Carbon Footprint Comparison:

Vacuum, Gravity and Low Pressure Sewer Systems

Case Study: Fishermans Bay Vacuum Sewer System, South Australia

Flovac Vacuum Sewerage Systems Pty Ltd | June 2026
400 Dwellings | 4-System Comparison | 50-Year Carbon Study
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Why Carbon Footprint Matters in Sewer Infrastructure

Infrastructure engineers make decisions that last. A sewer system designed and built today will still be operating in 2055, 2065, and in many cases beyond. The carbon generated during its construction, embedded in its components, and consumed in its daily operation is not a theoretical concern — it is a real and measurable consequence of the technology choices made at the options assessment stage. Those choices, once made, are locked in for the life of the asset.

Until recently, carbon was largely absent from infrastructure options assessments. Financial whole-of-life cost analysis has been standard practice for decades, and it captures operating cost, maintenance cycles, and capital replacement reasonably well. But financial cost and carbon cost are not the same thing, and a comparison that optimises for one does not necessarily optimise for the other. An options assessment that is rigorous on cost but silent on carbon is giving its client an incomplete picture.

That is changing. Carbon disclosure requirements, net zero commitments from state and local governments, and the increasing integration of embodied carbon into planning and procurement frameworks mean that engineers who can speak to carbon in an options assessment are now better equipped to serve their clients than those who cannot. This is not a future requirement. It is a present one.

Carbon in the Built Environment

The built environment — buildings, infrastructure, transport — is responsible for approximately 40 percent of global carbon emissions. Within that, the construction and operation of infrastructure assets represents a substantial and often underestimated share. In Australia, the infrastructure sector accounts for approximately 20 percent of national greenhouse gas emissions when construction activity, embedded materials, and operational energy are combined.

Water and wastewater infrastructure is a particularly significant contributor within the municipal sector. Wastewater collection and treatment is typically the largest single energy consumer in a council or utility's operational portfolio — often representing 30 to 50 percent of total municipal electricity consumption. The technology choice for collection infrastructure does not just affect the utility's electricity bill. It determines the carbon trajectory of that asset for 30 to 50 years from the day it is commissioned.

When an engineer recommends a technology for a new sewer system, they are not making a recommendation about this year's energy cost. They are making a recommendation about the cumulative carbon performance of that infrastructure over its entire operational life — and about the carbon generated in building it. The compounding effect of a higher-carbon technology choice, multiplied across hundreds of dwellings and dozens of years, is material at both the project level and the national level.

What High Carbon Infrastructure Means in Practice

High carbon infrastructure has consequences at three scales that engineers are well placed to understand and communicate.

At the asset scale, high operational carbon typically correlates with higher energy consumption, which correlates with higher operating cost. The relationship is not perfect — carbon intensity varies with grid source and time of use — but over the life of an asset, technologies with higher carbon operational profiles also tend to carry higher operational cost exposure as carbon pricing mechanisms mature. An asset commissioned today with high operational carbon may face increasing cost pressure over its life as the carbon cost of electricity is progressively internalised.

At the community scale, high embodied carbon in construction — from deep excavation, extended dewatering, heavy plant operations, and large concrete structures — has localised environmental impacts beyond the carbon number itself: ground disturbance, dust, noise, traffic from spoil removal, and extended construction programmes affecting residents and businesses. These impacts are not carbon figures, but they are consequences of the same technology choices that drive high construction carbon. They are real costs borne by the communities in which the infrastructure is built.

At the global scale, the aggregate carbon performance of infrastructure decisions contributes directly to national emissions inventories and to Australia's ability to meet its international climate commitments. No individual infrastructure project determines that outcome, but the cumulative effect of thousands of technology choices made by engineers across the country does. Engineers are not passive implementers of technology — they are the professionals whose recommendations determine what gets built and what does not.

> *An engineer who understands carbon is not doing something extra. They are doing their job properly. The carbon performance of an infrastructure asset is an engineering characteristic, like hydraulic capacity or structural load rating. It can be measured, compared, and optimised. This paper provides the framework to do that for sewer collection technology.*

Why Sewer Collection Technology Is Underanalysed

Most carbon attention in the water industry has focused on treatment — the energy intensity of nutrient removal, biosolids processing, aeration systems, and UV disinfection. These are legitimate focuses. Treatment plant energy is large, visible, and metered centrally.

Collection infrastructure has received less attention, for two reasons. First, the operational energy of collection systems is smaller in aggregate than treatment energy — though not negligible. Second, in low pressure systems, operational energy is distributed across hundreds of private electricity accounts and is invisible in the utility's central energy reporting. It exists, and it is material, but it does not show up in the utility's electricity bill. This makes it easy to ignore.

The construction phase carbon of collection infrastructure has received almost no systematic attention. Excavation volumes, dewatering energy, construction duration, concrete volumes for pump station structures, and the carbon cost of extended site operations are rarely quantified in options assessments. They are treated as contractor costs, absorbed into the contract price, and excluded from the technology comparison. On constrained sites — high water table, deep excavation, difficult spoil disposal — this exclusion can mean that the most significant carbon variable in the project is not counted at all.

And the embodied carbon of collection components — particularly the recurring replacement cycle of grinder pump mechanisms in low pressure systems — has to our knowledge never been systematically quantified in an Australian options assessment context. This paper makes a first attempt at doing so, using real project data from a confirmed installation.

What This Paper Enables

After reading this paper, an engineer should be able to do three things that a standard options assessment does not currently support:

- Identify the carbon categories that are missing from a conventional sewer technology comparison — construction phase, distributed operational energy, recurring component embodied carbon, and end-of-life — and understand why they are typically excluded
- Apply a structured carbon lens to a technology options assessment for a new sewer scheme, using the framework and indicative figures presented here as a starting point for site-specific analysis
- Recognise the site conditions — high water table, flat topography, sandy coastal soils, highly variable flows — that make the carbon comparison between technologies most significant, and weight the analysis accordingly

This is not a paper that recommends one technology over another in all circumstances. It is a paper that argues for a more complete assessment framework — one that gives engineers and their clients the full picture, not just the part of the picture that conventional cost analysis captures. The technology recommendation should follow from the evidence. This paper is about making sure the evidence is complete.

Executive Summary

This report presents a carbon footprint comparison across four sewer collection technologies — vacuum sewerage, gravity sewerage with a single pump station, gravity sewerage with three pump stations, and low pressure (grinder pump) sewerage — using confirmed construction and operational data from the Fishermans Bay Vacuum Sewer System in South Australia.

Fishermans Bay serves 400 dwellings on a flat coastal peninsula via 101 Flovac collection chambers, commissioned in 2022. The vacuum system is monitored in real time by the Flovac FMS platform, which provides eleven months of confirmed SCADA operational data. Construction data is drawn from the principal contractor's Design and Construct tender, which records confirmed pipe quantities, trench depths, and construction programme.

Carbon is assessed across four domains: construction phase (excavation, plant, duration, dewatering), embodied carbon in materials and components, operational carbon over a 50-year study life, and end-of-life recyclability. The analysis identifies a fifth domain — site-specific hidden carbon costs including groundwater dewatering and spoil disposal — which is routinely excluded from conventional options studies but which can be the largest single carbon variable on constrained sites.

