Authors: Sylvie Chell[a*], Matthew Robert Moore[a], Jonas Larsen[b], Ruby Naomi Michael[a]

[a] Green Infrastructure Research Labs (GIRLS), School of Engineering and Built Environment, Griffith University, 170 Kessels Road, Nathan, 4111, Queensland, Australia

[b] City of Logan, 150 Wembley Road, Logan Central, 4114, Queensland, Australia

* Corresponding author: s.chell@griffith.edu.au

Given name	Family name	Email address
Sylvie	Chell	s.chell@griffith.edu.au
Jonas	Larsen	jonaslarsen@logan.qld.gov.au
Matthew	Moore	matthewmoore@live.com.au
Ruby	Michael	ruby.michael@griffith.edu.au

Recommendations for improving the design, amenity and performance of privately owned, small-scale biobasins

Keywords: bioretention, biobasin, biopod, WSUD, water sensitive urban design, nature based solutions

Abstract

Due to spatial constraints in cities, it is increasingly challenging to integrate appropriate water sensitive urban design (WSUD) solutions. There has been a shift from larger, precinct-scale bioretention systems owned by local governments to smaller scale 'biobasins' managed by private landholders. This shift has brought about unique challenges in regulation, design, maintenance, and performance, while also intensifying the pressure to deliver high-quality amenity outcomes. This research triangulates: literature, site analysis of small, privately owned biobasins, and practitioner interviews in Southeast Queensland, Australia to inform the best practice design for functional biobasins that also contribute to public amenity value.

Fourteen biobasins on private land were critically evaluated through site visits, review of design and maintenance documentation and historical site images with an emphasis on the long-term health of the designed plant communities. About one third of the biobasins (n=4/14) had a deep (>1m) drop from the surrounding ground level to the filter media surface, restricting access for maintenance and leading to poor amenity outcomes.

Half (n=7/14) of the biobasins were fenced and three of the fenced basins further severely restricted maintenance by having no gate. Visual amenity of biobasins was low as exposed hardscapes limited the visibility of plants and basins failed to establish healthy target vegetation coverage. A lack of adequate maintenance access was strongly linked to low amenity biobasin outcomes with all basins that lacked gates showing weed intrusion and a low average amenity rating of 1.33/5. Practitioner interviews revealed concerns about herbicide-based interventions and site revisits after a minimum of 6 months confirmed the suspected lack of maintenance. As-designed species richness was low with an average of three species per biobasin and a minimum of one (monoculture). A higher plant species richness may lead to faster and sustained green coverage establishment and may reduce the required maintenance efforts and expenses. This study found the linear design process to be a major barrier to achieving good biobasin outcomes on private land. Expertise on plant requirements needs to be included early in the design process and independent actors should be enabled to collaborate across disciplines.

We recommend decreasing the depth and encourage pro-active maintenance regimes similar to publicly owned bioretention basins. Until the design barriers are remedied to make the systems easier to maintain and access, we are unlikely to see bioretention management plans practically implemented or high-quality amenity outcomes.

1. Introduction

Bioretention assets are commonly deployed to collect, filter, and purify stormwater on-site before it enters receiving waterways. They typically achieve this with a porous sandy loam filter media and pollutant uptake by plants and microbial populations (Szota et al., 2024). With increasing density of development these assets are commonly integrated into streetscapes, car parks and civic spaces. Simultaneously there are strong drivers for them to enhance the local environmental, social and cultural amenity by beautifying and softening the urban landscape (Water by Design, 2014b, p. 68). Local government city plans increasingly include requirements for visual amenity and landscape character for biobasins in addition to their primary water quality objectives (Tara & Thrupp, 2018).

Biobasin performance is seldom measured. Instead, we rely on the condition assessment of various components as indicators of likely performance. These include civil components like the inlet, outlet and sediment forebay, the filter area, ancillary components like maintenance access, and environmental components like vegetation cover / assemblage and weed intrusion (Kavehei et al., 2023). Of these, the presence of a healthy plant community is perhaps the most difficult to sustain over time and the most obvious sign of biobasin environmental success or failure. A healthy vegetation cover enhances the aesthetics of biobasins and serves as a proxy for effective filtration, dewatering through transpiration, and nutrient uptake by plants (Técher & Berthier, 2023).

Therefore, local benchmarks for biobasin vegetation establishment success in Queensland include: 90% plant survival, greater than 80% plant coverage, greater than one plant species and at least 5 plants/m^2 (preferably 6 - 10 plants/m^2). Furthermore, during establishment, plant height should increase by at least 50%, propagation should occur , and no weeds should be present Water by Design (2022). However, some local governments in Australia have set higher benchmarks, for example, a minimum of four species for rain gardens with a filter area $\leq 30m^2$, and six species for bioretention systems from $30m^2$ to $100m^2$ filter area (Blacktown City Council, 2022). Despite these intentions, a study on the Gold Coast, Queensland, found only 7% of systems within the local government area were achieving their >90% plant coverage benchmarks (McLeod, 2017).

A known cause of vegetation failure is the smothering of plants by sediment accumulation in poorly designed bioretention systems (Water by Design, 2012b) but also low permeability and uneven surfaces, blockages in the civil components and invasive weeds (Kavehei et al., 2023). Civic space biobasins that include shrubs and trees (canopy layer) in addition to understory plants like grasses and sedges have been observed to function well and the inclusion of a canopy layer of “appropriate tree species” is said to lead to less maintenance requirements due to shading out of weeds and self-mulching (Water by Design, 2015, 2022). Concerns about root ingress of trees into underdrainage have been mostly debunked, under the conditions that under-drainage pipes are designed and installed correctly to not hold water (Lim et al., 2021; Water by Design, 2022) and appropriate tree species are chosen (Dalrymple, 2012).

Climatically tailored plant species lists for Australian biobasins include groundcovers, shrubs, and trees that are proven to survive the periodical inundation and drought of bioretention systems and aid in water treatment (Water by Design, 2020). Szota et al. (2024) compared nine native Australian shrubs to the frequently specified biobasin sedge *Ficinia nodosa* and promotes the benefits of including woody species in biobasin design. Woody plant traits like high biomass accumulation and high root length establishment are known to enable high transpiration rates and to sustain infiltration rates under sediment loading scenarios while also being able to assist in pollutant removal (Payne et al., 2018; Read et al., 2008). However, woody species and ecologically based designs are less common in practice and there is a need to move away from prescriptive species lists towards more holistic considerations of ecology and visual amenity (Larsen & Michael, 2024).

