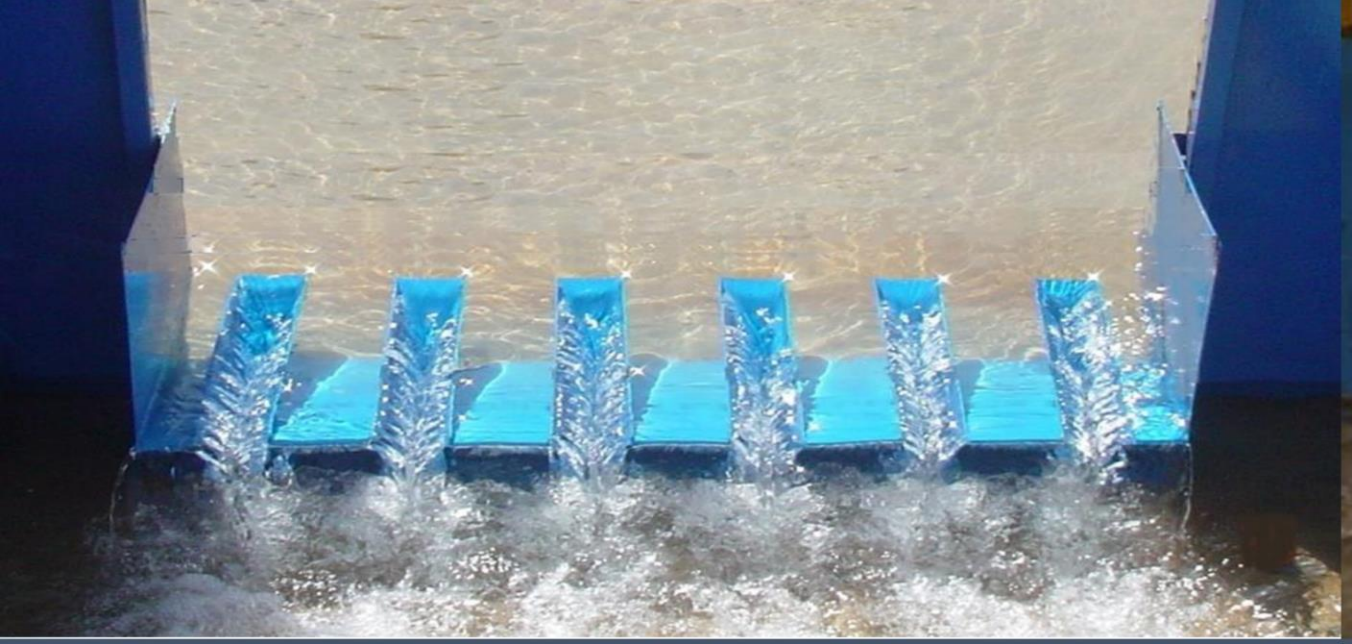
Mohamed Khider University of BISKRA – Algeria-
Laboratory of Hydraulic Planning and Environment

International Workshop on Labyrinth and Piano Key Weirs

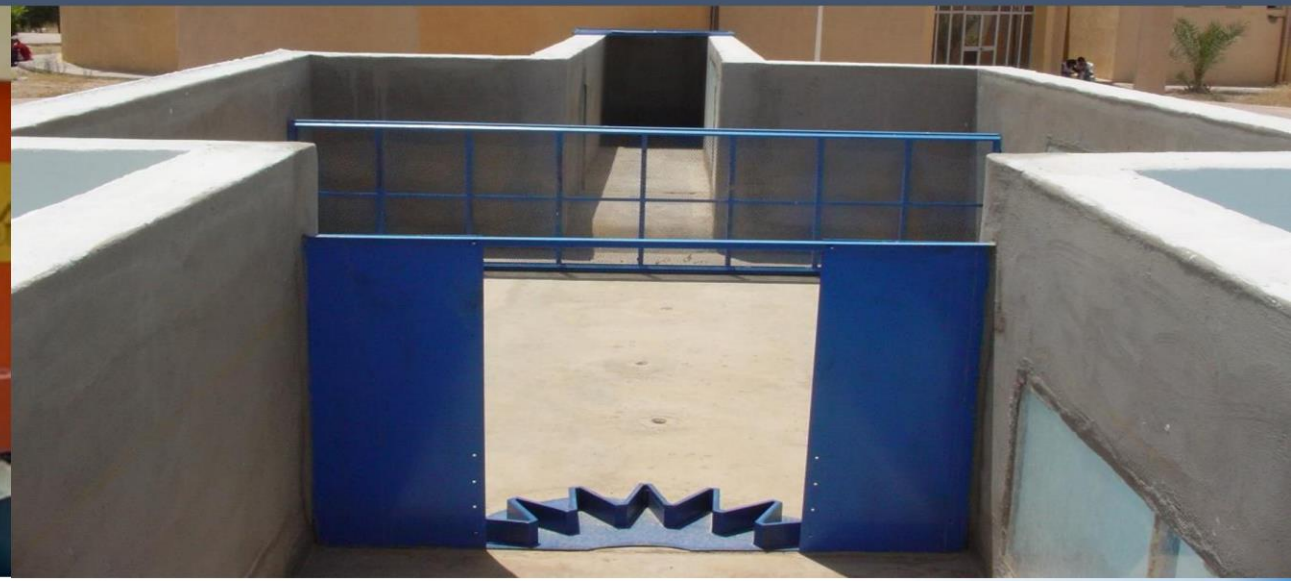
Marseille - France
Juin 2022

Twenty five years of research in Biskra University for Labyrinths, Piano Key Weirs and associated Fuse plugs And existing prototypes in Algeria

Presented by: Ahmed Ouamane



Twenty five years of Research in Biskra University for Labyrinths, Piano Key Weirs and associated Fuse plugs



These twenty five years have been marked by three research phases:

In the first phase, 1996-2000, several research projects were conducted on the shaft spillway and in particular the labyrinth weir in order to optimize its hydraulic efficiency.

