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THESIS OF SPECIALITY

Title

2D MODELLING OF SELF-CLEANING PROCESS IN RETENTION TANKS

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Author

LUIS CARLOS RUILOBA SÁEZ

Supervisor

MANUEL GÓMEZ VALENTÍN

Department

DEPARTMENT OF HYDRAULIC ENGINEERING

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ABSTRACT

Cities are developing and the sewer network are overloaded due to urbanisation of them. The urbanisation lead to an increasing of the impervious because of the concrete areas, bituminous pavements and building zones are in previous green areas which were more permeable than the new uses of soil. This is the mean cause of the problems in the sewage network designed on the past and one of the current and effective solutions are the retention tanks.

The main goal of the current thesis is to develop a 2D model using Iber software to study the hydrodynamic behaviour in this kind of infrastructure and at the same tame simulate a flushing event to observe the erosion capacity of the water volume inside the storage chamber. On the other hand, real data was not obtained due to a significant rainfall event were not occurs to dispose of a representative quantity of sediment over the lane. Instead of represent a real flushing event analysed in a real case, several scenarios have been studied.

Based on the hydrodynamic module run by Iber, the areas where the sediment transport will be more difficult has been detected. Due to the special geometry of the lane there are recirculation areas where an energy dissipation occurs causing deposition of material instead of remove it because of velocities values are lower than in other areas of the lane.

In the sediment transport module sands and organic material have been studied by bed load erosion and suspended transport respectively. Based on other studies where sediment transport was calibrated through real data and several laboratory tests the proposed scenarios are simulated with the estimated results.

Van Rijn formula does not fit properly for the flushing event studied and two parameters to calibrate the formula are studied in order to analyse the sensitiveness of them. Focussing on the suspended transport, the erosion rate of the studies consulted are not enough to clean the lane by only one emptying which is known that depending on the sediment in the lane sometimes doing one flushing is enough to clean the tank.

Key words: retention tank, detention tank, self-cleaning system, flushing systems, sediment transport, bed load transport, suspended transport, Iber.

Author: RUILOBA SÁEZ, Luis Carlos
Supervisor: GÓMEZ VALENTÍN, Manuel

RESUMEN

Las ciudades están en constante crecimiento lo que implica que las redes de saneamiento se vean sobrecargadas debido a la urbanización. Esto comporta que la impermeabilidad del terreno aumente su valor debido a las zonas hormigonadas, asfaltadas y a zonas edificadas que antes eran terreno de zonas verdes de mayor permeabilidad. Este es el principal problema en redes de saneamiento que no han estado diseñadas para soportar estas cargas adicionales y los tanques de retención son una solución para lidiar con ello.

El objetivo de la presente tesina es desarrollar un modelo bidimensional mediante Iber y así estudiar la hidrodinámica en este tipo de infraestructuras y al mismo tiempo la capacidad de erosión del agua retenida en la cámara de almacenamiento al realizar un vaciado. Sin embargo, no se ha podido analizar un vaciado real ya que no se ha producido un evento de lluvia que deje una muestra de sedimento representativa para llevar a cabo el estudio. No obstante diversos casos hipotéticos han sido estudiados.

Analizando el módulo hidrodinámico simulado con Iber, las áreas problemáticas de transporte de sedimento han sido detectadas. Por su especial geometría se producen áreas de recirculación donde hay disipación de energía y se deposita más material en vez de limpiarlo debido a las bajas velocidades en comparación a otras zonas.

En el módulo de transporte de sedimentos se han estudiado arenas y material orgánico mediante transporte de arrastre y transporte en suspensión respectivamente. Consultando otros estudios donde el transporte de sedimento se ha estudiado usando datos reales y haciendo pruebas experimentales se han estimado resultados para los casos propuestos.

La fórmula de Van Rijn no ha resultado adecuada para estudiar el vaciado, pese a ello se ha estudiado la sensibilidad de dos parámetros de cara a la futura calibración de ésta. De cara al transporte en suspensión, la tasa de erosión utilizada no ha sido suficiente para limpiar completamente el carril mediante un único vaciado cosa que se sabe que dependiendo la cantidad de sedimento es posible limpiarlo de una sola vez.

Palabras Clave: tanque de retención, sistema de auto lavado, sistema de descarga, transporte de sedimentos, arrastre de fondo, transporte en suspensión, Iber.

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Luis Carlos Ruiloba Sáez

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1. INTRODUCTION

Water is an essential element for life, it is vital for the most life forms. In general water term refers to its liquid state although it also can be found in two more states such as gaseous (steam) and solid (ice).

From the physic point of view, water flows in a constantly closed cycle which has neither a start nor an end. As it is known in a scientific way, hydrologic cycle is a continued water exchange which is carried out between for elements: the atmosphere, superficial water, groundwater and organisms.

As it is mentioned before, water is changing its state and location from a part of the cycle to another by means of the following physical processes:

- Evaporation: Liquid water becomes gaseous water from the oceans and other surface masses of water to the atmosphere (even sometimes rainwater does not reach the ground).
- Transpiration: Kind of evaporation carried out over living beings (both animals and plants) to the atmosphere.
- Run off: The variety of ways by which water moves across the land to reach the oceans.
- Precipitation: Condensation (rainfall) or solidification (snow) from the water vapour that occurs when this vapour rises reaching lower temperatures where these processes could be produced.

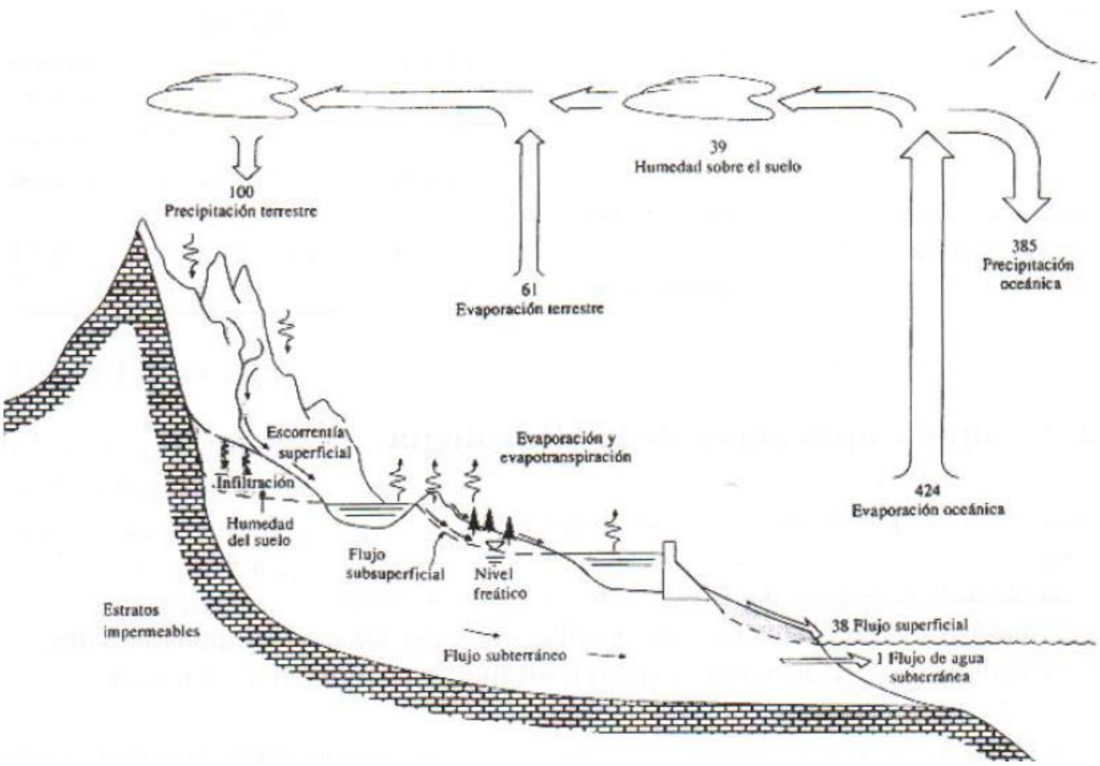


Figure 1. Hydrological Cycle

Facing to the current study research the most important point of the mentioned before is precipitation. In the civil engineer world precipitations are an elemental factor to confront initial sizing and the work life of several constructions. Determine the extreme maximum rainfalls is an essential step for the urban drainage to achieve the water volumes that could cause dangerous inundations.

Rainfall duration and its intensity are both characteristics which have to be known in these cases and also the *return period*[1] to carry out the initial sizing of the hydraulic structure in a proper way.

Other important factor to take into account is the increasing movement of the population unto huge cities and its peripherical areas. This movement involves a significant soil urbanisation and due to this city development, a decrease of green zones

[1] **Return Period**: It is the mean time between two equal or higher magnitude events. In numerical terms, return period is expressed as the probability that an event of a specific magnitude or higher will occurs in one year.

occurs while the concrete areas, bituminous road pavement and buildings zones are increased doing the soil more impervious than natural areas.

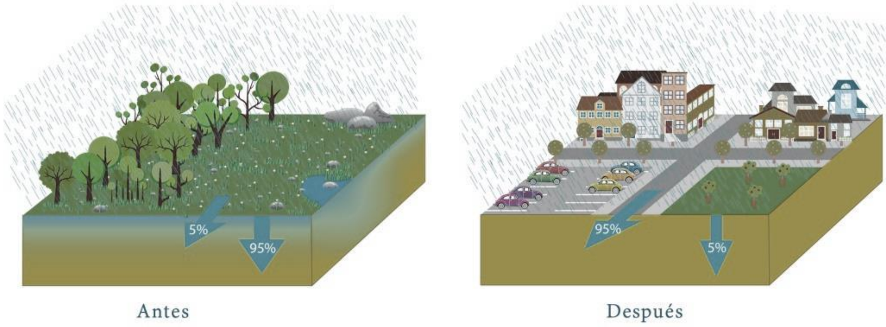


Figure 2. Urbanization example.

All these reasons change the mean conditions, which drainage networks have to deal to a new loads that have not been taking into account in the dimensioning step. The increase of the imperviousness is directly linked with the *runoff*[2] because there are more difficulties for the water infiltration in the soil and runoff increase making higher the volume of water in the drainage network causing further loads. At the same time, impervious rate is inversely proportional to roughness soil, hence if imperviousness rate increases water flows easily and faster due to the decrease of the soil roughness.

For all these reasons, peak discharges with higher values appears due to less infiltration and time to peaks (when the peak discharge is flowing or acting) are produced before previous estimations since water is flowing with higher velocities due to alterations in the terrain because of the urbanisation.

Taking into account all these phenomena that are linked, several cities are suffering flooding events which cause serious equipment or material damage, or worse, destroying human life.

It is particularly important to note that rainwater flows over the roofs and streets sweeping solid materials and a significant pollutant load in heavy metals, oils and hydrocarbons which are not to be spilled into rivers without a specific treatment and control.

[2] **Runoff**: Geological term in the hydrology that refers to water volume which is flowing over the drainage catchment surface.

One of the possible solutions to deal with all these events, are the retention tanks. In the current study a simulation of one retention tank lane, the retention tank "La Estrella" located in Badalona, is run using a mathematical 2D modelling software to study how is the hydraulic behaviour in this kind of structure and then a further study of sediment transport inside the lane to optimize the cleaning system using clean water in the storage chamber to realise a self-cleaning process.

Iber is a two-dimensional software for the simulation of free surface flow, morphodynamics and transport processes in rivers and estuaries, developed by the Water and Environmental Engineering Group, GEAMA (University of A Coruña) and the Flumen research Institute (Technical University of Catalonia, UPC, and International Centre for Numerical Methods in Engineering, CIMNE).

2. OBJECTIVES

The objective of the current study is to analyse the self-cleaning system of the retention tank in Badalona (Spain) due to the highly concentration of solids in order to guarantee the optimal operation of the storage chamber that is installed for each lane of the tank.

Firstly, using Leica ScanStation we get the exact geometrical data of the tanks without sediment. In a second field visit, after a significant rainfall event able to deposit a notable quantity of solids over the lane, using the same device to get the topography of the lane containing sediments and after one emptying of the storage chamber, scan again the first cleaning topography.

The second objective is to develop a 2D model by means of Iber software of the longest lane which correspond to the worst case regarding to clean the solids. This model will be used to study the hydrodynamic behaviour of one lane of La Estrella retention tank when it is completely clean.

Finally and as far as possible, the last objective is to calibrate a model using the collected data on the field visit and representing the real flushing event with Iber trying to fit as accurately as possible all the parameters in order to define in a proper way the sediment transport behaviour for this real case. If the required data is not available, by the model developed to study the hydrodynamic behaviour, several significant scenarios based on similar cases or studies will be presented in order to assess the effectiveness of the self-cleaning process in a retention tank.

A calibrated and validated model is a powerful tool to optimize the functionality of any infrastructure and it is also useful to deal with future problems in order to observe more detailed information due to the possibility to simulate several cases and analyse all of them and from the experiences, to take suitable decisions concerning dimensions of upstream chambers, width gates, slopes of tanks lanes, etc.

3. RETENTION TANKS

Figure 3. An example of a retention tank in the drainage networks in Tokyo.

3.1. Introduction

Retention tank is an element which is working in a sewer network whose function is to allow water to enter inside to hold this rainwater (reducing peak flow), especially when there are serious precipitation events with the aim of reducing the flooding possibility and beginning a pre-treatment of the water and at the same time, preventing the overflow of the first runoff, which is the most polluted due to water sweeps the roads, rooftops and any surface where is flowing, directly to natural systems.

This kind of structure is an alternative used to be built in public terrain (parks or playgrounds and sportive places) which means that building retention tanks only affect people who lives near the construction area and allows to have a shared use of the infrastructure. Retention tanks provide water regulation and lamination behaviour to supply water to the treatment plant in a way that could assume the water volume and at the same time, removing and retaining some of the suspended material.

3.2. Typologies

In order to build this kind of structures it is not only necessary to take into account its hydraulic behaviour whereas also the terrains availability to carry out a construction of this magnitudes. Two different typologies of retention tanks are known depending on the available place: on-line tanks and off-line tanks.

Any type of retention tank could be built with both configurations, sometimes both of them are combined (mixed retention tanks) with the goal of improving the conditions of the sewage system.

However, every kind of retention tank is able to achieve the objective of lamination of peak flow due to a rainfall episode. Moreover, in most cases the choice is usually decided by economic and urban considerations instead of the hydraulic behaviour of one typology or the other one.

3.2.1. On-line retention tanks

Online retention tanks or also kwon as serial retention tanks, are elements which are taking part of the integrated system. They are tanks with a large storage capacity and they begin to be filled when the discharge downstream reaches the limit condition. As tanks installed as a serial way, these tanks are located in specific points of the sewage network for the purpose of regulate the discharge.

Emptying discharge of these tanks is done by a downstream valve depending on the flow rate that we decide and always considering the downstream pipes and the entire network. Therefore, retention tank water level will be increased while water is entering and only part of this water leaves the tank.

The most significant factor in this type of tanks is that they require a large surface in extension to reduce the desired discharges and simultaneously this location place has to be inside the sewer network. Commonly, emptying of these retention tanks are carried out by gravity. Nevertheless, they could be emptied by a pumping system and in this case the extension surface needed will be minor due to the possibility to do a deeper excavation

With what it concerns to strong points of this kind of tanks, emphasize an easy design and the possibility of emptying by gravity in most of the cases are the most important advantages.

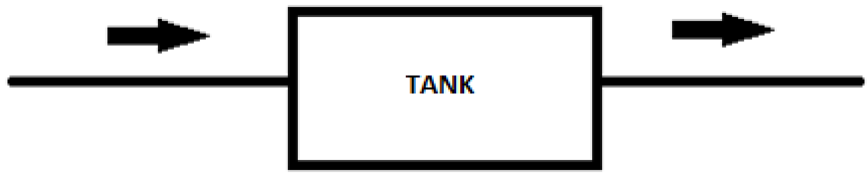


Figure 4. Sewer network scheme containing an online retention tank.

3.2.2. Off-line retention tanks

Offline retention tanks also known as parallel retention tanks due to physically they are located out of the drainage. Using systems like a lateral spillway or several gates, discharge excesses are diverted to the retention tanks to store inside themselves this water volume. As in the previous case, this water volume will be return to the drainage network in a regulated and controlled way taking into account the network capacity, which in many cases it will be a significant problem due to be emptied by gravity will be not possible and it forces us to empty the tank using pumping systems assuming an additional energy cost.

Therefore, the main advantage of this kind of infrastructures is the flexibility they offer talking in location terms. The main interest will be to provide them with a large storage volume and find a place where construction is physically possible. Taking into account all of these factors, when ground surface is limited this tank typology is the most used to solve the drainage network problems.

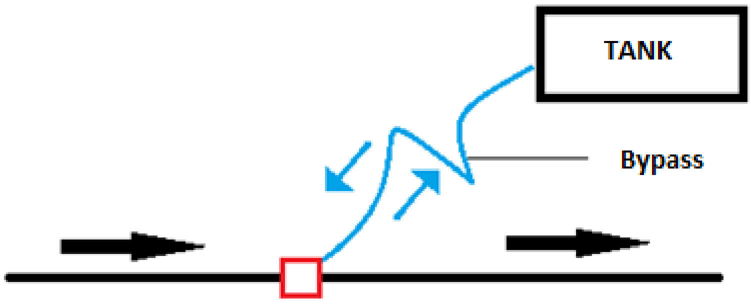


Figure 5. Sewer network scheme containing an offline retention tank.

3.2.3. Combined retention tanks

As the name of this type of retention tanks indicates, they are infrastructures that combine online tanks with offline tank connected in the same point of the sewage network.

It is possible that in some cases combination between both typologies is profitable to take advantage of the characteristics of each one and using combined tanks a major efficiency of the system could be achieved.

3.3. "La Estrella" retention tank from Badalona

In the current thesis study, "La Estrella" retention tank has been used to analyse the hydrodynamic behaviour and the sediment transport. This retention tanks belongs to "Rambla de Sant Joan / Sant Ignasi de Loiola" watershed. As it was mentioned, it is located in Badalona, in the neighbourhood of "Coll i Pujol" in the "Maragall" street corner with "Torrent de la Batllòria" street.

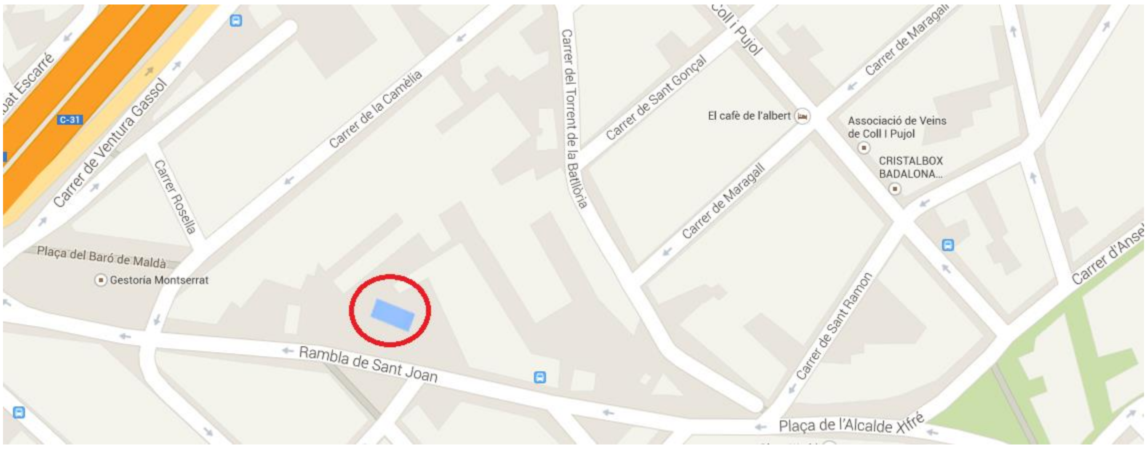


Figure 6. "La Estrella" retention tank location

The studied retention tank was designed in order to achieve two essential functions:

- Its retention volume has to be able to laminate the discharge in order to achieve a minimum exit discharge which is significantly reduced accordingly with the entry discharge. Hereby, retention tank is helping sewer network downstream due to the regulation of the discharge.

- The second one is an environmental function, retaining the highly polluted runoff from the city surface and to avoid the direct overflow to the Badalona beaches. Water is retained inside the tank while part of it is going out, in a controlled way, to the treatment plant. At the same time, pollution is decreased due to the sedimentation inside the tank.

The retention tank was built in a trapezoidal shape of 70 meters in length and 42 meters in width and its total useful height is 12.30 meters, hence its mean water level is around 9.55 meters and for all these factors the total storage volume of the retention tank reaches 20,800m^3. It contains 8 lanes with their respective storage chambers for the self-cleaning system. Each lane is around 5 meters (depending on the lane) width and their slopes are 1%. All the lanes end in a last one transversal lane which drives the water to a well where using a pumping system water could be extracted.

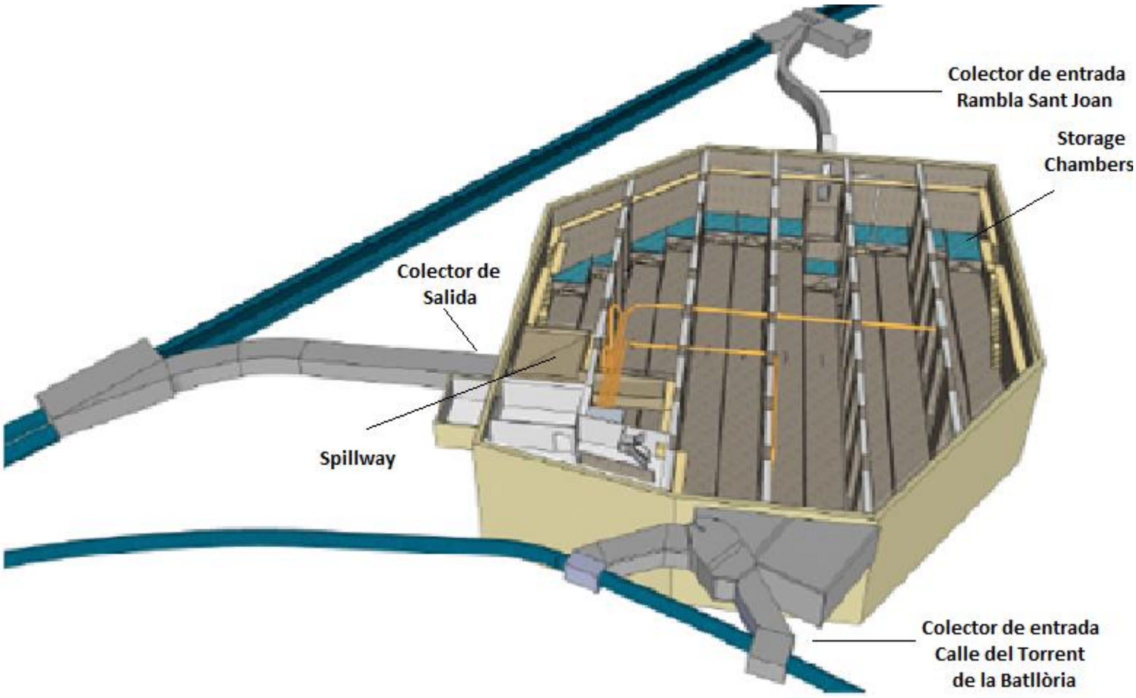


Figure 7. 3D overview of "La Estrella" retention tank

The tank also has a specific zone for a storage chamber which contains groundwater using a catchment method by a well (400 millimetres of diameter and 22 meters depth) equipped to extract the groundwater and store it in that specific chamber. This water is used to clean the roads near the retention tanks, irrigate a possible future park above the retention tank or it is also used for the self-cleaning process of the tank.

To carry out cleaning works of the retention tank manual and automatic systems have been installed:

- The manual system was projected by hoses of 25 meters in length which are using water from the storage chamber which contains the groundwater.
- The automatic system (study goal of the current thesis) consists in several storage chambers (8 exactly) located upstream of each lane where clean water volume is retained in these chambers and by opening suddenly the gate of the chamber, all the water flows over the lane. With the suddenly opening of the gate water starts to flow sweeping out all the sediments which are on the lane since the last rainfall event. The gate opening is defined by an oleo-hydraulic group which drives a key that opens the gate with the hydrostatic pressure of the water accumulated in the tank.

It should also be mentioned that the retention tank is controlled by a centralized device of control, supervision and monitoring. Hereby a regulated and integral coordination depending on the sensors operating conditions is allowed.

