Hyporheic Exchanges

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Dye Tracing Workshop
20th September 2010

Contents
NIWA - field measurements
OTIS modelling
Nunnebäcken, Scåne, Sweden
Field Study
EU @ HR Ltd. - lab. Study exchange
EPSRC Studentship - Dutton PhD lab & modelling (Hart & OTIS)
Warwick Water - The EROSIMESS-System

National Institute of Water & Atmospheric Research
Dr Kit Rutherford & Dr Niall Broekhuizen
Conducted at Whatawhata
Investigating the effect of landuse
3 different streams - DB4, PKR, NW5
100m study reach, using both in-stream measurements and in-bed hyporheic wells
Tracer studies with both instantaneous and "step" injection
Application of OTIS (4 parameter) model to determine exchange coefficients
Nunnäsbacken, Scåne, Sweden
Order ca. 3 (Strahler)

Hyporheic Flow Assessment
Experimental Site (1989-1994)

over 50 piezometers
Decay of salt concentration in the surface flow

Decomposed Hart Model

Hyporheic Exchange - Rich Dutton

Tracer introduced into recirculating flow
Clear water in bed, measure temporal changes in concentration.
Bed forms studied

natural ripples
natural dune/ripples
artificial sinuosoidal dunes
artificial triangular dunes


\[ f(x) = n(x \cdot x \cdot x) \sum_{i=1}^{n} p_i (x \cdot x \cdot x) \]

Decomposed Hart Model

\[ t_{bar} = 80 \text{ secs} \]

*EC Commission, HCM Large Installation Programme with
Dr Andrea Marion, University of Padua, Italy
Recirculating water & sediment tilting flume.*
Laboratory Channel Studies

Meandering Channel

Natural sand formed porous bed

Tracer studies using both sealed and porous bed

In-stream measurements unable to determine difference in exchange coefficients using a 4 parameter model

Test Series Slope (in.) Bedform Bed Thickness (mm)
1 10000 Flat 30, 50, 75, 100
2 4000 Flat 30, 100
3 4000 Oscillating 30, 100

Flat or undulating bed
Gravel & styrofoam

Straight Channel

In-flow concentration
0.0
0.1
0.2
0.3
0.4

Time (s)
0 200 400 600 800 1000 1200

Flow rate 3.1 l/s
100mm thick

In-bed concentration
Ave in-flow
22.5mm
52.5mm
82.5mm

Undulating gravel
Flow rate 2.46 l/s
100mm thick

Comments:
Difficulty in quantifying exchange parameters (OTIS or Hart).
To ensure a 'unique' solution, in-stream longitudinal dispersion
coefficient predefined using an ADE fit to the rising limb of the
downstream profile.
Transient storage model is reduced to a three parameter process.

From three parameter optimisation technique:
-Exchange rate parameter is proportional to discharge, suggesting
that exchange is a turbulent driven process.
-Rate of exchange into storage is constant over all bed shapes and
bed forms with the exception of flow over the 100mm undulating thick
bed.
-In-bed residence time appears independent of bed slope and bed
form.

The EROSIMESS-System

- An in-situ erosion-meter (erosimeter)
- Designed to cause sediment motion
- Modified to study effects of sediment re-suspension on dissolved oxygen content
- Now modified for hyporheic exchange studies

Historically

- Studied in the field or the laboratory
- Most laboratory studies conducted on re-circulating flumes
- Setup time approximately two days
- Run time approximately 10 to 100+ hours
- restricting the range of conditions tested
Experimental setup

- Instrumentation
  - In-flow and in-bed Cyclops 7 fluorometers
- Main section
  - Height = 300 mm, diameter = 97 mm
  - 6 baffles create uniform bed shear stress
- Base section
  - Depth = 70 mm
- Motor and propeller
  - Tri-bladed 20mm diameter propeller
  - Max. 600 rpm (u = 0.056 m/s)
  - Min. 50 rpm (u = 0.002 m/s)

Experimental setup

- Examine capabilities of system
- Test procedure
  - Instrument placed
  - Base filled with tracer
  - Sediment placed and tracer drained to sediment surface
  - 2 litres clean water placed above in main section
  - Motor placed and started
- Test run until equilibrium concentration reached

Theory

- In-bed $D_e$ calculation
  $$D_e = \left( \frac{2 \pi V_s \Delta C_s}{2 A_s} \right)^{1/2}$$
- $D_e = \text{effective diffusion coefficient (m/s)}$
- $V_s = \text{volume of fluid in the sediment pores (m)}$
- $A_s = \text{sediment surface area (m)}$
- $\Delta C_s = \text{normalised solute concentration in the sediment pore water}$
- In-flow $D_e$ calculation
  $$D_e = \left( \frac{2 \pi V_{\text{over}} \Delta C_{\text{over}}}{2 A_{\text{bed}}} \right)^{1/2}$$
- $D_e = \text{effective diffusion coefficient (m/s)}$
- $V_{\text{over}} = \text{void volume in the overlying fluid (m)}$
- $A_{\text{bed}} = \text{bed area (m)}$
- $\Delta C_{\text{over}} = \text{normalised solute concentration within the overlying fluid (m)}$
- $t = \text{time (s)}$

Effective diffusion scaling relationship

$$D_e = \left( \frac{2 \pi V_{\text{over}} \Delta C_{\text{over}}}{2 A_{\text{bed}}} \right)^{1/2}$$

- Shear Reynolds number
  $$Re_s = \frac{u_s}{k_s}$$
- $u_s = \text{bed shear velocity (m/s)}$
- $k_s = \text{roughness height (m)}$
- $v = \text{kinematic viscosity (m/s)}$
- Permeability Pécelt number
  $$Pe_k = \frac{k}{D_e}$$
- $k = \text{permeability (m)}$
- $D_e = \text{molecular diffusion coefficient through the sediment pores (m/s)}$

 Results
Results

- EROSIMESS-System can be used to study hyporheic exchange for a wide range of conditions
- The scatter of erosimeter derived exchange coefficients lies within that of the previous flume studies
- Advantages over flume tests
  - Repeatability of tests
  - Ability to generate a wide range of bed shear velocities
  - Small quantities of sediment and fluid required
  - Reduced testing time, whilst still achieving full scale hyporheic exchange
- The erosimeter system could be used to study many factors that affect hyporheic exchange
  - Chemical sorption and the initial location of pollutants
  - Sediment depth and stratification

Summary

- • Re-built erosimeter to include an in-situ permeability test and fibre optic fluorometer heads
- • Proposed tests
  - Depth to which turbulence driven hyporheic exchange penetrates into the bed
  - Effects of chemical sorption on exchange coefficients, through the introduction of organic carbon to the sediment bed

Ongoing work

- Proposed tests
  - Depth to which turbulence driven hyporheic exchange penetrates into the bed
  - Effects of chemical sorption on exchange coefficients, through the introduction of organic carbon to the sediment bed

Thankyou for listening

Google: Warwick Water