WHERE DOES RIVER WATER GO WHEN IT ENTERS THE OCEAN?

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1. Introduction

When river water enters the ocean, it does not spread out evenly in all directions. Its movement is instead controlled by three major factors: the rotation of the Earth, the density difference between the freshwater and the ocean, and the discharge rate of the river. This work develops a theoretical model to help to determine the properties of a river outflow, and ultimately help to improve predictions for the spread of pollution from rivers, thus allowing clean-up operations to focus on the areas most at risk.

2. Experiments

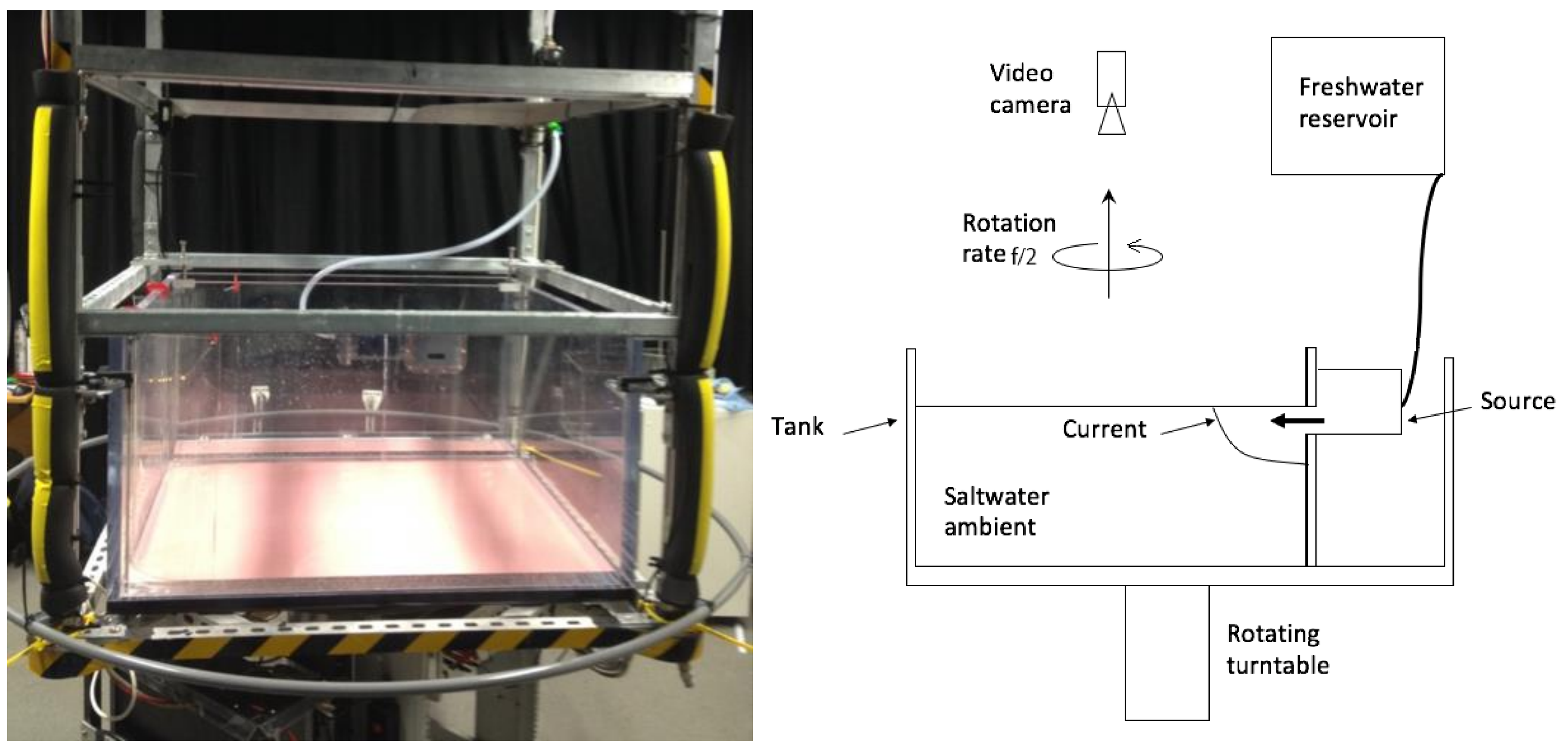

Figure 1: Experimental setup – photograph of tank and schematic diagram.

Experiments were conducted in a large acrylic tank (99cm x 79cm x 51cm) which was mounted on a rotating turntable and filled with saltwater to a depth of 32cm. Freshwater was then supplied to the tank at a constant rate from a reservoir above, which entered the rotating ocean through a specially designed 'source structure'. The structure ensured that the river outflow conditions remained constant throughout an experiment and provided a more realistic model of the real-world scenario than those used in previous studies, due to the horizontal direction of the outflow and the non-zero depth of the river mouth.

