Stormwater nutrient attenuation by constructed wetland on the Swan Coastal Plain

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[3]CRC for Water Sensitive Cities, Melbourne Australia
[4]Swan River Trust, Perth, Australia

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CRC for Water Sensitive Cities
An Australian Government Initiative
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Motivation

- Effect of urbanisation on water quality is a concern in Perth
  - Urban drainage contributes 180 tonnes of nitrogen and 16 tonnes of phosphorus to the Swan–Canning estuary annually (SRT, 2009)
- Substantial resources invested by water regulatory authorities to protect down stream water bodies by creating constructed wetlands (CWs)
  - Swan River Trust and partners have invests in several CWs as a part of the Healthy Rivers Action Plan (HRAP) to maintain water quality of the Swan–Canning estuary
  - Managed through the Drainage Nutrient Intervention Program (DNIP)

Background

Knowledge gaps:

- How does seasonality and antecedent dry condition affect the CW function?
- How does performance change over time?
- To what extent is nutrient reduction attributed to hydrological or biogeochemical processes?
  - *Considering inflow/ ungauged inputs/ GW connectivity/ rainfall event etc*
- What is particular role of compartments of CW to attenuate pollutant?
- Are there specific design elements that can improve performance on the Swan Coastal Plain (SCP)?

An Australian Government Initiative

Aim

To assess effectiveness of **Wharf Street Constructed Wetland** through synthesis of long term monitoring data.

- Focusing on nutrient attenuation by different compartments

Study site:

- Situated in Cannington
- Started operation in 2009
- Multiple surface flow (SF) and subsurface flow (SSF) systems
- Subsurface compartments were constructed of recycled concrete material (RCM)
- Due to alkalinity problem, RCM were replaced with laterite in June 2012. SSF were then connected to rest of wetland

Nutrient attenuation calculation

Standardised delta concentration (SDC):

Because of ungauged input, we estimated the *standardised delta concentration (SDC)* - difference in nutrient concentration between inlet (Cin) & outlet (Cout)

SDC (%) = (Cin- Cout)/Cin

To account for effect of ungauged flows we also computed a modified version

SDC_ave (%) = (*Cin- Cout)/*Cin

*Cin is average nutrient concentration of different inlets

Event mean concentration (EMC) and load attenuation:

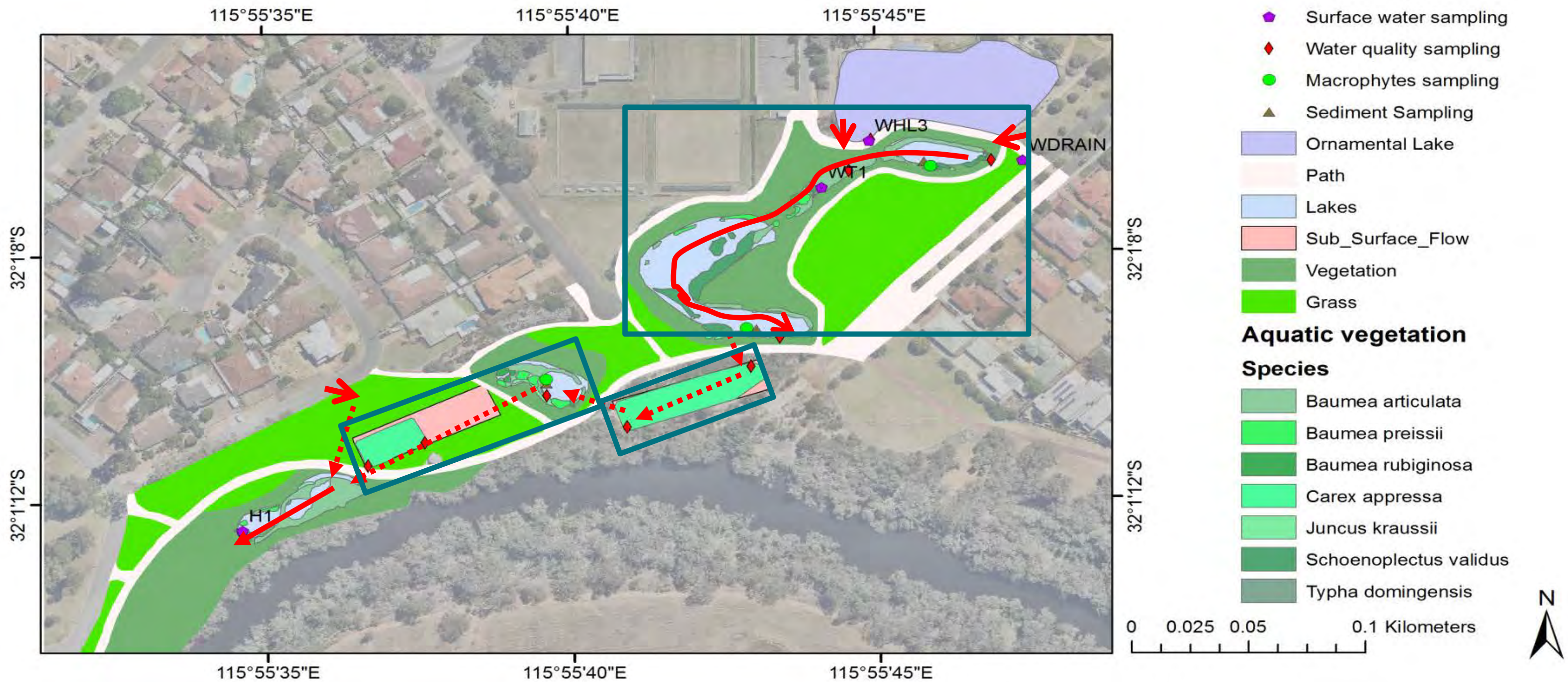
During event sampling (simultaneous flow and nutrient concentration measurement)

$$EMC(mg/L) = \sum_{i=1}^{n} V_i C_i / V$$

Vi is volume proportional to the flow rate at time i, Ci is nutrient concentration at time i, n is total number of samples, V is total runoff volume per event

$$\text{Load attenuation (\%)} = \frac{\sum Inlet\ loading - \sum Outlet\ loading)}{\sum Inlet\ loading}$$

Wharf Street Constructed Wetland

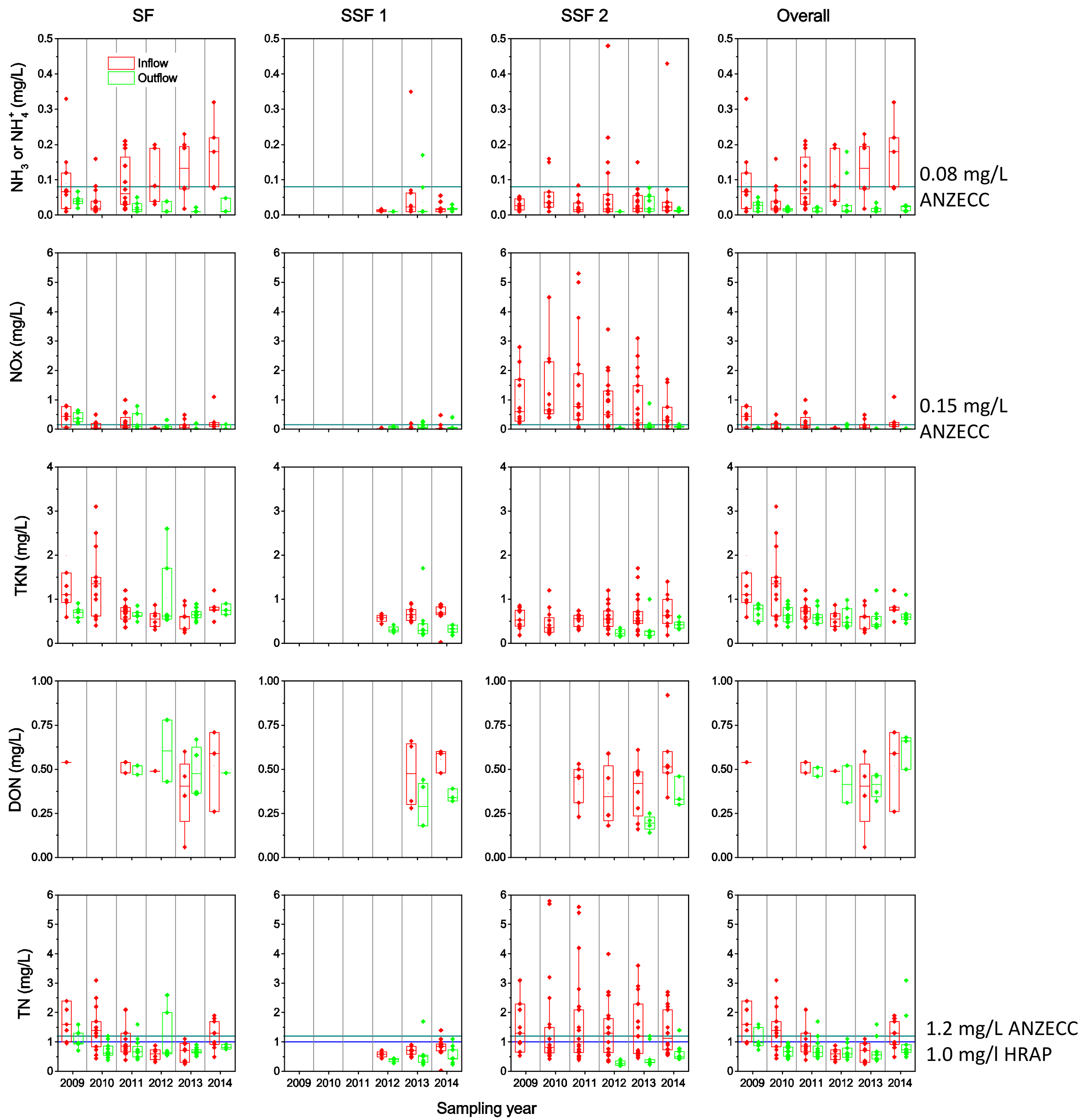


Compartments:

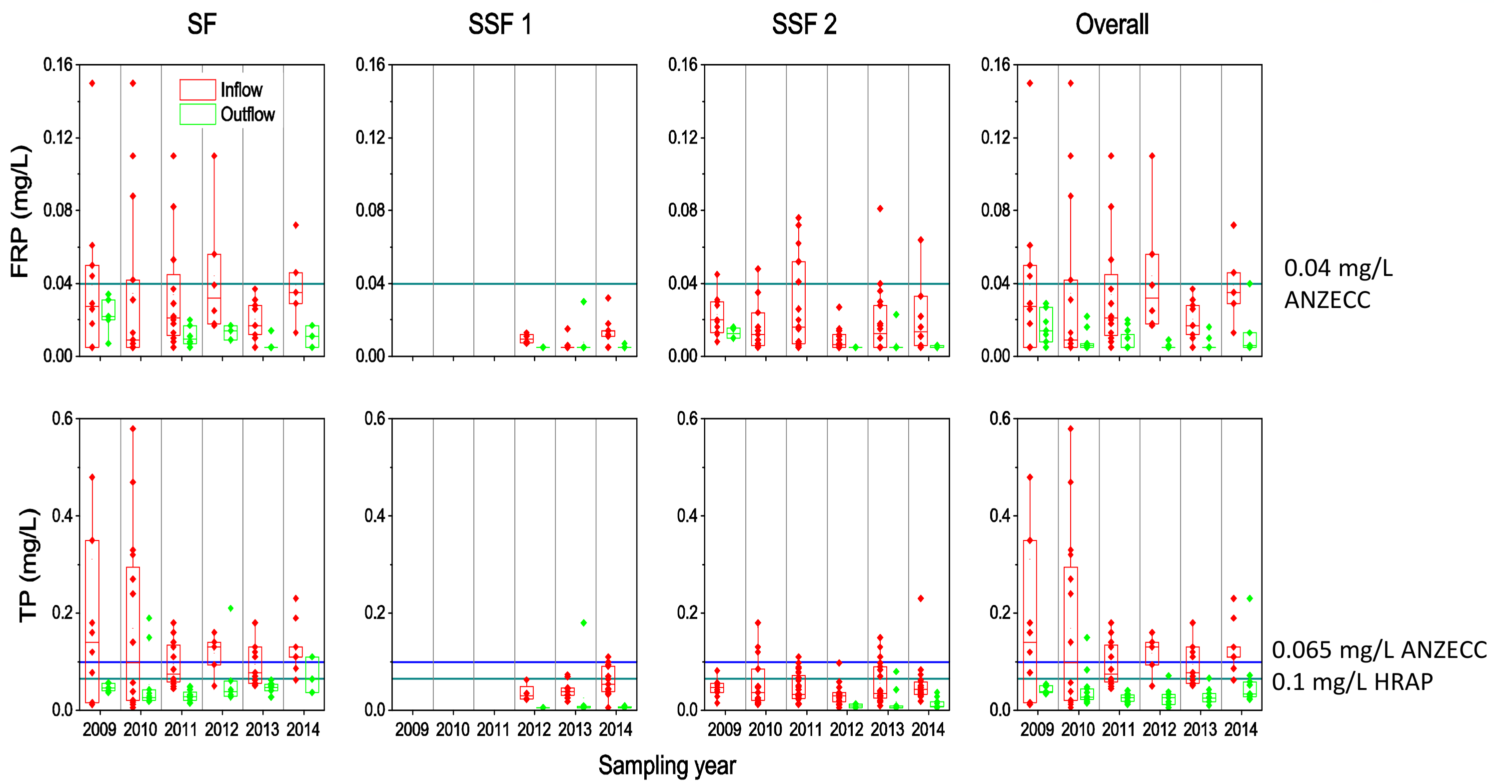
1: Surface flow (SF) 2: Laterite subsurface flow system 1 (SSF 1)

