Interactions between hyporheic flow produced by stream meanders, bars and dunes

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Outline

I. Introduction
II. Methods
III. Results
IV. Discussions and Conclusions
V. Future Works
• This study explores the relationship between topography and hyporheic exchange.

• Bars and dunes have been shown to induce hyporheic exchange through pressure variations induced by surface water flowing over these features.

• It is important to understand the effects of stream topography on both interfacial fluxes and hyporheic residence times of exchanged water.
• The region of the subsurface that receives stream water is referred to as the **hyporheic zone**

• The water flowing in and out of this zone is termed **hyporheic exchange**.
Homogeneous Channel slope constant Equal-width Channel

Meanders
- Dunes & Meanders
- Bars & Meanders
- Dunes, Bars, & Meanders

0° 45°
90° 180° 270°
Meanders

\[
\begin{align*}
\frac{d_{\text{max}}}{s^2} (\eta - s)^2 - d_{\text{max}} \eta \leq s \\
\frac{d_{\text{max}}}{(W - s)^2} (\eta - s)^2 - d_{\text{max}} \eta > s
\end{align*}
\]

- **W**: The stream width
- **S**: The location in maximum depth
- **d_{\text{max}}**: Maximum depth
- **\eta**: The transverse coordinate
Meanders

- Channel geometries use in simulations

![Diagram of meanders with parameters table]

<table>
<thead>
<tr>
<th>Parameter</th>
<th>0</th>
<th>45</th>
<th>90</th>
<th>180</th>
<th>270</th>
</tr>
</thead>
<tbody>
<tr>
<td>Arc angle: $\phi$ (degrees)</td>
<td>0</td>
<td>45</td>
<td>90</td>
<td>180</td>
<td>270</td>
</tr>
<tr>
<td>Sinuosity: $S$</td>
<td>1</td>
<td>1.03</td>
<td>1.11</td>
<td>1.57</td>
<td>3.33</td>
</tr>
<tr>
<td>Wavelength: $\lambda$ (widths)</td>
<td>N/A</td>
<td>3.06</td>
<td>5.66</td>
<td>8</td>
<td>5.66</td>
</tr>
<tr>
<td>Amplitude: $A$ (widths)</td>
<td>0</td>
<td>0.15</td>
<td>0.59</td>
<td>2</td>
<td>3.41</td>
</tr>
</tbody>
</table>
Meanders

Figure 2. Stream planforms used in the simulations.
Bars and Dunes

- Used two-dimensional Fourier series whose amplitude-to-wavelength ratio followed this relationship.

\[ S(K_x) = \alpha K_x^{-3} \]  

(Hino, 1968; Nicora and Hicks, 1997)

- \( S \) : Wave number spectrum
- \( K_x \) : Wave number
- \( \alpha \) : Constant that varies with the system
Bars and Dunes

Wavelengths (widths) | Amplitude and maximum stream flow depth
--- | ---
Dunes | $\pi/70 \sim \pi/16$ | 0.17
Bars | $\pi/15 \sim \pi/3$ | 0.25

The average dune slope was 3.8 times larger than the average bar slope.
Bars and Dunes

- Stream bed topographies used in the simulations.
3-D Subsurface Flow Simulation

A. Stream velocity 
   \( v = 0.003 \) widths/s

B. Hydraulic conductivity 
   \( k = 5 \times 10^{-5} \) widths/s

C. Channel slope = 0.001, valley slope was calculated from the channel slope for each platform.

D. Porosity = 0.35 (sand)

E. Use the MODFLOW
MODFLOW

\[ Q_{riv} = K L W (H_{riv} - H_{aq}) / M \]

- \( Q_{riv} \): Into the aquifer flow through the river bed (\( L^3 / T \))
- \( K \): Hydraulic conductivity (\( L / T \))
- \( L \): River length (\( L \))
- \( W \): River width (\( L \))
- \( M \): Bed thickness (\( L \))
- \( H_{riv} \): Water level (\( L \))
- \( H_{aq} \): Groundwater level (\( L \))
Average directly modeled interfacial flux values into the subsurface

