Optimising constructed wetland design, management and performance prediction quality

Healthy Waterways Strategy 2018-2028
Port Phillip & Westernport, Victoria

Strategic alignment

Regional Performance Objectives (RPOs):

- RPO18: Critical waterway health assets including stormwater treatment systems, fishways and erosion control structures, are maintained for their designed purpose or the same outcomes are delivered by alternative means.

Key Research Areas:

- Stormwater management & flooding: Improving stormwater treatment performance and determining the optimal maintenance of WSUD systems
- Stormwater management & flooding: Developing improved technologies and systems to support stormwater harvesting and re-use
- Hydrology and environmental flows: Investigating opportunities for managing stream flows in urban catchments to protect and improve aquatic biodiversity, amenity, recreation and reduce flooding.

Summary

This project provided a comprehensive assessment of stormwater wetland performance, with the aim improving the way these constructed wetlands are designed and maintained. Melbourne Water manages >200 constructed wetland systems, with a total asset value replacement cost of around $550 million. Many of these wetlands are constructed during urban residential development and are designed to meet best practice targets for pollutant load reduction.

However, due to the typically high costs in monitoring the performance of stormwater wetlands, there is uncertainty about how these wetlands are actually performing compared to modeled estimates provided during the design phase (Payne *et al* 2015). This constrains Melbourne Water's ability to develop optimal maintenance and renewal programs for this critical asset type (estimated spend of $60m over the next five years).

In addition, the design of wetlands is changing in order to assist with meeting the stormwater harvesting and infiltration targets set out in the 2018 HWS.

This project aimed to develop cost-effective indicators of hydrological and pollutant load reduction performance that would enable reliable, routine assessment of stormwater wetland performance across the entire asset base. This research also examined causes of high water levels and vegetation loss.

Despite continual improvement in guidance and compliance requirements, many wetlands are under-performing. In particular, online wetlands tend to have higher water levels and lower vegetation cover than required to meet minimum performance objectives. Based on the findings of this study, there may be opportunities to strengthen the process of wetland asset handover from developers to Melbourne Water, which was addressed in part of this project, focusing on the review of developer wetlands (see report: Factors influencing the water level regime and vegetation cover in constructed stormwater wetlands in Melbourne (Melbourne Waterway Research-Practice Partnership Technical Report 22.10).

Recommendations

- Emphasise the importance of the requirement in Melbourne Water's Wetland Design Manual that wetlands be located offline to waterways or drains and include a high flow bypass route
- Continuously monitor wetland water levels prior to handover to Melbourne Water, at least at the outlet, but preferably also at the inlet and in the downstream receiving water, in order to understand whether the water level regime is a function of outlet functioning, catchment inputs or downstream water levels.
- Use the water level data to assess compliance against the thresholds proposed in Table 2 as part of: a) the handover process, and b) an ongoing annual wetland performance reporting system.
- Expand the Wetland Analytics Visualisation Environment (WAVE tool) to provide timely (at least annual) vegetation cover estimates for all of Melbourne Water's existing wetlands
- Ensure that MUSIC models are updated to reflect 'as constructed' conditions in order to assess potential impacts of modifications on wetland performance.
- Continued use of the decision support tool (State of the Wetlands) for prioritising capital works on wetlands
- The use of real-time monitoring and control systems to improve wetland treatment performance and provide multiple benefits should continue to be trialed

What did we do?

Developer wetlands review

Water levels were continuously monitored in 20 wetlands across greater Melbourne for a period of 1 – 3 years. They varied in terms of their design, site and catchment characteristics. A suite of metrics (Table 1) were used to characterise typical water levels as well as the frequency and duration of inundation, drawdown (water levels receding below the design Normal Water Level, NWL) and dry (no standing water) spells (5+, 10+ and 20+ days). Vegetation cover estimates from aerial image analysis were used as an indicator of wetland performance. Vegetation cover data sources included aerial surveys conducted in 2017 and 2020 as well as a new web-based application, the Wetland Analytics Visualisation Environment (WAVE), developed by Melbourne Water to estimate vegetation cover multiple times per year. Vegetation cover varied across the study sites, with mean and maximum cover ranging from 21 – 79% and 34 – 92%, respectively.

Developing indicators of treatment performance

We monitored vegetation cover, water levels and water quality (on 26 occasions during both dry and wet weather) at 17 sites in the south-east of Melbourne to determine if vegetation cover is the most suitable proxy for nitrogen removal efficiency of wetlands, as it is used currently. Sites were selected in this particular geographic region due to logistics of event sampling. Although all sites were in the south-east, we had a good spread of catchment land-use and only four wetlands in the study were affected by backwatering. Estimates of N-removal based on vegetation cover are not limited to the south east region and can be used across the asset base.

