Rennie, M., Kirschbaum, M., Giltrap, D., Smiley, D. & van der Weerden, T. (2021). Improving the economic and environmental performance of a New Zealand hill country farm catchment:

4. Greenhouse gas and carbon stock implications of land management change, New Zealand Journal of Agricultural Research, 64:4, 540-564, DOI: 10.1080/00288233.2020.1775656

Doole, G. (2015). Description of mitigation options defined within the economic model for Healthy Rivers Wai Ora Project. Report No. HR/TLG/2015-2016/4.6

Fathollahi, A and Coupe, S.J. (2021). Life cycle assessment (LCA) and life cycle costing (LCC) of road drainage systems for sustainability evaluation: Quantifying the contribution of different life cycle phases. *Science of the Total Environment* 776 (2021) 145937

Getter, K.L., Row, D.B., Robertson, D.P.Cregg, B.M and Andresen, J.A. (2009). Carbon Sequestration Potential of Extensive Green Roofs. *Environ. Sci. Technol*. 2009, 43, 7564–7570

USDA. (2013). *Grassland Carbon Management.* Retrieved from https://www.fs.usda.gov/ccrc/topics/grassland-carbon-management

Horticulture New Zealand. (n.d.). *Soil and drainage management guide.* Retrieved from http://agrilink.co.nz/wp-content/uploads/2016/10/SoilDrainageMgmtGuide_PrinterFriendly.pdf

Intergovernmental Panel on Climate Change. (2006). *2006 IPCC Guidelines for National Greenhouse Gas Inventories* (Chapter 6). Retrieved from https://planning.lacity.org/eir/8150Sunset/References/4.E.%20Greenhouse%20Gas%20Emissions/GHG.27_IPCC%20National%20GHG%20Inventories.pdf

Ira S., Walsh P. & Batstone C. (2021). *Freshwater management tool: report 9. A total economic valuation approach to understanding costs and benefits of intervention scenarios – Part 1 Urban Devices*. Prepared by Koru Environmental, Manaaki Whenua Landcare Research and Batstone Associates for Auckland Council.

Ira, S. (2021). *Freshwater management tool: report 10. A total economic valuation approach to understanding costs and benefits of intervention scenarios – Part 2 Urban Source Control Costs*. Prepared by Koru Environmental for Auckland Council.

Jiahong Liu, Jia Wang, Xiangyi Ding, Weiwei Shao, Chao Mei, Zejin Li, Kaibo Wang. (2020). Assessing the mitigation of greenhouse gas emissions from a green infrastructure-based urban drainage system. *Applied Energy* 278 (2020). 115686

Journeaux, P., van Reenan, E. & Batley, L. (2021). *Review of Models Calculating Farm Level GHG Emissions. Prepared for He Waka Eke Noa*. Retrieved November 3, 2022, from https://hewakaekenoa.nz/wp-content/uploads/2021/03/GHG-Model-Assessment-Report-25-March.pdf

Journeaux, P., van Reenan, E. & Batley, L. (2021). *Review of Models Calculating Farm Level GHG Emissions #2 (2nd update).* Prepared for He Waka Eke Noa. Retrieved October 7, 2022, from https://hewakaekenoa.nz/wp-content/uploads/2022/09/Updated-Review-of-Models-Calculating-Farm-Level-GHG-Emissions-Sep-2022.pdf

Kavehei, E., Jenkins, G.A., Adame, M.F. and, Lemckert, C. (2018). Carbon sequestration potential for mitigating the carbon footprint of green stormwater infrastructure. *Renewable and Sustainable Energy Reviews* 94 (2018) 1179–1191

Levine, B. (2020). *The ability of detainment bunds to mitigate the impact of pastoral agriculture on surface water quality in the Lake Rotorua catchment: a thesis presented in partial fulfilment of the requirements for the degree of Doctor of Philosophy in Soil Science, Palmerston North, New Zealand* (Doctoral dissertation, Massey University). Retrieved from https://atlas.boprc.govt.nz/api/v1/edms/document/A3767993/content

Levine, B., Burkitt, L., Horne, D., Tanner, C., Sukias, J., Condron, L. & Paterson, J. (2021). The ability of detainment bunds to decrease sediments transported from pastoral catchments in surface runoff. *Hydrological Processes*, *35*(8), e14309.

Limpert, K. E., Carnell, P. E., Trevathan-Tackett, S. M. & Macreadie, P. I. (2020). Reducing emissions from degraded floodplain wetlands. *Frontiers in Environmental Science, 8, 8.*

Lin, X., Ren, J., Xu, J., Zheng, T., Cheng, W., Qiao, J., Huang, J., et al. (2018). Prediction of Life Cycle Carbon Emissions of Sponge City Projects: A Case Study in Shanghai, China. *Sustainability*, 10(11), 3978. MDPI AG. Retrieved from http://dx.doi.org/10.3390/su10113978

Mathers D. (2017). Part C: Farm Case Studies- Arable. In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

Matheson, L., Djanibekov, U., Bird, B. & Greenhalgh, S. (2018). Economic and contaminant loss impacts on farm and orchard systems of mitigation bundles to address sediment and other freshwater contaminants in the Rangitāiki and Kaituna-Pongakawa-Waitahanui water management areas. Final report, forming delivery for Milestone 2A, 2B, 2C & 2D. Version 1.3. 109 pages

Matheson, L. & Muller, C. (2020). Case Study 9: Pa-iti. Integrating dairy and hill country farming with forestry for profitable and sustainable land use. Report prepared by Perrin Ag Consultants Ltd for Te Uru Rākau. December 2020. 71 pages

Mithraratne, M. (n.d.). *Carbon footprint of green roofs in Singapore*. Research done for the National University of Singapore

Ministry for Primary Industries. (2017). *Carbon Look-up Tables for forestry in the Emissions Trading Scheme.* Retrieved from https://www.mpi.govt.nz/forestry/forestry-in-the-emissions-trading-scheme/emissions-returns-and-carbon-units-nzus-for-forestry/calculating-the-amount-of-carbon-in-your-forest-land/carbon-tables-for-calculating-carbon/

Ministry for the Environment. (2014). *New Zealand's Greenhouse Gas Inventory 1990-2011*. Retrieved from https://environment.govt.nz/assets/Publications/Files/greenhouse-gas-inventory-2013.pdf

Ministry for the Environment. (2021). *New Zealand's Greenhouse Gas Inventory 1990-2019*. Retrieved from https://environment.govt.nz/publications/new-zealands-greenhouse-gas-inventory-1990-2019/

Ministry for the Environment. (2022). *Te Rārangi Haurehu Kati Mahana a Aotearoa New Zealand's Greenhouse Gas Inventory 1990-2020.* Retrieved from https://environment.govt.nz/assets/publications/GhG-Inventory/New-Zealand-Greenhouse-Gas-Inventory-1990-2020-Chapters-1-15.pdf

Moore , T. and Hunt, W. (2013). Predicting the carbon footprint of urban stormwater infrastructure. *Ecological Engineering* 58 (2013) 44–51

Muller, C. & Stephens, T. (2020). Riparian area management scenarios for inclusion in Auckland Council's Fresh Water Management Tool- Stage 1. Final report for Auckland Council. 50 pages

Muller, C., Ira, S. & Stephens, T. (2020). Lifecycle Costs and Benefits for Rural Mitigations in Freshwater Management Tool. Final report for Auckland Council.

Muller, C., Stephens, T. & Ira, S. (2022). Addendum to- Lifecycle Costs and Benefits for Rural Mitigations in Freshwater Management Tool. Final report for Auckland Council.

Ministry for the Environment. (2021). *New Zealand's Greenhouse Gas Inventory 1990–2019*. Wellington: Ministry for the Environment.

Mott MacDonald. (2023). *Development of the New Zealand Stormwater Library for the Moata Carbon Portal.* Report for Auckland Council.

Newman, M. & Muller, C. (2017). Part C: Farm Case Studies- Dairy. In: The Southland Economic Project: Agriculture and Forestry. (Eds.: Moran, E., Pearson, L., Couldrey, M., and Eyre, K.) Technical Report. Publication no. 201904. Environment Southland, Invercargill, New Zealand.

