

EXPERIMENTAL INVESTIGATION OF FLOW AND DEPOSIT PATTERNS IN RECTANGULAR SHALLOW RESERVOIRS: PRELIMINARY ANALYSIS

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Abstract. *This document is a preliminary analysis (dimensional analysis, bibliographic review) for an experimental study about flow and deposit patterns in rectangular shallow reservoirs. The experimental device and first results are also presented.*

1 INTRODUCTION

Tanks, basins, ponds, lagoons (called reservoirs below) are commonly used in environmental hydraulics. Because of generally quiescent conditions, these works are conducive to the settling of particles. Therefore reservoirs must be carefully designed according to the role they will play. For example, sedimentation must be maximized in settling basins (stormwater treatment, protection of irrigation or hydro-electric power structures, *etc.*) whereas it must be minimized in storage facilities (irrigation, electric power generation, flood control, *etc.*).

The prediction of deposits as a function of the geometry of the reservoir, the hydraulic conditions and the sediment characteristics is still a great challenge. While empirical and semi-empirical methods^[1] have been developed for the last sixty years to determine the amount of deposits, they cannot determine their location, which is required to well define the sediment removal strategy. To get this information, the knowledge of the flow pattern is a prerequisite (possible various size recirculations).

This study focuses on rectangular shallow reservoirs, as illustrated in figure 1. Here, L is the length of the reservoir; B , its breadth; b , the breadth of the inlet and outlet channels; ΔB , the lateral expansion; and h , the water depth.

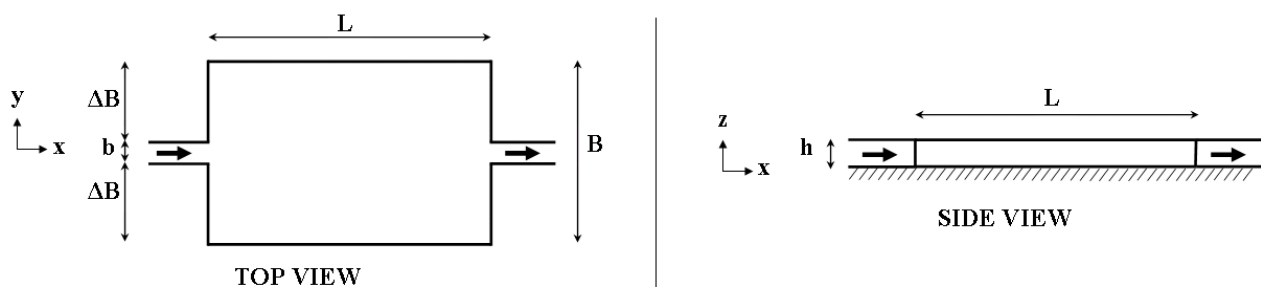


Figure 1. Schemes of a rectangular shallow reservoir

The aim of this study is firstly to describe all the flow patterns in rectangular shallow reservoirs (typology of flow). Secondly, to determine prediction criteria of the flow. Finally, to define a typology of short-term deposits. This paper presents a dimensional analysis, a brief bibliographic review, the experimental device and first results.

2 DIMENSIONAL ANALYSIS

We assume that the flow in rectangular shallow reservoirs is governed by nine parameters: the length of the reservoir (L), its lateral expansion (ΔB), the breadth of the inlet and outlet channels (b), the water depth (h), the mean depth-averaged velocity (U), the bed shear stress (τ), the water density (ρ), the water viscosity (μ) and the gravitational acceleration (g). Using dimensional analysis principles^[2], the relationship between these nine variables may be reduced to a relationship between six dimensionless parameters, which are for example a lateral expansion ratio, a longitudinal

confinement, a vertical confinement, a Reynolds number, a Froude number, and a bed friction coefficient (see equation 1). Any dimensionless parameter of this equation may be replaced by a product of powers of itself and others.

$$f\left(\frac{\Delta B}{b}, \frac{\Delta B}{L}, \frac{\Delta B}{h}, \frac{4\rho U h}{\mu}, \frac{U}{\sqrt{gh}}, \frac{2\tau}{\rho U^2}\right) = 0 \quad (1)$$

3 BRIEF BIBLIOGRAPHIC REVIEW

The objective of this bibliographic review is to show the influence of these dimensionless parameters (or combinations of any of them) in similar conditions.