4. STATE OF THE ART

4.1. Self-Cleansing of Retention Tanks

4.1.1. Introduction

The most common problems in retention tanks are due to the accumulation of the sediments and the necessity to clean the tank lanes. Sediments in retention tanks lead to malfunctions in the operation of the structure. The goal of this study is to analyse the self-cleaning in retention tanks to deal with sediments in an optimal way and to avoid the manual cleaning in most of the raining episodes that nowadays is required.

Surprisingly, no study focusing on the design of the cleaning system of retention tanks, the effect of the volume and slope of the cleaning cell on the wave energy, the impact of the wave on the sediments, depending on their height, volume, composition was found… This observation underlines the need to investigate this specific field study in order to improve and optimize cleaning volumes together with cleaning system technologies (i.e. flushing gates velocity opening, closing systems…), being a key component of the good operation of retention tanks.

The information available in this field is given by self-cleaning suppliers. Due to the lack of studies there are no wide variety of information, however, in this section, some data is collected in order to understand more accurately the current study using some examples.

4.1.2. Suppliers Information

The company CSO Technik (Flushing Gates – Tank Cleaning System report, n.d.) proposes the vacuum column system for rectangular tanks. The design parameters suggested by the company are reported in the next table.

Parameters	Design Values
Slope	Between 0.5 – 2 %
Lane width (m)	Max 10
Wall height (m)	Min 0.5
Flushing chamber breadth (m)	Min 0.8

Table 1. Main tank design parameters according to the company CSO Technik

The specific volume of cleaning water per meter width of the tank depends on the tank length, and it could be calculated using the available abacus from the providers.

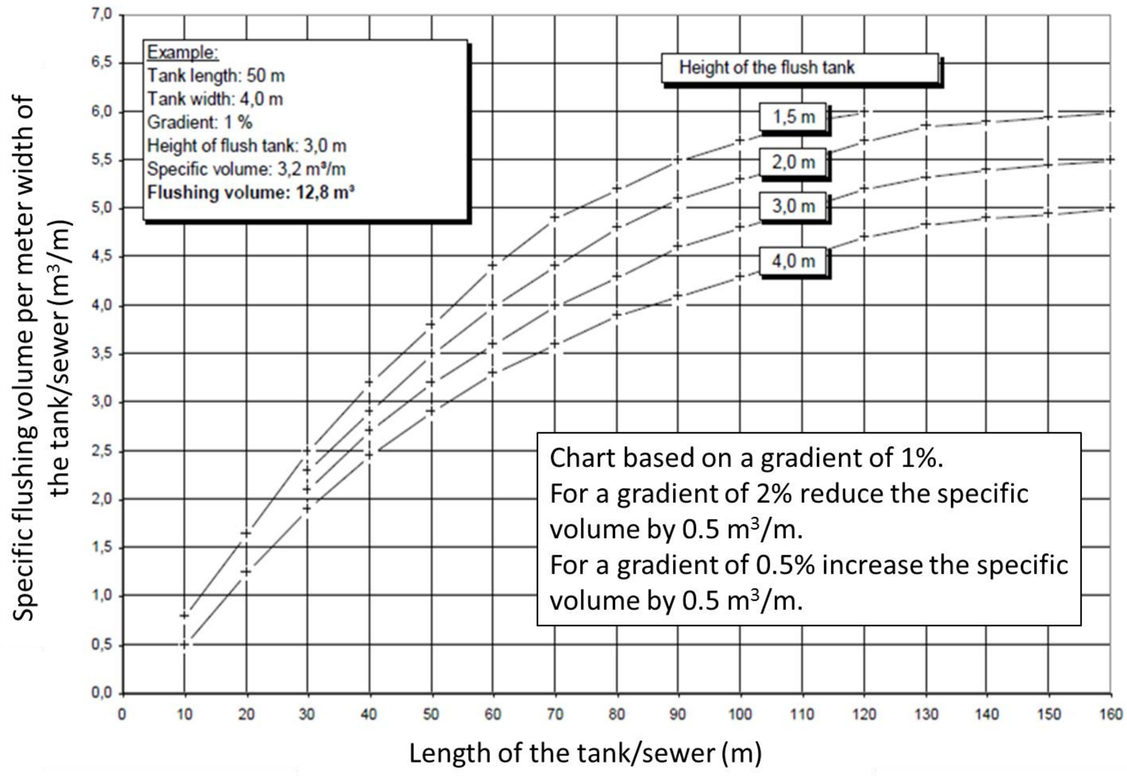


Figure 8. Cleaning water abacus for the vacuum column method in rectangular tanks.

In rectangular tanks the flushing gate method is more used than the last one, the same company proposes some recommendations for that method too. Depending on the tank width, the tank has to be separated in several lanes. An optimal design of the lane width is to be found according to the gate width. Each lane must be separated by a 0.4 meters height small wall. Depending on the lane width, they recommend you the corresponding width to use in the flushing gate.

4.1.3. Studies carry out by academic institutions

Two studies were madden in parallel in France and USA. In 1997 CERGRENE (French institute) and in 1998 the US Environmental Protection Agency (US EPA).

- *CERGRENE report*

They made studies of three different cleaning systems, tipping bucket system, flushing gate system and vacuum column system. The main conclusion was that vacuum column system are not recommended due to its limited water volume and the difficulties to make its column completely airtight.

In the following table are shown their conclusions between the three methods:

	Pros	Cons
Tipping buckets	1/ Light and stable construction made in stainless steel (around 500kg/bucket) 2/ Capacity 0,5 to 0,7 m^3/linear meter 3/ Well-known system 4/ Small sump	1/ Adapted to short length tanks (otherwise possibility to put many buckets in series) 2/ Minimum tank height required
Flushing gates	1/ Powerful system (big water volume) 2/ Simple civil engineering 3/ Low electrical energy consumption 4/ Raw water used (cleaning cells included in total storage volume) 5/ Well-known system	1/ A big sump volume needed
Vacuum column	1/ Raw water used (cleaning cells included in total storage volume)	1/ Airtightness failure risk 2/ A minimum stored water volume required for a correct operation 3/ Head loss problem when system triggered

Table 2. Pros and cons for each studied cleaning System provided by CERGRENE.

- *US EPA report*

In that study they work with various systems for off-line combined retention tank. They studied 11 retention tanks in operation through USA and Germany with either tipping buckets or flushing gates.

Main results show bad efficiencies in upstream section making these systems requiring a secondary cleaning system to perform a full sediment removal since sediments accumulate in dead zones. With the modelling study they provide design recommendations for tanks equipped with flushing gates or equipped with tipping buckets and also carried out a cost analysis which concludes that the flushing gate system is the most cost effective system for automatic cleaning system since it requires low maintenance and mechanical equipment:

Alternative	Capital Cost	Capital cost/m^2	O&M Cost/Event	O&M Cost/m^2
Manual	10,000$	2.91$	6,600$	1.92$
Flushing Spray	680,00$	197.67$	1,548$	0.45$
Tipping Flusher	525,000$	152.62$	378$	0.11$
Flushing Gate	350,000$	101.74$	250$	0.07$

Table 3. Alternatives capital and operation and maintenance cost assessment provided by US EPA Institution.

- *Other studies focus on sediments*

Due to the lack of studies of retention tanks, there are studies about the effect of the flushing wave on the sediment bed in sewers.

Bong et al. (2013) performed laboratory tests on a downscaled tipping flush gate in order to evaluate the number of flushes required to remove the sediment over the lane. The results are presented on the following figure:

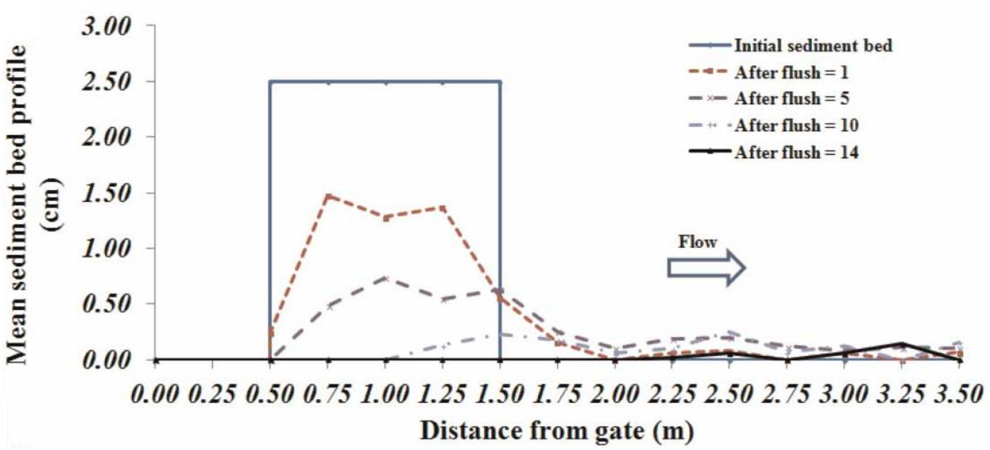


Figure 9. Results obtained by Bong et al. (2013). Evolution of the sediment bed regarding the number of flushes.

The flushing wave releases a volume of 0.1 m^3 while the initial sediment volume is 0.015 m^3 (non-cohesive sediment was used with d_{50} of 0.81 1.57 and 4.78 mm) and the main conclusion of that study is that generally the number of flushes to remove the sediment from the initial position increases by an average of 1.45 times as the sediment bed thickness doubled. In the following table the different examples are described:

Distance of initial sediment position from	Number of flushes required to totally remove the	
	For thickness of 25 mm	For thickness of 50 mm
0.5 m	13	17
1.0 m	11	18
1.5 m	12	17

Table 4. Relationship between the initial distances of the sediment bed from the gate with the number of flushes to totally remove the sediment for a distance of 1 m.

On the other hand, many studies were carried out to determine the flow velocity and bed shear stress impact on sediments. Pisano et al. (1998) summarized these studies highlighting the gap existing between experimental and theoretical studies:

- *Nalluri and Alvarez (1992), whose laboratory studies used synthetic cohesive sediments, concluded that there were two ranges of bed shear stress at which erosion occurred: 2,5N/m^2 applying for the weakest material, comprising a surface layer of fluid sediment: and 6 to 7 N/m^2 for the more granular and consolidated material below. It was found* *that, after erosion, the synthetic cohesive sediments behaved very much like non-cohesive material.*

- *Ristenpart and Uhl (1993) found in field tests that during dry weather an average bed shear stress of 0,7 N/m² was required to initiate erosion, increasing to an average of about 2,3 N/m² during wet weather, or to 3,3 N/m² after a prolonged period of dry weather and presumably, consolidation of the deposited bed.*
- *Ashley (1993) has suggested that the bonds between particles at the surface of a deposited bed are weakened by the presence of the water, so that surface layers can be successively stripped away by the flow. Measurements in the Dundee, Scotland sewers indicated that it began to move at a fluid shear stress of about 1 N/m², with significant erosion of a deposited bed occurring at bed shear of 2 to 3 N/m². Taking account of are view of work by other researchers, Ashley concluded that most deposits should be eroded at a shear stress exceeding 6 to 7 N/m².”*

4.1.4. Literature’s conclusions about cleaning systems

Therefore, there are some studies about sediment removal in sewers and few about retention tanks. More extensive studies should be carried out in order to achieve more accurate knowledge in this field and to optimize the automatic cleaning of retention tanks. Besides, there is no methodology or recommendation to form a consensus for retention tank design over the world so far.

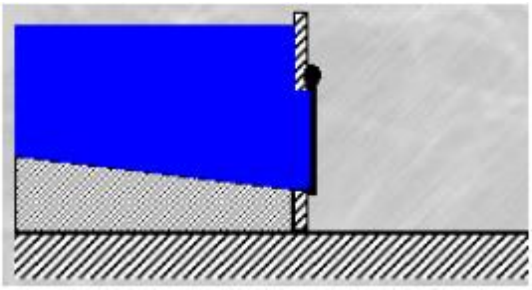
As it has been said in previous chapters, it was surprising to found a very poor literature on this topic. However, if some experience based abacuses from providers and some available literature on experimental and numerical studies were collected, these results still need further work to be transferred to retention tank cleaning system design.

4.1.5. “La Estrella’s” system

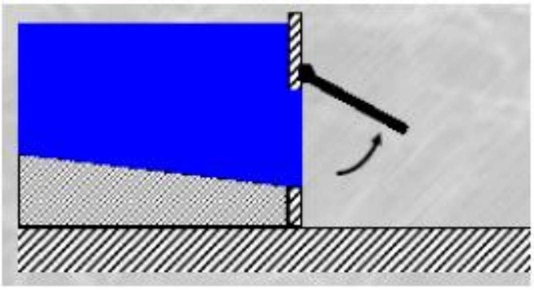
The retention tank of this study is using the flushing gate system to carry out the self-cleaning of the lane. For that reason, is important to explain with more detail this kind of method and understand in depth.

The system is based on the abrupt opening of the flushing gate to make a flushing wave, similar to a dam break. The flushing water retained in the storage chambers by the flushing gates flows out suddenly and moves with a powerful push force over the rails from the retention tank.

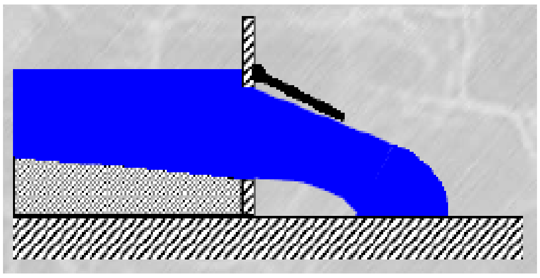
The system is simple, flushes storm water tanks and channels highly efficiently from a low level with the energy of the stored water. The storage chamber is located in the upstream area of the structure to flush clean water over the lane. At the beginning, the water is retained by the flushing gates until the process is initiated automatically or by hand. In the following figures, the processes is represented graphically:



Flush water is retained in one or several storage chambers.



The sudden opening of a flushing gate initiates the flushing process.



A powerful flushing wave is produced (similar to a dam break)

Figure 10. Illustration about the flushing gate system in the self-cleaning procedure.

Finally, due to the turbulent shock wave, high shear stresses are generated, that guarantees the removal of sediments from the tank and channel bed. The large flush water volume ensures that the dirt is reliably transported to the outlet.

4.2. Two-dimensional Saint-Venant Equations

4.2.1. Introduction

In order to study and analyse the fluid movement a set of equations, mass and momentum conservation, is used. This set are non-lineal partial differential equations which are known as Reynolds Averaged Navier-Stokes equations (RANS). Based on the mass conservation and equilibrium of forces principles applied to a fluid volume and by certain considerations on the mathematical development, the well known formulation used for solving problems in fluid mechanics is reached.

There is no a general solution for these kind of equations. Moreover, just in specific fluid types and precise situations exists an analytic solution, on the other cases, which are the majority of cases, a numerical analysis are required to approach the solution.

4.2.2. Mathematical Formulation

Two-dimensional Saint-Venant equations also kwon as 2D Shallow Water Equations (2D-SWE) are used to define as accurately as possible the real behaviour of the fluid inside a retention tank.

2D Saint-Venant equations are obtained based on the physical conservation of mass and the momentum laws. From these equations, particularising to a *Newtonian*[3]and *isotropic*[4] fluid the Navier-Stokes equations are reached (as it was mentioned). Particularising even more, to describe the average variables in a small time increment considering the turbulent fluctuation, these equations are specified in the Reynolds equations.

Moreover, fluid flows inside a retention tank is changing accordingly on time and for this reason the analysis has to be as an unsteady flow. At the same time, following hypothesis could be considered:

[3] **Newtonian Fluid**: is a fluid in which the viscous stresses arising from its flow could be linear with velocity gradient. Water is an example as opposed to glue, honey and blood.
[4] **Isotropic Fluid**: A fluid whose properties are not dependent on the direction along which they are measured.

- Horizontal dimensions predominate over the vertical one which is the same as the water depth has really low values over the other dimensions that are considerate in the problem.
- Hydrostatic distribution of pressures over the vertical axis.
- Reduced slope of the lane

These three hypothesis are highly related to each other and if we take them into account implies that velocity and acceleration components in z axis are negligible compared with the other axes components.

Based on the Navier-Stokes equations Reynolds equations are deducted whose resolution requires to a three-dimensional discretization in the study domain. Due to the characteristics of the fluid behaviour inside the retention tank (mentioned on the last paragraph) based on the Reynolds equations and integrating it the vertical dimension is negligible reaching an equations set in a two-dimensional way which is the most predominant and it is shown in the following equations:

$$\frac{\partial z}{\partial t}+\frac{\partial(hu_1)}{\partial x_1}+\frac{\partial(hu_2)}{\partial x_2}=0 \quad (1)$$

$$\frac{\partial}{\partial t}(hu_1)+\frac{\partial}{\partial x_1}(hu_1^2)+\frac{\partial}{\partial x_2}(hu_1u_2) = -gh\frac{\partial}{\partial x_1}(h+z_0)-\frac{\tau_{0x_1}+\tau_{sx_1}}{\rho}+fhu_2+\frac{1}{\rho}\frac{\partial}{\partial x_1}\left(hT_{x_1x_1}\right)+\frac{1}{\rho}\frac{\partial}{\partial x_2}\left(hT_{x_1x_2}\right) \quad (2)$$

$$\frac{\partial}{\partial t}(hu_2)+\frac{\partial}{\partial x_1}(hu_1u_2)+\frac{\partial}{\partial x_2}(hu_2^2) = -gh\frac{\partial}{\partial x_2}(h+z_0)-\frac{\tau_{0x_2}+\tau_{sx_2}}{\rho}+fhu_1+\frac{1}{\rho}\frac{\partial}{\partial x_1}\left(hT_{x_1x_2}\right)+\frac{1}{\rho}\frac{\partial}{\partial x_2}\left(hT_{x_2x_2}\right) \quad (3)$$

Where:

u_1 y u_2: velocity components integrated with depth.

x_1 y x_2: studied plain directions.

τ_0 y τ_s: second order stresses tensor between bed friction and superficial friction respectively.

f: Coriolis coefficient to take into account the Earth rotation.

z: vertical axis

h: water depth

T_{xixj}: component refers to energy dissipation stresses.

As it has been shown, the Saint-Venant equations are a non-linear hyperbolic system of differential equations in partial derivatives, which means that a numerical methods as an approximation solution tool are required due to just in really few cases the analytic solution could be achieved.

4.2.3. Saint-Venant Equations Terms

- Local acceleration:

$$\frac{\partial u_1}{\partial t} \ \& \ \frac{\partial u_2}{\partial t} \tag{4}$$

These terms represent the variation in time in a fixed point. With them the unsteady behaviour of the flux could be studied.

- Convective acceleration:

$$u_1\frac{\partial u_1}{\partial x_1}, u_1\frac{\partial u_2}{\partial x_1}, u_2\frac{\partial u_1}{\partial x_2} \ \& \ u_2\frac{\partial u_2}{\partial x_2} \tag{5}$$

These terms represent the transport with the flux as velocity gradient. Due to these factors vortices appear and they are more significant when Reynolds number is higher (because of they depend on the inertial and viscosity forces).

It is important to emphasise, from mathematical point of view when there are high values of velocity or low viscosity, these terms are the main cause of the non-linearity of the equations.

Total acceleration of the water particles is the sum of the local acceleration and the convective one.

- Bed slope:

$$\frac{\partial}{\partial x_1}(h + z_0) \tag{6}$$

This factor appears on the equations multiplied by gravity constant, which means that is representing the gravity forces. This term arises of applying the hypothesis of hydrostatic pressure in Reynolds's equations.

It is also possible to express this term as the sum between bed slope and depth gradient. In this way, bed slope just depends on the geometry of the problem that is known. The no homogeneity of the equations is due to this term and at the same time it increases the complexity of the numerical schemes applied on the resolution.

- Bed stresses and superficial stresses:

These terms refer to bed water friction ($^{\tau_0}/_{\rho h}$) and they causes in a non-lineal way a delay of the flow. Manny times in several models the turbulence is not considering and using the Manning formula the bed stresses could be approximated.

Supposing the hydraulic radius equal to the depth the expression $\tau_0 = \rho g h S_f$ (Caudhry 1993) is obtained where S_f is the slope used in the Manning formula:

$$S_{fx_1} = \frac{u_1\sqrt{u_1^2 + u_2^2}n^2}{h^{4/3}}, S_{fx_2} = \frac{u_2\sqrt{u_1^2 + u_2^2}n^2}{h^{4/3}} \tag{7}$$

Where n is the roughness Manning coefficient.

On the other hand, superficial friction τ_s could be an essential factor in a huge extensions with extremely wind velocities. There are several proposes to evaluate that term.

- Energy dissipation stresses:

These stresses included in the hydrodynamic equations describe the effects of the viscous stresses, of the turbulent stresses and the dispersion terms due to the non-homogeneity of the depth velocity profile.

Turbulent component is highly important in turbulent flows developed where the turbulence is more significant than the laminar viscosity stresses. In a flux gradually varied the turbulence component is usually negligible due to the bed stresses are highly significant.

4.3. Iber

4.3.1. Introduction

Iber is a numerical model for simulating turbulent free surface unsteady flow and environmental processes in river hydraulics. The ranges of application of Iber cover river hydrodynamics, dam-break simulation, flood zones evaluation, sediment transport calculation and wave flow in estuaries. (Hydraulic Reference Manual Iber)

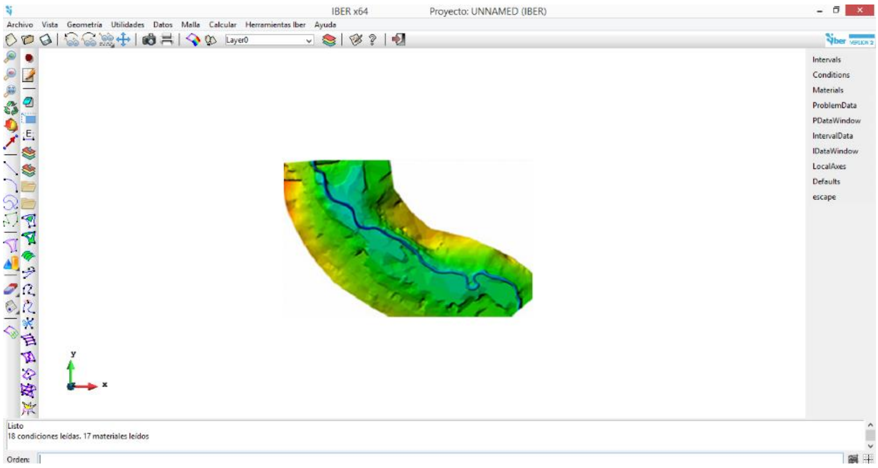


Figure 11. Iber's Interface

At this moment Iber works with 3 main computational modules, a hydrodynamic module, a turbulence module (not used in the present essay) and a sediment transport module.

These modules work using a finite volume non-structured mesh made by triangular or quadrilateral elements where the equations will be solved in their integral and conservative form.

The following chapters describes how Iber works in the hydrodynamic module (which constitutes the base of Iber), where the depth averaged two-dimensional shallow water equations are solved (2D Saint-Venant Equations), and on the sediment transport module The bedload and the turbulent suspended load transport equations are solved based on the sediment mass balance evolution at the bed load.

4.3.2. Hydrodynamic Module

4.3.2.1. Introduction

In that module the Shallow Water Equations (2D-SWE), also known as the two-dimensional Saint-Venant Equations are solved. Hydrostatic pressure distribution and relatively uniform distribution of the depth velocity are assumed in these equations. As it was explained in last chapter, the three-dimensional component is neglected due to its low effect in these kinds of problems. Nowadays, numerical models using 2D Shallow Water Equations are the most used in coastal and river dynamics studies, flood zones evaluation and sediment and contamination transport calculations.

The equations have been presented in the Saint-Venant's chapter where each has been explained.

4.3.2.2. Boundary Conditions

Along the equations, to solve a two-dimensional problem boundary conditions are required. Two types of boundaries are distinguished: open and closed, the latter, also called wall-type boundaries, are water-resistant, meaning that they don't allow water though them.

Closed boundary generates a lateral friction force in the fluid in a similar way than the friction due to bed's toughness. At a closed boundary two conditions can be used in Iber.

On one hand, slip condition (null tangential stress). That condition is equivalent to undermining the friction stress generated by the wall over the fluid. When the lateral boundaries is much lower than the surface contact with the bed huge separation between horizontal and vertical scales are produced and the friction forces in the wall boundaries can be undermined. Hydraulic engineering and especially river engineering are examples of problems were the slip condition is used.

On the other hand, where the horizontal and vertical dimension are similar (narrow section channels) this toughness force can have some importance in the flow development, even though in most of the cases the influence is really small. In the problems that lateral friction wanted to be considered, Iber allows (imposing a tangential force in the opposite flow's direction) to introduce the wall friction condition (wall functions) where Iber distinguishes between smooth turbulent regime and tough turbulent regime in function of the wall's roughness and the flow velocity close to the wall.