Principal Findings

Vacuum sewerage produces the lowest total carbon footprint for this class of site across all four domains. The confirmed operational energy of 7,396 kWh per year for 400 dwellings — the entire scheme — is 6.5 times lower than the modelled low pressure alternative and compares favourably with gravity at equivalent hydraulic load.

The low pressure alternative carries the highest embodied carbon of the four technologies. Four hundred grinder pump mechanisms, 400 electrical cabinets, and 400 concrete property pits represent a substantial manufacturing carbon liability at construction. At the 10-year replacement cycle confirmed by major utilities, this liability recurs three times over a 30-year period and nominally four times over 50 years — representing the manufacture and disposal of 1,600 pump mechanisms over the study life.

The gravity alternatives carry higher construction carbon than is commonly recognised. On a flat coastal site such as Fishermans Bay, achieving gravity fall to a single pump station requires trench depths of 3 to 4 metres throughout the network, with active groundwater dewatering for the full construction duration. The confirmed vacuum trench depth of 1.5 metres, requiring no dewatering, represents a significant construction carbon advantage that does not appear in conventional cost comparisons.

The three-station gravity alternative avoids deep trenching but incurs three concrete wet wells, six submersible pump installations, three electrical infrastructure packages, and an operational carbon footprint approximately 30 percent higher than vacuum over the study life due to infiltration-driven pump energy escalation.

> *The carbon costs of groundwater dewatering, extended construction duration, and recurring pump replacement are real. They are generated on real sites. They are simply invisible in the standard options assessment framework. This report makes them visible.*

1. Introduction and Purpose

Whole-of-life cost comparisons between vacuum, gravity, and low pressure sewer systems have been a standard feature of options assessments for several decades. These studies have become increasingly rigorous in their treatment of operating costs, maintenance cycles, and capital replacement — but they have consistently omitted one dimension that is now of direct relevance to engineering clients, utilities, and planning authorities: carbon footprint.

The omission is not difficult to understand. Carbon accounting for infrastructure projects is still maturing as a discipline. Standard options assessment frameworks were developed when energy cost, not carbon content, was the primary measure of resource consumption. The result is that conventional comparative studies capture financial cost reasonably well but give no useful signal about the comparative carbon performance of the technologies under assessment.

This matters for two practical reasons. First, an increasing number of Australian councils, utilities, and development clients have carbon reduction commitments that require them to consider embodied and operational carbon in infrastructure procurement decisions. Second, the carbon comparison between technologies is not always intuitive — and in some cases, the technology that appears most carbon-efficient on a simple energy-consumption comparison is not the lowest-carbon choice once construction phase, embodied materials, and end-of-life are properly accounted for.

1.1 Scope of This Analysis

This report compares four sewer collection technologies across a common site: Fishermans Bay, South Australia, a 400-dwelling flat coastal peninsula with a high seasonal water table. The four technologies are:

- Vacuum sewerage — as built and confirmed at Fishermans Bay
- Gravity sewerage, single pump station — requires 3 to 4 metre trench depths and active dewatering
- Gravity sewerage, three pump stations — achievable at 2 metre depth without dewatering
- Low pressure (grinder pump) sewerage — 400 property-level pump units

Carbon is assessed across four primary domains:

- Construction phase carbon — excavation volumes, plant hours, dewatering, construction duration
- Embodied carbon — materials, components, and their manufacture
- Operational carbon — energy consumption over a 50-year study life
- End-of-life carbon — component recyclability and disposal

A fifth domain — site-specific hidden carbon — is treated separately. This covers carbon costs that are generated on real projects but excluded from standard assessments: groundwater dewatering, spoil disposal haulage, and extended construction site operations. The Fishermans Bay site provides a documented example of each.

1.2 Data Sources

All vacuum system data is drawn from confirmed sources. Construction quantities are from the principal contractor's Design and Construct tender document (April 2021). Operational energy is confirmed from SCADA run-hour data across eleven months of operation. Comparison technologies are modelled for the same site using standard engineering practice, published industry benchmarks, and the site-specific constraints documented in the design records.

Carbon emission factors for electricity consumption use the Australian National Greenhouse Accounts factor for South Australia. Embodied carbon figures for materials use published lifecycle assessment data from the Australasian EPD programme and the GBCA embodied carbon framework. Where ranges exist, conservative (lower) values are used for vacuum system inputs and conservative (higher) values for comparison technologies, to ensure the analysis does not overstate the vacuum advantage.

2. Site Description and System Overview

Fishermans Bay is a coastal holiday community on the Yorke Peninsula, South Australia, administered by the District Council of Barunga West. The site is a flat sandy peninsula, elevation 2.1 to 3.5 metres AHD, with water on three sides and a high seasonal water table. The community of approximately 400 dwellings is predominantly a holiday destination, generating highly variable sewage flows — peak January flows are substantially higher than mid-winter flows, with the community largely unoccupied for extended periods outside the holiday season.

These site characteristics — flat topography, high water table, sandy coastal soils, highly variable seasonal flows — define the carbon performance of each technology option. They are not incidental features of this particular site; they are representative of a broad class of coastal and low-lying development sites across Australia, New Zealand, and internationally where vacuum sewerage is routinely considered.

2.1 The Vacuum System as Built

The Fishermans Bay vacuum sewer system was commissioned in 2022 and serves 400 dwellings via 101 Flovac FV80 collection chambers. The vacuum pump station houses two Busch MINK MV 0502B vacuum pumps (7.5 kW each) and two Grundfos SEV sewage pumps (11 kW each), all in duty/assist configuration, discharging via a 7 kilometre rising main to the Barunga West Sewage Treatment Plant at Port Broughton.

The confirmed construction quantities from the D&C contractor tender are:

Component	Quantity	Material	Notes
Vacuum collection chambers	101 (89 tendered)	Polyethylene	Final as-built count from FMS
DN90 vacuum main	870 m	HDPE PE100	Property connection mains
DN125 vacuum main	2,885 m	HDPE PE100	Primary reticulation
DN160 vacuum main	600 m	HDPE PE100	Sub-mains
DN200 vacuum main	625 m	HDPE PE100	Primary trunk mains
150mm gravity drains	2,670 m	PVC	Property connection to pit
Vacuum pump station	1	Steel frame / Colorbond	Single building, compact footprint
Trench depth (vacuum mains)	~1.5 m	—	No dewatering required
Construction duration	~12 months	—	All reticulation, pits, hook-ups

2.2 Why Trench Depth Matters for Carbon

The 1.5 metre trench depth for vacuum mains is not a minor technical detail — it is the central carbon advantage of vacuum construction on this class of site. Understanding why requires understanding what the alternatives require.

Gravity sewerage operates by fall. On a flat site like Fishermans Bay, achieving the minimum hydraulic gradient for self-cleansing velocity requires the pipe to descend continuously toward the pump station. On a site with only 1.4 metres of total elevation change across the entire peninsula, gravity sewers serving the furthest properties would need to reach 3 to 4 metres below surface to maintain adequate fall — well below the seasonal water table.

Constructing in saturated sandy coastal soils at 3 to 4 metres depth requires active groundwater dewatering for the duration of the works. Dewatering on this site would require wellpoints or deep wells, continuous pump operation, and a discharge point for the extracted groundwater. The D&C contractor tender for the vacuum system explicitly excluded dewatering because the vacuum design did not require it. That exclusion represents avoided carbon, avoided cost, and avoided construction risk — none of which appears in a standard options cost comparison.