NIWA. (2010). Waikato River Independent Scoping Study. NIWA, Hamilton, HAM2010-032

O'Sullivan, A.D., Wicke, D., Hengen, T.J., Sieverding, H.L. and Stone, J.J. (2015). Life Cycle Assessment modelling of stormwater treatment systems. *Journal of Environmental Management* 149 (2015) 236-244

Parkyn, S. (2004). *Review of riparian buffer zone effectiveness* (Vol. 2005). Wellington, New Zealand: Ministry of Agriculture and Forestry.

Pattle Delamore Partners. (2021). *Carbon Sequestration of Green Infrastructure*. Report for Auckland Council.

Picek, T., Čížková, H. & Dušek, J. (2007). Greenhouse gas emissions from a constructed wetland—plants as important sources of carbon. *Ecological engineering*, 31(2), 98-106.

Rutherford, J. C. & Nguyen. M. L. (2004). Nitrate removal in riparian wetlands: Interactions between surface flow and soils. Journal of Environmental Quality 33(3): 1133-1143.

Rutherford, J. C., Schroer, D. & Timpany, G. (2009). How much runoff do riparian wetlands affect? New Zealand Journal of Marine and Freshwater Research 43: 1079-1094.

Rutherford, J. C. (2017). Review of Nitrogen Attenuation in New Zealand Seepage Wetlands. NIWA Client Report 2017241HN.

Schipper, L. & McLeod, M. (2002). Subsidence rates and carbon loss in peat soils following conversion to pasture in the Waikato Region, New Zealand. Soil Use and Management, 18(2), 91-93.

Simmonds, K., Ferris, L., Austin, D., Madison, M. and Emond, H. (n.d.). *The Humble Wetland – A Carbon Superhero?* Water New Zealand conference paper.

The Agribusiness Group. (2014). Nutrient Performance and Financial Analysis of Lower Waikato Horticulture Growers. Prepared for Waikato Regional Council, Ministry of Primary Industries and HortNZ. Retrieved from http://www.hortnz.co.nz/assets/Uploads/nutrient-performance-and-financial-analysis-of-lower-waikato-horticulture.pdf

Urban Insight. (n.d.). *Carbon Cost in Infrastructure*. SWECO

Whiting, G., & Chanton, J. (2001). Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration. Tellus B, 53(5), 521-528.

Whiting, G., & Chanton, J. (2001). Greenhouse carbon balance of wetlands: methane emission versus carbon sequestration, Tellus B: Chemical and Physical Meteorology, 53:5, 521-528, DOI: 10.3402/tellusb.v53i5.16628

Zhang, L., B. K. Wylie, L. Ji, T. G. Gilmanov, L. L. Tieszen, and D. M. Howard (2011). Upscaling carbon fluxes over the Great Plains grasslands: Sinks and sources, J. Geophys. Res., 116, G00J03, doi:10.1029/2010JG001504

# 10 Appendices

## 10.1 Appendix 1: Rural intervention assets assumptions for wetlands (<1 ha and >1 ha) detainment bund, sediment retention pond and riparian planting

Moata consists of a series of carbon emission factor libraries based on national and international research and focusses specifically on the water sector (i.e. stormwater, wastewater and water supply). The libraries and assets within Moata were searched for projects and emission factors which could be representative of the rural FWMT detainment bund mitigation throughout their life cycle (i.e. including maintenance and renewals). The assets that were decided were based on suitability and applicability to actual device.

**Table 34:** Wetland (<1 ha and <1 ha) assets and related assumptions

| | Source of carbon | Assets | Type of asset | Assumptions |
|---|---|---|---|---|
| **Earthworks construction** | Earthworks | Topsoil Clearance & Stockpiling | Process | Assume 750 $m^3$ to uplift 150 mm thick topsoil and stockpile to site. |
| | | Fill from stockpile on site | Process | Assume 750 $m^3$ of topsoil is spread back on top of wetland after construction. |
| | Bulk excavation | Bulk excavation to stockpile on site | Process | Bulk excavation of 8,660 $m^3$ soil, trim and shape of wetland bays and embankments. |
| | Cut & Fill | Bulk excavation to stockpile on site | Process | Cut and fill of wetland levels, assume 403 $m^3$. |
| | | Fill from stockpile on site | Process | |
| | Site Clearing | Vegetation clearance | Process | Removal of existing pasture/vegetation. Assume 5,000 $m^3$. |
| | Other | Underdrain pipe | Physical | Assume 150 kg HDPE plastic pipe. |
| | | Travel | Maintenance | Assume 30 km travel for "2 in a ute" with an emissions factor of 0.28 kg $CO_2e$. |
| | | Silt fence | Process | Assume 1 m high silt fence, 200 m length. Erosion control during construction. |
| | | Grassing | Physical | Assume 450 $m^2$ of hydroseed required to stabilise outside berm areas and exposed areas. |
| | Roading | Crushed Rock | Process | Assumes 120 $m^3$ of crushed gravel to enable access for machinery. |
| **Planting** | Travel | Diesel | Maintenance | Assume three trips required with a total of 18 L, two trips for plants and one trip for trees. |
| | | Travel "2 in a ute" | Maintenance | Assume 30 km travel. |

| | Source of carbon | Assets | Type of asset | Assumptions |
|---|---|---|---|---|
| **Stormwater** | Physical | Stormwater | Maintenance | Assume 600 kg weight of compactor and 30 km travel radius (two ways). Vibratory roller with 600 mm compactor drum. |
| | | Rip rap (driver=wingwall pipe diameter) | Physical | Includes geotextile lining, riprap and excavation. Transport distance is 30km. |
| | | Scruffy dome | Physical | High profile scruffy dome. Includes the excavation and reinstatement of the paved surface, manhole riser, channel type A, Kerb block S and galvanised steel dome screen. Transport distance is 30 km. |
| | | Stormwater pipe | Physical | Pipe transport to site, Excavation, Plant, Backfill and reinstatement. Commissioning, material disposal. |
| | | Manhole | Physical | Excavation, backfill, reinstatement, base, wall and roof materials, DI cover. Includes construction of manhole in precast rings including access, benching, covers, earthworks and craneage. - Excludes: flow diversions, temporary works, inlet/ outlet pipework, weirs, valves and square man holes material composition: precast concrete. |
| | | Inlet/outlet concrete wingwall | Physical | Includes the inlet wingwall, single pipe outlet only. Concrete wingwall. Excludes riprap apron. Also includes extra concrete to seal around the pipe inlet/outlet, amount determined as 150 mm thick and pipe diameter + 150 mm in each dimension minus pipe diameter. Transport distance is 30 km. |
| | | Concrete Spillway | Physical | Assume 1% of wetland area at 0.3 m thickness. |
| **Maintenance** | Travel | Travel “2 in a ute” | Maintenance | Assume 30 km travel. |
| | | Trimming, Weeding & Vegetation Maintenance | Maintenance | Assume 1kg of waste per 100 $m^2$ of wetland from weeding/pruning. |
| | Establishment | Planting Aftercare | Maintenance | Assume bi-annual for five years. |

**Table 35:** Assets comprising Detainment Bund in Moata and related assumptions

| | Asset | Assumptions |
|---|---|---|
| **Construction & Renewal** | Type 1 Scruffy Dome in field | Includes the excavation and backfill of the field, manhole riser, channel type A, Kerb block S and galvanised steel dome screen. Transport distance is 30 km |
| | Pipework-Rigid-(above ground) - GRP<=750. | Includes the pipe material (used and wastage) and pipe transport to site. Excludes installation, commissioning and material disposal as these are considered minimal and not relevant in above ground inter-process pipework.<br>Assumptions: No transport included. 5% pipe material wastage. (Source: Above Ground Pipework tab). |
| | Bulk excavation to stockpile on site. | Assume excavated soil will be used to create bund with spillway to outlet. |
| | Rock | Assumes 1 $m^3$ rock based on average required prevent erosion around outlet for 300 mm diameter pipe. |
| | Geotextile | 130 $m^2$ material to cover bund at height of 3.5 m and width of 26 m on surface. |
| | Fencing | Treated wooden batten posts at 5 m centres, height 1.40 m, 8 wire, 4 mm. |
| | Planting (05: low maintenance; 0.04 kg/m2) | UK Highways: Maintenance Works V2<br>Based on models Mott MacDonald developed using traceable sources (ICE v3.0) relating to materials and plant used on highways engineering projects according to the HWY4 method of measurement. Contains a mix of items which are materials only, plant only or materials and plant. |
| **Maintenance** | Diesel | Assume 30 km travel radium and fuel consumption of 10 litres per 100 km. Assume annual maintenance over LCA, excluding years 1 and 50. |
| | Bulk excavation to stockpile on site | Assume 30% of bund capacity is excavated annually for maintenance. |

