Seasonal and Hurricane Irma effects on the hydrology of a subtropical constructed urban stormwater treatment wetland complex in southwest Florida

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Introduction: *Background*

- Urban stormwater has become a large source of pollution to surrounding bodies of water, while simultaneously increasing the risk of large flood events (Merriman et al., 2016)
  - Green infrastructure will be critical to stormwater management in these regions to reduce peak flows and mitigate for the changes in hydrographs (Pennino et al. 2016)
- Hydrologic regime is critical to overall wetland function (Mitsch et al., 2005, 2008, 2012; Richardson et al., 2011)
- Urban constructed wetlands are designed to protect and restore the water quality of downstream water bodies by attenuating nutrients from stormwater runoff (Adyel et al., 2017)
  - It is imperative to understand how these systems operate during storm events
  - Most studies lack comprehensive hydrologic data, further indicating its importance in complete understanding of wetland performance factors (Land et al. 2016)
- Urban stormwater treatment wetlands are relatively new, leaving them understudied compared to other treatment wetlands (Moore and Hunt, 2012).

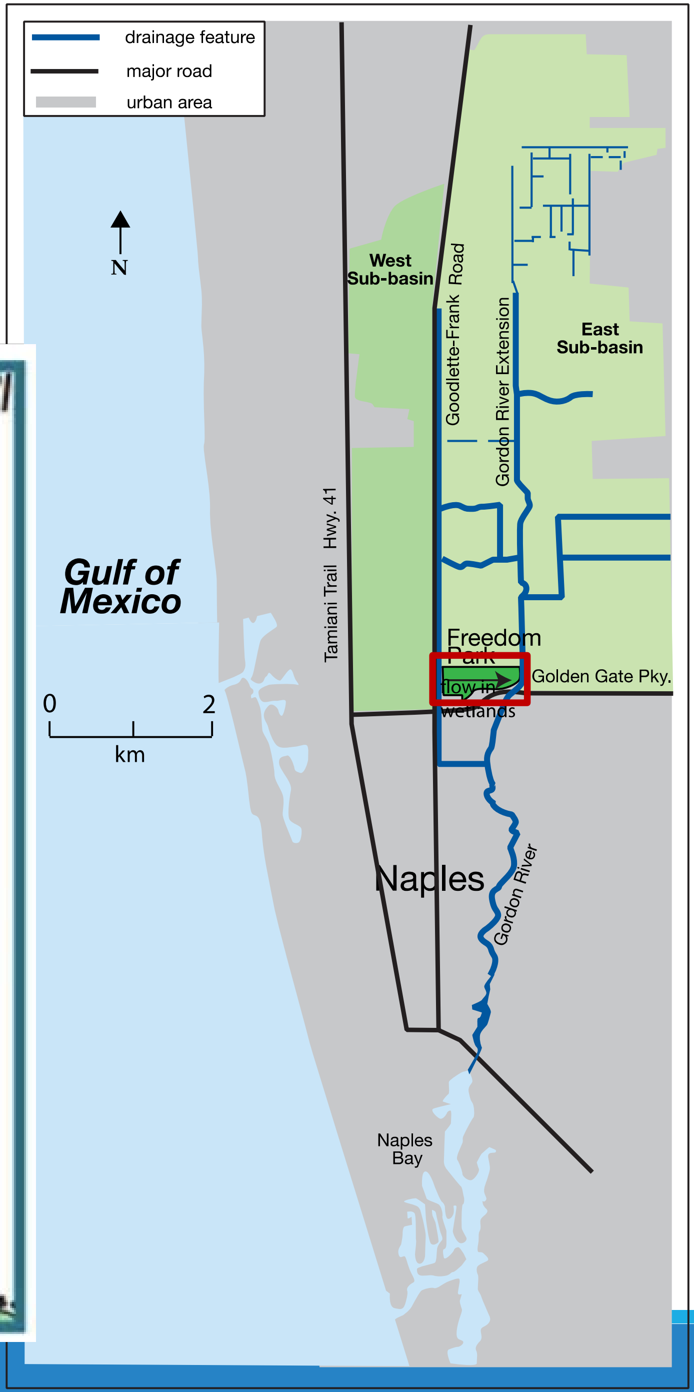
Introduction: *Research Goal and Objectives*

Goal: Evaluate the hydrologic functioning of an urban stormwater treatment wetland in southwest Florida to provide crucial insights into how nutrients and hydrology are interlinked in different seasons, during storm events, and even hurricanes.