The three-station gravity alternative avoids deep trenching by limiting the gravity network to 2 metre depth and intercepting flow at three pump stations located at strategic low points. This is achievable without dewatering, but it replaces one carbon problem with another: three concrete pump station wet wells, six submersible pump installations, and three independent electrical infrastructure packages, each of which carries both embodied carbon at construction and operational carbon over the study life.

> *On a flat coastal site, the choice is not simply between gravity and vacuum. It is between deep trenching with dewatering, multiple pump stations, or vacuum at shallow depth. Each configuration has a different carbon profile. This analysis examines all four.*

3. Construction Phase Carbon

Construction phase carbon covers all carbon generated during the physical construction of the sewer system: excavation and spoil handling, plant and equipment operation, dewatering, concrete and materials delivery, and the duration premium — the additional carbon generated by having construction plant, supervision, and site operations running for longer.

This domain is routinely excluded from options assessments because it does not produce an ongoing cost. It is a one-time expenditure that falls to the construction contractor and is absorbed into the contract price. But the carbon it generates is real, and on sites with difficult ground conditions it can represent the largest single carbon variable in the comparison.

3.1 Excavation Volume

Excavation volume is a function of trench depth, trench width, pipe length, and the number and size of structures (chambers, wet wells, manholes). The four technology options produce significantly different excavation volumes on this site.

Technology	Pipe Length	Avg Trench Depth	Est. Excavation Volume	Dewatering Required
Vacuum	4,980 m mains	1.5 m	~3,700 m³	No
Gravity — 1 station	~4,200 m estimated	3.2 m avg	~8,100 m³	Yes — full network
Gravity — 3 stations	~4,200 m estimated	2.0 m	~5,000 m³	No
Low pressure	~3,200 m estimated	1.2 m	~2,300 m³ mains only	No — but +400 property pits

The low pressure figure requires qualification. The small-diameter PE pressure main network has the lowest trench excavation volume of the four technologies. However, this understates the total excavation for the LP option because 400 property-level installations are required — each involving excavation for the pump pit, pump chamber, and electrical conduit at the property boundary. At approximately 2 m³ per property installation, this adds approximately 800 m³ of property-level excavation, bringing the LP total to around 3,100 m³ — comparable to vacuum.

The gravity single-station option has by far the largest excavation volume: more than double the vacuum figure, with the additional complexity of active dewatering throughout. Spoil from deep dewatered trenches in sandy coastal soils typically requires testing and classification before disposal. The D&C contractor tender allowed for spoil carted locally within 3 km with no environmental testing required — a condition that would not apply to the deeper gravity excavation in the same soils.

3.2 Dewatering Carbon

Active groundwater dewatering for a gravity single-station scheme on this site would require wellpoint or deep well systems operating continuously for the duration of the deep excavation works. Based on the pipe network length and depth, this is estimated at 8 to 14 months of continuous dewatering pump operation.

A typical wellpoint dewatering system for this scale of work consumes 15 to 25 kW continuously. At 20 kW for 10 months continuous operation, dewatering energy alone is approximately 144,000 kWh — nearly 20 times the confirmed annual operational energy of the entire vacuum system. At the South Australian grid emission factor of 0.27 kg CO_2e/kWh (2024), this represents approximately 39 tonnes of CO_2e generated during construction alone, before a single pipe is laid.

This figure does not include the carbon cost of tanker movements if extracted groundwater cannot be discharged on site or to a nearby watercourse — a constraint that applies to many coastal sites where discharge to the foreshore or bay is not permitted.

> *The dewatering carbon for a gravity single-station scheme on this site is estimated at approximately 39 tonnes CO_2e — generated before construction begins. This cost does not appear in any standard options assessment. It is not hypothetical: it is the direct consequence of choosing a technology that requires deep excavation in a high water table environment.*

3.3 Construction Duration

The confirmed vacuum construction duration for Fishermans Bay — all reticulation, pits, and property hook-ups — was approximately 12 months. Construction was completed by a crew of 4 to 6 persons with 4 to 6 machine operators using light to medium excavation plant.

Estimated construction durations for the alternative technologies on the same site:

Technology	Est. Duration	Primary Duration Driver	Site Plant
Vacuum	12 months (confirmed)	Network reticulation and pit install	Light-medium excavator
Gravity — 1 station	28–36 months	Deep excavation + dewatering + wet well construction	Heavy excavator, dewatering plant, concrete crews
Gravity — 3 stations	18–24 months	Three wet well structures + network	Medium excavator, three concrete pours
Low pressure	14–18 months	Network + 400 property installations	Light excavator, electrical crews

Duration premium matters for carbon because construction plant — excavators, tippers, compactors, dewatering pumps, site vehicles — consumes diesel continuously while on site, whether or not productive work is being done. A site running for 30 months rather than 12 months generates 2.5 times the plant-idle carbon, independent of the actual excavation volume. On remote coastal sites where equipment must be mobilised and demobilised, the carbon cost of extended programmes is further amplified.

4. Wet Weather Design Load — The Hidden Carbon Multiplier of Gravity Sewerage

One of the most significant and consistently overlooked differences between gravity and non-gravity sewer technologies is not operational — it is structural. Gravity sewers are open to the ground environment in a way that vacuum and low pressure systems are not. Over time, and particularly during wet weather events, groundwater and stormwater enter the gravity system through pipe joints, maintenance hole covers, property connections, and construction defects. This is infiltration and inflow — collectively I&I — and it has direct carbon consequences at every level of the system.

Vacuum reticulation operates under continuous negative pressure. The sealed pipe system has no pathway for groundwater or stormwater to enter. Low pressure systems operate under positive pressure. Neither technology admits I&I, and neither requires design allowances for it. This is not a maintenance advantage — it is a structural characteristic of the technology that has significant implications for pipe sizing, pump station sizing, treatment plant sizing, and energy consumption over the life of the asset.

4.1 What the SA CWMS Design Criteria Requires

The South Australian Community Wastewater Management System (CWMS) Design Criteria (LGA SA / Department for Health and Wellbeing, July 2019) is the governing design standard for council-operated wastewater schemes in South Australia, including Fishermans Bay. It defines the Hydraulic Design Load (HDL) — the flow rate that each system component must be designed to accommodate.

For gravity networks in areas subject to seasonal loadings — which the guidelines specifically define as including coastal holiday communities — the required HDL is:

> *HDL = (ADF × 1.5 × PF) + sum of upstream pumped flows Where ADF is the Average Daily Flow and PF is the standard peaking factor. The 1.5 multiplier is applied specifically to account for seasonal flow variation in holiday community contexts. (SA CWMS Design Criteria, Section 4.7)*

This means gravity infrastructure at Fishermans Bay would need to be designed for flows 50 percent above the standard peaking factor applied to average daily flow. Pipes, wet wells, pump stations, and rising mains are all sized accordingly — not for the sewage the community generates, but for a design flow that may only occur during peak holiday periods coinciding with wet weather events.

Critically, the SA CWMS Design Criteria makes clear that this wet weather design obligation falls specifically on gravity systems. The document explicitly states that wet weather flows have not been included in the assessment of HDL for non-gravity collection components — meaning vacuum and low pressure systems are designed and sized for actual sewage flows, not for the inflated wet weather design load that gravity requires.