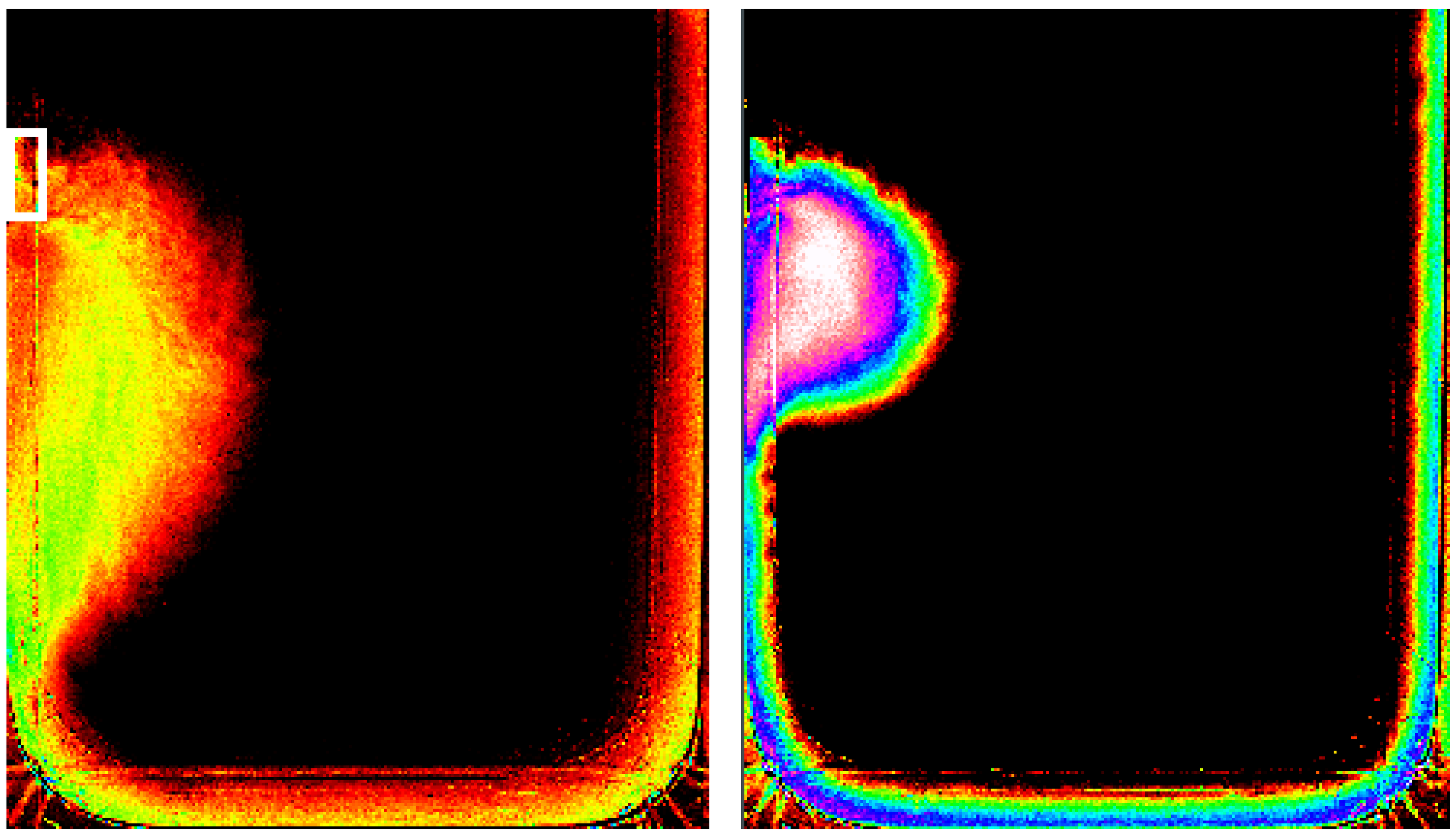

Figure 2: Plan view of typical experiments. The two main features of the outflow vortex and boundary current can clearly be seen in both images.

For each experiment two main features could be seen: a rotating vortex near to the river mouth and a boundary current propagating along the coast. The depth, width and velocity of each feature were measured and compared to the predictions from the theoretical model and from field measurements in the North Sea. This information can be used in practice to determine how far from the coast and how deep in the ocean river pollution may spread, enabling clean-up operations to focus on the most susceptible areas.

3. Results and Discussion

Three key questions are addressed in this study:

- What is the effect of the finite depth of the river mouth on the properties of the outflow vortex and the boundary current?
- What role does the outflow vortex play in determining the behaviour of the boundary current?
- How does turbulence in the ocean modify the vortex and current properties?

We find that the finite depth of the river mouth is only important for small or slow-moving rivers. For large, fast-moving rivers a simplified model is sufficient with the current depth (h_0), width (w_0) and velocity (u_0) given by the following formulae:

$$h_0 = (\frac{2fQ}{g'})^{1/2}, \quad w_0 = (\frac{8g'Q}{f^3})^{1/4}, \quad u_0 = \frac{3}{2^{9/4}}(fg'Q)^{1/4}.$$

The rotation rate is given by f (s^{-1}), the density difference between the river water and the ocean is represented by g' (m s^{-2}), and the discharge rate of the river is given by Q (m^3 s^{-1}). Perhaps the most important insight of this work is that the behaviour of the boundary current is entirely determined by the conditions in the outflow vortex. The vortex takes over the role of 'source' from the river and supplies the current with the required initial conditions to determine its behaviour completely. We introduce an original time-dependent model to capture this new behaviour.