**Table 36:** Assets comprising sediment retention pond built in Moata and related assumptions

| | Asset | Assumptions |
|---|---|---|
| **Construction & Renewal** | Plastics - HDPE Pipe | Assume 10kg pipe based on Novoflo 30 m pipe. |
| | Geotextile | Geotextile material liner to prevent erosion of the sediment retention pond 130m$^2$. |
| | Rock | Assume 1m$^3$ to prevent erosion at pipe outlet. |
| | Bulk excavation to stockpile on site | Assumes material disposed on site and utilised for another part of the farm. |
| **Maintenance** | Diesel | Assumes 30 km travel radius and fuel consumption of 10 L per 100km. Assume annual maintenance over LCA, excluding years 1 and 50. |
| | Bulk excavation to stockpile on site | Assume 30% of bund capacity is excavated annually for maintenance. |

**Table 37:** Assets comprising riparian planting built in Moata and related assumptions

| | Asset | Assumptions |
|---|---|---|
| **Construction & Renewal** | N/A | |
| **Maintenance** | Diesel | Assumes 3 0km travel radius and fuel consumption of 10 L per 100km. Assume annual maintenance over LCA, excluding years 1 and 50. |
| | Bulk excavation to stockpile on site | Assume 30% of bund capacity is excavated annually for maintenance. |

## 10.2 Appendix 2: MfE Agricultural Emissions Calculator Raw Data for Dairy Bundles (for 118 ha farm)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 828.6 emitted | None | None | **828.6** emitted |
| Manure management | 81.6 emitted | 5.3 emitted | None | **86.9** emitted |
| Agri soils | None | 171.3 emitted | None | **171.3** emitted |
| Fertiliser use | None | 47.6 emitted | 21.8 emitted | **69.4** emitted |
| Forests | None | None | None | None |
| **Totals** | **910.2** emitted | **224.2** emitted | **21.8** emitted | **1156.2** emitted |

**Figure 20:** Dairy Mitigation bundles base carbon impact (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 774.3 emitted | None | None | **774.3** emitted |
| Manure management | 76.3 emitted | 4.9 emitted | None | **81.2** emitted |
| Agri soils | None | 160.1 emitted | None | **160.1** emitted |
| Fertiliser use | None | 24.6 emitted | 11.3 emitted | **35.9** emitted |
| Forests | None | None | None | None |
| **Totals** | **850.6** emitted | **189.6** emitted | **11.3** emitted | **1051.4** emitted |

**Figure 21:** Dairy Mitigation bundle M2 carbon impact (MfE Agricultural Emissions Calculator)

## Yearly emissions breakdown
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 747.1 emitted | None | None | 747.1 emitted |
| Manure management | 73.6 emitted | 4.8 emitted | None | 78.3 emitted |
| Agri soils | None | 154.4 emitted | None | 154.4 emitted |
| Fertiliser use | None | 11.9 emitted | 5.5 emitted | 17.4 emitted |
| Forests | None | None | None | None |
| **Totals** | **820.7** emitted | **171.1** emitted | **5.5** emitted | **997.3** emitted |

**Figure 22:** Dairy Mitigation bundle M3 carbon impact (MfE Agricultural Emissions Calculator)

## 10.3 Appendix 3: MfE Agricultural Emissions Calculator Raw Data for Sheep & Beef Bundles

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1635.2 emitted | None | None | **1635.2** emitted |
| Manure management | 21.1 emitted | None | None | **21.1** emitted |
| Agri soils | None | 249.9 emitted | None | **249.9** emitted |
| Fertiliser use | None | 54.8 emitted | 25.1 emitted | **80** emitted |
| Forests | None | None | None | None |
| **Totals** | **1656.2** emitted | **304.7** emitted | **25.1** emitted | **1986.1** emitted |

**Figure 23:** Sheep & Beef Mitigation bundles base & M1 carbon impact for 584 ha farm [<10SU/ha] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1611.2 emitted | None | None | **1611.2** emitted |
| Manure management | 20.3 emitted | None | None | **20.3** emitted |
| Agri soils | None | 236.9 emitted | None | **236.9** emitted |
| Fertiliser use | None | 25.2 emitted | 11.6 emitted | **36.8** emitted |
| Forests | None | None | None | None |
| **Totals** | **1631.5** emitted | **262.1** emitted | **11.6** emitted | **1905.2** emitted |

**Figure 24:** Sheep & Beef M2 carbon impact [<10SU/ha] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1611.2 emitted | None | None | 1611.2 emitted |
| Manure management | 20.3 emitted | None | None | 20.3 emitted |
| Agri soils | None | 236.9 emitted | None | 236.9 emitted |
| Fertiliser use | None | 10.1 emitted | 4.6 emitted | 14.7 emitted |
| Forests | None | None | None | None |
| **Totals** | 1631.5 emitted | 247 emitted | 4.6 emitted | 1883.1 emitted |

**Figure 25:** Sheep & Beef M3 carbon impact [<10SU/ha] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1128.5 emitted | None | None | 1128.5 emitted |
| Manure management | 54.9 emitted | 3.1 emitted | None | 57.9 emitted |
| Agri soils | None | 178 emitted | None | 178 emitted |
| Fertiliser use | None | 10.1 emitted | 4.6 emitted | 14.8 emitted |
| Forests | None | None | None | None |
| **Totals** | 1183.3 emitted | 191.2 emitted | 4.6 emitted | 1379.2 emitted |

**Figure 26:** Sheep & Beef Mitigation bundles base & M1 carbon impact [>10SU/ha] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1065.2 emitted | None | None | **1065.2** emitted |
| Manure management | 44.6 emitted | 2.4 emitted | None | **47** emitted |
| Agri soils | None | 159.7 emitted | None | **159.7** emitted |
| Fertiliser use | None | 10.1 emitted | 4.6 emitted | **14.8** emitted |
| Forests | None | None | None | None |
| **Totals** | **1109.8** emitted | **172.2** emitted | **4.6** emitted | **1286.7** emitted |

**Figure 27:** Sheep & Beef M2 carbon impact [>10SU/ha] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | 1065.2 emitted | None | None | **1065.2** emitted |
| Manure management | 44.6 emitted | 2.4 emitted | None | **47** emitted |
| Agri soils | None | 159.7 emitted | None | **159.7** emitted |
| Fertiliser use | None | 4.1 emitted | 1.9 emitted | **5.9** emitted |
| Forests | None | None | None | None |
| **Totals** | **1109.8** emitted | **166.2** emitted | **1.9** emitted | **1277.8** emitted |

**Figure 28:** Sheep & Beef M3 carbon impact [>10SU/ha] (MfE Agricultural Emissions Calculator)

## 10.4 Appendix 4: MfE Agricultural Emissions Calculator Raw Data for Horticultural Bundles

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 1 emitted | 0.5 emitted | **1.5** emitted |
| Forests | None | None | None | None |
| **Totals** | None | **1** emitted | **0.5** emitted | **1.5** emitted |

**Figure 29:** Horticultural bundles base [low and medium impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 0.9 emitted | 0.4 emitted | **1.3** emitted |
| Forests | None | None | None | None |
| **Totals** | None | **0.9** emitted | **0.4** emitted | **1.3** emitted |

**Figure 30:** Horticultural bundles M1 [low and medium impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 0.5 emitted | 0.2 emitted | **0.7** emitted |
| Forests | None | None | None | None |
| **Totals** | None | **0.5** emitted | **0.2** emitted | **0.7** emitted |

**Figure 31:** Horticultural bundles M2 [low and medium impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 0.3 emitted | 0.2 emitted | **0.5** emitted |
| Forests | None | None | None | None |
| **Totals** | None | **0.3** emitted | **0.2** emitted | **0.5** emitted |