3: Laterite subsurface flow system 2 (SSF 2) 4: Overall system

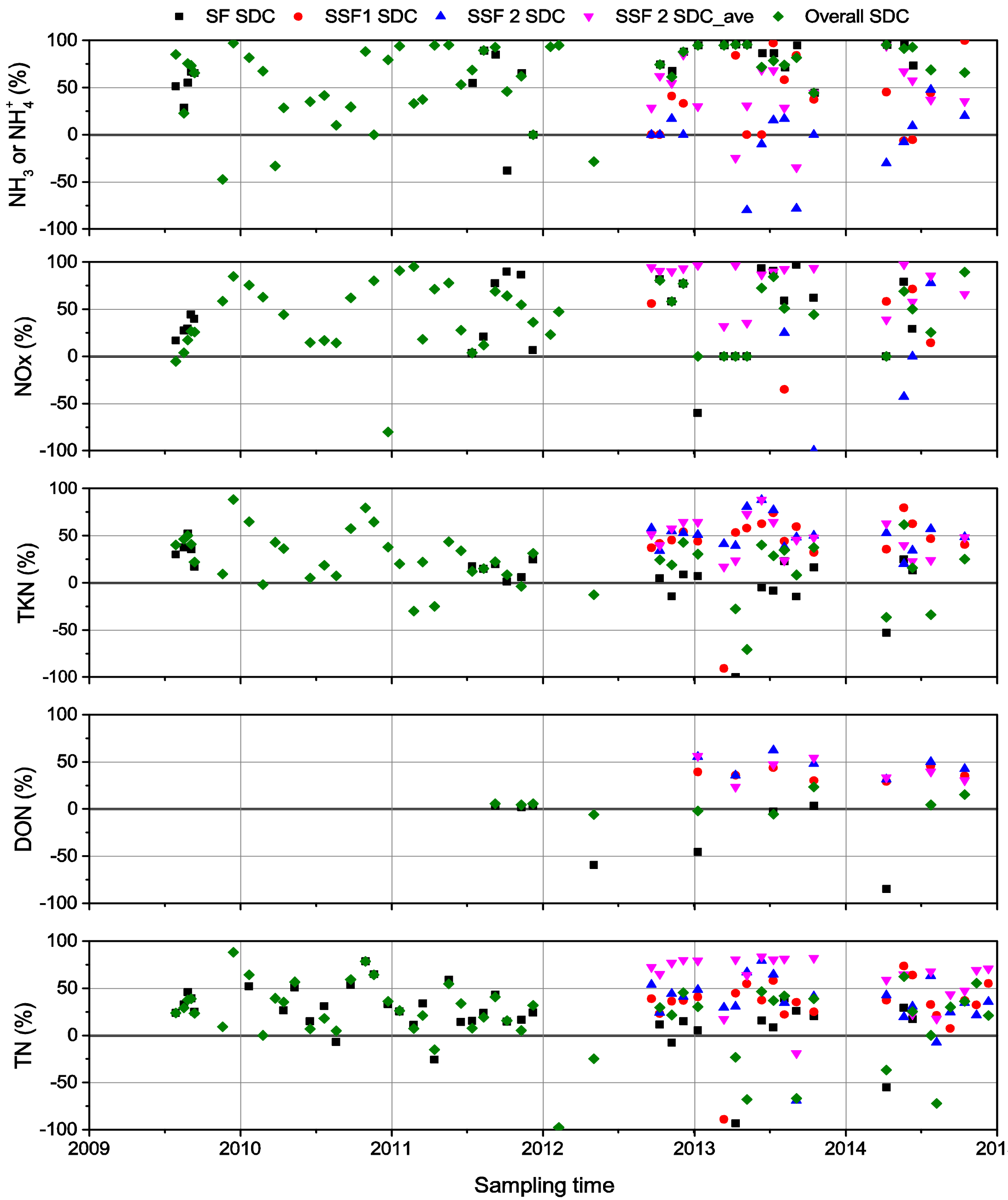
Nutrient dynamics
N species



Nutrient dynamics - P species



SDC (%)- N species



SDC (%) - N species

Findings - Nutrient attenuation

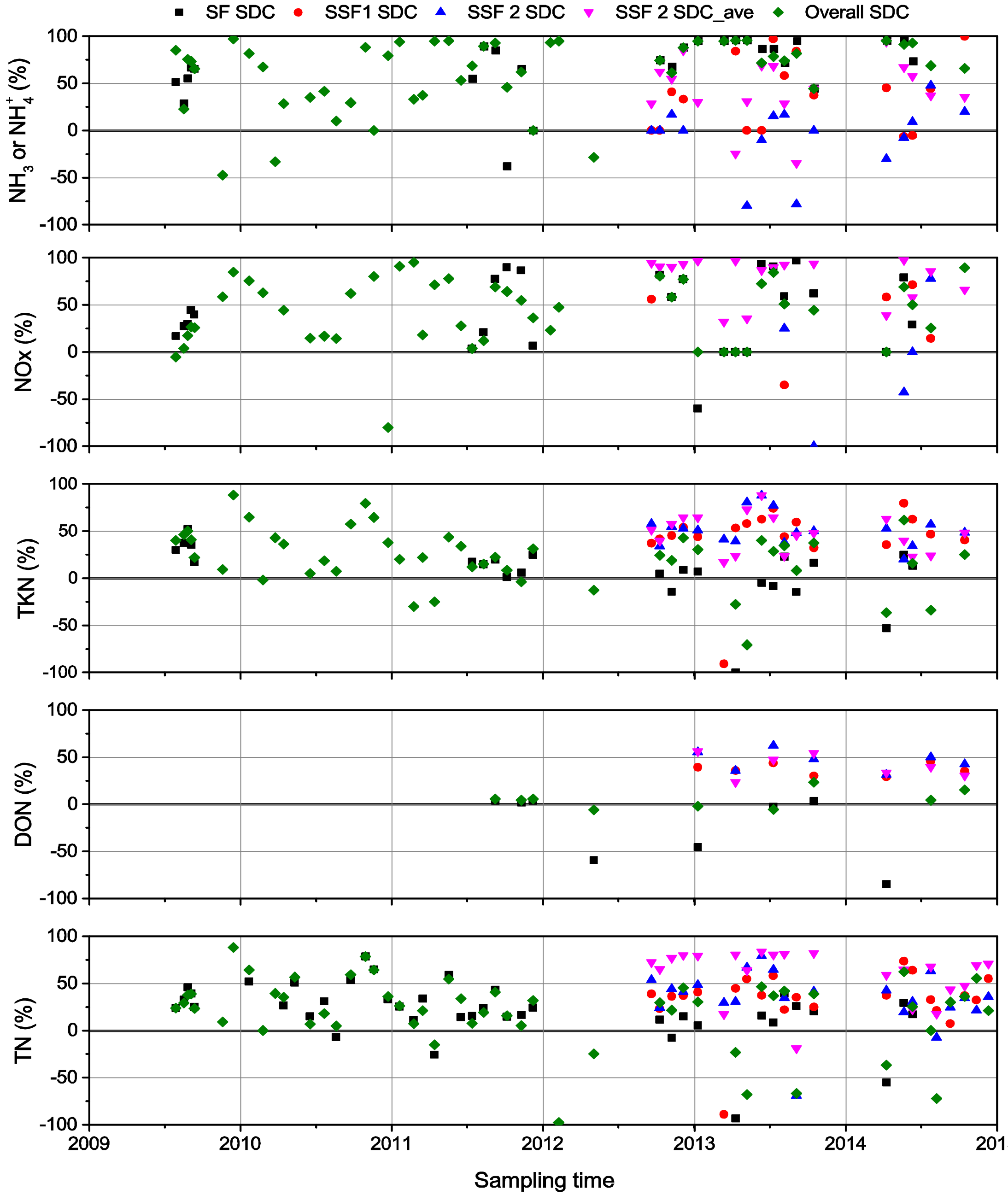
- Significant concentration attenuation for TN and DIN

-Up to 78% attenuation for TN by SF

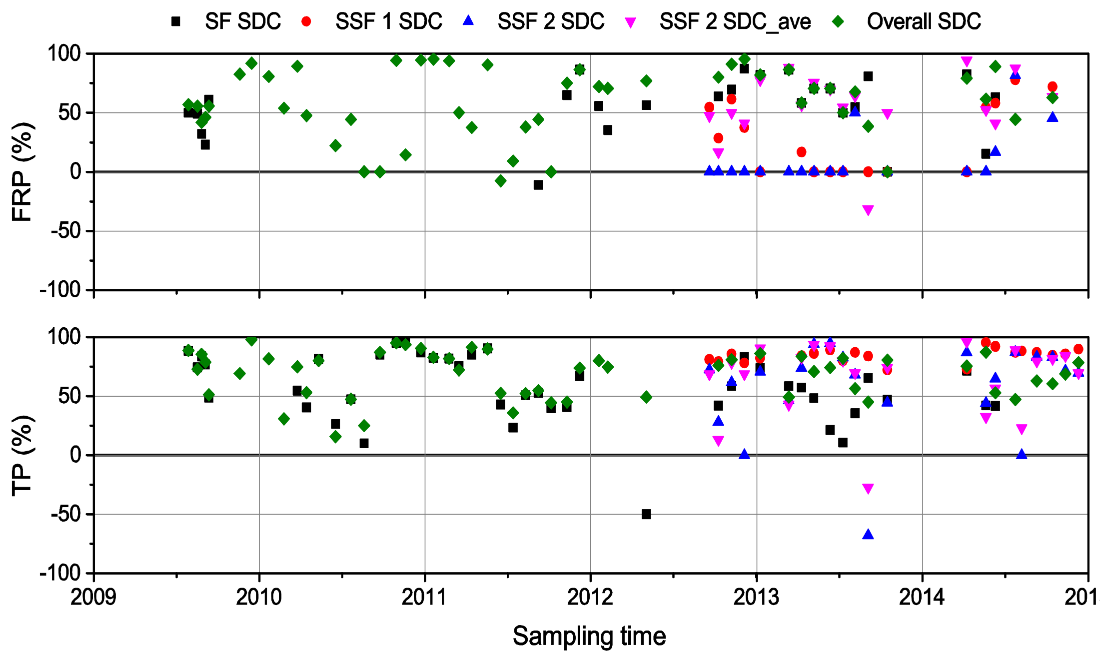
-Up to 73% attenuation for TN by SSF

-Up to 88% attenuation for TN by WSCW

- Limited attenuation during high flows due to short retention time
- High attenuation during dry period
- Variable significance and contribution of ungauged sources depending on antecedent condition
- Disproportionate role of first SF in total attenuation
- SDC periodically negative for NOx in SSF 1 and SSF 2



SDC (%) - P species



SDC (%) - P species

Findings - Nutrient attenuation

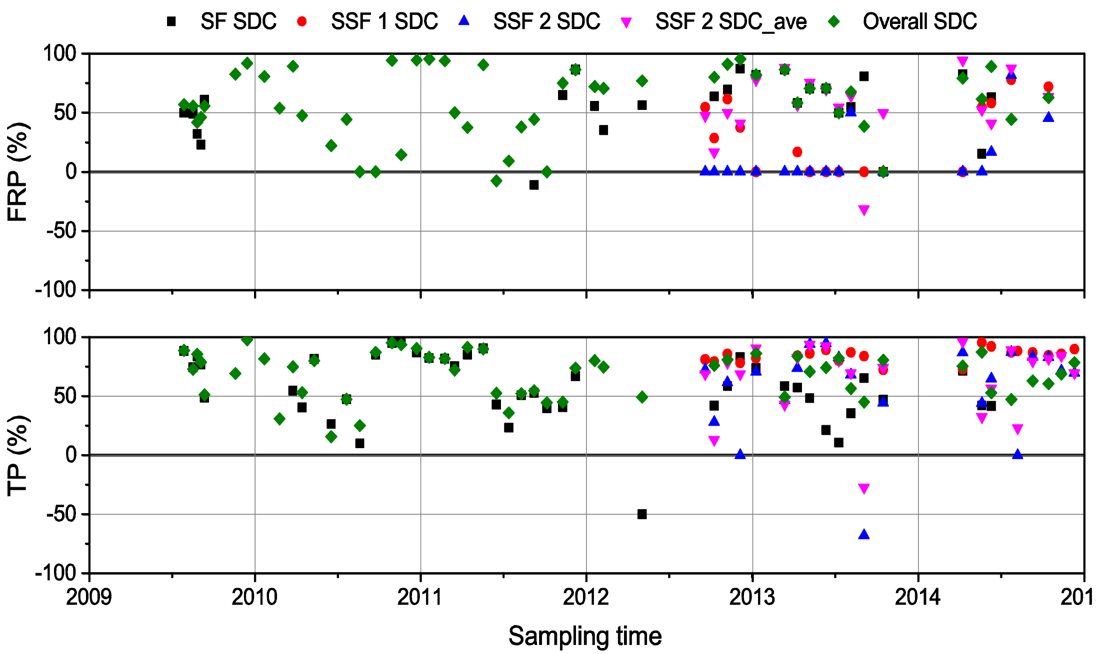
- Significant concentration attenuation for FRP and TP

-Up 95% attenuation for TP by SF

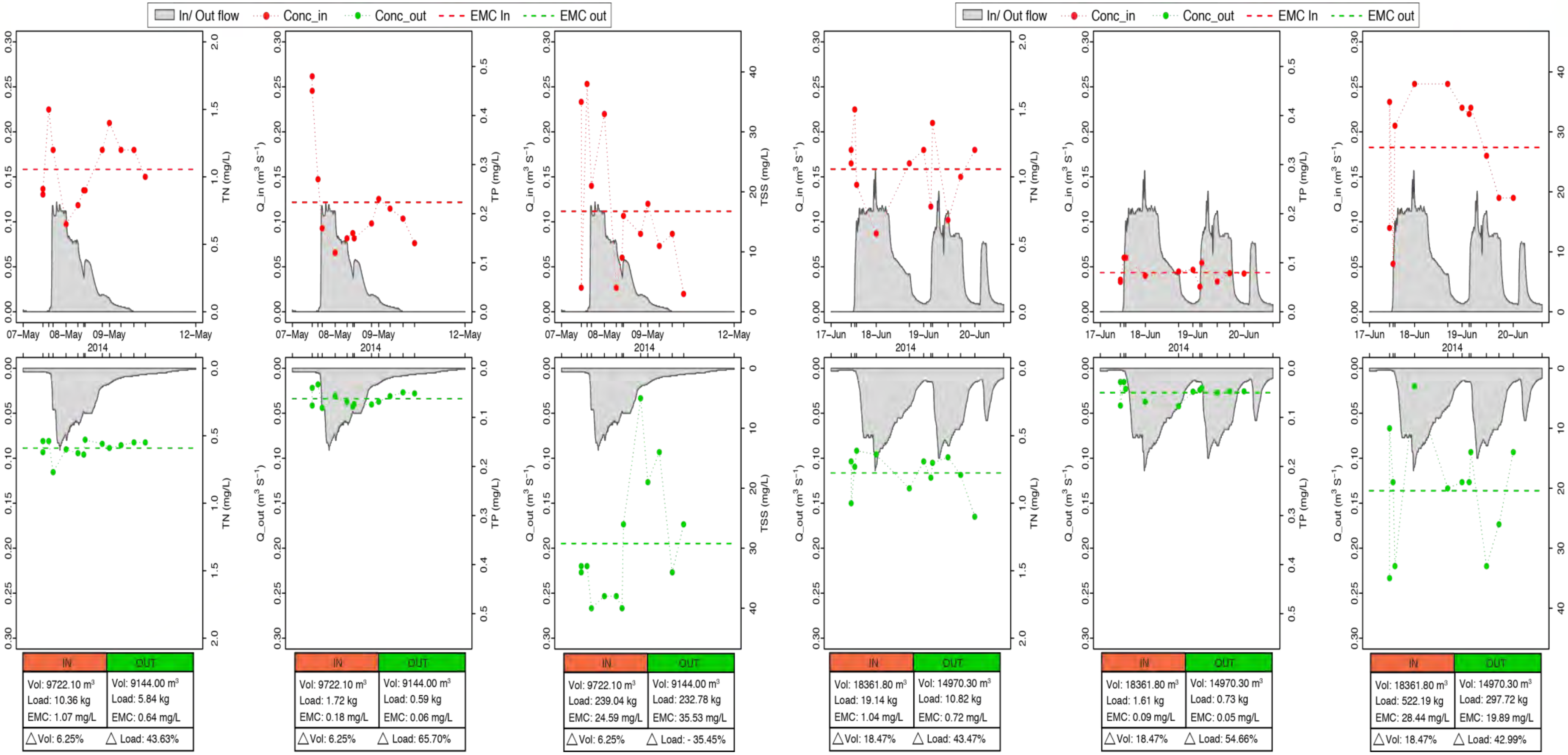
-Up 98% attenuation for TP by SSF

-Up 95% attenuation for TP by WSCW

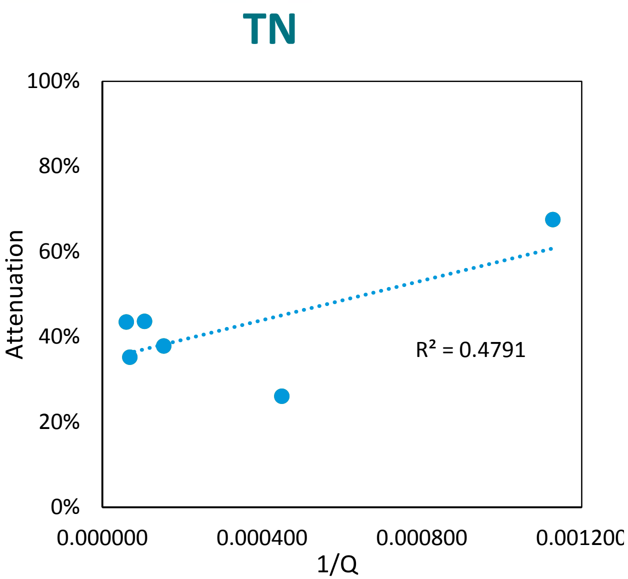
- High attenuation during dry period
- SSF compartments are more effective for P attenuation than SF

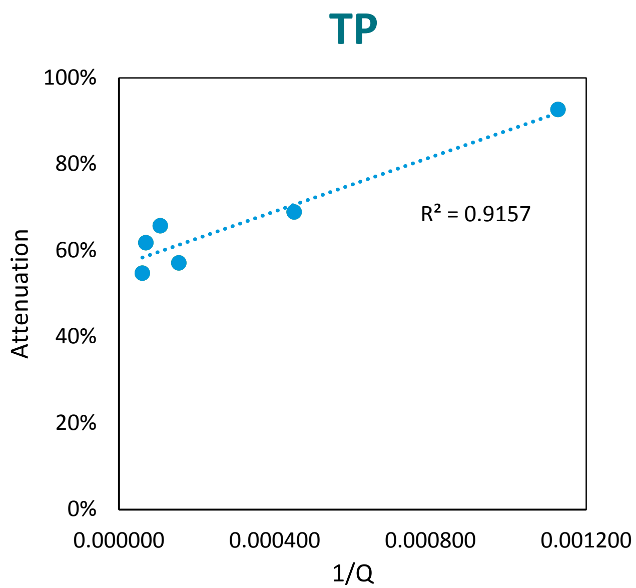


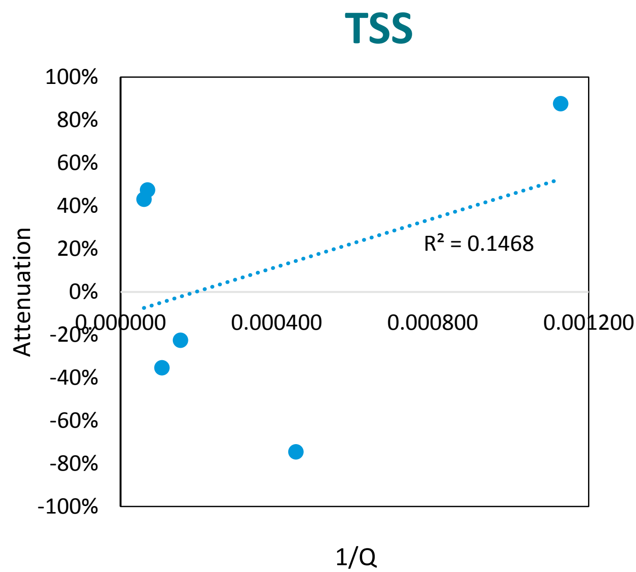
Event sampling-load calculation



Nutrient attenuation as a function of travel time







Conclusion

- Significant concentration attenuation for TN , TP, DIN and FRP - *base flow condition*
  - -Up to 78% for TN, 95% for TP by SF
  - -Up to 73% for TN, 98% for TP by SSF
  - -Up to 88% for TN, 95% for TP by overall wetland
- Load attenuation ranged from 26-67% for TN and 54-92% for TP – *event flow condition*
- Attenuation increased during dry period
- SSF compartments are more effective for P attenuation than SF
- Variable significance and contribution of ungauged sources depending on antecedent condition
- Relatively consistent outlet concentration over last five years

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Acknowledgement

- UWA SIRF
- CRC WSC
- Swan River Trust
- Department of Water, WA
- City of Canning
- Water Corporation, WA
- SERCUL
- Public Transport Authority

- Carlos Ocampo
- Ana Ruibal
- Hasnein Bin Tareque

Thanks...