Tool to prioritise maintenance and renewal works on wetlands

Melbourne Water plans to spend around $60m over the next five years on maintaining and improving the performance of our stormwater wetland assets. We developed a new method and decision support tool ('State of the Wetlands') for prioritising major capital works on wetlands. We compiled and analysed existing datasets, then developed a new prioritisation framework incorporating considerations of treatment performance, conservation values, importance of the asset in the network in terms of the expected level of pollutant reduction, risk of asset failure and an estimation of how difficult the asset would be to fix. This tool has greatly improved confidence in planning and delivery of the major capital works program for 2022/23.

What did we find?

Developer wetlands review

High (>80%) emergent vegetation cover was only achieved where the median water level was less than 100mm above the design NWL (Figure 1). Vegetation cover declined as the median water level relative to the design NWL increased; this relationship was stronger for maximum vegetation cover than mean vegetation cover. This relationship was linear and predicted a 15% reduction in vegetation cover for every 100mm increase in the median relative water level. There was a general negative relationship between vegetation cover and the frequency and duration of inundation spells at depths of >200mm and >300mm above the design NWL. In contrast, vegetation cover increased with the frequency and duration of drawdown spells as well as dry spells in the shallow marsh zone. The median relative water level was strongly related to most spell metrics and, as such, is proposed as a robust, easily calculated indicator of the suitability of a water level regime.

Design factors that were identified as risks for unsuitable water level regimes were wetlands being online to a waterway, not having a high-flow bypass and, to a lesser extent, being located within a retarding basin. Wetlands that were located within a retarding basin and did not have a high-flow bypass were at particular risk of having unsuitable water level regimes. These findings provide clear evidence for the relevant 'deemed-to-comply' criteria in Melbourne Water's 2020 Wetland Design Manual, specifically that wetlands must be offline from all waterways and drains and must include bypass routes.

A suite of thresholds for assessing the suitability of a water level regime is proposed in Table 1. It is recommended that wetland

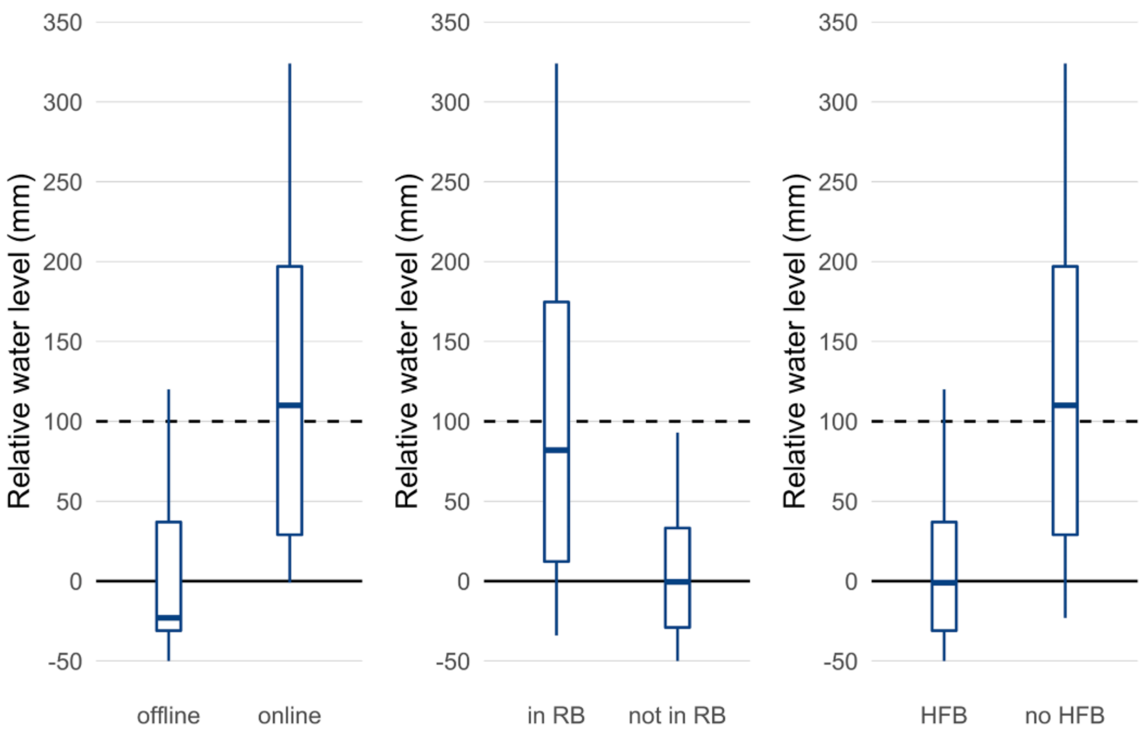

Figure 1. Range of median water levels relative to the design NWL (0 mm) at 18 study sites, grouped by design factors: online (n = 9) vs offline (n = 9), in (n = 12) vs not in a retarding basin (RB, n = 6), and with (n = 9) vs without a high-flow bypass (HFB, n = 9). The horizontal dashed line indicates the threshold above which the median water level was considered significantly higher than the design NWL.