This study sought to accomplish this goal through the following research objectives:

1. Create an annual water budget and identify seasonal trends for an urban stormwater treatment wetland in southwest Florida;
2. Evaluate nutrient loading and retention patterns during seasonal storm events;
3. Understand treatment wetland functioning during extreme storm events, such as hurricanes.

Methods: *Study Site*



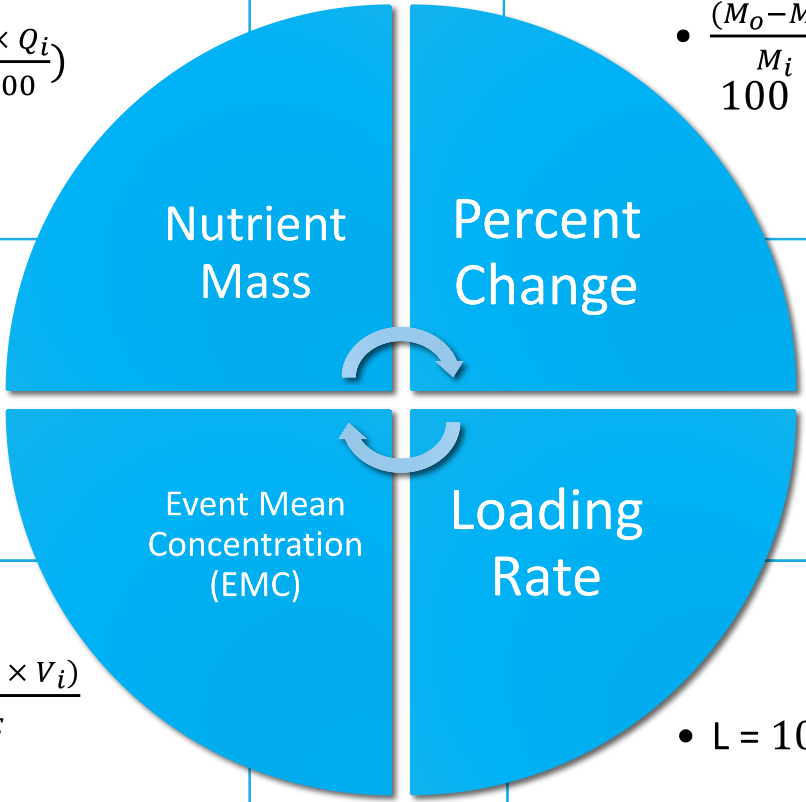
Methods: *Hydrology*

Hydraulic Loading Rate (HLR)	• $q = 100\ (c/d)\ (Q_s/A_t + Q_r/A_w)$
Weir Outflow	• $Q = (CLH^{1.5}) \times 0.0283$
Potential Evapotranspiration (PET)	• $ET_i = 1.6(\frac{10T_i}{I})^a$
Water Budget	• $\frac{\Delta V}{\Delta t} = P_n + S_i + G_i - ET - S_o - G_o$
Relative Water Level	• $\Delta h = \frac{\Delta V}{A_t}$