The treatment plant obligation is unambiguous: the CWMS Design Criteria states that the wastewater treatment plant must have the capacity to treat the peak wet weather flow. For a gravity scheme, this means the Port Broughton treatment plant serving Fishermans Bay would need to be sized for a peak wet weather flow that includes infiltration and inflow — not just the sewage generated by 400 holiday dwellings. For a vacuum scheme, the treatment plant receives only actual sewage flow, regardless of rainfall.

4.2 What I&I Means for Pipe Sizing and Embodied Carbon

Gravity pipes are sized to carry the HDL, not average flow. On a high water table coastal site like Fishermans Bay, the HDL for a gravity system is substantially higher than the equivalent vacuum or LP flow rate for the same number of dwellings. This has a direct consequence for pipe diameter selection.

A gravity main carrying dry weather flow from 133 dwellings (one-third of Fishermans Bay, serving one of the three modelled pump stations) might be adequately served by DN150 or DN200 pipe at standard peaking factors. When the 1.5 seasonal multiplier is applied and wet weather infiltration is added, the same pipe reach may require DN225 or DN300. The embodied carbon in a DN300 PVC pipe is approximately 2.5 times that of a DN150 pipe per metre of length. Across the full gravity network, this oversizing premium represents real additional embodied carbon — material manufactured, transported, and installed solely to accommodate water that should not be in the sewer system at all.

Wet well volumes at pump stations are similarly affected. A wet well sized for peak wet weather flow on a coastal site may be 30 to 50 percent larger than one sized for dry weather flow alone. That additional concrete volume — reinforced, waterproofed, placed at depth — carries embodied carbon that has no equivalent in the vacuum pump station comparison.

4.3 Treatment Plant Carbon — The Downstream Consequence

The carbon consequence of I&I does not stop at the collection system boundary. Every litre of groundwater or stormwater that enters the gravity reticulation is transported to the treatment plant, screened, and processed. On a coastal site with a high water table and permeable sandy soils, the volume of infiltration entering a mature gravity system can be substantial — published data suggests that infiltration in coastal gravity systems can represent 40 to 100 percent of dry weather sewage flow in the 10 to 20 year period after construction.

The treatment plant must be designed for this combined flow from day one, because it will arrive once the system matures. A treatment plant sized for 2x dry weather flow requires roughly twice the tankage, twice the aeration capacity, twice the UV or chlorination capacity, and twice the biosolids handling capacity of a plant sized for actual sewage flow. The embodied carbon in that additional plant capacity is a direct consequence of the collection technology choice — and it is never attributed to that choice in a standard options assessment.

On coastal sites with tidal influence, the I&I problem has an additional dimension. During king tides or storm surge events, the water table may rise above the invert level of gravity sewers, and saline water can enter the system through pipe joints and maintenance hole covers. The treatment plant then receives a diluted, saline influent that is not sewage. Treating it as sewage — aerating it, dosing it, processing it through biological treatment — is energy and carbon intensive, and entirely avoidable with a sealed collection system.

> *At Fishermans Bay, the vacuum system presents only actual sewage to the Port Broughton treatment plant — consistently, regardless of rainfall or tidal conditions. A gravity alternative would present a variable influent that includes groundwater infiltration, potential stormwater inflow, and in tidal surge conditions, saline coastal water. The treatment plant sized for that variability is larger, more energy intensive, and more carbon intensive than one sized to receive vacuum-collected sewage. That difference in treatment plant carbon is a direct consequence of the collection technology decision.*

4.4 Overflow Risk and Environmental Carbon

When peak wet weather flow in a gravity system exceeds the hydraulic capacity of pipes or pump stations, the system overflows. In Australia, gravity sewers are designed with emergency relief structures — overflow points that discharge to the environment when capacity is exceeded. This design is deliberate: it is considered preferable to discharge diluted sewage to the environment than to allow sewage to back up into properties.

Wet weather overflows from gravity systems are a documented and recurring operational reality across Australia. They represent a direct environmental discharge of partially treated or untreated sewage — diluted by stormwater, but carrying pathogens, nutrients, and biochemical oxygen demand into receiving waters. The ecological carbon cost of these events — the oxygen demand placed on receiving waterways, the impact on aquatic ecosystems, the remediation and regulatory response — is real but unquantifiable in standard carbon accounting terms.

What is quantifiable is the comparison: vacuum systems do not overflow in the same way. The sealed reticulation does not admit stormwater, so peak wet weather flow at the vacuum pump station is essentially indistinguishable from peak dry weather flow. There is no trigger condition for overflow, because the flow presented to the system does not surge during rainfall. The environmental risk that emergency relief structures are designed to manage in gravity systems does not exist in the vacuum equivalent.

4.5 Summary: The I&I Carbon Premium on Gravity Systems

Carbon Impact	Gravity System	Vacuum / LP System
Pipe sizing	Oversized for wet weather HDL — larger diameter, more material	Sized for actual sewage flow only
Wet well volume	30–50% larger to accommodate I&I peak flows	Not applicable (vacuum tank sized for sewage flow)
Treatment plant capacity	Sized for peak wet weather flow including infiltration	Sized for actual sewage flow — smaller, lower carbon
Operational energy (collection)	Escalates as infiltration builds — more pump cycling	Stable over system life — no infiltration pathway
Operational energy (treatment)	Higher per unit volume treated — diluted influent, variable load	Consistent influent — optimised treatment energy
Overflow risk	Present — emergency relief structures required by design	Not applicable — sealed system, no overflow pathway
Tidal / saline ingress	Risk on coastal sites — treatment plant processes saltwater as sewage	No risk — sealed reticulation

5. Embodied Carbon in Materials and Components

Embodied carbon covers the carbon generated in manufacturing, transporting, and installing the physical components of each system. For infrastructure assets with 30 to 50 year design lives, embodied carbon is a significant fraction of lifetime carbon — and for systems with components that require periodic replacement, the embodied carbon of replacement cycles must be counted over the full study life.

4.1 Pipe Networks

All four technologies use plastic pipe for the reticulation network. The embodied carbon differences between pipe materials are relatively modest compared to the differences in component manufacture, but pipe quantities vary substantially between technologies and the comparison is worth making clearly.

Technology	Pipe Material	Network Length	Approx. Embodied Carbon
Vacuum	HDPE PE100	4,980 m (mains)	~4.5 tCO_2e
Gravity — single	PVC / DI	~4,200 m + gravity mains	~5.8 tCO_2e
Gravity — 3 stations	PVC / DI	~4,200 m	~5.8 tCO_2e
Low pressure	MDPE / HDPE	~3,200 m	~2.1 tCO_2e

Low pressure has the lowest pipe embodied carbon. Vacuum is higher because of greater network length — vacuum pipe connects every collection chamber back to the pump station, whereas low pressure mains only carry flow from the property pump to the collection main. This is the one category where LP and gravity have a carbon advantage over vacuum, and it is acknowledged directly.

However, pipe network embodied carbon is a one-time event at construction and is modest relative to the component comparisons that follow.

4.2 Collection Infrastructure — The Critical Comparison

The most significant embodied carbon difference between the four technologies lies not in the pipe networks but in the collection infrastructure installed at each property or grouping of properties.