Bioretention assets exist at different scales from precinct scale (largest) to smaller systems like biopods, rain gardens, or biobasins that are generally about 5-50 m^2 in size (Water by Design, 2015). Increasing urban sprawl and infill development has resulted in a shift towards smaller, biobasins situated on private land. These on-lot biobasins face unique challenges with their design and integration as they compete for land area with other site components, including building footprint, private recreational space, public recreational space, car parking, and driveways. The aim of this study is to improve amenity and water quality outcomes for biobasins on private land with an emphasis on the long-term health of the designed plant communities. The following three objectives assist the fulfilment of the study aim: 1) To evaluate the design and condition of current biobasin assets; 2) to gain insights from experienced biobasin practitioners; and 3) to integrate insights into best practice recommendations for biobasin design on private land. This was achieved by triangulating insights from the literature, site visits and documentation review of biobasin assets and practitioner interviews.

2. Methodology

This research first explored existing literature on biobasin design, performance, and failure modes. Secondly, local biobasins occurring on constrained infill sites were investigated through observational site visits and documentation review. Lastly, semi-structured interviews were conducted with local government, and consultancy involved in biobasin design, approvals, construction, or maintenance. These three elements were triangulated to form an overall picture of biobasin design and performance on private land.

2.1 Literature and practice review

A literature search in scientific databases 'Web of Science' and 'Google Scholar' was conducted using the keywords: [Bioretention AND biobasins AND biopod] AND [small scale AND constrained AND civic] AND [performance AND filter media AND specification* AND planting methods AND density AND irrigation AND saturated zones AND signage AND maintenance]. Prior to conducting this study, the research team also visited biobasins across the Gold Coast, Moreton Bay, and Logan local governmental areas (Figure 4, Supplementary material). This was done to establish a foundational knowledge and experience of biobasin design and landscape integration across the region for small-scale, public and privately owned assets.

2.2 Biobasin site analysis

There has been a concentration of bioretention research in the humid-subtropical climate (Köppen-Geiger classification Cfa) in the USA and Australia (Corduan & Kühn, 2024) which includes Southeast Queensland (SEQ) where this is study is situated. All publications from the local peak body for bioretention assets were consulted (Water by Design, 2009, 2012a, 2012b, 2012c, 2014a, 2015, 2020, 2022, 2023a, 2023b) as bioretention systems have been implemented in Queensland since 2001 and received a lot of government and research attention (Water by Design, 2015).

Fourteen privately-owned biobasins in Southeast Queensland were selected for analysis. The 14 biobasins ranged in size from 6 m^2 to 166 m^2, with an average size of 44 m^2. The maturity of the systems ranged from 1 year to 13 years, with an average age of 6 years.

Documentation from the development applications was provided by the local government for the chosen basins and they were inspected twice during the one-year study duration with site visits being a minimum of six months apart (mid 2023-early 2024) to assess vegetation cover, visual amenity and maintenance efforts.

2.2.1 Impact factors on biobasin condition

Data collection during site visits included observations on the following impact factors for biobasin condition: the filter area (sediment accumulation, presence of cryptogam cover, scouring, presence of mulch, weediness, green coverage estimate), and ease of maintenance (including accessibility and depth of the systems), and whether signage or permanently installed irrigation fixtures were present. Green coverage was ranked on-site as 1= very low (≤10%), 2= low (>10% ≤30), 3= acceptable (>30% ≤50), 4= good (>50 ≤70%), 5 = very good (≥80%).

The site visits were supplemented with review of each basins documentation and historical satellite images using Nearmap (2025). Analysis of satellite imagery gave insights into the history and maintenance success of the systems before the site visits. Data extracted from the design and development documentation included the size, shape, age, and filter media depth of the biobasins.

2.2.2 Vegetation specification and performance

Vegetation related information was obtained from the design and development documentation, and plant survival was further verified by site visits. Plant success (as occurrence of specified target species in visited basins) was assessed during site visits. Gathered data included target species, species richness (total number of different species present in the biobasin) and plant community, planting density and planting method of the biobasins. Plant families, growth forms, and habitats of each species used in the biobasin sites were researched to gain additional insights into plant designs.

2.2.3 Visual amenity

Visual amenity was assessed at pedestrian level using criteria developed in conjunction with the local government with ratings refined by the research team. Six contributing factors to visual amenity at pedestrian level were assessed and scored (Table 1). In accordance to the scores received for the contributing factors, visual amenity as seen from the streetscape was then classified from one (very poor) to five (very good).

Table 1 Assessed contributing factors to visual amenity & streetscape amenity ranking of biobasins

Contributing factors to visual amenity	
Criteria	**Description / details**
i) Sympathetic spatial integration into the landscape	Substantial volume of plants visible that contribute to the local landscape character. For example, greater depth means poorer integration.
ii) Visual interest provided to the streetscape	Vegetation diversity by species, in colour, form, height.
iii) Health of the system	Lushness, living green coverage provision of target species.
vi) Weediness	Absence of weeds.
v) Waste accumulation	Absence of waste.
vi) Extent of hardscape elements	Absence of bare retention walls, fences.
Streetscape amenity ranking of biobasins	
Ranking	**Description**
1 (very poor)	Biobasin visually distracting from the streetscape (scoring ≤1 when assessing visual amenity factors).
2 (poor)	Scoring 2.
3 (moderate)	Featuring 3 of the factors, i) including substantial visible plants.
4 (good)	Featuring 4-5 of the factors (including i) substantial visible plants, ii) diversity, and iii) health of the system.
5 (very good)	Biobasin is visually adding character to the streetscape and scoring for every contributing factor to amenity.

2.3 Practitioner interviews

Eight (8) semi-structured practitioner interviews were conducted with an average duration of 51 minutes. Participants expertise covered design and engineering (n=4, including stormwater engineering and landscape design), maintenance (n=2), and implementation (local government, n=2). The experts had a combined 125 years of experience with biobasins, with five of the experts having worked on biobasins since the early adoption of the systems in Southeast Queensland. Some experts had experience in more than one of the fields listed above but are categorised by their primary area of experience.