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Aquatic Eco Dynamics

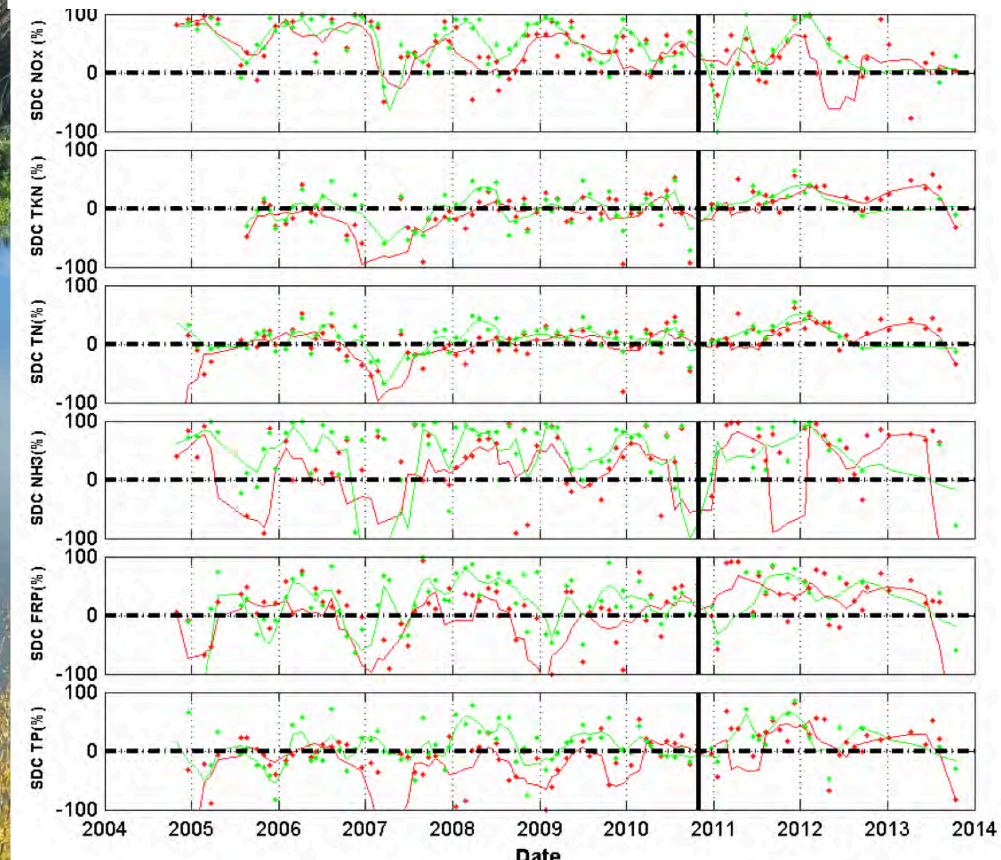
An Ecohydrological Model Framework to Assist Constructed Wetland Design

WaterWays Seminar 1st May2015

Jana Coletti
Matt Hipsey

Background: Anvil Way

Variable nutrient reduction (+ve = loss)



Ruibal-Conti et al., 2015

Motivation

Ongoing questions

- Hydrological conditions X attenuating nutrients?
- Can we manage the wetland to improve its performance?
- What is the link between hydrological pathways and pollutant reduction?
- What is the significance of groundwater – how much comes in or out?
- How can we account for role of unguaged inputs?

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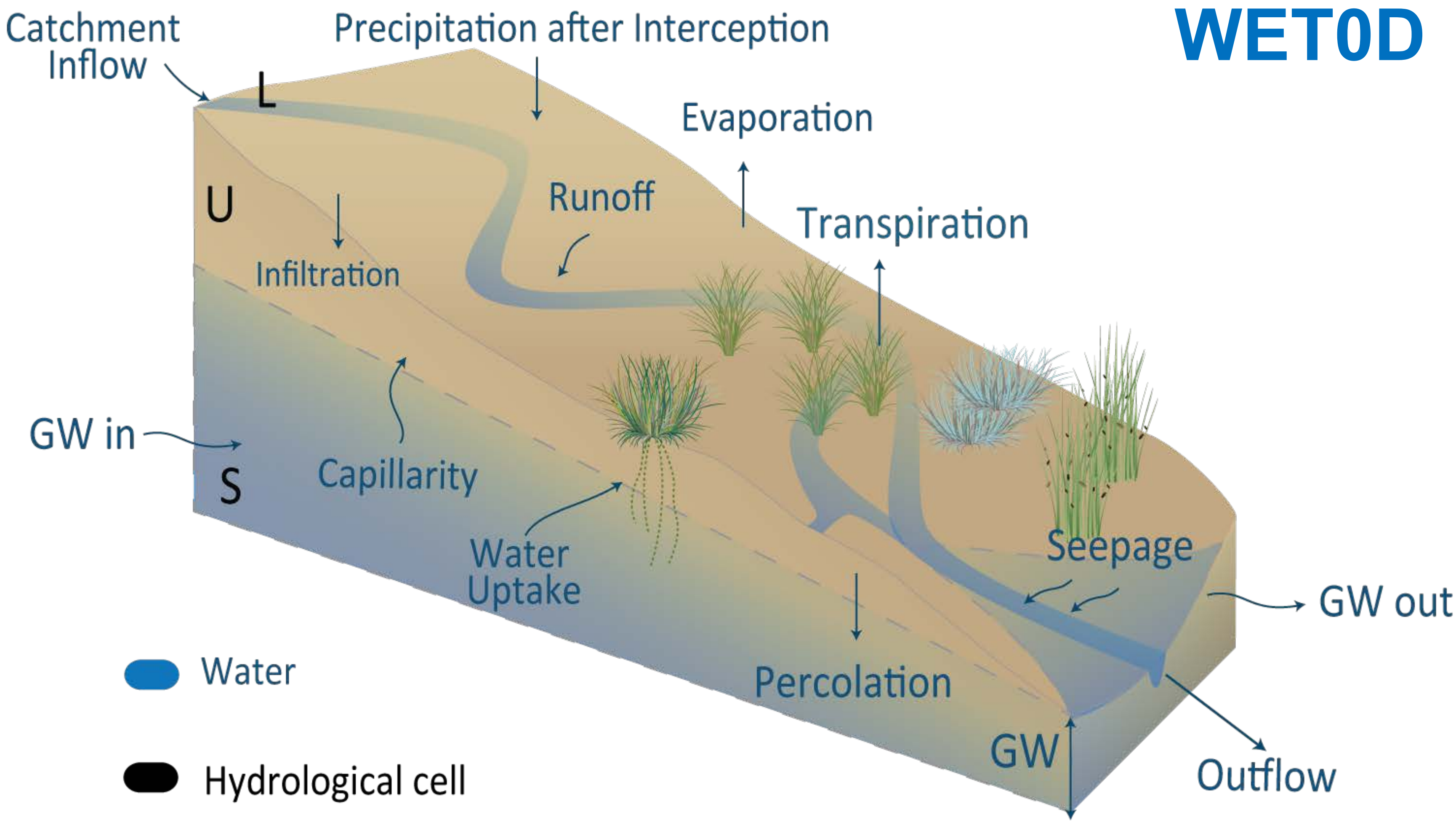
AED Aquatic Eco Dynamics

1. Ecohydrological Model



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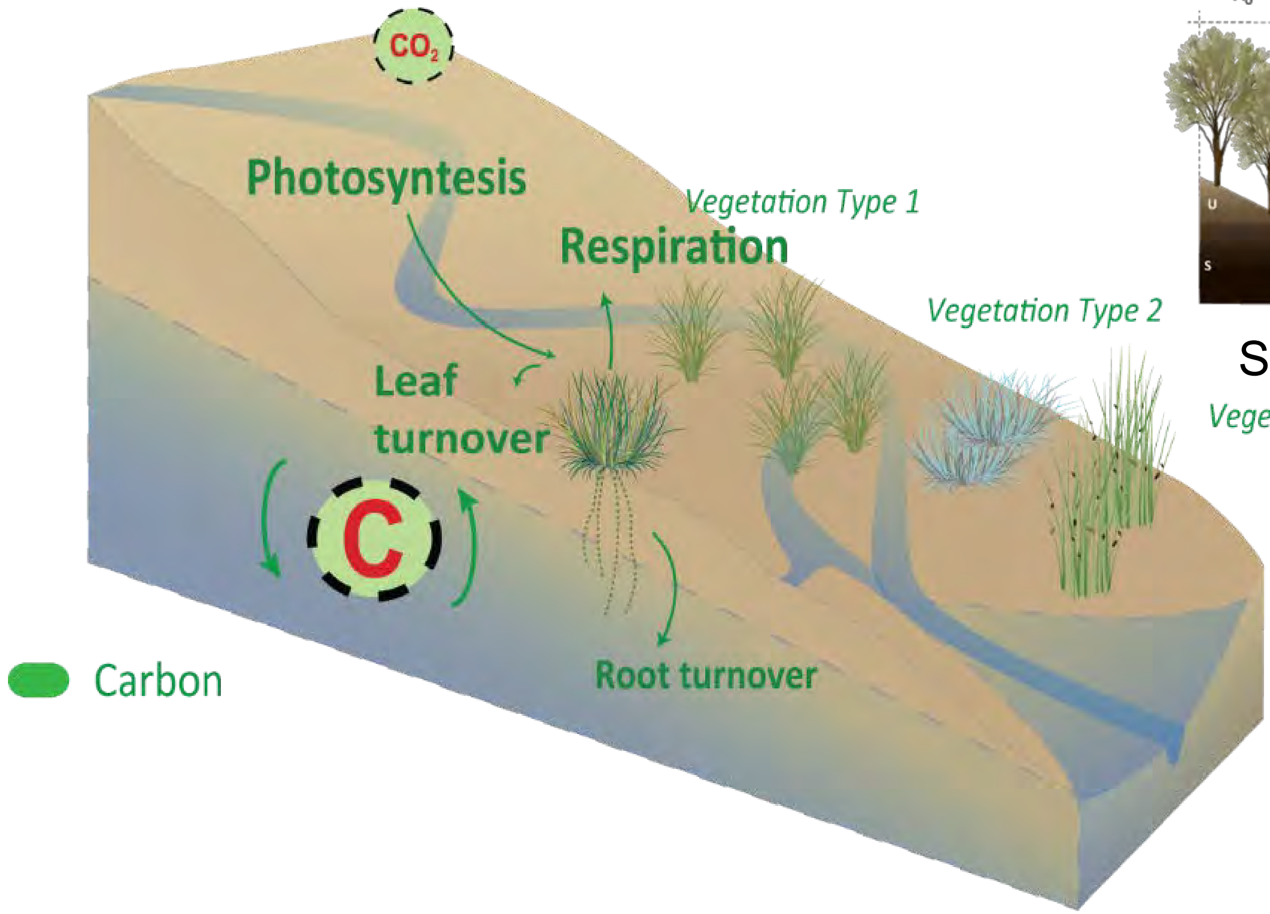

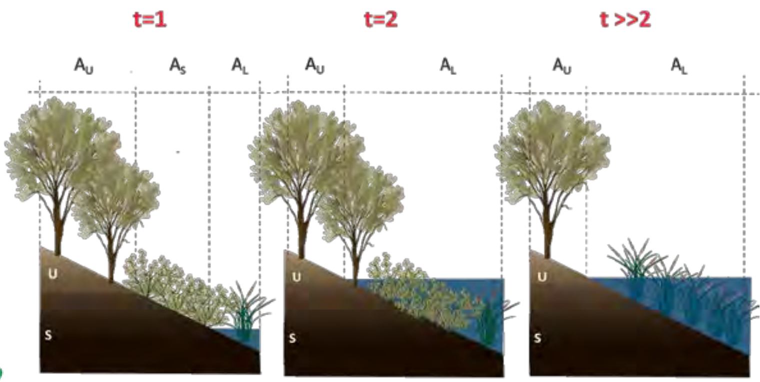

Simulating Vegetation Zonation

Vegetation Type 3

WET0D

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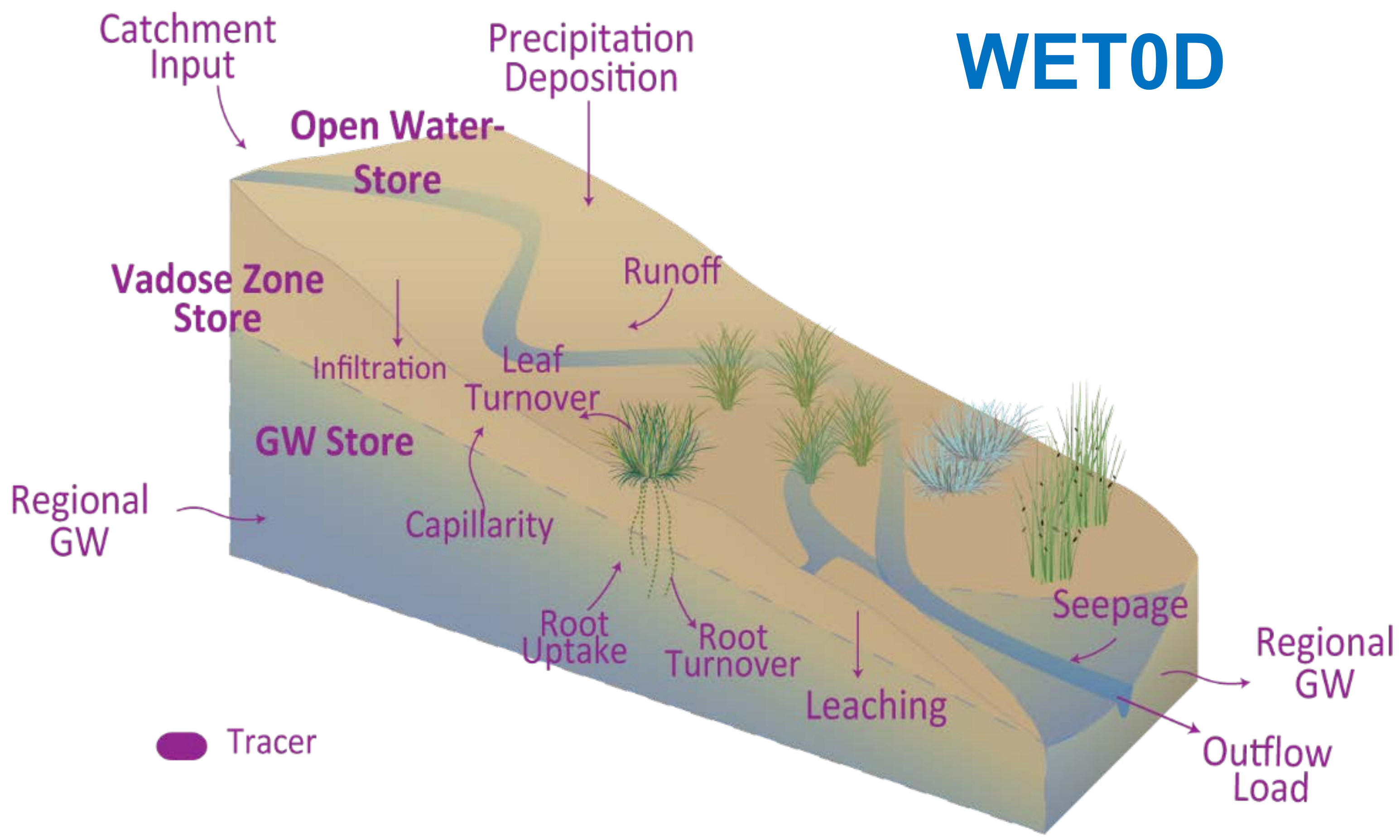