At Fishermans Bay, the vacuum system uses 101 polyethylene collection chambers. Each chamber houses one FV80 interface valve. Polyethylene is a thermoplastic that can be recycled at end of life, and the FV80 valve body — glass-filled polypropylene — is similarly recyclable. The 50-year design life of the Flovac collection chamber means that for a 50-year study life, no chamber replacement is required. Valve internals require a scheduled service at 10-year intervals, but the chamber itself and the valve body are not replaced.

The low pressure alternative requires one grinder pump unit at each of the 400 properties. Each grinder pump mechanism consists of a cast iron housing, stainless steel impeller, electric motor, capacitor, and pump seals — components with significantly higher embodied carbon per unit than a polyethylene chamber. Published lifecycle data for residential grinder pumps indicates an embodied carbon of approximately 85 to 120 kg CO_2e per unit, compared with approximately 35 to 45 kg CO_2e for a Flovac PE collection chamber.

More significantly: grinder pump mechanisms require replacement approximately every 10 years. This is not a conservative assumption — it is confirmed operational data from major utilities including JEA in Jacksonville, Florida; Watercare in Auckland; and Victorian water corporations. Over a 50-year study life, this represents four full replacement cycles — meaning that for a 400-dwelling scheme, the total number of grinder pump mechanisms manufactured, installed, and disposed of over 50 years is approximately 2,000 units.

> *400 grinder pump mechanisms at construction. 400 replacements at years 10, 20, 30, and 40. 2,000 pump mechanisms manufactured over 50 years for a 400-dwelling scheme. The embodied carbon of this replacement cycle is not incidental — it is the defining embodied carbon characteristic of low pressure sewerage.*

4.3 Pump Stations and Wet Wells

The pump station comparison between technologies is stark and is often misrepresented in options assessments that compare only headline pump station costs without considering scale and number.

Technology	Pump Stations	Wet Well Construction	Pumps Installed	Electrical Panels
Vacuum	1 compact building	None — tank above floor	2 vacuum + 2 sewage	1 central SCADA panel
Gravity — 1 station	1 large wet well	Deep concrete structure	2 submersible (duty/standby)	1 panel
Gravity — 3 stations	3 wet wells	3 concrete structures	6 submersible pumps	3 panels
Low pressure	1 small collection point	Minimal	400 grinder pumps (private)	400 property cabinets

The Fishermans Bay vacuum pump station is a steel-framed Colorbond building — compact, above-ground, with a concrete apron slab. The vacuum collection vessel sits below floor level within the building. Construction of this structure generates modest embodied carbon relative to the alternatives.

A gravity wet well is a different proposition. A concrete wet well for a pump station serving one-third of the Fishermans Bay network (133 dwellings) would typically be 2.5 to 3.5 metres internal diameter and 4 to 6 metres deep — placed in sandy coastal soils at the water table. The concrete volume for three such structures, plus their access covers, valved rising mains, and electrical infrastructure, represents a substantial embodied carbon liability. For the single-station gravity option, one larger wet well at 5 to 7 metres depth would be required.

For low pressure, the 400 electrical cabinets installed at individual properties carry both embodied carbon at manufacture and a replacement carbon cost when the grinder pump mechanism is renewed — because the pump and cabinet are typically replaced together.

6. Operational Carbon Over 50 Years

Operational carbon is driven primarily by electricity consumption. For all four technologies, electricity powers the pumping equipment that moves sewage from the collection point to the treatment plant. The differences between technologies in energy consumption are substantial and are well documented.

5.1 Confirmed Energy Data — Fishermans Bay

The vacuum system energy consumption at Fishermans Bay is confirmed from SCADA run-hour data across eleven months of operation. The two Busch MINK vacuum pumps (7.5 kW each) and two Grundfos SEV sewage pumps (11 kW each) are logged continuously. Total confirmed annual consumption:

System Component	Motor Rating	Confirmed Annual Energy	Carbon at 0.27 kg CO_2e/kWh
Vacuum pumps (duty/assist)	2 × 7.5 kW	Included in total	—
Sewage pumps (duty/assist)	2 × 11 kW	Included in total	—
Total vacuum system	—	7,396 kWh/year	2.0 tCO_2e/year
Per dwelling	—	18.5 kWh/dwelling/year	5.0 kg CO_2e/dwelling/year

This is the energy cost of collecting and transferring sewage from 400 dwellings to the treatment plant. It is the entire system — reticulation vacuum, sewage transfer pump, controls, and monitoring — running for a full year on a real operational system.

5.2 Modelled Energy for Comparison Technologies

Technology	Annual Energy	Annual Carbon	50-Year Carbon (nominal)	Notes
Vacuum	7,396 kWh (confirmed)	2.0 tCO_2e	100 tCO_2e	SCADA-confirmed
Gravity — 1 station	9,750 kWh (modelled)	2.6 tCO_2e	130 tCO_2e*	Escalates with infiltration
Gravity — 3 stations	11,700 kWh (modelled)	3.2 tCO_2e	160 tCO_2e*	Escalates with infiltration
Low pressure	48,000 kWh (modelled)	13.0 tCO_2e	650 tCO_2e	Distributed across 400 accounts

* Gravity energy figures include a modelled escalation factor for infiltration. New gravity sewers on high water table coastal sites typically show increasing pump energy from year 10

to 20 as groundwater infiltration builds. By year 15, infiltration can add 50 to 100 percent to the hydraulic load, increasing pump cycling frequency and energy consumption proportionally. The nominal 50-year figures for gravity include a conservative 40 percent energy escalation factor applied from year 15.

5.3 The Hidden Energy of Low Pressure Systems

The 48,000 kWh/year figure for low pressure deserves specific attention because it is the most commonly misrepresented number in LP options assessments. This energy is not consumed at a central pump station. It is consumed by 400 individual grinder pumps installed at private properties, each drawing from the property's private electricity account.

From the utility's perspective, the LP system appears to consume no energy — there is no central pump station electricity bill. In reality, 400 residential electricity accounts are each paying approximately $48 per year in additional electricity costs to operate the grinder pump. The aggregate cost is $19,200 per year and the aggregate carbon is 13 tCO_2e per year. Neither figure appears in the utility's operational reporting.

This is not a technical criticism of low pressure technology — it is a systemic accounting problem. The energy is real. The carbon is real. Options assessments that compare only utility-side energy costs systematically undercount LP operational carbon by a factor of 6.5 on this site.

> *The low pressure system at Fishermans Bay would consume 48,000 kWh per year — 6.5 times the confirmed vacuum figure. This energy is distributed across 400 private electricity accounts and is invisible in the utility's central energy bill. Over 50 years, the operational carbon differential between vacuum and low pressure is approximately 550 tonnes CO_2e on this site alone.*

7. End-of-Life Carbon

End-of-life carbon covers the carbon generated — or avoided — when system components reach the end of their useful life. This domain is rarely considered in options assessments but becomes increasingly significant as design lives are extended and as circular economy requirements enter infrastructure procurement.

6.1 Vacuum System Components

The Flovac FV80 collection chamber is manufactured from polyethylene — a thermoplastic with established recycling pathways. At end of life, PE chambers can be processed through plastic recycling streams, recovering material value and avoiding landfill disposal carbon.

The FV80 interface valve body is glass-filled polypropylene — similarly recyclable as a thermoplastic. The valve internals (diaphragm, seat, spring assembly) are the components most likely to require replacement during the system's life, and these are small components that can be serviced without disturbing the chamber or the pipe network.

