CRC for Water Sensitive Cities

Eric Singleton Bird Sanctuary Constructed Wetland

Monitoring and assessment for optimal stormwater treatment performance

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The University of Western Australia

Water Sensitive Speaker Series

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Perth, Western Australia

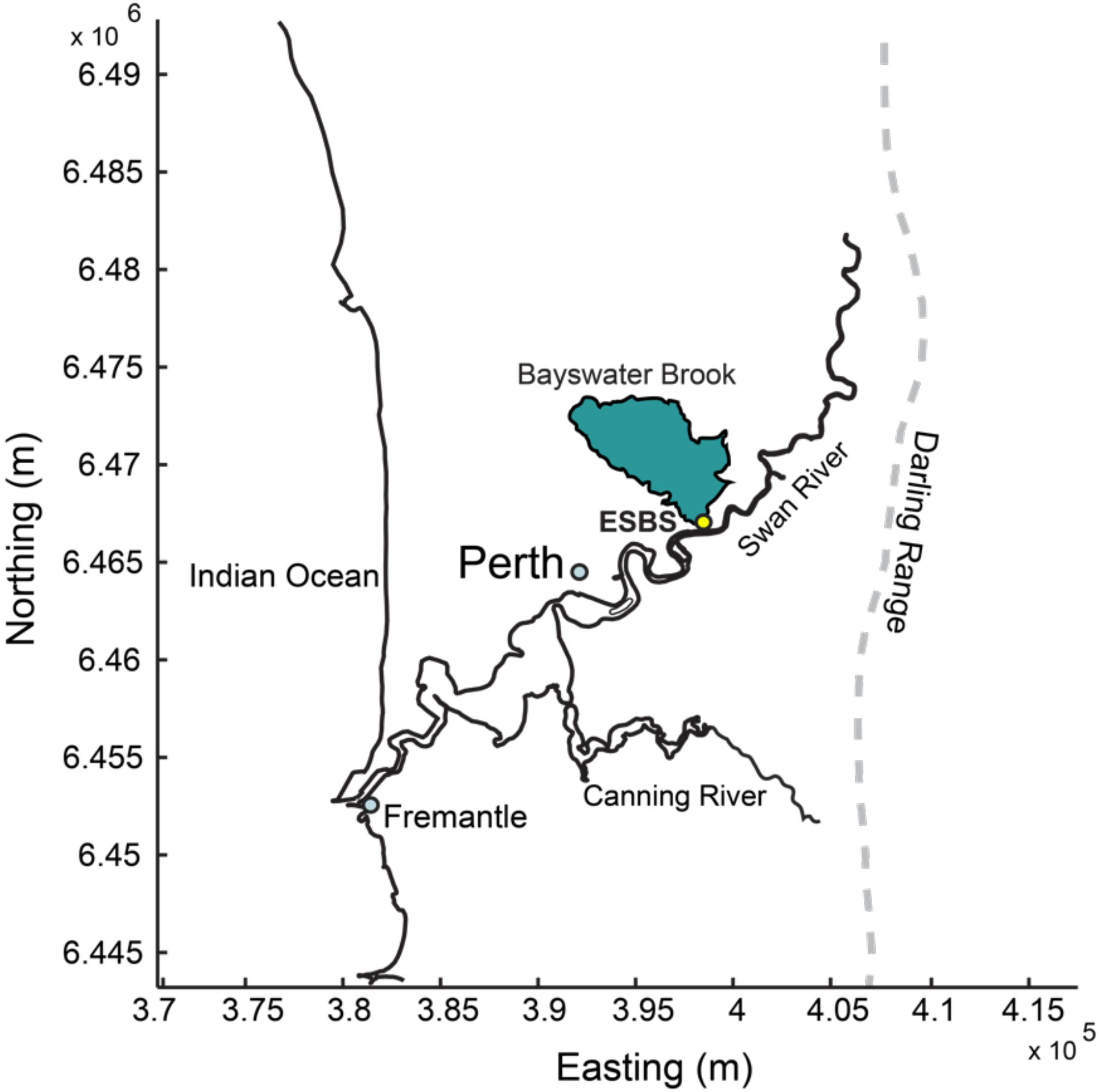
An Australian Government Initiative

Outline

- Eric Singleton Bird Sanctuary (ESBS) constructed wetland.
- Hydrological and nutrient attenuation performances for the period October 2017 - September 2019.
- Discussion of difficulties found affecting the water and nutrient balances for performance assessment.
- Recommendations for future work.

ESBS location and context

- ESBS is located at the outlet of the Bayswater Brook catchment in the City of Bayswater, Perth, Western Australia.
- Bayswater Brook drains a residential catchment area of 2600 ha and also receives water from the Slade Street sub-catchment (1 ha).



ESBS evolution

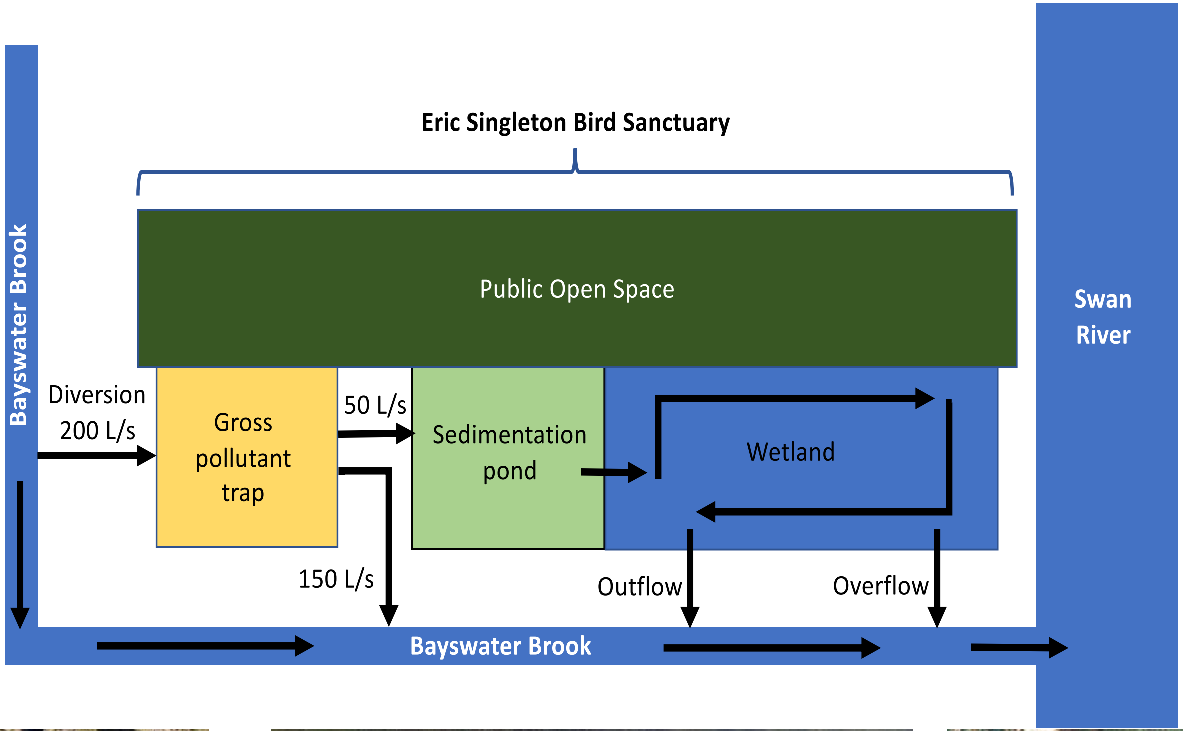
- A seasonally wet depression in Riverside Gardens drained in the 1950s.
- A permanent wetland since the 1970s.
- Artificially recharged with groundwater since 1979 (sustains bird population in summer and prevents acidification).
- Reconfigured in 2015 with diverted water from Bayswater Brook (GHD, 2013).
- Improved amenity, habitat and recreational opportunities for the community.

