TECHNICAL UNIVERSITY OF CIVIL ENGINEERING OF BUCHAREST
FACULTY OF HYDROTECHNICS
HYDROTECHNICAL ENGINEERING DEPARTMENT

# PhD THESIS

## Summary

*SEDIMENT DYNAMICS IN THE AREA OF RESERVOIRS AND RIVER BED EVOLUTION*

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**BUCHAREST**

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*Eng. Laurențiu LUNGU*

# PhD THESIS CONTENTS

# INTRODUCTION

The PhD thesis entitled “Sediment dynamics in the area of reservoirs and river bed evolution”, developed within the Technical University of Civil Engineering of Bucharest, Faculty of Hydrotechnics, taps an existing issue both local and global, adding contributions into the field of study regarding sediment and erosion phenomena.

Reservoirs produce large discontinuities in terms of flow regime, leading to the cessation of alluvial transport, initially in the area of change of the flow regime (tail of reservoir), as well as changes in riverbed profiles and adjacent slopes. The loss of storage represents the main effect of the sedimentation phenomenon with direct consequences on the attenuation volume, as well as on its other functions.

Flood discharge through spillways reaches the downstream area with very high forces, concentrating significant excess kinetic energies. The results of an inadequate energy dissipation can have undesirable consequences during the operation period such as: the appearance of erosion pits downstream the dam, the exposure of foundations and subsequent loss of stability, bank erosion and degradation of adjacent uses, general erosion of the downstream riverbed, followed by the lowering of the downstream level.

Globally, the sedimentation phenomenon has a significant social, economic and ecologic impact and is a key issue in the sustainability of reservoirs. Anthropogenic intervention is significant and requires a sustainable management of water resources by monitoring and controlling sediment dynamics. The application of solutions in order to reduce the sedimentation rate must be standardized for each reservoir due to the different conditions of location, construction, operation etc.

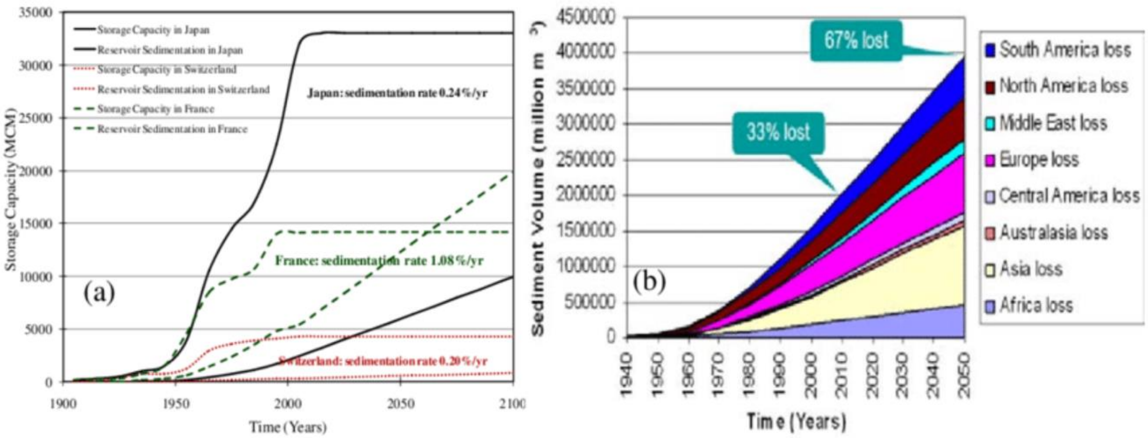
Sediment transport and erosion modeling represent difficult processes, due to the fact that the data used to assess morphological changes are extremely sensitive to a very wide range of physical parameters. The models represent calculation step-based models (transient), with time-consuming simulations, related to the analyzed time periods and meshing of the analyzed domain.

# SYNTHETIC PRESENTATION OF THE CHAPTERS

The PhD thesis entitled “Sediment dynamics in the area of reservoirs and river bed evolution” is structured in 9 chapters, of which the first 7 chapters present general notions regarding the sedimentation and erosion process, and the last 2 chapters are composed from the case studies.

**Chapter 1 and 2** present general notions regarding the problem of morphological changes both global and local in the Romanian rivers and reservoirs. At the same time, the effects of the sedimentation process are highlighted, as well as the reservoir sedimentation stages.

Currently, the gross storage volume of dams worldwide is 6 100 km$^3$, of which 2 000 km$^3$ of it has been lost due to the sedimentation process. According of the forecasts, without taking into account the execution of new dam constructions, it is estimated that by 2050 the total capacity of the reservoirs will be reduced by more than half




*Forecasts regarding the reservoir sedimentation*

In Romania the analysis of gathered data has revealed that in an average of 15 years, about 200 million m$^3$ of sediments have been deposited, almost half only in the reservoirs located on Arges and Olt rivers, with an annual rate of 13,4 million m$^3$, which represents 27% of the total multi-annual average sediment transport. The most important sedimentation rates were recorded on the reservoirs located on Arges river, average annual rates of sedimentation were registered at the reservoirs located on Olt, Bistrita and Ialomita, and low sedimentation rates are registered at large reservoirs as Izvoru Muntelui and Vidraru Dams.

**Chapter 3** presents general notions regarding the movement of alluvium, the alluvium proprieties, the criteria of assessing the riverbed stability, the transport and sediment depositing.

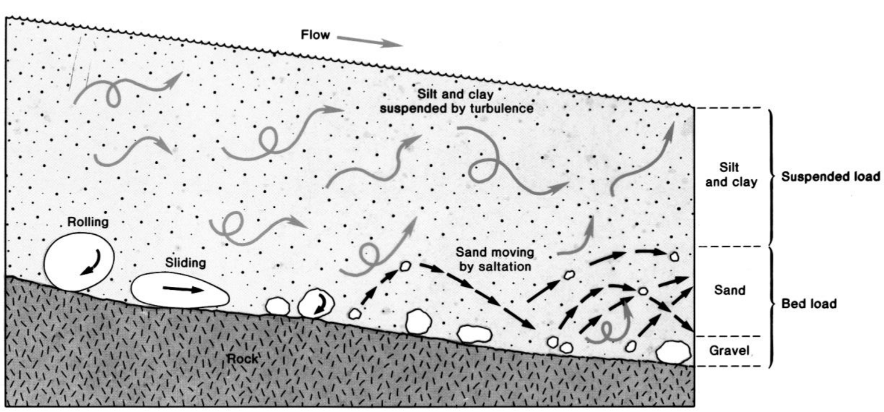
In nature, alluviums are made up of inhomogeneous particles with different shapes and sizes. Sediments can be characterized by granule size, specific gravity, particle shape, particle size, settling velocity.

The study of the movement of sediments highlights three phases: the erosion phenomenon, transport and deposit / sedimentation.