Abbott & Kline^[3] intensively studied the stall of turbulent free surface flows over double lateral expansions using dye visualization. They showed that the recirculation zones in each side of the expansion were equal in length for expansion ratio (as defined in equation 1) less than ~ 0.25 . For expansion ratio greater than ~ 0.25 , the reattachment lengths were different.

Abbott & Kline claimed that the flow pattern was not sensitive to the Reynolds number, provided the flow is fully turbulent before the expansion. Casarsa & Giannattasio^[4] carried out PIV measurements in order to check this behavior and showed that the influence of this dimensionless parameter on the shorter recirculation length was not completely negligible (a few percents).

Vertical confinement leads to modify the turbulence mechanisms^[5] so that the flow properties (velocity field, concentration profile in case of dye transport) are in scale with the water depth^[6,7]. For example, Giger et al.^[6] showed that a characteristic feature of shallow jets was the formation of meandering structures at distances from the orifice larger than ten times the water depth.

Experimental studies about the shallow recirculating flow over single lateral expansions^[8,9,10] highlighted two asymptotic behaviors, depending on the bed friction number (defined as the product of a vertical confinement coefficient and a bed friction coefficient). For small values of this number, the length of the recirculation zone is only dependent on the lateral expansion. For large values, the length of the recirculation zone is only dependent on the friction length scale (defined as the ratio of the water depth to the bed friction coefficient). Chen & Jirka^[11] showed that for Reynolds numbers greater than 6000 (as defined in equation 1), the shallow wake generated by a two-dimensional body was uniquely dependent on a similar number (the shallow wake parameter).

Kantoush^[12] experimentally studied the flow field in rectangular shallow reservoirs (as illustrated in figure 1), varying the length of the reservoir, its breadth, the water depth and the inflow velocity. His benchmark case was a 0.2 m high water flow entering a 6 m long and 4 m wide reservoir by a 0.25 m wide channel at a velocity of 0.14 m/s. In this situation, the main flow was deflected on the right wall, leading to the formation of a large counter clockwise recirculation in the whole structure and a small clockwise recirculation zone in the right inlet corner (the sense may be reverse, depending on the experiment). Similar patterns have been observed with decreasing the breadth of the reservoir (3 m, 2 m, 1 m and 0.5 m for which a plug flow takes place in the downstream zone of the reservoir). Asymmetry disappeared with decreasing the length of the reservoir (5 m, 4 m, 3 m). For these geometries, the main flow was not deflected at issuance in the reservoir, leading to the formation of two large symmetrical recirculation zones.

With decreasing the water depth to 0.15, 0.1 and 0.075 m (but increasing the Froude number in the same time), Kantoush showed that the flow started to meander (in a similar way to the observations of Giger et al.^[6] and those of Chen & Jirka^[11]).

4 EXPERIMENTAL DEVICE

We decided to focus on the lateral expansion, the longitudinal confinement, the vertical confinement and the Froude number, provided that the Reynolds and the bed friction number are respectively high and low so that they do not significantly influence the flow pattern.

The experimental device consists of a ~ 10 m long and ~ 1 m wide glass channel in which blocks (to change ΔB) and walls (to change B) can be arranged to build different reservoir geometries (see pictures below). The sizes of these blocks and walls have been chosen, based on an assumption about the influence of the geometry of the shallow reservoir on the flow pattern.

This assumption is based on the combination of the experimental data of Abbott & Kline^[3] and Kantoush^[12], numerical simulations of Dufresne^[13], and preliminary analysis of Dufresne^[13] and Dewals et al.^[14]; it is illustrated in figure 2. In region δ , the flow field is dominated by two large symmetric recirculation zones (see Kantoush^[12]). In region γ , a large asymmetric recirculation zone (clockwise or counter clockwise) takes place in the whole reservoir (see Kantoush^[12]). In region β , the flow field is still asymmetric but fully reattached in the downstream zone of the reservoir (see Abbott & Kline^[3] and Kantoush^[12]). In region α , the flow is still fully reattached in the downstream zone of the reservoir but, contrarily to region β , the two upstream recirculation zones are equal in length (see Abbott & Kline^[3]).