**Figure 32:** Horticultural bundles M3 [low and medium impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 0.8 emitted | 0.4 emitted | 1.2 emitted |
| Forests | None | None | None | None |
| **Totals** | None | **0.8** emitted | **0.4** emitted | **1.2** emitted |

**Figure 33:** Horticultural bundles base and M1 [high impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| Digestion | None | None | None | None |
| Manure management | None | None | None | None |
| Agri soils | None | None | None | None |
| Fertiliser use | None | 0.7 emitted | 0.3 emitted | 1.1 emitted |
| Forests | None | None | None | None |
| **Totals** | None | **0.7** emitted | **0.3** emitted | **1.1** emitted |

**Figure 34:** Horticultural bundles M2 [high impact] (MfE Agricultural Emissions Calculator)

**Yearly emissions breakdown**
(tonnes $CO_2$-e per year)

| Source | Methane tonnes $CO_2$-e | Nitrous oxide tonnes $CO_2$-e | Carbon dioxide tonnes | Total tonnes $CO_2$-e |
|---|---|---|---|---|
| **Digestion** | None | None | None | None |
| **Manure management** | None | None | None | None |
| **Agri soils** | None | None | None | None |
| **Fertiliser use** | None | 0.7 emitted | 0.3 emitted | **1** emitted |
| **Forests** | None | None | None | None |
| **Totals** | None | **0.7** emitted | **0.3** emitted | **1** emitted |

**Figure 35:** Horticultural bundles M3 [high impact] (MfE Agricultural Emissions Calculator)

## 10.5 Appendix 5: Urban intervention carbon model assumptions

### Table 38: Moata model assumptions for green roofs

| Embodied Carbon (Construction) | | | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Green roof (200m2) | | | Continuous Living Roof - 45.35 kg CO2 eq/m2 | Based on international literature which provided a mean embodied carbon between 36.7 and 58 kg CO2 eq/m2 |
| | | | | |
| **MAINTENANCE COSTS** | | | | |
| **Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspections (planted zone including all edges; overflows and drainage points, irrigation) (allows for working at heights certification). | 3 | labour cost per hr | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Mowing of sedum-based roof garden (not lawn mowing) | 2 | per m2 | n/a | n/a |
| Weeding / pruning / fertilizing/ edge, drain and overflow clearance (low rate - standard landscaper) | 1 | labour cost per day | Vegetation Clearance: 842.01.01.01.01<br>Garden Waste Disposal NZ_MfE_2022_766 | Assumes 25% of roof cleared per event<br>Assumed 1kg of waste per 10m2 of roof cleared |
| Weeding pruning /fertilizing/ edge, drain and overflow clearance (high rate - working at heights certification) | 2 | labour cost per day | | |
| | | | | |
| **Additional RMC** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Additional visits for initial Aftercare of Plants (for first 3 years): | 3 | per m2 | Vegetation Clearance: 842.01.01.01.01<br>Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br>Garden Waste Disposal NZ_MfE_2022_766 | Assumes 25% of roof cleared per event<br>Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br>Assumed 1kg of waste per 10m2 of roof cleared |
| | | | | |
| **Corrective Maintenance** | **Frequency (No. of Yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Corrective Maintenance Repair Costs (plants/ media) | 25 | per m2 | | |
| Corrective maintenance Repair Costs (perimeter drainage edges and overflow mulch topping up/replacement) (estimate based on roof perimeter) | 15 | lump sum | As per construction emission factor. | Assumes 10% of of roof area to be replaced at construction emission rate. |
| Corrective Maintenance Repair Costs (under-drainage layer) (estimate 0.25 of roof) | 25 | per m2 | HDPE Impermeable Liner: | Felicioni et al., 2023 (assumes 25% of roof area) |
| Working at Heights Certification | 3 | per course | n/a | n/a |
| Council Inspections – cost to private green roofs | 3 | per inspection | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| | | | | |
| **COMPLETE RENEWAL COST** | **Frequency (No. of yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| End of life renewal | 50 | | As per construction emissions | As per construction emissions |

## **Table 39:** Moata model assumptions for swales

| Embodied Carbon | | | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Constructed drained swale (30m) | | | Swale design from Moata Library: NZ_STORMWATER_82. | Inclusions - Excavation, backfill and replanting of vegetation on slopes. Exclusions - Any other works not within cradle to built asset boundary. |

| MAINTENANCE ACTIVITIES | | | | |
|---|---|---|---|---|
| **Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Assumption** | **Carbon Trigger** |
| Routine General Maintenance for grass swale (tractor mowing, edge-spraying or trimming, weeding). | 6 | m2 | Diesel: NZ_MfE_2022_34 - assumes fuel consumption of 3.5L/hour | Tractor mower |
| Routine General Maintenance for planted swale in perennial vegeation (maintaining healthy vegetation cover, weeding, edge trimming, mulch replacement). | 3 | hr | 01: Vegetation Clearance - 842.01.01.01.01<br>Garden Waste - NZ_MfE_2022_766<br>Custom component: Travel - "2 in a ute" petrol ute post 2015 fleet: Assume 30km of travel. Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Vegetation clearance, weeding and waste.<br>Travel to site. |
| Inspections (inlets for scour, ruts and preferential flow, debris, outlets, integrity of swale/ dispersed flow) and removing debris/ litter and sediment (e.g. From inlet or overflow structures) | 2 | per swale | General Waste: NZ_MfE_2022_748<br>Travel: as above | Debris clearance<br>Travel for inspections |
| Deciduous Trees - sweep and remove leaves | 2 | hr | | |

| Routine Maintenance | Frequency (Per Yr) | Unit | Assumption | Carbon Trigger |
|---|---|---|---|---|
| Additional maintenance during the establishment period | 3 | hr | 05: low maintenance; 0.04 kg/m2:<br>1272.02.01.10.05 assume quarter replanting<br>Garden Waste - NZ_MfE_2022_766<br>Custom component: Travel - "2 in a ute" petrol ute post 2015 fleet: Assume 30km of travel. Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Vegetation clearance, weeding and waste.<br>Travel to site. |

| Corrective Maintenance | Frequency (No. of Yrs) | Unit | Assumption | Carbon Trigger |
|---|---|---|---|---|
| Maintaining even, dispersed flow - removing accumulated sediment; regrading, filling and decompaction to remove tyre ruts or scoured areas | 25 | per 100m of swale | Topsoil: NZ_STORMWATER_109 (assumes replacement of top 100mm)<br>Excavation disposed at tip site (includes travel): NZ_STORMWATER_3<br>05: low maintenance, 0.04kg/m2: 1272.02.01.10.05 | Materials, disposal and travel |
| Disposal of sediment to landfill | 25 | m3 | | |
| Re-grassing (assume turf mat or coir/wool seeded mats used given swale is online) | 25 | m2 | | |
| Replanting - plugs with coir/wool erosion mat (high amenity has 9 plugs/m2 or larger plants, low amenity has 4 plugs/m2 with no large plants) | 25 | m2 | | |
| Replanting/ grassing (where road closures are required) | 25 | m2 | | |
| Minor repairs to inlet or outlet structures | 10 | per 100m of swale | Rip rap: NZ_STORMWATER_99<br>Type 1 Scruffy Dome in field: NZ_STORMWATER_68 (assume 1% of total construction emmissions)<br>Concrete inlet/ outlet wingwall: Z_STORMWATER_65 (assume 1% of total construction emmissions)<br>Kerb replacement of 5m: CR_1025<br>Travel: as above | Materials and travel associated with repair of structures. |
| Replacement of bollards (discontinous kerbing) | 10 | per 10m | | |
| Replacement of underdrain | 25 | m | Geotextile: NZ_STORMWATER_101 (assumes a 110mm dia pipe)<br>Plastics HDPE Pipe: ICEV2.180 (Novaflo 30m = 10kg)<br>Excavation to stockpile on site: NZ_STORMWATER_2 | Materials and travel associated with replacement of underdrains. |

| Renewal | Frequency (No. of yrs) | Unit | Assumption | Carbon Function/ Trigger |
|---|---|---|---|---|
| End of life renewal | 50 | per m2 | Swale design from Moata Library: NZ_STORMWATER_82. | Inclusions - Excavation, backfill and replanting of vegetation on slopes. Exclusions - Any other works not within cradle to built asset boundary. |