Methods: *Storm Event Sampling*

- $\frac{M_t}{\Delta t} = \sum_{i=1}^{n}(\frac{C_i \times Q_i}{1000})$

- $\frac{(M_o - M_i)}{M_i} \times 100$



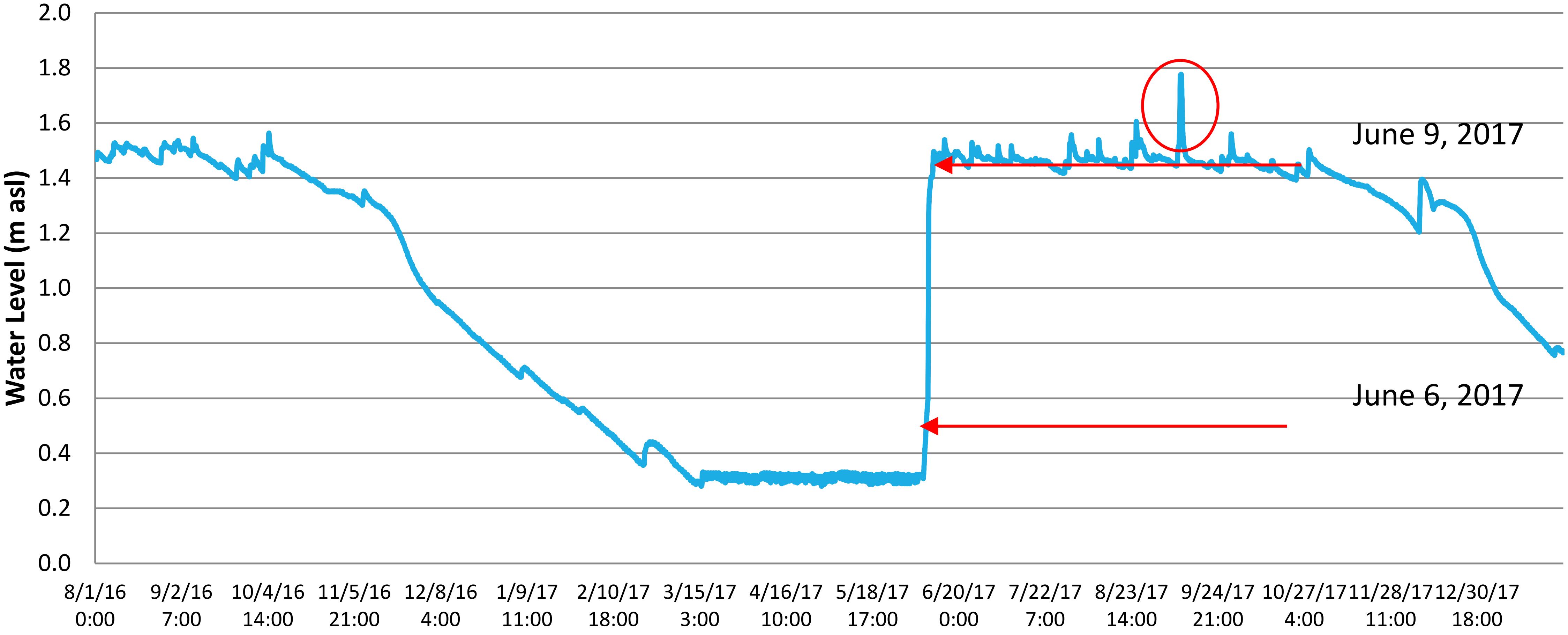
- EMC = $\frac{\sum_{i=1}^{n}(C_i \times V_i)}{V_E}$