HDPE vacuum mains have design lives of 50 to 100 years. At end of life, HDPE can be recycled or — in the case of buried infrastructure — left in place if structurally sound, avoiding excavation and disposal carbon entirely.

6.2 Low Pressure Components

Grinder pump mechanisms are composite assemblies of cast iron, stainless steel, copper windings, and elastomeric seals. While the metallic components are theoretically recyclable, the mixed material construction and contamination from sewage contact means that in practice most decommissioned grinder pumps are disposed of as mixed waste rather than recycled. At 400 units replaced four times over 50 years, the end-of-life disposal volume for LP is 1,600 pump units — a material waste stream with no equivalent in the vacuum comparison.

6.3 Gravity Components

Gravity wet wells are reinforced concrete structures. Concrete cannot be readily recycled — decommissioned wet wells are typically broken up and disposed of as inert fill, or abandoned in place. The carbon cost of demolition and disposal for three gravity pump stations at end of life is not negligible, and is higher for the deep single-station option where excavation is required to access the structure.

Submersible sewage pumps in gravity wet wells operate in highly corrosive H_2S environments and typically reach end of life ahead of their nominal 10-year design interval in coastal installations. End-of-life pump disposal carries similar mixed-material waste issues to grinder pumps, but at lower unit volume.

Technology	Primary Material	Recyclability	End-of-Life Volume (50yr)	Assessment
Vacuum chambers	Polyethylene	High — established thermoplastic stream	101 units (once)	Low
Vacuum valves	Glass-filled PP	High — thermoplastic	101 valve bodies (once)	Low
HDPE mains	HDPE	High — or leave in place	4,980 m (once)	Low

Technology	Primary Material	Recyclability	End-of-Life Volume (50yr)	Assessment
LP grinder pumps	Mixed — CI, SS, Cu	Low — mixed material	2,000 mechanisms over 50yr	High
LP electrical cabinets	Mixed	Partial	1,600+ over 50yr	Medium-High
Gravity wet wells	Reinforced concrete	None — demolition waste	3 structures (once)	Medium
Submersible pumps	Mixed metal	Partial	12–18 over 50yr (3 stations)	Medium

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LP electrical cabinets	Mixed	Partial	1,600+ over 50yr	Medium-High
Gravity wet wells	Reinforced concrete	None — demolition waste	3 structures (once)	Medium
Submersible pumps	Mixed metal	Partial	12–18 over 50yr (3 stations)	Medium

8. Site-Specific Hidden Carbon

The four domains addressed in Sections 3 to 6 cover the carbon that is visible in a well-conducted lifecycle assessment. This section addresses carbon costs that are specific to constrained sites and that are routinely excluded from options assessments — not because they are unimportant but because they arise from decisions made outside the standard options assessment boundary.

7.1 Groundwater Dewatering

On sites with high water tables, the choice of sewer technology determines whether dewatering is required and for how long. At Fishermans Bay, the vacuum system required no dewatering. A single-station gravity scheme on the same site would have required continuous wellpoint or deep well dewatering for an estimated 10 to 14 months during deep excavation.

The carbon cost of this dewatering — approximately 39 tCO_2e based on 20 kW continuous operation for 10 months at the SA grid emission factor — is a direct consequence of the technology choice. It does not appear in any standard options assessment because dewatering is treated as a site condition cost rather than a technology comparison variable. On sites where it applies, it is not a minor adjustment — it can be the largest single carbon item in the construction phase comparison.

7.2 Spoil Disposal and Haulage

Deep excavation in waterlogged coastal soils generates spoil that may require testing, classification, and haulage to an approved disposal site. At Fishermans Bay, the D&C contractor tender allowed for spoil carted locally within 3 km with no environmental testing required — a condition that reflects the shallow vacuum excavation depth and the dry, manageable character of the spoil.

Deep gravity excavation at 3 to 4 metres in the same saturated sandy soils would produce spoil with different characteristics: wet, potentially requiring classification, and in greater volume. If the site is in a coastal zone where spoil disposal options are restricted, the haulage distance and carbon cost can increase substantially.

7.3 The Treasure Island Dewatering Precedent

The Fishermans Bay dewatering comparison is instructive, but it represents a relatively contained example of a problem that can reach very different scales on major development sites. Treasure Island, the former naval air station in San Francisco Bay currently being developed for mixed residential use, provides a reference point for what dewatering carbon can look like at larger scale.

Treasure Island sits at approximately 1.5 metres above mean sea level, with a water table that is effectively tidal. Development of the island's infrastructure — including sewerage — requires dewatering of excavations throughout the construction programme. Groundwater extracted from the site cannot be discharged to San Francisco Bay under the applicable environmental permits. The extracted water must be tankered off the island, transported approximately 60 to 90 minutes north of the city to an approved disposal facility, and discharged there.

The carbon cost of this tanker operation — fuel consumption across hundreds of vehicle movements carrying contaminated groundwater across a major metropolitan area — is a direct consequence of the technology choice for sewerage on that island. A system requiring deep excavation generates dewatering that must be removed. A system requiring shallow excavation avoids it. The carbon is real in either case; it is simply not counted in the options assessment that determines which technology is selected.

> *The carbon costs of groundwater dewatering, extended haulage, and spoil disposal are site-specific and cannot be generalised. But they are consistently excluded from comparative assessments, and on constrained coastal and waterfront sites they can dominate the construction phase carbon balance. Engineers and clients undertaking options assessments on such sites should treat dewatering carbon as a first-order variable, not a contingency item.*

9. Summary Carbon Comparison

The following table consolidates the carbon assessment across all four domains for the four technologies at the Fishermans Bay site. Figures are indicative estimates based on confirmed construction data, SCADA operational data, published embodied carbon databases, and standard engineering assumptions for comparison technologies. They are presented as order-of-magnitude comparisons, not precise lifecycle assessment outputs.

All vacuum system figures are derived from confirmed data. Comparison technology figures are modelled for the same site. Conservative assumptions have been applied throughout: where ranges exist, lower values are used for vacuum inputs and higher values for comparison technologies.

Carbon Domain	Vacuum	Gravity — 1 Stn	Gravity — 3 Stn	Low Pressure
Construction — excavation	Low	Very High	Medium	Low-Medium
Construction — dewatering	None	~39 tCO_2e	None	None
Construction — duration	12 months	28–36 months	18–24 months	14–18 months
Embodied — pipe network	~4.5 tCO_2e	~5.8 tCO_2e	~5.8 tCO_2e	~2.1 tCO_2e
Embodied — collection	~4.0 tCO_2e (once)	~12 tCO_2e wet wells	~8 tCO_2e wet wells	~170 tCO_2e (2,000 pumps)
Operational — 50 years	~100 tCO_2e	~130 tCO_2e*	~160 tCO_2e*	~650 tCO_2e
End-of-life	Low — recyclable PP/PE	Medium — concrete demolition	Medium-High	High — mixed waste
INDICATIVE TOTAL	~110 tCO_2e	~190+ tCO_2e	~175+ tCO_2e	~825 tCO_2e

** Gravity operational figures include modelled infiltration escalation from year 15.*

The low pressure system produces approximately 7.5 times the total indicative carbon of the vacuum system over 50 years on this site, driven overwhelmingly by the grinder pump replacement cycle and the distributed operational energy. The gravity alternatives produce approximately 1.6 to 1.7 times the vacuum carbon, with the single-station option carrying additional dewatering carbon not reflected in the table if estimated dewatering is included.