(GHD, 2013)

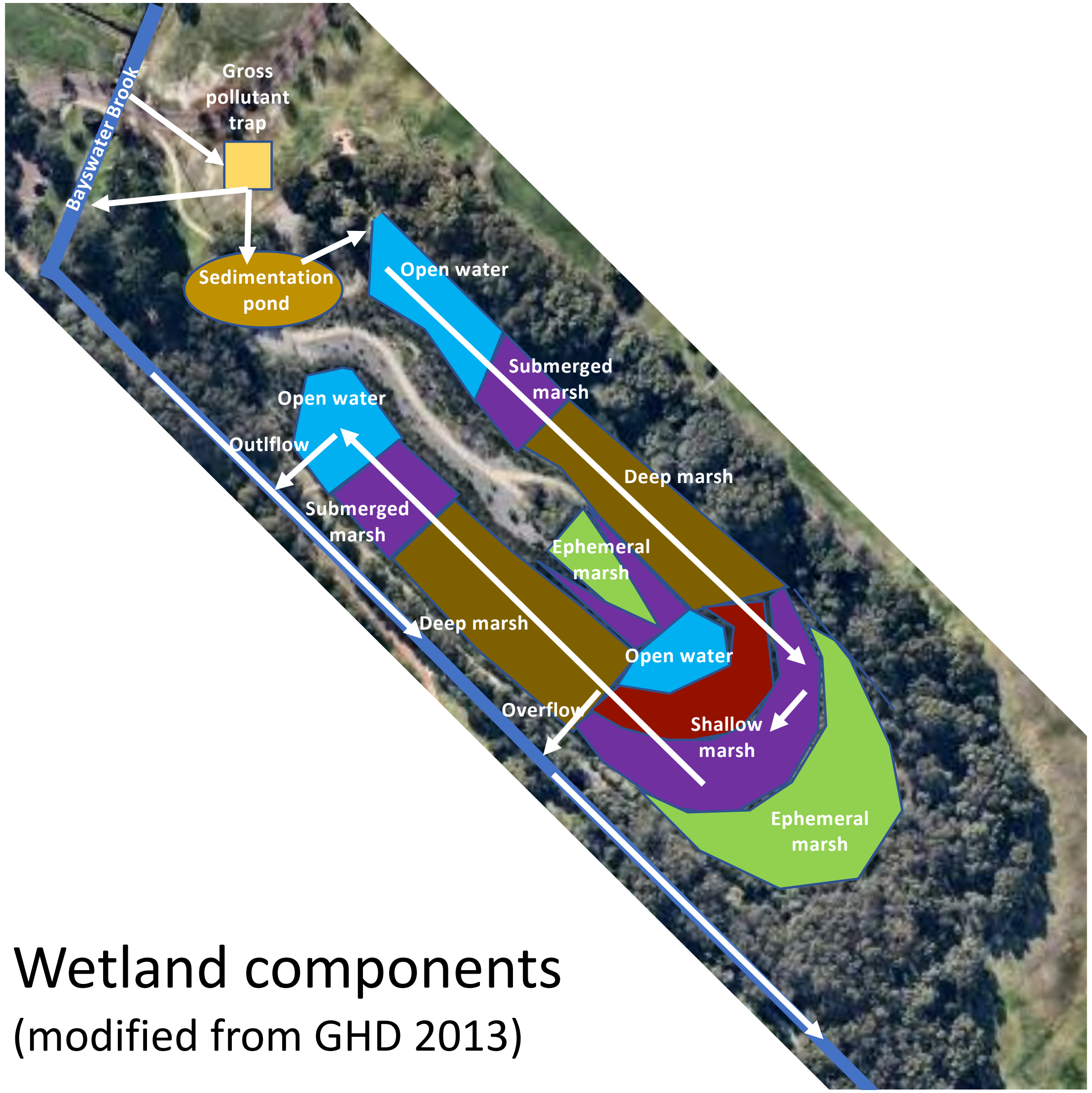
ESBS reconfigured wetland

- Elevation range of -0.85 to 1.2 m Australian Height Datum (AHD).
- Design criteria (GHD, 2013) includes:
  - Maintenance of a permanent water body
  - Creation of bird habitats
  - Active management of potential acid sulfate soils
  - Shallow gradients (mostly 1:6) and stable embankments
  - Low water velocities (<0.05 m/s)
  - Wetland length to width ratio > 5:1
  - Hydraulic retention time (HRT) < 48 hours; ARI 1 year < 21 hours

ESBS treatment components



ESBS treatment components



Wetland components
(modified from GHD 2013)

For normal levels

Surface area: 27,000 m^2

Volume: 8,816 m^3

For operational levels

Surface area: 29,700 m^2

Volume: 14,822 m^3

Vegetated area (shallow pools); Open water areas (depth 1 m) followed by submerged marsh, deep marsh zones (depth 0.45-1 m) and shallow marsh (depth 0.15 m) in the wetland bend areas.

ESBS outlet structures

Outflow structure

Penstock watergate controlling flow to a submerged concrete pipe (0.4 m diameter). A large overflow weir (10 m wide, 6 m length and water depth up to 0.5 m) for high water level.

Movable floodgate designed to stop discharge and avoid water intrusion (e.g., tide or stormflow from Bayswater Brook).

Penstock watergate

Outflow pipe and floodgate

Overflow weir - high tide

Overflow weir - low tide

ESBS outlet structures

Overflow structure

Overflow structure comprising a concrete culvert (3 m wide x 5 m length) with three (3) pipes (0.45 m diameter). Removable weir boards (board dimensions 1 m length by 0.1 m high).

Movable floodgate designed to stop discharge and avoid water intrusion (e.g., tide or stormflow from Bayswater Brook).

Concrete culvert

Movable floodgate

ESBS site constrains

- A seasonally high water table.
- Intrusion of river tides and salinity.
- Small hydraulic gradient across the wetland and high water levels in the Bayswater Brook (winter baseflow).
- Inability to implement control structures within Bayswater Brook.
- Maintain a shallow wetland area (average depth of 0.5 m).
- Area/volume ratio smaller than required to treat annual average flow in the Bayswater Brook and its first flush of pollutants.
- Maintain the pre-existing impermeable clay layer and manage potential acidification of the wetland (e.g., sediments are potentially acid sulfate soil).

Aims of this work

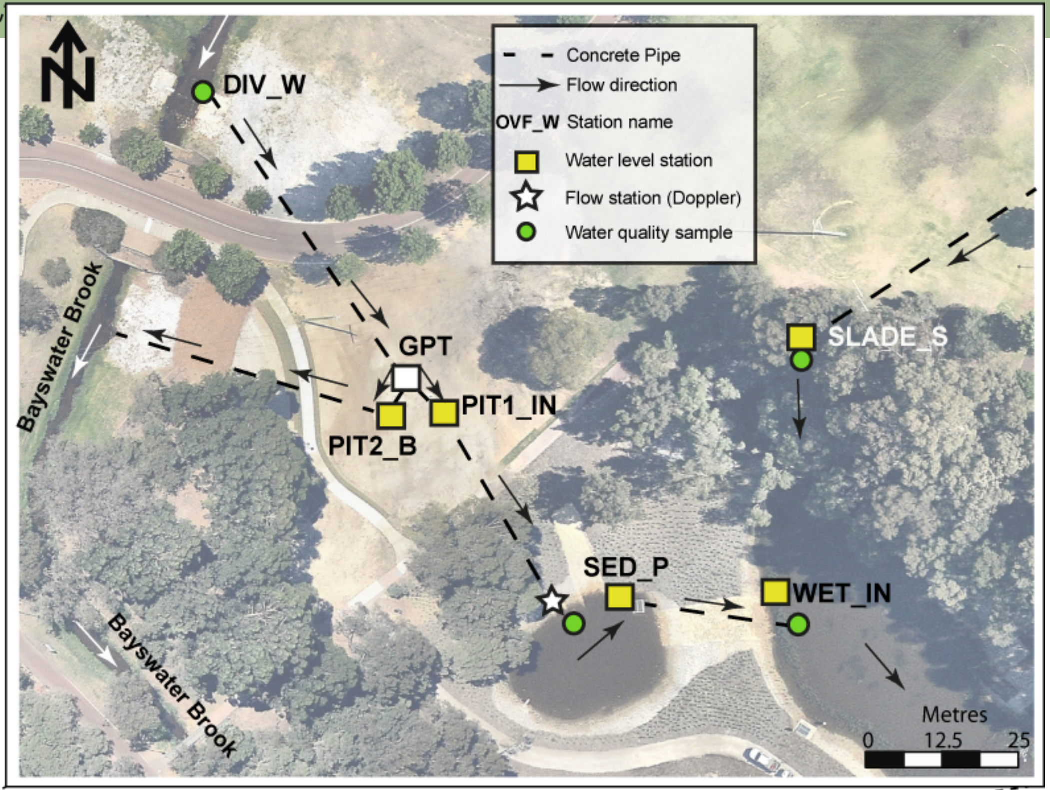
- Validate water quality improvements and estimates; develop a better understanding of the wetland function and management.
- Research questions:
  a) Meeting annual nutrient and sediment reduction targets?
     - Up to 40 tonnes of sediments and rubbish per year
     - 1.3 tonnes of Nitrogen and 200 kg of Phosphorus per year
  b) Overall water quality improvements (between inlet and outlet) (during base flows and during high rainfall events).
  c) Contribution of functional parts (GPT, sediment basin, wetland)?
  d) Where are pollutants being stored (sediments, macrophytes, location along the treatment train)?

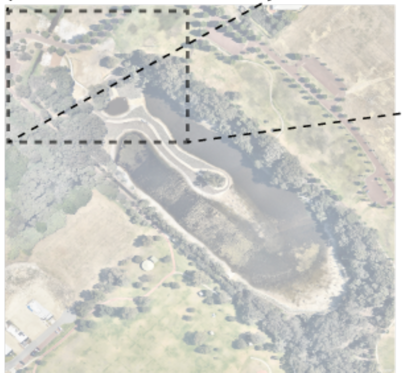
How should the wetland be operated?