- L = $100\frac{f}{g}(\frac{M_T}{A_T})$

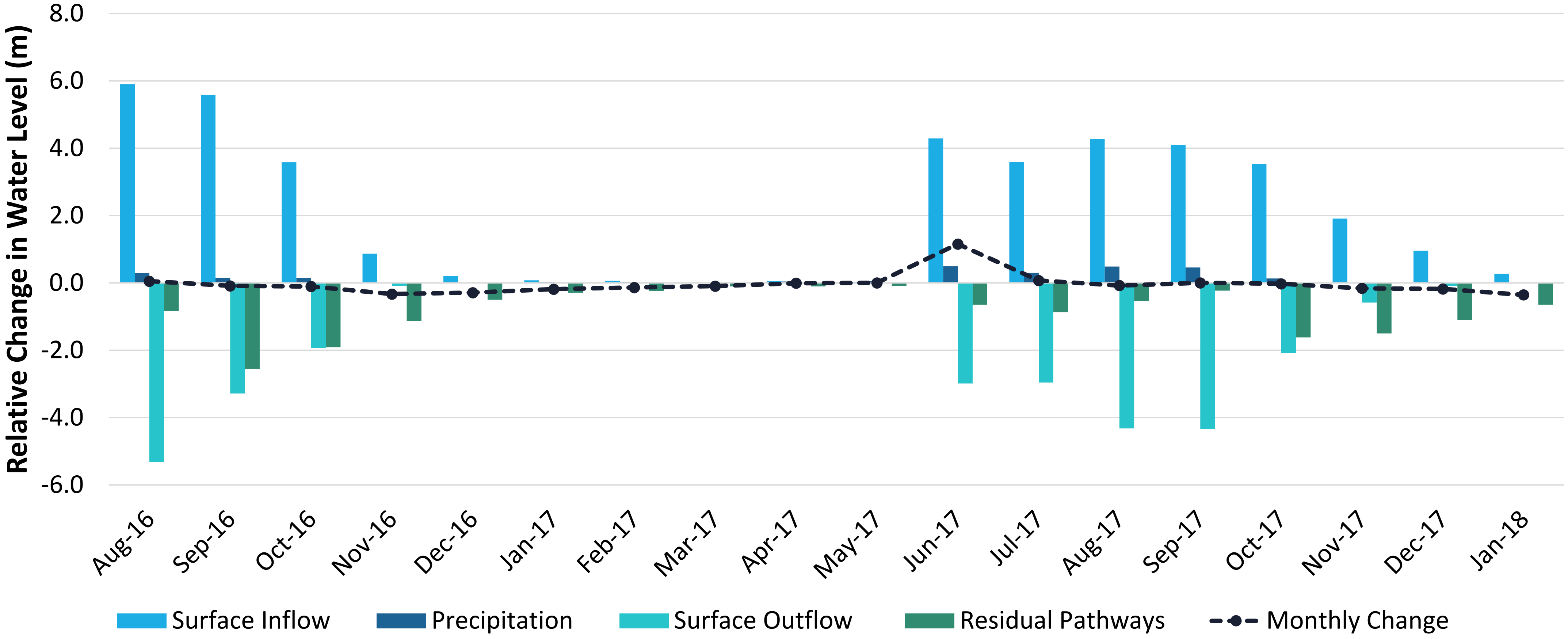
Methods: *Total storm events sampled*

- July 30 – August 2, 2017 (Tropical Storm Emily): 14.5 cm
- August 16 – August 22, 2017: 2.39 cm
- August 23 – August 29, 2017 (unnamed tropical event before Hurricane Irma): 22.2 cm
- September 9 – September 15, 2017 (Hurricane Irma): 27 cm
- October 27 – November 1, 2017: 5.97 cm