Interviews explored the reasoning for engineering and amenity design choices and maintenance decisions as well as the learnings from ongoing practice. Interviewees were asked about their experiences with biobasin best practice tailored to their area of expertise. To allow for a qualitative analysis of themes from the stakeholder interviews, formal research ethics approval was obtained from Griffith University's Ethics Committee (GU Ref No: 2024/369).

3. Results

3.1 Biobasin site analysis

3.1.1 Impact factors on biobasin condition

Four of the basins (~29%) had a narrow and elongated shape, as opposed to wider basins. Condition assessment of the fourteen biobasins revealed that the filter media surface showed cryptogam cover in ~29% of basins (n=4), sediment deposition in 21% (n=3), and mulch was present in ~14% (n=2) biobasins (Table 2). Additionally, 21% of biobasins (n=3) could not be verified due to extensive leaf litter or vegetation coverage. None of the basins had signage and only one of the recently installed basins had installed irrigation fixtures.

Table 2 Investigated impact factors of biobasins during document review and initial site visits to biobasins in 2023

Investigated impact factors	Findings from biobasin site analysis
Filter media	
Sediment accumulation	in n=3/14 biobasins.
Cryptogam cover	29% of basins (n=4/14), No = 7, Unknown = 3.
Scouring or unevenness	of filter media n=5/14.
Mulch	Generally absent or washed away. One of the four establishing ≤ 1 year old biobasins had pinned down sugar cane mulch present and a three-year-old biobasin had hardwood mulch (as did the conventional landscaping in beside it).
Presence of weeds	50% of the Biobasins (n=7).
Green coverage	Very low-low green coverage (n=4), acceptable (n=5), good (n=4), N/A as in early establishment (n=1).
Maintenance	
Ease of maintenance (access, depth)	7 biobasins fenced, 3 of those had no access gate. Four biobasins (~29%) were difficult to access.
Signage	None.
Irrigation	No permanently installed irrigation fixtures visible in~93% (n=13/14) biobasins.

3.1.2 Vegetation specification and performance

Examining the design documentation for the 14 biobasins, the average specified species richness was 3.2 (Table 3) and the remaining target species richness during the second site visit was 2.4 (reduced by ~24%).

Plant maturity at installation varied with groundcovers and herbaceous plants generally being installed as tubestock, and larger, shrubby species or trees being larger, ranging from 140 mm to 45 L pots.

Table 3 Planting specifications and success in the 14 biobasins selected for analysis

Specified species richness in original design	Lowest specified as monoculture, highest six species and average ~3 species.
Planting density	Ranged from 3 plants /m^2 to 11/m^2 and was vegetation community dependent. Most specified was 4 plants/m^2 (n=5).
Planting method (maturity & size)	Mostly tubestock for groundcovers, shrubs like *Banksia robur* in 140-300 mm pots and trees like *Waterhousea* sp. In 45 L pots.
Plant community (as per design)	13 different plant species from 6 families were specified. Lowest species richness was a monoculture (19 m^2 biobasin) and two species in the second smallest (10 m^2) biobasin. The most prevalent habitat was freshwater wetland. Growth forms dominated by clumping, followed by tufted, shrubs and trees.
Plant success (as occurrence of specified target species in visited biobasins)	*Lomandra hystrix* and *Lomandra longifolia* (Asparagaceae), *Banksia robur* (Proteaceae), and *Melaleuca* 'candy pink' (Myrtaceae) had the highest success rates of the species that were used in more than one basin.

Vegetation specifications included 13 different species (Table 4): *Lomandra hystrix* (n=9), *Ficinia nodosa* (former *Isolepis nodosa*, n=9), *Banksia robur* (n=7) were the most commonly used, followed by *Carex appressa* (n=5), *Juncus usitatus* (n=3), *Gahnia sieberiana* (n=2), *Lomandra longifolia* (n=2), *Melaleuca* 'candy pink' (n=2), with the following species used on only one occasion: *Carex fascicularis* (n=1), *Cymbopogon refractus* (n=1), *Gahnia aspera* (n=1), *Poa labillardieri* (n=1), *Waterhousea floribunda* (syn. *Syzygium floribundum*, n=1).

Specified species belonged to six plant families, including Cyperaceae (n=5), Asparagaceae (n=2), Myrtaceae (n=2), Poaceae (n=2), Juncaceae (n=1), and Proteaceae (n=1).

Growth forms of the plant species used in the biobasin sites (Table 4) included clumping sedges, rushes and grasses (n=8/13, ~62% of plant species), tufted sedges and grasses (n=2, 15%), shrubs (n=2, 15%) with trees only used on one occasion (n=1, ~8%).

Table 4 Plant species used in the biobasin sites *Note: the one basin without survival was sprayed with herbicides. Habitat extracted from (Leiper et al., 2019).

Species (Common name / cultivar)	Growth form	Family	Specified (count of biobasins)	Survival [presence per basin]	Habitat(s)
Lomandra hystrix (Creek mat rush)	Rush, clumping	Asparagaceae	9	8, ~89% *	Freshwater wetland, along creek banks
Ficinia nodosa (Knobbly club-rush)	Sedge, clumping	Cyperaceae	9	5, ~56%	Freshwater wetland, sandy coastal swamp
Banksia robur (Swamp banksia)	Shrub, erect, multi-stemmed	Proteaceae	7	6, ~86% *	Freshwater wetland
Carex appressa (Tall sedge)	Sedge, clumping	Cyperaceae	5	1, 20%	Freshwater wetland, along creeks
Juncus usitatus (Common rush)	Rush, clumping	Juncaceae	3	0, 0%	Freshwater wetland, damp areas
Gahnia sieberiana (Red-fruited Sawsedge)	Sedge, clumping	Cyperaceae	2	1, 50% *	Coastal heath
Lomandra longifolia (Spiny-headed mat rush)	Rush, clumping	Asparagaceae	2	2, 100%	Eucalypt forest, watercourses rainforest edges and in drier areas
Melaleuca cultivar 'Candy Pink'	Shrub	Myrtaceae	2	2, 100%	Not applicable (cultivar)
Carex fascicularis (Tassel sedge)	Sedge, tufted, erect	Cyperaceae	1	0, 0% *	Freshwater wetland, creek banks, swamps
Cymbopogon refractus (Barbed-wire grass)	Grass, clumping	Poaceae	1	0, 0%	Eucalypt forest, woodlands, grasslands, coastal areas
Gahnia aspera (Large-fruited Sawsedge)	Sedge, clumping	Cyperaceae	1	0, 0% *	Eucalypt forest (open)
Poa Labillardieri (Tussock grass)	Grass, tufted	Poaceae	1	0, 0% *	Eucalypt forest, creek bank or moister elevated area
Waterhousea floribunda (Weeping Lilly Pilly)	Evergreen tree	Myrtaceae	1	1, 100%	Rainforest, along shady watercourses