**Table 40:** Moata model assumptions for rain gardens

| Embodied Carbon (Construction) | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|
| Rain garden (5m2) | Raingarden Design from Moata: NZ_STORMWATER_81<br>Type 1 Scruffy Dome in field: NZ_STORMWATER_68<br>Plastics - HDPE Pipe: ICEV2.180 (assumes Novaflo 30m = 10kg) | Model is of a single raingarden cell, model includes 3x1.5m precast conrete raingarden surround, excavation, backfill, raingarden soil mix backfill, planting, lining, and rock and sand layer. Assumed transport distance of 30 km. The installation of underdrain and overflow structure are excluded from the model. |
| Rain garden (500m2) | NZ_STORMWATER_8 | Fill / Fill from stockpile on site |
| | NZ_STORMWATER_2 | Excavation / Bulk excavation to stockpile on site / 20% stockpiled and spread on site |
| | NZ_STORMWATER_3 | Excavation / Bulk excavation disposed at tip site / Assume 80% material disposed off site |
| | ICEV2.180 | Plastics / Plastics - HDPE Pipe / Based on Novaflo 30m = 10kg |
| | NZ_STORMWATER_109 | Surfacing / Topsoil / 0.6m x 500m2 topsoil - to be used for the biofiltration media |
| | NZ_Water_v2_17 | Filtration / Filter - Sand / Sand layer 0.2m |
| | NZ_STORMWATER_100 | Surfacing / Hardfill / Drainage layer 0.1m |
| | NZ_STORMWATER_101 | Geotextile lining |
| | NZ_STORMWATER_99 | Surfacing / Rock for rip rap erosion protection |
| | NZ_STORMWATER_111 | Surfacing / Mulch / 0.2m mulch layer |
| | NZ_STORMWATER_96 | Surfacing / Planting |
| | NZ_STORMWATER_68 | Inlet/Outlet / Type 1 Scruffy Dome in field |
| | NZ_STORMWATER_89 | Surfacing / Kerb and Channel / Assume square RG with one side facing road needing kerb and channel |
| | NZ_MfE_2022_34 | Diesel / Diesel / Assumes 30km travel radius and fuel consumption of 10L/100km - Media |
| | NZ_MfE_2022_34 | Diesel / Diesel / Assumes 30km travel radius and fuel consumption of 10L/100km - gravels |
| | NZ_MfE_2022_34 | Diesel / Diesel / Assumes 30km travel radius and fuel consumption of 10L/100km - plants + mulch |

**Table 40** (cont): Moata model assumptions for rain gardens

| MAINTENANCE ACTIVITIES | | | | |
|---|---|---|---|---|
| **Establishment Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| **Initial aftercare of plants (first 3 years)** | 4 | m2 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br>NZ_MfE_2022_766<br>842.01.01.01.01 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br>Garden waste to landfill, assumes 0.5kg of waste per 1m2 of raingarden from weeding/pruning.<br>01: vegetation clearance (assumes ~1/3 of raingarden to be cleared) |
| **Initial aftercare of tree pits (first 3 years)** | | | | |
| Checking stakes/supports and then their removal where required | 3 | m2 | N/A | N/A |
| May need fertilisation in sandy and large rain gardens in clean catchments (note: if high-fertilty-requiring trees less than 4 m tall are planted, then double to twice per year, using slow-release fertilisers/ organic mulch amended with compost) | 1 | m2 | N/A | N/A |
| 24 monthly pruning for first 6 years to develop healthy structural form and lift canopy to required sight lines | 1 | m2 | N/A | N/A |
| **Routine Landscape Maintenance:** | | | | |
| Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.<br>It includes up to 5% replanting or remulching (especially at inlets and edges).<br>It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity. | 4 | m2 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br>NZ_MfE_2022_766<br>842.01.01.01.01 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br>Garden waste to landfill, assumes 0.5kg of waste per 1m2 of raingarden from weeding/pruning.<br>01: vegetation clearance (assumes ~1/3 of raingarden to be cleared) |
| **Functional Drainage Maintenance:** | | | | |
| Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.<br>Flush out drainage. | 4 | per RG | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| **Traffic Control Costs:** | | | N/A | N/A |
| TMPs and traffic lane closure (static or mobile works) | 8 | m2 | N/A | N/A |
| **Unstabilised Sites:**<br>Removal & disposal of sediments (including replacement with new media) + cartage - top 10mm of rain garden media | 1 | m3 | N/A | N/A |

| **Ongoing Annual Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
|---|---|---|---|---|
| **Routine Landscape Maintenance:** | | | | |
| Maintaining vegetation in 'Functional' status is ensuring plants are trimmed to ensure inflows, overflows and outflows are clear to the extent design capacity is maintained.<br>It includes up to 5% replanting or remulching (especially at inlets and edges).<br>It does not include trimming vegetation infringing on footpaths or roads more than once per annum due to poor plant selection or placement, or higher amenity. | 3 | m2 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br>NZ_MfE_2022_766<br>842.01.01.01.01 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br>1kg removal per 1m2<br>One third of RG to be weeded at a time |
| **Functional Drainage Maintenance:** | | | | |
| Inspections (for debris, inlets, outlets, overflows, integrity of biofilter) and clearance of debris at inlets.<br>Flush out drainage. | 3 | per RG | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br>NZ_MfE_2022_748 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br>1kg removal of general waste to landfill per m2 - 1/3 of RG surface area |
| **Traffic Control Costs:** | | | | |
| TMPs and traffic lane closure (static or mobile works) | 3 | m2 | N/A | N/A |
| **Minor repairs:** | | | | |
| Repairs to grills on outlets/ inlets; additional soil/ mulch needed; erosion | 1 | per RG | Debris Screen:<br>NZ_STORMWATER_70<br>Rock:<br>NZ_STORMWATER_99 | Assumes 1% of construction cost for repairs<br>Erosion protection/ rip rap replacement: |
| **Make good following vandalism:** | | | | |
| Relates to primarily vegetation and graffiti removal | 2 | per RG | Debris Screen:<br>NZ_STORMWATER_70 | Assumes 1% of construction cost for 'repairs' |

**Table 40** (cont): Moata model assumptions for rain gardens

| Long Term Corrective Maintenance | Frequency (No. of Yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Additional mitigative actions:<br>- Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation.<br>- Removal of deciduous leaves from inlets/overflows and preventing deciduous leaves smothering groundcover vegetation.<br>- Additional trimming of vegetation around signs or lights (services and signage should not be placed in raingardens).<br>- Removing dead vegetation due to ponding because of incorrect rain garden mix or poor outlet design. | 5 | m2 | Landfilling of General Waste:<br>NZ_MfE_2022_748 | 1kg removal per m2 (assume ~1/3 of total surface area) |
| Fixing erosion of outlets due to poor slope control or undersized rain gardens. | 5 | m2 | Planting:<br>NZ_STORMWATER_96<br><br>Rock:<br>NZ_STORMWATER_99 | Includes replanting and replacing rip rap. |
| Removal & disposal of sediments (including replacement with new media) + cartage - top 10mm of rain garden media | 5 | m3 | Bulk excavation disposed at tip site<br>NZ_STORMWATER_3<br><br>Topsoil:<br>NZ_STORMWATER_109<br><br>Mulch:<br>NZ_STORMWATER_111 | Assume 100mm removal across entire surface area<br><br>Assume 100mm removal across entire surface area |
| TMPs and traffic lane closure (static or mobile works) | 5 | m2 | N/A | |
| Infiltration Testing (if needed) | 4 | per test | N/A | |
| Removal & disposal of sediments (including replacement with new media) + cartage | 50 | m3 | N/A | Not included as covered by renewal. |
| Complete replanting | 50 | m2 | N/A | Not included as covered by renewal. |
| Major maintenance of drainage system, eg replacement of parts | 15 | per RG | Fill from stockpile onsite:<br>NZ_STORMWATER_8<br><br>Bulk excavation to stockpile on site:<br>NZ_STORMWATER_2<br><br>Geotextile:<br>NZ_STORMWATER_101<br><br>Plastics - HDPE Pipe:<br>ICEV2.180 | Assumes that some level of earthworks needed, and entire geotextile and underdrain needs to be replaced (assumed Novaflo 30m = 10kg). |

| RENEWAL EMISSIONS | Frequency (No. of yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| End of life renewal | 50 | per m2 | As per construction emissions | As per construction emissions |