The vertical axis of figure 2 is the lateral expansion ratio, as defined in equation 1; therefore regions α and β are

separated by a horizontal line (see Abbott & Kline^[3]). Based on preliminary analysis of Dufresne^[13] and Dewals et al.^[14], the horizontal axis is a combination of the longitudinal confinement and the lateral expansion ratio, so that the border between regions γ and δ is a vertical line. The expression of this dimensionless number is not final yet; this study will allow us to define it precisely.

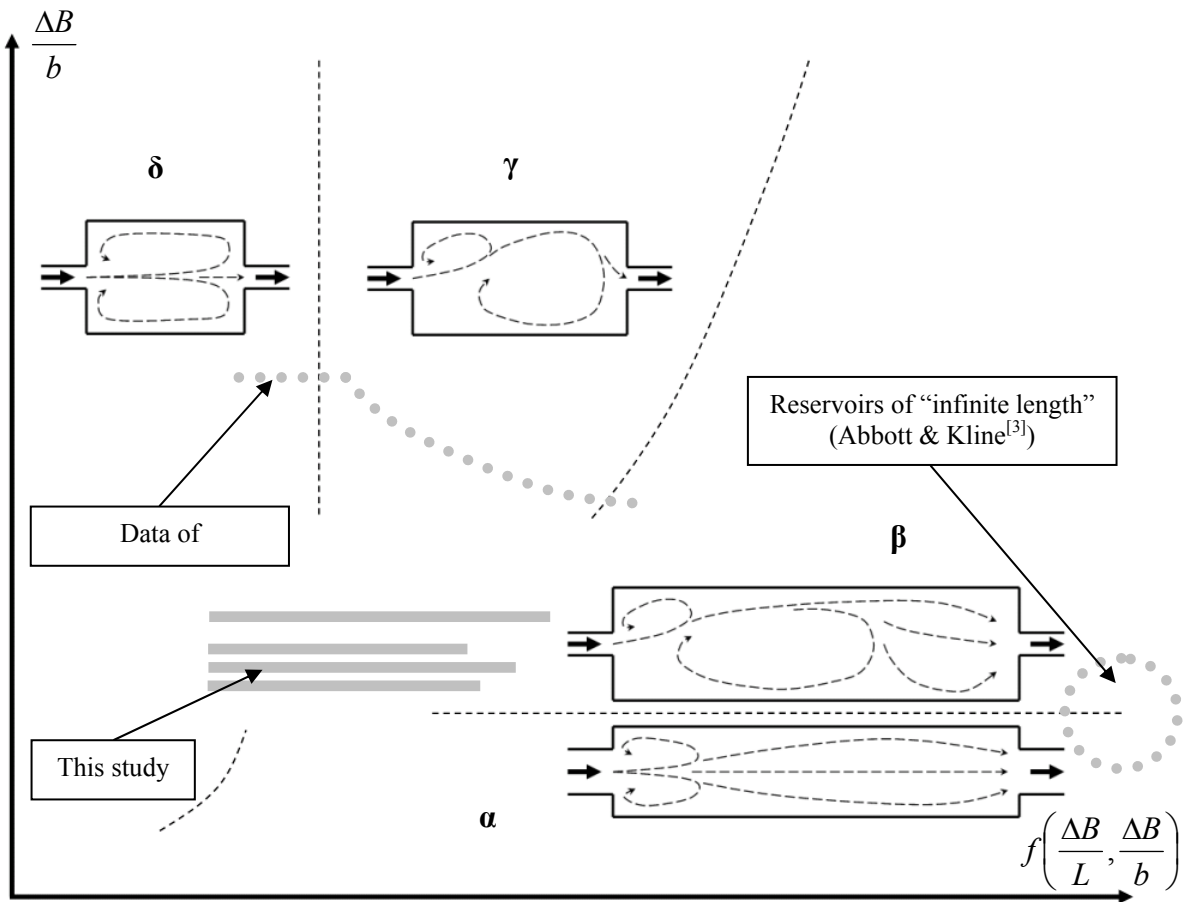


Figure 2. Assumption about the influence of the reservoir geometry on the flow pattern (dimensions of the reservoirs are not to scale)

In figure 2, the zone that will be experimentally investigated corresponds to the four horizontal grey lines (two sets of blocks times two breadths).