The second period of 2001-2003, was the subject of intensive research for development of a new type of labyrinth weir. The Laboratory of hydraulic development and environment of Biskra University has been deeply associated with Hydrocoop-France. the hydraulic theory and permanent experimental research of Biskra are associated with a practical approach of HydroCoop on shapes optimization, structural design, structures, construction facilities and cost efficiency.

Some specific tests coordinated by HydroCoop in France, China, India and Vietnam have used to validate the permanent tests in Biskra.

The last phase, 2003-2021, was the has been focused in particular on the optimization of PK-Weir, labyrinth weir, several study of the Fuse plugs and combining innovative systems.

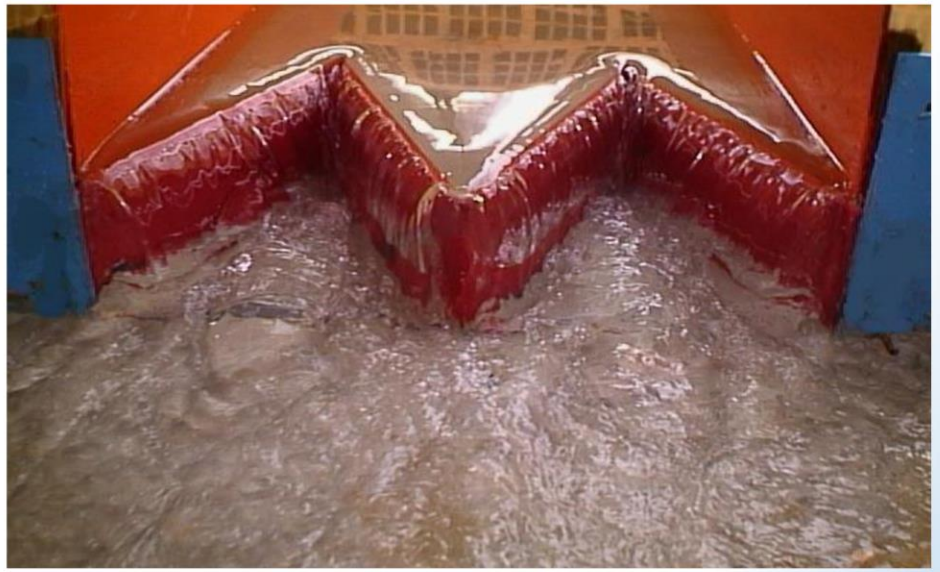
Experimental devices 1996- 2004

Experimental devices 2004- 2022

LABYRINTH STUDIES

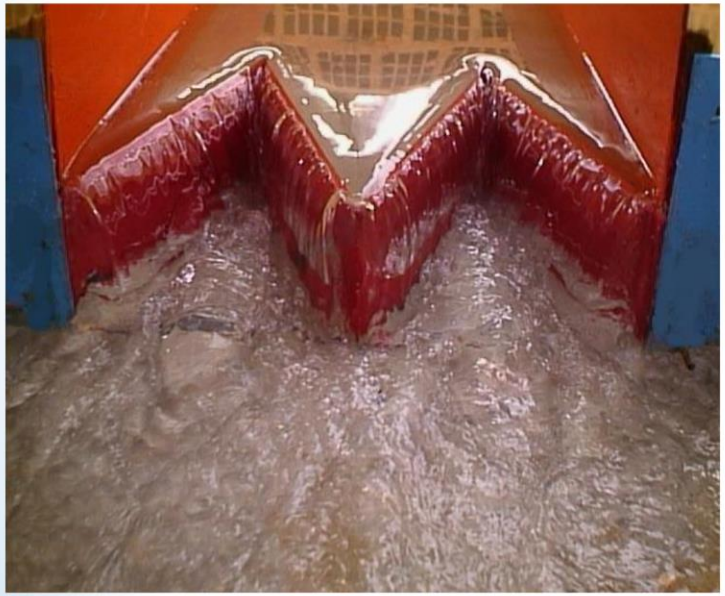
During the **1996-2000** period, several research projects were conducted on the labyrinth weir in order to optimize its hydraulic efficiency.

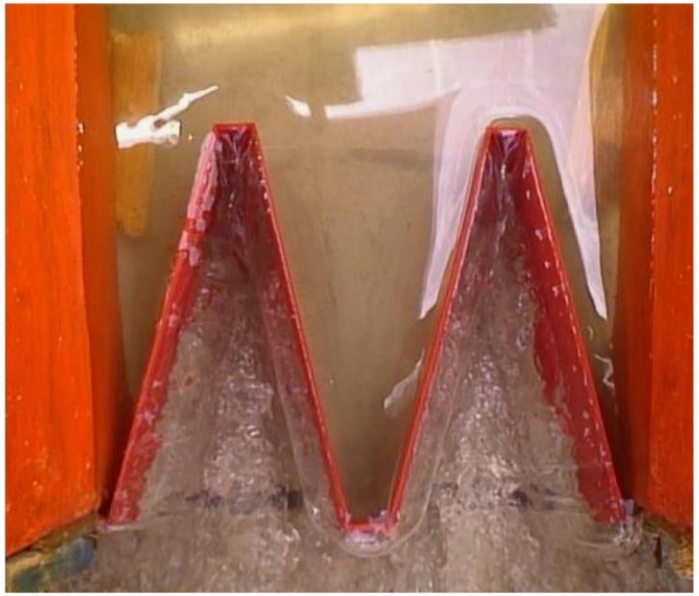
These studies focused in particular on the geometry of labyrinth weirs (curvilinear weir, arrangement of the cycles and influence of the corner on the flow of a triangular labyrinth weir …) and on the approach flow conditions.