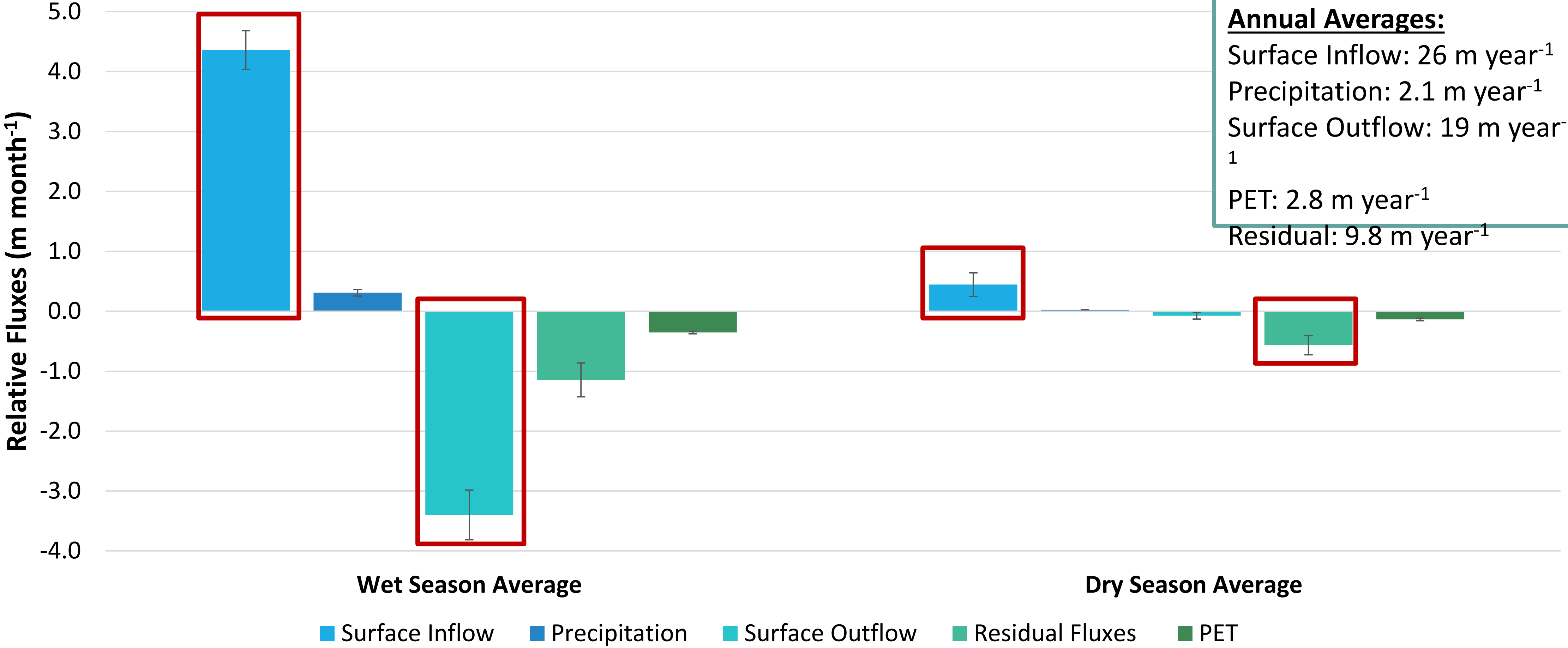
Results: *18-Month Hydroperiod*



Results: *18-Month Water Budget*

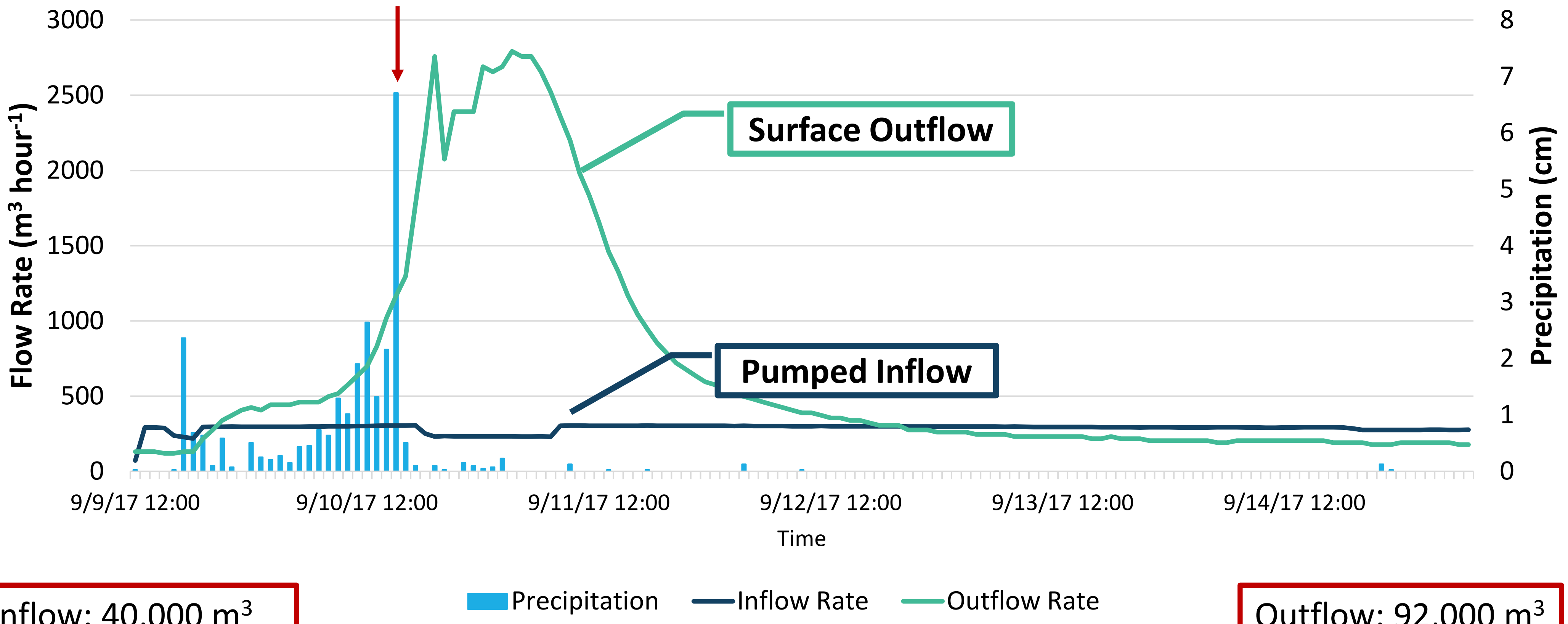


Results: *Seasonal Water Budget*



Annual Averages:
Surface Inflow: 26 m $year^{-1}$
Precipitation: 2.1 m $year^{-1}$
Surface Outflow: 19 m $year^{-1}$
PET: 2.8 m $year^{-1}$
Residual: 9.8 m $year^{-1}$