The second boundary condition required are open boundaries. To determinate correctly the 2D-SWE equations from a mathematical point of view, the number of conditions to use in open boundaries will depend if the boundary is an inlet or an outlet, and also depends on the type of regime at the boundary (fast/slow). In the following table the boundary conditions required are shown:

Boundary		Regime	Boundary Conditions
Inlet	Discharge	Subcritical/Critical	Total discharge in normal direction to the boundary
		Supercritical	Total discharge in normal direction to the boundary
	Unit discharge	Subcritical/Critical	Specific discharge in normal direction to the boundary
		Supercritical	a)Specific discharge in normal direction to the
			b)Specific discharge in normal direction to the
Outlet	Subcritical		a)Water depth
			b)Water surface elevation
			c)Weir (elevation and discharge coefficient)
			d)Rating curve
	Supercritical/Critical		Not necessary to introduce any condition

Table 5. Iber Contour Conditions implemented in open contours.

If fewer conditions than those necessaries are introduced from a mathematical point of view the equations will be undetermined and no correct solution will be found.

4.3.2.3. Internal Boundary Conditions

The internal conditions are used to define hydraulic structures like gates, weirs or bridges which change the conditions of the system. Using that conditions the following cases can be modelled to represents the reality:

- Flow below a gate
- Flow over a free falling weir
- Weir-Gate combination
- Local loss

In this study, to represents the suddenly opening of the storage chambers the flow bellow a gate has been used. The equation used is the gate drainage, which works on free or submerged flow. The discharge coefficient, the gate's bed level, the gate opening and its width are the data required by Iber.

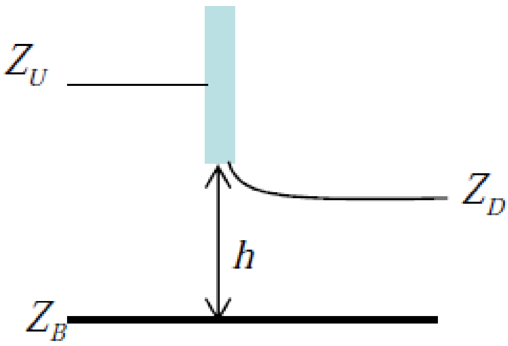


Figure 12. Scheme and equations of the gate internal contour condition

	$(Z_D-Z_B)/(Z_U-Z_B)$	Discharge Equations
Free Flow	0.00-0.067	$Q = C_d B h\sqrt{2g(Z_U - Z_B)}$
Transition	0.67-0.80	$Q = C_d B h\sqrt{6g(Z_U - Z_D)}$
Submerged Flow	0.80-1.00	$Q = C_d B h\sqrt{2g(Z_U - Z_D)}$

Table 6. Gate drainage equations depending on the situation

4.3.2.4. Others

In this module, Iber also can simulate infiltration (with methods like Green-Ampt, Horton or Linear method) to do more accurate simulation for the rainfall processes. Likewise, Iber can consider the initial abstraction.

4.3.3. Sediment Transport Module

In this module the non-cohesive sediment non-stationary transport equations are solved. Bed-load transport equations and suspended-load sediment transport equations can be solved separately or at the same time. The sediment transport module uses the velocity, depth and turbulence fields from the hydrodynamic and turbulence modules (in case of use last one). The bed-load is calculated using an empirical formula, chosen from the Meyer-Peter Muller or the Van Rijn Methods. The suspended load transport is modeled from depth averaged turbulent transport equation.

The bed level variation is calculated with the Exner sediment conservation equation:

$$(1-p)\frac{\partial Z_b}{\partial t}+\frac{\partial q_{sb,x}}{\partial x}+\frac{\partial q_{sb,y}}{\partial y}=D-E \tag{9}$$

Where,

p: is the porosity of the sediment that forms the bed layer

∂Z_b: is the bed level

$\partial q_{sb,x}$ and $\partial q_{sb,y}$ are the two solid flow components

D-E: is the balance between the bed-load and suspended load

4.3.3.1. Bed Transport

The total bed-load stress is generated by the grain's roughness (which is proportional to the sediment diameter) and the shape of the bed layer. The grain stress is the factor that Iber estimates to know how it is contributing in the bed-load movements. Iber uses the Einstein formula:

$$\tau_{bs}^{*} = \tau_{b}^{*}\left(\frac{n_s}{n}\right)^{1.5} \quad (10)$$

$$n_s \approx \frac{K_{s(m)}^{1/6}}{25} \quad (11)$$

$$\tau_{bs}^{*} = \frac{\tau_{bs}}{(\rho_s - \rho)gD_s} \quad (12)$$

$$\tau_{b}^{*} = \frac{\tau_{b}}{(\rho_s - \rho)gD_s} \quad (13)$$

Where,

n is the total Manning coefficient

n_s is the equivalent Manning coefficient doe to the gran

D_s the sediment's diameter

K_s the grain's toughness's height (measured from the grain's diameter)

τ_b is the bed total stress

τ_{bs} is the bed stress because of the grain

$\tau_{bs}^{*}\ and\ \tau_{b}^{*}$ are dimensionless total and grain stress

$\rho_s and \rho$ are the solid density and water density

Iber uses a value of K_s=2.5D_s that value usually is between 2 and 3 times D_s.

To get the bed transport solution the bed-load discharge has been calculated too. Iber uses empirical formulas.

- Meyer-Peter Müller (Meyer-Peter & Muller, 1948)

$$q_{sb}^{*} = 8(\tau_{bs}^{*} - \tau_{c}^{*})^{3/2} \quad (14)$$

Where dimensionless discharge is calculated as:

$$q_{sb}^{*} = \frac{q_{sb}}{\sqrt{\left(\frac{\rho_s}{\rho} - 1\right) g D_s^3}} \tag{15}$$

In the case of flat beds, a dimensional critical bed stress is considered of $\tau_c^* = 0.047$. On the contrary, Iber makes a bed slope correction.

- Van Rijn (Van Rijn, L.C., 1984)

According to Van Rijn the bed-load discharge is calculated by the following expressions:

$$T < 0.3 \rightarrow \ q_{sb}^{*} = 0.053 \frac{T^{2.1}}{D_*^{0.3}} \tag{16}$$

$$T > 0.3 \rightarrow \ q_{sb}^{*} = 0.100 \frac{T^{1.5}}{D_*^{0.3}} \tag{17}$$

Where T is a dimensionless parameter that measures the excess of bed friction above a critical value which defines the movement threshold.

$$T = \frac{\tau_{bs}^* - \tau_c^*}{\tau_c^*} \tag{18}$$

The dimensionless diameter is defined as:

$$D_* = D_s \left(\frac{gR}{v^2}\right)^{1/3} \rightarrow R = \frac{\gamma_s - \gamma}{\gamma} \tag{19}$$

Iber automatically corrects the equations including the effects of gravity whenever the bed is not flat. The correcting factor is applied over the critical stress of movement threshold, as detailed by Apsley and Stansby (2008), where they present and generalize the works of many other authors, citing at least (Dey, 2003) and (Wu, 2004).

Iber also applies an avalanche sliding model to avoid those slopes higher than the bed material's friction angle and allows to define a non-erodible layer like a rock layer below which the bed erosion cannot go further.

4.3.3.2. 2D Turbulent Suspended Load Module

To model the suspended load, Iber uses a depth-averaged equation and the velocity, depth and turbulence fields calculated in the hydrodynamic and turbulence modules. The depth-averaged equation is shown below:

$$\frac{\partial hC}{\partial t}+\frac{\partial hU_xC}{\partial x}+\frac{\partial gU_yC}{\partial y}=\frac{\partial}{\partial x_j}\left(\left(\Gamma+\frac{v_t}{S_{c,t}}\right)h\frac{\partial C}{\partial x_j}\right)+\frac{\partial D_{sx}}{\partial x}+\frac{\partial D_{sy}}{\partial y}+(E-D) \tag{20}$$

Where,

C is the depth-averaged concentration of suspended solids

U_x and U_y are the horizontal depth-averaged velocity components

v_t is the turbulent viscosity

Γ is the molecular diffusion coefficient for suspended solids

$S_{c,t}$ is the Schmidt number, which relates the moment turbulent diffusion coefficient with the suspended turbulent diffusion coefficient

D_{sx} and D_{sy} model the suspended sediment dispersion due to the non-homogeneous vertical velocity profile sediment concentration.

E and D respectively model those bed-load grains which become suspended (entrainment) and deposition of suspended sediments to the bed layer. That difference represents a balance, and thus a coupling of the bed-load and suspended load.

To calculate the Entrainment/Deposition (E-D) term, three formulas are implemented in Iber. These three formulas are especially recommended in the latest ASCE Manual of Sediment Transport, among them, the most widely used is the Van Rijn Formula and is explained below.

$$E-D=W_s(c_a^*-c_a)=\alpha W_s(C^*-C) \tag{21}$$

Where,

α is a coefficient that relates the mean suspended particle concentration and the river bed-load concentration, which value comes from the Rouse profile for the depth sediment concentration distribution

W_s is the sediment grain velocity

C is the depth-averaged suspended load concentration

C^* is the depth-averaged suspended load concentration at equilibrium condition (suspended load transport capacity)

$c_a^* \; and \; c_a$ are respectively the instantaneous concentration and the equilibrium concentration at a height z=a above the river's bed layer in which the transport is produced (theoretical separation limit between the bed-load and suspended load). Van Rijn proposed the following equilibrium concentration:

$$c_a^* = 0.015 \frac{D_{50} T^{1.5}}{a D_*^{0.3}} \tag{22}$$

Where

$$a = k_s \quad \rightarrow \quad k_s = 3D_s \quad \rightarrow \quad D_* = D \left(\frac{gR}{\upsilon^2}\right)^{1/3} \tag{23}$$

For cohesive soils the formula proposed by Ariathurai and Arulanandan (Ariathurai & Arulanandan, 1978) is used, in it the erosion depends on the difference between the tangential stress and the critical tangential stress to start the erosion τ_{ce}, it is also dependant of a value M representative of the erosion rate (equivalent to an erosion rate when $\tau_b = 2 \cdot \tau_{ce}$):

$$E = M \left(\frac{\tau_b}{\tau_{ce}} - 1\right) \tag{24}$$

Sedimentation velocity is also calculated based on its diameter (Van Rijn, 1987):

$$W_s = \frac{RgD_{50}^2}{18v} \rightarrow D_{50} < 10^{-4}m \tag{25}$$

$$W_s = \frac{10v}{D_{50}}\left(\sqrt{1 + 0.01D_*^3 - 1}\right) \rightarrow 10^{-4}m < D_{50} < 10^{-3}m \tag{26}$$

$$W_s = 1.1\sqrt{RgD_{50}} \rightarrow 10^{-3}m < D_{50} \tag{27}$$

5. MODELLING OF SELF-CLEANING PROCESS OF THE LANE BY IBER

5.1. Introduction

The main goal of this chapter is to create a model of the reality. Here, the engineering skills are required to represent in the best way the real retention tank. Therefore, take care of each input data is very important to achieve more accuracy on the final results and thus make them more useful for a future.

First of all, a hydrodynamic module is run to study how the retention tank is working without sediment on the lane, completely cleaned. Thereby, several ideas could be obtained studying the maximum velocity and its areas, how many time emptying takes, if there is recirculation or not and if there is it in which areas, and also observing the bed shear stress we could deduct in broad terms the sediment transport behaviour. Likewise, a general idea about how hydrodynamic works in a lane of a retention tank will be obtained in this section.

Thereupon, the sediment transport module will be added to the first model and depending on the characteristic of the retention tank “La Estrella” and the data collected upon its sediment some cases have been presented and studied to determine how the self-cleaning systems works in this specifically retention tank and extrapolate the results to other retention tanks that share similar properties to improve the systems of other deposits or even to do previous studies to future retention tanks and optimize its cleaning systems.

Taking into account Iber’s structure, the following sections have been organized regarding to pre-process (where the input data is introduced to create the model) and post-process (where the results can be studied after the process time that Iber needs to solve all the equations explained in last chapters).

La Estrella retention tank has several lanes, to create a model the longest lane with its storage chamber has been chosen for this study. Studying the longest lane we can know how is working the self-cleaning system in the worst case and extrapolate the results to the shortest lanes.

5.2. Field Measurements

Figure 13. La Estrella retention tank. First visit.

The procedure to study the self-cleaning retention tank in a proper way is getting real the real data of the sediment to determine its mean characteristics. On the other way, a minimum of two visits to the La Estrella retention tank were thought.

In the first visit, in order to get the maximum precision, La Estrella retention tank was measured using a Scan Station from Leica Geosystems company. The specific model has been Leica ScanStation P40 which is able to capture a 3D geometry of civil infrastructure generating a complete scanning solution processed in a point cloud data. It is able to up in its memory of 256 GB 1,000,000 points per second and its field of view in the horizontal plane is 360º and in the vertical plane is 270º.

Figure 14. Setting the Leica ScanStation P40 inside La Estrella retention tank

Using this powerful device more accurate and complete data is achieved in order to define the geometry data and the sediment for a one rainfall episode, better quality and higher level of detail of the infrastructure and easier way to manage the data using Geographic Information Systems (GIS) before to import in Iber Software.

The points scanning was made from two different areas (beginning and top of the lanes) to obtain more accurate topography. Some targets at strategic points of the retention tank were used as a references in order to generate further scans using the same references in the second visit.

The second visit to La Estrella detention tank could not be done due to there were not significant rainfall episodes to deposit substantial amount of sediments inside the tank.

Figure 15. Inside of the tank. First visit.

The idea of this last visit was to scan again all the studied lane containing significant amount of material over itself and take a moisture to analyse the characteristics of the sediment. Thereupon, filling the storage chamber using clean water an emptying process of the tank would be done in order to scan again all the lane to achieve the data which represents how the self-cleaning process acts with that specific quantity of sediment.

Therefore, the goal using these data was to calibrate a model based on a real case and using very accurate data. With the sediment data obtained at first in the second visit the real amount and distribution of material could be represented on the lane in order to calibrate using Iber parameters to reach the second scan of the second visit (after the self-cleaning process).

As already was mentioned, due to the lack of a significant rainfall episode several scenarios are studied in the next chapters in order to study the self-cleaning process and in a future when the data is available the current study will be improved with the real data to obtain a model which could be useful in the future operation and functionality of the tank.

5.3. Hydrodynamic Results

5.3.1. Problem Definition

As has been mentioned, some previous steps and the input data are necessary to define the model before to beginning with the process time to solve the Saint-Venant Equations. Starting with geometry, followed by defining boundary and initial conditions and ending up with the definition data about the problem.

5.3.1.1. Geometry Data

Using the tank layout drawings about “La Estrella” retention tank the geometry could be define in Iber. The length of the lane is 55.02 meters and its width is 4.80 meters, the slope of the lane is 1%.

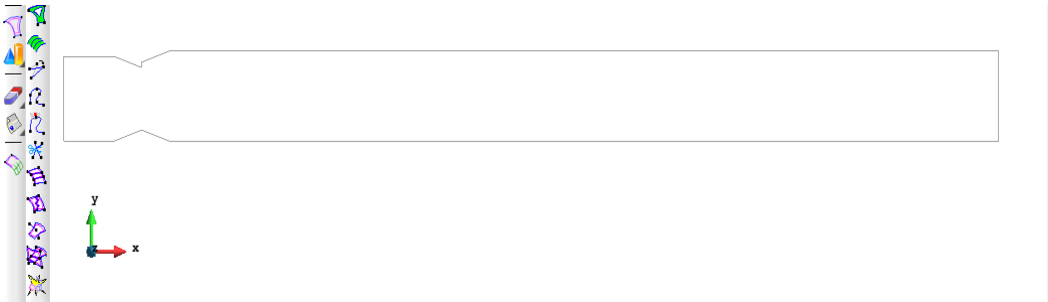


Figure 16. Retention tank’s geometry

As is shown on the last figure, the storage chamber is not symmetric, hence the lane is not symmetric either taking into account the gate of the storage chamber. For that reason the expected hydrodynamic movement along the lane will be not symmetric, which is unusual in this kind of structures. In the next figure gate measures are shown:

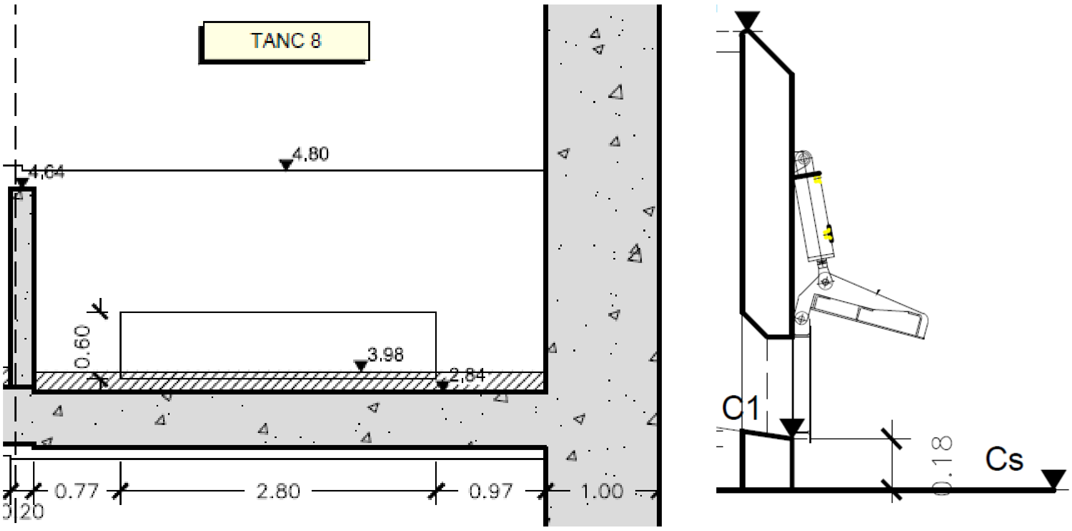


Figure 17. Gate measures

Another important factor to consider for making the geometry is that Iber cannot contain two points with same (x,y) coordinates. To ensure the proper closing of the gate in the storage chamber there is 18 centimetres to avoid the contact between the gate and the lane. To represent this step, the hypothesis that has been taken is to draw this point one centimetre further than its real position. The following figure shows the step and also shows that the storage chamber contains two different slopes being the latter much steeper.

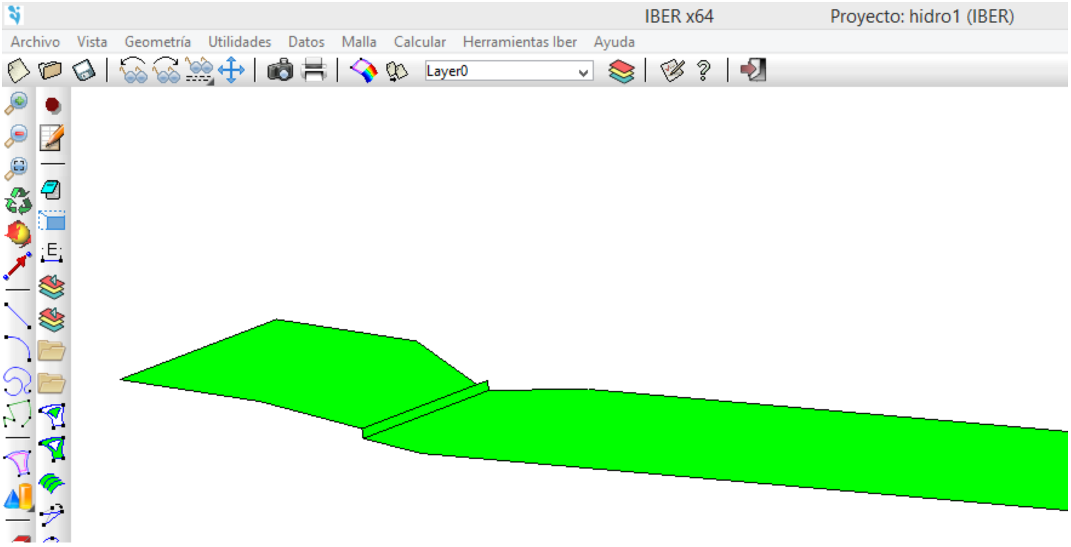


Figure 18. Step in the storage chamber gate.

Once all the geometry is properly introduced, Iber requires a surfaces definition in order to create later a mesh for whole model. To create the surfaces (NURBS Surfaces called in Iber) a closed polygon has to be drawn. In that case, three surfaces are defined: one on the storage chamber, one on the step in front of the gate and the last one on the lane.

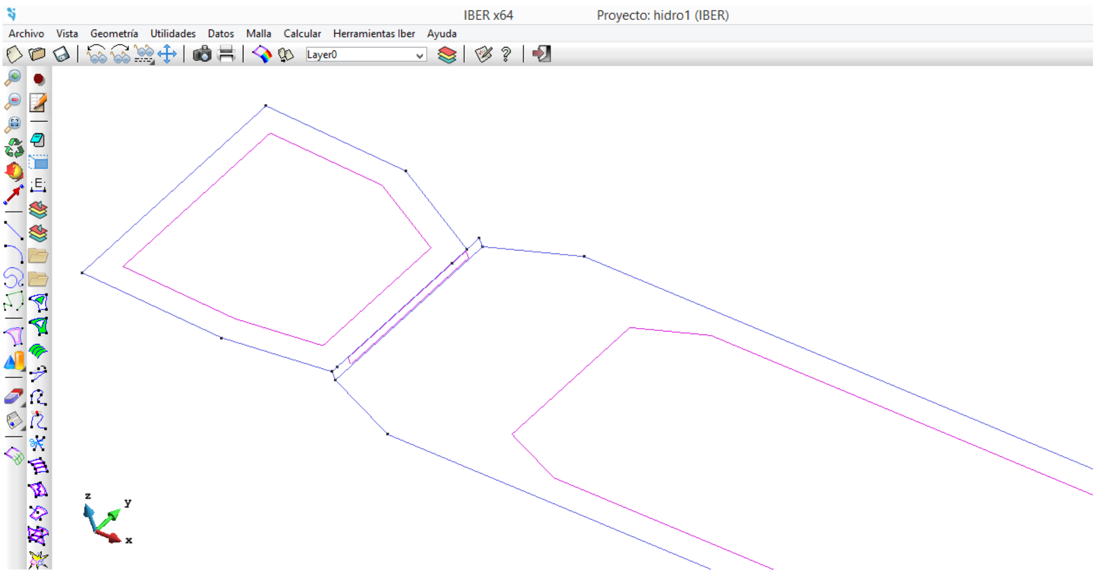


Figure 19. Three surfaces defined on the retention tank.

5.3.1.2. Hydrodynamic Conditions

Iber allows to introduce the hydrodynamic conditions in the geometry or in the mesh. In this study the geometry is fixed and depending on the case is interesting to change the mesh, for this reason to introduce the conditions over the geometry has been chosen.

First of all, initial conditions have to be introduced over all the domain (each surface), in the storage chamber's surface the elevation of the water is the initial condition and the other two surfaces there are not water on the beginning. In this way, on the initial step of the simulation there will be no water on the lane, all the water is retained in the storage chamber waiting the gate opening.

The next step is to decide the boundary conditions, there is no inlet condition due to we are doing the study of the self-cleaning behaviour in a retention tank, therefore, there is not water inlet in the system during all the process, all water is inside the system since the first moment as we have defined using the initial conditions. At the end of the lane, an outlet supercritical/critical condition is assigned to indicate the exit boundary in the system.