8.1 What This Comparison Does and Does Not Show

This analysis uses Fishermans Bay as a case study because it provides confirmed data. Not every vacuum sewer project will show the same relative carbon advantages — the comparison changes with site conditions, technology configuration, grid emission factors, and study life assumptions.

Vacuum does not always come out ahead on every measure. On pipework quantity and network length, LP has a genuine advantage. On pipe embodied carbon, LP is lower. These are acknowledged directly in this analysis because an honest comparison is more useful to engineers than an advocacy document.

What the analysis does show clearly is that conventional options assessments — which typically compare capital cost, annual operating cost, and sometimes whole-of-life NPV — are systematically incomplete as carbon assessments. They exclude the construction phase almost entirely. They exclude dewatering. They fail to count distributed energy in LP systems. They do not account for the recurring embodied carbon of grinder pump replacement cycles. And they treat end-of-life as outside the study boundary.

Correcting these omissions does not change the technology recommendation on every site. But it changes the evidence base on which that recommendation is made — and on coastal, flat, or high water table sites of the type represented by Fishermans Bay, it consistently strengthens the case for vacuum sewerage.

10. Scaling the Comparison — What These Numbers Mean at Real Project Scale

The Fishermans Bay case study demonstrates the carbon comparison at 400 dwellings — a useful and well-documented scale. But the sites where these technology choices matter most are often considerably larger. Major greenfield residential subdivisions in Australia and New Zealand routinely range from 1,000 to 12,000 dwellings, and the carbon differences between technologies scale with project size in ways that are not always intuitively obvious.

This section applies the Fishermans Bay carbon framework to three real projects — Calypso Bay in Queensland, Prestons Park in Christchurch, and Riverlea in South Australia — to illustrate what the comparison looks like at the scales engineers actually encounter. All three share the site characteristics that make the technology comparison most significant: flat topography, high water tables, and proximity to sensitive water environments.

A note on the pit-to-dwelling ratio: Flovac vacuum systems typically serve four dwellings per collection pit. This ratio is used throughout this section to derive pit counts from dwelling numbers.

10.1 Calypso Bay, Queensland — 2,600 Dwellings

Calypso Bay, Queensland — canal residential development surrounded by waterways. Water table at or near surface throughout.

Calypso Bay is a canal-front residential development south of Brisbane, designed for approximately 2,600 dwellings. The site is surrounded by water on multiple sides, with the water table at or near the surface throughout. It represents one of the most extreme examples of the site conditions that make gravity sewerage problematic — not just operationally difficult but structurally challenged from day one.

At 2,600 dwellings, the four-technology comparison produces the following infrastructure profile:

Technology	Collection Infrastructure	Pump Stations	50-yr Component Carbon
Vacuum	650 PE pits (once)	3–4 VPS	Low — recyclable PE, no replacement
Gravity	Gravity mains + manholes	Est. 18–22 wet wells	Medium — concrete structures, pump cycles
Low pressure	2,600 grinder pumps (install)	Minimal central	Very High — 13,000 mechanisms over 50yr
LP — 50yr total mechanisms	—	—	13,000 pump units manufactured and disposed

The operational carbon differential at Calypso Bay scale is equally significant. Extrapolating from the confirmed Fishermans Bay SCADA data of 18.5 kWh per dwelling per year for vacuum, the LP alternative at 6.5x that rate would consume approximately 313,000 kWh per year — generating around 85 tonnes of CO_2e annually from collection alone. This energy is distributed across 2,600 private electricity accounts and invisible in the utility's operational reporting.

On a canal development with water on three sides, the gravity single-station option would require continuous dewatering throughout construction across the entire site. The construction carbon of that dewatering — and the structural I&I challenge of a gravity system sitting permanently below the water table on a canal estate — makes the gravity option almost unworkable on carbon grounds before operational considerations are even reached.

10.2 Prestons Park, Christchurch — 2,200 Dwellings

Prestons Park during construction — 203 hectares of flat Canterbury plains land, north-east Christchurch. High water table throughout.

Prestons Park completed — flat terrain, shallow water table, post-earthquake ground conditions that made deep gravity excavation impractical.

Prestons Park is a 203-hectare residential development on the outskirts of Christchurch, designed for 2,200 homes. It is New Zealand's largest greenfield vacuum wastewater system. The site sits on the flat Canterbury plains with a high water table — conditions that, combined with the post-earthquake Christchurch context, made deep gravity excavation both technically difficult and community-unacceptable.

The infrastructure comparison at Prestons is documented by the project's own engineering team. Aurecon, the project's engineering group, confirmed that a conventional gravity system would have required approximately 14 pump stations to serve the same site. The vacuum system requires one.

> *"The 203-hectare Prestons development would have required approximately 14 traditional wastewater pump stations. The whole site can be serviced by one vacuum sewage pump station. You also don't have to dewater the ground to lay the pipes." — Alistair Greig, Project Director, Aurecon (Infrastructure News NZ, November 2013)*

The confirmed infrastructure comparison at Prestons:

Infrastructure Item	Vacuum (Confirmed)	Gravity (Confirmed Alternative)	Ratio
Pump stations	1 VPS	14 gravity stations	14:1
Collection pits	500 PE vacuum pits	Manholes throughout 19km network	—
Vacuum main	19 km HDPE	—	—
Trench depth	Shallow — above water table	Would require dewatering	—
Earthquake resilience	HDPE flexes — survives ground movement	Rigid joints — documented failure mode	—

The 14:1 pump station ratio is the most striking infrastructure comparison in this paper. Fourteen concrete wet wells, 28 submersible pumps, 14 electrical installations, and 14 ongoing maintenance obligations — versus one compact vacuum pump station. The embodied carbon in those 13 additional concrete wet wells that were never built at Prestons represents a real and quantifiable avoided carbon outcome. The developer chose vacuum specifically because the site conditions made deep gravity excavation impractical — a decision that also happened to be the right carbon decision, even though carbon was not the primary driver.

The post-earthquake context adds a dimension that is directly relevant to the carbon and resilience argument. Christchurch's 2011 earthquake caused catastrophic damage to the city's gravity sewer network — joints failed, pipes fractured, and the system was submerged in liquefied ground. The Prestons vacuum system's HDPE pipe network is flexible — it bends rather than breaks under ground movement. The sealed negative-pressure system also means that earthquake damage does not result in sewage contamination of the surrounding ground environment, a direct environmental and public health carbon avoided cost that gravity systems cannot match.

10.3 Riverlea, South Australia — 12,000 Dwellings

Riverlea, South Australia — major greenfield subdivision on Adelaide's northern flood plain. Standing water visible at approximately 2 metres depth across the site.

Riverlea is a major greenfield residential development on Adelaide's northern plains, planned for approximately 12,000 dwellings. The site is a flood plain — standing water is visible across the site at approximately 2 metres depth. This is not a seasonal high water table condition. It is a permanent characteristic of the site that makes any technology requiring deep excavation fundamentally problematic.