Erosion represents the dislocation and transport of particles throughout water. A particle is detached and tends to move due to the action of an active force (in the case of water the hydrodynamic force) and is held by its own weight and friction forces (in the case of water the friction force corresponding to the submerged weight).

Sedimentation represents the process by which suspended particles carried by water streams are deposited due to gravity. The sedimentation of the reservoir closely related to the settling rate which depends on the shape and size of the sediment particles, water density, settling rate. Depending on the method of transport, we encounter two types of deposits: alluvial deposits and the settling of the suspended load.

The forms of movement of an isolated particle can be: sliding, rolling, saltation or suspended movement.




*Alluvium movement*

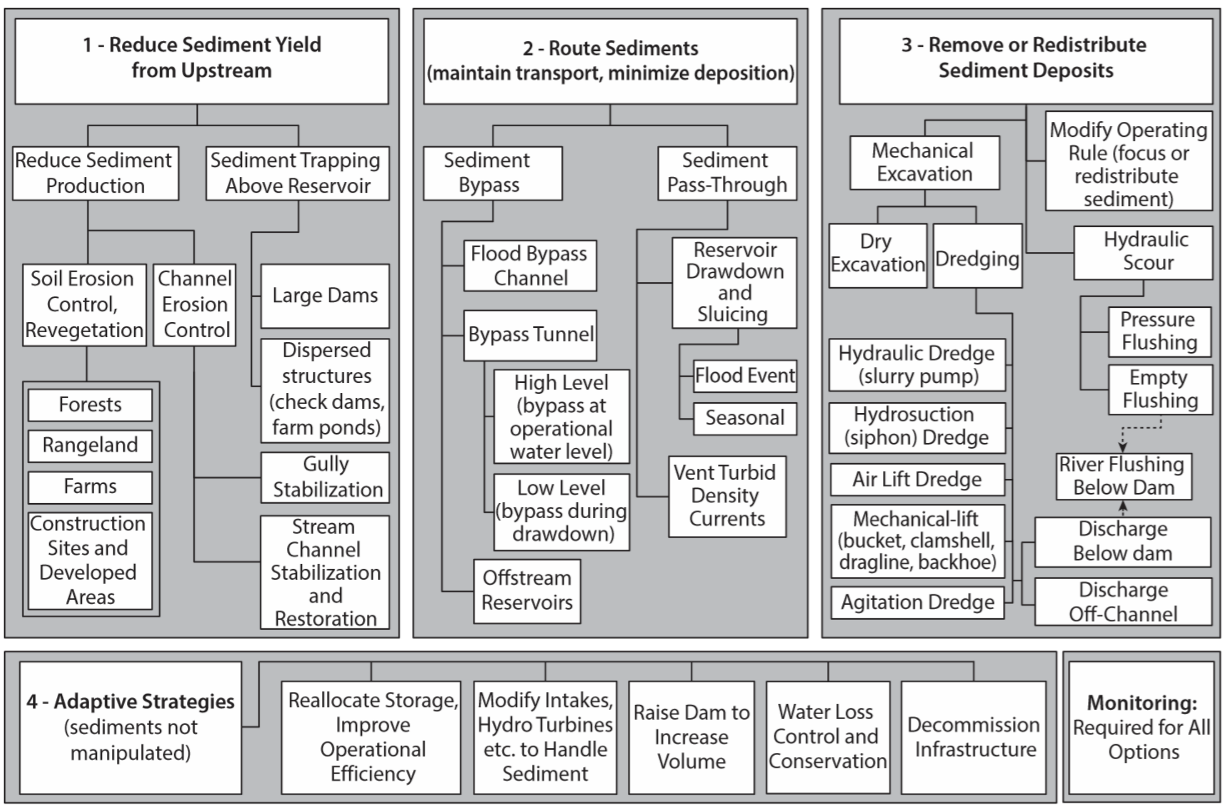
**Chapter 4** presents general notions regarding measures for sediment control in reservoirs. In order to extend the life of a reservoir, it is necessary to adopt a concept of both water and sediment management. Sustainable use is achieved by applying basic strategies for sediment control during the design and operation period.

*Reduction of sediment yield from upstream* – the amount of sediments can be reduced by source control of the erosion and upstream sediment retention.

*Sediment routing* – sediment that enter the reservoir can be hydraulically routed through sediment galleries or concentrated in areas where they can be easily removed without affecting the dam functions (water intakes, gates, etc.).

*Sediment removal* – by hydraulic washing, dredging or excavation during in dry weather.

*Adaptive measures* – including increasing the reservoir storage (raising the dam), adopting an specific operating rules etc.




*Sediment management strategies*

**Chapter 5** presents the evolution of the sedimentation process that occurred in the reservoirs Prundu, Pucioasa and Three Gorges Dam, that have undergone a strong sedimentation process since their commissioning.

According to the topo-bathymetric measurements performed in 1976, the Prundu reservoir, located on Arges river, was clogged between 1971 and 1976 in percentage of approx. 87%. Based on the visual observations made when emptying the reservoir, it was estimated that currently the degree of clogging is around 85%.

The bathymetry of the Pucioasa reservoir, located on the middle watercourse of Ialomita river, carried out during several years: 1993, 1999, 2002, 2006, 2009, 2010, 2016, reveals a reduction by one third (33%) of the storage at Normal Retention Level, between the years 2010-2016, from 3,31 to 2,22 million $m^3$.

Studies conducted on the Three Gorges Reservoir, located on Yangtze river, have shown that the amount of sediment deposited annually in the reservoir is about 1,64 billion tons, only 40% of the projected value during the design period, the highest part (50% of the annual amount) being deposited during a single flood. The results of the analyzes according to which the sedimentation process occurs in a single flood offer advantages for optimizing measures to control the amount of sediments discharged from the reservoir during flood events, respectively the amount deposited.

**Chapter 6** presents solutions for erosion control in the discharge area, respectively energy dissipators.

Flood discharge through spillways reaches the downstream area with very high forces, concentrating significant excess kinetic energies. The results of an inadequate dissipation can have undesirable consequences during the operation period such as: the appearance of erosion pits downstream the dam, the exposure of foundations and subsequent loss of stability, bank erosion and degradation of adjacent uses, general erosion of the downstream riverbed, followed by the lowering of the downstream level. The hydraulic jump associated with energy dissipation represent a decisive element in the design of the stilling basin. The constructive solution is chosen based on the analysis of several criteria such as: the hydraulic phenomenon, nature of the downstream uses and riverbed, the type of construction they serve.

**Chapter 7** presents two examples of hydrotechnical structures from Romania affected by the phenomenon of the riverbed lowering, respectively the displacement second step of the stilling basin of the dam and powerplant Movileni and also the Ogrezeni dam accident.