## Table 41: Moata model assumptions for wetlands

| ITEM | DESCRIPTION | UNIT | QUANTITY | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|---|
| **Quantity estimation for a 5000 m2 wetland construction** | | | | | |
| 1 | **PRELIMINARY & GENERAL** | | | | |
| 1.1 | Site Establishment | | | | |
| | Including stabilised construction entrance, site offices, stabilised parking facilities for personnel & visitors and storage facilities. Position of site facilities to be confirmed with client | LS | 1 | | |
| 1.2 | Setting-Out All Works | LS | 1 | | |
| 1.3 | Insurance & Bonds | LS | 1 | | |
| 1.4 | Site Specific Health & Safety Plan | LS | 1 | | |
| 1.5 | Contract Administration & Management | LS | 1 | | |
| 1.6 | Construction Management & Plan | LS | 1 | | |
| 1.7 | Quality Management Plan | LS | 1 | | |
| 1.8 | Supervision & Administration | LS | 1 | | |
| 1.9 | Environmental Management & Plan | LS | 1 | N/A | N/A |
| 1.10 | Traffic Management (Overall) | LS | 1 | | |
| 1.11 | Traffic Management (Construction Entrance) | LS | 1 | | |
| 1.12 | Site Security | LS | 1 | | |
| 1.13 | Existing Services (Locate, Expose & Protect) | LS | 1 | | |
| 1.14 | As-built Records | | | | |
| | (Including as-built surveys, as-built drawings (CAD & PDF) signed off by a licensed/registered surveyor, and all QA Checklists according to specifications & requirements). | LS | 1 | | |
| 1.15 | Producer statements | LS | 1 | | |
| 1.16 | Site disestablishment | LS | 1 | | |
| 1.17 | Unscheduled Items | | | | |
| | Temporary orange mesh fencing | m | 450 | NZ_ISCAv2.0.4_LCI.2021.42 | HDPE: Assumes 1 x 450m of fencing, at a weight of 8 kg per 50m of length as per product CP-SM160-A. |
| 2 | **WETLAND: SITE CLEARANCE, ESC, EARTHWORKS & PLANTING** | | | | |
| 2.1 | Site Clearing (including vegetation) | LS | 1 | 1272.01.01.01 & NZ_MfE_2022_766 | 01: vegetation clearing & garden waste: UK Highways: Maintenance Works V2<br>Based on models Mott MacDonald developed using traceable sources (ICE v3.0) relating to materials and plant used on highways. |
| 2.2 | Erosion and sediment control | | | | |
| 2.2.1 | Install Silt Fence (TP90 Spec) (Assuming one of the long sides required) | m | 200 | NZ_Stormwater_101 | Geotextile Fabric: Assumes 1m high silt fence, 200m length |
| 2.2.2 | Install Clean Water Diversion Bund (Assuming one of the long sides required) | m | 200 | NZ_STORMWATER_2 | Bulk excavation to stockpile on site (200m long, 0.5m high) |
| 2.2.3 | Maintenance of all sediment & Erosion control measures | LS | 1 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| 2.2.4 | Removal of all sediment & erosion control measures | LS | 1 | BEIS_2021_1.33 | Based on HDPE Orange fencing weight |
| 2.2.5 | Water Cart for Dust Suppression (Earthworks) | Hr | 90 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Towable water cart behind a ute: Assumes 90hrs of operation at 20kmph, a petrol ute towing a 1000-2000L cart. |
| 2.2.6 | Water Cart for Other Use | Hr | 20 | N/A | |
| 2.2.7 | Dewatering (Pumping) with 75 mm pump | Hr | | | |
| 2.3 | Earthworks | | | | |
| 2.3.1 | Topsoil - Uplift topsoil (150mm thick) & stockpile on site | m3 | 750 | NZ_Stormwater_1 | Topsoil Clearance & Stockpiling |
| 2.3.2 | Pre & post topo survey to confirm uplifted topsoil areas & volumes | LS | 1 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| 2.3.3 | Cut / Bulk Excavation of wetland to design levels & stockpile | m3 | 3660 | NZ_Stormwater_3 | Bulk excavation disposed at tip site |
| 2.3.4 | Pre & post topo survey to confirm cut / bulk excavation volume | LS | 1 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Assume ute for travel to site for surveys. |
| 2.3.5 | Install 150mm diameter subsoil drain around wetland perimeter | m | 450 | ICEV2.180 | Plastics - HDPE: Based on Novaflo 30m = 10kg |
| 2.3.6 | Cut to Fill & compact from general earthworks | m3 | 403 | NZ_Stormwater_2 & NZ _Stormwater_8 | Bulk excavation to stockpile & Fill from stockpile onsite |
| 2.3.7 | Trim and shape wetland bays and embankments | m2 | 5000 | NZ_Stormwater_2 | Fill from stockpile onsite - used for trimming and shaping wetland bays and embankments |
| 2.3.8 | Replace topsoil (150mm thick) in Wetland as planting media from stockpile on site | m3 | 750 | NZ_Stormwater_8 | Fill from stockpile onsite |
| 2.3.9 | Hydroseeding of wetland outside berm areas & exposed areas | m2 | 450 | 842.02.01.10.05 | 05: low maintenance 0.04kg/m2 - UK Highways: Maintenance Works V2 |
| 2.3.10 | Mulch stabilisation (Provisional Item) on Wetland berm areas & exposed areas | m2 | 450 | N/A Provisional Item not included | |
| 2.3.11 | Disposal of excess material to an approved dumping site to be identified by the contractor. | m3 | 3660 | NZ_Stormwater_3 | Bulk excavation disposed at tip site |
| 2.4 | Planting | | | | |
| 2.4.1 | Aquatic species | | | | |
| 2.4.1.1 | Baumea articulata (Jointed Twig Rush) | No | 294 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.1.2 | Eleocharis sphacelata (Kuta) | No | 294 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.1.3 | Schoenoplectus tabernaemontani | No | 294 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.1.4 | Juncus edgariae | No | 294 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.1.5 | Juncus pallidus | No | 294 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.2 | Aquatic Edge Species | | | | |
| 2.4.2.1 | Carex virgata (Purei) | No | 989 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.2.2 | Carex lessoniana (Rautahi) | No | 989 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.3 | Aquatic Wetland Margin Species | | | | |
| 2.4.3.1 | Carex virgata (Purei) | No | 593 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.3.2 | Carex lessoniana (Rautahi) | No | 510 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.3.3 | Cordyline australis (Cabbage Tree) | No | 19 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.3.4 | Cyperus ustulatus (Giant Umbrella Sedge) | No | 340 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.4 | Edge Planting | | | | |
| 2.4.4.1 | Apodasmia simili (Oioi) | No | 1360 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.5 | Type A: Batter & Boundary Planting | | | | |
| 2.4.5.1 | Muehlenbeckia complexa (Groundcover) | No | 804 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.5.2 | Phormium cookainum | No | 939 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.4.5.3 | Apodasmia similis(Oioi) | No | 626 | 1272.03.01.01.05 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 |
| 2.5.6 | Trees | | | | |
| 2.5.6.1 | Prunus 'Shirotae' (Flowering Cherry) | No | 4 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.2 | Podocarpus totara (Totara) | No | 13 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.3 | Dacrycarpus dacrydoides (Kahikatea) | No | 11 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.4 | Liquidamber 'Worplesdon' (Sweet Gum) | No | 7 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.5 | Quercus coccinea (Oak Tree) | No | 6 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.6 | Platanus acerfolia (Plane Tree) | No | 8 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| 2.5.6.7 | Platanus acerfolia (Plane Tree) | No | 8 | 1272.03.01.01.01 | 01: trees; standard - PC GBP 30.00 per Nr |
| | Transporting of plants | | | NZ_MfE_2022_34 | 6L assumed for one trip, two trips needed for plants. |
| | Transporting of trees | | | NZ_MfE_2022_34 | 6L assumed for one trip, one trip needed for plants. |
| 3 | **ROADING AND PAVEMENTS** | | | | |
| 3.1 | Maintenance access | | | | |
| 3.1.1 | Trim and compact subgrade material for access track (as per design and testing criteria) | m2 | 800 | NZ_MfE_2022_34<br>NZ_MfE_2020_382 | Assume, vibratory roller with 600mm compactor drum, travelling at 1.0kmph, compacting an 800m2 area, 1.5L/km fuel consumption.<br>Plus urban delivery truck: Assumes 600kg weight of compactor and 30km travel radius (two ways) |
| 3.1.2 | Subgrade: Under channel drainage | m | 150 | ICEV2.180<br>1392.06.01.03.01 | Plastics - HDPE: Based on Novaflo 30m = 10kg.<br>Level spreading of material |
| 3.1.3 | Supply, lay & place 150mm thick GAP65 sub-base material | m3 | 120 | NZ_ISCAv2.0.4_LCI.2021.5 | Crushed Rock: Assumes 120m3 of GAP 65 + 11t = 7.1m3 |
| 3.1.4 | Construction of 150mm 30MPa concrete with 5kg/m3 -10kg/m3 black oxide with one centrally placed layer of 665 steel reinforcing | m2 | 800 | NZ_STORMWATER_107 &<br>NZ_ISCAv2.0.4_LCI.2021.123 | Concrete: Assumes 800m2 and 0.3m thickness<br>Reinforced Steel Mesh: Assumes 35kg per 12m2 effective |
| 4 | **STORMWATER** | | | | |
| 4.1 | Inlet structure | | | | |
| 4.1.1 | 1500 mm manhole (Includes excavation, backfilling, benching, chanles, steps and connection to pipes) | No | 1 | NZ_Stormwater_51 | Circular Pre-cast Manhole, Road/paved path, depth 2-4m |
| 4.1.2 | Stormwater pipe (675 mm Concrete pipe) | m | 20 | NZ_Stormwater_27 | Opencut Pre-cast - Field, DN 225-1800, depth 2-4m |
| 4.1.3 | Inlet structure (Wingwalls) | No | 1 | NZ_Stormwater_65 | Inlet concrete Wingwall |
| 4.2 | Outlet structure | | | | |
| 4.2.1 | 1050 mm manhole (Includes excavation, backfilling, benching, chanles, steps and connection to pipes) including a scruffy dome | No | 1 | NZ_Stormwater_51 & NZ_Stormwater_66 | Type 1 Scruffy Dome in Paved surface and Circular Pre-cast Manhole, Road/paved path, depth 2-4m |
| 4.2.2 | Stormwater pipe (675 mm Concrete pipe) | m | 20 | NZ_Stormwater_27 | Opencut Pre-cast - Field, DN 225-1800, depth 2-4m |
| 4.2.3 | Outlet structure (Wingwalls and riprap) | No | 1 | NZ_Stormwater_65<br>NZ_Stormwater_71 | Outlet concrete Wingwall<br>Rip rap (driver = wingwall pipe diameter) |
| 4.3 | 150mm water pump for major groundwater pumping as directed by the engineer | Hr | 100 | NZ_MfE_2022_9 | Diesel - To operate 150 mm water pump, assume fuel consumption of 1.5l/hr for 100 hrs. |
| 4.4 | Emergency overflow spillway, concrete apron | No | 1 | NZ_Stormwater_107 | Concrete - Assumes 1% of wetland area (in absense of flow information) at 0.3m thickness. |