Table 1.Comparison of mean and maximum vegetation cover against the water level regime metrics used in the design process. Shading indicates whether the metric meets the target: green = meets, yellow = close to meeting, red = fails. The plant inundation frequency could not be calculated at Site 13 because the planting design was not available.

Site	1	2	3	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
Mean Veg Cover (%)	75	69	21	42	59	63	68	64	79	48	40	30	23	43	44	63	72	51
Max Veg Cover (%)	92	78	35	92	84	84	84	77	88	69	43	34	38	76	71	84	87	67
Median relative water level (mm)	-34	114	278	-50	9	37	22	120	-23	93	201	22	193	-31	110	-1	-23	324
Plant inundation freq: shallow marsh	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	NA	Y	Y	Y	Y	Y	Y	Y
Plant inundation freq: deep marsh	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	NA	Y	Y	Y	Y	Y	Y	Y
10+ day spells/yr ≥300mm	0	0	3.8	0	0	0	0	0	0	0	2.0	0	0.3	0	0	0	0	1.4

water levels be continuously monitored in all constructed wetlands (or at least critical assets, or for a defined period early in the life of the asset), because this can provide an early and relatively low-cost indicator of problems with wetland function, potentially enabling a response prior to widespread vegetation loss. Characterising the water level regime in wetlands that are designed, constructed and operated by developers, together with vegetation cover estimates, prior to handover to Melbourne Water would help to ensure Melbourne Water only assumes responsibility for wetlands that are functioning as intended and don't have unexpected rectification costs.

Developing indicators of treatment performance

We found that TN removal can be estimated from vegetation cover (Figure 2), providing a simple indicator of treatment performance that can be used to prioritise corrective action. Our simple function suggests a 9% loss in TN removal efficiency per 10% loss in vegetation cover, (although a linear function is likely an over simplification).

TN removal efficiency was in part driven by NOx removal, which was effective across most sites. To further enhance TN removal, we need to develop more effective net removal pathways for organic N.

Sites with very low vegetation cover (less than 35%) are potentially generating N, specifically PON (Particu- late Organic Nitrogen). The generation of PON indicates breakdown and mobilisation of organic material within the wetland. The practical interpretation of generation of PON from wetlands with low vegetation cover is important. If sites with low vegetation cover are generating N, rather than simply not removing N, then they should become a higher priority; in contrast to current thinking.

We used water level data to identify whether: i) wetlands were receiving excessive inflow and ii) whether outlet efficiency was low. Both metrics were related to the median water level (Robertson et al., 2018), but not vegetation cover, likely due to lags in vegetation response (Squires and Valk, 1992). In combination, these two metrics explained 50% of the variation in median water level, suggesting monitoring water level can diagnose specific faults and inform corrective management action.

Future direction and Knowledge gaps

- Exploration of the links between plant inundation frequency and resulting vegetation cover.
- Assessment of how well MUSIC predicts wetland hydrological performance.
- Assessment of wetland assets to confirm the frequency of bypass (possibly through modification of current condition assessments). A research program developing a low-cost

Metric	Threshold
Median relative water level	Within 100mm of the design NWL
Inundation spells: >200mm above the design NWL	5+ day spells should occur no more than twice per year
	10+ day spells should occur no more than twice per ten years
	20+ day spells should occur no more than once per ten years
Inundation spells: >300mm above the design NWL	5+ day spells should occur no more than once per five years
	No 10+ day spells should occur during the establishment period
	10+ day spells should occur no more than once per ten years
	No 20+ day spells should occur
Drawdown spells: <design NWL	Spells of any duration should occur at least ten times per year
	5+ day spells should occur at least five times per year
	10+ and 20+ day drawdown spells should occur at least once per year
Dry spells (no standing water): shallow marsh	5+ day dry spells should occur at least once per year
Dry spells (no standing water): deep marsh	Insufficient evidence to make recommendations

Table 2 Proposed thresholds for assessing the suitability of the water level regime in a constructed stormwater wetland.

monitoring and reporting network could also be established to target this specific issue.

- We are currently developing a research program to investigate real-time control of wetland hydraulic structures to i) restrict inflow when outflow is not possible and ii) harvest treated water from wetlands to rapidly lower water levels and prevent vegetation loss. In addition, we suggest: i) developing a low-cost water level monitoring network to identify affected wetlands, ii) a research project to investigate the impact of removing extended detention zones on treatment performance, and iii) a study to investigate alternative wetland configurations which can de-water the macrophyte zone even when receiving water levels are high.