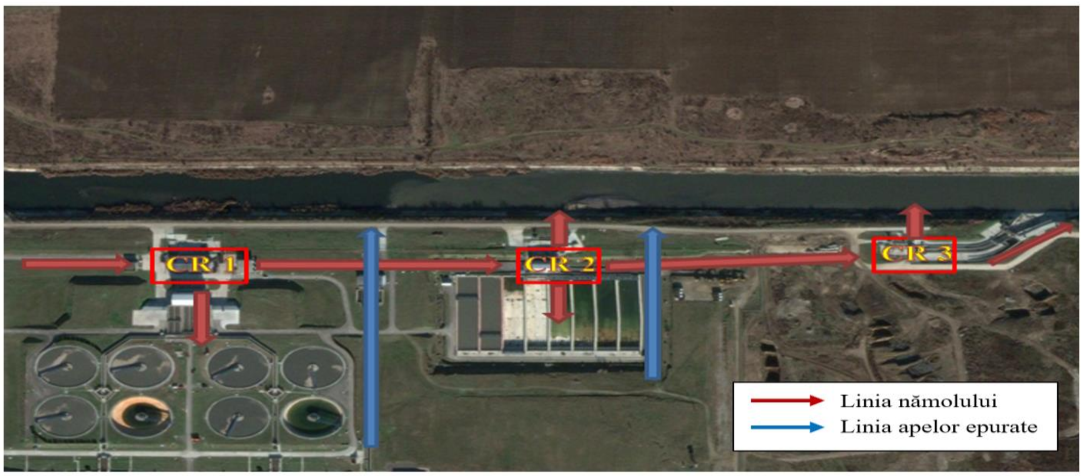
The lowering of the riverbed directly leads to the increase of the hydraulic gradient and at the same time in the seepage flow, having a negative impact on the hydraulic jump associated with the energy dissipation. The most dangerous effect regarding dam safety is the regressive erosion that affects the foundations of the rear aprons and stilling basins and sometimes even the dam foundation itself. The processes occur due to the cumulative effects of the aggregate exploitation and the decrease of sediment input, when the natural passage of the sediment transport is interrupted by upstream dams. At the same time, the significant flows transported during the flood periods have an important effect.

In Romania, among the structures affected by the lowering of the riverbed are: at the Movileni dam located on Siret river, the downstream protection of the 3$^{rd}$ stage collapsed in the erosion pit on a length of approximately 71 m, in the center of the downstream improvement area; at the Ogrezeni dam located on the Ialomița river, the erosion of the foundation of the rear apron and stilling basin.

**Chapter 8** presents the first case study that focuses on the mathematical modeling of the sediment process in the Dâmbovița river. The case study was conducted on Dâmbovița river, in the port area, located in the proximity of the Wastewater Treatment Plant of Bucharest.

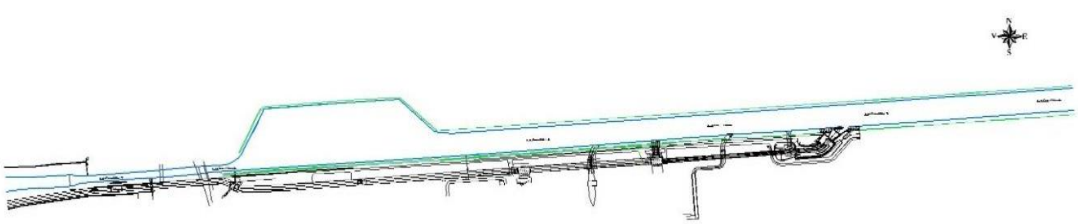

*General layout*

The wastewater of Bucharest is collected through the unitary sewerage system and transported to the Glina treatment plant through the Wastewater Cassette. The connection between the Wastewater Cassette and the WWTP is made through 3 connection chambers as follows: CR 1 – biological treatment stage, CR 2 – mechanical treatment stage (storm basins) + emissary spillway and CR 3 – connection with Phase II + emissary spillway. Downstream CR 3 there is an open channel that connects with Dâmbovița river. In addition, upstream the WWTP is located the NH Popesti Chamber where a spillway is designed in order to ensure, during extreme rain events, the discharge of excess water into the emissary.



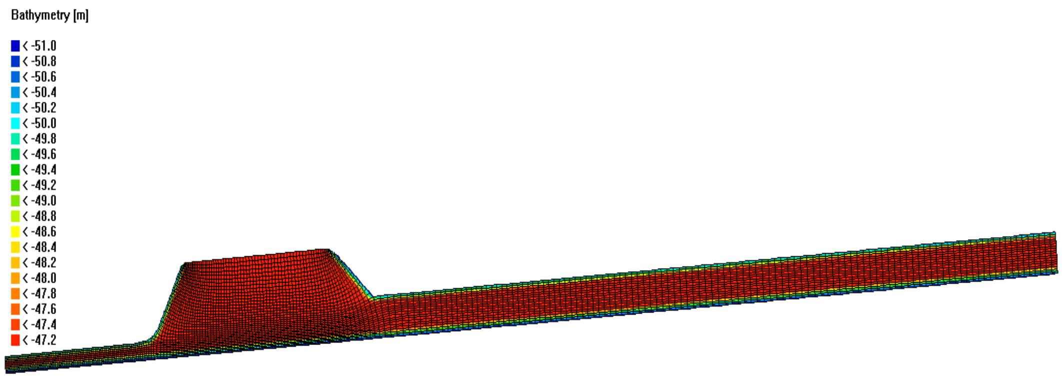

*Layout with the location of WWTP Glina discharges*

The mathematical modeling was performed through the Delft3D software package, based on a meshing of the analyzed domain, with curved-linear elements on which were subsequently added the bathymetry and boundary conditions related to the Dambovita river and the operation conditions of the WWTP.

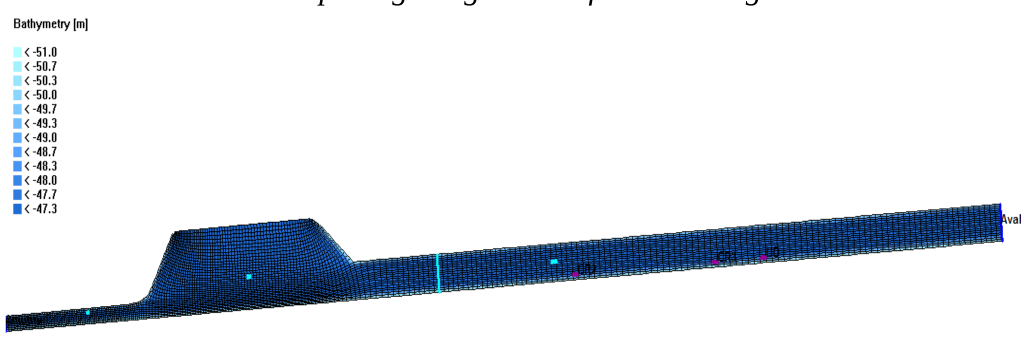


*General layout of the analyzed domain*

The general limits were introduced, after which the area was meshed, first 2D, following that the node depths of the created grid to be established from the cross sections conducted in the topo-bathymetric study. The boundary conditions for the upstream section were extracted from the hydrometric records, and for the downstream the depth-flow key was imposed. The WWTP discharges were introduced in accordance with the measurements made by the monitoring equipment, located based on to the field data. The associated sediment concentrations were also added to the boundary conditions. The resulted grid allows morphological analysis in calculation steps depending on the imposed boundary conditions.