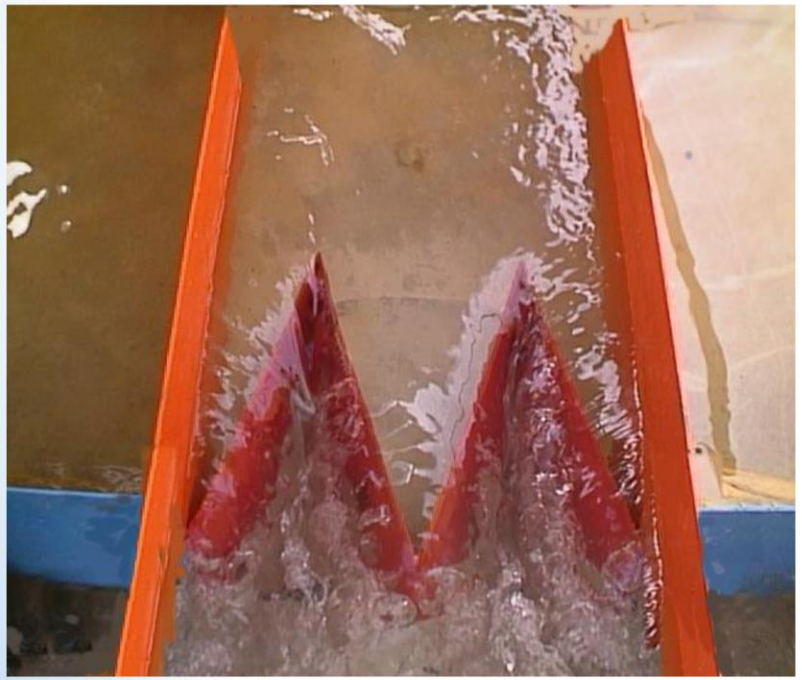
These studies had as themes:

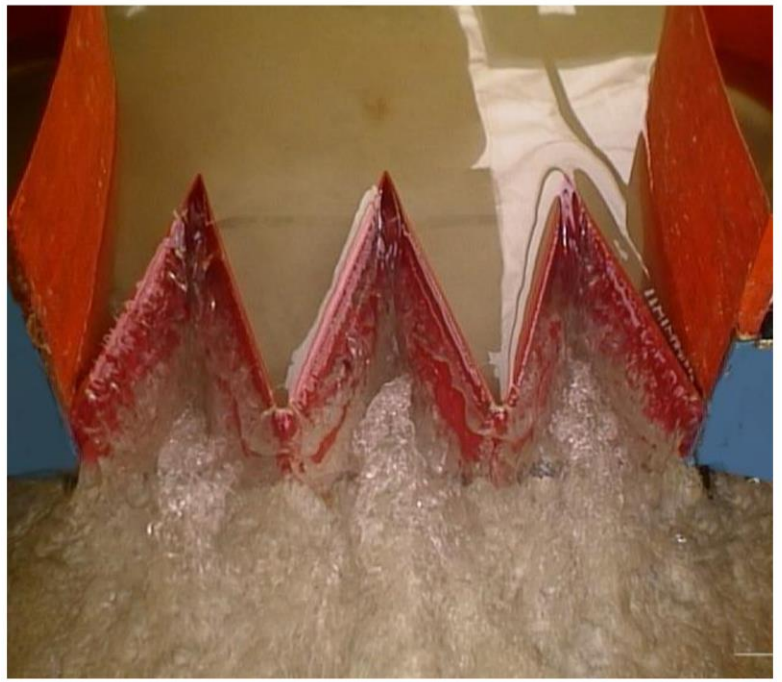
- Contribution to the study of labyrinth spillways (1996).
- Contribution to the study of curvilinear spillways (1996).
- Study of the hydraulic jump in a suddenly enlarged circular gallery (1996).
- Study of the labyrinth weir of the Fontaine des Gazelles dam, Algeria (1997).

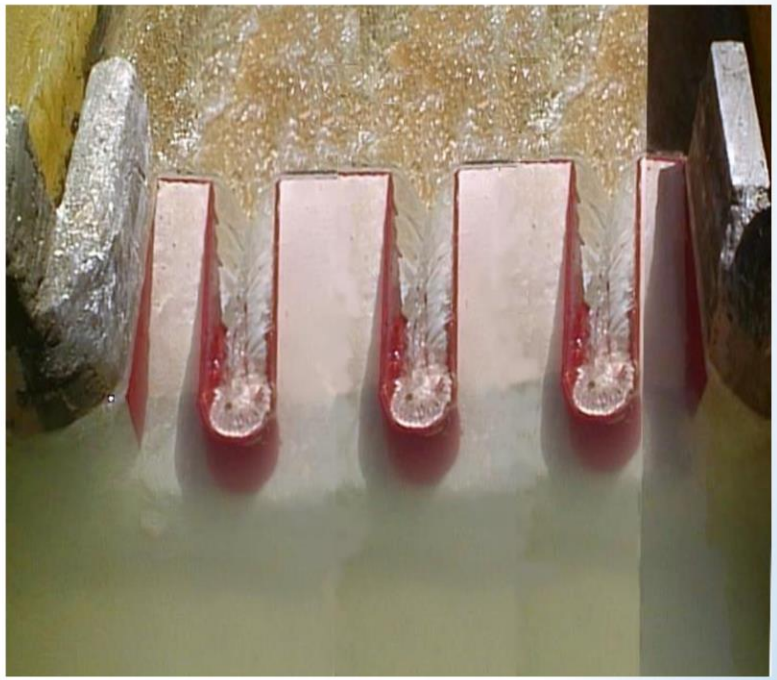




- Study of the influence of the corner on the flow of a triangular labyrinth weir (1998).
- Influence of the approach conditions on the flow of the labyrinth weir. (1999).
- Experimental study of the geometry of the tulip of a shaft spillway (1997).
- Effect of the geometric parameters on the performance of a trapezoidal labyrinth weir (2000).
- Study of the effect of the number of cycles on the flow of a labyrinth weir (2001).