Research approach: field monitoring

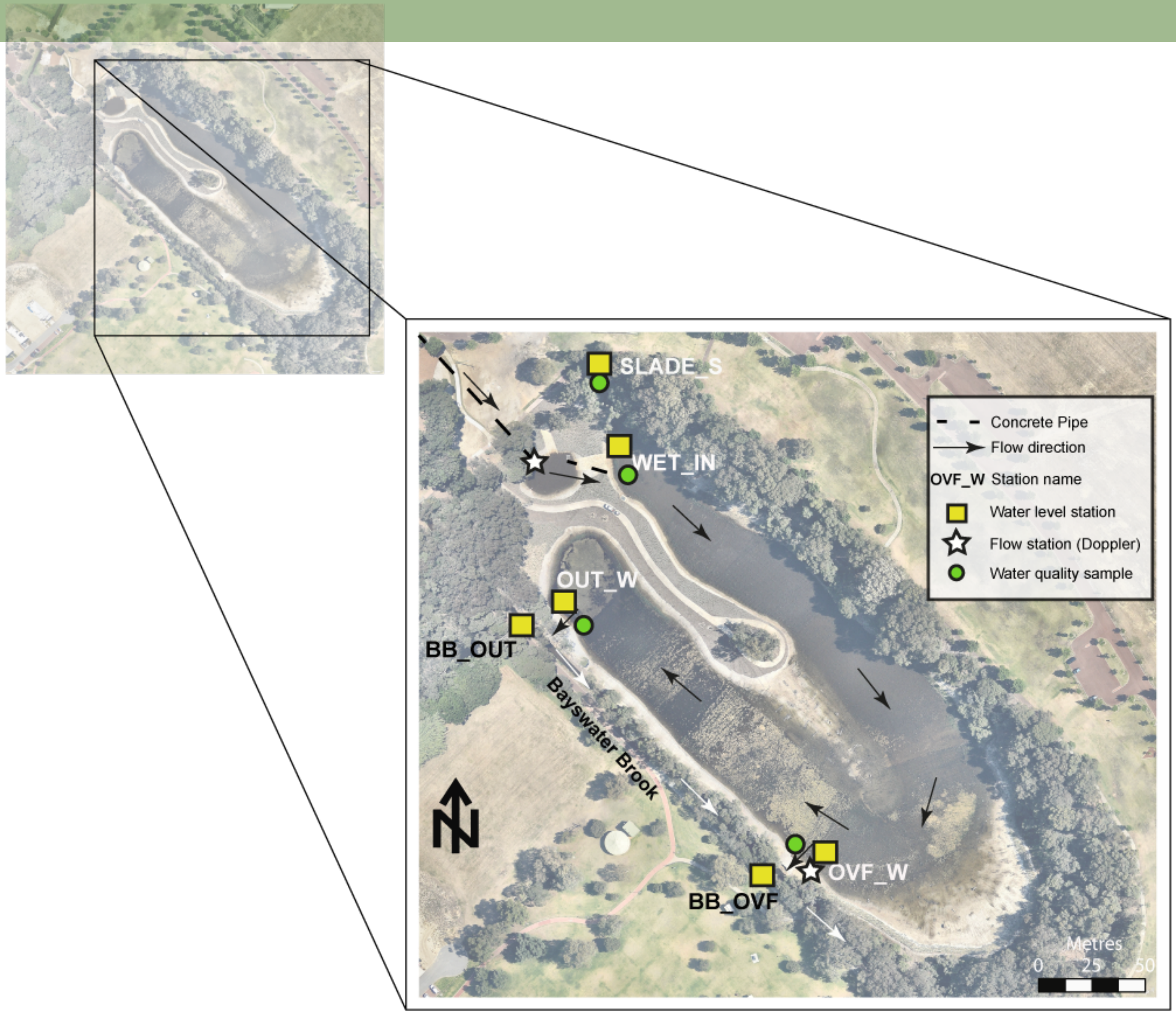
- A Sampling and Analysis Plan (SAP) developed by McGuinness (2017) in consultation with DBCA and ChemCentre.
- SAP for water quality sampling included baseflow conditions (e.g., dry weather) and stormflow sampling (wet weather).
- Hydrometric data (water levels) was continuously monitored at seven (7) locations across the treatment components plus two (2) stations at the Bayswater Brook.
- Opportunistic discharge measurements (DM) at the inflow and outflow points were undertaken for seven events.

Sampling and monitoring points





Sampling and monitoring points



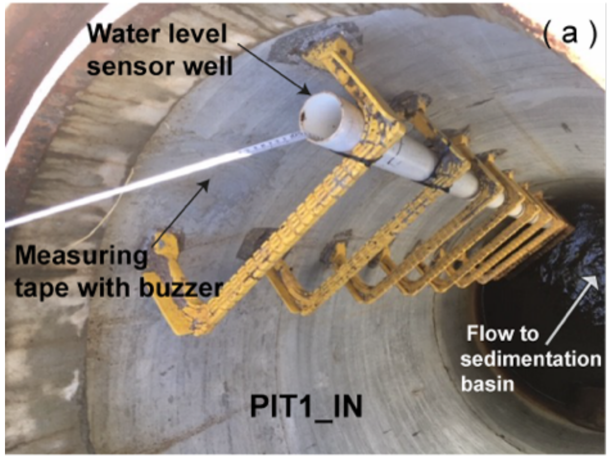
Sampling and monitoring frequency

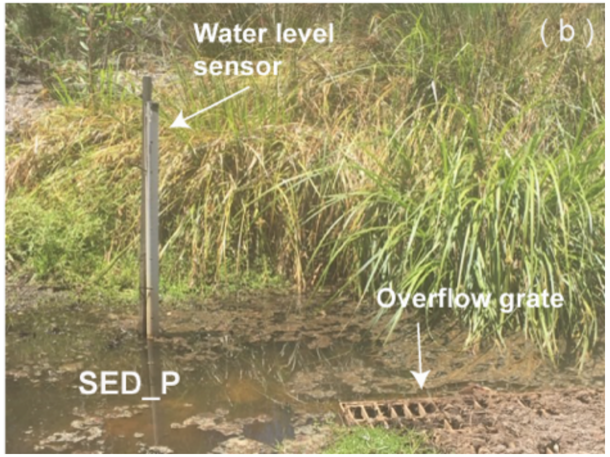
Component	Parameters	Frequency	Site codes
Surface water			
Water quality	Total nitrogen (TN)	Event based sampling	PIT1_IN and OVF_W
	Total phosphorus (TP)		
	Nitrate/nitrite (NOx-N)		
	Total Kjeldahl nitrogen (TKN)		
	Ammonia (NH3-N)		
	Filterable reactive phosphorus (FRP)		
	Total suspended solids (TSS)		
	All the above plus:	Monthly	DIV_W, SED_P, WET_IN, OVF_W, OUT_W and SLADE_S
	Metals (dissolved and total)		
	Temperature, pH, electrical conductivity (EC), dissolved oxygen, turbidity, and redox potential (ORP)		
	Temperature	Continuous (10-minute intervals)	PIT1_IN and OVF_W
	Electrical conductivity (EC)		

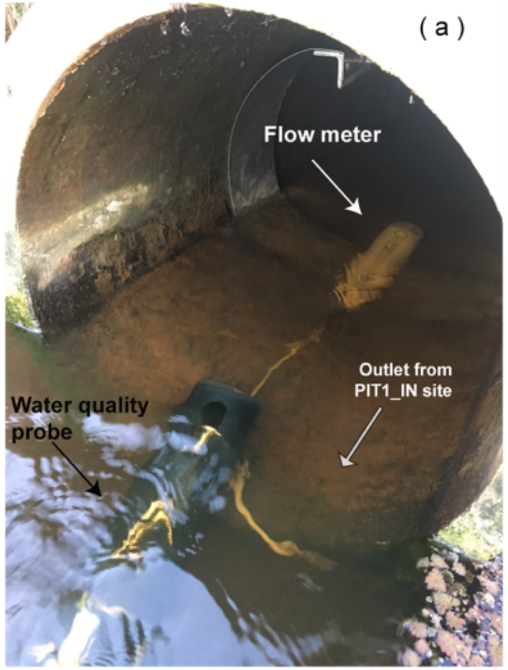
Autosampler at PIT1_IN

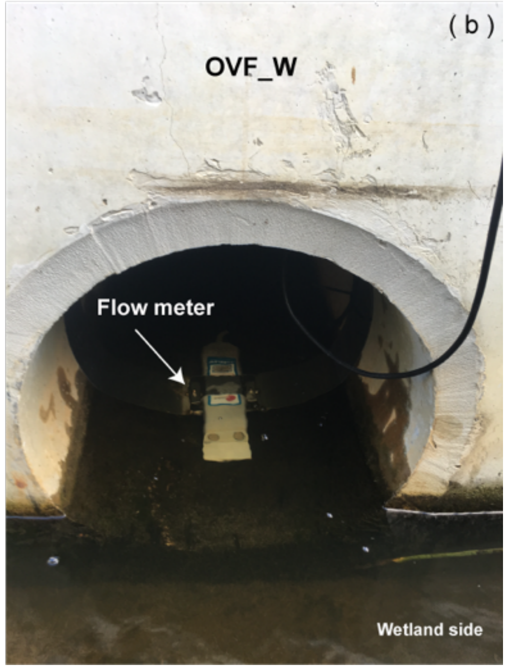
Sampling and monitoring frequency

Component	Parameters	Frequency	Site codes
Surface water			
Hydrology	Water level	Continuous (5- to 10-minute intervals)	PIT1_IN, PIT2_B, SED_P, SLADE_S, WET_IN, OVF_W, OUT_W, BB_OUT and BB_OVF
	Water velocity (Doppler)	Event based sampling (2- to 5-minute intervals)	Outlet pipe of PIT1_IN and OVF_W