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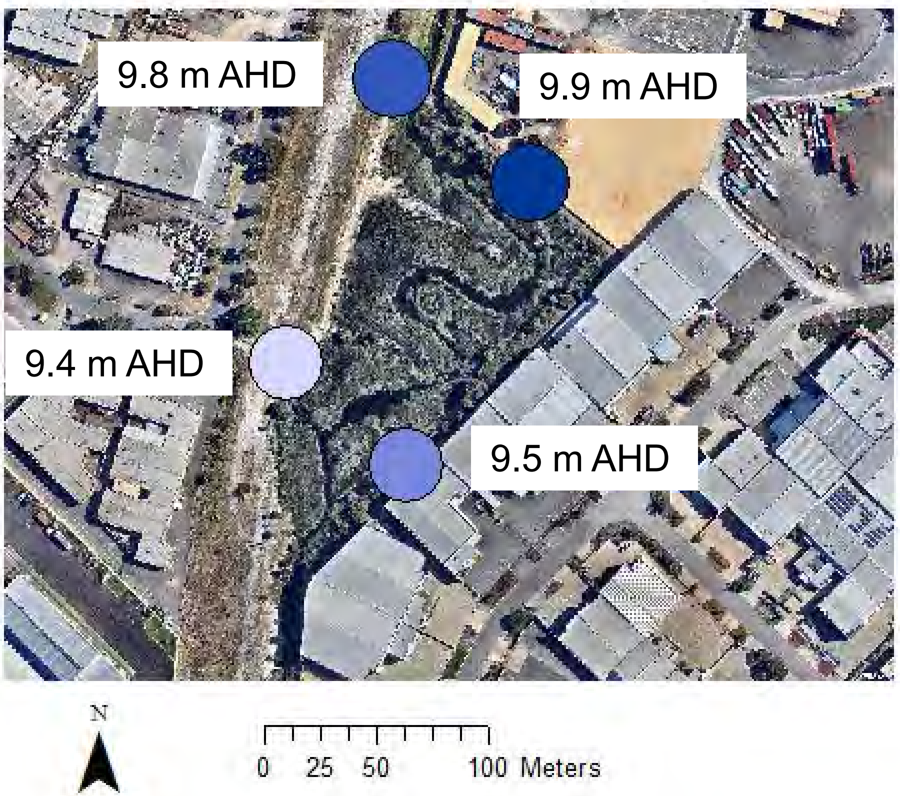
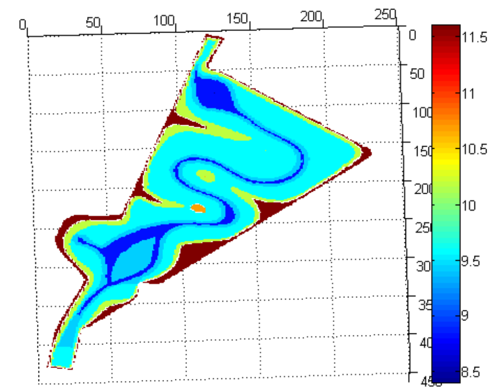
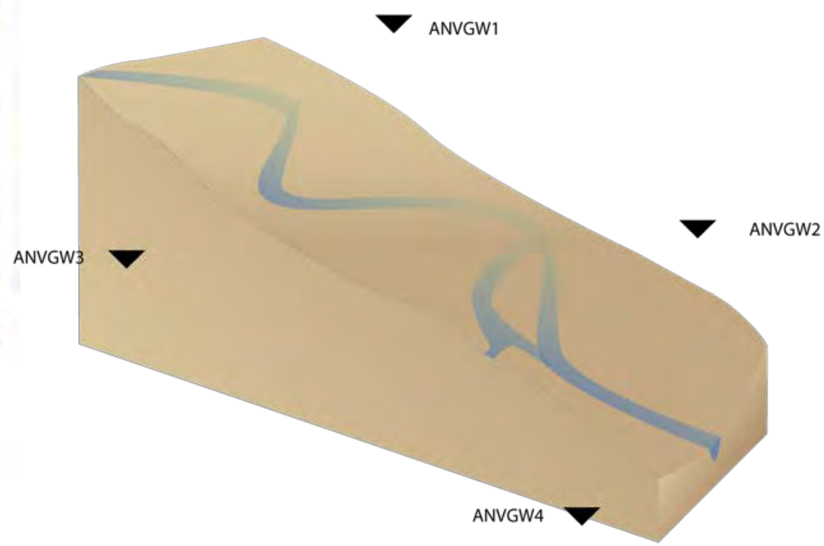
AFD Aquatic Eco Dynamics

2. Application to Anvil Way CW







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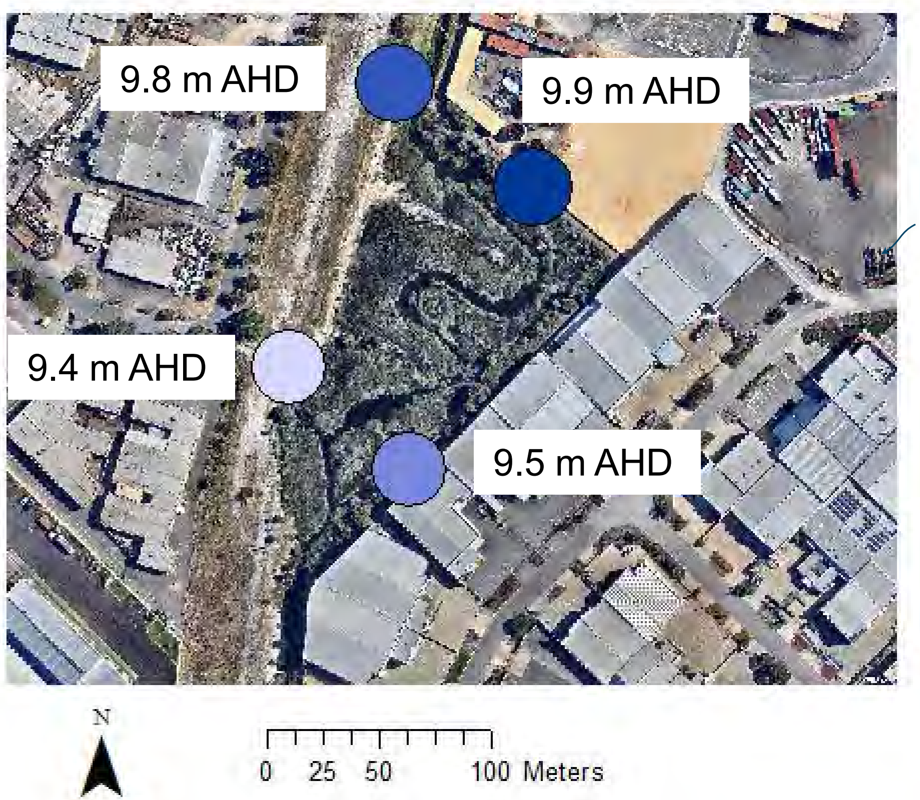

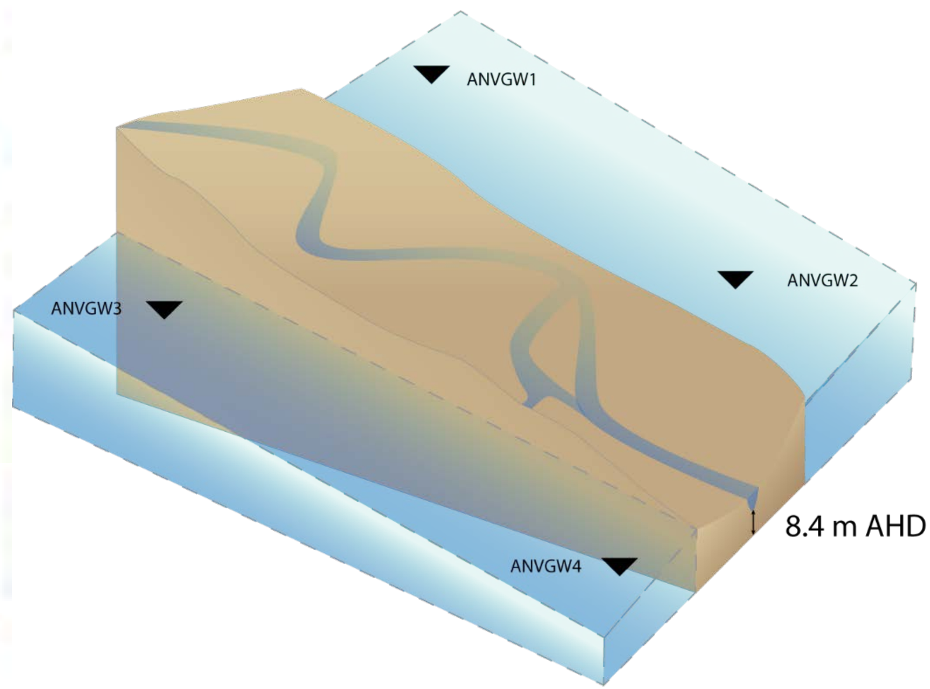

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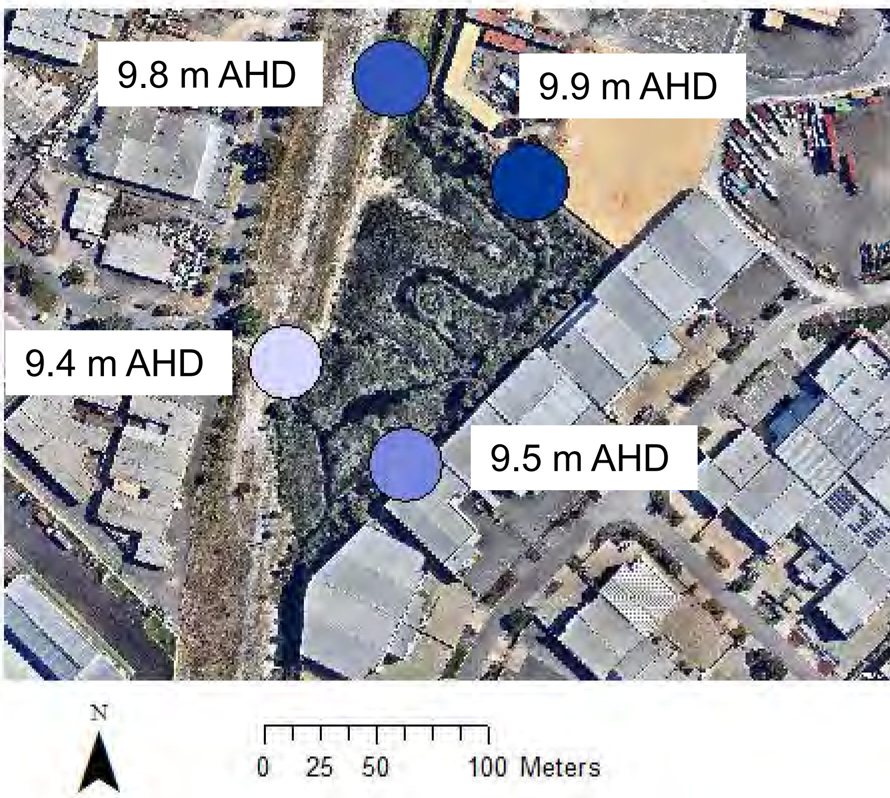
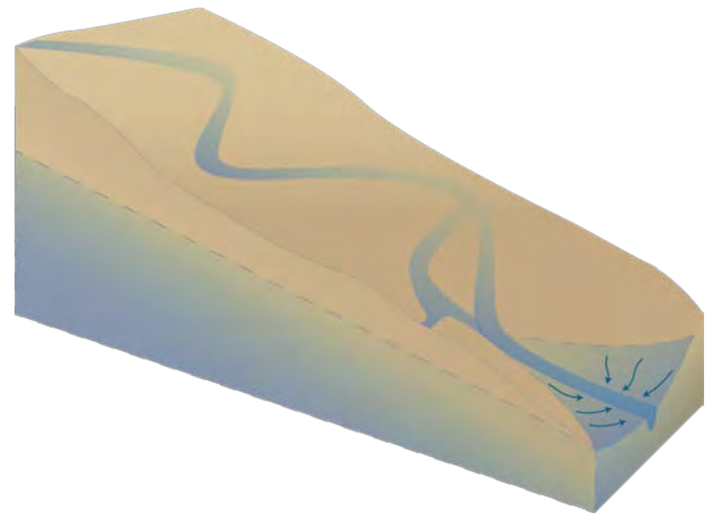
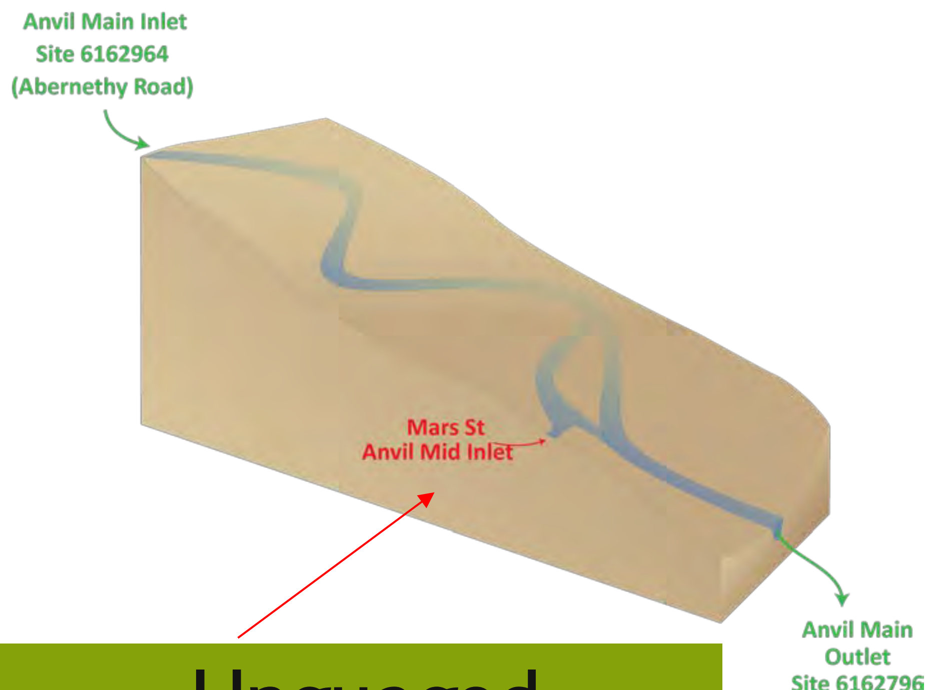




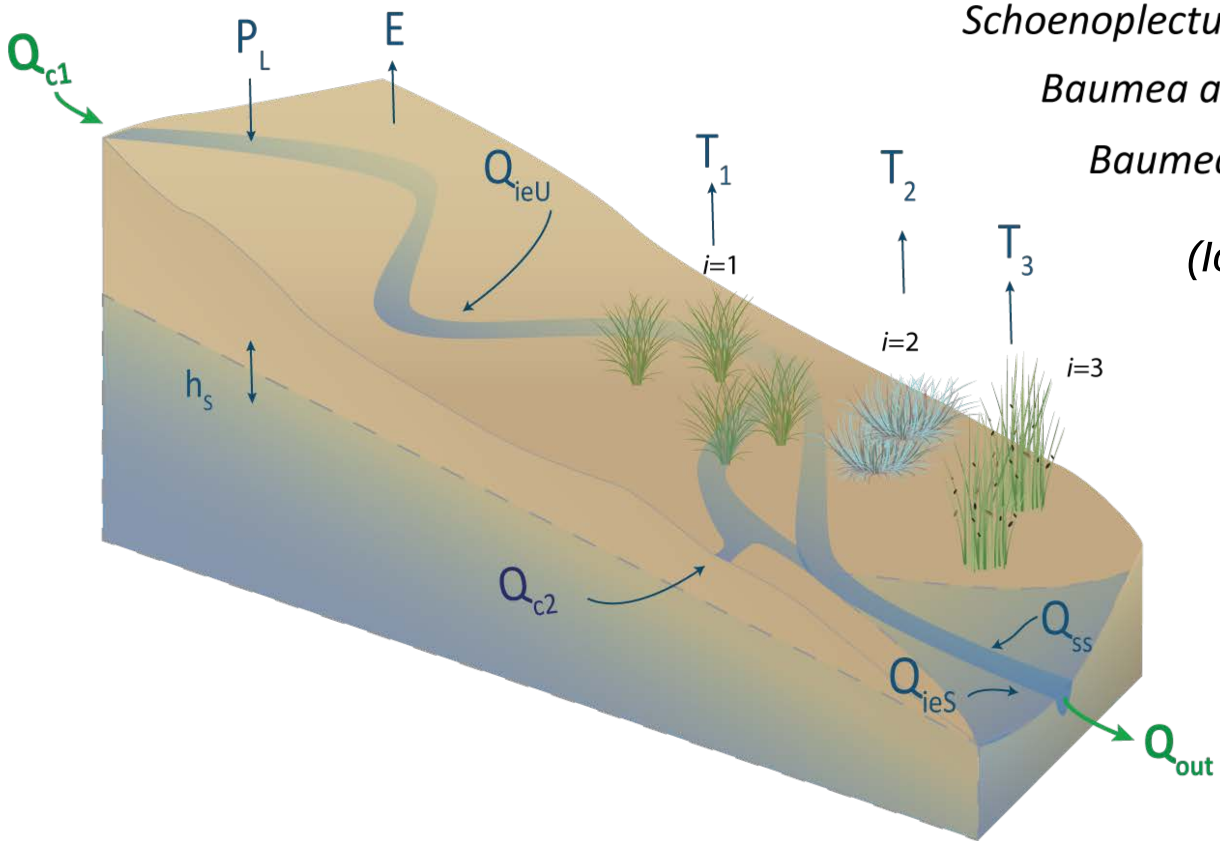
Likely GW contribution

2. Application to Anvil Way CW



Unguaged hydrological input

2. Application to Anvil Way CW



Schoenoplectus validus

Baumea articulata

Baumea preissii

(Ioannidis, 2014)

$$Q_{c1} + Q_{c2} + Q_{ieU} + Q_{ies} + Q_{se} + Q_{SS} + P_L = Q_{out} + \sum_{i=1}^{3}\sum_{n=1}^{3} T_{i,n} + \sum_{n=1}^{3} E_n + \Delta S$$

2. Application to Anvil Way CW

$$Q_{ieU} = (P_U \; A_U - I)$$

$$I = \begin{cases} -k_S \, \Delta_{LAI} \; \Delta_I \; (\theta - 1)^{k_I} \; A_U & \text{if} \quad I < P_U \, A_U \\ P_U \, A_U & \text{if} \quad I \geq P_U \, A_U \\ U_c & \text{if} \quad I > U_c \end{cases}$$

$$Q_{ieS} = P_S \, A_S$$

$$P_n = (P_t - I_{max} \, (LAI_n / LAI_{L\,max}) \; A_n$$

$$E_L = k_E \, E_0 \; \left(1 - k_{LAI} \frac{LAI_L}{LAI_{max}}\right) A_L$$

$$Q_{c2} = c \;\; P \quad AreaQ_{c2}$$

$$E_U = \left(\frac{\theta}{\theta_{fc}}\right) E_0 \left(1 - k_{LAI} \frac{LAI_U}{LAI_{max}}\right) A_U$$

$$Q_{out} = CL(H - H0)^{3/2}$$

$$E_S = k_S \, E_0 \quad \left(1 - k_{LAI} \frac{LAI_S}{LAI_{max}}\right) A_S$$

$$\Psi_{i,n} = c_{i,n} \;\; \beta_{i,n} \;\; \alpha_{i,n} \;\; \Gamma_{i,n}$$

$$T_{i,n} = \sum_{i=1}^{3} \Psi_{i,n} \, E_0 \left(\frac{LAI_{i,n}}{LAI_{max_{i,n}}}\right) A_{i,n}$$