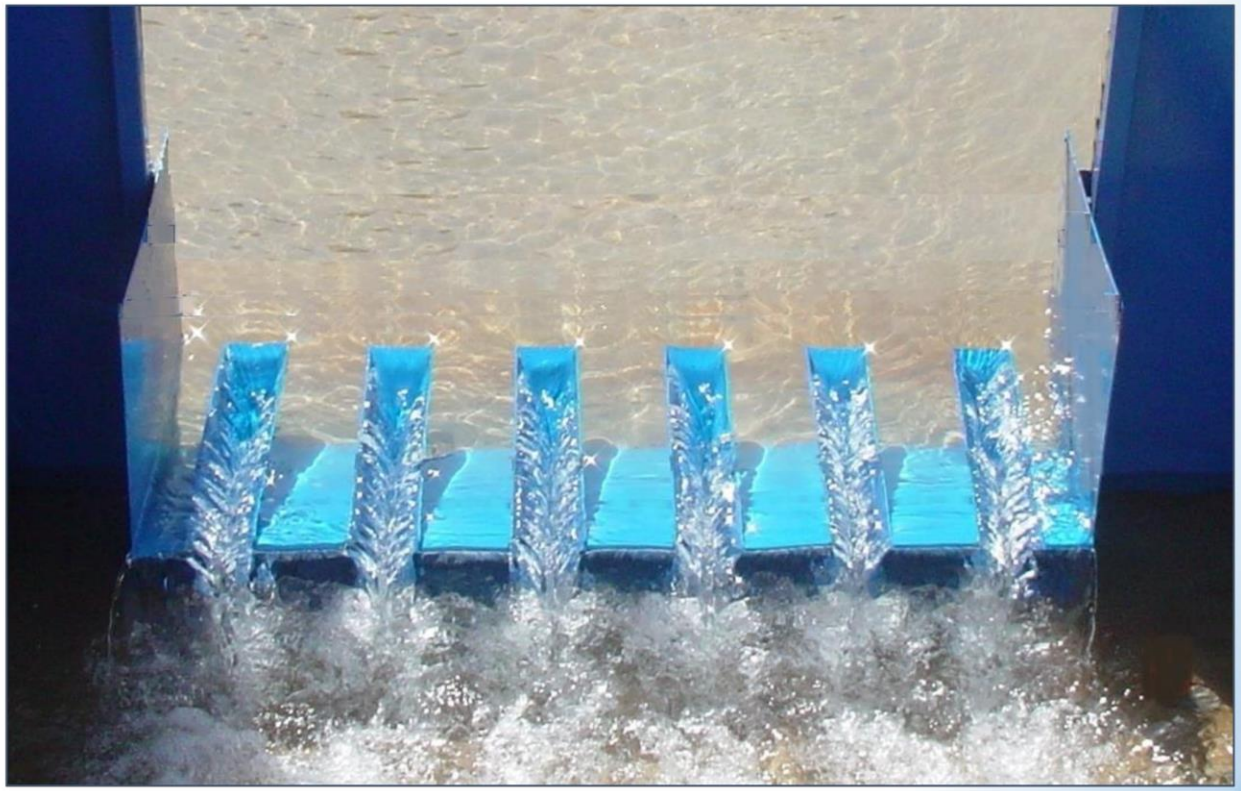




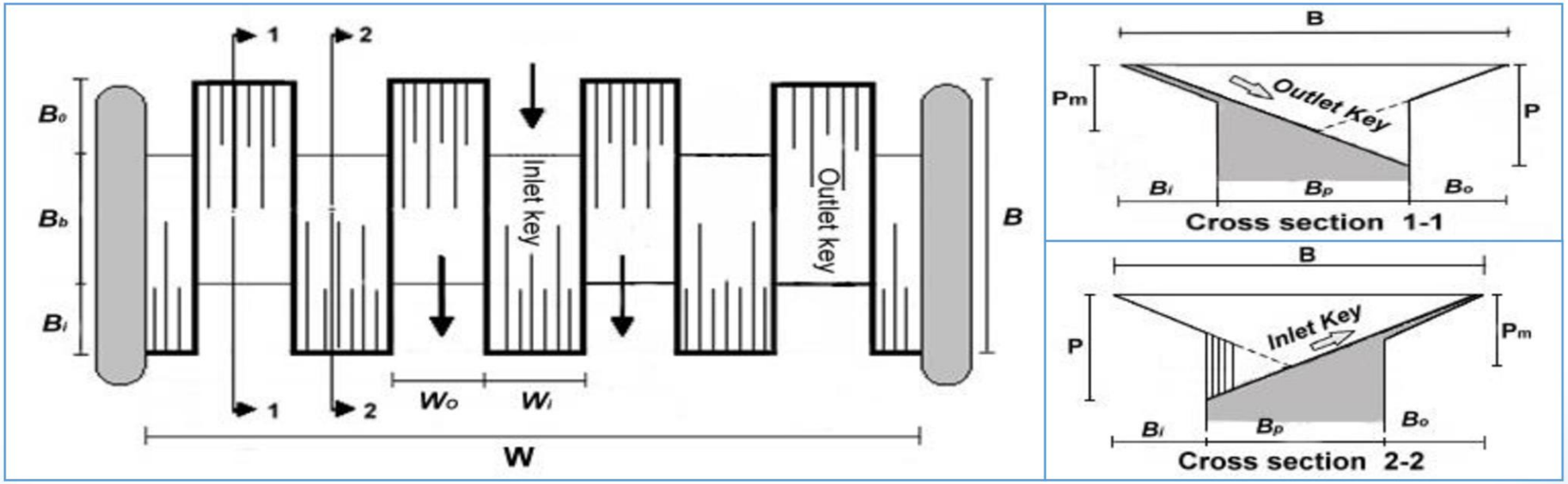
PK-WEIR BASIC DESIGN

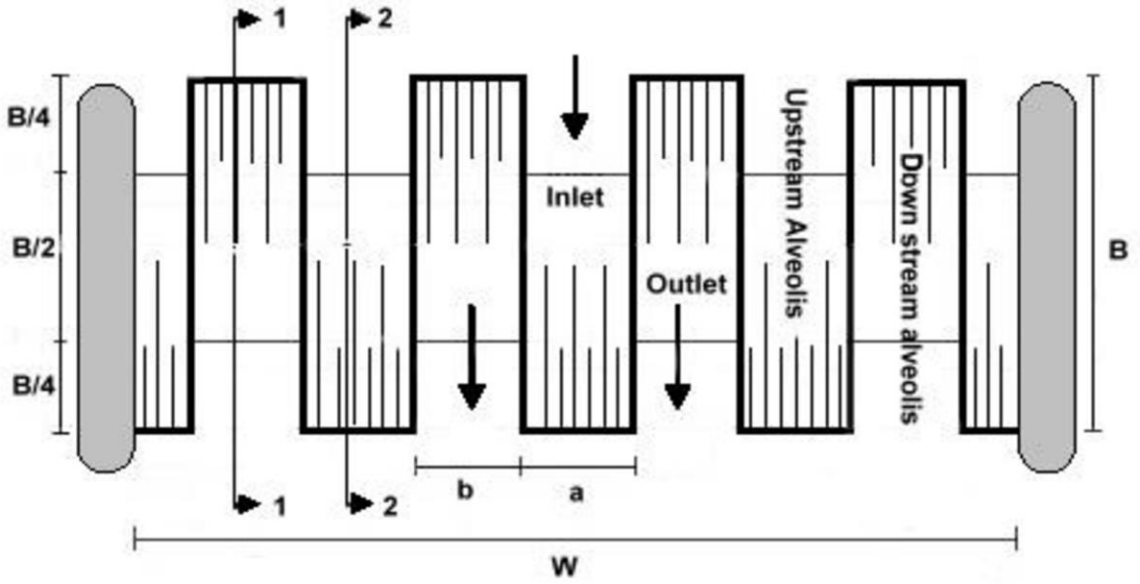
The second phase of research (**2001-2003**) was devoted to intensive studies for the development of a new type of labyrinth weir.

The basic purpose was to improve the performance and the cost efficiency of traditional labyrinths and to reduce the base of the structure for placing it on existing spillways and on the tops of gravity dams. This is favored by a rectangular layout that is easier to design than a trapezoidal layout if combined with overhangs and an inclined invert of the inlet and outlet.

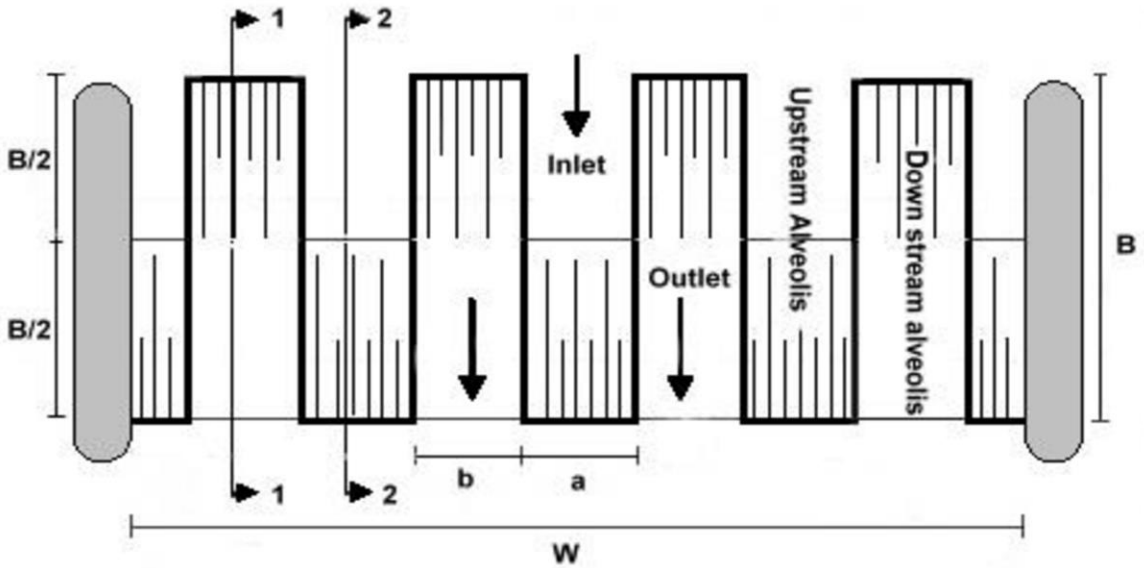