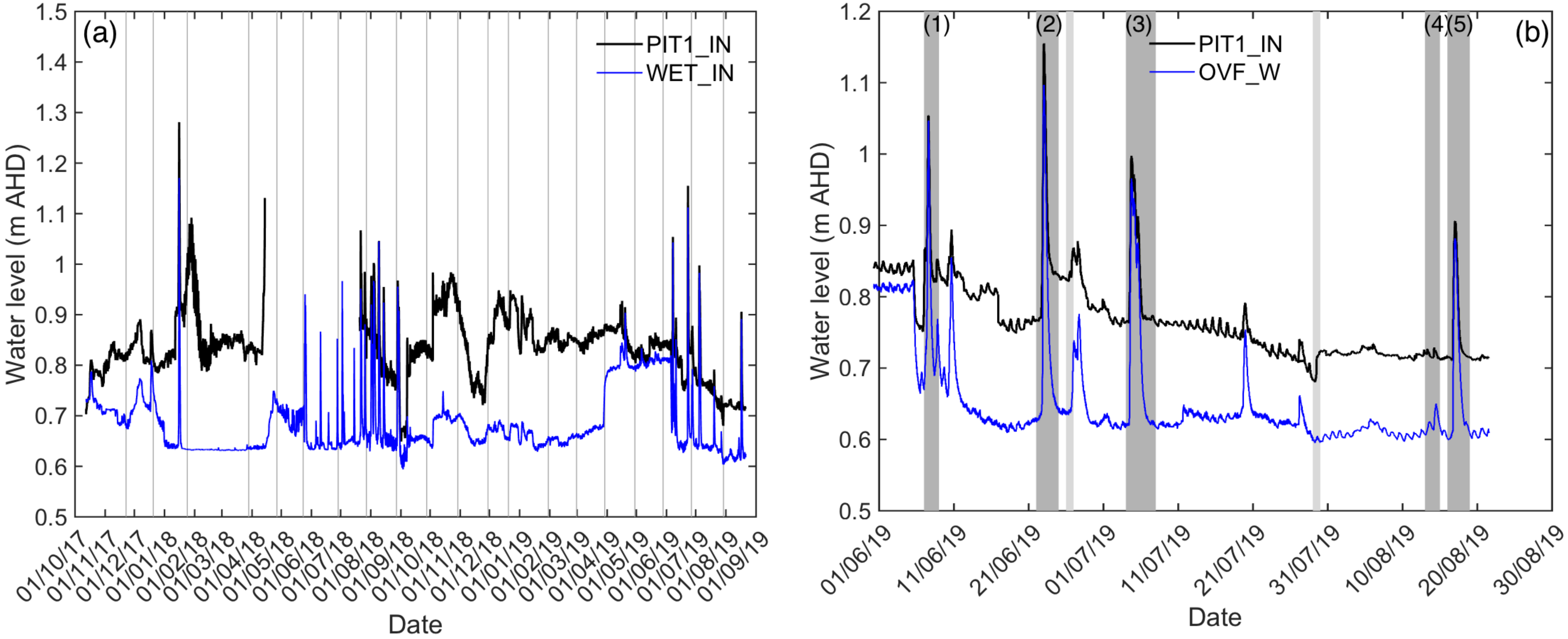








Sampling and monitoring frequency



Methods: hydrological data

- Rating curves were constructed for inflow and outflow locations. Flow hydraulic conditions and theoretical discharge were computed using Bodhaine (1968) method.

- Simple water balance equation was applied for rainfall events (terms in m^3/unit of time):

$$\frac{dS}{dt} = R + Q_{IN} + Q_{UNG} - Q_{OVER} - Q_{OUT} \pm Q_{WEIR} \pm Q_{BANKEX}$$

- Water level data was converted into discharge using obtained rating curves.

- At OUT_W, the weir structure was also monitored as water exchange between the wetland and the Bayswater Brook could occur under high water level.

Methods: water quality data

- More recently, it was suggested that nutrient concentrations discharged from the Bayswater Main Drain should be compared with ANZECC trigger values for slightly disturbed lowland rivers of the southwest of Australia (ANZECC and ARMCANZ 2000).

- The ANZECC trigger values for lowland rivers are TN 1.2 mg/L and TP 0.065 mg/L.

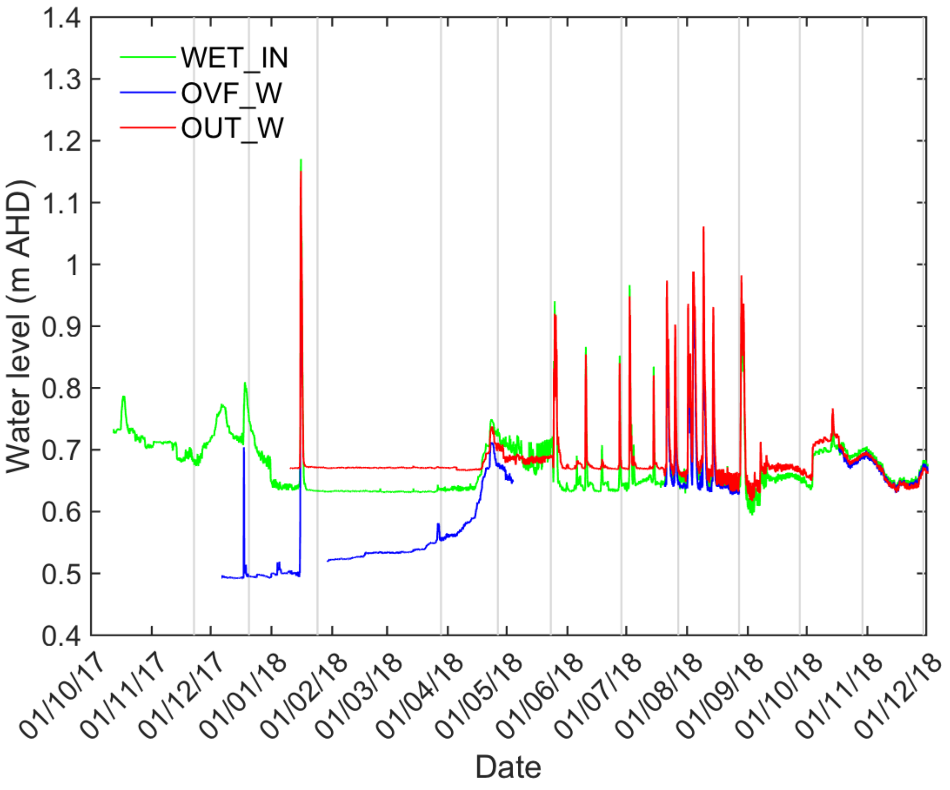
Methods: water quality data

- The event mean concentration (EMC), defined as the total nutrient load (mass) divided by the total runoff volume of an event, has been recommended by guidelines to assess nutrient removal by structural elements such as constructed wetlands (Winer 2000, DoW 2004).

- Nutrient load attenuation is also a critical performance measure and of interest for the purpose of wetland operation and management.