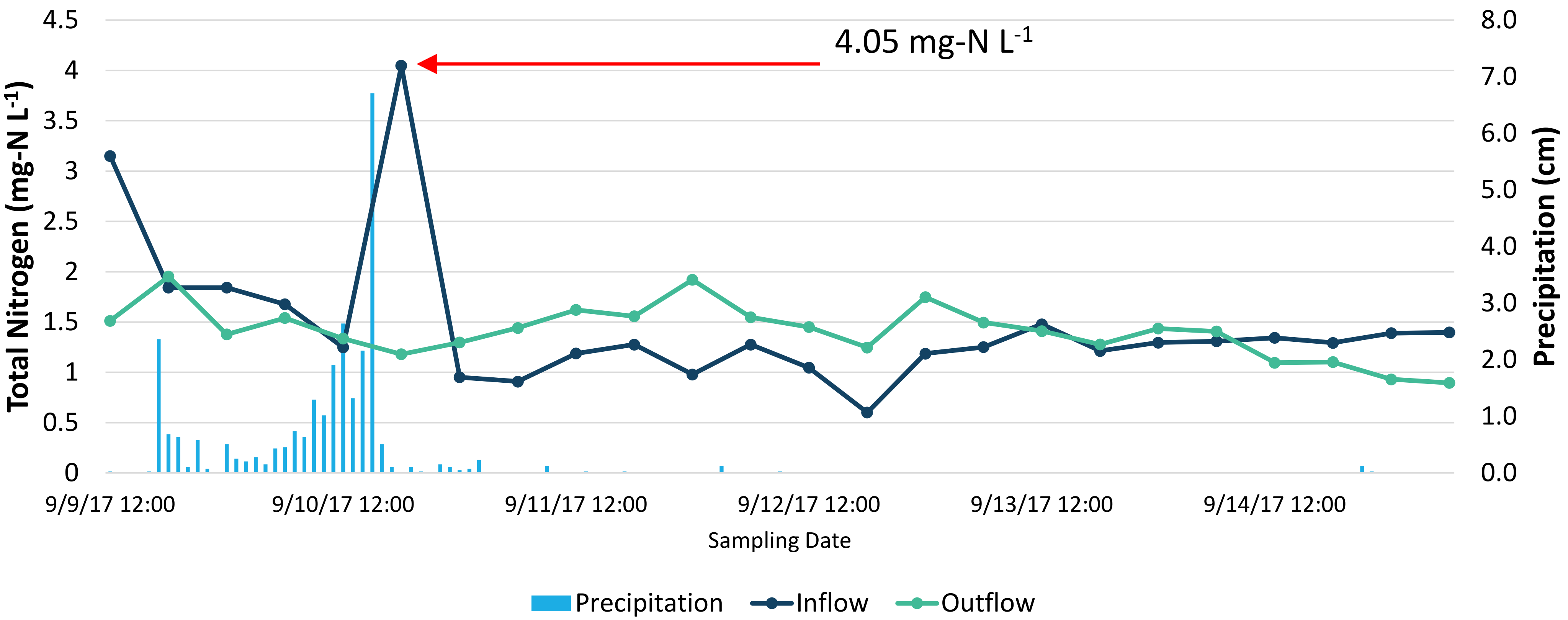
Results: *Hurricane Irma Hydrology*



Inflow: 40,000 m^3
HLR: 104 cm $week^{-1}$

Outflow: 92,000 m^3
241 cm $week^{-1}$

Results: *Hurricane Irma Nitrogen*

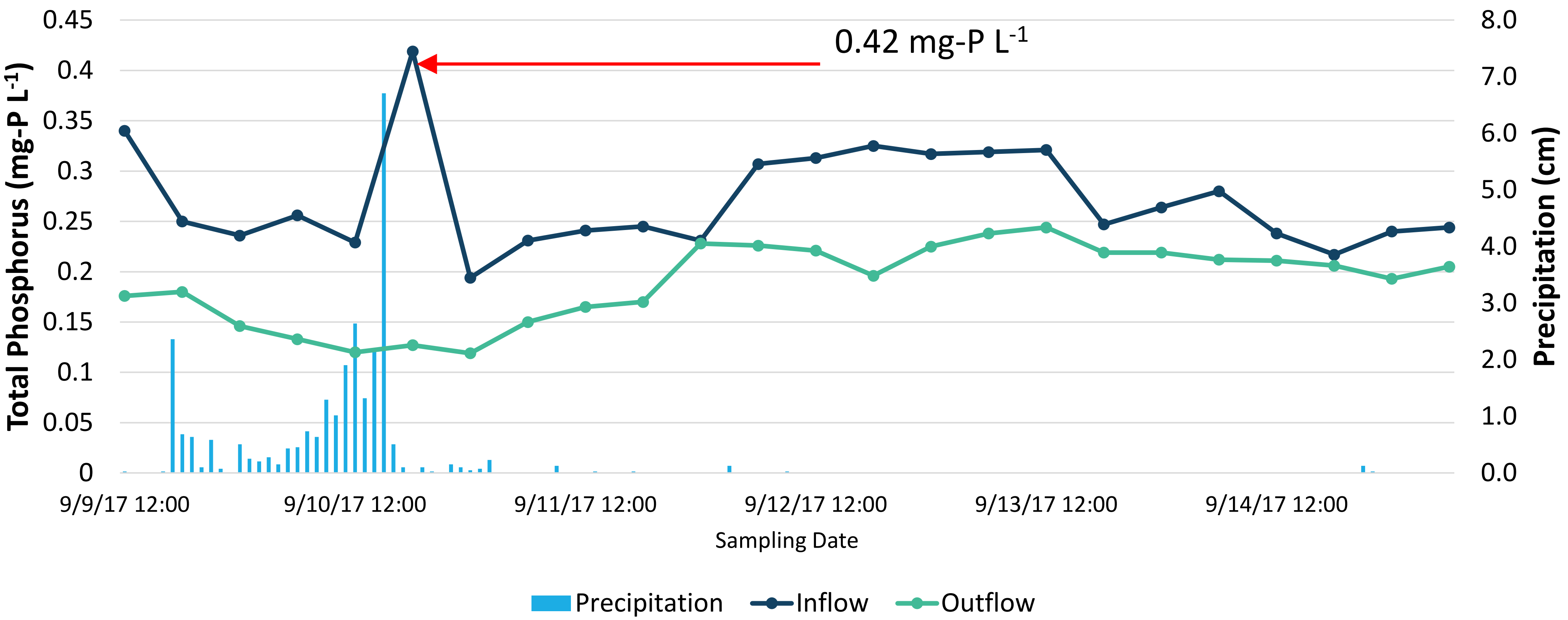


Inflow: 56.2 kg N

+130%

Outflow: 129.6 kg N

Results: *Hurricane Irma Phosphorus*



Inflow: 10.7 kg P

+37%

Outflow: 14.6 kg P

Discussion: *Storm event nutrient transport*

Most significant hydrologic factor influencing nutrient transport during storm events was the rate and volume of water outflow from the system

- Increased outflow led to a larger export in the mass of nutrients, though this trend was more closely followed for nitrogen ($p < 0.01$) than phosphorus ($p < 0.05$)
- Net flux of nitrogen also largely determined by outflow ($p < 0.05$); phosphorus more variable
- Concentrations at outflow largely variable