These principles of research were easily adopted between the Biskra University and Hydrocoop but the main issue was to optimize the choice between a great numbers of parameters for a same specific discharge: total width and length of elements, length and slopes of the overhangs, i.e. seven parameters for various nappe depths. Over 90 tests were made worldwide (at this period) of which 80 tests were made in University of Biskra. These tests associated with theoretical analysis of their results were the basis of **the innovation of the Piano Key Weirs (PK-Weir) presented in 2003** in International Journal on Hydropower & Dams (Lempérière & Ouamane) and in 2006 in the symposium and congress of ICOLD 2006 in Barcelona, Spain (Ouamane & Lempérière).

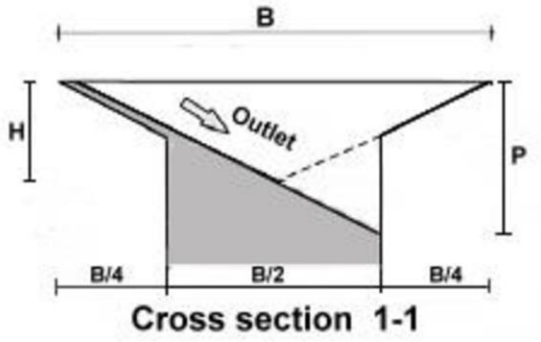


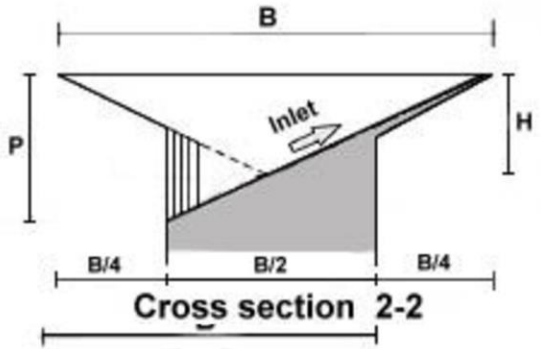


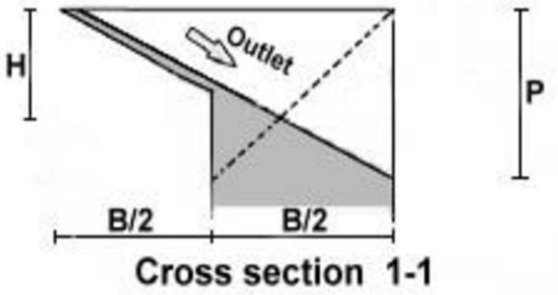
PK-Weir (Model A)