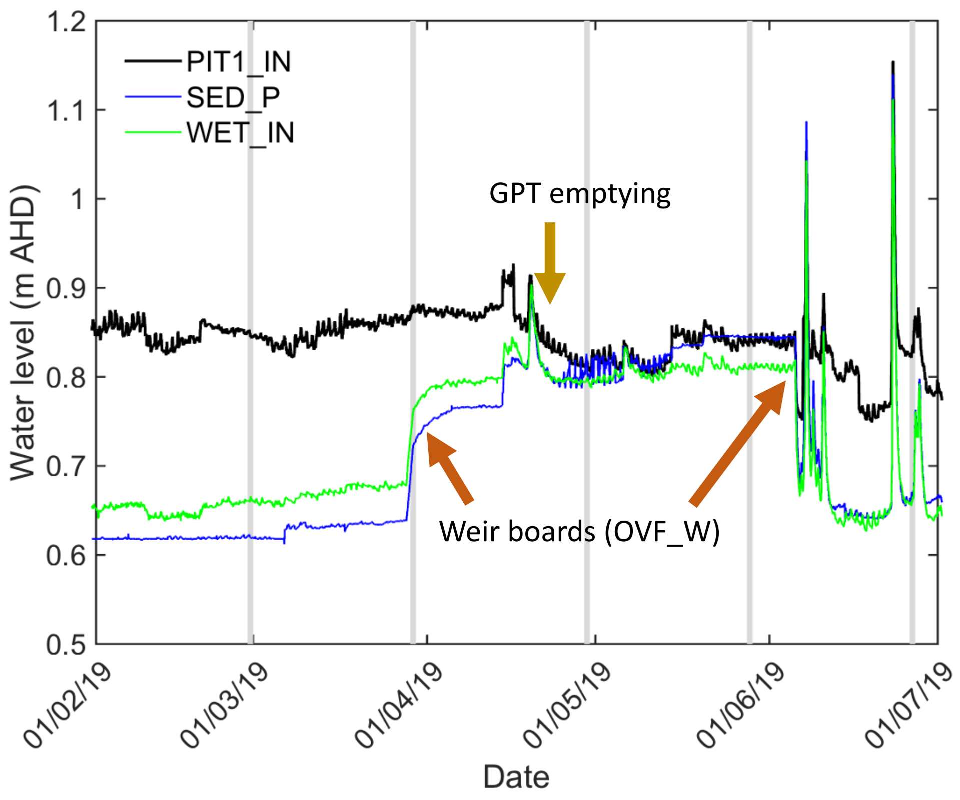
$$Load\ attenuation\ (\%) = \left(\frac{L_{IN} - L_{OUT}}{L_{IN}}\right)$$

Results - Water level dynamics (2017-2018)



- Wetland mean water level at 0.71 m (AHD) from (Oct-Dec 2017).
- Rapid drops in Dec 2017 due to DIV_W weir board removal.
- The 50-year ARI event recorded on January 15, 2018 (Tropical storm Joyce) with a peak level of 1.17 m AHD.
- Operated a lower level (0.63 m AHD) until April 2018.
- Twelve rainfall events recorded during winter.
- Weir board at the OVF_W station were removed and not reinstated for the remaining of 2018. OVF_W becomes the outlet point for the wetland.
- Weir board added to the DIV_W towards the end of the year resulted in mean water level at 0.65 m.
- Wetland water levels at its inlet point drove flow towards OVF_W and OUT_W; the wetland discharge point at the Overflow structure confirmed (lower level).

Results - Water level dynamics (2019)



- Wetland mean water level at 0.68 m (AHD) until March 2019.
- Management action restored wetland intended hydraulic functioning in March 28. GPT clean up in April 2019. Inflow rate at 41 L/s.
- Wetland operated at a higher level than 2017 at 0.8 m AHD.
- OUT_W discharge stopped on June 4 (high water level in Bayswater Brook). OVF becomes the main outlet for the wetland.
- Water levels dropped to 0.67 m AHD in 20 hrs.
- Water levels at 0.61 m AHD during the winter period (blockage of GPT reduced inflow).

Results - Event water balance (2019)

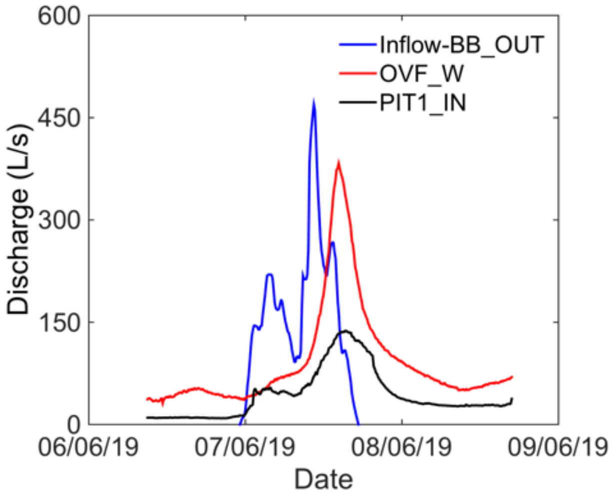
- Focused on identifying and quantifying main inflows and outflows over the course of an event that explain observed variation in water levels in the wetland.

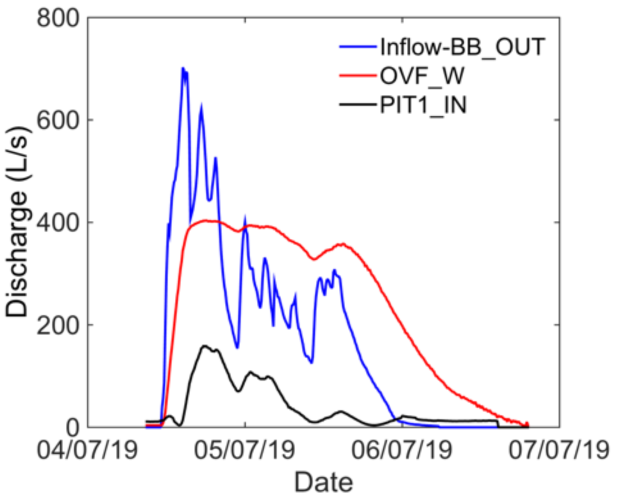
Event	Duration (hr:min)	Rainfall (mm)	Rain1h (mm)	Tide	Tide observations^
7–8 June 19	10:00	26.2 +9.3	5.6	Very high	Rising tide (0.32 m) affecting wetland functioning – Peak at 1.01 m
22–23 June 19	7:45	46 +7.6	13.2	Average	Receding tide (0.31 m) affecting wetland discharge
4–5 July 19	13:50	33.5 +18.5	19.3	High	Peak tide (0.8m) affecting wetland discharge on following day
13-14 Aug 19	3:10	4.6 +8.9	4.3	Average	Receding tide (0.2 m) with minor effect on wetland discharge
16 Aug 19*	6:00	24.4 +1.5	16.0*	Low	Receding tide (0.2 m) with no effect on wetland discharge

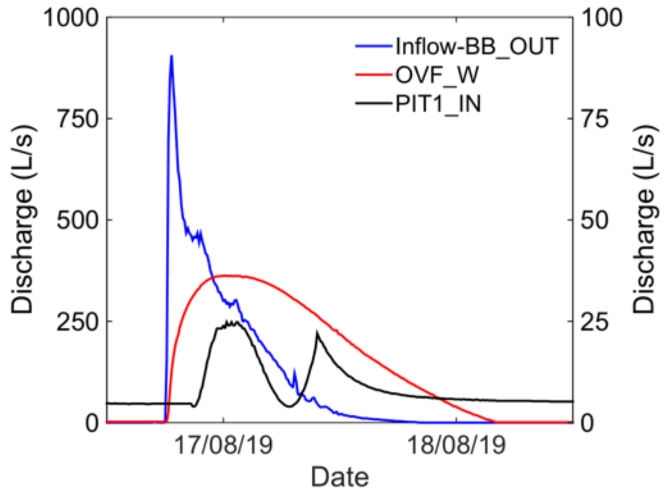
** Event close to the 1-year Average Recurrence Interval (ARI).*

^ Tidal level corresponds to Australian Height Datum (AHD). Source: Australian Bureau of Meteorology (BOM).