Accounting for the combined survival of species per family in the investigated basins, the most successful families were: Myrtaceae (100% survival, 2 species specified in 3 biobasins) > Asparagaceae (~91% survival, 2 species specified in 11 biobasins) > Proteaceae, represented by *Banksia robur* (~86% survival, in 7 biobasins) > Cyperaceae (~39% survival, 5 species in 11 biobasins). This makes Asparagaceae (formerly Laxmanniaceae, ~79% of biobasins, n=11) and Cyperaceae (~79%, n=11) the most successful plant families.

3.1.3 Visual amenity

During the initial site visit, none of the biobasins provided very good amenity, only three (~21%) provided good amenity value (Figure 1) and moderate amenity was achieved by one biobasin (~7%). The majority of biobasins provided poor amenity (n=6, ~43%) or very poor amenity (n=4, ~29%, Figure 5, Supplementary material).

During the second visit, none of the biobasins increased in amenity value but almost a third of the biobasins (n=4) decreased in score due to weed intrusion (n=3) or due to plant dieback, decreased vegetation health, and waste accumulation (n=1).

The contributing factors to visual amenity at pedestrian level that were encountered the most were the absence of waste (~64%), followed by the absence of weeds (~57%), while the health of the system was achieved by half of the basins (50%). Biobasins amenity was impacted by the presence of hardscapes (found in ~43% of basins), low visual interest provided to the streetscape (diversity, achieved by ~43%), and by the sympathetic spatial integration into the landscape (achieved by only ~36% of basins).

When considering age, more recently installed biobasins of ≤ 2 years (n=5) showed poor visual amenity with an average rating of 1.6, being below the average rating of 2.2 of all the investigated biobasins.

Figure 1 Example of high visual amenity. Biobasin with structural diversity and stratification of healthy vegetation. While including hardscapes like fencing and a retaining wall, the native tree was visible from the street, providing some amenity.

3.2 Practitioner interviews

The main themes of the interviews are summarised in Table 5. Half of the interviewees raised concerns about the suitability of privately owned and maintained biobasins and reported to have previous experience with and perceiving these biobasins as commonly neglected systems. Larger, local government owned bioretention systems were seen as favourable due to easier integration and the potential to use natural batters in place of retaining walls.

One element of design that had a strong positive practitioner confidence, was mulching. While one interviewee refrained from comment as did not have expertise with mulch, all others (n=7) were in favour of mulching biobasins. Three practitioners recommended sugarcane mulch and four highlighted that mulch should be pinned down. One interviewee was not in favour of sugarcane as mulch due to its fast decomposition.

Areas where there was lower confidence or concern included changes to filter media and plant communities as well as a high level of uncertainty about irrigation requirements. Practitioners expressed the need for further research prior to increasing the organic content of filter media which might lead to improved plant performance but could potentially affect nutrient leaching. They were interested in a more diverse plant palette and in some cases increasing the number of flowering species was also expressed by the practitioners (Table 5).

Table 5 Interview core theme summary (n=8)

Themes	Interviewee responses (consensus)	Alternative opinions or suggestions
Mulching	Preferred, for example pinned-down sugarcane mulch due to retaining water in the system.	One not in favour of sugarcane mulch (fast decomposition).
Irrigation	Requirements are not well known by designers, but usually seen as part of maintenance, one interviewee highlighted the importance of seasonal irrigation schedules, while another recommends riser pipes during establishment that are later cut to encourage root growth.	
Media composition	Current media specifications generally seen as suitable, if proper system design and maintenance are ensured. Healthy systems are seen to receive nutrients through stormwater and build own biology over time.	The health of plants might benefit from more organic content in the filter media, but this needs further investigation. Need to be aware of slumping / compaction and reduction in hydraulic conductivity and the impacts on plants.
Planting	All participants agree that biobasins are not planted with enough species diversity. The current (local for SEQ) Water by Design plant list might need a review, and some practitioners rely too heavily on a limited number of species (particularly a small number of macrophytes).	Some practitioners are interested in including more flowering species, shrubs and trees. More shrubs should be encouraged (mentioned genera included *Callistemon*, *Melaleuca* and *Banksia*).
Integration into landscape and amenity	Currently poorly integrated (appear as separate entity) and create issue at property frontage due to line of sight. Detention for flood mitigation needs to be detached from small biobasins. Healthy vegetation crucial for amenity value. Retaining walls are considered unsightly.	Four interviewees highlighted concerns about privately owned biobasins and advocated for local government operated systems with natural batters that resemble bushland. One suggested park-like bioretention systems with seating on the batters - Industrial estates could use those as restorative natural spaces for workers.

<table>
<tr><td>Design process</td><td colspan="2">Needs to involve more stakeholders, be more flexible to address site constraints, and requires additional time for practitioners to meaningfully collaborate. Particularly landscapers, horticultural professionals, ecologists and the community were mentioned as stakeholders that need to join the design process.</td></tr>
<tr><td>Challenges of small scale biobasins</td><td colspan="2">Detention depth requires high walls and safety fences, and the compliance of small-scale assets in private ownership is hard to monitor and police. Biobasins might not be the best solution for every context (they may be unsuitable for very steep or flat sites).</td></tr>
<tr><td>Pipeless or lined designs</td><td colspan="2">There is no consensus among practitioners. While pipeless systems ensure access to natural ground, lined systems with saturated zones may support plants in times of drought.</td></tr>
<tr><td>Management and maintenance</td><td>It is crucial to detect failure modes early through regular inspections. However, it is uncertain whether biobasin management plans reach maintenance personnel. Maintenance access is not always considered enough. Body corporates should be obliged to prove that management plans from the development application have been passed on. Most practitioners see privately owned assets as generally poorly or not maintained and also note issues with illegal dumping by the public. Foreign investors are mentioned to have low interest in maintaining high amenity biobasins after property development. Private contractors are observed to use unskilled labourers and herbicides instead of best management practices.</td><td>Some stakeholders say maintenance access is generally considered in the design.