How are we sharing findings

Reports

- MWRPP Report 22.10: Factors influencing the water level regime and vegetation cover in constructed stormwater wetlands in Melbourne (2022). Belinda Hatt.
- MWRPP report 23.5: Predicting nitrogen and phosphorus removal from vegetation cover and the water level regime of constructed stormwater wetlands (2023). Christopher Szota, Al Danger, Peter Poelsma, Belinda Hatt, Rob James, Alison Rickard, Matthew J. Burns, Frédéric Cherqui, Rhys Coleman and Tim D. Fletcher.

For more details on the research outcomes of this project, or other projects of the MWRPP, please contact:

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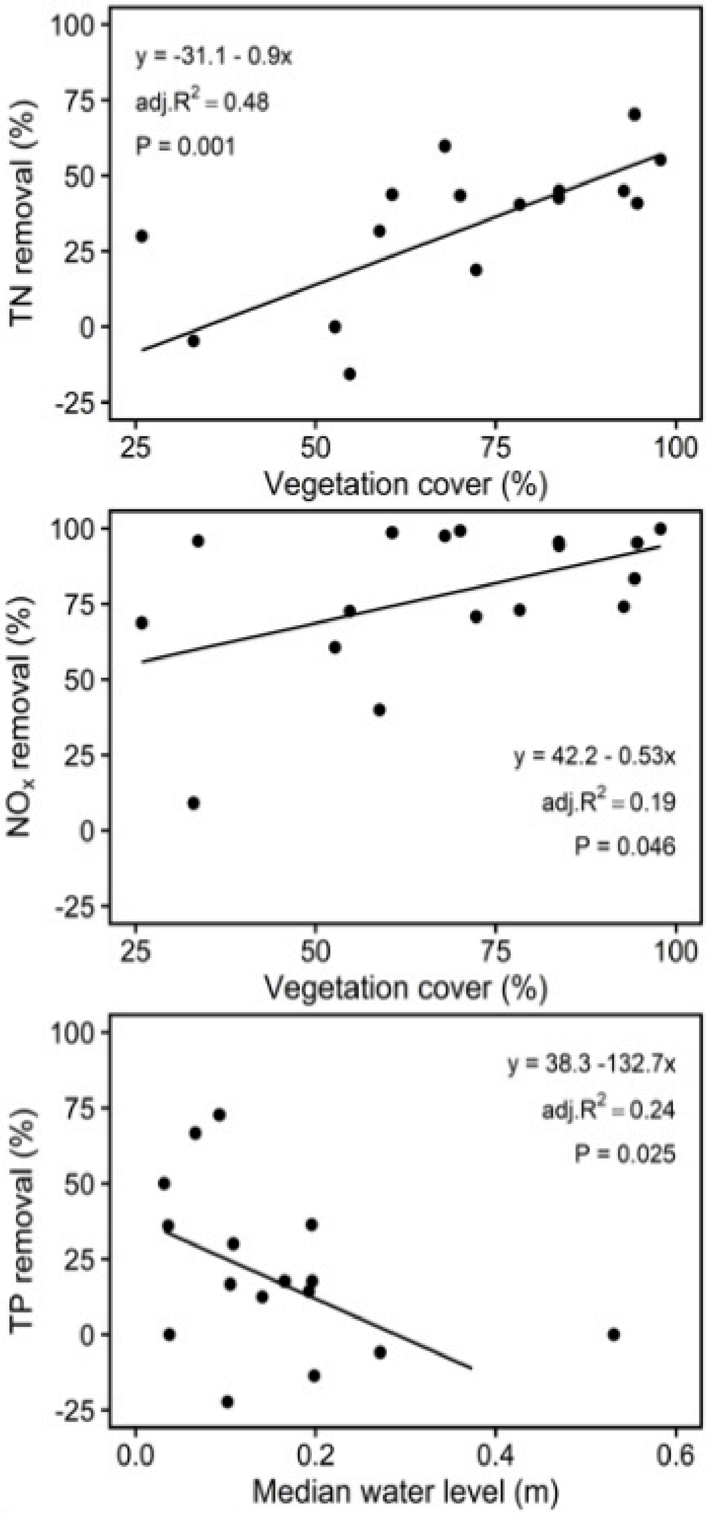
- Robertson, J.J., Fletcher, T.D., Danger, A. and Szota, C. 2018. Identifying critical inundation thresholds to maintain vegetation cover in stormwater treatment wetlands. Ecol. Eng. 116, 80-86.
- Squires, L. and Valk, A.G.V.d. 1992. Water-depth tolerances of the dominant emergent macrophytes of the Delta Marsh, Manitoba. Canadian Journal of Botany 70(9), 1860-1867.



Fugure 2: Relationships between vegetation cover and removal efficiency of total nitrogen (TN) and oxidised nitrogen (NOx), as well as between median water level and removal efficiency of total phosphorus (TP).