*Morphological grid with final meshing*




*Morphological grid with the location of the boundary conditions*

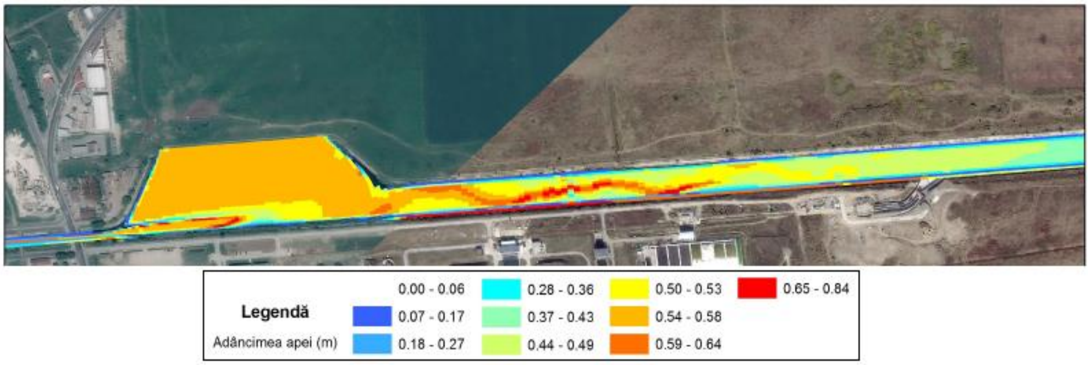
The model is a step-by-step calculation model and is calibrated to ensure the accuracy of the results, the time step for which the morphological update is made is less than one minute. If referred to the analyzed time periods (order of years even decades) this calculation step confers a very high accuracy. The fine meshing (elements 3x3 m) and the small time step (seconds) lead to time consuming simulations (about 7 days / model).

The analysis was made based on a number of 5 scenarios that try to simulate the situations most likely to occur in reality in Dâmbovita River. For the modeling the following conditions were considered: discharges and sediment load of N.H. Popesti, WWTP Glina (treated water), side discharges (CR 2 and CR 3) and open channel (CD).

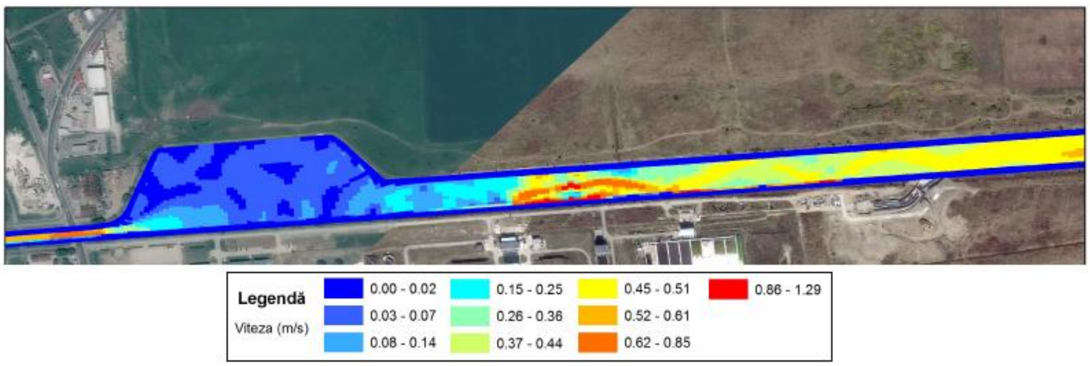
1. ***Daily operation scenario*** *– daily average flow on Dâmbovița river and WWTP with normal operation with the discharge of treated water.*
2. ***Rainfall scenario with discharge*** *– a flow of 30 m$^3$/s on Dâmbovița river, flow discharged by the N.H. Popesti spillway, as well as discharge of treated water according to scenario no. 1 and flows from CR 2, CR 3 and open channel according to the operation conditions.*
3. ***Rainfall scenario without discharge*** *– daily average flow on Dâmbovița river, discharges of WWTP Glina and additional flows through CR2 and CR3 according to the operation conditions.*
4. ***Normal operation during one year scenario for highlighting the monitoring sections*** *– based on the analysis of recorded data there are 295 days according to scenario 1, 40 days according to scenario 3 and 20 days according to scenario 2, their alternation being corresponding to the year 2015.*
5. ***Sediment flushing scenario*** *– based on the sediment distribution obtained in Scenario 4, several simulations were performed to remove the sediment deposits by flushing. Thus, it was assumed a 6 hours flow of 45 m$^3$/s on Dâmbovița river (flow discharged from lake Morii). A first hypothesis consists in flushing after 3 months of operation, after 6 months, after 9 months and after one year. In a second hypothesis, the flushing was assumed every 3 months.*

The parameters that can be observed with the help of the model are: velocity distribution in every node of the discretization (both water and sediment), erosion / sediment at any calculation step, water level variation, flow variation, etc.