Note by authors: this was not consistently observed in the biobasin site analysis (Table 2).</td></tr>
</table>

3.3 Barriers and best practice

After triangulation of literature, analysis of biobasin sites and practitioner insights, barriers to the amenity provision and performance of small scale, privately owned biobasins have been distilled and best practice solutions proposed (Table 6).

During the site visit of one of the investigated biobasins, the research team asked permission to closer inspect a biobasin that was difficult to view from a public vantage point but was denied access. While talking to the biobasin owner, it was evident that there was limited knowledge of the maintenance of the 10-year-old biobasin, which raises concerns about existing management plans being passed on to maintenance contractors.

When comparing insights from site visits to biobasin documentation, discrepancies were evident for mulching and maintenance activities, which did not match the included management plans. Best practice management plans in the development applications generally stipulated hand weeding and plant replacement, the implementation of both were not evident from recurring biobasin site visits or historic satellite imagery.

Table 6 Summary of insights and recommendations from site visits and practitioner interviews

Barriers	Solutions
Low amenity value due to plant failure because of poor design or a lack of maintenance / -access.	o Including horticulturists and landscape designers early in the planning stage o Ensuring easy maintenance access by design (gates, ramps) o Educating and upskilling maintenance personnel on best practice biobasin care (for example in avoiding herbicides) o Use of signage to inform maintenance personnel and the public on the function of biobasins o Encouraging proactive maintenance regimes with early failure mode detection o Potentially introducing a requirement for record keeping of asset owners or independent assessment by certified third party
Vegetation diversity and visual interest of current biobasins is low.	o Potentially Increase vegetation diversity in height, colour and growth form to add visual interest o Introduce stratification to enhance visual amenity and simultaneously reduce maintenance requirements o Species selection and layout in accordance with an experienced landscape architect or vegetation ecologist; considering the character of the site and surrounding environmental context o Planting density of greater or equal to six plants per square meter o The use of shrubs and flowering species can introduce additional variety and amenity
Mulch was often not encountered at poorly performing biobasin but can support vegetation success.	o Use of pinned down sugarcane mulch (jute netting with biodegradable pins) as recommended by bioretention design guidelines as well as interviewed practitioners o Single grind / larger sized hardwood mulches with slow decomposition should also be considered o Alternatively fast coverage achievement of target species needs to be ensured through design (adjusted planting densities, growth forms and species diversity to minimise opportunities for weed intrusion)
Good integration of biobasins into the landscape is often hindered by ambitious detention goals in addition to the stormwater filtration function, leading to deep systems which require fall protection (usually high fences) while simultaneously making maintenance access more difficult.	o Potentially use of a higher number of smaller systems with deeper filter media to reduce the required added detention depth of a system o Flood mitigation objectives may need to be detached from small bioretention systems and underground tanks could be considered instead o Creative solutions for stormwater detention are needed to not overbear small bioretention systems with dual functionality (for example design temporary low-depth detention into other areas such as carparking) o Water by Design recommends 200 mm of maximum water levels on top of extended detention depths of 200 mm for constrained bioretention situations that should be adhered to o To increase frontage amenity, hardscapes can be enveloped by climbers and external shrubbery / high quality landscaping in front of biobasins

4. Discussion

After triangulating literature, biobasin site analysis data and practitioner insights, a large discrepancy was noted between the success parameters outlined by the local industry body and practice for small scale, publicly owned biobasins. Performance indicators like 90% plant survival, greater than 80% coverage, preferably more than one species, at least 5 plants/ m^2, but preferably 6 – 10 plants/ m^2 and no occurrence of weeds, were frequently not achieved by the investigated basins. These performance indicators are in agreement with the overall negative practitioner sentiment towards constrained, privately owned biobasins. The following sections will discuss reasons for this low performance and propose solutions.

4.1 Defining the problem for small-scale biobasins on private land

Practitioner insights revealed a situation where actors that are positioned later in the design and operational phases of biobasins have limited influence on the practitioners before them. Therefore, they must work with the resulting constraints of not being able to influence outcomes early in the process (Figure 2). Usually, the linear process starts with a stormwater engineer preparing a stormwater management plant for the site to include in the MOU (Material Change of Use) during the development application. Following this, the construction documentation is prepared and built structures like biobasins are sized for inclusion in the building application. As a last design step, the landscape construction documentation is included in the landscape operational works application, with landscape designers or landscape architects being limited by locations and sizes of biobasins from the previous steps. While some city plans recommend that landscape architects prepare a site analysis to inform how a site gets developed, this step is not often encountered in practice. The following construction and maintenance phases of biobasins also do not allow for feedback about the design choices to the practitioners involved in the design of the biobasins.