$Q_{out} = Q_{out}$

✓ Many ways to get it =

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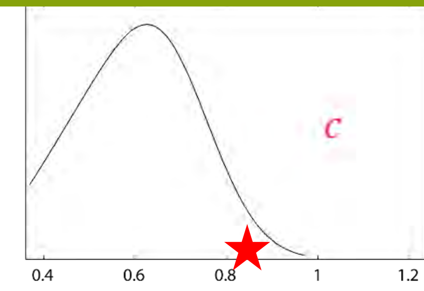
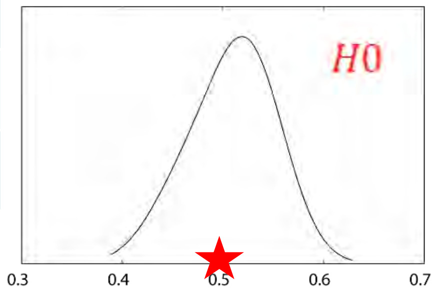
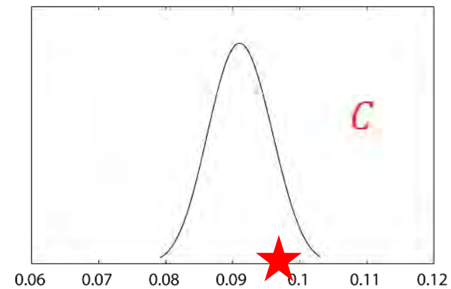
2a. Using WET0D with MCMC

Parameter	Initial Value	Minimum	Maximum
$Runoff\ Coeff.$	0.88	0.44	0.99
$Weir\ Coeff.$	0.1 (1.84)	0.05	0.15
$Area\ Mars\ St.$	0.6 km^2	0.3 km^2	1.2 km^2
$Width\ Weir$	0.7 m	0.35 m	1.4 m
$H0$	0.5 m	0.25 m	0.75 m

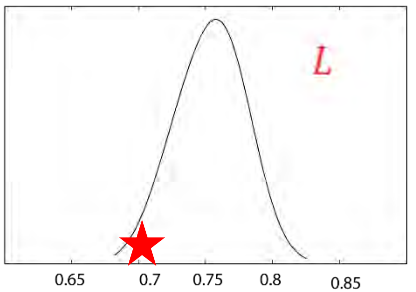
Probability Distribution Function of the Parameters Tested

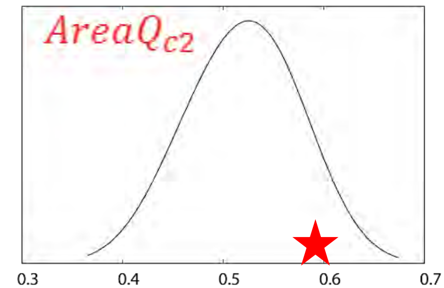






RMSE (Q_{out}, Q_{out}) >>0





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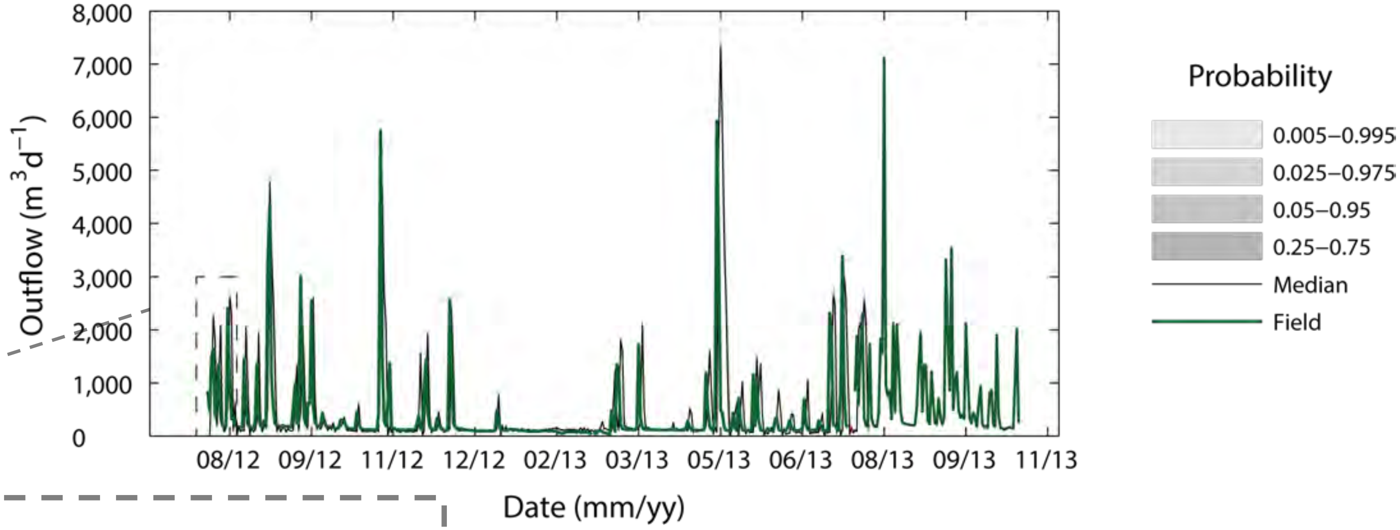
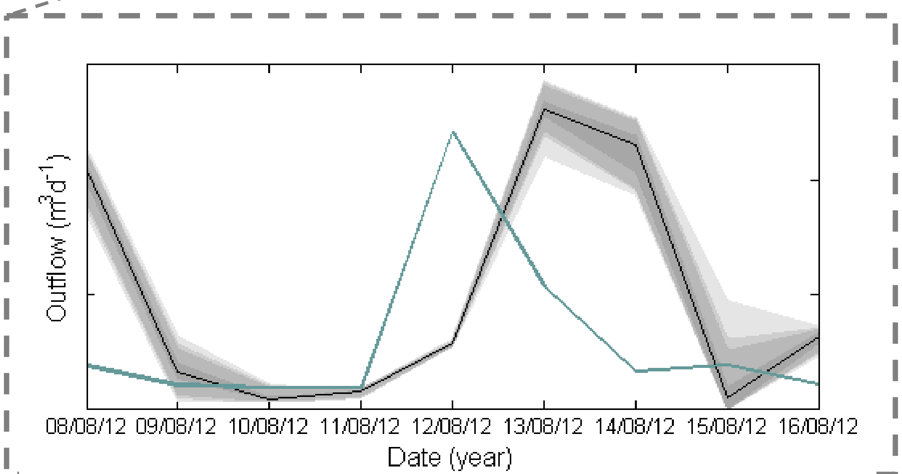
3. Preliminary Results





$$\text{RMSE}\ (\mathbf{Q}_{out}, Q_{out}) >> 0$$

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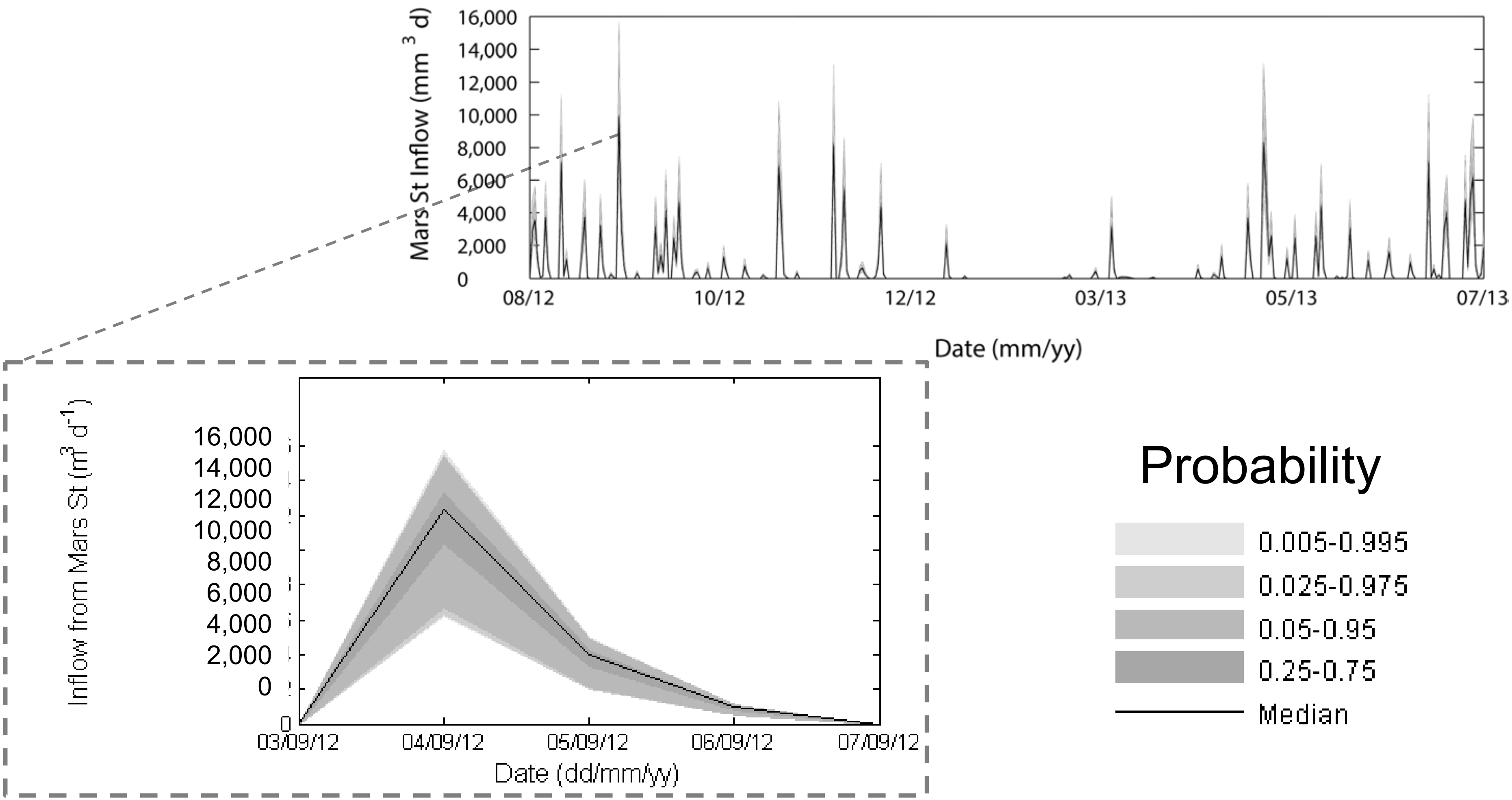

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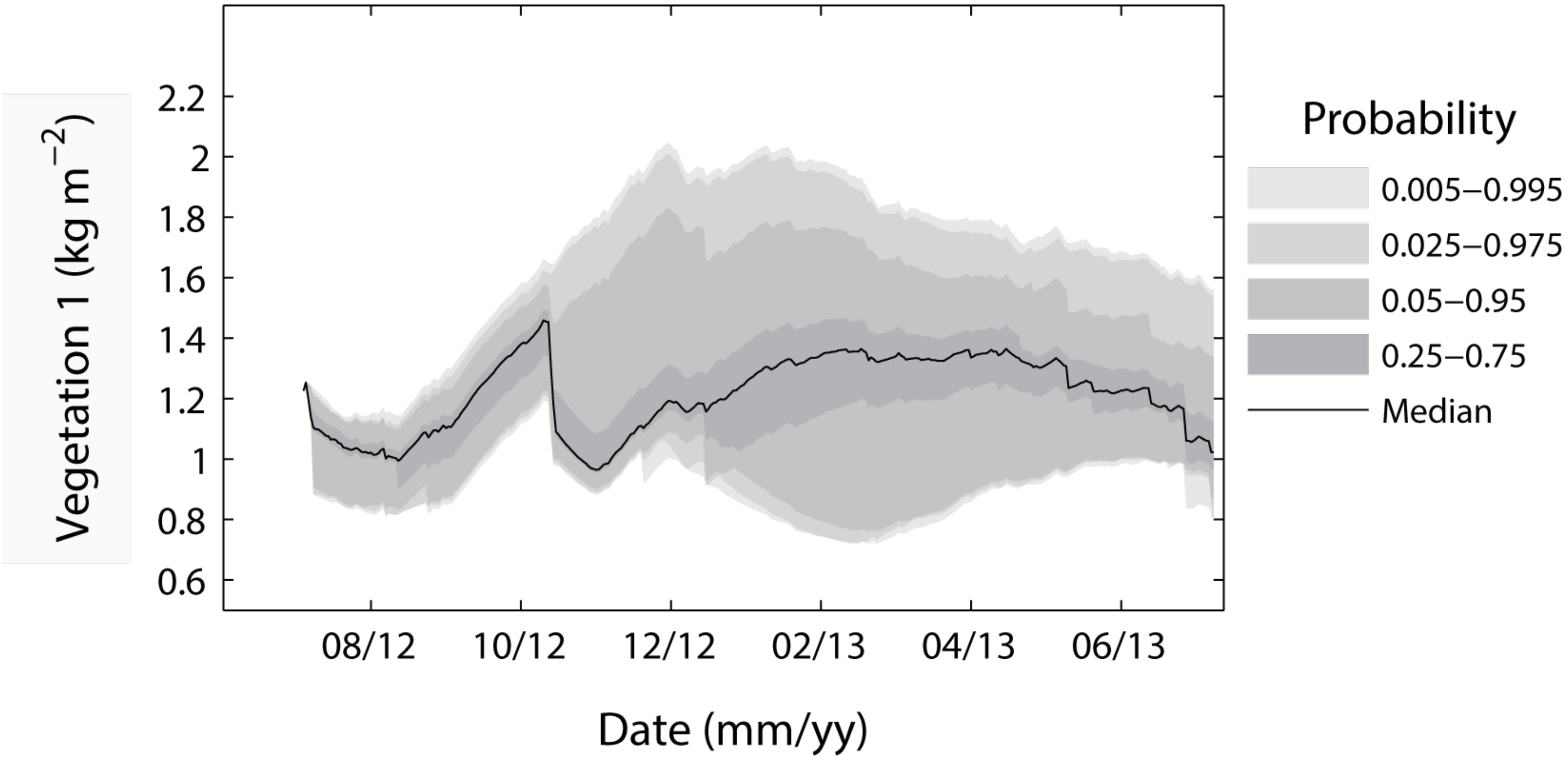

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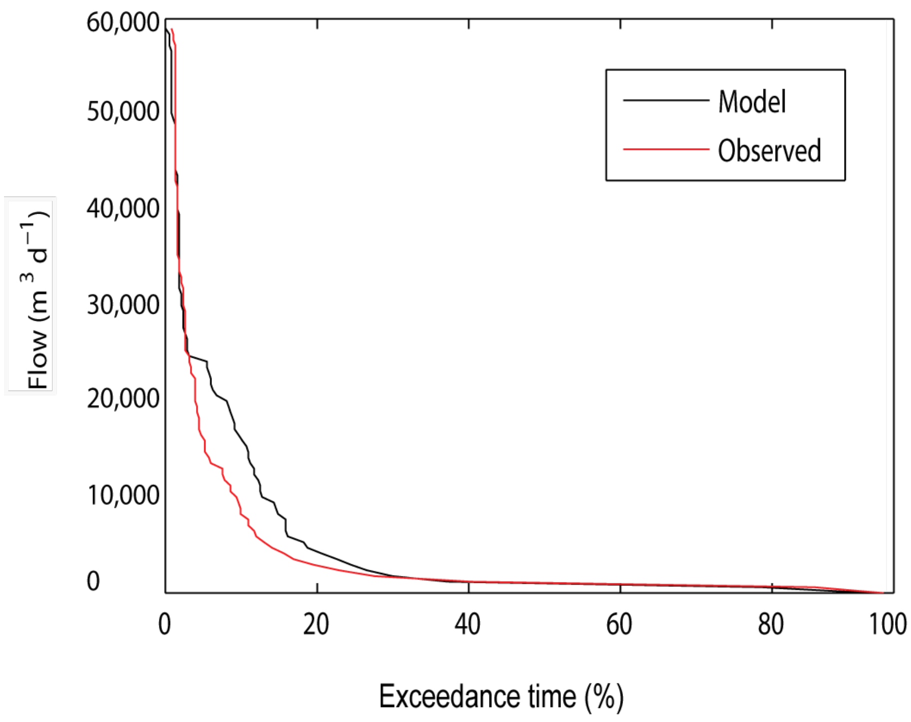
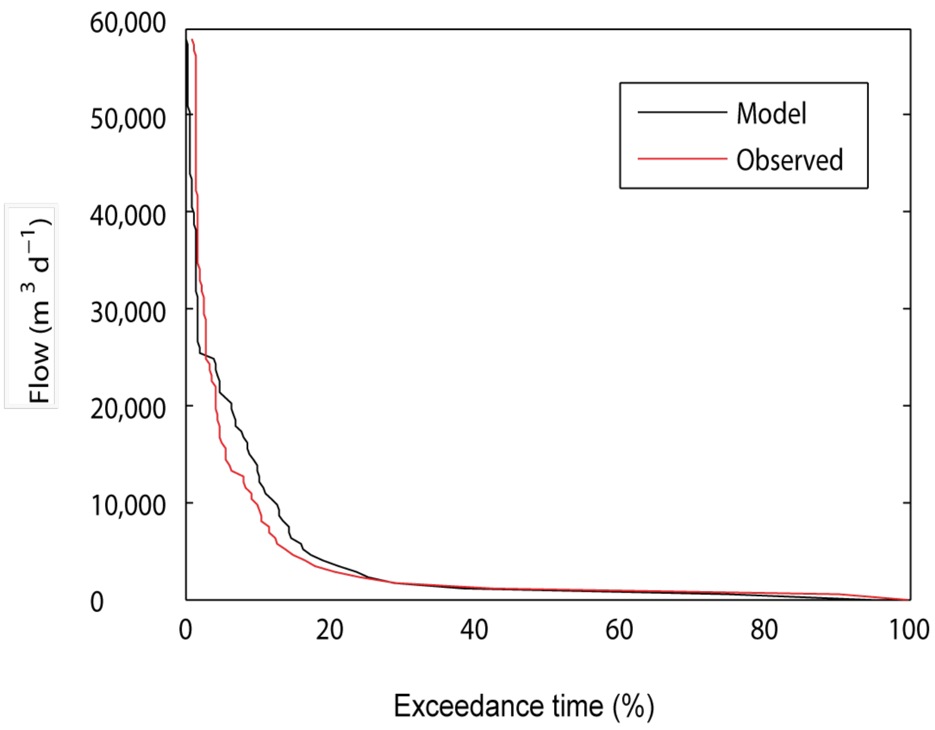
3. Preliminary Results