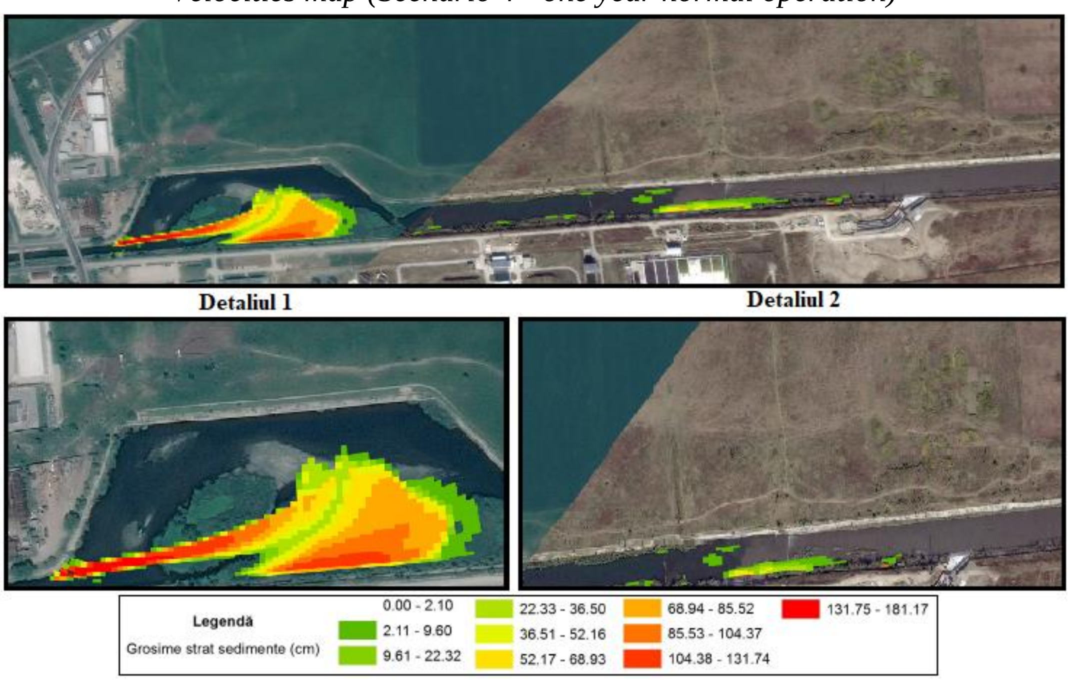
The amount of sediment deposited resulting in the simulation of Scenario 4, Normal operation during one year scenario, is **22 545 509 kg**, which for a volumetric mass of sediments between 2100 – 2800 kg/m$^3$, the volume deposited in Dâmbovița river will be between: **8 050 – 10 730 m$^3$/year**.




*Water depth map (Scenario 4 - one year normal operation)*




*Velocities map (Scenario 4 - one year normal operation)*

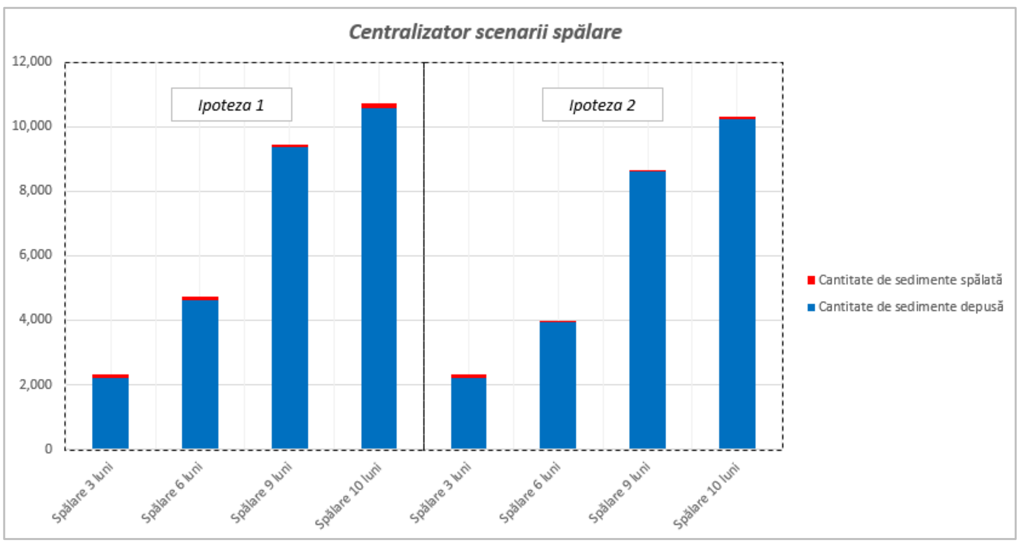



*Sediment layer map (Scenario 4 - one year normal operation)*

The case study aimed to determine the problems related to the sedimentation and reduction measures of Dambovita river in the adjacent area of the Wastewater Treatment Plant Glina. The increase in levels in the river, especially in the port are, can lead to the blockage of the discharges of Glina WWTP, as well as to the flooding of the neighboring areas by decreasing the transport capacity of the cross section.

The removal of deposits from the river can be done by mechanical, hydromechanical means, or by flushing, the last mentioned being previously analyzed in the case study which highlighted the evolution of the amount of sediment in the riverbed after supplementing the flow. The amount of sediment flushed is relatively small compared to the amount of sediment deposited, the flushing having a significant impact on the distribution of alluvium in the riverbed.

In order to reduce the clogging phenomenon, measures can be taken such as: building a wall from metal sheet piles (continuous or alternating) in the port area, with a direct result in cross section reduction and an increase in flow rates, consequently leading to the entrainment of alluvium particles, or sediment management by concentrating them in area where they can be easily removed. The effectiveness of the measures can be determined with the help of a mathematical model.

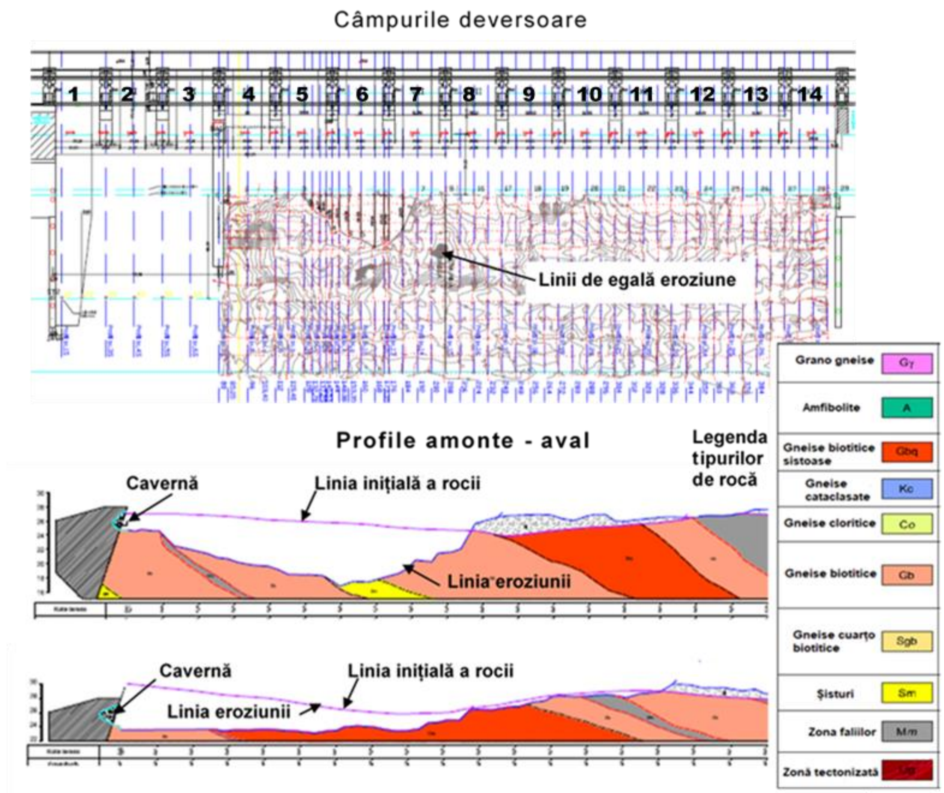



*Graphical analysis of the removed sediment by flushing*

Knowing the dynamics of the sedimentation process is of great interest, in this sense it is necessary to conduct periodic bathymetric maps to be compared with the initial conditions or previous measurements, in order to estimate the degree / rate of sedimentation and the main negative effects that may occur.