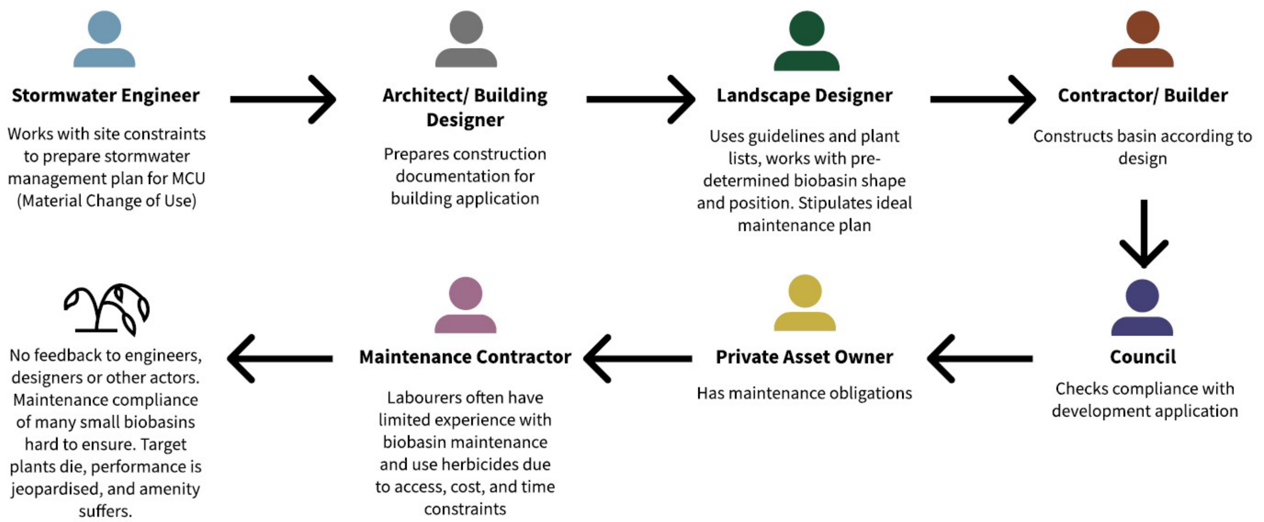

Figure 2 Simplified, linear biobasin design and operational phases, highlighting the lack of feedback between actors involved in design and operation through the one-way direction of arrows.

Research insights from site analysis and interviews show that this disconnectedness of practitioners is one reason that leads to poor outcomes for biobasin amenity and performance, due to plant failures and weed intrusion. The current design process does not allow for feedback loops to occur and therefore lacks self-correction mechanisms to improve future designs. This is also evident in the lower average visual amenity of more recently installed basins ≤ 2 years when compared to the average of all investigated basins. Until the issues with biobasin design processes are rectified, maintenance efforts will remain limited in their long-term impact on biobasin performance and amenity.

4.2 Design elements and impact on performance

Only half the analysed biobasins were considered healthy with four of fourteen biobasins achieving good green coverage (~29%). Likely due to budget allocation and design constraints in tandem with a lack of knowledge about biobasins and their importance, privately owned, small systems have a reputation for being neglected. As a consequence, many biobasins are expected to have reduced performance of their main aim of stormwater treatment instead of providing multiple secondary benefits. Visual condition is correlated with system performance, as plants contribute to the filtration capacity of biobasins and maintain the hydraulic conductivity of the filter media through root development. To reduce ongoing maintenance efforts while ensuring biobasin performance and aesthetics, good target species coverage is necessary (Water by Design, 2014b). Extensive coverage reduces weed intrusion and aids stormwater objectives by water and pollutant uptake. It is therefore critical that stormwater engineers need to ensure plant health as a primary consideration during design, and if this is not within their primary area of expertise, it is crucial to consult with a botanist, ecologist, ecological engineer or landscape designer to ensure correct plant selection. Additionally, a compromise between hydraulic conductivity and a filter media that supports healthy plants by providing the required organic content for plant sustenance needs to be reached (Larsen, 2018). Specified species diversity was generally low and reduced further by about 35% as the biobasins aged. It is a well-established concept in ecology that monocultures and low diversity plant communities are more prone to failure, as they are susceptible to specialised pests, diseases, and lack differentiated adaptive strategies towards harsh environmental conditions that may be more favourable towards one species than another. Designing high-diversity, resilient plants communities with complimentary functional traits can ensure all performance parameters of a biobasin are met, including pollutant removal, plant survival, water uptake, and ensuring long-term porosity of the filter media. In addition, strategic plant placements can introduce shading where needed. This study also found that local biobasins showed a limited vegetation diversity in height and leaf structure, leading to limited stratification, which can have flow on effects beyond aesthetics to a limited stormwater filtration performance. A recent review has determined the general importance of vegetation type in maintaining infiltration rates of bioretention systems to grasses < shrubs < trees (Técher & Berthier, 2023). Additionally, local guidance has also recommended the combined use of grasses, sedges, shrubs, and trees to prevent filter media clogging (Water by Design, 2014b, p. 134). The use of trees was rare in the visited biobasin sites, with only one species of tree used (*Waterhousea floribunda*). While half the biobasins included shrubs, this was mainly limited to one species (*Banksia robur*, Proteaceae) with two of the basins also having a second shrub present (*Melaleuca* ‘candy pink’, Myrtaceae). This is despite the high survival rates of the used tree and shrub species, which should encourage the use of more shrub and small tree species. The high prevalence of clumping and tufted macrophytes in the designed plant communities might be one reason leading to biobasins experiencing reduced infiltration rates, sediment accumulation and, as a result, higher failure rates. Incorporating higher structural diversity, might enable long-term performance and prevent plant die back caused by sediment accumulation.

Overambitious goals (additional flood detention) lead to theoretically high performing designs, however, these often don't align with practicality in real word applications. Narrow and deep biobasins (n=4) limit sun availability to plants, while making maintenance activities more difficult for contractors. This modification of microclimatic site conditions needs to be improved for better plant establishment that aids in pollutant filtration and reduces weed infestations. Only about half of the deep biobasin sites had any maintenance access (gate), yet the depth of all the deep biobasins was prohibitive for meaningful maintenance interventions. Additionally, other basins were long and narrow while only providing maintenance access at one point, which makes maintenance including hand weeding of these systems similarly unfeasible once plants start to become established. Both issues (depth and narrow designs with limited accessibility), which were encountered in a total of 50% of the biobasins lead to herbicide spraying, or a complete lack of maintenance and negatively influences water quality and amenity outcomes. While signage could educate the public and alert labourers to the existence of maintenance documentation, it is unsightly, and the idealised maintenance regime often tedious, time consuming and not aligned with common practices used by maintenance contractors.

Mulching was seen as beneficial by practitioners but not often observed during site visits. During the second visit to inspect the biobasins, one of the two mulched basins (~1 year of age) had severe weed intrusion, meaning the planting density of target species to maintenance ratio were not favourable and mulching alone without maintenance inputs may not effectively reduce weed encroachment, particularly early on during establishment. While the use of the practitioner recommended pinned-down sugarcane mulch can assist in plant survival by reducing water evaporation and slowly releasing nutrients during its breakdown, it does not replace suitable plant designs with site-tailored planting densities and plant communities.

Previous publications have highlighted inherent difficulties of field research as a result of poor design and uncertainties in biobasin construction and maintenance (Cooperative Research Centre for Water Sensitive Cities, 2020, pp. 8-15). Our research encountered this for small, privately owned biobasins, as even consulted biobasin owners were not aware of existing maintenance plans or how their biobasins were to best be maintained.