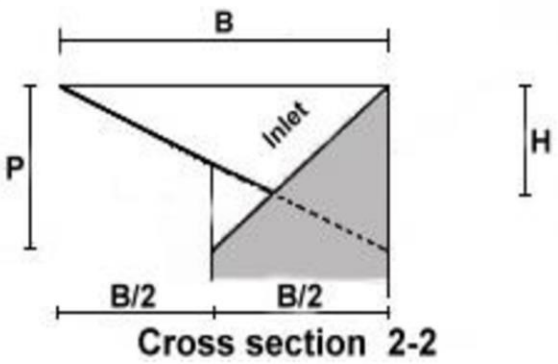


PK-Weir (Model B)









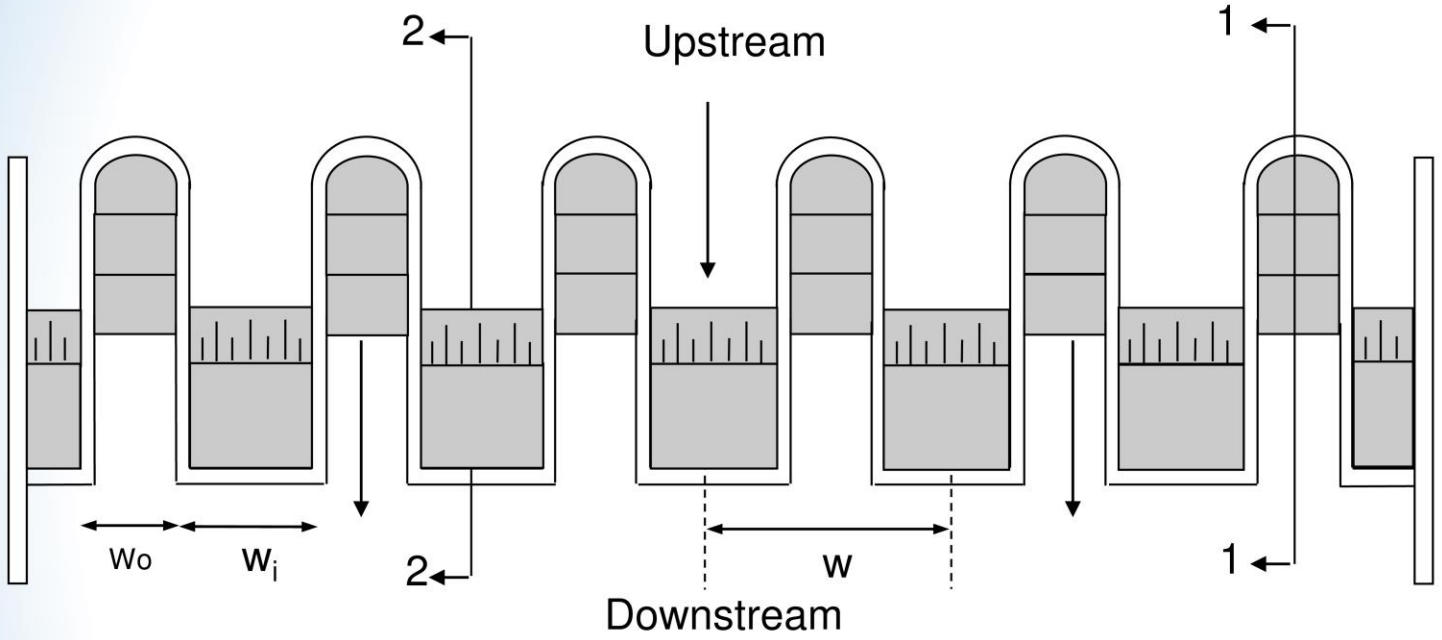
Beyond overhangs and rectangular layout the models presented in 2003 included three main improvements as compared with traditional labyrinths:

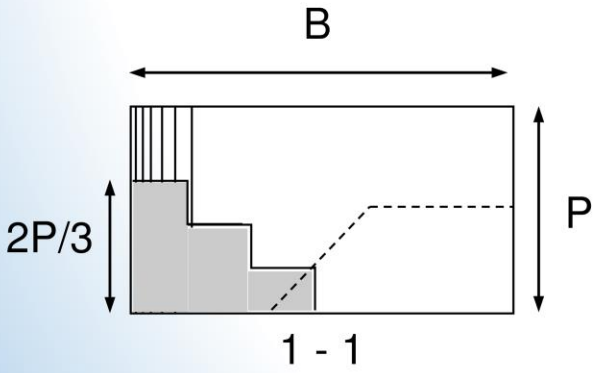
- **An optimized L/W ratio, in the range of 4 or 5 for most sites,**
- **A much less expensive ratio L/H, in the range of half of the existing labyrinths ratio,**
- **A different width for inlet and outlet.**

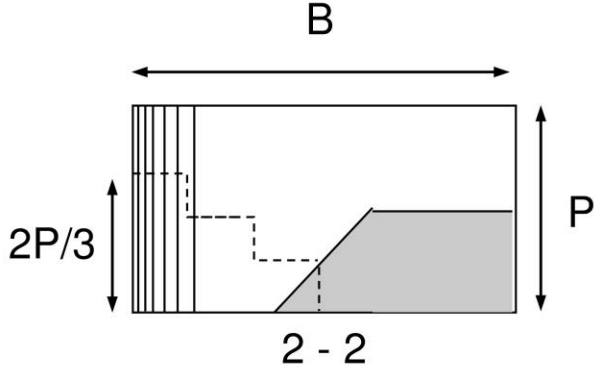
These improvements have been used in most of the existing PK-Weirs.