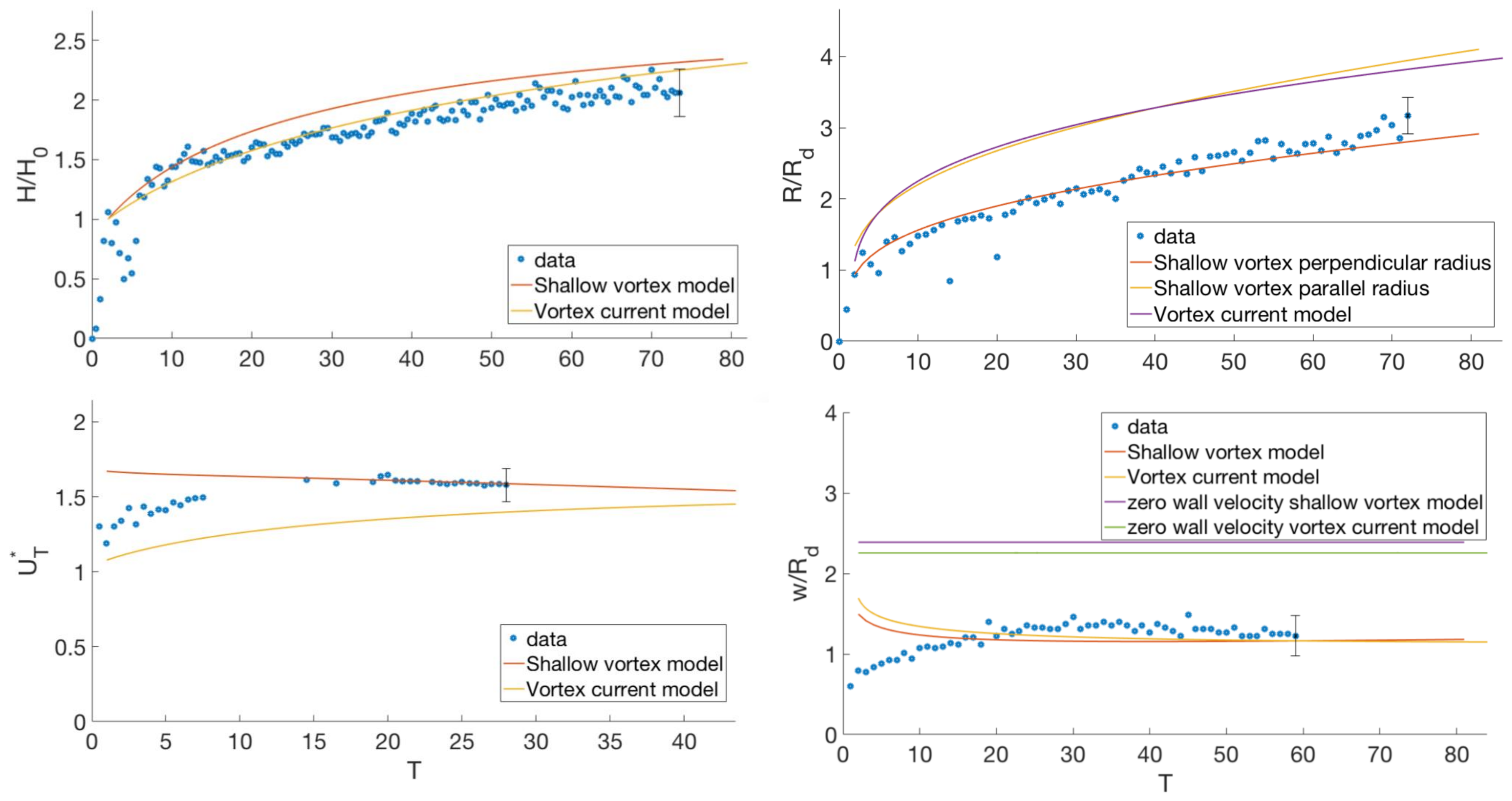

Figure 3: Comparison of the experimental data with the new time-dependent model for the vortex depth H, radius R, and current velocity U_T, width w.

Finally, the effect of ocean turbulence on the flow is found to be highly dependent on the structure of the turbulence, with different results for 2D and 3D structures.

4. Conclusions

The results of the model are compared with field measurements for the River Rhine and Norwegian coastal currents in the North Sea below.

Location	Current depth (h_0 m)	Current width (w_0 km)	Current velocity (m s^{-1})
River Rhine	Predicted: 5-10 Measured: 10	Predicted: 10 - 20 Measured: 20	Predicted: 0.25 - 0.5 Measured: 0.5
Norwegian coastal current	Predicted: 100 Measured: 100	Predicted: 50 Measured: 75	Predicted: 1 Measured: 1 - 2

5. References

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