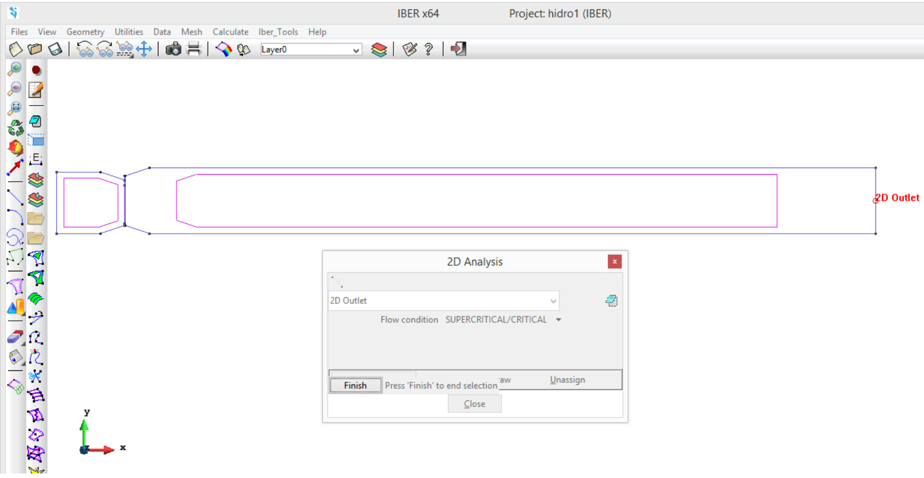


Figure 20. Outlet boundary condition

As it was explained in the state of the art chapter, internal conditions are required to define as accurately as possible the behaviour of the gate. The parameters to define the gate are shown in the next figure:

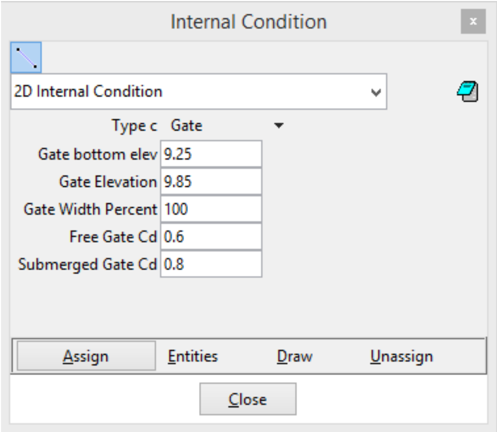


Figure 21. Internal condition parameters

Finally, the roughness has to be defined to each surface. The storage chamber and the lane are built using concrete, 0.015 Manning's coefficient has been adjudicated accordingly with the tank material.

5.3.1.3. Mesh

The quality of the mesh calculation is an essential element for success. Iber has many ways to get a good mesh calculation, depending on the characteristics of the problem a type of mesh is better than another. Iber can work both with triangular elements as quadrilaterals, or mixed mesh of triangles and quadrilaterals.

To generate structured meshes Iber needs quadrilateral surfaces. In this case the storage chamber and the lane both are not quadrilateral and not structure mesh has been generated en each surface trying to get inside the step surface (transition zone between the storage chamber and the lane) the most structured mesh, taking into account that this zone is a very small area sensitive to generate weird mesh elements which can lead to errors or inconsistencies. In the picture below, how it has attempted to obtain the most structured transition is shown:

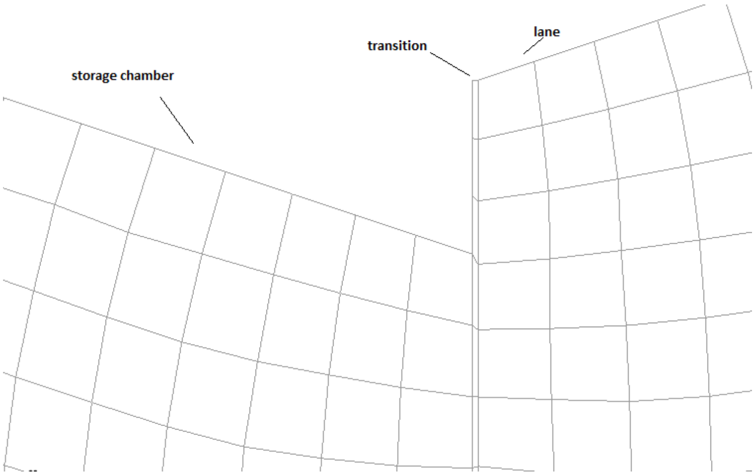


Figure 22. Mesh detail in transition zone

In the hydrodynamic study, a mesh with 14,874 quadrilateral elements has been used.

5.3.1.4. Problem Data

This is the previous step before run the simulation, several options are available using Iber to choose depending on the case different ways to achieve less computational time, select the simulation time, decide which results do you prefer for your study, to impose the wet-dry limit in each element of the mesh or even to choose the value of the Courant-Friedirchs-Levy (CFL) coefficient (used to achieve a stable numerical scheme).

This field is more used in this study in the sediment transport module. Regarding hydrodynamic module, a simulation time of 80 seconds, results writing time of 1 second and the defaults values of CFL (0.45) and Wet-Dry limit (1cm) have been chosen.

Once all the data discussed throughout this chapter is introduced to define the model, Iber is ready to simulate the emptying of the storage chamber. It is advisable to consult the information window of the calculation process to check possible error messages.

```
 Calculating edge connectivities
    10.%
    20.%
    30.%
    40.%
    50.%
    60.%
    70.%
    80.%
    90.%
   100.%
Initial volume:              27.71 m3

Simulation time      Time step       Time            Qin          Qout

          1.000       0.00129     10:05:51:12       0.000        0.000
          2.000       0.00129     10:05:54:31       0.000        0.000
          3.000       0.00134     10:05:56:57       0.000        0.000
          4.001       0.00146     10:05:58:84       0.000        0.000
          5.001       0.00139     10:06:01:34       0.000        0.000
          6.001       0.00154     10:06:04:06       0.000        0.000
          7.001       0.00156     10:06:06:78       0.000        0.000
          8.001       0.00172     10:06:10:56       0.000        0.000
          9.000       0.00199     10:06:13:69       0.000        0.000
         10.000       0.00226     10:06:15:94       0.000        0.000
```

Figure 23. View output information window

In the view output information window is it possible to check calculation process course, if there have been some errors and the initial water volume inside the system that in our case is the storage chamber volume (27.71 m^3). Another important aspect that can be observed is that the emptying time of all that volume of water from the system is 72 seconds, hence the simulation time of 80 seconds is appropriate or even it could be decreased until 75 seconds.

5.3.2. Analysis of Results

Hereinafter, to analyse all the results obtained the post-process interface is used. This interface provides multiple options to visualize the results, personalize the colour maps, legends, show label values and others. The most relevant results are analysed and shown in this chapter.

The first parameter to observe is the depth over all the process. At the beginning, as it was indicated introducing the initial conditions, there is water just in the storage chamber and the depth value is depending on the bed layer, where the highest depth value is located just before the gate where the bed elevation is the lower value.

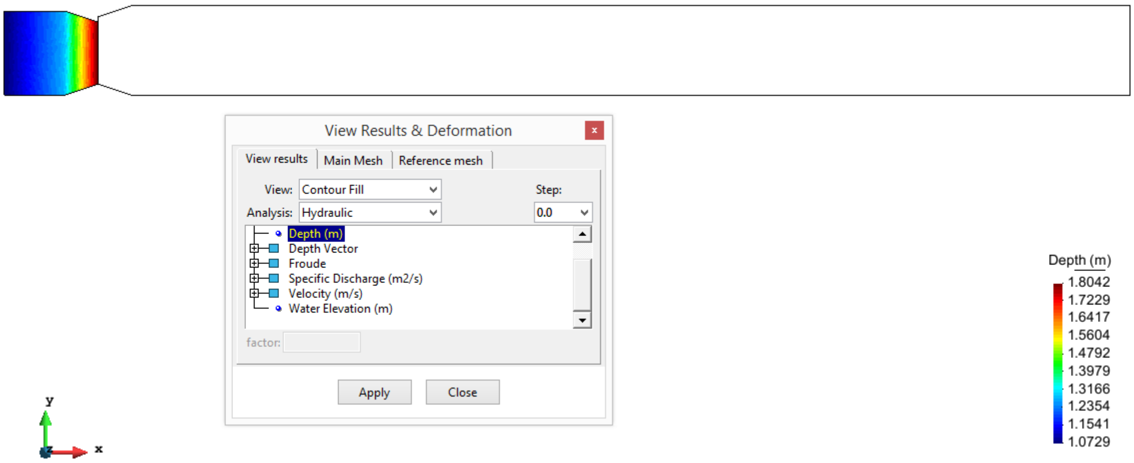


Figure 24. Contour fill of depth. Step 0

After 80 seconds of simulation the following depth map of maximums can be observed:

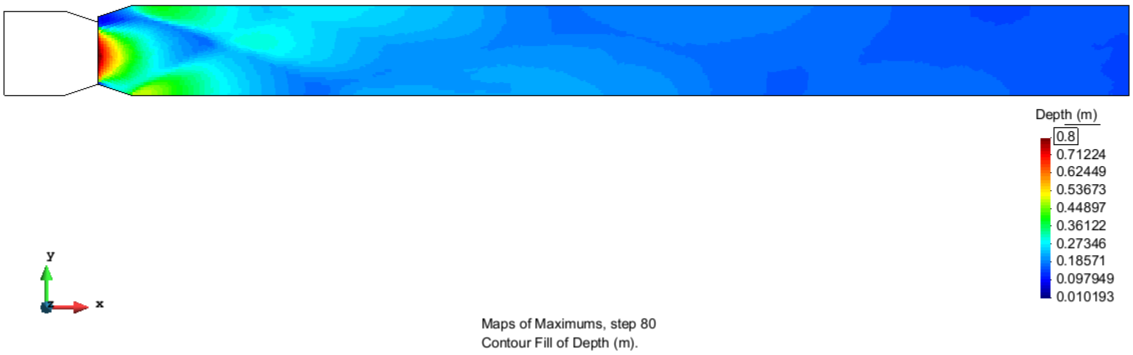


Figure 25. Depth map of maximums. Step 80

The highest values are obtained just in front of the gate and how was expected and mentioned in last chapters, due to the no symmetry of the lane regarding the storage chamber, the results along the entire lane are not symmetrical either. The lowest value is 0.01 m according to the Wet-Dry limit which indicates that over all the lane has been wet.

Several cross sections have been taken on the lane to represent how the depth is evolving as lane width, where the differences between the beginning of the lane and the end could be appreciated:

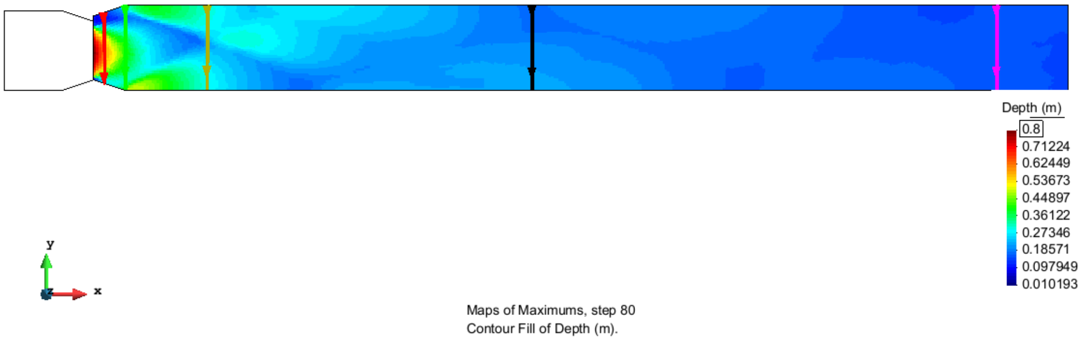
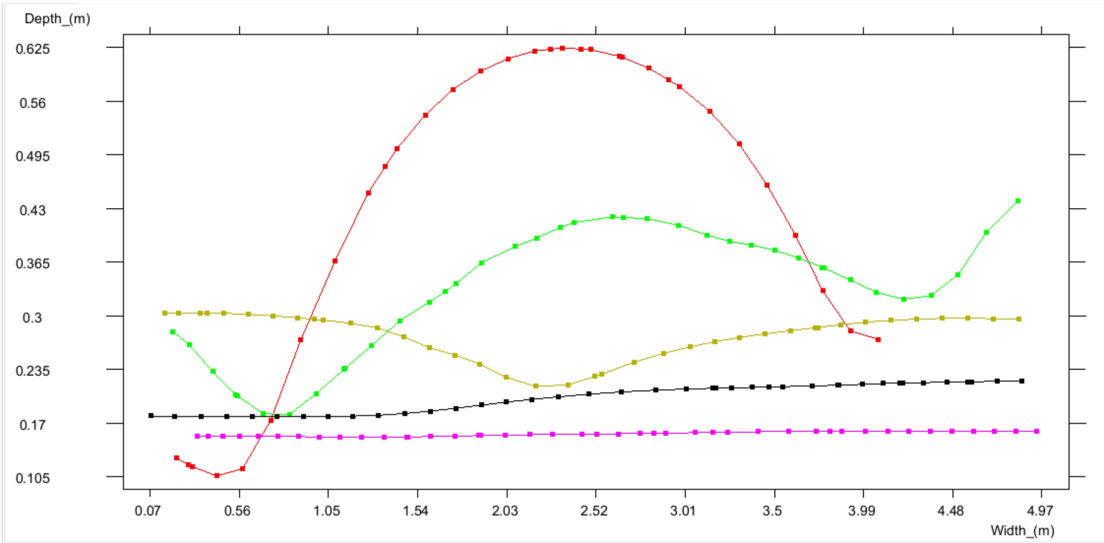


Figure 26. Cross sections in significant zones.

All these significant sections are represented together on the following graph:



Graph 1. Cross sections representing the water depth on the width lane.

Foremost, the section in front of the gate (red one) shows the highest values mainly on the middle of the lane, it is because the water flows by the gate at the first moment and then tend to occupy the rest of the width lane how it is shown on the next section (green one), where we could see how the water starts to fill the sides of the lane and the depth on the middle continues being the highest value but almost the right side of the lane is reaching same value. The yellow one section is showing how the depth on the middle gets lower values than on the sides, accordingly with these fluctuations, water is moving to walls and then to centre again until reach an equilibrium. Due to these fluctuations cross-waves are produced on the channel, later, cross-waves will be shown with more detail. Both last sections (purple and black one), the depth is the same over the width of the lane that means water is flowing straight through the lane.

Next important parameter to take into account is the velocity. Focusing on the maximum velocity during the simulation the next map of maximums is obtained:

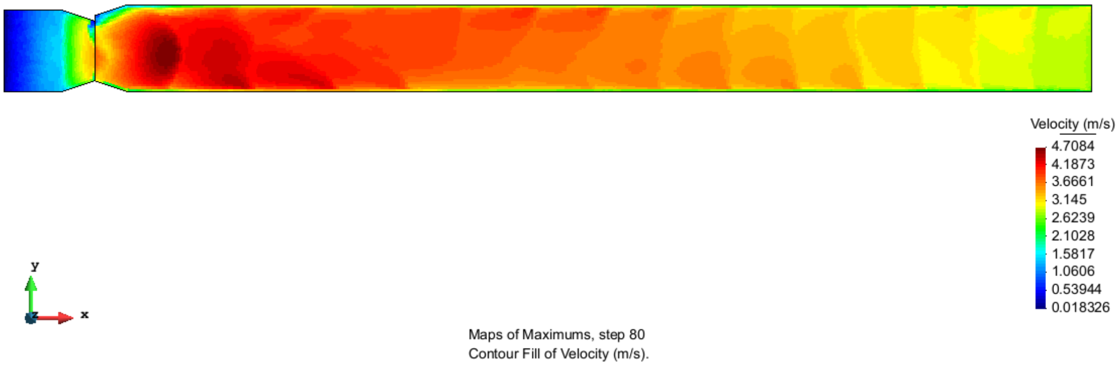


Figure 27. Velocity map of maximums. Step 80

On one hand, we can notice how the highest velocity occurs on the beginning of the lane and in the centre of it. On the other hand, the lowest values are on the walls (at the lateral sides of the lane). Difficulties to erode that areas, especially at the beginning of the lane and in the left side (regarding flow direction), could be expected due to the lowest values of velocity are located in these zones. Likewise, the difficult outing of the water from the storage chamber could be observed because of the gate is not occupying all the wall causing retention water on the lateral areas just behind the gate.

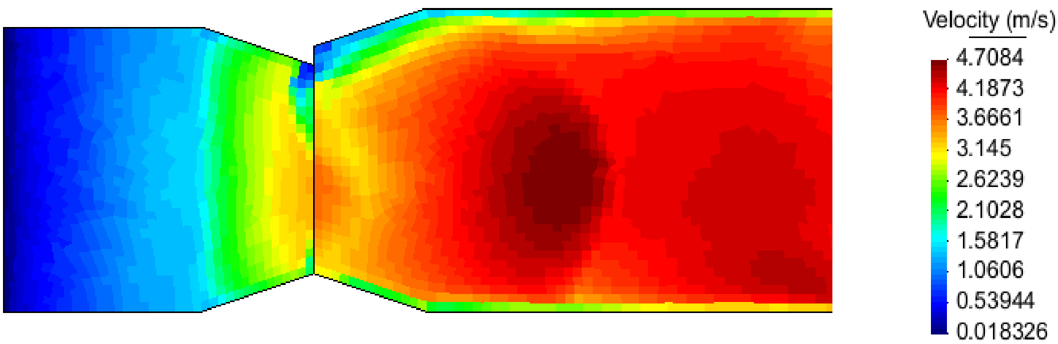


Figure 28. Initial part of the retention tank. Velocity map of maximums.

To analyse velocity parameter, could be more interesting to see how a point evolves on time. Several points are chosen to observe the time evolution of each one.

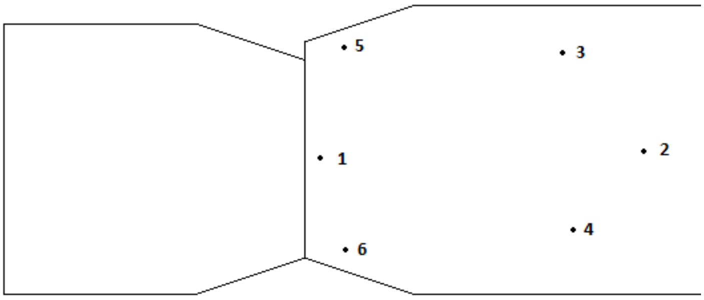
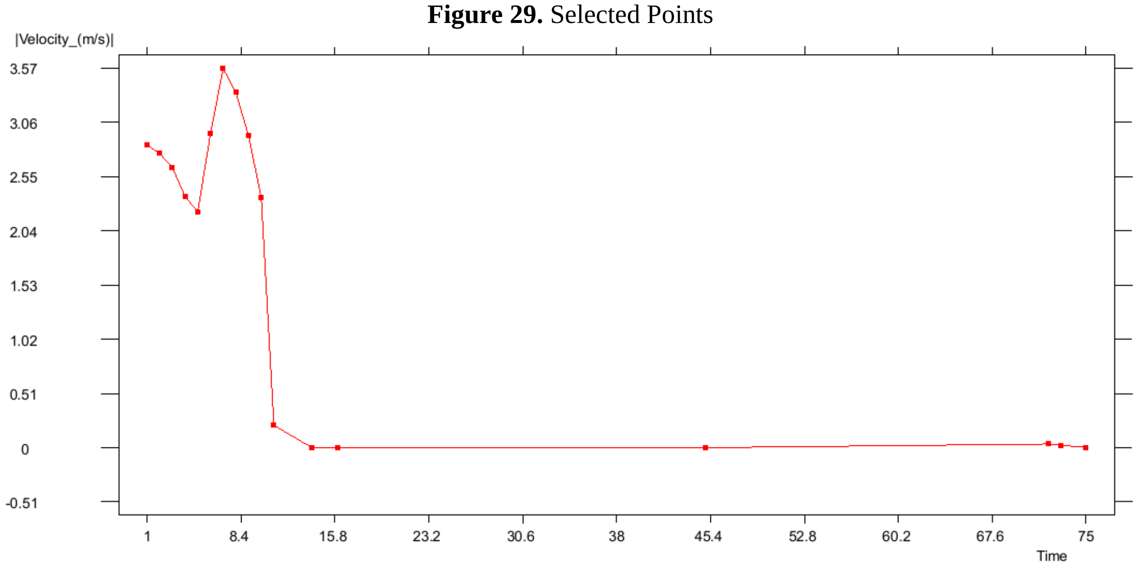
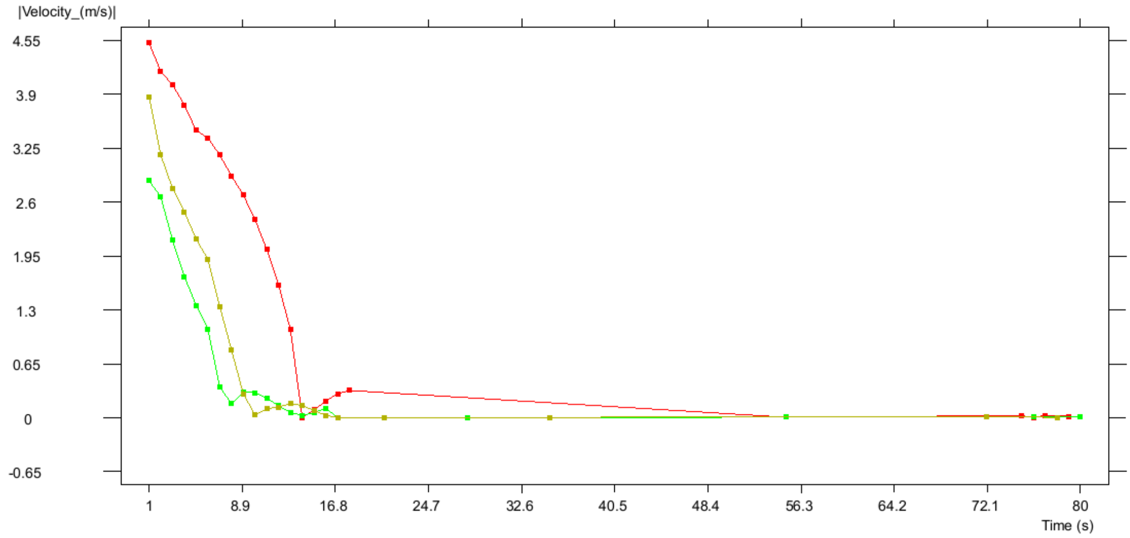


Figure 29. Selected Points



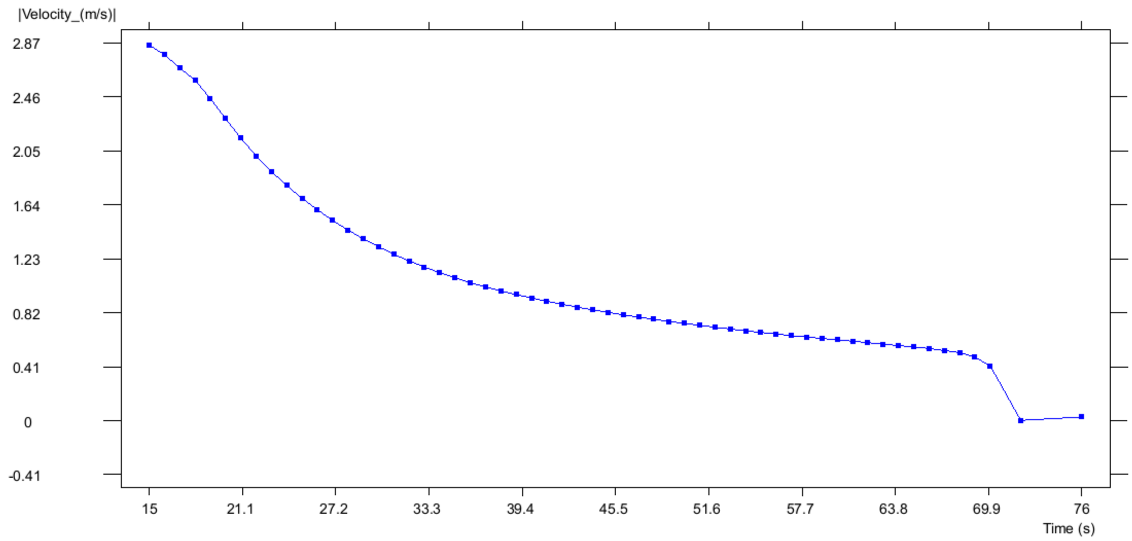
Graph 2. Velocity Evolution. Point 1

In that figure the central point just in front of the gate is represented. The velocity in that point starts around 3 m/s when the gate is opened, then the velocity decreases until there is a huge increasing of the velocity. The final increment of velocity is due to the emptying of the storage chamber is slower at first than at certain moment around 6 seconds of simulation.