**Chapter 9** presents the second case study that aims to determine the causes of the morphological changes downstream the hydropower and navigation dam Iron Gates I located on the Danube river.

After a period of 40 years from the commissioning of the Iron Gates I, the geometry of the downstream the stilling basin has undergone changes in certain areas. The conducted measurements (surface of 441 x 100 m) highlighted the evolution of erosion in the Danube riverbed, downstream the stilling basin, and also detected the appearance of the degradation in the concrete at the terminal threshold of the stilling basin (extended caverns). The highest depth of the erosion pit in the bedrock was 11,44 m downstream the spillway field no. 9.

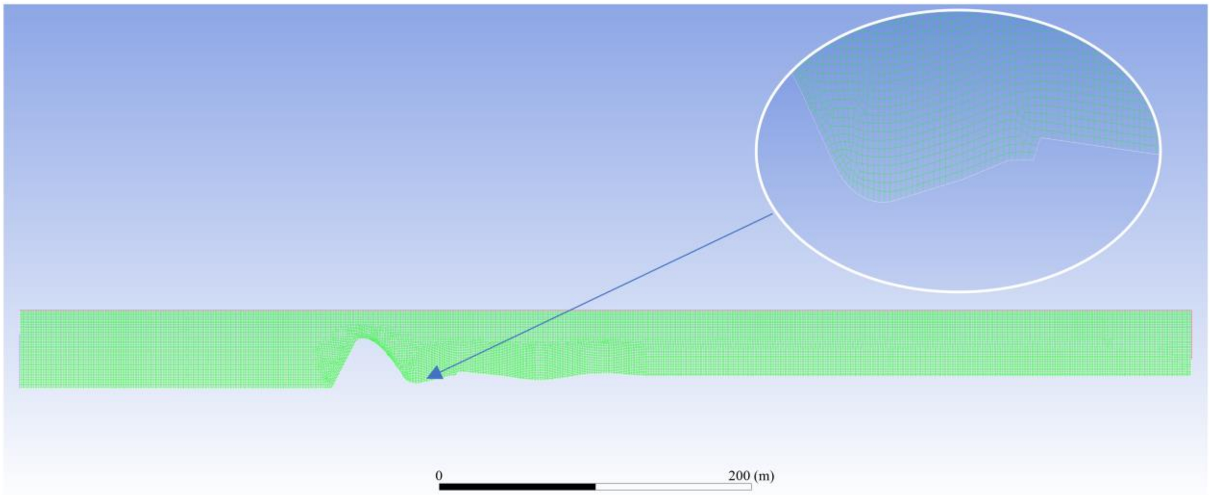



*Morphological changes downstream the Iron Gates I dam (2010 measurements)*

The mathematical modeling of the erosion phenomenon was performed through the software Ansys Fluent for computational fluid dynamics (CFD), on 3 distinctive profiles based on the evolution of the erosion line downstream of the Iron Gates 1.

The length of analyzed domain used for the mathematical model is 1000 x 50 m (300 m upstream / 700 m downstream), on which was assigned a 2D meshing with curved-linear elements with values below 1 x 1 m / cell. The model is a computational step-by-step (transient), turbulent (kepsilon), ”multiphase” (biphasic water / air) and ”discrete phase” model in order to assess the downstream erosion.

The model was based on dam geometry data, bathymetry measurements and recorded data of specific flows, levels and loads both upstream and downstream of the targeted section. The boundary conditions for the upstream and downstream were extracted from the hydrometric records as follows: for the upstream velocity (m/s), and downstream was imposed the average water level recorded.



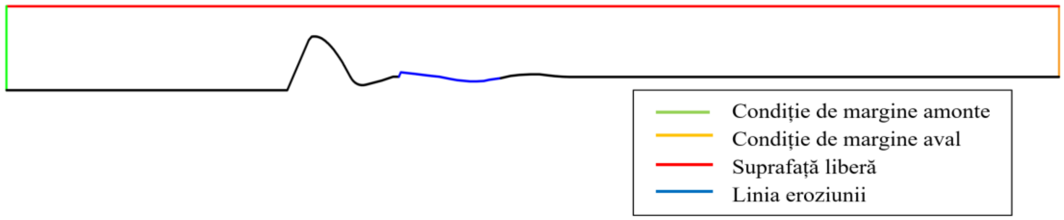

*Meshing of the domain*

For the upstream boundary condition, the load of sediments was assigned, which was determined as the average load of the recorded data for the targeted section. This resulted in an average load of 2000 kg/s, with fine particles with a diameter of 0,1 mm for which a density of 2500 kg/m$^3$ was considered according to the literature.

The fine meshing (elements of maximum 1 x 1 m), the length of the domain (1000 m x 50 m) and very small time step (0,05 s) lead to simulation time of approximately 5 days.

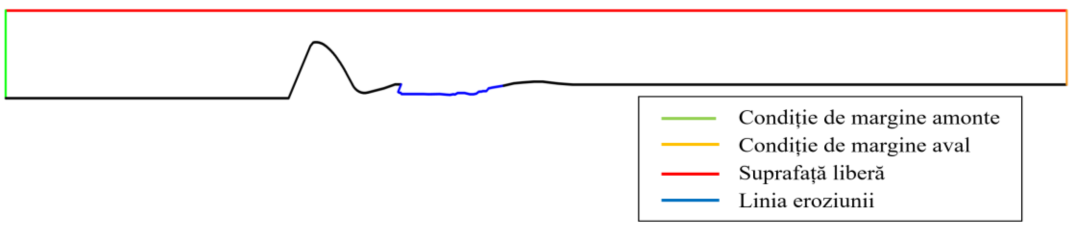
For the mathematical modelling, were considered a number of 4 scenarios, on 3 distinct profiles based on the evolution of the erosion line downstream of the Iron Gates 1. For the upstream was considered a wide range of flows starting from 10 m$^3$/s·ml to 65 m$^3$/s·ml, with an average recorded load of 2000 kg/s and the above-mentioned particle proprieties. The downstream boundary condition was considered as the average water level registered at the Drobeta Turnu Severin hydrometric station, located downstream the domain.