## **Table 41** (cont): Moata model assumptions for rain gardens

| Establishment Maintenance | Frequency (Per Yr) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Additional visits for initial Aftercare of Plants (for first 5 years): includes initial tree form prune and canopy lift to retain de | 2 | m2 | NZ_MfE_2022_766 | Garden waste to landfill, assumes 1kg of waste per 100m2 of wetland from weeding/pruning. |
| | | | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| | | | 1272.03.01.01.01 | Replacement of trees/ plants |
| Asset handover maintenance (for first 2 years) | 2 | per visit | | |

| Routine Maintenance | Frequency (Per Yr) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Routine General Maintenance (line trimming/lifting, mowing, maintaining healthy vegetation cover, removing litter) | 4 | per visit | NZ_MfE_2022_766 | Garden waste to landfill, assumes 1kg of waste per 100m2 of wetland from weeding/pruning. |
| Removing debris (eg litter, dead vegetation) from outlet and inlet /forebay structures | 4 | per wetland | NZ_MfE_2022_748 | General Waste: Assume 0.2kg removal per m2 |
| Inspections (Weeds, QA, inspection of embankments, spillways, outfalls, overall functioning of facility, integrity of fences | 12 | per visit | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Scheduled Mechanical Inspections (pumps, outlets, removing mosquito breeding areas) | 1 | per wetland | | |
| Additional inspections (significant events) | 0.5 | per visit | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Aquatic weed management | 1 | m2 | NZ_MfE_2022_766 | Garden waste to landfill, assumes 1kg of waste per 100m2 of wetland from weeding/pruning. |

*mowing relates to access tracks only - other mowing is associated with non-functional components of wetland.

| Corrective Maintenance | Frequency (No. of Yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Cleaning of debris/ litter after significant events | 10 | per wetland | NZ_MfE_2022_748 | General Waste: Assume 0.2kg removal per m2 |
| Terrestrial weed management | 10 | per wetland | 1272.01.01.01.01 | 01: vegetation clearance - Assumes 20% of wetland surface area as terrestrial |
| Corrective Structural Maintenance (repairs to pumps, concrete components, dam embankments/baffles, erosion) | 10 | per wetland | NZ_STORMWATER_65<br>NZ_STORMWATER_71<br>NZ_STORMWATER_107<br>NZ_STORMWATER_7<br>Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Inlet/ Outlet wingwall - Assumes 1% of material cost.<br>Rip rap - Assumes 1% of concrete volume for surface repairs.<br>Concrete - Assumes 1% of concrete volume for surface repairs.<br>Erosion redemediation - fill from imported material. Assumes 1m3 of fill per 100m2 of wetland.<br>Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Replacement of parts (grates, trash screens) | 20 | per wetland | NZ_STORMWATER_66<br>NZ_MfE_2022_34 (diesel) | Type 1 Scruffy Dome in paved surface - replacement.<br>Travel - Diesel: assumes 30km travel radius and fuel consumption of 10L/100km. |
| Replanting the wetland zone | 50 | m2 | N/A due to renewal at 50 years | |
| Reseeding/ landscaping disturbed terrestrial area | 25 | m2 | 1272.03.01.01.05<br>NZ_MfE_2022_34 | 05: emergent, mariginal and aquatic plants; PC GBP 4.50 each<br>6L assumed for one trip, one trip needed for plants. |
| Desilting and disposal of sediment from forebay | 25 | m3 | NZ_STORMWATER_3 | Bulk excavation disposed of at a tip: assume desilting of a sediment with a depth of 0.5m |
| Desilting and disposal of sediment from main pond | 50 | m3 | N/A due to renewal at 50 years | |

| Renewal | Frequency (No. of yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| End of life renewal | 50 | per m2 | As per construction emissions | As per construction emissions |

## **Table 42:** Moata model assumptions for rain tanks

| Embodied Carbon (Construction) | | | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Rain Tank (5,000L and 10,000L) | | | Rain tank - PE:<br>NZ_Stormwater_77<br><br>Bulk excavation disposed at tip site:<br>NZ_Stormwater_3<br><br>Multistage Pump:<br>EQU - PMP - 211.14N<br><br>Concrete:<br>NZ_Stormwater_107<br><br>Traffic Management Vehicle:<br>Diesel, NZ_MfE_2022_34 | Equivalent to concrete volume (see below)<br><br>Assumes a 1.1 kW motorcapacity and does not include electricity consumption.<br><br>Concrete Pad, assume 1.75 diameter, therefore 2.3 x 2.3 and 150mm thick<br><br>Assumes 30km travel radius and fuel consumption of 10L/100km |
| | | | | |
| **MAINTENANCE ACTIVITIES** | | | | |
| **Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspection of tank, orifice outlet, pipework, first flush device, pest screens, erosion protection. Inspection of electrical parts. Maintenance of screens/ filters. Clean out as necessary. Check surrounding area for overhanging branches/ nuisance potential. | 1 | per inspection | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br><br>General Waste:<br>NZ_MfE_2022_758<br><br>Waste - Garden:<br>NZ_MfE_2022_751 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br><br>Assumes 0.0001kg per litre tank volume for both garden and general waste |
| | | | | |
| **Corrective Maintenance** | **Frequency (No. of Yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Maintenance of filters, pumps, etc | 5 | per tank | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Replacement of water supply pump | 15 | per pump | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br><br>Multistage Pump:<br>EQU - PMP - 211.14N | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br><br>Assumes a 1.1 kW motorcapacity and does not include electricity consumption. |
| Minor Repairs to concrete and structural components (eg sealing cracks; tank stand; etc) | 15 | per tank | 01: Caulking; PC4AF:<br>1542.05.07.04.01 | Concrete repairs using caulk to seal cracks |
| Council Inspections – cost to private rain tanks | 3 | per inspection | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| | | | | |
| **COMPLETE RENEWAL COST** | **Frequency (No. of yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| End of life renewal | 25 | per m2 | As per construction emissions | As per construction emissions |