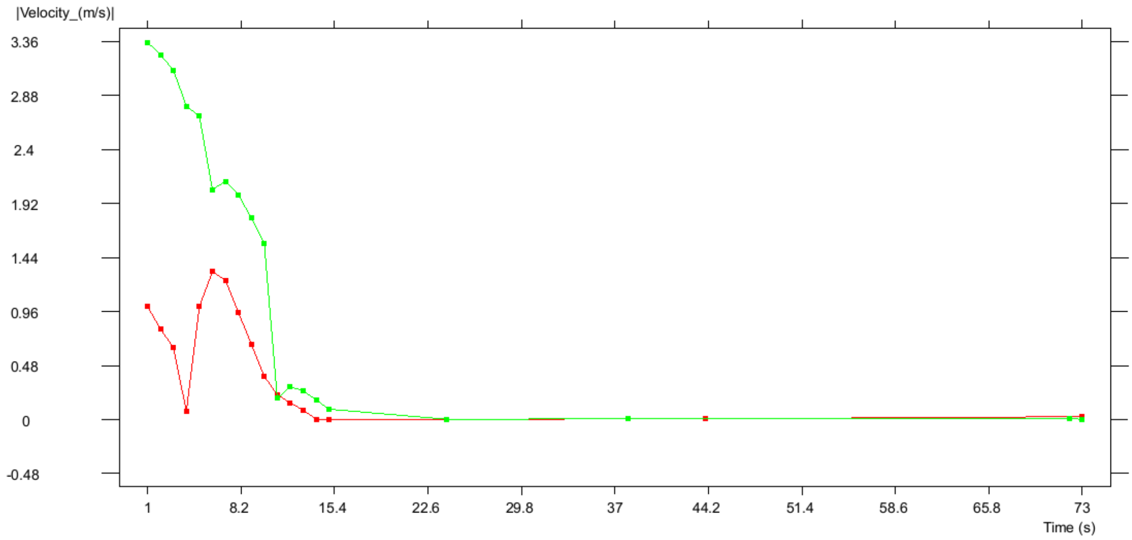
Graph 3. Velocity Evolution. Points 2 (red), 3 (green) and 4 (yellow)

In all these three points the highest velocity occurs at the first step and after that there is a decreasing of the velocity. Due to the no symmetry, a little increase of the velocity appears, that is because of how is flowing the water after the gate opening, how the water is moving from one side to the other side. On the contrary, if we observe the evolution in one point at the end of the lane, we can see how the decreasing on the velocity is more regular and there is not the final increase of velocity due to the water movement at the end is stable.



Graph 4. Velocity Evolution at the end of the lane.

Finally, points 5 and 6 are represented on the following graph:



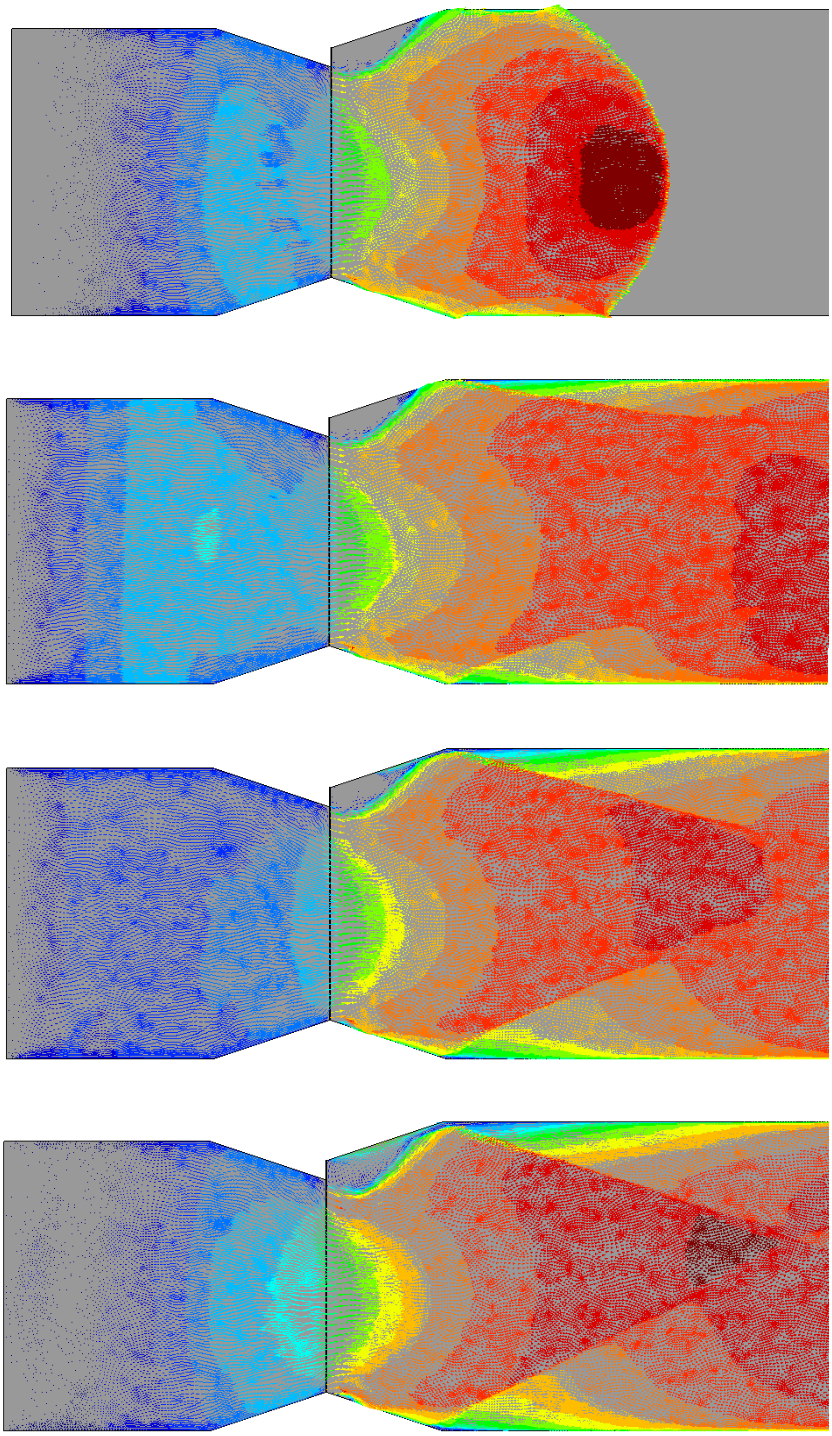
Graph 5. Velocity Evolution. Points 5 (red) and 6 (green)

In these two points there are differences due to the velocity values and at the same time there are differences on the evolution behaviour. As it was mentioned on last chapters, velocity in the left side has low values which could cause difficulties to erode that zone, as it was expected. The behaviour is similar to point number 1 but the magnitude of the velocity is too low. Nevertheless, right side presents an evolution with the same behaviour like points number 2, 3 and 4 and similar values of velocity.

In order to analyse velocity, not only the magnitude is important. Velocity direction is important because it could be the reason to get low values of it due to the recirculation phenomenon. Recirculation could lead to a significant energy lost, doing these areas less efficient to deal with sedimentation problem.

To study recirculation, a new mesh (more accurate mesh) has been created. The idea is to get a new mesh with smaller elements to achieve more precision and more detailed information. To generate the mesh for the whole system is not optimal due to computational cost is higher and this much detailed mesh is only required in the sensitive area of recirculation (in front of the gate). For these reasons, it was decided to study only the beginning of the lane.

Just as in the previous mesh generation, the transition zone has been the zone which presents major problems. Focusing special attention in that area to get the most regular possible mesh and avoid strange elements, a new mesh was generated. In this case, instead of 55.02 meters of lane, 18.66 meters have been referred in the model. 65,265 elements are obtained. Using the display vectors of velocity recirculation can be analysed:



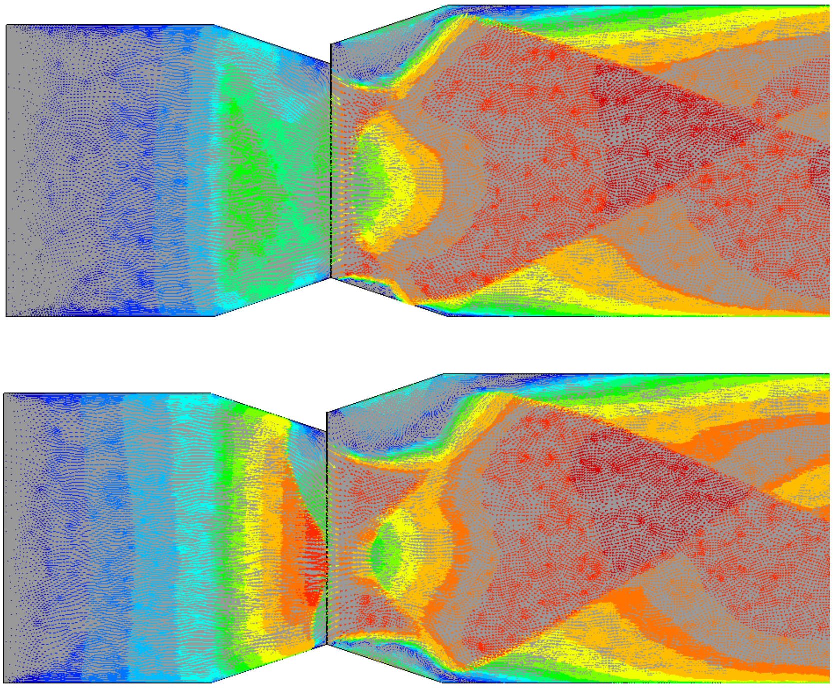


Figure 30. Six first simulation steps. Display vectors of velocity.

In these 6 steps the presence of recirculation is obvious. Since first moment, left side is sensible to recirculation, it occurs because of the location of the gate. On the right side gate is closer to the wall than in the left side, for that reason the phenomenon does not appears until two last steps.

Taking into account the results, the beginning of the lane has the initial inclination to deal with the recirculation. Also seems that it is working well on the right side, whereas on the left side is not successful and because of this strong recirculation velocities are lower in this zone causing problems to remove the sediments deposited.

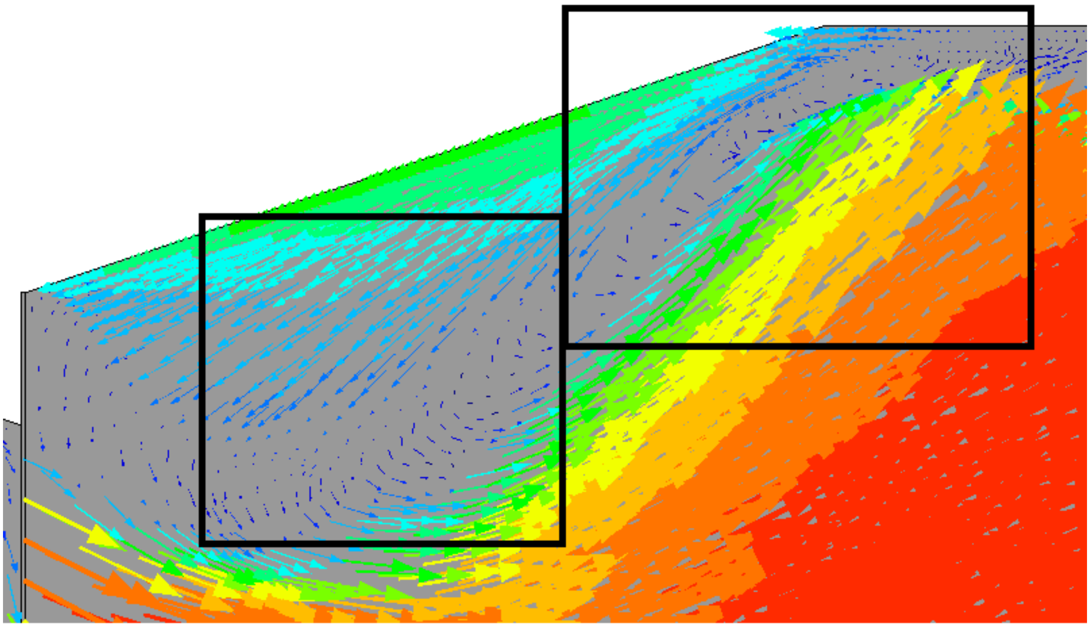


Figure 31. Recirculation Detail. Left side. Step 5

The last figure shows the swirls formed due to the recirculation, which are the responsible of the energy dissipation. Water changes its directions going to the opposite side causing the swirls and the energy lost. The first steps of the simulation are those which have more energy because of the suddenly opening of the gate, this energy should be harnessed to erode the sediments easily.

Taking benefit of this detailed mesh, the cross-waves points can be determined with more accuracy. The mesh quality is higher and the cross-wave phenomenon could be shown clearest than on the depth chapter where all the lane was represented and to study the cross-waves that it is appearing on the beginning of the episode it is better just focus in this area getting more detail and precision.

On the following figures, the different cross-waves cases could be seen and also determine in which part of the lane and the step of the simulation they occur. As it was done on the last chapter, several cross sections have token too.

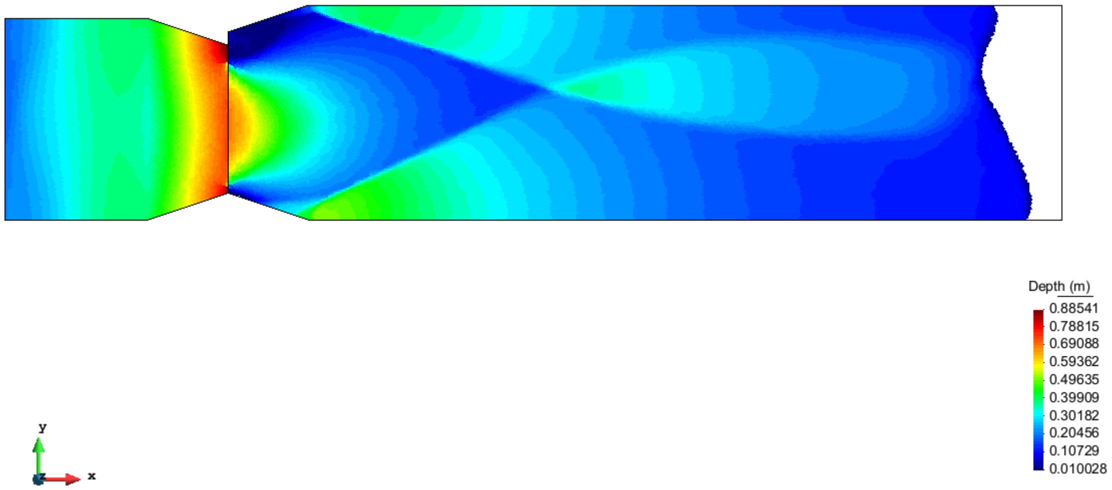
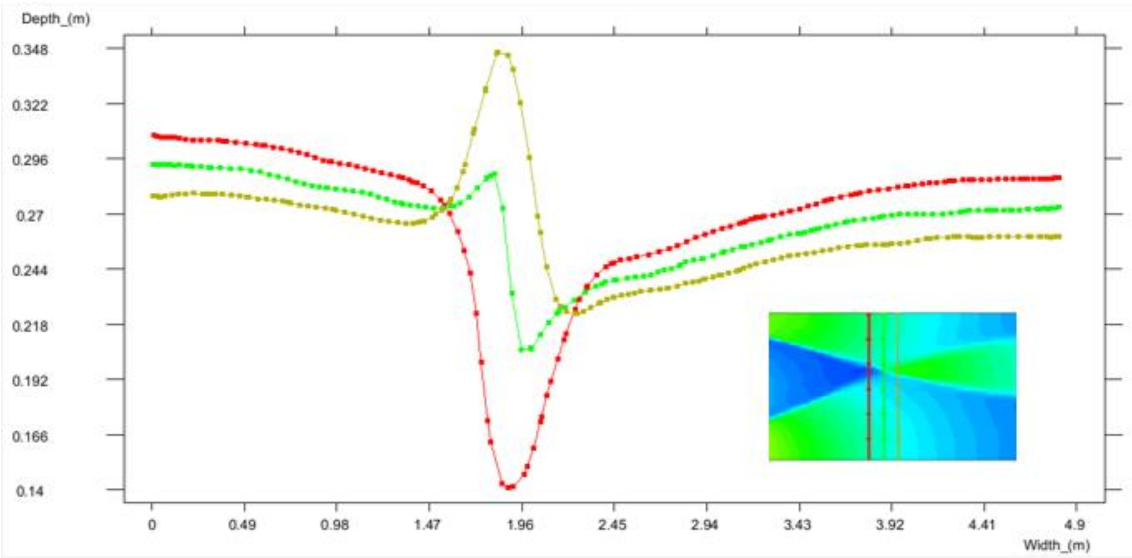


Figure 32. First cross-wave phenomenon. Step 4.

This first crossing point could be shown in the last figure, it happens 7 meters from the storage chamber gate in the step number 4 (4 seconds after the gate opening).



Graph 6. Cross sections around cross-wave zone.

In this graph is it possible to appreciate how the water is going from the walls to the centre (red one line), then the green one section is representing the instant where the waves (right one and left one) are crossing and finally, behind the cross-wave section the highest value of the depth is on the point of the lane where waves are crossing and the waves are going again from the centre to the walls.

4 seconds later the following crossing waves appear in the lane:

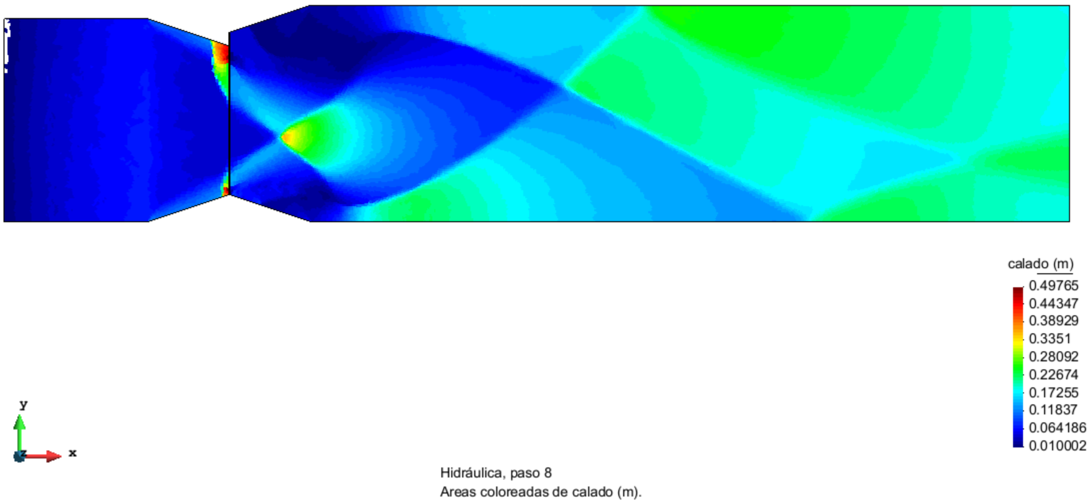
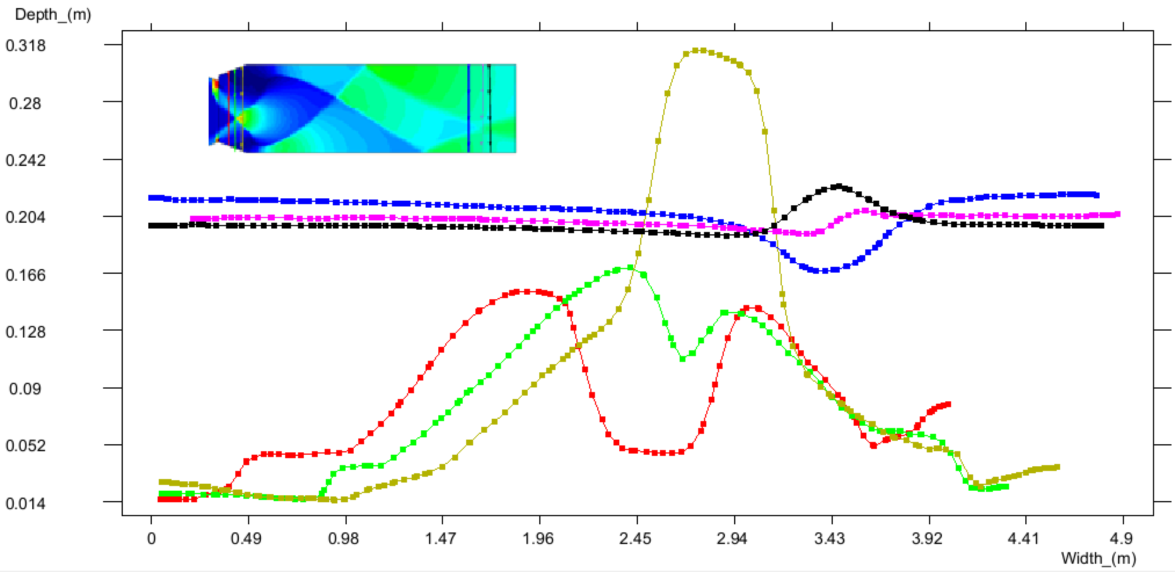


Figure 33. Second instant where the cross-wave phenomenon occurs. Step 8.

In this case there are three crossing points, the first one occurs 1 meter from the storage chamber gate, the second one is still 7 meters from the gate and the last one occurs 16 meters from the gate.



Graph 7. First and third cross-waves representation by cross sections.

In the last graph, the differences between the first cross-waves and the last one are clear. The first one, which is just in front of the gate, the phenomenon is more pronounced due to the abrupt entry of water through the gate. On the other hand, the third cross-wave is really small indicating that water is reaching a balance in that area.

The last important parameter to study in the hydrodynamic module are the bed shear stresses, which gives information about how the erosion is working in the lane. In the state of the art part different authors conclusion were commented about from which value of bed shear stress the sediment could be eroded. In case of the weakest materials 2 N/m^2 and 7 N/m^2 for more consolidated and granular material are values of the bed shear stress that could be enough to erode the materials from the lane.

Iber can show where the fluid has bed shear stresses below theses ranges of values, which means that we can expect where the fluid will have more difficulties to erode the material from the bed of the lane.

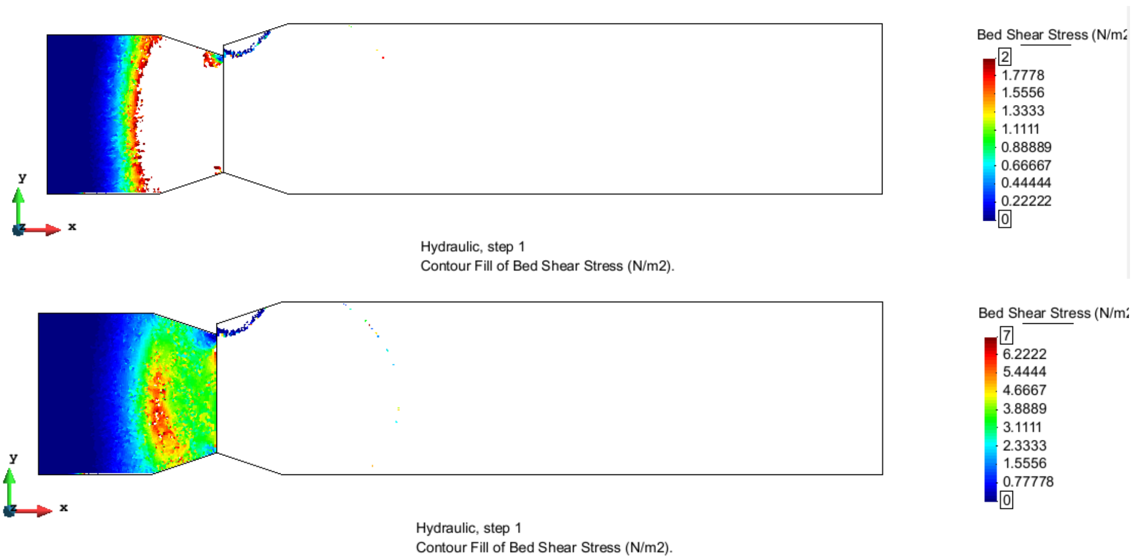


Figure 34. Bed Shear Stresses bellow 2 and 7 N/m^2. Step 1.

In this figure the first step of the simulation is shown. The low values of bed shear stresses are located in the recirculation zone due to the low velocity in that area. How it was expected erosion problems will be produced in the lateral areas at the beginning.

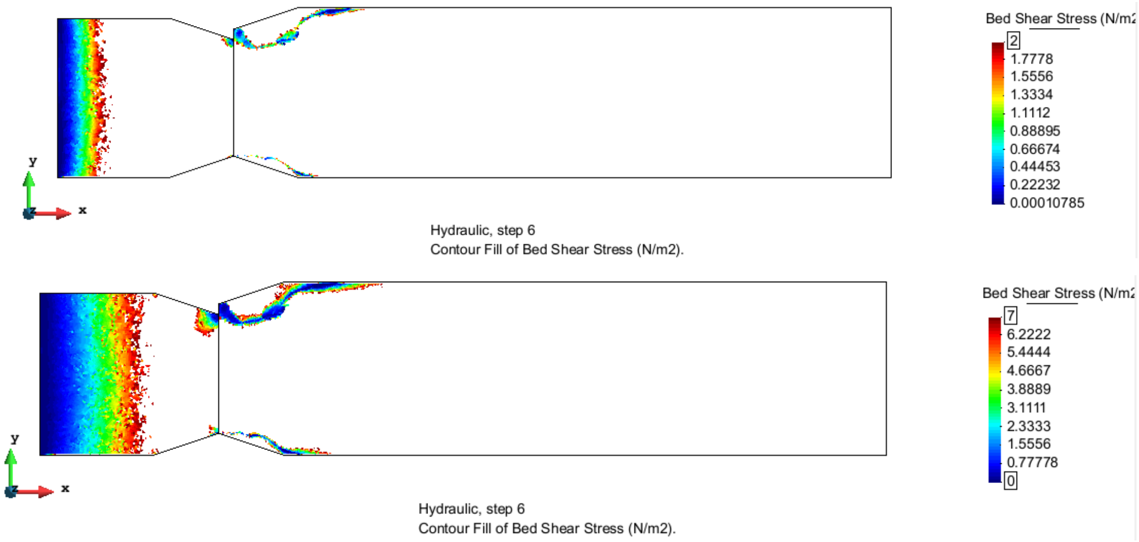


Figure 35. Bed Shear Stresses bellow 2 and 7 N/m^2. Step 6.