1. ***Initial morphology simulation*** *– the first scenario is based on the initial morphology downstream the stilling basin in order to highlight the erosion zones. The simulation was performed for flows starting from 10 $m^3/s \cdot ml$ to 65 $m^3/s \cdot ml$, with an average sediment load of 2000 kg/s and the above-mentioned particle proprieties. The downstream condition was imposed as the average recorded water level.*



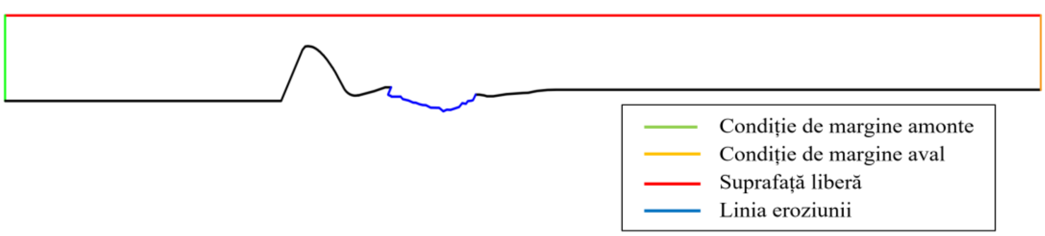

*Scenario 1 geometry – initial morphology*

2. ***Medium evolution of the erosion line simulation*** *– the second scenario is based on the morphology of the downstream riverbed resulting from bathymetric measurements, being considered as an average depth of erosion. The boundary conditions are similar to scenario no. 1.*




*Scenario 2 geometry – medium erosion line*

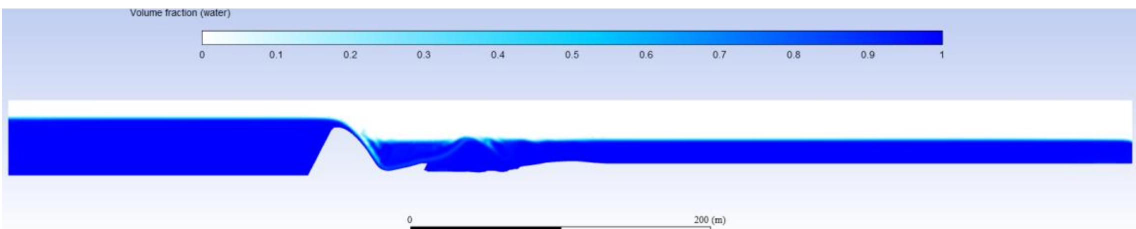
3. ***Actual erosion line simulation*** *– based on the morphology of the downstream riverbed resulted from bathymetric measurements, being considered as the current depth of erosion. Boundary conditions similar to those in scenario no. 1.*



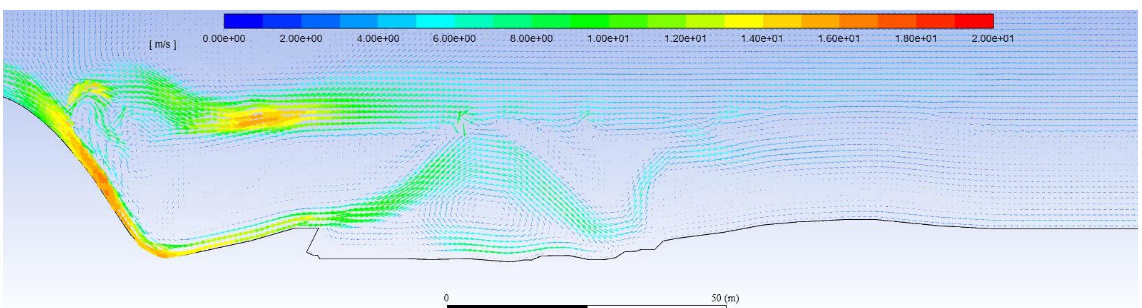

*Scenario 3 geometry – actual erosion line*

4. ***Simulation of the Iron Gates II influence*** *– scenario 4 represents a hypothetical simulation for the designed conditions, without the influence of the Iron Gates II, in order to compare the evolution of the downstream riverbed and the determine the influence of the second dam. The simulation is based on the morphology used in scenario no. 2m and the downstream boundary condition was imposed as free water level.*

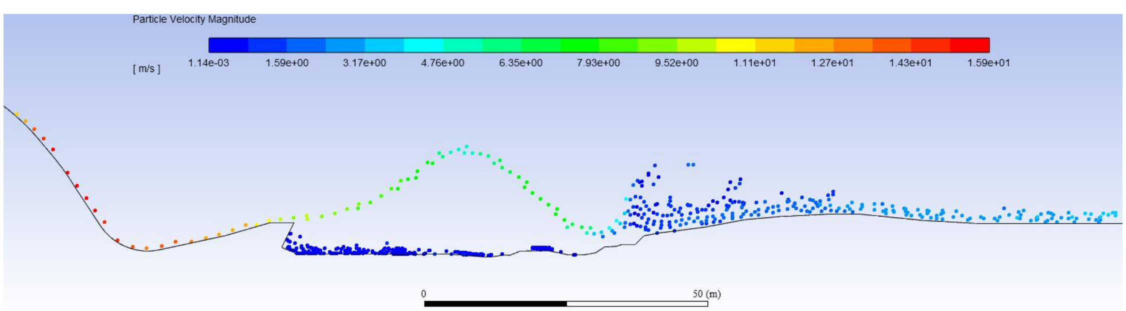
The parameters that can be observed using this model are: velocity distribution and velocity vectors orientation at any point of the grid erosion distribution as a result of the abrasion phenomenon, solid flow distribution relative to different parameters (speed, diameter, etc.), pressure distribution, water balance etc. Following the simulations, the maps of the velocity vectors, the erosion zones as well as the distribution of the solid flow with the afferent velocities were extracted.



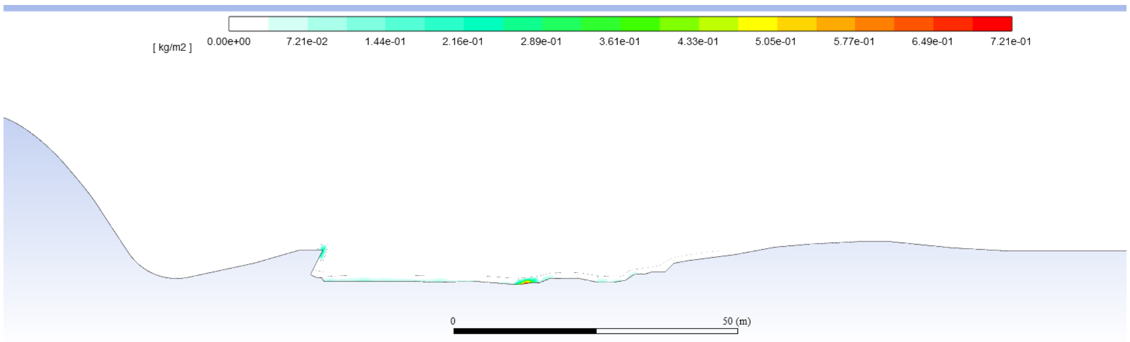

*Water volume distribution for a flow rate of 30 m$^3$/s·ml – medium profile*




*Velocity vectors for a flow rate of 30 m$^3$/s·ml – medium profile*




*Solid flow distribution for a flow rate 30 m$^3$/s·ml – medium profile*




*Erosion zones for a flow rate of 30 m$^3$/s·ml – medium profile*

The case study aimed to determine the problems related to the erosion phenomenon of the riverbed downstream the Iron Gates I dam, which formed during the operation period. The most important consequences of the erosion phenomenon are the erosion caverns in the stilling basin, which are evolutive in nature and can endanger the safety of the dam.