Before MCMC



After MCMC



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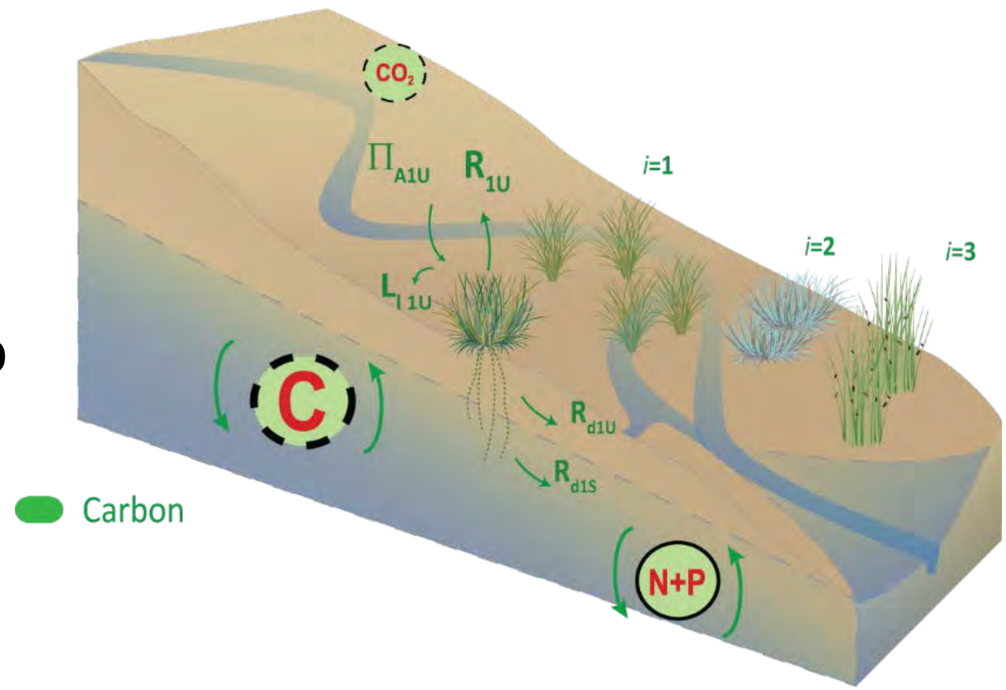
4. Next Steps

- ✓ Include biogeochemistry
  - Integrate with the General Lake Model (GLM)
  - Capture water, soil & sediment: C, N & P processing
- ✓ Validating vegetation biomass
- ✓ Hourly time-step
- ✓ Use within MCMC optimization framework to identify management effort to meet targets



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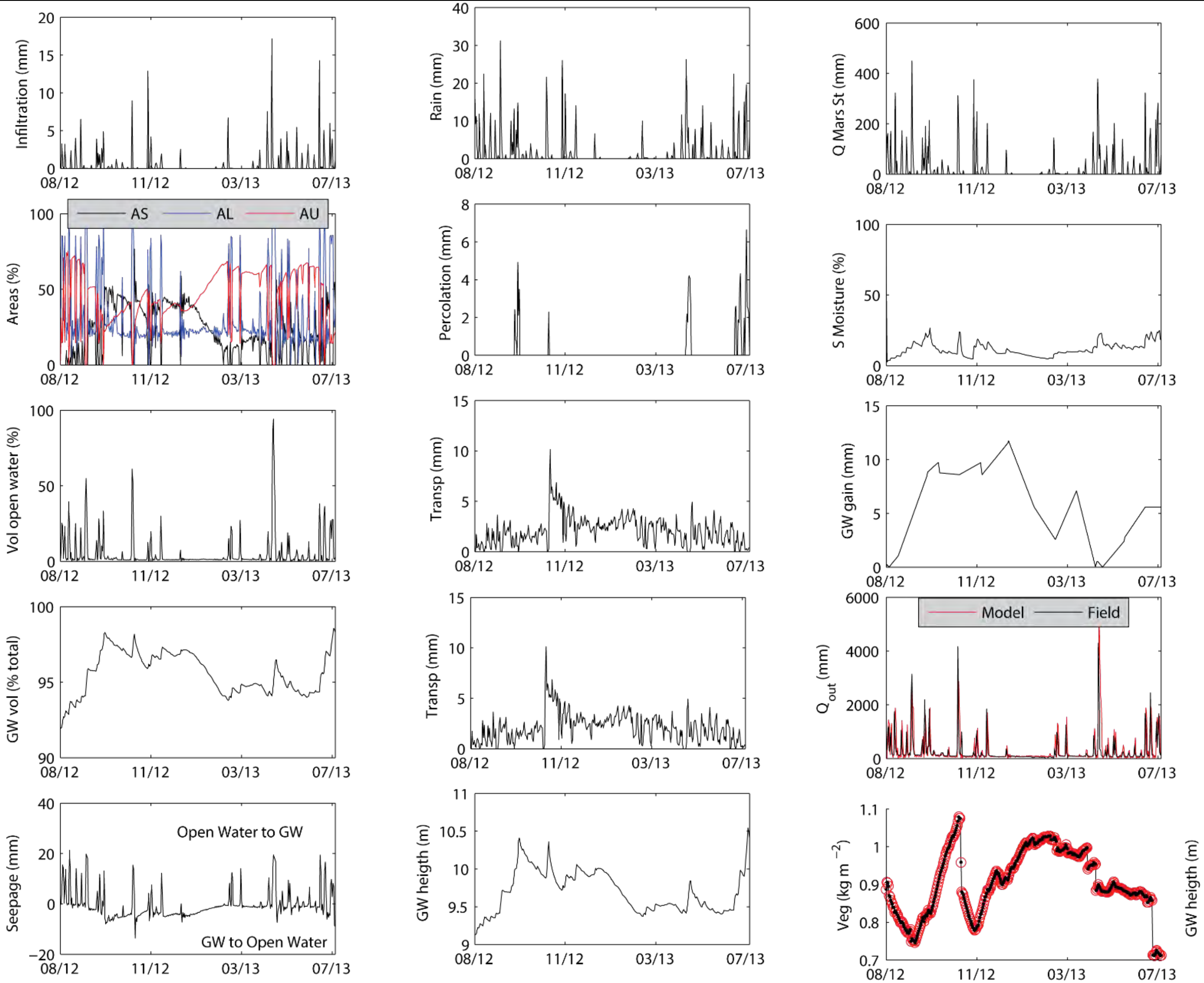

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FACULTY OF SCIENCE

ARC Linkage Project LP110200975

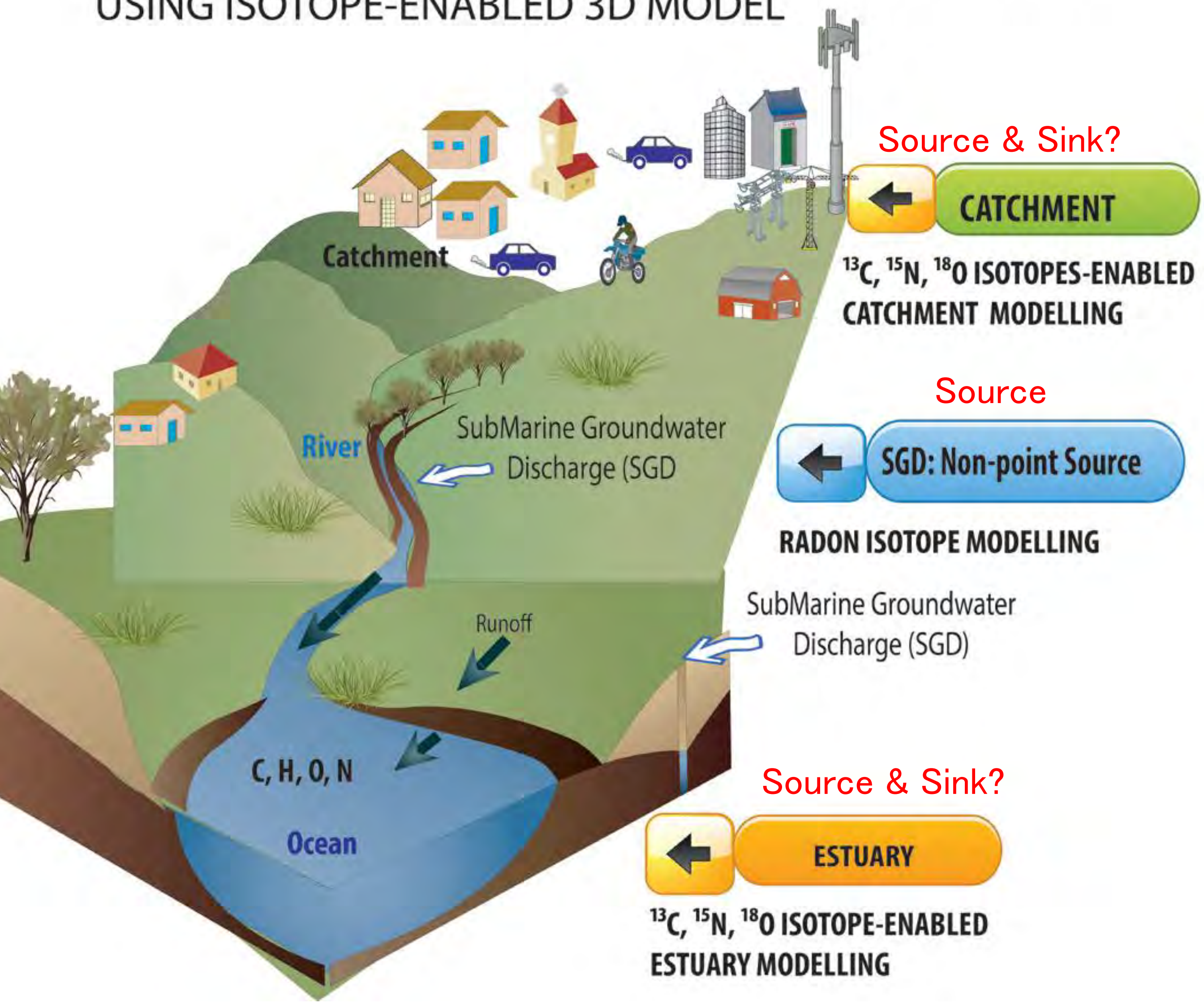
From Where to Where?

UNRAVELLING PATHWAYS OF NUTRIENT FROM SOURCE TO SINK IN URBANISING CATCHMENT

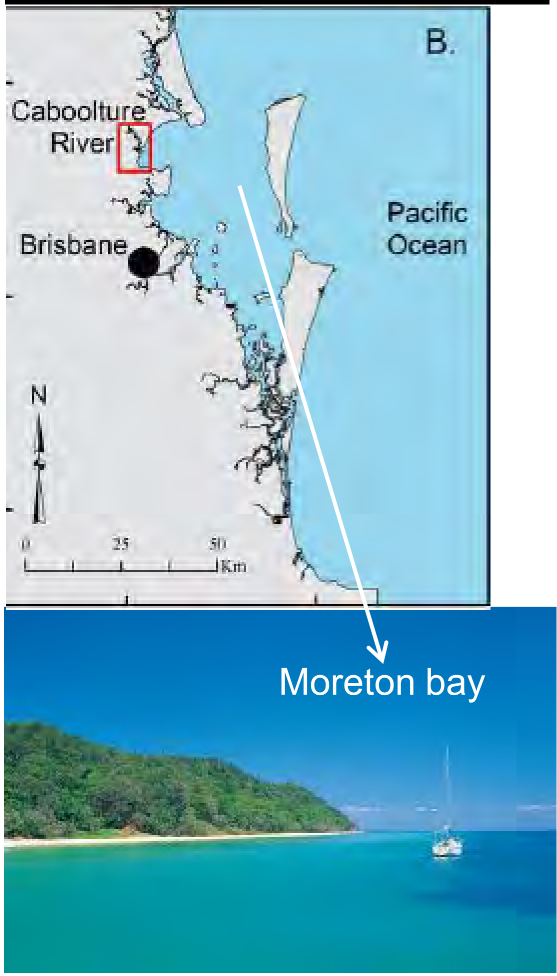
Sri Adiyanti[*], Bradley D. Eyre[#], Damien T. Maher[#], Isaac Santos[#], Perrine Mangion[#], Meti Yulianti[*], Matthew R. Hipsey[*]

[*] Aquatic Ecodynamics, School of Earth & Environment, UWA, Crawley WA 6009, Australia.
[#] Centre for Coastal Biogeochemistry, Southern Cross University, Lismore, NSW 2480, Australia.

UNRAVELLING SOURCES OF NUTRIENT TO AN ESTUARY USING ISOTOPE-ENABLED 3D MODEL



Caboolture River Catchment



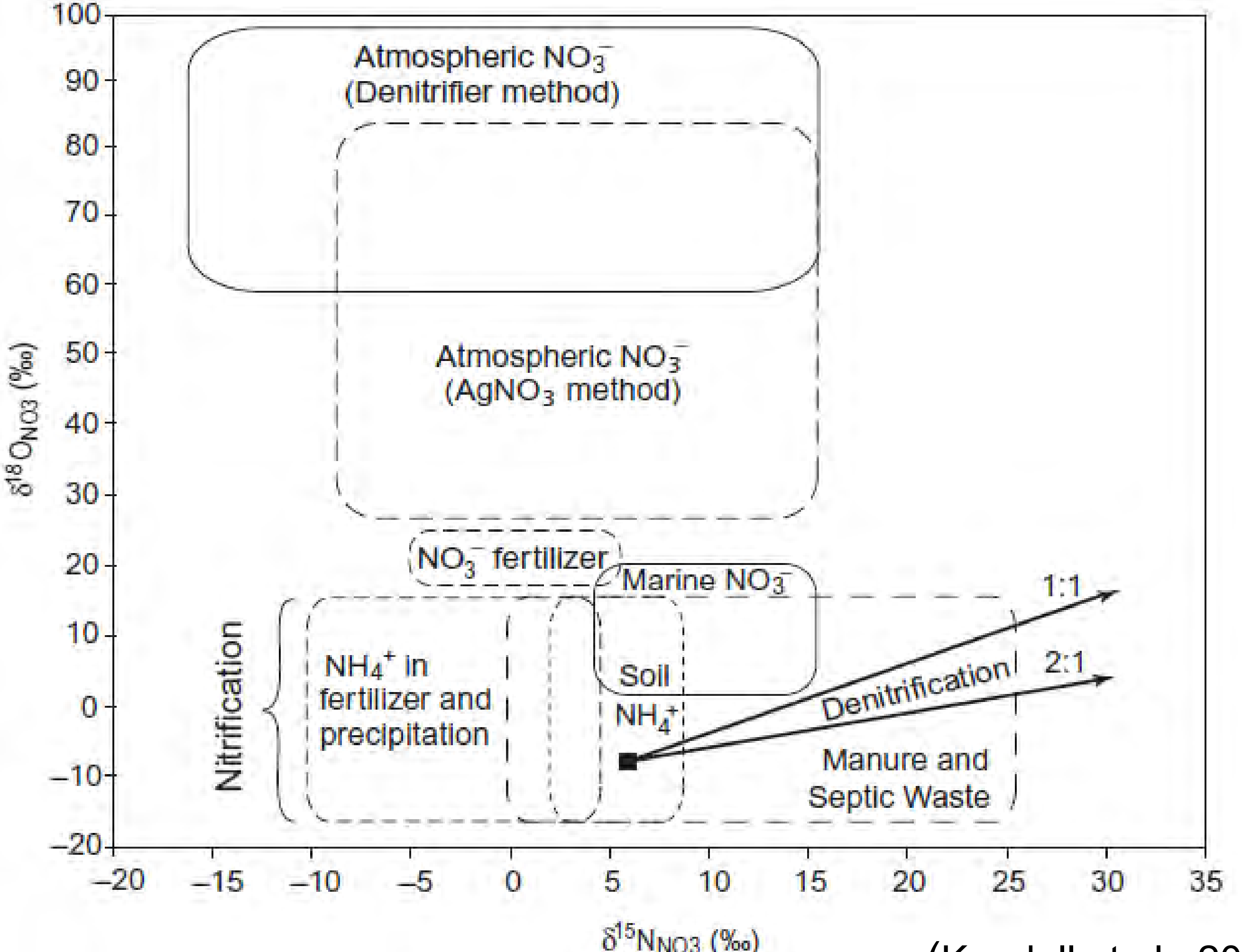
MOTIVATION

- **Caboolture River Estuary WQ: steady decline due to:**
  - **Agricultural (?)**
  - **Industrial activities (?)**
  - **Urbanization (?)**
- **"Nutrient Accounting": trace and identify nutrient pathways**
- **Acknowledge:**
  - Large spatiotemporal variability in water quality of contributing environments and biogeochemical processes along freshwater-marine continuum, and this variability are not captured with routine monitoring programs. [Need to use 3-D Hydrodynamic Model]
  - Uncertainty in model results. [Need Bayesian Hierarchy Model]

