The contribution of evapotranspiration to the annual water budget of an aridland urban wastewater treatment wetland

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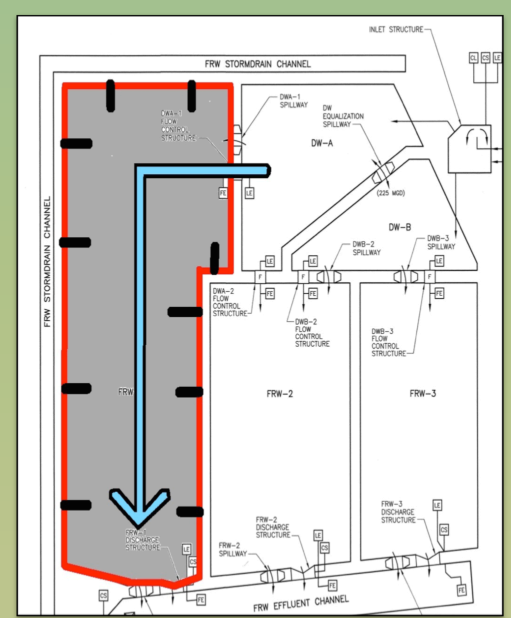
Introduction

- One of the most important aspects of systems-level analysis of wetlands is the water budget. Specifically, quantifying how evaporation and evapotranspiration contribute to water residence time is crucial to understanding the cycling of biogeochemically active and non-active solutes through the water column, plants and soils—particularly in arid climates.
- Our primary objectives were to:
  - determine species-specific transpiration rates using a handheld infrared gas analyzer (IRGA)
  - quantify aboveground biomass and species composition of the plant community
  - calculate a whole-system annual water budget using these rates plus inflow and outflow
- We hypothesized that:
  - leaf-specific transpiration rates are controlled by photosynthetically-active radiation (PAR), relative humidity, and air temperature but…
  - annual evapotranspirative water losses will be driven by seasonality in macrophyte biomass and community composition
- Ultimately, we want to understand how this arid wetland's hydrology (water budget) affects its ecology (nutrient uptake and ecosystem services) through the process of evapoconcentration

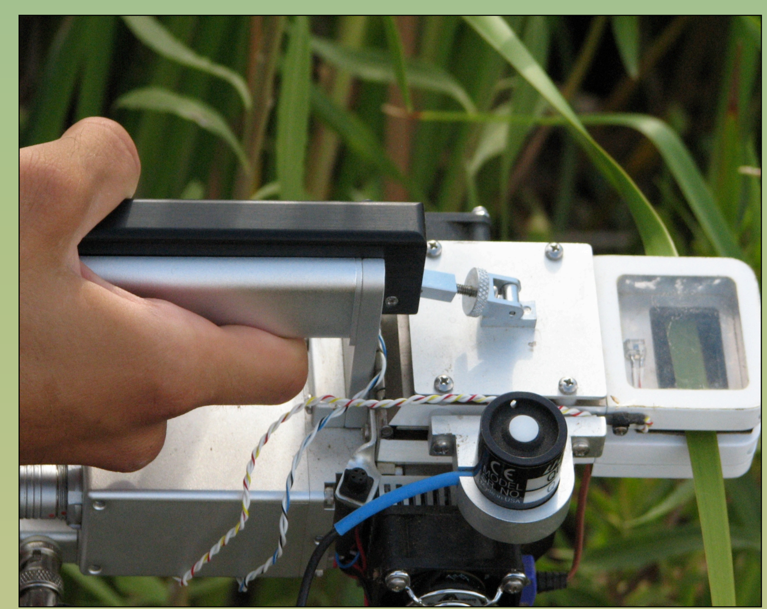
Experimental Design and Field Sampling

- 10 shore-to-open-water transects were distributed proportionally across a treatment flow cell based on the total area of vegetated subsections (vegetation bracketed by roads)
- In each transect we used a LICOR-6400 handheld infrared gas analyzer (IRGA) to sample leaves of each species present along a height gradient and a handheld YSI conductivity meter to measure conductivity and water temperature.
- Round or triangular stemmed *Schoenoplectus* macrophytes required the use of leaf chamber extensions