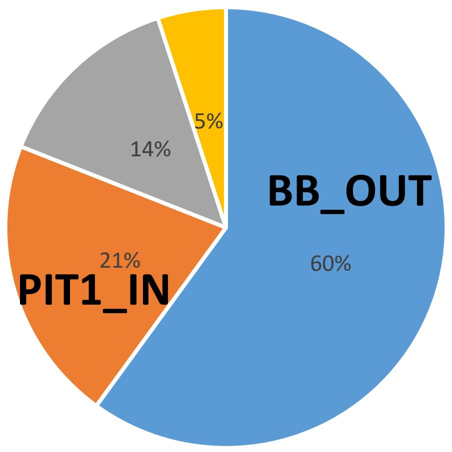
Results - Event water balance (2019)



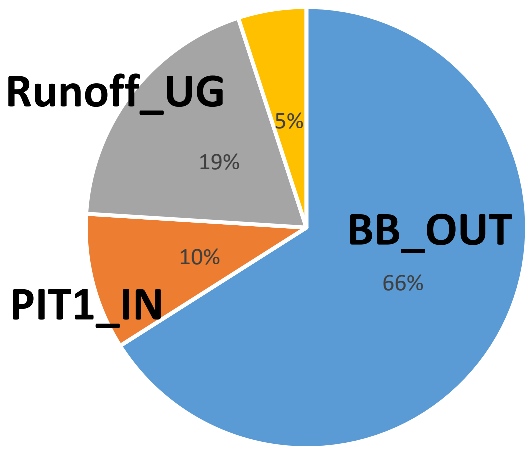




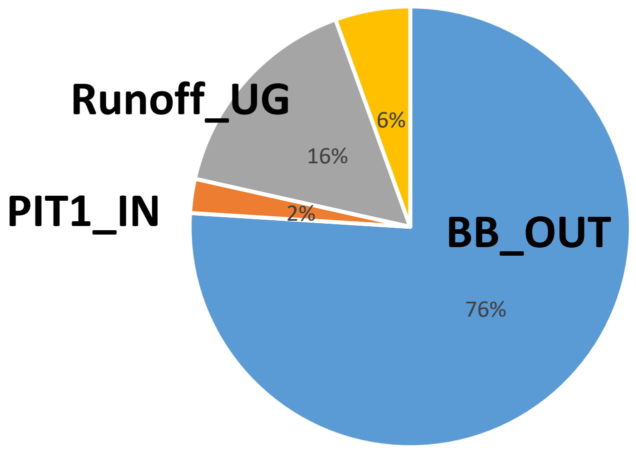
Event 1 - Volumetric contribution



Event 3 - Volumetric contribution

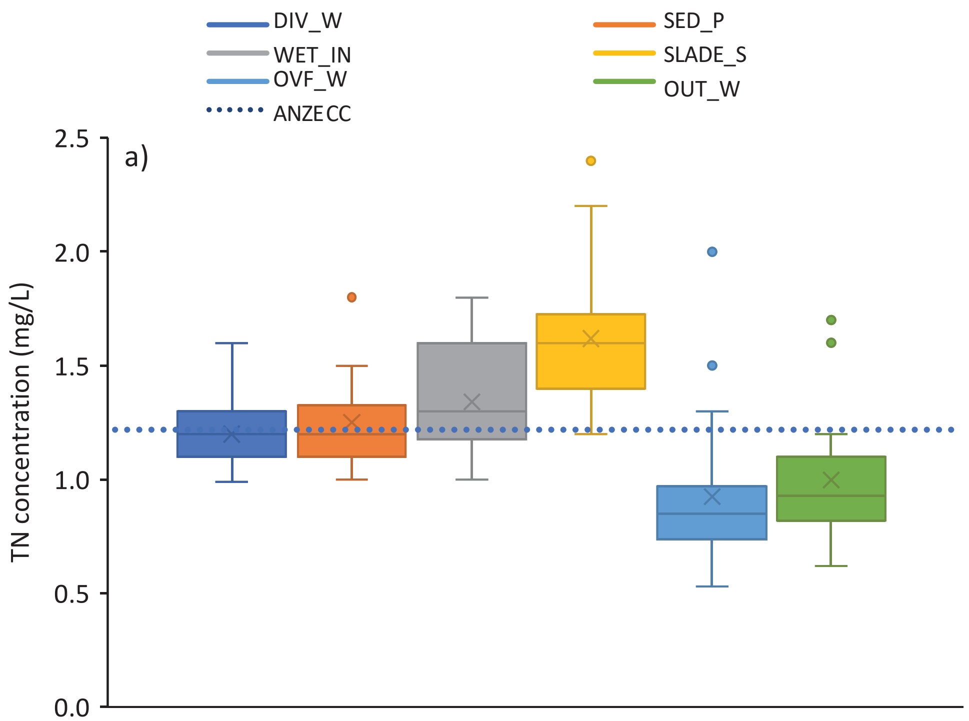


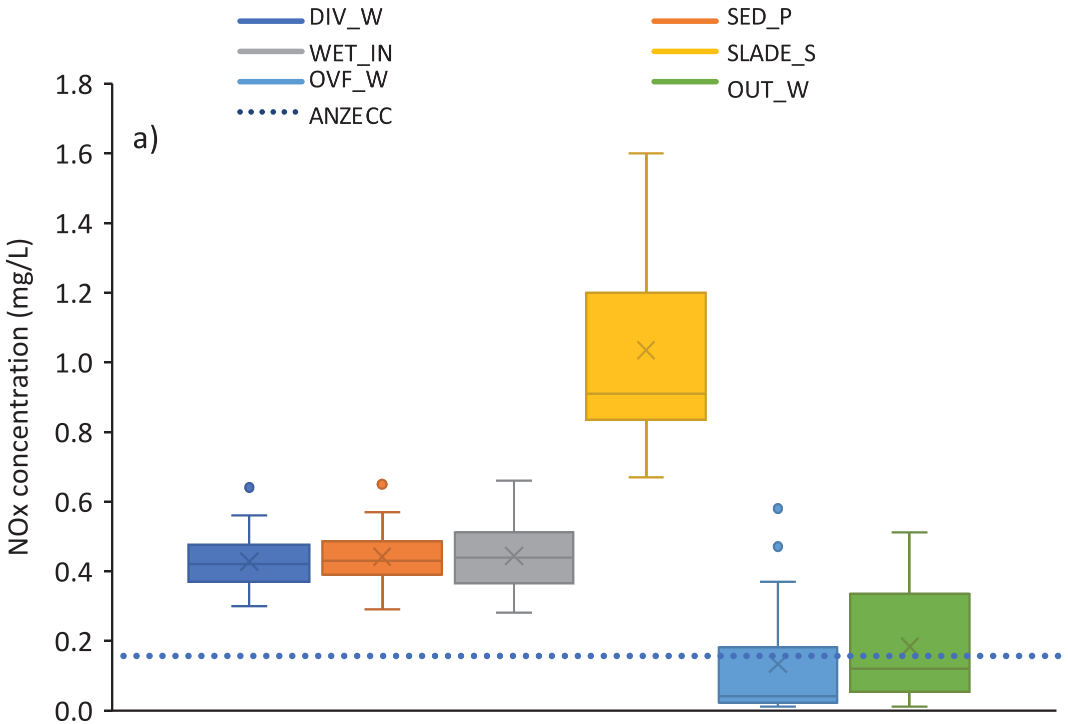
Event 5 - Volumetric contribution



Results - Nutrient concentration attenuation

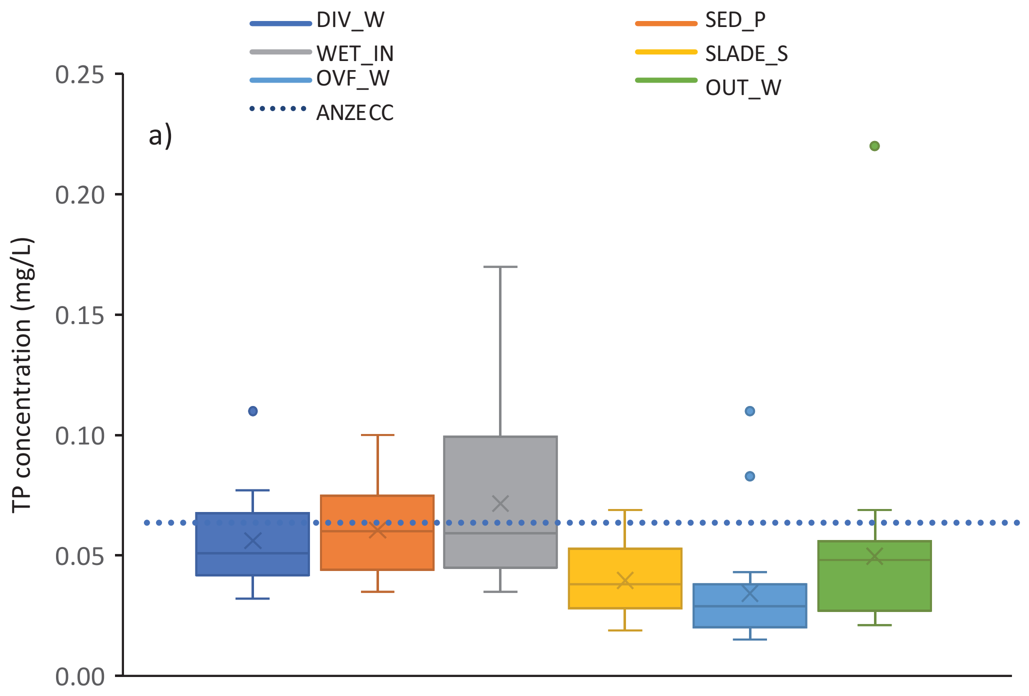
Baseflow nitrogen concentrations

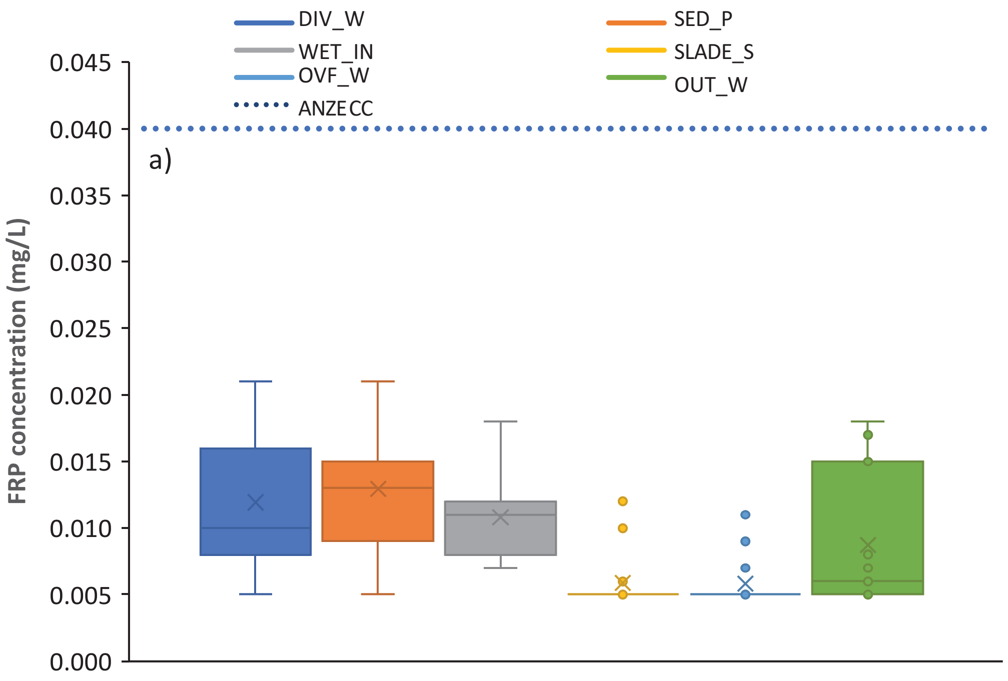




Results - Nutrient concentration attenuation

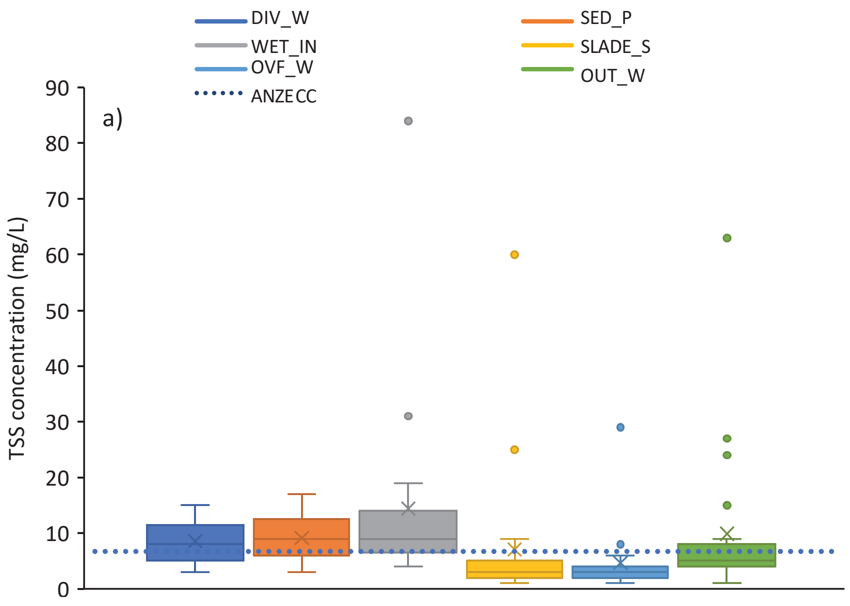
Baseflow phosphorus concentrations

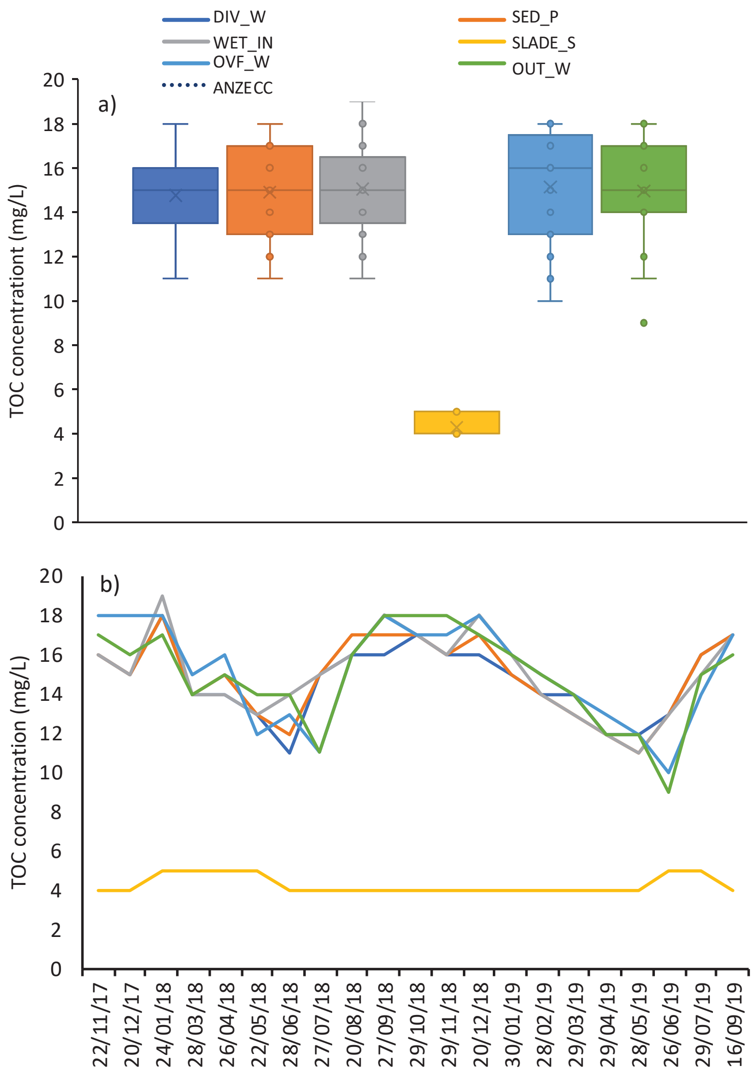




Results - TSS and TOC concentration attenuation

Baseflow concentrations





Remarks - GPT concentration attenuation

The GPT predicted to reduce 30% of TSS and 15% of TP but,

- GPT acted at times as source (minor) for TSS and TP.
- TSS concentration attenuation was found on four (4) sampling dates when inflow rate was < 35 L/s.
- Minimal impact on other nutrient concentrations.

Remarks - SED_P concentration attenuation

The sedimentation pond:

- Unable to properly assess its functioning due to lack of representativeness of outlet concentrations.
- Attenuation impacted by GPT emptying practices (total of 11 operations in two years).