Improving biobasin integration into the landscape is important, as it can lead to positive community interest, creating a sense of place, added visual interest and improved amenity. Prominent focal point locations also require biobasin owners to maintain biobasins effectively, if they want to uphold a positive image. This study highlighted how poorly integrated basins were commonly sunk-in, with no vegetation tying in the basin with the street frontage, detracting from the landscape character. The biggest impediment to providing visual amenity was that vegetation was not utilised as a landscape feature or contributing to site aesthetics in most of the biobasin sites. A core finding of this research is that the requirement for fall protection fencing diminished aesthetic values, as a result of poor biobasin integration. Issues with deep systems have previously been acknowledged by designers to reduce visual impacts and require risk assessments (Water by Design, 2014b, p. 43). Alternatively, carpark bioretention on private land in three of the biobasin sites eliminated the drop off by introducing stoppers and adding trafficable surfaces, leading to minimised footprints of the biobasin. To create visual impact the standard shape of a rectangular pit could also be varied to include more natural shapes, or the vegetation structure could be increase by adding trees. For shallow basins, trees can be included in feature tree pits, that extend beyond the main depth of the biobasin.

4.3 Institutional interventions

Besides the protection of receiving aquatic systems like streams and rivers, bioretention systems can play a role in achieving a multitude of additional strategic objectives like contributing to urban tree canopy coverage targets, biodiversity, carbon sequestration, air quality, and the provision of visual amenity in high-density developments (Su et al., 2024). A desire to realise this was expressed by practitioners but is not currently evident in built biobasins. The cost efficiency of creating multi-benefit biobasins, should be highlighted to asset owners. This could include explaining the reduced ongoing lifecycle costs of proactively managed, healthy biobasins and co-benefits like passive recreation, cooling, and company image to biobasin owners.

While reviewed documentation generally had detailed maintenance plans included, it is questionable whether these are handed down to maintenance personnel in practice. Regular maintenance does not seem to be the case, or it is not impactful for many privately owned assets, as judged by their state during site inspections, from historical aerial images over time, and from practitioner perspectives in interviews. Practitioners were generally not in favour of small privately owned assets, as they are aware of the lack of maintenance and the issue around reinforcing proper maintenance. Proactive and regular maintenance can help to achieve this by "prioritising maintenance budgets" and through designs that "introduce trees and shrubs into the filter media, providing benefits to the system and reducing maintenance costs" (McLeod, 2017). However, almost 1/3 of the biobasins were difficult to access for ongoing maintenance. These difficulties with maintenance that impede biobasin functionality and increase costs are not a new, nor an Australia specific issue, as the lack of appropriate maintenance has already been raised as core issue leading to biobasin failure in research over a decade ago (Blecken et al., 2015). The authors caution to abstain from maintenance activities that compromise water quality and recommend to "include factors-of-safety in the design", or by requiring annual inspections by a professional that can attest that the system is working as intended. It is difficult for local governments to monitor compliance with maintenance obligations of the many privately owned biobasins in the local government area. Local governments could combat this issue by requiring (automated) condition reporting including photographic evidence or maintenance records, random inspections and potential penalties for negligence. However, a mindset shift of property owners and developers to see biobasins as amenity assets that can add value to their residence or business through upkeep and maintenance is needed to facilitate lasting improvements.

To simultaneously improve long-term biobasin performance and amenity, this research has shown that practitioners involved in biobasin design and operation cannot operate independently in a linear fashion but need to collaborate from an early stage (Figure 3). This is to ensure the needs of later actors in the process are met though design. Multidisciplinary collaboration is needed to create "unique localities that reference local character and enhance a sense of place" (Water by Design, 2014b, p. 58). Landscape designers need feedback from maintenance contractors on plant performance so they can refine their species selection and layout, while identifying potential reasons for failure and stipulate actionable maintenance manuals. When landscape designers and maintenance personnel can communicate design parameters to aid plant health and maintainability, this can be considered by the layout and engineering specifications of stormwater engineers, who can size interventions like saturated zones and increased media depth. Maintenance contractors should consult engineers as to which type of access and biobasin shape is feasible for them to maintain, according to the tools used and employee safety requirements. A challenge to realising this cross-disciplinary collaboration is the question of which actor(s) can facilitate this. One option is that the design process needs to ensure that all actors are included in an iterative (non-linear) collaboration process to express every stakeholders' expectations and needs. A lead consultant could manage the team of subject experts, which is often the case in projects within the private sector. Alternatively, local governments could require documentation from the engineers, landscape designers and accredited maintenance contractors that the system is feasible from every stakeholder's perspective over the long term.

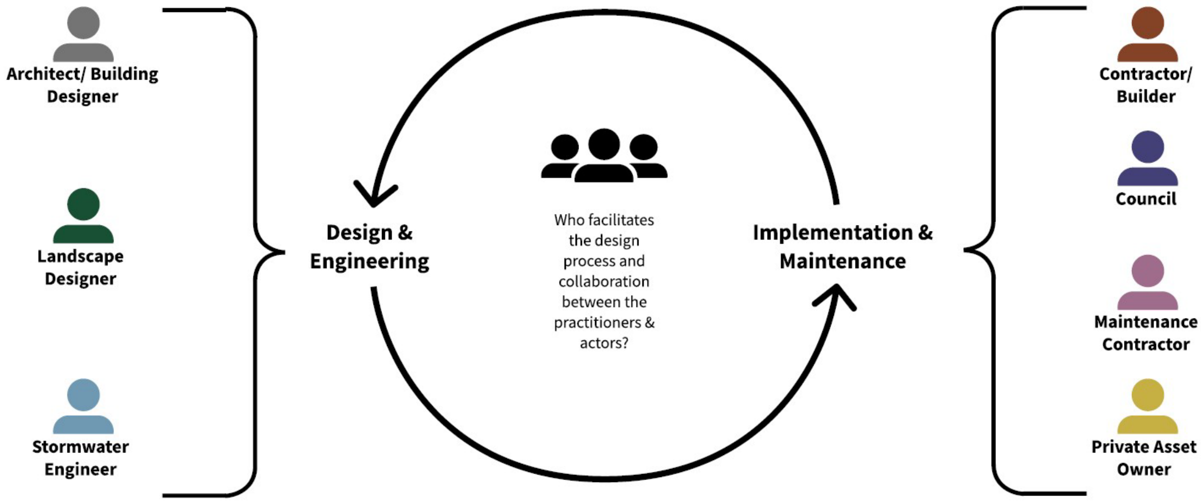

Figure 3 Biobasin design and operation processes, aimed to improve biobasin longevity and amenity, highlighting the need for iterative and collaborative processes that ensure feedback between actors involved in design and operation.