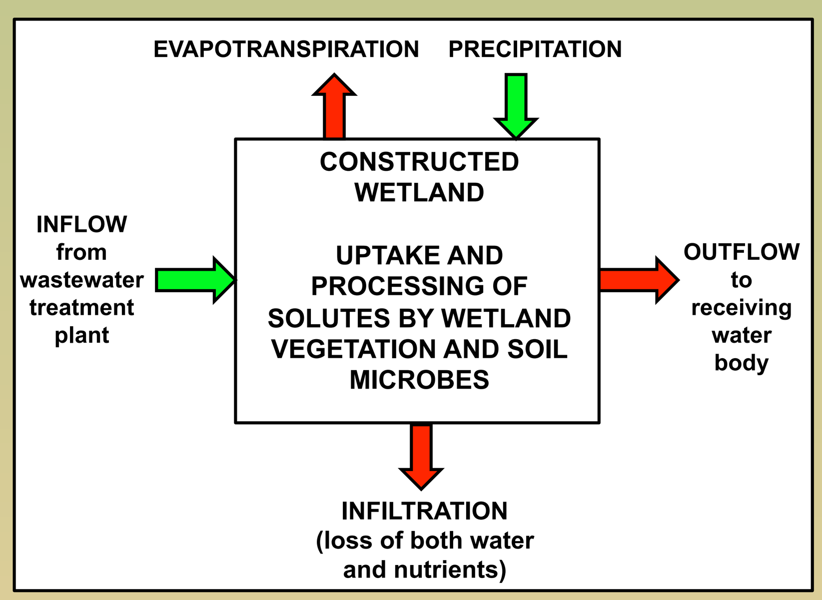
Aerial photo of the treatment flow cell



Design schematic for the treatment flow cell



Handheld IRGA clamped onto a *Typha spp.* leaf

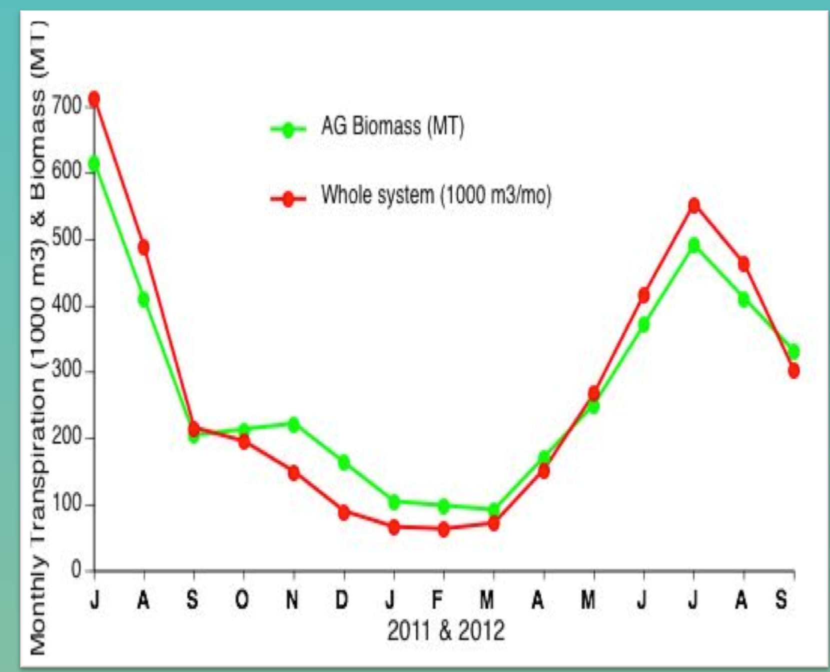


Conceptual model for whole-system water budget
(note: infiltration is negligible in this case)

Water Budget Development

1. Species-specific IRGA measurements included evapotranspiration, air temperature, relative humidity, and PAR. Evapotranspiration (ET) was measured by the IRGA in mmol H_2O/m^2 of leaf area/sec.
2. In-chamber leaf samples were harvested, dried and weighed to provide a species-specific conversion factor to ET in mmol H_2O/gdw/sec
3. Multivariate regressions comparing ET to air temperature, relative humidity, and PAR were generated to determine the significant climatic drivers of ET for each species and create models to predict ET from these drivers.
4. We regressed canopy climate data from the IRGA against simultaneous data from a meteorological station at Tres Rios to generate correction factors, allowing us to use the latter data to predict hourly climatic conditions in the canopy.
5. These predicted hourly canopy climate conditions were entered into the multivariate ET models (#3) to generate time-series ET estimates for June 2011 through June 2012.
6. We scaled time-series ET data spatially for each species using system-wide aboveground biomass data (gdw/m^2) and then summed across species and time to yield whole-system daily evapotranspiration losses (m^3 H_2O/day).
7. The City of Phoenix provided data for inflow and outflow rates for the treatment cell, allowing us to calculate total daily inflow and outflow for 2012.