<table>
<thead>
<tr>
<th>Topography Planform (sinuosity)</th>
<th>Meanders</th>
<th>Dunes and Meanders</th>
<th>Bars and Meanders</th>
<th>Dunes, Bars, and Meanders</th>
</tr>
</thead>
<tbody>
<tr>
<td>0° (1.00)</td>
<td>0</td>
<td>4.67 × 10⁻⁸</td>
<td>3.04 × 10⁻⁹</td>
<td>4.73 × 10⁻⁸</td>
</tr>
<tr>
<td>45° (1.03)</td>
<td>3.06 × 10⁻⁹</td>
<td>4.93 × 10⁻⁸</td>
<td>1.03 × 10⁻⁸</td>
<td>5.25 × 10⁻⁸</td>
</tr>
<tr>
<td>90° (1.11)</td>
<td>6.83 × 10⁻⁹</td>
<td>4.74 × 10⁻⁸</td>
<td>1.26 × 10⁻⁸</td>
<td>4.97 × 10⁻⁸</td>
</tr>
<tr>
<td>180° (1.57)</td>
<td>1.73 × 10⁻⁸</td>
<td>5.30 × 10⁻⁸</td>
<td>2.10 × 10⁻⁸</td>
<td>5.44 × 10⁻⁸</td>
</tr>
<tr>
<td>270° (3.33)</td>
<td>8.76 × 10⁻⁸</td>
<td>1.10 × 10⁻⁷</td>
<td>8.90 × 10⁻⁸</td>
<td>1.11 × 10⁻⁷</td>
</tr>
</tbody>
</table>

(widths/second)
Distribution of interfacial flux (flux into the subsurface) associated.
Volume remaining in bed

- Cumulative residence time distribution for each meandering case divided by the 270° Dunes, Bars, and Meanders case.
Flux

Comprehensive comparison of different scales

- The average flux into the subsurface for the modeled Dunes, Bars, Meanders topography compared with predictions calculated as the sum of the exchange due to each topographical feature.

✓ Interfacial flux for the summations and direct multi-scale simulations differed by 1.7–35.2%.
Cumulative residence time distributions associated with different scale.

Dashed: multiscale direct simulations
Solid: isolated-scale simulations
Conclusion

- The Dunes more significantly influence both interfacial flux and residence times in stream with small sinuosity.
- Bar-scale topography did not significantly affect hyporheic flow.
- The planform features can often be neglected in low-sinuosity streams.
- Simulations using isolated scale of topography can be compared to determine the dominant scale of topography and under some circumstances can be summed to make good multi-scale predictions.
• Development of index overlay and numerical model to assess multiscale dynamics of hyporheic flow

Data analysis (sediment caliber, bedform, channel morphology…)

To define the weighting values by index-overlay method.

To using Hydrus 3D that estimate the amount of hyporheic flow.
Introduction

Methods

Results

Conclusion

Future work

(1) Wide well

(2) Radial well

(3) Catchment channel

(4) Horizontal collecting conduit
Wide well

\[ Q = 1.37K \frac{(2H-S)\cdot S}{\log R - \log r} \]

Q : Total quantity of water intake (L^3/T)
K : Hydraulic conductivity (L/T)
H : Groundwater aquifer thickness (L)
l : Well to waterside distance (L)
R: Influence radius (L)
r : Well Radius (L)
S: Water level deepens (L)
Radial well

- \( Q = q \times n \)

\[
q = \frac{Ksl}{0.37 \log N_0}
\]

Q: Total quantity of water intake (L^3/T)
q: Single radiant tube quantity of water intake (L^3/T)
n: Radial tube number
K: Hydraulic conductivity (L/T)
s: Water level from surface to catchment (L)
l: Radiator length (L)

\[ N_0 = \frac{4mz_0l}{b(m-z_0)\left(\sqrt{1^2+16z_0^2}+1\right)} \times \left(\frac{\sqrt{1^2+16(z_0-m)^2}+1}{\sqrt{1^2+16m^2}+1}\right) \]
Catchment channel

Water supply estimate:

\[ Q = KIA \]

K : Hydraulic conductivity (L/T)
I : Vertical infiltration flow conditions
A : Cross-sectional area (L²)
Horizontal collecting conduit

\[ Q = KL \left[ \frac{H_1^2 - h_0^2}{2l} + S_1 q_{r1} + \frac{H_2^2 - h_0^2}{2L} + S_2 q_{r2} \right] \]

Q : Total quantity of water intake (L^3 /T)
K : Hydraulic conductivity (L/T)
H : Head (L)
L : Length of collector (L)

(供水水文地質手冊)
Collecting channel

\[ Q = L \times \frac{2\pi K (H + a - h_0)}{\log(2 \times \frac{a}{r_0})} \]

- **K**: Hydraulic conductivity (L/T)
- **H**: Depth of water surface (L)
- **a**: Depth of the collecting channel (L)
- **h0**: Depth after the pumping (L)
- **r0**: Radius of collecting conduit (L)
- **L**: Length of collecting channel (L)

(南區水資源局
Southern District Water Resources Bureau)
Hydrus 3D
THANK YOU FOR YOUR ATTENTION