- **USING ISOTOPE-ENABLED 3-D HYDRODYNAMIC MODEL & BAYESIAN HIERARCHY MODEL**

USING STABLE & RADIOACTIVE ISOTOPES SIGNALS as TRACERS of SOURCES and PATHWAYS

Typical Values of δ15N-NOx and δ18O-Nox (at source):



(Kendall et al., 2007)

Typical Values of δ222Rn:

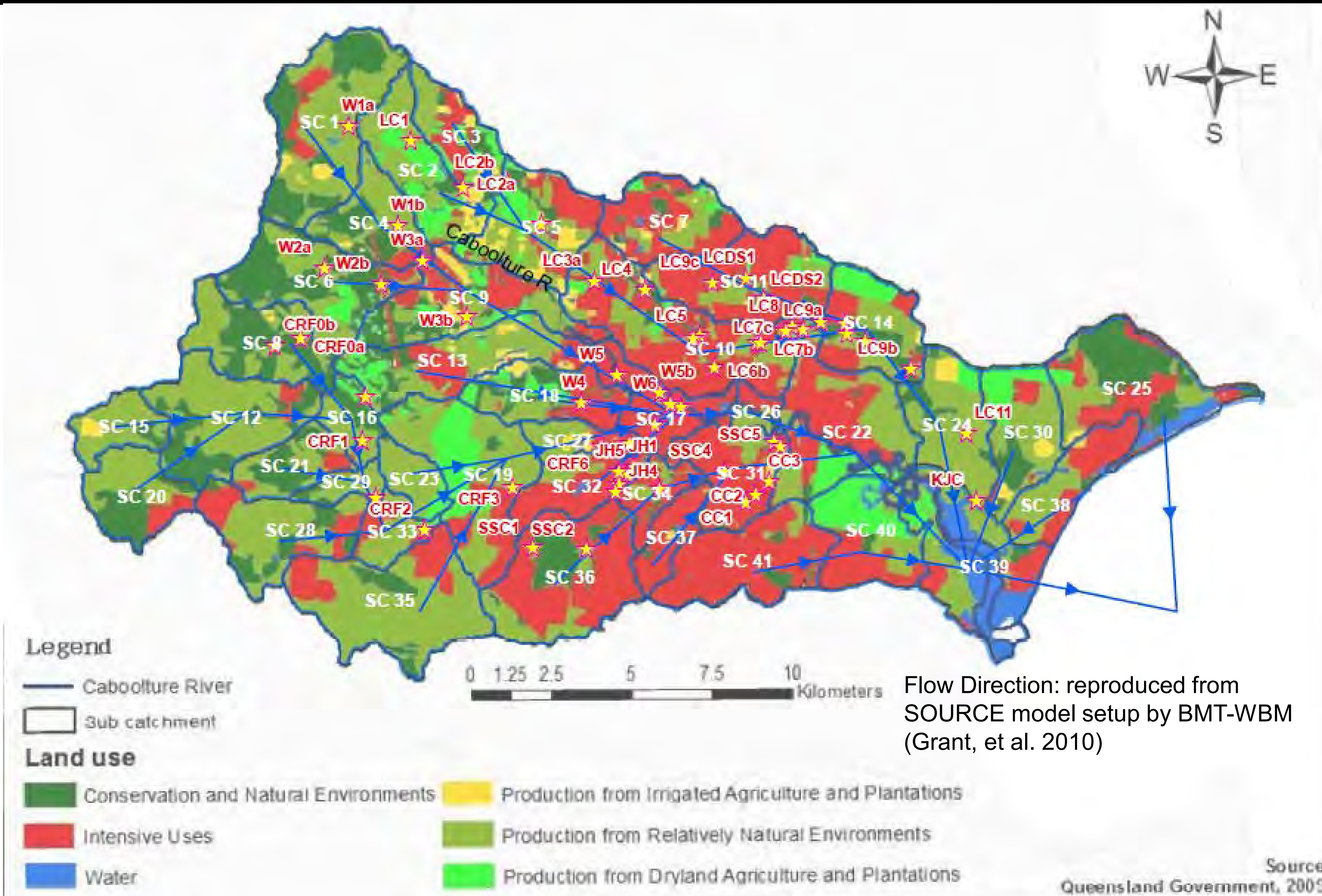
GW: $10^2 - 10^3$ Bq/m^3
SW: 10^1 Bq/m^3
Estuary: $10^{-2} - 10^2$ Bq/m^3

Data: Caboolture (2011-2013)

COMPREHENSIVE DATASETS: e.g.

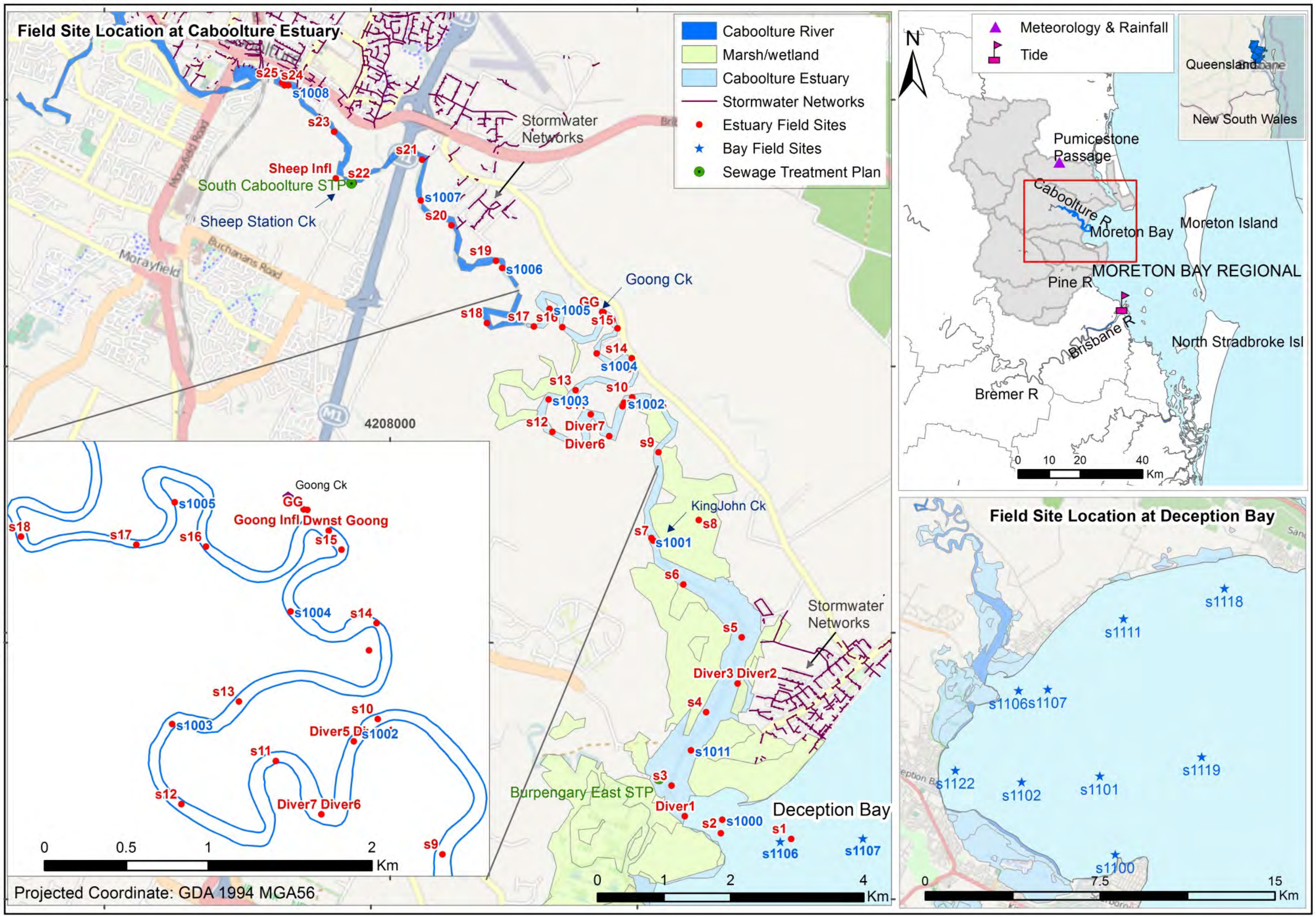
- Southeast Queensland Ecosystem Health Monitoring Program (SEQ-EHMP) since 2000: physico-chemical, nutrient (Healthy Waterways, 2014).
- Centre for Coastal Biogeochemistry, Southern Cross University: physico-chemical, nutrient, chl-*a*, isotopes (2011-2013).
- South Caboolture & Burpengary WWTP Effluent Flow & Nutrient (2006-2014).
- Caboolture Shire Council: physico-chemical, nutrient, chl-*a*, metal (2001-2010).

CABOOLTURE RIVER CATCHMENT: LANDUSE & FLOW DIRECTION

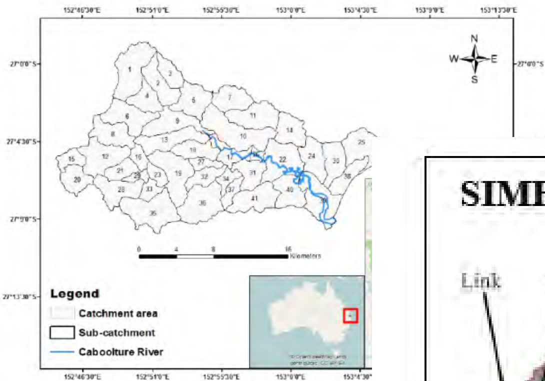


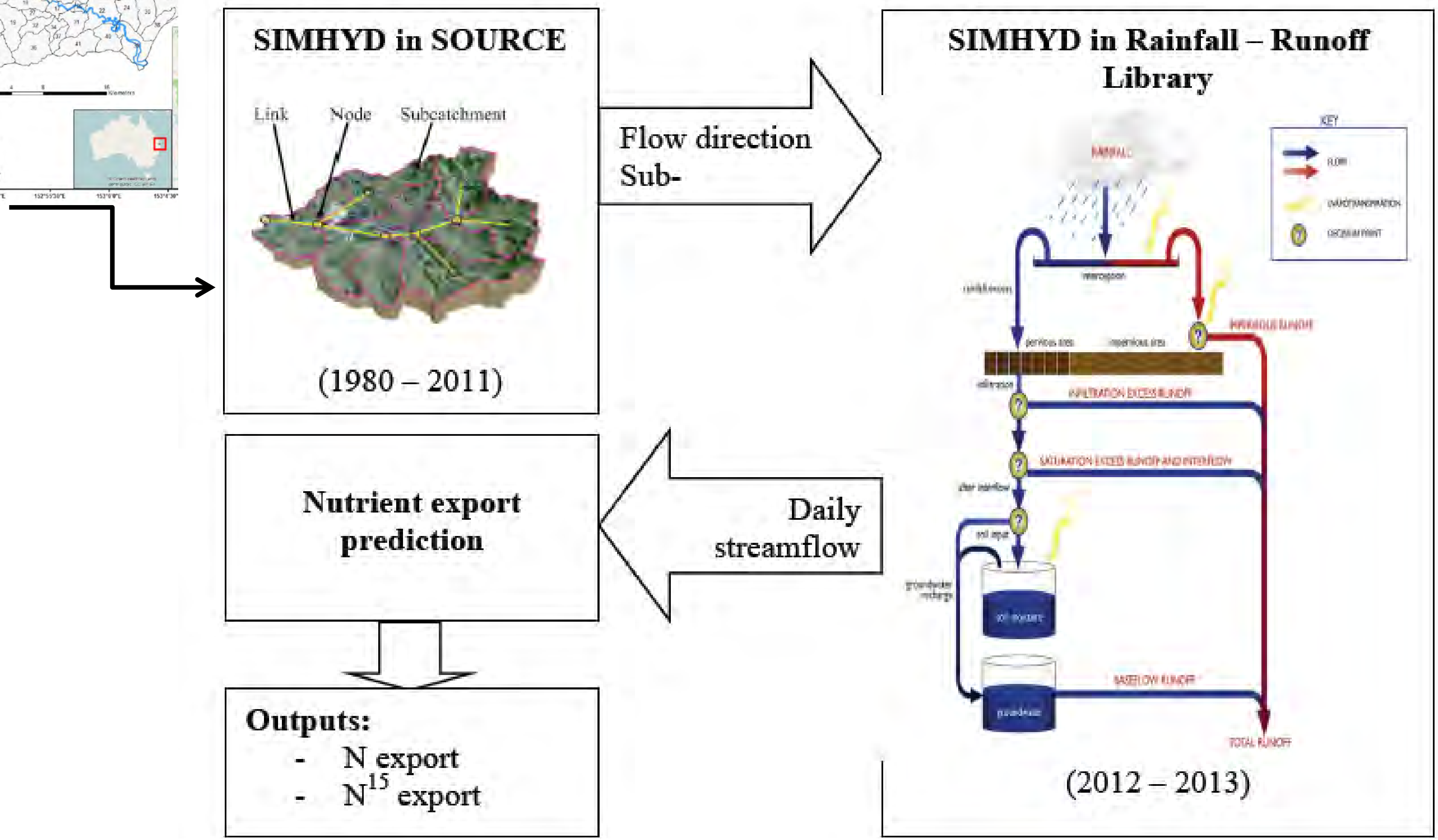
Flow Direction: reproduced from SOURCE model setup by BMT-WBM (Grant, et al. 2010)

ESTUARY WATER SAMPLING LOCATION



CABOOLTURE RIVER CATCHMENT NUTRIENT LOADING MODEL





Workflow of daily streamflow and nutrient export prediction (modified from eWater, 2010)

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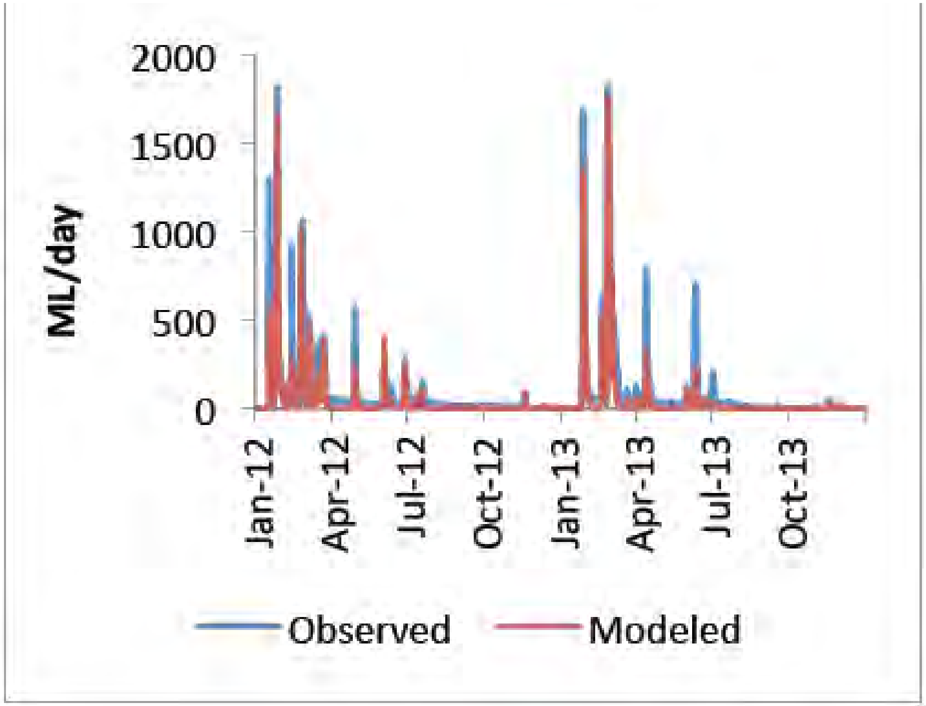
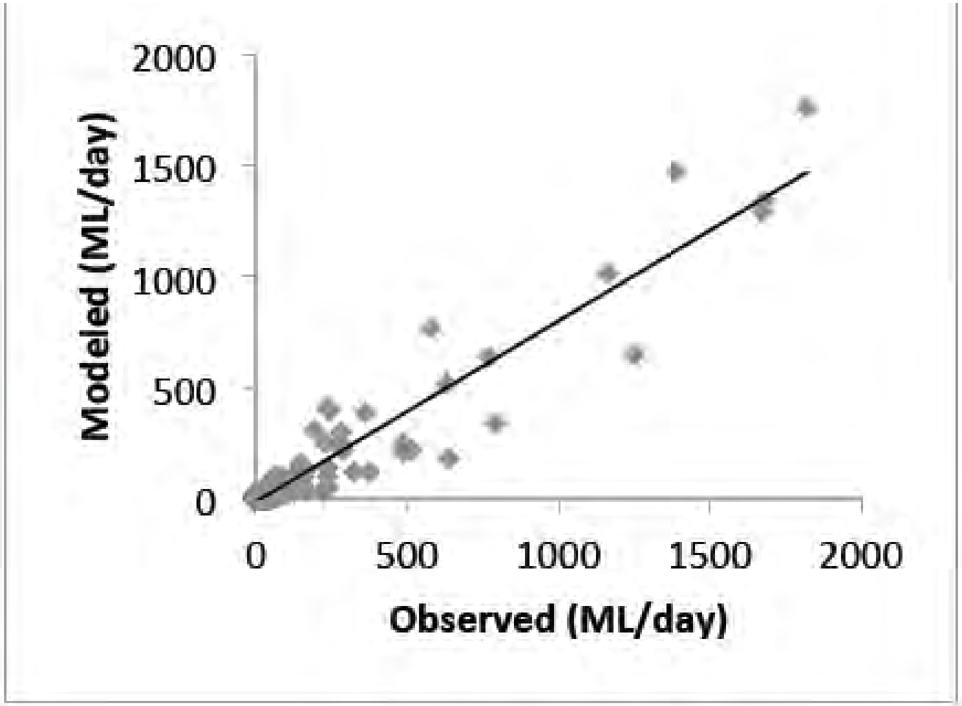
Discharge at UpperCaboolture Gauging St:

R^2 0.8705 and Nash-Sutcliffe coefficient of efficiency (NSF) of 0.89





(Yulianti, M. 2014)

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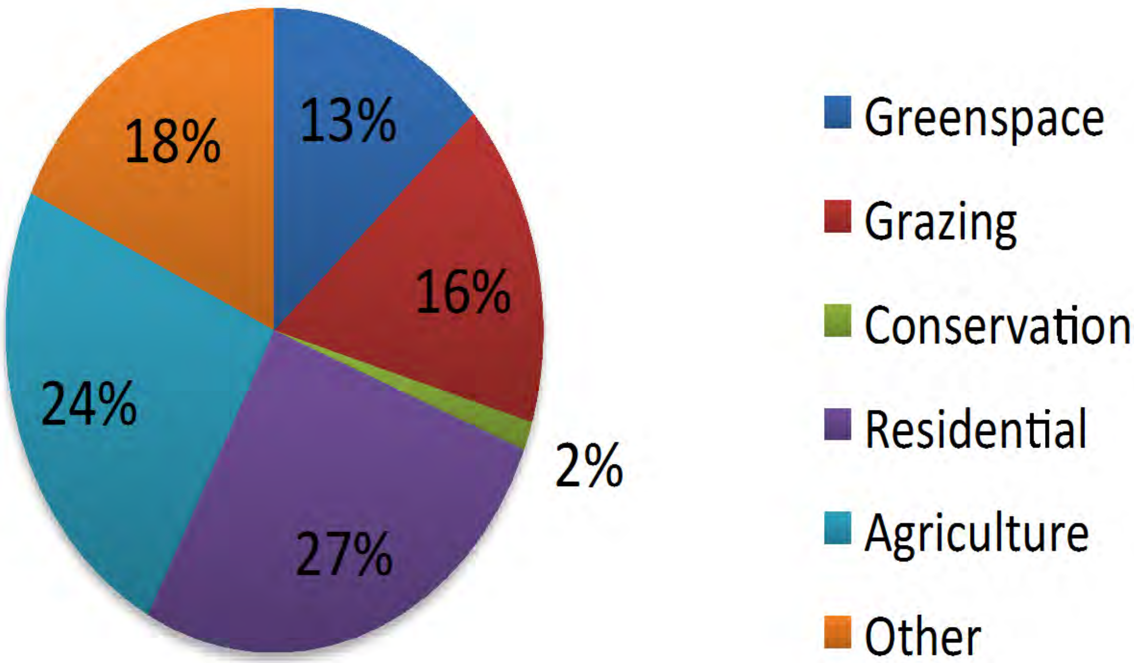
IF (ONLY) USING CATCHMENT NUTRIENT LOADING MODEL:

CABOOLTURE: SOURCE OF NUTRIENT (2012-2013) BASED ON LANDUSE:



Modelled using SOURCE MODEL and NUTRIENT data

(Yulianti, M. 2014)

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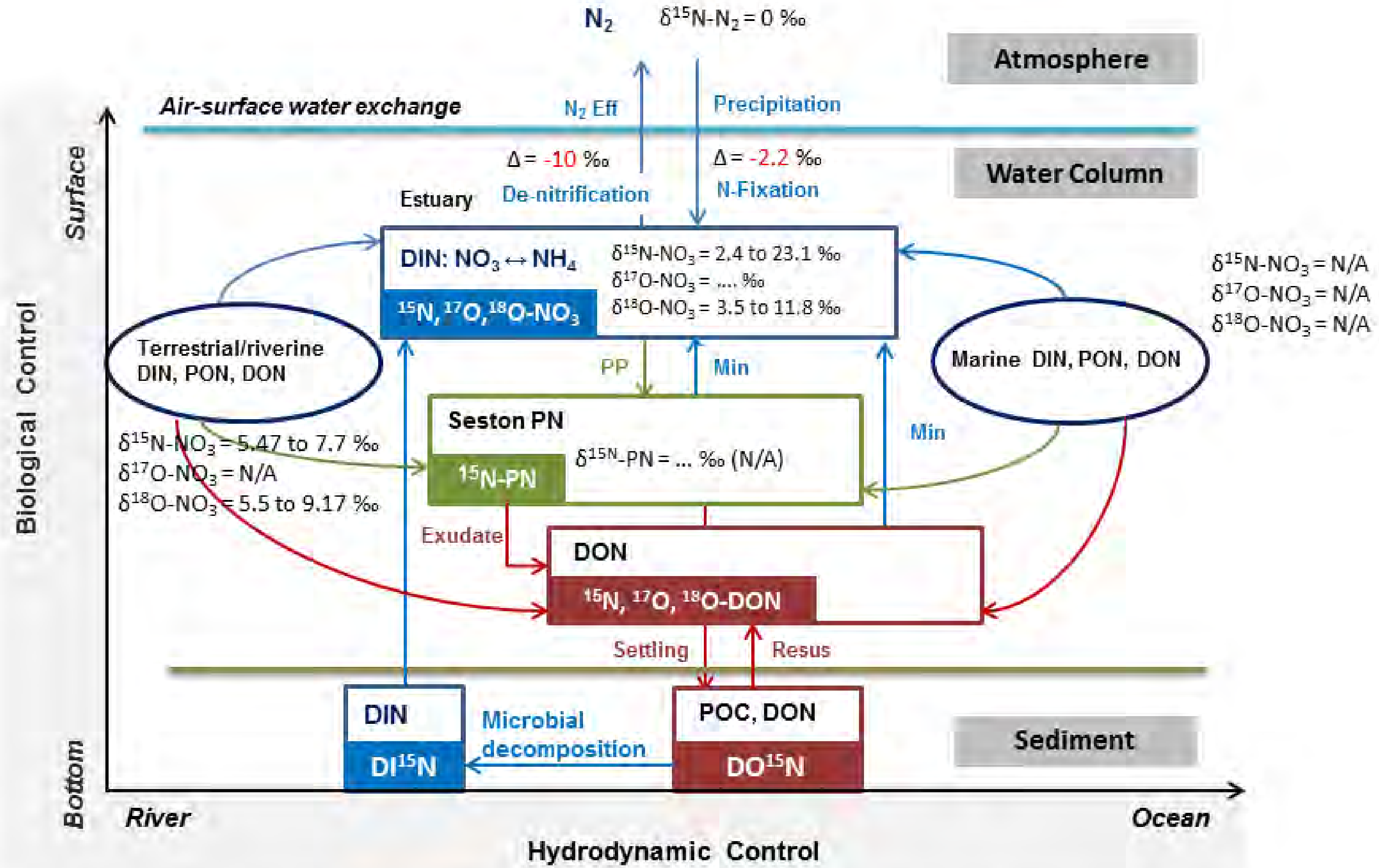
IF USING ISOTOPE-ENABLED 3-D HYDRODYNAMIC MODEL:

We can trace nutrient pathways



Env: Envasion, Eff: Efflux, Res: Respiration, PP: Primary Production, Min: Mineralisation, Sed: Sedimentation, Res: Resuspension

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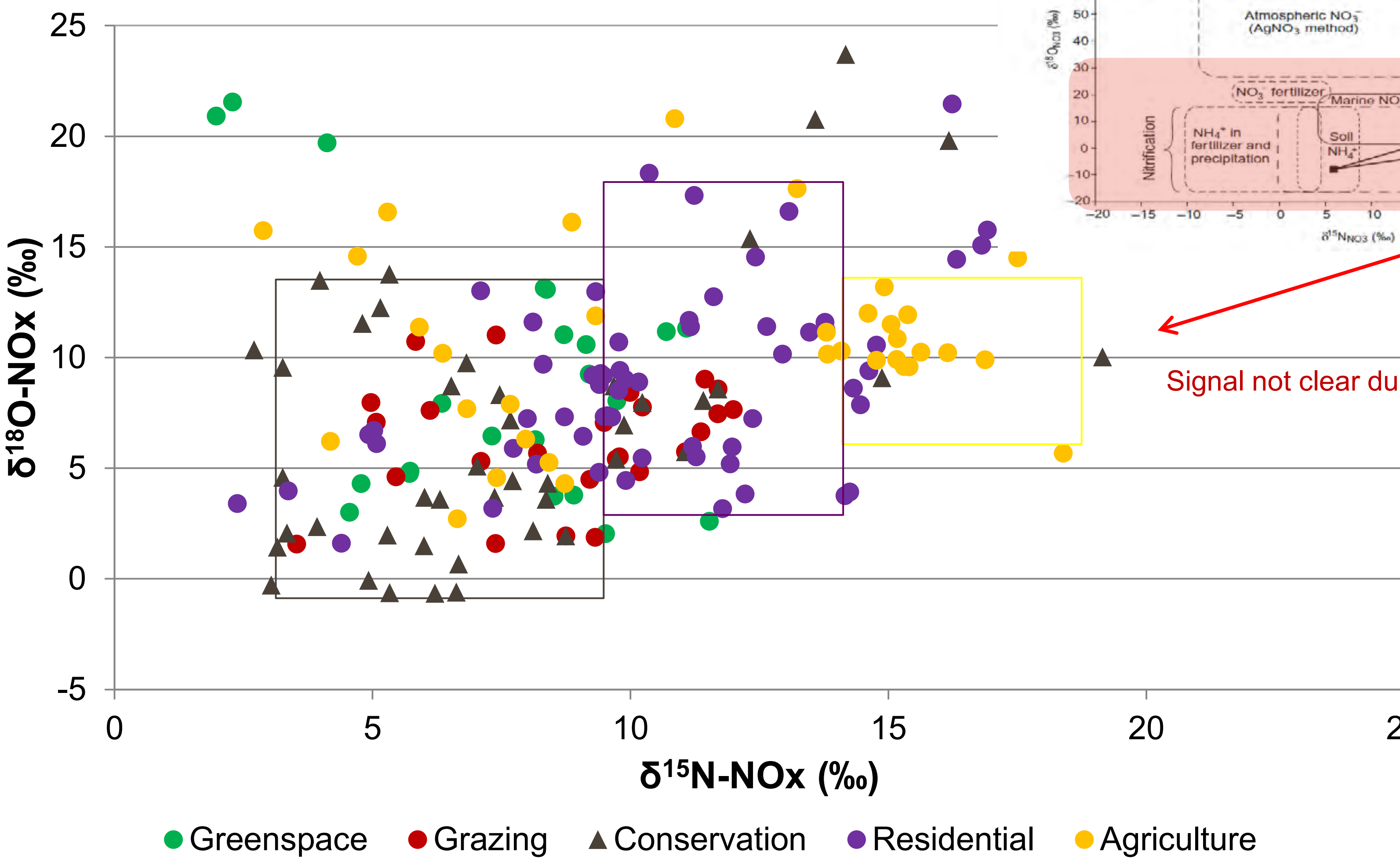
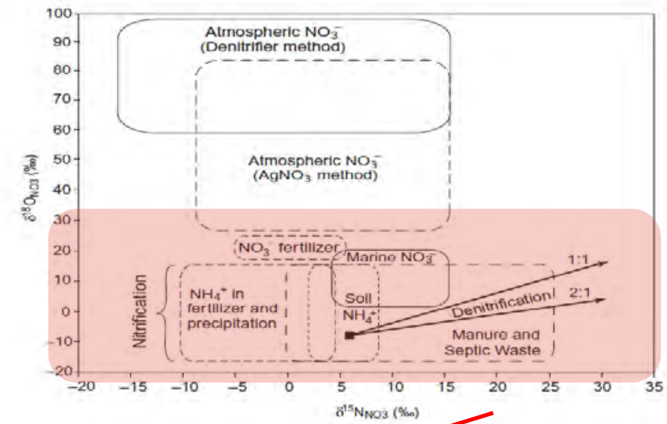
Caboolture: Biplot Isotope Signature

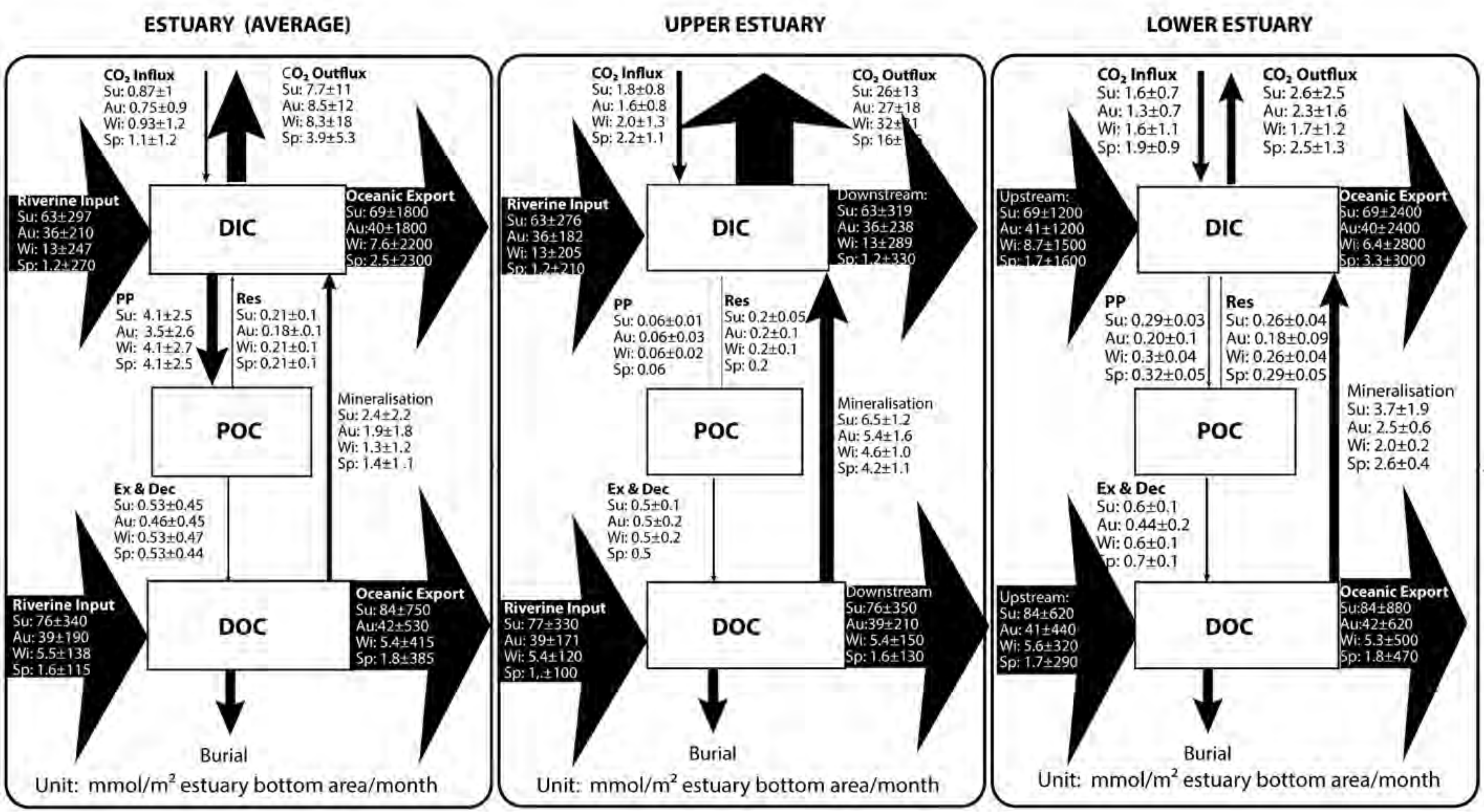




Signal not clear due to isotope mixing

Example of Large Spatiotemporal Variability: Carbon Budget

based on $\delta^{13}C$-DIC & $\delta^{13}C$-DOC 3-D model result



[Adiyanti et al. (submitted) An isotope-enabled biogeochemical model combined with uncertainty assessment for quantifying carbon flux pathways in a salt-wedge estuary. A manuscript submitted to *Environ. Model. Softw.*, Dec 2014]

CONCLUSIONS:

ISOTOPE-ENABLED 3-D HYDRODYNAMIC MODEL & BAYESIAN HIERARCHY MODEL is a powerful tool to:

- trace and identify nutrient pathways;
- show spatiotemporal variability in WQ of contributing environments and biogeochemical processes;
- take into account uncertainty introduced in the model due to boundary condition, parameters, model description.

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THANK YOU...