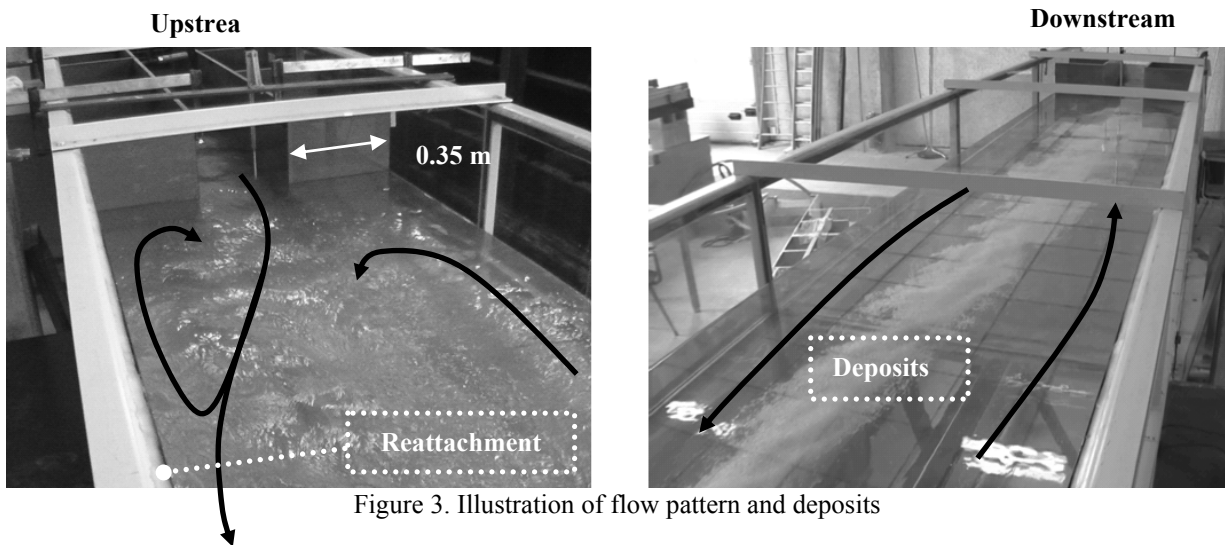


Figure 3. Illustration of flow pattern and deposits

5 FIRST RESULTS

First results are illustrated in figure 3. Here, the reservoir is ~ 7 m long and ~ 1 m wide; the lateral expansion is equal

to 0.35 m.

Using several dye and sawdust injections, we observed that a first reattachment was clearly identifiable on the right wall (but not completely stable). A second one was sometimes present on the left wall (in the downstream zone of the reservoir), showing that the flow is highly unsteady. This flow pattern is so located around the border between region β and region γ in figure 2. Given these results, we developed a protocol to measure not only the mean reattachment lengths but also their temporal variations (using dye injections at different locations).

Concerning the deposits, we can see in the right side of figure 3 that they are massively located in the core of the recirculation zone.

6 CONCLUSIONS AND PERSPECTIVES

Based on dimensional analysis and bibliographic review, an experimental device has been built in order to study the flow and deposit patterns in rectangular shallow reservoirs.

Next weeks will be dedicated to the measurement of reattachment lengths (mean position and temporal variation), varying four dimensionless parameters (the lateral expansion ratio, the longitudinal confinement, the vertical confinement and the Froude number). Deposits will be mapped for each flow pattern.

Based on the work of Dewals et al.^[14], numerical simulations will also be carried out. After validation against experimental data, they will be used to explore unknown zones in figure 2.

7 ACKNOWLEDGMENTS

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