4.4 Limitations

Assessment criteria for visual amenity are inherently subjective and impacted by a variety of local and seasonal considerations. The research team took care to chose universally applicable criteria that are transferable to wider bioretention contexts and locations.

The qualitative research component is derived from practitioner perspectives and therefore limited by the number of consulted participants. However, a variety of experts with a combined practical experience of over a century was consulted to inform the findings of this paper from their unique perspectives related to design, engineering, maintenance and implementation of biobasins. The collection of quantitative primary data was possible due to the spatial extent of the visited biobasins spanning coastal Southeast Queensland. However, design process and failure mode implications have wider applicability than this region.

5. Conclusions

This study found that many of the small biobasins existing on private land have low amenity value and environmental performance. This is caused by spatially constrained designs which result in plant failure, low coverage of target species, a lack of maintenance access and a lack of responsibility taken by asset owners for biobasin performance and amenity. Biobasins sit at the intersection between urban design, engineering (hydrology) and ecology, making multi-benefit outcomes possible but challenging for the independent actors involved in their planning, construction and maintenance at various stages of the asset delivery pipeline. This study highlights the importance of improving the design process and combining form and function to achieve multi benefit objectives. Despite, problems throughout the asset delivery pipeline, fundamental design problems need to be addressed before any other problems can be remedied. If small-scale, privately owned biobasins are going to provide long-term functionality and add amenity to landscape character, there needs to be a shift in the design process to include professionals with plant expertise to design thriving biobasins with functional and beautiful vegetation communities. Additionally, maintenance access needs to be ensured through the design process by excluding designs that are excessively deep with high fences and creating solutions that are easy to access and well-integrated with surrounding landscaping. Further, specialised maintenance personnel need to be employed and provided with a realistic maintenance plan. Ideally, a well-designed biobasin system integrates into the landscape providing easy access and beauty, blending seamlessly with traditional landscaping for maintenance by contractors. To reduce maintenance costs and ensure the achievement of stormwater management objectives, biobasin functionality needs to be first and foremost ensured by design. Currently there is no avenue for local governments to assess compliance and functionality of privately owned biobasins over the life span of the assets. This could be improved by requiring automated reminders for asset condition reporting (with photographic evidence and maintenance records), or spot inspections with penalties for non-compliance. There is a need for further research into the use of supplementary irrigation, how the addition of organic matter to sustain healthier plants affects leaching, and plant designs that meet biobasin pollutant reduction performance alongside a need for more integrated, floristically diverse, aesthetically pleasing and ecologically enriched landscapes.

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7. Supplementary materials

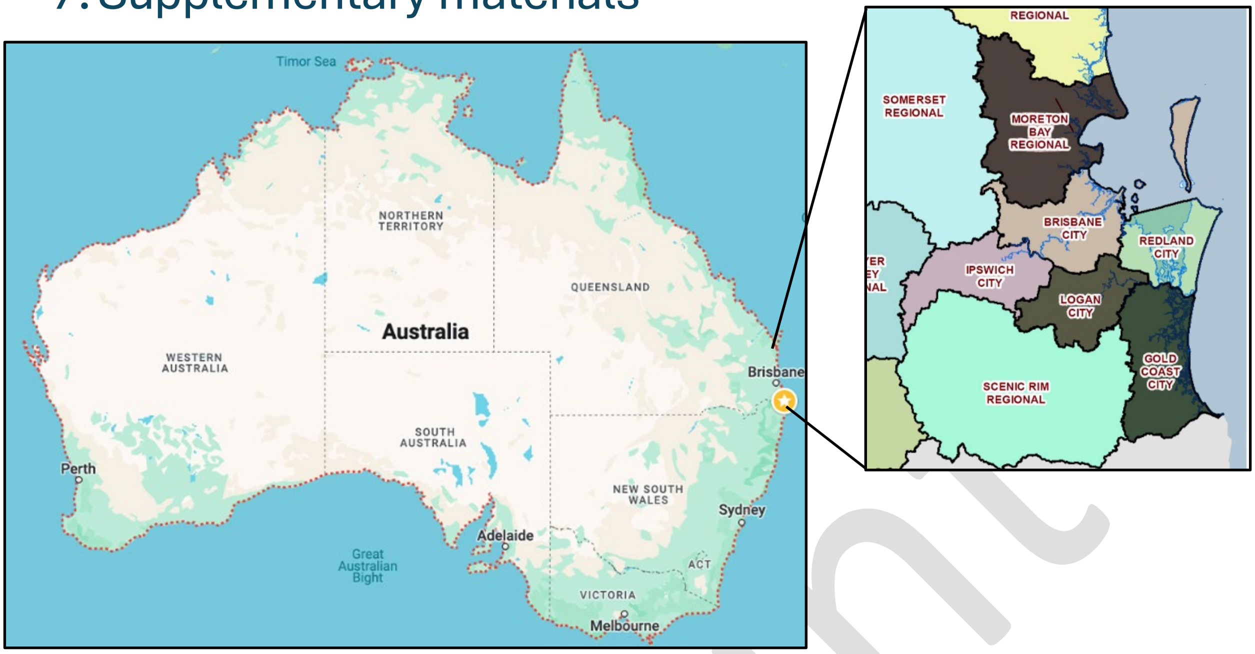

Figure 4 Map of Australia with inset of local government areas (LGA's) of Southeast Queensland. Research areas are highlighted. Inset map modified from DILGP (2015).

Figure 5 Examples of failed and neglected / mismanaged biobasins without amenity provision

Examples of biobasin types

Figure 6 Street scape bioretention

Figure 7 Car park bioretention

Figure 8 Civic space bioretention system

Figure 9 Small-scale, privately owned system