Observing 6 seconds after the gate opening, there are still the lowest values of bed shear stresses in the left side and also in the right side. As it was seen analysing the recirculation phenomenon, at the beginning occurs on the left side until the fifth step where the recirculation starts on the right side causing a decrease velocity values on this area. The colour area that represents the range between 0-7 N/m^2 is higher than the 0-2 N/m^2 which means a most difficult erosion process if the sediment characteristics tend to be granulated and consolidated material.

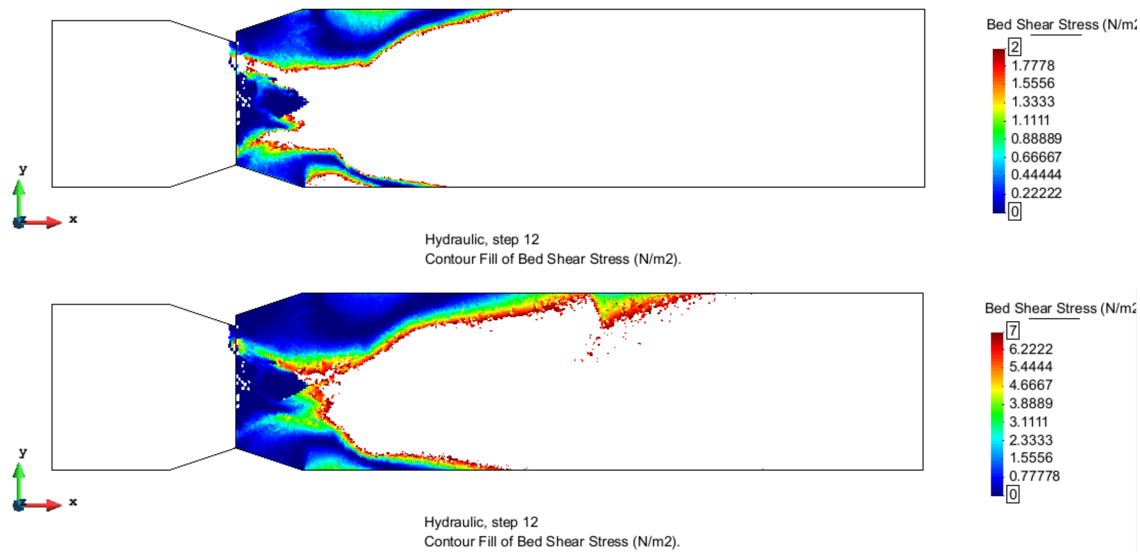


Figure 36. Bed Shear Stresses bellow 2 and 7 N/m^2. Step 12.

This step represents the time step where the storage chamber is empty of water. As it was observed in the last steps the lowest values near the walls but in that case is also on the middle of the lane. These values on the middle are obtained due to the velocity of the last water inside the storage chamber is not as high as it was at the beginning causing lower values of the bed shear stresses.

5.3.3. Proposal geometry to deal with recirculation

Regarding to recirculation, we have seen how the problem is focus on the wall sides. To avoid that energy lost in the sides zones would be useful to prevent the sedimentation in that places. Looking at the following figure, there are velocities going to the opposite flow direction:

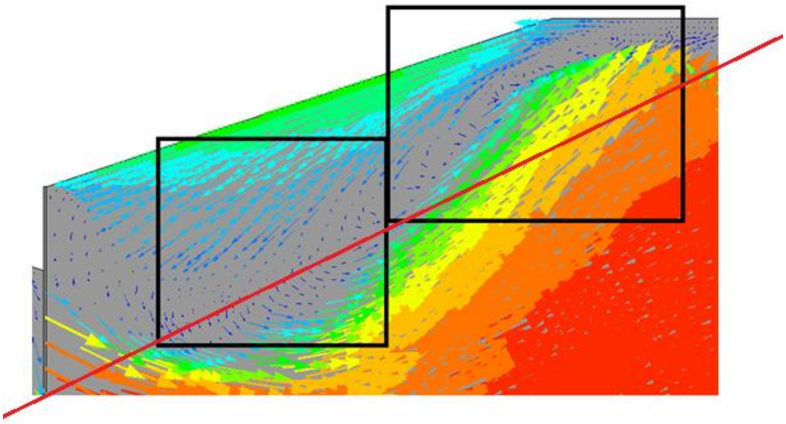


Figure 37. Recirculation left side zone.

Furthermore, it seems that there is a clear separation limit. Viewing the problem area a boundary line between the recirculation zone and the area where there is no recirculation can be drawn. Based on this idea, a new channel is proposed to deal the recirculation phenomenon.

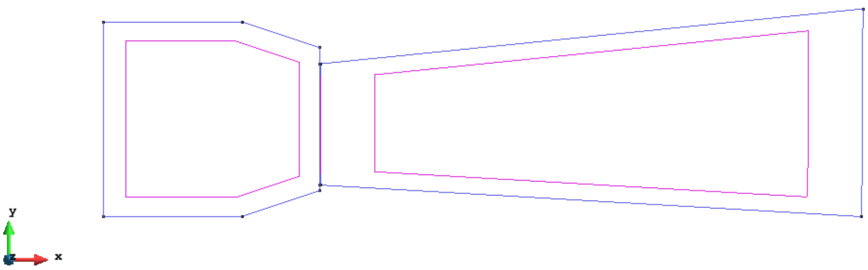


Figure 38. New geometry of the retention tank lane.

Taking into account the observations and the analysis of the recirculation inside the lane, it makes sense to start the lane with a narrow width until overcome the recirculation zone which the lane recovers the original width. The idea is to drive water to the maximum width progressively.

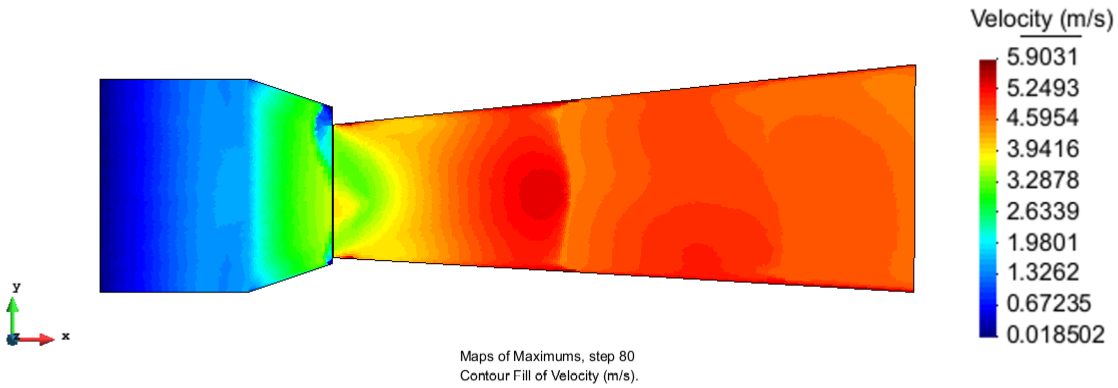
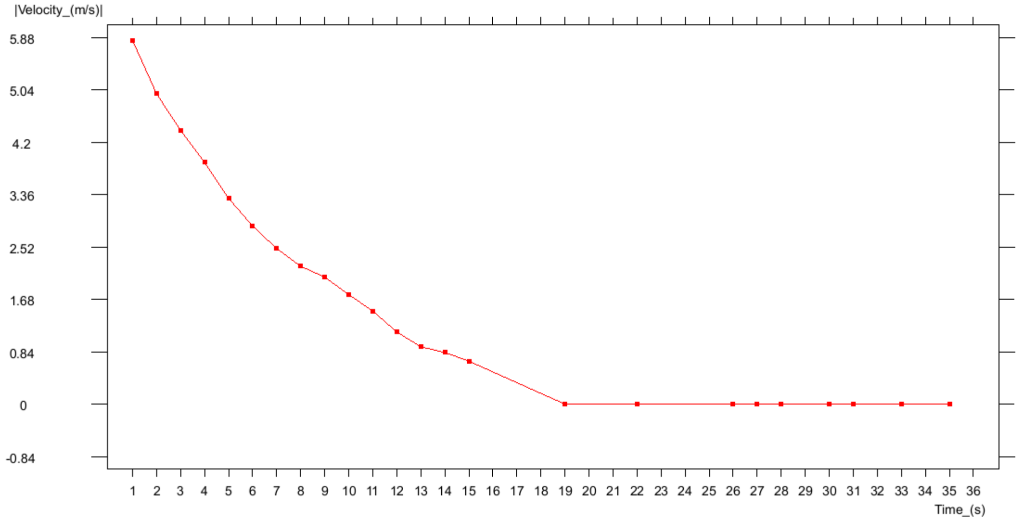


Figure 39. Velocity map of maximums with the new geometry. Step 80

At first sight, velocities that occurs in the lane are higher than using the other geometry. With the original geometry maximum velocity was around 4.7m/s and using this one the maximum velocity is around 5.9m/s. Nevertheless, we should take into account that these peak velocities are instant velocities and some cases they are not acting during a significant interval of time.



Graph 8. Evolution point on the middle of the lane 5m from the gate

For example, on the last graph, the highest values between 5.9-3.3 m/s are obtained in the first five seconds, this will take importance in order to see if water can erode the sediment and transport it to the end of the lane.

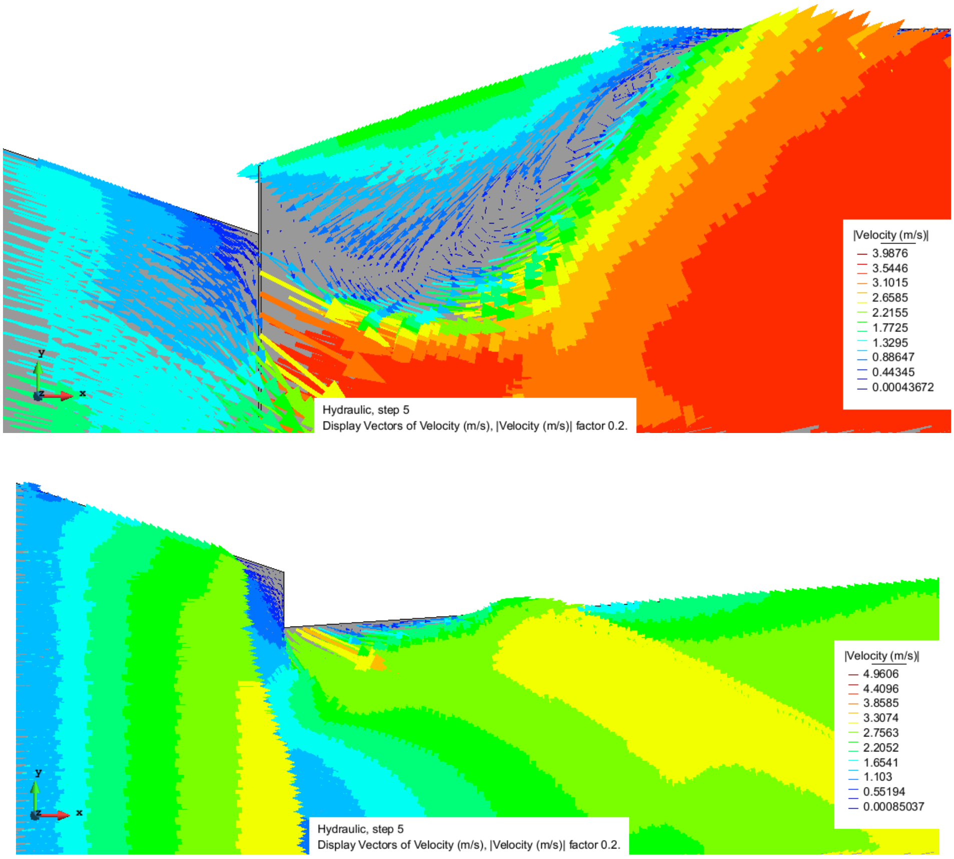


Figure 40. Comparison between both geometry. Step 5.

In the last figure, the first scenario is using the real geometry and the recirculation is taking place on the area removed in the proposal geometry which shows how the recirculation problem is avoid. In addition, the highest values of velocities in the lane are reaching in this time step 4.9 m/s instead of 3.9 m/s reached on the real geometry.

Bed shear stresses could be analysed as it had done on last chapters to compare the results obtained with the original one. As on the bed shear stress chapter the following results could be shown:

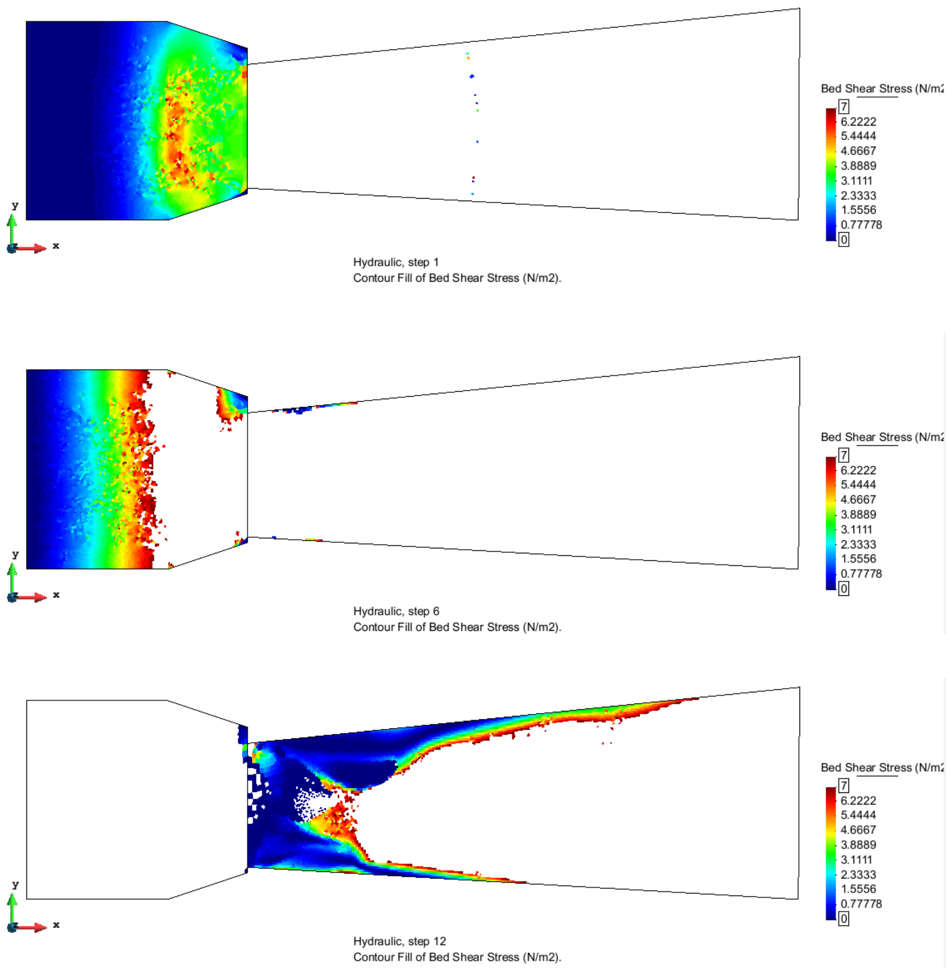


Figure 41. Bed Shear Stresses bellow 7 N/m^2 with the new geometry. Steps 1, 6 and 12.

In these pictures the colour area is shown where the bed shear stress has values in a range of 0-7 N/m^2. In the last chapter was also shown the range 0-2 N/m^2 whereas the differences in that case are more clear due to it is covering a major range of values.

In the step number 1 there is no presence of areas in the lane with values between 0-7 N/m^2, and with the original geometry in this step there were colour areas in the left side.

In the step number 6 a small zone begins to be colour in the left side whereas compared with the original one in that step there were extensive colour zones in the left side and also in the right side.

Finally, in step 12, the colour area is very similar to the original one. It is important to know that in this step all the water is on the lane which means that there is not flowing water by the gate, therefore is the last amount of water flowing over the lane and how is logical its intensity and velocity is lower than on the beginning of the gate.

As it has been shown, it seems logical to think that using the proposal geometry on the first steps velocities are higher, the recirculation phenomenon is avoided and bed shear stresses have values over the range 0-7 N/m^2. As a first observation and before starting to include the sediment transport module better cleaning results by using the proposal geometry could be expected.

5.3.4. Final Comments

As a result of analyse the Hydrodynamic Module, a primary trend of an erosion difficulties will be located in the lane sides, where the fluid velocities presents the lowest values due to the dissipation energy produced in the first moments caused by the recirculation phenomenon.

Several parameters have been observed and analysed and all of them lead to the same ideas:

- The lowest velocity results are obtained in the sides of the lane.
- Recirculation phenomenon appears in the sides of the lane due to the design of the gate regarding to the geometry lane.
- The values under 7 N/m^2 of bed shear stresses are obtained in the same areas that the two last points.

For these reasons, these three parameters are strongly linked with the erosion of the retention thank and them allows us to have a first estimation of the erosion behaviour before to include the Sediment Transport Module on Iber's procedure.

Furthermore, at the end of the lane are obtained low values of velocities logically, water is decreasing his velocity on time and reaches the end of the lane with less force, implying difficulties to erode the material and depositing material that has been eroded upstream.

Before running the model using the sediment transport module, a proposal geometry for the lane of the tank has been run using the same condition like the original one in order to be compared.

As a first approximation, when the sediment transport will be analysed the following improvements should be expected:

- The cleaning in the wall sides zones at the beginning of the lane will be cleaner than in the original case due to the bed shear stresses are higher and the recirculation is avoided in that areas. If the influence of these factors is significant differences between both geometries will be shown.
- It is also possible to obtain better results in the central area on the beginning of the lane because of velocity reaches high values. Nevertheless, in the centre the expected improvements are less significant than in the sides of the lane because, as it has been shown in last chapters the mean relevant differences are in the lateral areas.

5.4. Sediment Erosion and Transport in the Cleaning Lane

5.4.1. Introduction

Due to the lack of real data to run the model and calibrate it, several cases are run pretending to observe the behaviour of the self-cleaning process. These scenarios are chosen accordingly the experience, other studies with similar characteristics or depending on the Iber tools to simulate the sediment transport.

In the current study, two different specific densities of the solid material have been analysed. In case of sand material inside the tank, the scenarios have been run using γ= 2.65 Kg/dm^3 and for the same cases where the hypothesis is an organic material γ= 1.40 Kg/dm^3 has been used.

Moreover, four different depth of solids (1, 3, 5 and 10 centimetres) over the lane have been studied to analyse the influence of the depth sediment inside the tank.

Accordingly with other studies of sediment transport in similar condition, organic material has been simulated using suspended transport. On the other hand, to run the model using sand material Van Rijn bed transport formulation has been used.

One of the scenarios is also run using the proposal geometry on the last chapter in order to observe how is affecting the geometry on the beginning of the lane.

Emphasize again, in case to get the real sediment data and using field measurements the model could be calibrated in order to represent the real behaviour of the sediment tank and achieve a powerful tool to guarantee the proper operation and functionality of the retention tank.

5.4.2. Problem Definition

As in the hydrodynamic module, to use sediment transport module some initial information is required in order to define the problem. The procedure to define this information is explained in this chapter because is the same mechanism in each scenario. On the following chapters some pre-process information is explained for a particular case while here the general and basic information is assigned by same way for all the scenarios.

The first condition is to define water inside the storage chamber as clean water with the Iber bed load conditions tools. Selecting the first boundary where the water is contained and assigning to it cleaning water property.

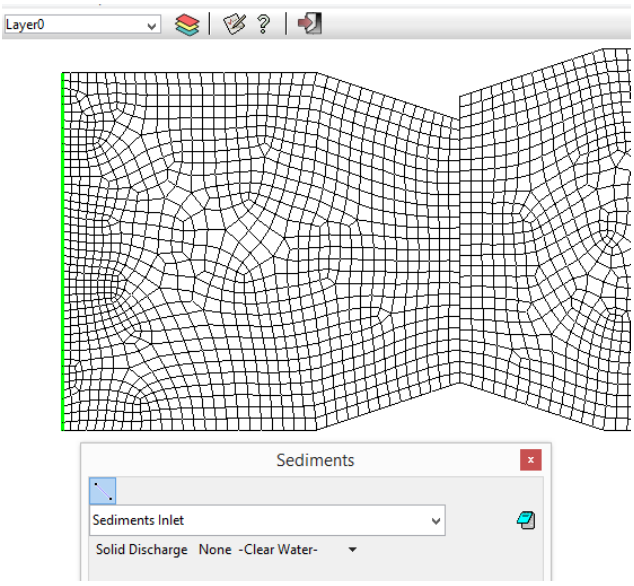


Figure 42. Clean Water condition.

Next condition is the most delicate for the sediment transport module. This condition is to assign the rock layer position. The main problem of this condition is that to assign this condition it has to be done on the geometry or on the mesh (like the other conditions). That means to assign in a defined surface or in several elements of the mesh.

Moreover, there are different elevations of solids inside the tank lane as it occurs in the real cases. The difficulty in Iber is to link each element with the corresponding erodible depth. On the following chapter how to deal with this hardness will be explained in detail because is required to simulate a second emptying case of the retention chamber storage.

Facing the 4 cases that will be studied in the current thesis, a constant sediment elevation is considered over all the lane. For each particular case a new geometry is defined increasing just the elevation of the lane (1, 3, 5 and 10 centimetres) and by Iber is assigned the rock layer position over the lane as the erodible depth for each situation (1, 3, 5 and 10 centimetres respectively).

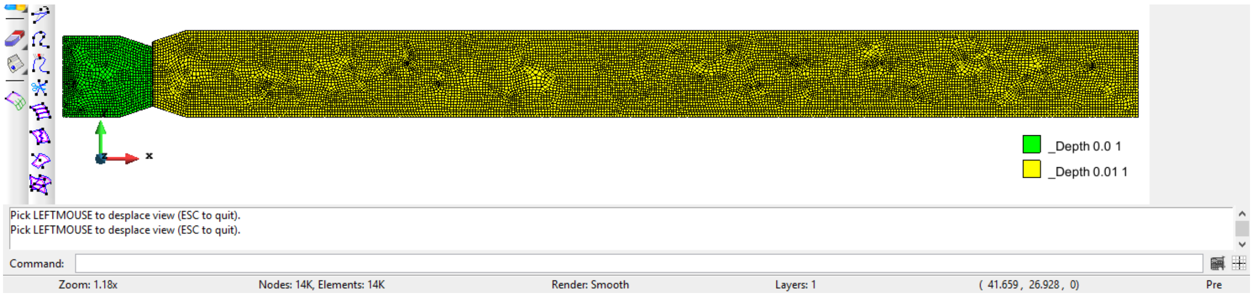


Figure 43. Rock Layer Position assigned on the retention tank.

As it is shown on the last figure, the storage chamber is non erodible assuming that there is no sediment inside this zone. On the other hand, over the lane is assigned the depth that the water can erode and Iber recognise that layer as sediment material which can be removed or deposit in other place of the lane.

The last setting before run the model is to activate the sediment transport module in order to apply the formula explained in previous chapters. As it was executed in the hydrodynamic module, by the data problem tool sediment transport could be activated in order to setup the model.

First of all, there are two choices of sediment transport. In order to simulate the sand erosion, bed load transport will be used:

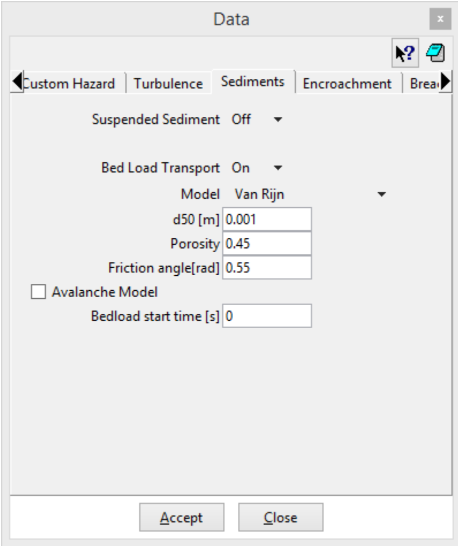


Figure 44. Bed load transport. Setting tools.