- Ammonia-N and FRP consistently attenuated (20-30%).
- No attenuation observed for TP, TN and NOx-N.

Remarks - Wetland concentration attenuation

The wetland component: from inlet (WET_IN) to overflow (OVF_W)

- No seasonal pattern in TN concentrations at inlet site. Seasonal patter at OVF_W outlet (e.g., higher winter concentrations). Attenuation around 33%.
- NOx-N concentrations were high for early winter flows at the inlet but consistently lower at the Overflow.
- Observed change in TN composition from WET_IN to OVF_W sites. Dissolved organic nitrogen (DON) concentration increased by 21 % from WET_IN to OVF_site.
- TP concentrations showed seasonal trend at the inlet (e.g., low in winter and spring) but no changes at the OVF_W station. Attenuation of 52%.

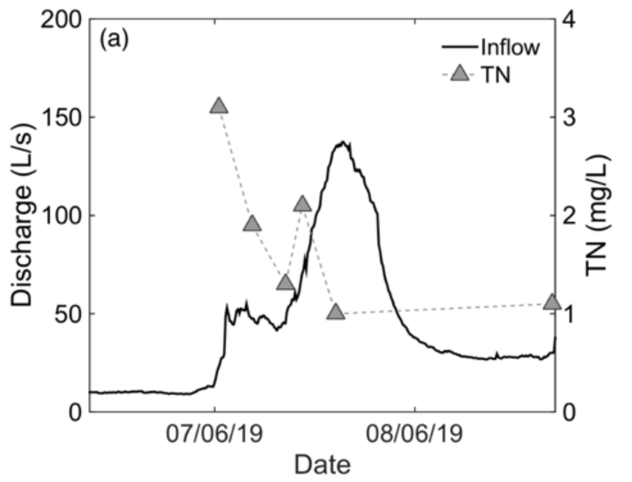
Remarks - Wetland concentration attenuation

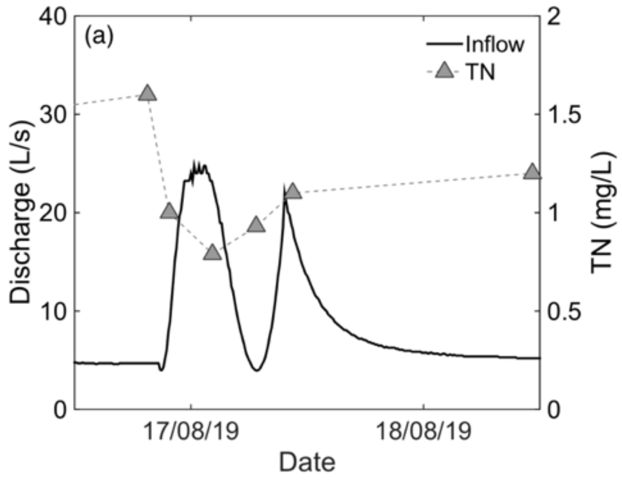
- FRP represents only 12% of TP and showed no seasonal pattern in concentrations. Concentration attenuation was 71% on average.
- TSS showed 72% reduction in concentration between WET_IN and OVF_W sites.
- Comparison between concentrations at the two outlet locations OVF_W and OUT_W indicated accumulation of nutrients around OUT_W location; this area acted as a flow stagnation point with no discharge for most of the monitoring period.