The Flovac vacuum system design for Riverlea comprises approximately 3,000 collection pits and 5 vacuum pump stations. The scaling comparison against the alternatives at this size produces numbers that are difficult to contextualise in conventional infrastructure terms:

Comparison Item	Vacuum	Gravity	Low Pressure
Collection pits / pumps at construction	3,000 PE pits	Manholes throughout network	12,000 grinder pumps

Comparison Item	Vacuum	Gravity	Low Pressure
Pump stations	5 VPS	Est. 35–40 gravity wet wells	~3 central collection points
Property electrical cabinets	None	None	12,000 units
Grinder pump mechanisms — 50yr total	None	None	48,000 units
Trench depth	~1.5m — no dewatering	3–4m — continuous dewatering	~1.2m — no dewatering
Dewatering — construction	None required	Continuous across flood plain for 5+ years	None required
Annual energy (indicative)	~222,000 kWh	~290,000 kWh (escalating)	~1,440,000 kWh
Annual operational carbon	~60 tCO_2e	~78 tCO_2e (escalating)	~389 tCO_2e

The 48,000 grinder pump mechanisms figure deserves to be stated plainly. Over a 50-year study life, a low pressure system serving 12,000 dwellings would require the manufacture, installation, and disposal of 48,000 cast iron and stainless steel pump mechanisms — at 10-year replacement intervals across 400 mechanisms per cycle for 12,000 units. No options assessment for a development of this scale has ever placed that number in a carbon comparison. It belongs there.

The gravity alternative on a flood plain with permanent standing water at 2 metres presents a different order of construction challenge. Deep trench excavation across a 12,000-lot subdivision would require continuous active dewatering across a very large construction footprint for the full duration of staged construction — potentially 5 to 8 years given the scale of the development. The carbon cost of that dewatering is not a contingency item. It is the predictable consequence of selecting a technology that requires deep excavation on a flood plain, and it should be quantified and attributed to the technology choice in the options assessment.

> *At Riverlea scale, the choice between vacuum and low pressure is a choice between 3,000 PE collection pits installed once versus 48,000 grinder pump mechanisms manufactured and disposed of over 50 years. Between 5 compact pump stations and 35 to 40 concrete wet wells. Between no dewatering on a flood plain and continuous dewatering across a major construction zone for years. These are not marginal differences. They are defining characteristics of the technologies, and they have carbon consequences that dwarf the operational energy comparison.*

10.4 The Scaling Summary

The table below applies the Fishermans Bay carbon framework to all four projects. Figures are indicative extrapolations from the Fishermans Bay confirmed data, adjusted for project scale. They are not precise lifecycle assessments — they are order-of-magnitude comparisons intended to show how the relative carbon positions of the four technologies change as project scale increases.

Project	Dwellings	Vacuum Pits	LP Mechanisms (50yr)	Gravity Stations	LP Op. Carbon (50yr)
Fishermans Bay SA (confirmed)	400	101 (once)	2,000	3 wet wells	~650 tCO_2e
Calypso Bay QLD (indicative)	2,600	650 (once)	13,000	18–22 wet wells	~4,225 tCO_2e
Prestons Park NZ (confirmed)	2,200	500 (once)	11,000	14 (confirmed avoided)	~3,575 tCO_2e
Riverlea SA (indicative)	12,000	3,000 (once)	48,000	35–40 wet wells	~19,500 tCO_2e

The LP operational carbon figures in the final column represent the carbon generated by grinder pump electricity consumption alone — distributed across private electricity accounts, invisible in utility reporting, but real. At Riverlea scale over 50 years, that figure approaches 20,000 tonnes of CO_2e from collection energy alone. The vacuum equivalent for the same site and study period is approximately 3,000 tonnes CO_2e — a difference of roughly 17,000 tonnes on one subdivision.

These numbers are not arguments for a particular technology in every circumstance. They are arguments for counting the carbon properly when the options assessment is done.

11. Conclusions

- Vacuum sewerage produces the lowest total carbon footprint for this class of site across all domains assessed. The confirmed operational energy of 7,396 kWh/year for 400 dwellings is 6.5 times lower than the modelled LP alternative and compares favourably with gravity at equivalent hydraulic load.
- Low pressure (grinder pump) sewerage carries the highest total carbon footprint of the four technologies assessed. The dominant driver is the grinder pump replacement cycle: 2,000 pump mechanisms manufactured, installed, and disposed of over 50 years for a 400-dwelling scheme, with associated electrical cabinet replacement. This embodied carbon liability has no equivalent in the vacuum system.
- Gravity sewerage on flat coastal sites carries higher construction carbon than is commonly recognised. On sites where achieving gravity fall requires deep trenching, active dewatering is required for the duration of the deep excavation works. At Fishermans Bay, this would represent approximately 39 tCO_2e of construction-phase dewatering carbon alone — a figure that does not appear in any standard options assessment.
- The three-station gravity alternative avoids dewatering but introduces three concrete wet wells and six submersible pump installations, with operational carbon approximately 60 percent higher than vacuum over 50 years due to infiltration-driven energy escalation.
- Conventional options assessments are systematically incomplete as carbon assessments. They exclude construction phase carbon, fail to count distributed LP energy, do not account for recurring grinder pump replacement embodied carbon, and treat end-of-life as outside the study boundary. Correcting these omissions consistently strengthens the relative carbon position of vacuum sewerage on the class of site for which it is designed.
- The carbon costs of groundwater dewatering and extended construction duration are site-specific, but they are consistently the largest excluded variables on constrained coastal and low-lying sites. Engineers conducting options assessments on such sites should treat dewatering carbon as a first-order comparison variable.
- Vacuum system components — polyethylene chambers, glass-filled polypropylene valves, HDPE pipe — have established recycling pathways and 50-year or greater design lives. The system generates no equivalent of the LP grinder pump end-of-life waste stream.

This analysis is based on confirmed operational data from Fishermans Bay and modelled alternatives using standard engineering practice. The indicative carbon figures presented are order-of-magnitude comparisons intended to inform engineering decision-making, not precise lifecycle assessment outputs. All figures should be independently verified for any formal carbon assessment or infrastructure procurement process.

Data Sources and References

Local Government Association of South Australia / Department for Health and Wellbeing, South Australian Community Wastewater Management System (CWMS) Design Criteria, July 2019, Revision 1.0 — Section 4.6 Hydraulic Design Load, Section 4.7 Seasonal Loadings, Section 4.8.2 WWTP Wet Weather Event Peak Flows

Flovac FMS SCADA data, Fishermans Bay SA, Jul 2025 to Jun 2026

Busch MINK MV0502B vacuum pump datasheet (2021)

Grundfos SEV.80.80.110 sewage pump datasheet (2024)

D&C Contractor, Request for Tender — Fishermans Bay Waste Water Collection System D&C (April 2021)

Flovac Whole-of-Life Cost Comparison, Fishermans Bay (June 2026)

Australian National Greenhouse Accounts (NGA) Factors, Department of Climate Change, Energy, the Environment and Water (2024) — SA grid emission factor 0.27 kg CO_2e/kWh

Australasian EPD Programme — product category rules for plastic pipe systems

GBCA, Embodied Carbon in Buildings: A Review of the Literature (2022)

E/One Sentry grinder pump published specifications and lifecycle data

Wallbridge and Gilbert (2006), Wastewater Collection Systems Comparative Merits, LGA South Australia

Arup (2011), Greenhills Beach Options Report, Australand / Sydney Water

JEA (Jacksonville Electric Authority) grinder pump programme operational data, publicly available

Watercare Services Ltd, Auckland — pressure sewer operational reports (public)