In order to study the bed load transport the model used to simulate the movement is Van Rijn which allows to define the mean diameter (D_{50}) the material porosity and the friction angle. In the current study inorganic cases have been simulated using 1 millimetre of diameter, 0.45 of porosity factor and 0.55 rad to the friction angle according to similar material found in other sewer system.

The second option is the suspended sediment which is used to simulate the same cases but taking into account an organic material deposit in the tank:

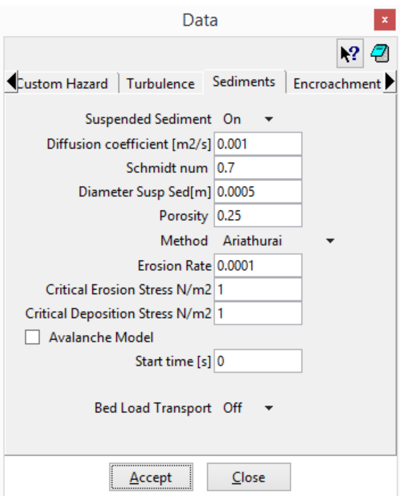


Figure 45. Suspended transport. Setting tools.

In this section some common parameters are defined for each calculating method. Based on studies with similar characteristics where organic sediment is analysed, the parameters used to run the model are shown on the last figure. Instead of 1 millimetre with the organic material it has been used a diameter of 0.5 millimetres and 0.25 of porosity.

The method used in this case is Ariathurai where the critical erosion stress and the critical deposition stress is defined as 1 N/m^2 and the most sensitive and significant parameter is the erosion rate, same methods used by most authors working with organic cohesive material.

To determine the value of the erosion rate basically it has been used the results from a recent PhD dissertation accomplished in Universitat Politècnica de Catalunya (Seco, 2014). It is a study of the release of sediments during wet-weather from combined sewer systems in the Mediterranean region in Spain.

The erosion rate (M) is a transport parameter used as a calibration factor, in our case the calibration is not possible to do due to the lack of real data, whereas in this PhD was calibrated and validated in laboratory conditions (erosionmeter) and for an organic material. It is also important to mention erosion rate has a relationship with the duration of the consolidation period and with the mean particle size or particle fall velocity during the deposition period when the bed is formed.

Furthermore, erosion rate depends on the hydrodynamics of the event and in this study the hydrodynamic is very particular. In order to use more accurate value of the erosion rate a proper calibration of the model would be done due to the special behaviour in the self-cleaning system where despite velocity values are high the duration of them is too short (few seconds). The velocities obtained in the laboratory tests are acting for longer times than in the studied retention tank lane.

For all these factors, in the current study a 0.0001 m/s erosion rate has been used and for each scenario is estimated a particular erosion rate assuming that by one emptying of the storage chamber the cleaning system is successful.

Once defined all the sediment conditions in the pre-process, the calculation is run to study and analyse the self-cleaning process.

5.4.3. Sandy Sediment

As it was mentioned several cases have been run in order to study the self-cleaning process using different material and diverse elevation of it. In order to organise the results in the current study the cases using sands and organic will be shown separately.

Sand material inside the lane has been run using Van Rijn method and the specific density of the sand is 2.65 Kg/dm^3. The following results are obtained for a 1 centimetre of deposit:

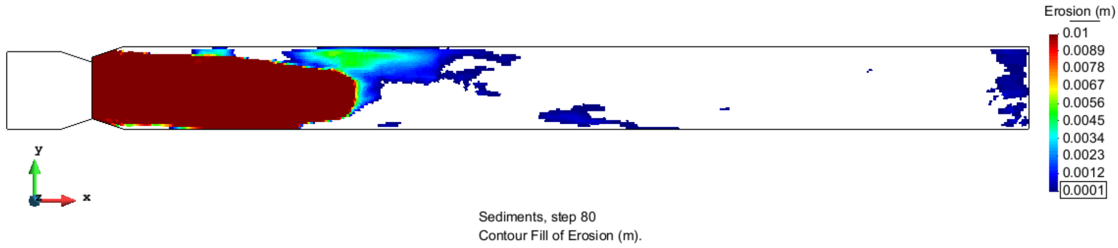


Figure 46. Erosion produced in 1 cm sand case.

The maximum erosion is produced on the middle of the lane and at the beginning of the gate. It is logical due to the highest velocities are sweeping the sediments and moving them by water forces. Total cleaning is achieved until 15 meters from the storage chamber gate, being the case with less material over the lane, the result obtained is not really promising due to the cleaning process is not successful by one emptying of the storage chamber.

As it was expected in the hydrodynamic study, on the wall sides the erosion is more difficult because of the lower velocities and the recirculation phenomenon seen in last chapters. At the beginning the erosion trend is on the right side and after highest erosion is reached on the left side. This was also deductible analysing the hydrodynamic module where the movement of the waves where seen in the cross-waves section.

Analysing the negative results of erosion the sediment over the lane is shown in the next figure:

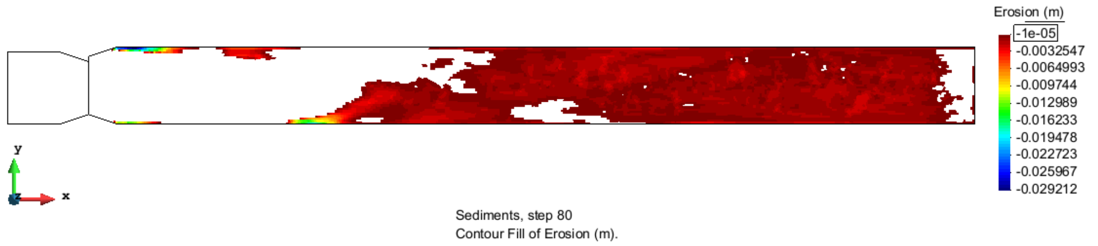
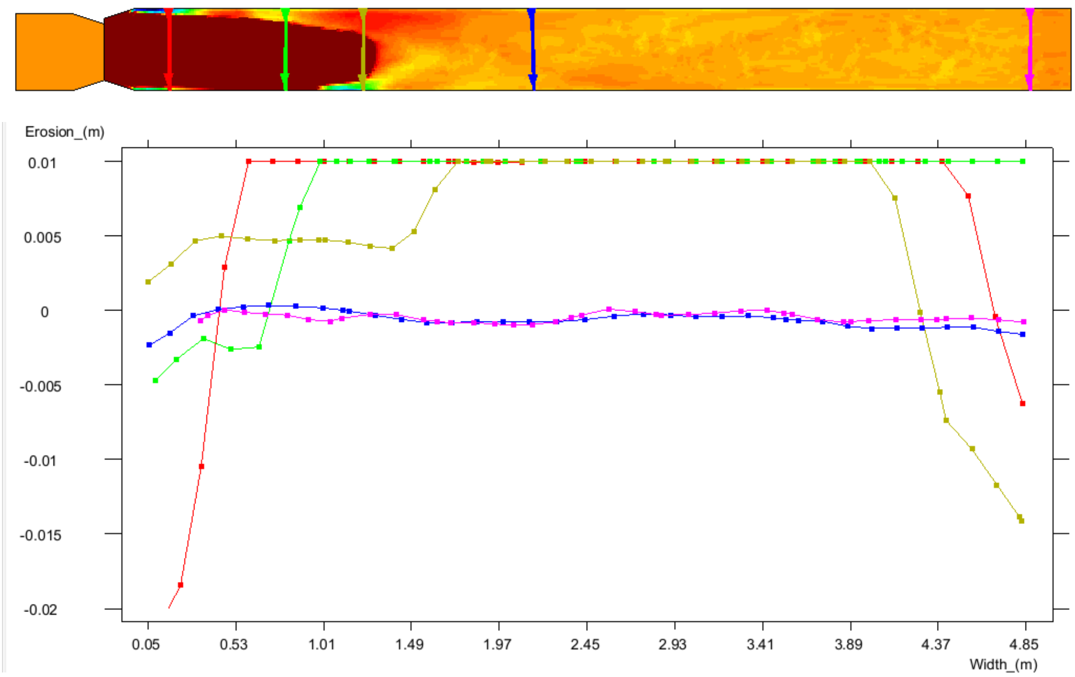


Figure 47. Sedimentation produced in 1 cm sand case.

Most of material is **overflown of system** while a part of it is deposited on the lane. In these coloured areas the sediment elevation is the 1 initial centimetre material plus the deposit value (negative erosion) that is shown in the figure. The main sedimentation is from 3 to 5 millimetres whereas the worst cases are located in the recirculation areas even reaching values over 2 centimetres which means a 5 centimetres of deposit in these areas.



Graph 9. Several transversal section of the erosion.

Analysing by transversal cuts over the lane, the behaviour of the sediment transport is shown. On the first section (red, green and yellow one) the total erosion is reached in the centre and depositions appear on the sides where the velocity due to the recirculation has values on the opposite flow direction. On the middle of the lane and on the end of it (blue and purple sections) the sediment transport is not relevant, not significant zones with erosion or sediment occur on the process.

The cases where the sediment elevation is 3 and 10 centimetres are explained in the annex number 1. The results show similar behaviour and the mean differences are orders of magnitude. Studying the 1 and 5 centimetres sediment scenarios the significant ideas of the model could be deducted.

For these reasons the following scenario to be analysed in this chapter is 5 cm sand situation:

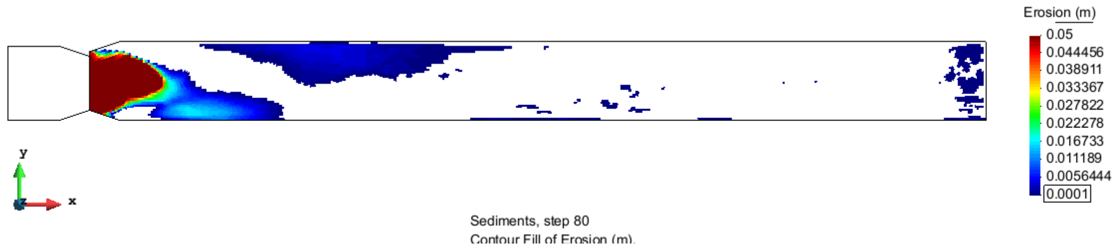


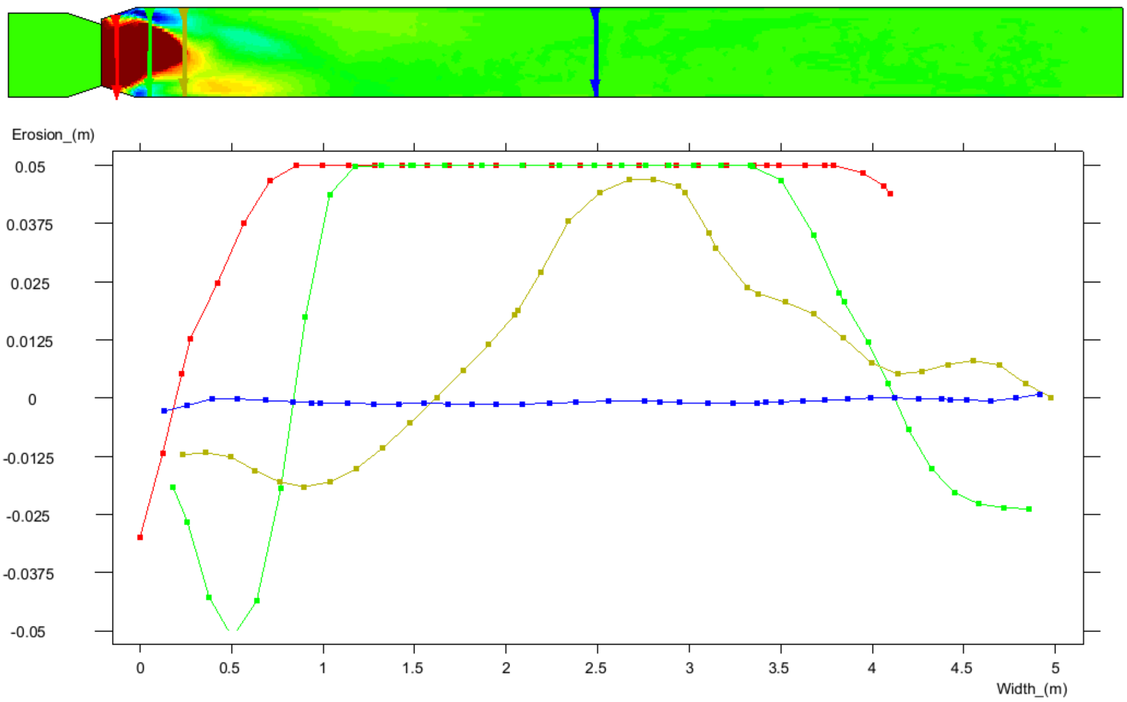
Figure 48. Erosion produced in 5 cm sand case.

In the last figure the erosion produced in the lane could be seen as in the last scenario. The behaviour is similar, the completed cleaning is on the beginning of the lane just in front of the gate due to the powerful energy in the opening time. In this case the erosion is not effective to clean the lane, just a little bit more than 5 meters of the lane are totally cleaned by the emptying of the storage tanks.

As in the 1 centimetre scenario depending on the distance from the gate water can transport more or less material, at first is acting effectively on the right side and after that the erosion is seen on the left side. When the cross-wave is done and the water is moving with a clear wave-front eroding similar quantities of material over the lane width water has not enough power to move the sands.

Figure 49. Sedimentation produced in 5 cm sand case.

Regarding deposition over the lane the behaviour is similar but in this case the situation is worst due to the major part of the moved sediment is not removed from the system and it is accumulated on the recirculation areas reaching values over 5 centimetres of deposition which means a final sediment elevation over 10 centimetres.



Graph 10. Several transversal section of the erosion.

In this case the erosion reaches the maximum allowed of 5 centimetres but it is not significant because it happens just in a very small area and it is deposited at the sides of the section due to the recirculation that are decreasing the velocities in those areas. As in the last case the sediment transport is occurring only on the beginning of the lane (red green and yellow one) while it has not any effect on the rest of the lane and the movement of material is about 0 (blue line). Comparing with the 1 centimetre scenario, the sedimentation on the sides occurs from the beginning of the lane and the self-cleaning process is not efficient.

Previously, on hydrodynamic module chapter a new geometry was done in order to avoid the recirculation phenomenon near the walls on the beginning of the gate. In this chapter this geometry will be analysed for one of the scenarios keeping the same condition to study if there advantages or not.

Running the proposal new geometry the following results are obtained:

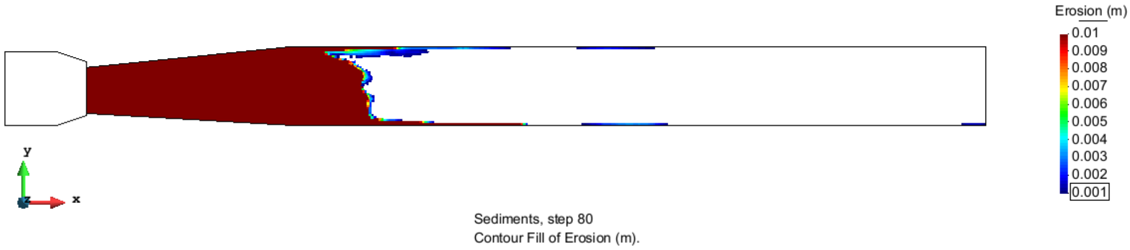


Figure 50. Erosion produced in 1 cm sand case.

The scenario represented is the 1 cm sand case. This time the completely erosion reach 20 meters from the gate instead the 15 meters of the previous case. It is also represented how is avoided the sedimentation due to there are no recirculation area, hence the water energy is higher to move the material.

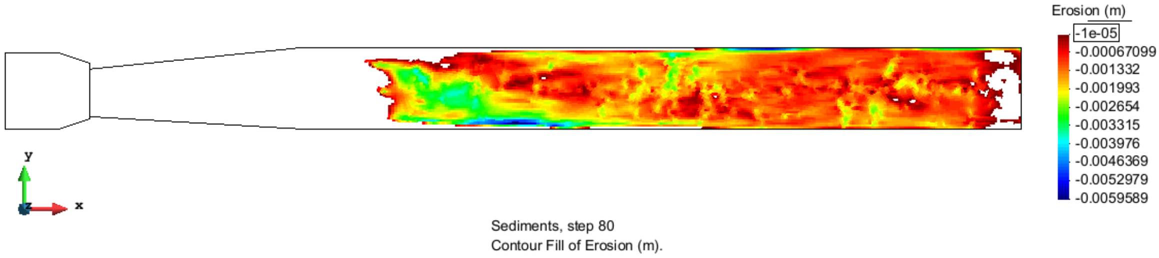


Figure 51. Sedimentation produced in 1 cm sand case.

Focusing on the sedimentation, all material moved is not overflow from the system whereas the deposition that occurs on the lane is not really significant. The deposit reaches 5 millimetres instead the same scenario run with the original geometry where the maximum deposition was over 2 centimetres.

We can conclude that average values of parameters proposed for the Van Rijn method are not enough representative. Standard values have been obtained for sand but for a completely different hydrodynamic conditions: lower velocities but maintained during many time, maybe hours. In our case, the hydrodynamics shows peak velocities close to 5 m/s or more, but operating just few seconds, 10 to 20 in some cases. So the only way to obtain right parameters will be from real data measured in the tank lane during the cleaning operation.

5.4.4. Organic Sediment Behaviour

Next step is to study how is working self-cleaning system dealing with an organic material. It is also important to empathise that relative density is a very significant parameter regarding sediment transport. For that reason, sediment transport is really sensitive and the transport expected is higher than in sand scenarios.

As it was done on the last chapters the following results are obtained:

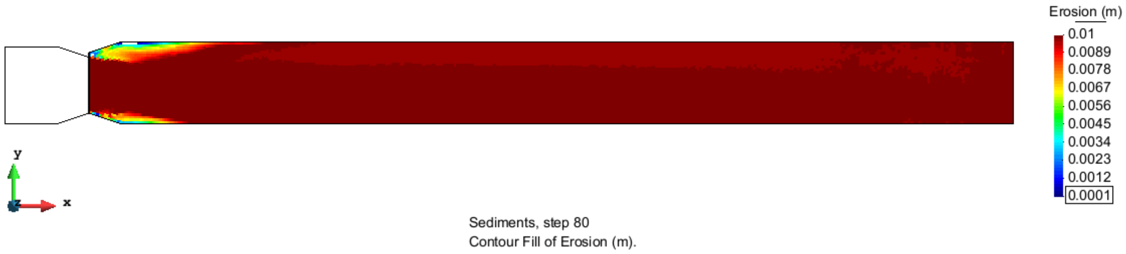


Figure 52. Erosion produced in 1 cm organic material case.

As it was expected, almost all the lane is cleaned. It is clear to distinguish how on the recirculation areas water energy is not enough to move all the material. The clear line which is separating the whole erosion and the partial erosion is similar with the recirculation boundary line studied on the hydrodynamic module. This behaviour drives again the proposal to narrow the lane to improve this cleaning deficiency.

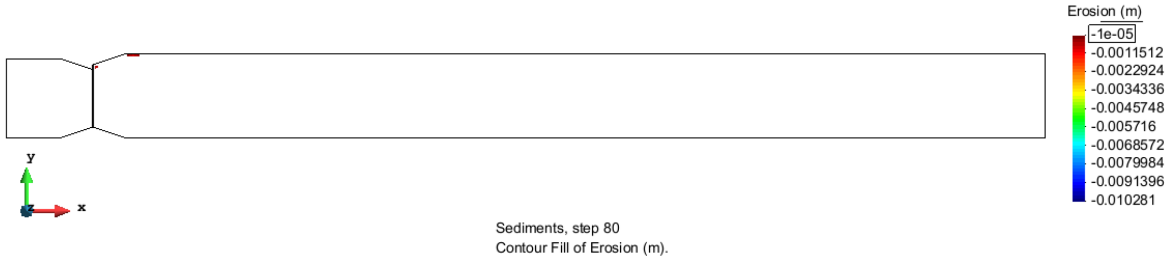
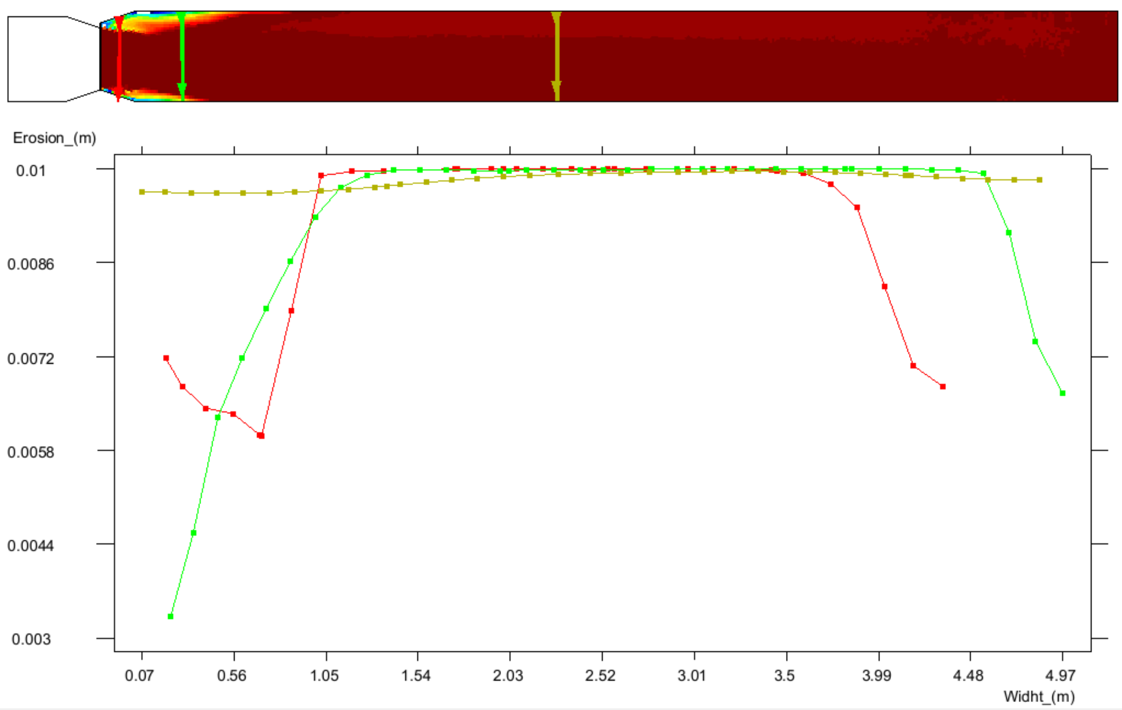


Figure 53. Sedimentation produced in 1 cm organic material case.

As it is seen on the previous figure all the material moved is eliminated from the system, a really small quantity of material is deposited on the left wall at the beginning of the lane. For this case the self-cleaning process is completely successful.



Graph 11. Several transversal section of the erosion.

In the previous graph shows how during all the process there is no sedimentation. The sediment transport occurs in all the sections where on the beginning of the lane (red and green one) the completely erosion happens on the middle while on the sides near the walls the erosion is lower due to the energy dispersion.

The erosion rate used for this scenario is sufficient to clean all the lane by one emptying of the storage chamber.

Regarding sand scenarios the organic situations with 3 and 10 centimetres are also shown on the annex number one. Following studied scenarios is 5 centimetres of organic material sediment.

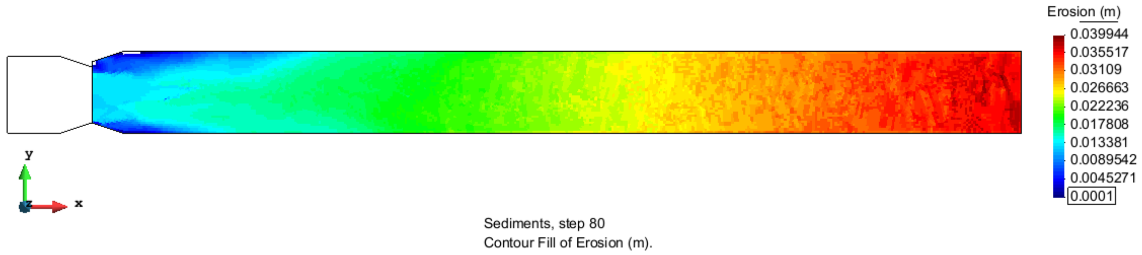


Figure 54. Erosion produced in 5 cm organic material case.