Results

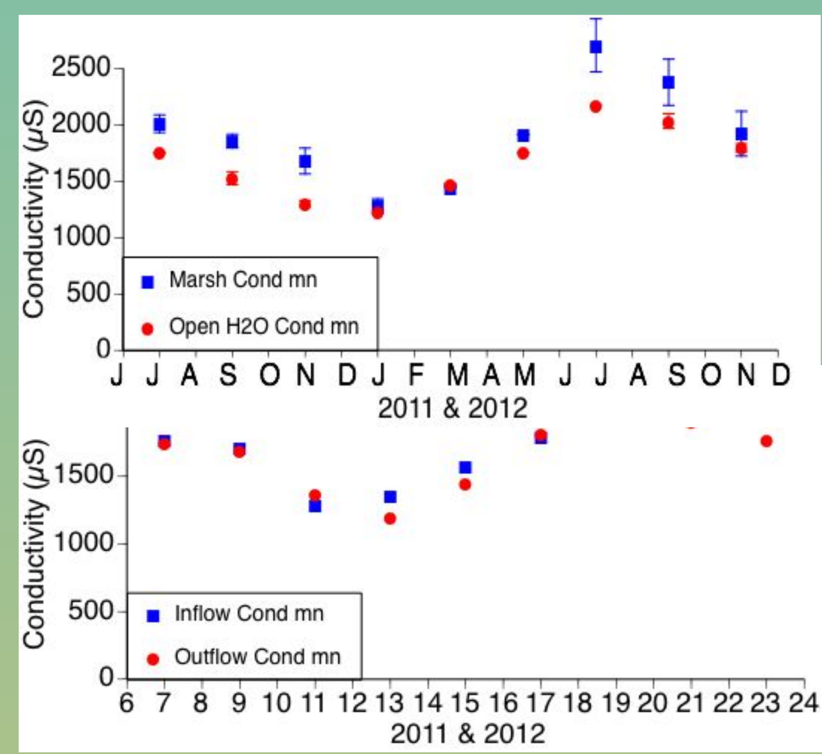


Evapotranspirative losses showed seasonal variation

- ET losses varied seasonally alongside seasonal variations in aboveground biomass
- ET for all plant species was driven primarily by air temperature and PAR ($p < .01$, r^2 0.57 to 0.67)
- Relative humidity was not a significant driver of ET ($p > .05$)

Evapotranspiration represented a significant portion of the whole-system water budget

- ET was responsible for between 10% and 89% of the total water loss from the treatment wetland throughout 2012
- Other water losses (blue line, inflow-outflow) did not have a clear origin, but are likely due to water management practices
- Whole-system water budget (other water losses, ET) varied seasonally, with greater losses in hotter months and smaller losses in cooler months
- Infiltration was assumed to be a negligible component of the water budget
- Precipitation (not shown) represented only 0.014% of the water budget for 2012



Conductivity increased along marsh transects

- From open water (no vegetation) to the shore line (dense vegetation), marsh transects showed considerable increases in conductivity, suggesting evapoconcentration of solutes
- The inflow-outflow (system-wide) gradient did not demonstrate the same trend, but did follow a seasonal variation

Discussion and Conclusions

- As was hypothesized, annual ET water losses appears to be driven by seasonal variations in the total aboveground biomass of the treatment wetland. We found that only air temperature and PAR were significant climatic drivers of ET. However, unlike our hypothesis, relative humidity was not a significant driver, with further literature review needed to fully understand the cause of this.
  - Further investigation is required to determine the contribution of open-water evaporation to the whole-system water budget.
- ET volume and the percentage of total water losses reported here are significantly higher than those reported in mesic constructed and natural wetlands.
  - Depths of water lost due to ET at study site range from 0.79 cm/day in winter 11.2 cm/day in summer, whereas Abtew (1996) reports a mean ET rate of 0.36 cm/day for a cattail dominated region of the Florida Everglades.
  - At a constructed wetland near the coast in the Netherlands, Meuleman et al. (2003) report that ET comprised 13% of total system water losses.
- Solute concentrations as measured by specific conductivity suggested an evapoconcentration effect along marsh transects. The drawdown of water in the vegetative canopy associated with high ET rates increases solute concentrations and could negatively affect the ability of wetland macrophytes to provide the desired ecosystem services (i.e. nutrient removal).
  - However, preliminary nutrient data suggests that other biological processes may be able to maintain treatment efficacy in the short term.
  - In addition, evapoconcentrative effects are not as apparent across the inflow-outflow gradient
- We suspect there may be a biological ET-driven hydraulic pump operating in the treatment wetland. High volumes of water lost due to ET from the vegetated areas of the wetland are likely causing comparable volumes of water to be drawn into the marsh from the open water.
  - Preliminary calculations suggest that between 5% and 42% of total water volume contained in the marsh may be evaporating out of the marsh and subsequently replaced every day.

Acknowledgements

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