**Table 43:** Moata model assumptions for permeable paving

| Embodied Carbon (Construction) | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|
| Permeable Paving (75m2) | Pervious Paving: NZ_Stormwater_84 | Inclusions - Excavation, geotextile layers and labour required to lay permeable paving. Exclusions - Any other works not within cradle to built asset boundary. |

| MAINTENANCE COSTS | | | | |
|---|---|---|---|---|
| **Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspections and regular cleaning of organic sediments and debris. Includes yearly clean for weed/ moss control. NB to ensure inspections co-incide with storm events to check drainage function. | 4 | per driveway | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br><br>Garden Waste: NZ_MfE_2022_766 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br><br>10% surface area cleaned/disposed. 1m2 = 1kg |
| Minor repairs | 1 | per driveway | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br><br>Pervious Paving: NZ_Stormwater_84 | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br><br>Assumes minor repairs = 1% of construction cost. |

| Corrective Maintenance | Frequency (No. of Yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Cleanout sediment, oils, etc and removal of top layer of stone and re-establishment (top up joint chip or sand between pavers) | 5 | m3 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Top-up of low fines joint mix | 5 | m2 | Sand: NZ_ISCAv2.0.4_LCI.2021.10 | Replacement of top 100mm across the driveway. Used 1.6 conversion factor m3 to tonnes for sand. |
| Disposal of unsuitables | 5 | m3 | Bulk excavation to tip site: NZ_Stormwater_3 | Assumes top 100mm excavated across full surface area of device. |
| Replacement of permeable pavers (if necessary)* | 15 | m2 | Pervious Paving: NZ_Stormwater_84 | Assumes 35% replaced every 15 years i.e. 35% of total construction cost. |
| Uplift pavers, replace sand and bedding | 15 | m2 | n/a | n/a |
| Erosion repair | 5 | per driveway | n/a | n/a |

*35% of pavers to be replaced every 15 yrs

| COMPLETE RENEWAL COST | Frequency (No. of yrs) | Unit | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| End of life renewal | 50 | per m2 | As per construction emissions | As per construction emissions |

**Table 44:** Moata model assumptions for an underground filtration device

| Embodied Carbon (Construction) | | | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Filtration Device (20m2 surface area, 1 ha area treated) | | | Underground Infiltration Chamber: NZ_Stormwater_86<br><br>Outlet to SW Network: Opencut PE- SDR17 - Field, depth 0-2m: NZ_STORMWATER_20<br><br>Inlet to sandfilter: Opencut PE- SDR17 - Field, depth 0-2m: NZ_STORMWATER_20<br><br>Circular Per-cast Manhole, Road/paved path, depth 0-2m: NZ_Stormwater_50<br><br>Bulk excavation to stockpile onsite:<br><br>Fill from stockpile onsite: NZ_Stormwater_8 | Assume 20m x 1m, but sand bed is 75% of footprint area (sedimentation chamber is min 25%)<br><br>Assumes 150 mm diameter<br><br>Assumes 500 mm diameter<br><br>Assumes 1 per 10 m2<br><br>Additional excavation needed for sedimentation chamber and surrounds to sand filter)<br><br>Assumes 100% of excavated material filled in. |
| | | | | |
| **MAINTENANCE COSTS** | | | | |
| **Routine Maintenance** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspections | 2 | per device | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Yearly maintenance clean | 1 | per m2 | Bulk excavation disposed at tip site: NZ_STORMWATER_3 | Disposal of 200mm sediment in across base of sedimentation chamber |
| TM solutions (road closure - mobile solution) | 1 | per device | Traffic Management Vehicle: Diesel, NZ_MfE_2022_34 | Assumes 30km travel radius and fuel consumption of 10L/100km |
| | | | | |
| **Additional Clean/ Inspection at Vesting (RMC)** | **Frequency (Per Yr)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspection for vesting | 1 | per device | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Initial maintenance clean | 1 | per m2 | Bulk excavation disposed at tip site: NZ_STORMWATER_3<br><br>Traffic Management Vehicle: Diesel, NZ_MfE_2022_34 | Disposal of 200mm sediment in across base of sedimentation chamber<br><br>Assumes 30km travel radius and fuel consumption of 10L/100km (traffic management) |
| | | | | |
| **Corrective Maintenance** | **Frequency (No. of Yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| For sand filters: Cleaning of treatment devices (sediment removal (top layer); disposal; etc) | 10 | per device | Sand: NZ_ISCAv2.0.4_LCI.2021.10<br><br>Bulk excavation disposed at tip site: NZ_STORMWATER_3<br><br>Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Replacement of sand. 1.6 conversion factor m3 to tonnes for sand<br><br>Disposal of 200mm sediment in across base of sedimentation chamber + top 200mm of sand filter<br><br>Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| TM solutions (road closure - mobile solution) | 10 | per device | Traffic Management Vehicle: Diesel, NZ_MfE_2022_34 | Assumes 30km travel radius and fuel consumption of 10L/100km |
| | | | | |
| **COMPLETE RENEWAL COST** | **Frequency (No. of yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| End of life renewal | 50 | | As per construction emissions | As per construction emissions |

**Table 45:** Moata model assumptions for inert roofs

| Embodied Carbon (Construction) | | | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|---|
| Inert roof (200m2) | | | Traffic Management Vehicle: Diesel, NZ_MfE_2022_34<br><br>Colorsteel Maxx 0.4 mm BMT (NZ Steel): BRANZ MS012 | Assumes 30km travel radius and fuel consumption of 10L/100km |
| | | | | |
| **Corrective Maintenance** | **Frequency (No. of Yrs)** | **Unit** | **Carbon Emissions Identifier** | **Description/ Assumptions** |
| Inspection and removal of moss/ lichen/ clean | 3 | per device | Electricity used: NZ_MfE_2022_55<br><br>Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc | Pressure washer for roof cleaning, assumes electrical unit operating at 1.5 kWh.<br><br>Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel. |
| Repainting/ touch-ups | 15 | m2 | Source - Emission Factors Guidance, MFE Aug 2022 LCV - petrol, 2000-3000cc<br><br>01: Zinc Coated or aluminium surfaces; 300 x 200mm access hatch and frame in wall; poainting one side | Travel - "2 in a ute" - Petrol (post 2015 fleet): Assume 30km of travel.<br><br>Assumes painting/touch-up of 90% of the roof |
| Replacement | 25 | m2 | Traffic Management Vehicle: Diesel, NZ_MfE_2022_34<br><br>Colorsteel Maxx 0.4 mm BMT (NZ Steel): BRANZ MS012 | Assumes 30km travel radius and fuel consumption of 10L/100km<br><br>Assumes complete replacement of roof with construction material. The same weight and size. |
| Removal and disposal of old roof | 25 | per 1t | Waste disposal - construction - metals - landfill: BEIS_2021_1.18 | Disposal of old roof to landfill |
| Scaffolding | 25 | per building | n/a | Temporary, and transport included in replacement item. |

**Table 46:** Moata model assumptions for street sweeping

| Ongoing Maintenance | Unit Per Day | Carbon Emissions Identifier | Description/ Assumptions |
|---|---|---|---|
| Street sweeping (truck) | 35 km | NZ_MfE_2022_669 | 10,000 - 12,000 kg truck as for a surrogate street sweeper |
| Disposal of sediments | 3.5 t | BEIS_2021_1.2 | Waste Disposal - construction - soils to landfill |