With the help of Ansys Fluent software, for computational fluid dynamics, mathematical models were conducted for the qualitative evaluation of the potential erosion areas (by abrasion), for different profiles of the downstream riverbed (initial, medium and actual morphology). At the same time, a hypothetical simulation was performed for the designed conditions, without the influence of Iron Gates II, in order to compare the evolution of the downstream riverbed.

The simulations revealed that the erosion phenomenon is closely related to the discharged flows and the morphology of the downstream riverbed. The simulation of the actual condition, with the maximum erosion depth, indicates that the process of erosion in the riverbed will stabilize. However, the degradation of the concret of the downstream stilling basin has a dynamic and evolutive nature, due to the turbulence and vortices produced during the discharge.

A first cause of the uneven depths of erosion along the discharge fields is the uneven distribution of the duration and volumes of water discharged. The most important depths were formed in the areas of the spillways through which the highest maximum flows and with the longest discharge time were evacuated. Another cause in terms of the distribution of the erosion may be the different erodibility of the riverbed downstream the dam. The geological map of the downstream area indicates that next to each spillway there are different representative rocks, with different resistance to erosion.

## BIBLIOGRAPHY

Administrația Bazinală de Apă Argeș-Vedea (2011). *Amenajarea hidrotehnică Pitești*.

Annandale, G., Morris, G., Karki, P. (2016). *Extending the life of reservoirs, sustainable sediment management for dams and run-of-river hydropower*. International Bank for Reconstruction and Development / The World Bank

Dimache, G. *Evaluarea stării de siguranță în exploatare a acumulării Crivina – Ogrezeni, Vol. 1, Vol. 2, Vol. 3, Vol. 4, Vol. 5*. București

Giurma, I. (*1983*). *Studiul influenţei bazinelor de recepţie asupra procesului de colmatare din lacurile de acumulare mijlocii şi mici.* Hidrotehnica.

Giurma, I., Stănilă Al. (1988). *Contribuţii la dimensionare şi protecţie împotriva colmatării*. Iași

Giurma, I. (1997). *Colmatarea lacurilor de acumulare*. Ed. H*G*A*, București.

Institutul Național de Hidrologie și Gospodărire a Apelor (2016). *Studiu batimetric acumulare Pucioasa*.

Institutul National de Cercetare Dezvoltare pentru Geoelogie si Geoecologie GEOECOMAR (2019). *Măsuri de protecție suplimentară a disipatorului barajului deversor Porțile de Fier I – Etapa I Studii de teren.* București

International Committee of Large Dams (2017). *General report – Reservoir sedimentation and sustainable developement*, Praga.

International Committee of Large Dams (2018). *General report – Reservoir sedimentation and sustainable developement*, Viena.

Ionescu, F. (1971). *Studiul mișcării aluviunilor*. București.

Ionescu, F. (1974). *Modelarea matematică a sedimentării acumulărilor*. București.

Mateescu, C. (1963). *Hidraulică*. Editura Didactică și Pedagogică, București.

Miotiu, C., Marin, G (1999). *Ingineria râurilor. Regularizarea râurilor și îndiguiri*. Ed. BREN, București.

Morris, G., Fan, J. (2009). *Reservoir sedimentation handbook. Design and management of dams, reservoirs, and watershed for sustainable use*.

Novak, D., Popescu, M. (2013). *Soluţie tehnică pentru remedierea eroziunilor apărute la disipatorul de energie al barajului deversor Porţile de Fier I*. Hidrotennica, vol. 58.

Popescu, C. (2012). *Evaluarea rezultatelor principiilor metodei acustice de înaltă rezoluţie şi a aparaturii aferente propuse pentru măsurarea / caracterizarea volumelor şi tipurilor de* *sedimente transportate în suspensie de către râuri precum şi a grosimii straturilor sedimentare*. Universitatea Tehnică de Construcții București.

Popescu, C. (2012). *Proceduri de prioritizare, identificare si trasare a ariilor tehnologice in domeniul aparaturii pentru caracterizarea hidrodinamicii sedimentelor.* Universitatea Tehnică de Construcții București.

Popovici, A. (2000). *Dams in Romania*. Romanian International Committee on Large Dams, Monitorul oficial, București

Popovici, A. (2010). *Expertiza stării disipatorului barajului deversor de la Porțile de Fier I cu propunere de măsuri pentru protecție suplimentară*. București

Prişcu, R. (1974). *Construcții Hidrotehnice – Volumul I*. Editura Didactică și Pedagogică, București.

Prişcu, R. (1974). *Construcții Hidrotehnice – Volumul II*. Editura Didactică și Pedagogică, București.

Răzvan, E. (1974). *Ecuaţia mişcării neuniforme a unui curent de densitate cu aplicare la prevenirea sedimentării acumulărilor*. Editura Academiei.

Răzvan, E. (1974). *Despre sedimentarea acumulărilor*

Stematiu, D. (2008). *Mecanica rocilor pentru constructori.* Conspress București

Stematiu, D. (2011). *Expertiza starii disipatorului barajului deversor Portile de Fier I faza II* . Studiul de fezabilitate - Punct de vedere al consultantului roman.

Stematiu, D. (2016). *Evaluarea stării de siguranța in exploatare pentru AHE Movileni*.

Strand, R,, Pemberton, E. (1982). *Reservoir sedimention.* Denver, Colorado

## LIST OF WORKS AND PUBLICATIONS

Popescu, C., Lungu, L., Mihailovici, M., Zaharia, V. (2017). *Analysis of river morphology in the downstream area of an urban dam and river segment*. International Committee of Large Dams

Popescu, C., Mihailovici, M., Zaharia, V., Lungu, L. (2018). *Analysis of multi-purpose reservoirs subjected to heavy sediment deposits*. International Committee of Large Dams

Popescu, C., Lungu, L., Zaharia, V., Sarghiuta, R. (2018). *Mathematical modelling and interpretation of results for siltation phenomena of rivers in the vicinity of reservoirs*. EENVIRO