HLR by itself is **not** a significant factor influencing <u>nutrient</u> loading rates ($p > 0.05$)

- Loading rate of phosphorus was closely linked to the event mean concentration (EMC; $p < 0.05$)
- Loading of nitrogen more variable; more susceptible to ambient conditions
- It is not uncommon that nitrogen is more variable in nature due to the multiple ways in can be removed via denitrification and plant uptake

Discussion: *Nutrient Pulsing and Retention*

NITROGEN

Inflow

- Stormwater treatment wetlands: 1.7 mg L^{-1}
- Freedom Park storm events: 1.22 mg L^{-1}

Retention

- Stormwater treatment wetlands: 33%
- Freedom Park annual average: 26%
- Freedom Park storm events: 12%

PHOSPHORUS

Inflow

- Stormwater treatment wetlands: 0.24 mg L^{-1}
- Freedom Park storm events: 0.197 mg L^{-1}

Retention

- Stormwater treatment wetlands: 54%
- Freedom Park annual average: 55-58%
- Freedom Park storm events: 47%

Collins et al., 2010; Griffiths & Mitsch, 2017; Land et al., 2016

Discussion: *Constraints and Limitations*

A similar storm pulsing study in Australia found that the constructed stormwater treatment wetland removed an average of **45-48%** of nitrogen and **67%** of phosphorus *during storm events*

- Higher than the 12% of nitrogen and 47% phosphorus

Catchment Area to Wetland Size ratio

- Australian constructed stormwater treatment wetland- 129:1
- Freedom Park- 384:1
- Suggested 50:1 to 200:1 for stormwater treatment wetlands
- Higher than the 22:1, 14.2:1 found in agricultural treatment wetlands
- Ensuring an appropriate size of the wetlands promotes increased nutrient attenuation

Adyel et al., 2017; Larson et al., 2000; Carleton et al., 2000; Fink & Mitsch, 2004; Lim & Lu, 2016

Discussion: *HLR of Urban Treatment Wetlands*

FREEDOM PARK

- Subtropical climate
- 2017 Annual precipitation: 2,080 mm $year^{-1}$
- 2017 Annual HLR: 22.9 m $year^{-1}$
- Could be treating more water

OTHER URBAN TREATMENT WETLANDS

- 7 urban stormwater treatment wetlands evaluated (temperate and subarctic climates)
- Average precipitation: 1,050 mm $year^{-1}$
- Average HLR: 71.2 m $year^{-1}$
- Importance of:
  - Reliable baseflow → improved nutrient retention
  - Natural land overflow → balance of inflows and outflows

Griffiths & Mitsch, 2017; Land et al., 2016; Heyvaert et al., 2006; Carleton et al., 2000

Discussion: *Wetlands and Hurricanes*

2004 hurricane season in Florida Everglades (Williams & Boyer, 2008)

- Nutrient concentrations 2-5x higher than long term averages
- Increasing freshwater inflow and discharge
- Shift in downstream microbial communities
- “normal” conditions resumed 3 months after storm

2017 Hurricane Irma at Freedom Park

- Nutrient concentrations 1-3x annual average
- Hydraulic Loading Rate (HLR) did not change
- Limit of pumps instead of natural overflow
- Design underutilized its effectiveness during hurricane

Conclusions

- These wetlands need true major storm inflow that bypasses the pumps; the current design does not allow for an increased hydraulic loading rate proportional to increased precipitation as seen in other stormwater treatment wetlands.
- Extreme events such as hurricanes will result in a flush from the system, but because these wetlands turned out to be resilient, the vegetation, hydrology, and nutrient chemistry have already returned to normal conditions within days or weeks after the hurricane.
- While total phosphorus removal during and after storm events is comparable to normal conditions at the Freedom Park wetlands and other stormwater treatment wetlands, total nitrogen removal decreases during and after storm events.
- Expanding these treatment wetlands (in size and inflow) would lead to a greater ability to capture runoff from its watershed and subsequently allow for a longer hydraulic residence time and increased nutrient removal efficiency.

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Thank you!