Quantifying pollution mixing across low velocity real emergent vegetation patches and borders

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Introduction - What is the problem?

Natural system Physically modelled

How does the mixing across patches and borders affect the total pond residence time?

Introduction – what is lacking?

Current models treat system as three mixing zones:
- Vegetated
- Open channel
- Mixing layer

Extensively investigated for idealised homogeneous and artificial vegetation.

Paucity of research employing naturally cultivated real vegetation in the control of a laboratory.

Motivation was to aid the development of a practically useful 2D application to predict pond residence times.

How does the theory developed in these conditions apply to random real vegetation borders?
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Methodology

- Naturally cultivated winter and summer *Typha* vegetation imported into the laboratory
- Compare to high and low density artificial vegetation
- Continuous tracer release – steady-state simulation
- Laser Induced Fluorometry (LIF)
- Acoustic Doppler-shift Velocimetry (ADV)
- Black-out conditions and detailed calibration – precise measurement system
- Quantify vegetation characteristic – stem counting, diameter measurements, image processing.

Results - Velocity

- Velocity profiles in artificial vegetation agree with classical shear-layer forms
- Velocity in real vegetation is non-classical - multiple inflection points
- Vortex penetration poorly defined;
- Heterogeneous distribution causes deviation from classical description making characterisation difficult.

Result - Tracing

Continuous injection 2D distributions (5.25 l/s example).
< 1% of maximum converted to white for visual purposes.

Temporal average between > 20% of maximum concentration to give steady-state profiles.

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Optimised Finite Difference Model (OFDM) Analysis

Proposed functionality for transverse mixing coefficient, \( D_y(y) \)

\[ D_y = k_1 U_1 \]

\[ D_y = k_2 U_2 \]

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Model analysis Results

Steady-state concentration

<table>
<thead>
<tr>
<th>Vegetation Type</th>
<th>Finite Difference Model</th>
<th>OFDM Model</th>
</tr>
</thead>
<tbody>
<tr>
<td>Triangular</td>
<td>0.9349</td>
<td>0.9118</td>
</tr>
<tr>
<td>Artificial</td>
<td>0.9378</td>
<td>0.9702</td>
</tr>
<tr>
<td>Winter Typha</td>
<td>0.9305</td>
<td>0.9603</td>
</tr>
<tr>
<td>Summer Typha</td>
<td>0.9305</td>
<td>0.9603</td>
</tr>
</tbody>
</table>

The model was then evaluated for various characteristic mixing profiles.

OFDM Results

Triangular

High density artificial

Low density artificial

Winter typha

Summer typha

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OFDM Limitations

- Defining the regions of steady-state concentration difficult given the temporal variability in the record.
- Profiles \( U(y) \) assume an average velocity field between upstream and downstream.
- Non-classical nature of \( U(y) \) limits definition of vortex penetration lengths.
- Definition of the regions of constant mixing (e.g. wake and open channel zones) reliant on vortex and mean velocity estimations.
- Models were sensitive to the magnitude of peak mixing more than the location.

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1. Quantification of mixing across shear layer; real emergent vegetation;
2. Precise measurement of velocity fields in controlled real vegetation;
3. Application of theory developed in homogeneous, artificial conditions to real vegetation;
4. Application of Finite Difference Model to optimize different functional forms of transverse mixing coefficient to both artificial and real shear layers.

- Heterogeneous vegetation limits application of theory developed in homogeneous conditions.
- Velocity profiles are rough averages and the quantification of the vegetation has large error.
- OFDM useful tool for quantifying mixing field although there is potential to find non-physical solutions; therefore further constraints may be needed for real vegetation.
- Various functionalities for \( D(y) \) yield acceptable fits, where the unconstrained functions give good predictions.
- However, a simple step model is acceptable for the real vegetation.

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