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Water & Environmental Resources

Wetlands and ponds: Studies on flow patterns and solute transport

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THE UNIVERSITY OF WARWICK

Outline

- Flow in wetlands and ponds
- Heathrow constructed wetlands
- ADZ model for solute transport

Natural wetland systems have often been described as the "earth's kidneys" because they filter pollutants from water that flows through on its way to receiving lakes, streams and oceans.
...
Constructed wetlands are treatment systems that use natural processes involving wetland vegetation, soils, and their associated microbial assemblages to improve water quality.
(Source: US EPA)

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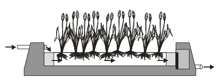
Natural and constructed wetlands



Subsurface constructed wetland

Boeng Cheung Ek Wetland
Phnom Penh, Cambodia

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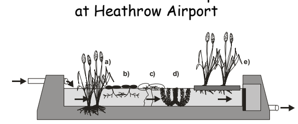
Natural and constructed ponds

Natural (but constructed) Pond

Stormwater retention pond at Heathrow Airport

Laboratory Model Pond



Free water surface wetland

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Why study flow in wetlands and ponds ?

- Natural and artificial wetlands and ponds are used for storm water management and waste water treatment
- Flow patterns and pollutant transport is dominated by several factors, such as
  - Advection and dispersion (Rivers)
  - Shape, e.g. ratio of width to length
  - Wind effects
  - Vegetation
  - Stratification
  - Substrate

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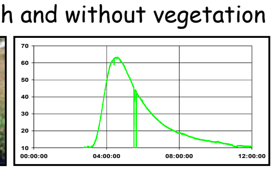
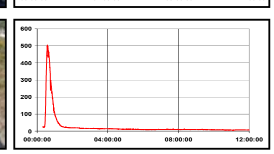
Effect of vegetation

- Residence time distribution of a channel section with and without vegetation





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Heathrow Constructed Wetlands

- To ensure wintertime flight safety glycol based fluids used for the de-icing of aircraft, runways and pavement
- Issues with de-icing fluids:
  - high BOD;
  - fluids are slow to biodegrade

Heathrow Constructed Wetlands

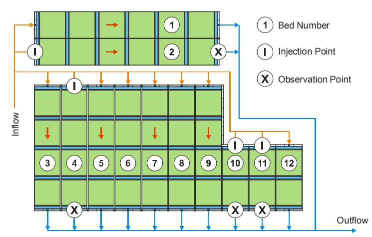
- Layout

Heathrow Constructed Wetlands

- Subsurface flow wetlands
  - Gravel beds are planted with reeds
  - Water flows horizontally through gravel beds
  - Biological treatment (biofilm system)

Heathrow Constructed Wetlands

- Layout



- total size 2 ha
- 12 beds
- 3 bed layouts
- equal hydraulic load
- total hydraulic load: 40 L/s
- Design BOD_5-load: 115 mg/L BOD_5
- Design effluent load: 40 mg/L BOD_5

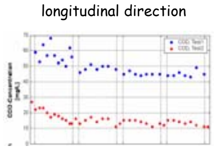
Treatment Efficiency Test

- Tests on different bed layouts
- Steady state flow condition
- Constant injection of dye and glycol
- Observation of RTD with fluorometer
- Pollutant parameters observed: BOD, DO, COD

Injection system

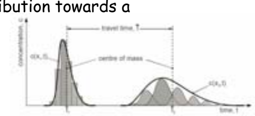
Residence time distributions

Observed COD in longitudinal direction



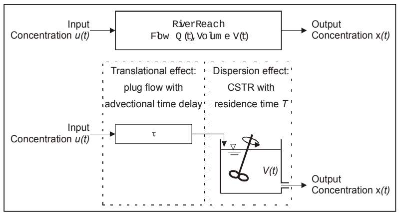
Modelling solute transport

- The residence time distribution of such a system (Pond or wetland) is quite long (5-6 days).
- In comparison the injection period is relatively short (10 minutes).
- Thus the injection has the form of a Dirac Delta impulse (Spike).
- Dispersion coefficients in advection domiated systems, such as rivers, are generally estimated by a routing procedure by routing a upstream Gaussian distribution towards a downstram Gaussian distribution.
- The routing, with a input of a Dirac Delta impulse, cannot reproduce the observed RTD.



- An alternative approach has to be selected.

The ADZ Model



Mass balance for steady state conditions

$$\frac{dx(t)}{dt} = \frac{Q}{V}u(t-\tau) - \left(\frac{Q}{V}+k\right)x(t)$$

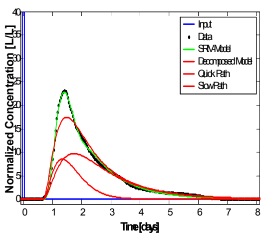
Transfer function for the discrete time ADZ model

$$x_k = \frac{bz^{-\delta}}{1-az^{-1}}u_k \qquad u \rightarrow \boxed{G_1} \rightarrow x$$

The ADZ Model

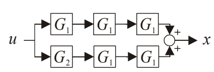
- The simple ADZ model is a based on a transfer function (of first order)
- Transfer functions are linear functions that are parametrically efficient to describe time series data
- A transfer function model is a "grey-box" model that describe the overall system behavior
- The parameters of a ADZ model transfer function can be interpreted in terms of mixing volumes and residence times
- Several transfer functions can be connected to build more complicated systems
- Parameter estimation by numerical algorithms, such as Equation Error / Least Squares / Instrumental Variable methods (origin in systems engineering)

Parameter estimation and interpretation for a higher order transfer function



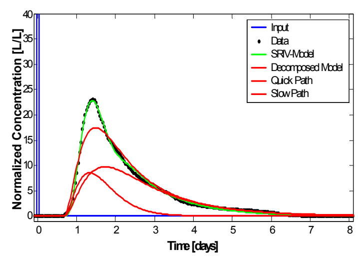
Best estimated ADZ model for all bed layouts

- 2 parallel pathways
- each 3 ADZ cells in series



$$x(k) = \frac{[b_0 + b_1 z^{-1}]z^{-\delta}}{1+a_1z^{-1}+a_2z^{-2}+a_3z^{-3}+a_4z^{-4}}u(k)$$

Parameter estimation and interpretation for a higher order transfer function



R_T^2 = 0.95739

$T_C(G_1)$ = 0.33 days

$T_C(G_2)$ = 1.41 days

T = 0.73 days

t (quick) = 1.67 days

t (slow) = 2.72 days

t (total) = 2.40 days

Summary

- The flow pattern of wetlands and ponds is different compared to the flow pattern of riverine systems.
- Systematically, the period of injection is short compared to the residence time.
- Thus modelling techniques are different compared to modelling of riverine systems.
- Combined ADZ models modelled by higher-order transfer functions are an efficient means to obtain.
- Parameters of the ADZ "Grey Box" model can be interpreted in physical means.

Questions?

Where ? do contaminated flows go ?

When ? will they arrive ?

What ? are the physical, chemical and biological changes ?

How much ? will occur ?