Special things occur in this scenario. The highest erosion is at the end of the lane and never reaches the maximum, therefore there are no areas completely cleaned. The maximum is around 4 centimetres still leaving one centimetre to clean. Moreover, it is distinguished where a clear wave-front is acting because of the sediment transport is homogenous regarding the width lane.

As all the cases in front of the gate the transport behaviour is the same, the middle is eroded while in the sides the difficulty is higher and the erosion is not as effective as in other areas.

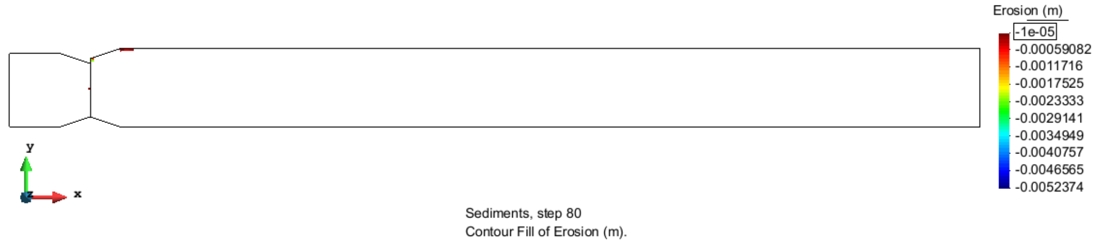
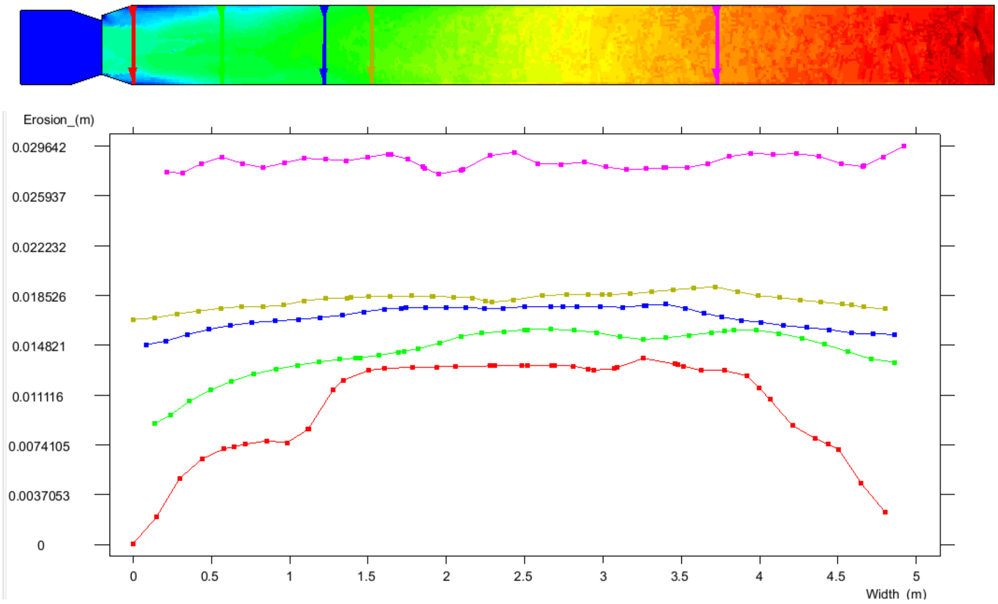


Figure 55. Sedimentation produced in 5 cm organic material case.

Regarding the deposition of the material, the results are exactly the same. That means that water has enough energy to move the material and at the same time transport this moved material out of the system without depositing sediment on the lane.



Graph 12. Several transversal section of the erosion.

Through this graph how the erosion is getting more homogeneous behaviour regarding the width of the lane is shown. Yet again, there is no sedimentation over the lane as it was mentioned in the last paragraph. The difficulties to erode and move the material on the sides are clearly represented on the line red and green one. On the other hand, looking at the blue and yellow one there erosion is also the same in all the width.

We can conclude that the parameters that were studied in the laboratory tests are not representatives in the operation of the tank. As it has been mentioned, the particular hydrodynamic condition requires to obtain real field data measuring the cleaning operation of a flushing event in order to achieve a right calibration.

5.4.5. Sensitivity analysis of sediment transport formulation

In this chapter the sensitiveness of the parameters for each formula are studied due to the results lead to the necessity of carry out a calibration using field data. In the suspended transport sedimentation the erosion rate (M) is the parameter which could be calibrated. On the other hand, in bed load transport two parameters (α and β) are used to calibrate the model.

Assuming that a significant part of the lane could be cleaned by one flushing process more simulations are run and by using M value of 0.0003 m/s (three times bigger than the first simulation) the following results are obtained:

Figure 56. Erosion between 4 and 5 cm in the 5 cm organic material case.

Here is shown where the emptying is able to transport out of the system more than 4 centimetres layer of material where the lane is almost completely clean. In the middle part just in front of the gate the erosion values reached are 3 centimetres while in the recirculation areas are from 1 to 2 centimetres.

Considering sand cases, conventional Van Rijn formula is not a suitable to define the sediment transport in this kind of success. For this reason and based on the results obtained by Van Rijn, Iber allows calibrate two parameters in the mathematical expression. In a similar way as was done with the erosion rate for the suspended sediment, in the following step how much sensitive is the bed load transport with both parameters will be analysed.

In order to represents the real behaviour in this infrastructure bed load transport formula should be calibrated to define the case. Iber contains AdHoc formula which allows to modify two parameters. This formula has the following structure:

$$q_{sb}^* = \alpha(\tau_{bs}^* - \tau_c^*)^\beta \quad (28)$$

This formula has a Meyer-Peter Müller structure and the parameters for the calibration are alpha and beta.

In other thesis dissertation accomplished in Universitat Politècnica de Catalunya (Espinal Navarro, 2012) Van Rijn correspond to MPM formula (Meyer-Peter Müller structure formula) with the alpha value of 5, beta parameter 2.45 and $\tau_c^* = 0.047$.

To study the sensitiveness of both parameters, using one of the previous scenarios and increasing 2 and 5 times each parameter separately the following results are achieved:

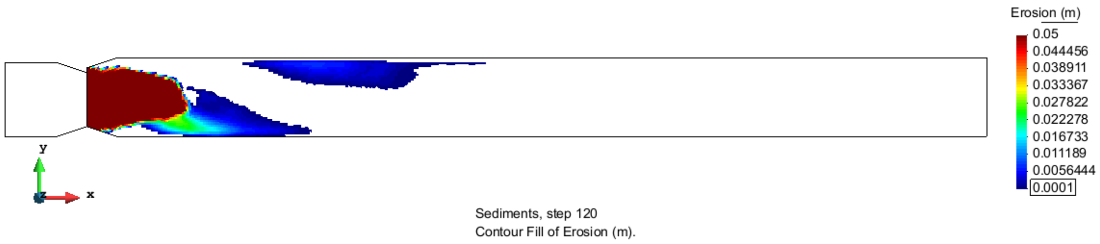


Figure 57. Erosion results for 5cm sands scenario. α=10 β=2.45.

At first appearance the results are the same than using Van Rijn formula. Looking with more detail the distance of the completely cleaning from the gate is little bit more of 6 meters, it is one meter more than the Van Rijn case. Moreover, the width of the eroded zone is also bigger but not in a significant way.

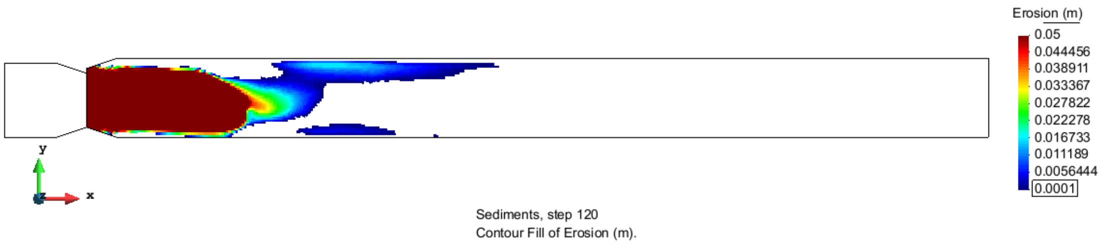


Figure 58. Erosion results for 5cm sands scenario. α=25 β=2.45.

Increasing five times alpha value, the erosion are starts to appear in the right side where the recirculation phenomenon is lower than in the left side and also the distance from the gate increases until 10 meters. Increasing 5 times alpha value the total cleaning distance increase 2 times regarding Van Rijn formula.

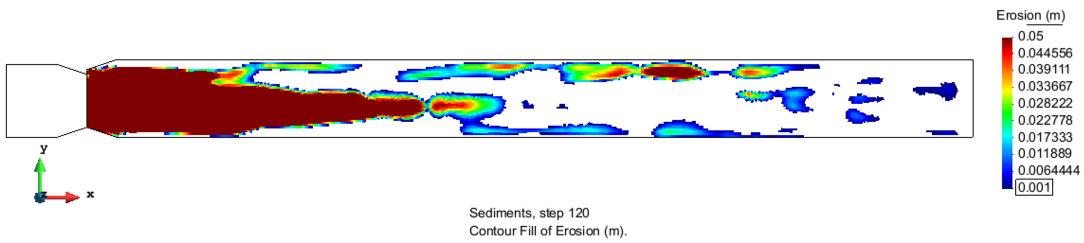


Figure 59. Erosion results for 5cm sands scenario. α=5 β=4.9.

Increasing the beta value the transport capacity increases significantly. The recirculation area keeps the difficulties to clean its material. On the other hand, the completely cleaning of the lane reaches 21 meters from the gate instead of the 5 meters that were reached using Van Rijn parameters. The totally cleaned area is getting narrow on the distance.

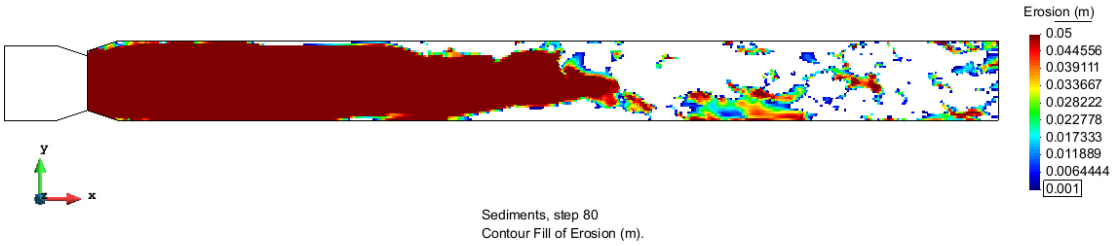


Figure 60. Erosion results for 5cm sands scenario. α=5 β=12.25.

Increasing 5 times beta parameter not also the erosion distance is increasing, also in the recirculation area is improved the sediment transport. In this case the distance from the gate is 35 meters and until the 20 meters water is also sweeping all the lane width.

According with this brief test, beta parameter is more sensitive than alpha parameter. On the other hand, when the beta parameter is changed at the end of the completely area zone is getting narrow, however when alpha parameter is modified the distance of the erodible zone is not highly increased but the width of this area is the same even in the last part of the completely erosion area.

Observing all the results achieved until this point, it seems suspended transport is more effective at the end of the lane while bed load transport is more active on the beginning of the lane. Using both sediment transport methods, the model could be calibrated assuming that in real cases of self-cleaning procedure in retention tanks the sediment transport is described by both methods. With the bed load transport parameters the beginning part could be adjusted while the erosion rate is to fit the end part of the lane.

A simulation of one case using conventional Van Rijn and for the suspended transport an erosion rate value of 0.0003 m/s studied in this chapter, the following results are obtained:

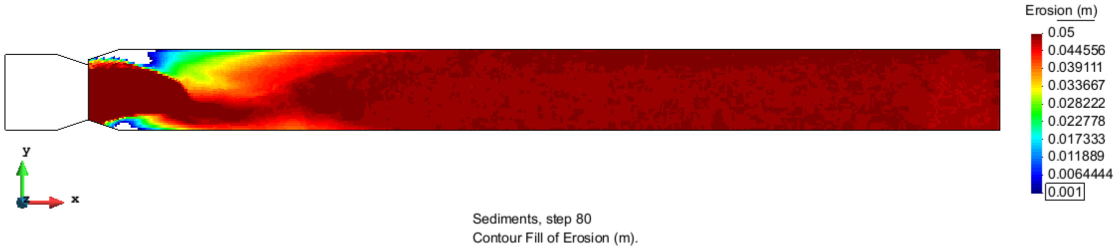


Figure 61. Erosion procedure combining bed load and suspended transport with organic material sediment.

As it has been mentioned, using both methods the highest erosion is just in front of the gate and then at the end of the lane. As all of the situations, side parts are the most difficult to clean and the material depositions (white area of the lane) are occurred on the recirculation zone.

It is worth noting that there is a necessity of do a validation. Using bed load transport parameters the beginning of the lane could be adjusted and by the suspended transport fit the rest of the lane. The model should be calibrated using real data taking into account the hydrodynamics of the cleaning lane to adjust all the parameters.

5.4.6. Second Flushing Simulation

The last simulation and possibly which requires a more complex and detailed work to assign in a proper way all the characteristics is the simulation for a second flushing process in order to be required in a real case.

Based on the results obtained on the first flushing by Iber an ASCII file of the bed elevation could be obtained. The bed elevation over the lane is changing regarding the erosion over the lane. In the pre-process, a rock layer position was assigned and the bed elevation could change until reach this rock layer position.

Generating this ASCII file and other ASCII file with the initial bed elevation without sediment over the lane using ArcGis software is possible to convert both files in raster file and operate with these raster fields. The idea is to rest both raster to get the exactly depth erosion produced on the lane.

The following step, has been to reclassify the values depth in 10 different ranges to generate a new raster field which define the new erodible layer and in this case is not constant over all the lane as it was in the first emptying process.

Using the conversion tools of ArcGis the last raster could be transformed in an ASCII file in order to import in Iber where by an external code provided by one member of Flumen Institute (Georgina Corestein) was possible to assign different erodible depth over the lane instead of assign to each element one by one its erodible depth.

Once all the steps are properly conducted the second flushing could be simulated in order to study it. First of all, by Iber_Tools window the mesh has to be edited, using the ASCII file obtained with the bed elevation after the first flushing the new mesh will be modified taking into account the erosion that was produced.

Figure 62. Bed elevation taking into account the first flushing procedure.

Once the new mesh is generated and using the external numerical code which was mentioned it is possible to assign the erodible depth regarding this new bed elevation to the elements taking into account the 10 ranges defined with ArcGis. This external code is able to link each element which contains a bed elevation value corresponding of one of the 10 ranges defined by reclassifying ArcGis tools obtaining the following distribution.

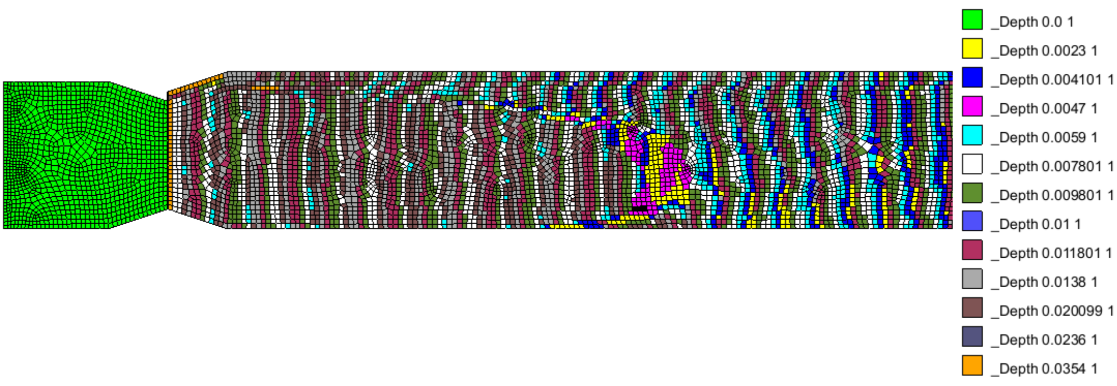


Figure 63. Erodible depth assigned for each element in order to simulate a second flushing. Sands.

The area which was eroded in the first emptying is clearly shown on the last figure and it is corresponding with the bed elevation shape shown in previous figure. Running the model second emptying results are obtained and exporting the ASCII files of the first and second flushing and doing the same procedure as it was explained in previous paragraph both erosion could be summed in order to get the final erosion.

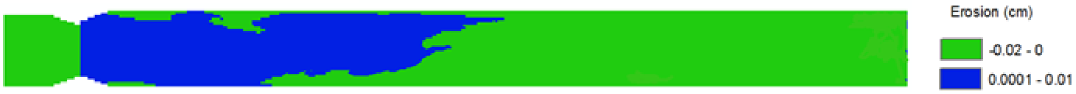


Figure 64. Erosion after two flushing events.

After the combination of both values by ArcGis the last result is obtained where the blue area is almost completely clean zone in the 1 centimetre sand scenario. By the second emptying the total erosion reaches 25 meters from the gate and then 5 meters more cleaning just a narrow part of the left side.

Due to in the 1 centimetre of organic material almost all the lane was cleaned, in the organic material scenario the second flushing event is run to 5 initial centimetre of sediment over the whole lane. By the same procedures next mesh regarding first flushing event has been generated:

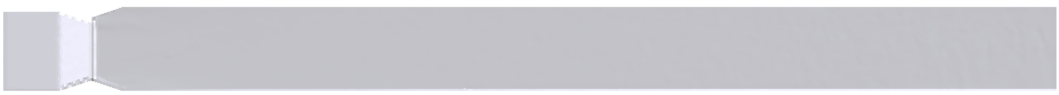


Figure 65. Mesh generated after the first emptying with 5 cm organic material.

In this case the mesh deformation cannot be appreciated clearly because of the sediment transport is more homogeneous than in the sand cases. On the other hand, in the erodible depth assignation the first flushing episode is clearer:

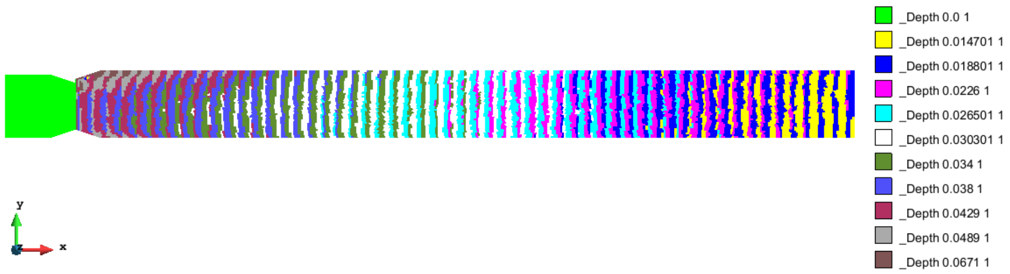


Figure 66. Erodible depth assigned for each element in order to simulate a second flushing. Organic Material.

In the last figure the depth assignation is shown in the same way that it was done in the sands case. The shape of the erosion is appreciated and running the model and exporting the ASCII files to ArcGis the total erosion of two flushing events are obtained:

Figure 67. Erosion after two flushing events.

Yet again, the total erosion after two cleaning events are shown. With 5 centimetres of organic material over the lane, two flushing episodes are enough to get a complete and successful lane cleaning. Blue colour represents erosion from 1 centimetre to 5 centimetre, the purple one is from 0 to 1 centimetre erosion and green one is non erodible area which means that the wall sides have the same problem than the other cases due to the energy dissipation in the recirculation zone.

5.4.7. Final Comments

As a result of analyse the Sediment Transport Module, the conflict areas in order to get optimal results using the self-cleaning system are detected. These areas were expected studying the hydrodynamic module.

Due to non-significant rainfall events the second visit to achieve real measures of the erosion inside the retention tank could not be done. On the other hand, based on cases with similar characteristics and using information of other studies that were carried out in PhD dissertation or thesis making tests with real data several scenarios have been modelled in order to study the sediment transport in La Estrella detention tank.

Based on experiences in the studied retention tank, the cleaning is successful by two or three flushes which means that Van Rijn formula does not fit to study the sediment transport with these particular hydrodynamic characteristics where the water is flowing by some sections less than 5 seconds.

Focussing on the organic material, the erosion rate from other studies could be not adequate in the current study due to this parameter also depends on the hydrodynamic behaviour inside the lane.

The proposal geometry to deal with recirculation phenomenon shows better results avoiding deposition near the walls and increasing the erosion distance from the gate. It was observed also, the deposition after the complete cleaning are is lower than using the original geometry which means that water can overflow more sediment material out of the system.

How alpha and beta parameters affect in the AdHoc formula has been studied based on the initial Van Rijn assumptions where the alpha and beta parameters are 5 and 2.45 respectively. Beta has been the most sensitive parameter in these study but as it was mentioned real data and real tests are required in order to represent with high accuracy the real behaviour to achieve an optimal and useful model for a future works.

Assuming both methods (bed load and suspended one) to describe the sediment transport over the lane the calibration could be adjusted using the parameters of each mathematical method to achieve higher precision on the beginning on the lane (calibrating bed load transport parameters) and at the end (erosion rate). Nevertheless, it is necessary to dispose of real field data to carry out the validation of the model.

6. CONCLUSION AND FUTURE WORK

The current thesis presents the 2D modelling of self-cleaning process for the longest lane of La Estrella retention tank. As a first conclusion, there is a lack of studies and experimental tests for the self-cleaning systems or at least, it this information exists is not published.

In order to calibrate a useful model, real data and analysis of samples are required to develop a more powerful and accurate tool.

Hydrodynamic behaviour of the event contains a lot of information about how could be the sediment transport over the lane. As a first analysis of the hydrodynamics characteristics the critical zone were located on the sides of the lane due to its geometry. This specific geometry causes on the beginning of the lane two recirculation zones where the water energy is dissipated decreasing the velocity in that areas due to next to the walls the velocity has an opposite direction regarding the flow direction.

Studying the recirculation phenomenon a boundary between the non-recirculation and the recirculation area was almost deducted and changing the geometry of the lane regarding this boundary the effectiveness of the self-cleaning process is improving.

The gate of the storage chamber is not installed symmetrically regarding the lane of the tank which causes different zones of erosion or deposition depending on the movement of the waves at the beginning of the opening gate. Also the distance between the gate and the walls is not the same for each side, there is 20 centimetres more on the left side causing highest magnitude order of values in the recirculation phenomenon.

Focussing on the sand scenarios, Van Rijn is not modelling in a right way the sediment transport due to its particular hydrodynamics. The first meters in front of the gate the total erosion is achieved while on the rest of the lane the sediment transport has not any effect. If the elevation of solids is higher, as is expected the cleaning process is less effective. Nevertheless, with real data of the material and one flushing event the proper calibration model could be developed by AdHoc formula which corresponds a Van Rijn formula using alpha value as 5 and beta value as 2.45. This is a confirmation that direct measurements to calibrate the parameters of the Van Rijn or any other expression are needed.

On the other hand, the organic material scenarios has been run with suspended sediment transport based on other researches carried out in PhD thesis studies in the Universitat Politècnica de Catalunya (UPC) to take benefit of real data that was achieved by several tests in laboratory conditions. As on the last case, the hydrodynamic is important to characterize the parameters of the sediment transport formula. In this case, the erosion rate is the most sensitive parameter and the initial values used to simulate the scenarios where not enough to clean all the lane by one emptying.

This erosion rate parameter must be used to calibrate this sediment transport expression and in cases as the flushing event in a retention tank where the water flows in some sections just for 3 or 4 seconds with the used erosion rate is not possible to clean all the tank by just one emptying. An erosion rate parameter has been determined for each scenario assuming that by one emptying the whole lane is almost cleaned (excepting the recirculation area which is in almost all the cases the mean problem).

Both sediment transport methods could be run at the same time in order to represents in a proper way a real event, where bed load parameters have more influence in front of the gate while suspended transport influences more on the rest of the lane.

Although it is not directly implemented in Iber, in the cases where more than one flushing event is required, it is possible to simulate the sediment transport for more than one emptying.

This thesis has covered a wide range of aspects in the area of flushing systems as a self-cleaning process in a retention tank and it has been analysed and observed in several proposed scenarios. Therefore, the recommendations for future work will be to develop the model through sample data and flushing events in order to achieve a calibrated and validated model useful for the operation and maintenance of the tank.

It is worth noting that to develop this studies in a future retention tanks could be taken into account in the design and implementation phase in order to optimize the alternative studies, to avoid future problems and to define the best geometry, the location of the gate or the storage chamber volume required regarding the construction and location area.

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