Results - Event concentrations

Events concentration: patterns and attenuation

- Inflow concentrations displayed a typical "flushing" pattern (after the long dry spell of summer and autumn seasons).
- TSS concentration showed remarkable reduction of up 10 folds from its initial value for Event 1.
- Clear differences in event concentration patterns between TN, TP and TSS as the wet season progressed.





Remarks - Intended functioning period

The as intended hydraulic functioning period: March 29 - June 5, 2019

- Inflow rates over the period dropped from 47 L/s to 38 L/s (± 5 L/s).

- Weir boards reinstated at OVF_W station.

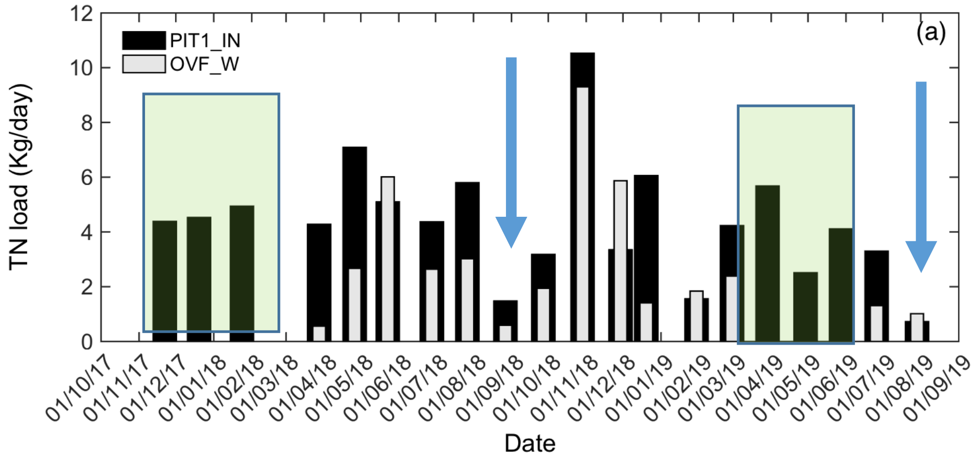
- Wetland’s main outflow point at OUT_W station.

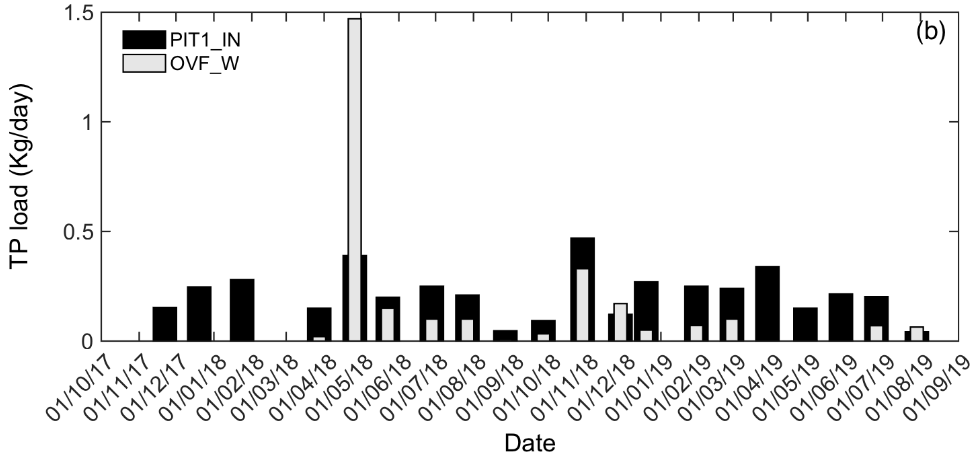
Concentrations were below guidelines for all nutrients!

Results - Load attenuation across ESBS

- Nutrient and sediment loads better reflect changes in inflow and outflow rates to the wetland.
- Flow rates responded to seasonal changes in hydrology and particularly management operations.
- Load attenuation will better quantify effectiveness of the treatment train in complex systems.

Results - Baseflow load attenuation





- Average of 27% load attenuation for TN.
- Average of 72% load attenuation for NOx-N.
- Average of 45% load attenuation for TP.
- FRP load attenuation at 69% on average.
- Average of 56% load attenuation for TSS.

Results - Event load attenuation

Event	Station	TP [kg]	TN [kg]	TSS [kg]
Event 1	Inflow	7.5 (0.38)	32.1(1.6)	1479.4(75)
	Outflow	5.8 (0.33)	31.5 (1.8)	1386.8(77)
Event 2	Inflow	13(0.23)	46.2(0.8)	2031.8(36)
	Outflow	1.5(0.04)	32.2(0.9)	241.2(6)
Event 3	Inflow	4.9(0.11)	32.6(0.7)	818.6(19)
	Outflow	3.9(0.08)	32.3(0.7)	346.6(7)
Event 4	Inflow	0.23(0.1)	2.6(1.2)	29.8 (44)
	Outflow	0.04(0.03)	1.1(0.8)	5 (10)
Event 5	Inflow	4.2(0.23)	20.7(1.1)	799(44)
	Outflow	2.1(0.08)	20.6(0.8)	254(10)

- Average of 20% load attenuation for TN.
- High variability in load attenuation for NOx-N shifting from sink (43% load reduction) to source (20% load increase).
- Average of 50% load attenuation for TP.
- FRP load attenuation at 53% on average.
- Average of 60% load attenuation for TSS.

* (Number in brackets represent Event Mean Concentration value)

Final remarks - ESBS overall nutrient performance

- Despite the poor performance of the GPT, the wetland achieved good attenuation of nutrients and TSS.
- TN and TP concentrations at the outflow of the wetland were below ANZECC guideline values (TN 1.2 mg/L; TP 0.065 mg/L).
- Event load reduction indicated better performance overall, than predicted by early MUSIC modelling of the system.

How to improve ESBS performance?

- Wetland water pathway for water treatment is not working as intended during rainfall events.
- Results suggest that 1/3 of the length of the wetland component treatment pathway is currently used for small and minor events including the 1-yr ARI event.
- Major inflow to the wetland during rainfall events is water from the Bayswater Brook, entering at the Outflow weir location.
- The area between the Overflow and the Outflow appeared to be a source of nutrients, TSS and metals.

How to improve ESBS performance?

Recommendations:

- Restore conveyance capacity of a 400 m reach in the Bayswater Brook around the Outflow weir location. Overgrown vegetation in the channel increased the water level in the brook.
- Overall, the system performance will likely benefit from a simplification in flow paths (bypassing the GPT, leaving the overflow weir boards in place, and removing the tidal flood gates). This would also greatly reduce the maintenance costs for ESBS.

How to improve ESBS performance?

Actions taken in December 2019 (before)

Diversion weir (tide 0.6 m)

Outflow weir (tide 0.6 m)

Source: K. Busby (DBCA)

How to improve ESBS performance?

Actions taken in December 2019 (after)

Diversion weir (tide 0.6 m)

Outflow weir (tide 0.6 m)

Source: K. Busby (DBCA)

How to improve ESBS performance assessment?

- Improve reliability of existing rating curves for as intended hydraulic functioning and develop new rating curves for ungauged inflows and outflows.
- Change water quality sampling collection method for baseflow conditions.
- Relocate sampling collection points at the sedimentation pond and wetland component inlet site.
- **Recommendation:** Modify SAP document accordingly. Undertake changes in monitoring program in two stages.

Acknowledgements

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Full Report can be downloaded from https://watersensitivecities.org.au/content/eric-singleton-constructed-wetland-monitoring-and-assessment-for-optimal-stormwater-treatment-performance/

Summary Report by DBCA can be requested from rivers.systems@dbca.wa.gov.au