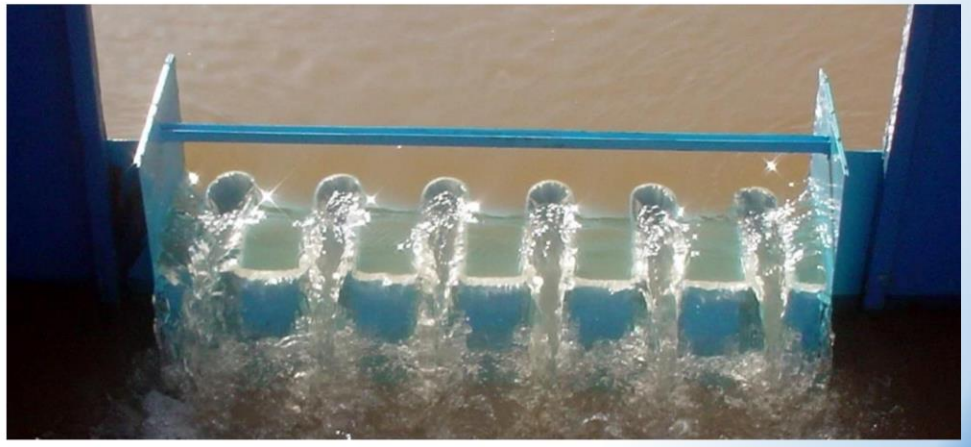
OPTIMIZATION OF THE LABYRINTH AND PK-WEIR AFTER 2003

- **After the innovation and design of the PK-Weir in 2003, a third phase of complementary work was initiated to optimize the PK-Weir and the traditional labyrinth weir.**

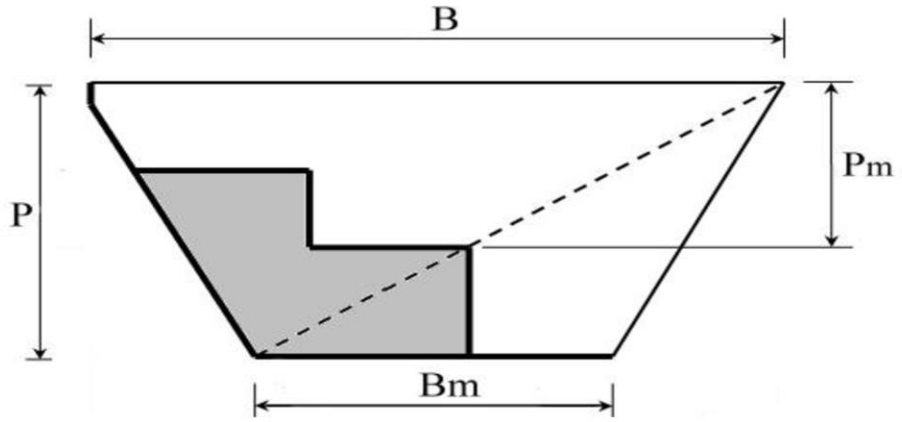


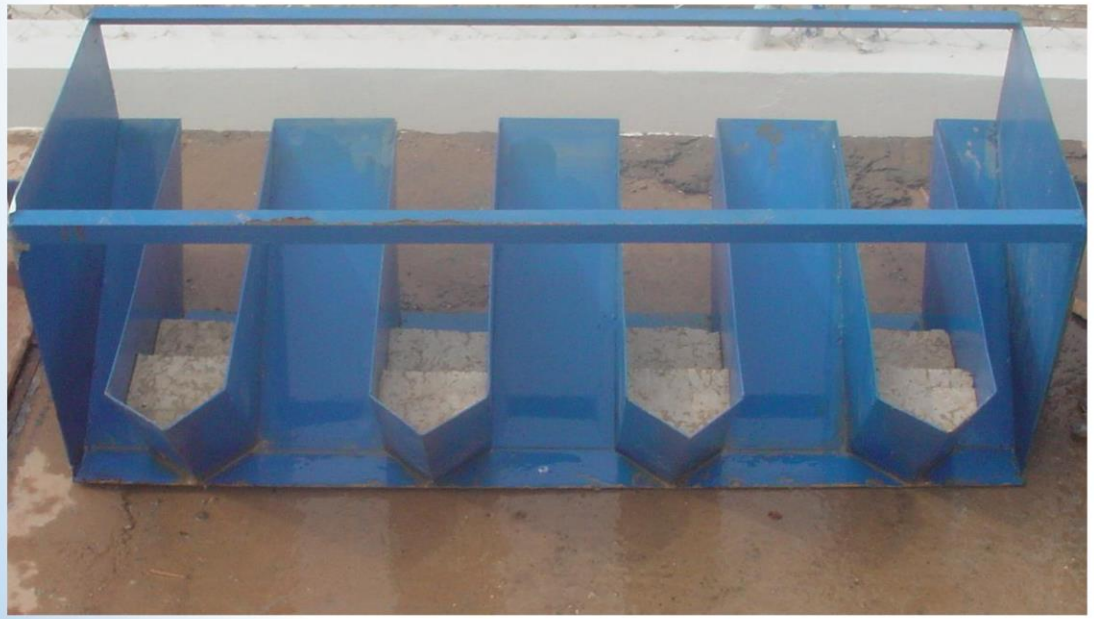


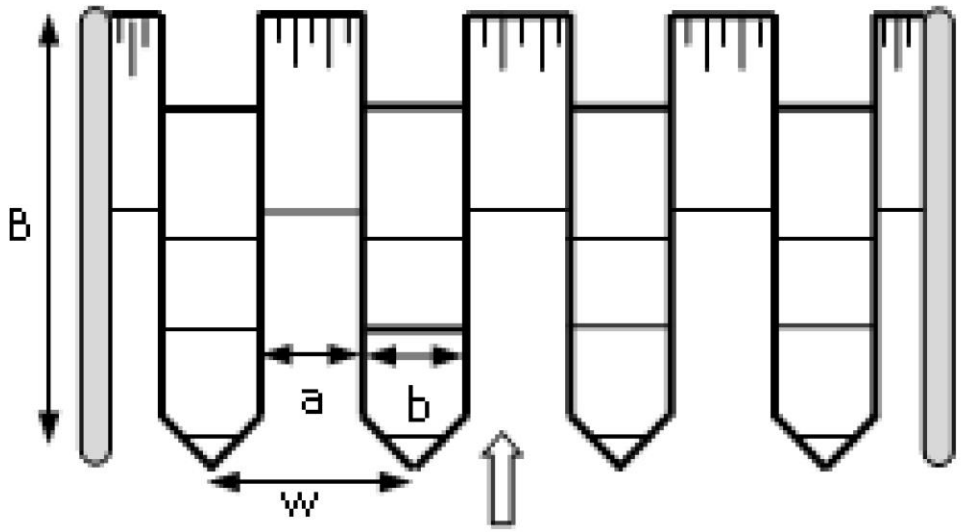




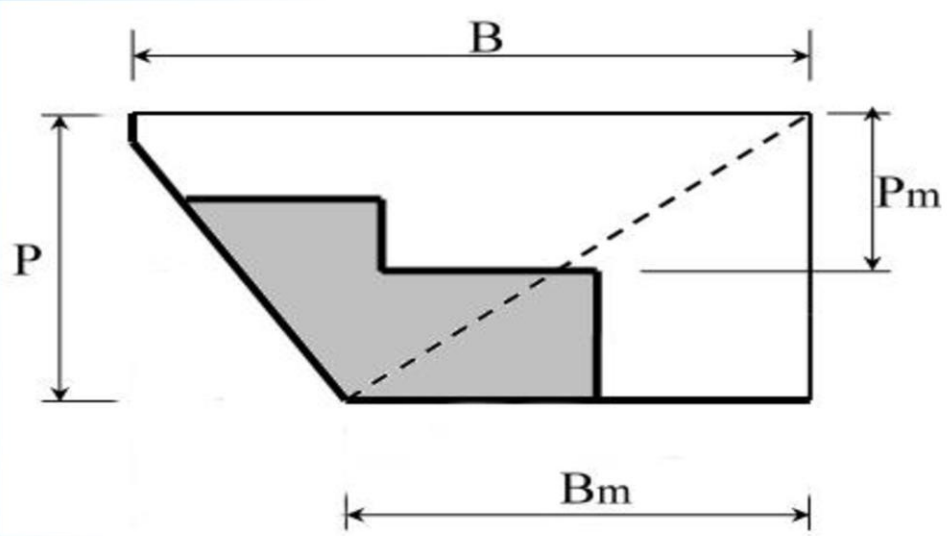
The analysis of existing labyrinths, the results of PK-Weirs tests, and the analysis of cost efficiency demonstrated the possibility of improving the shape and performance of the labyrinth weir. These various improvements have been studied in Biskra theoretically as well as with model tests.

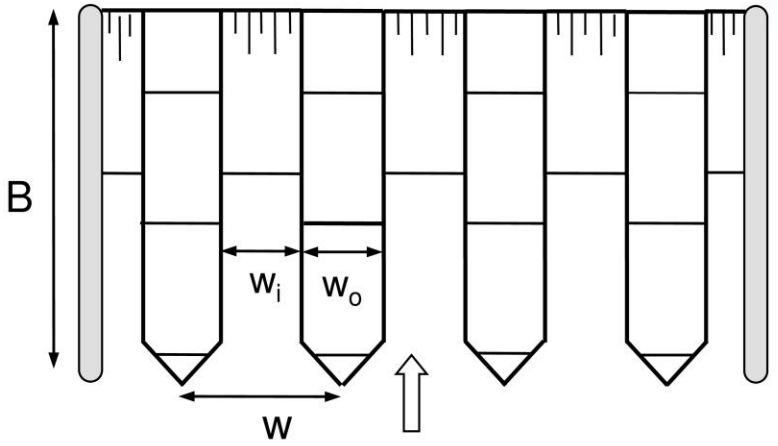


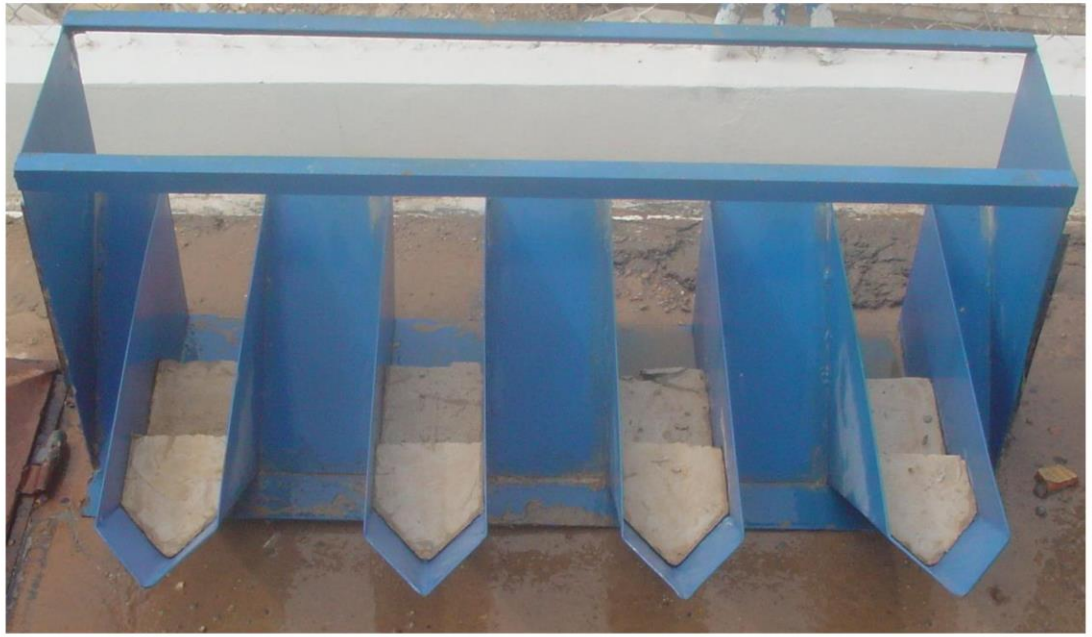




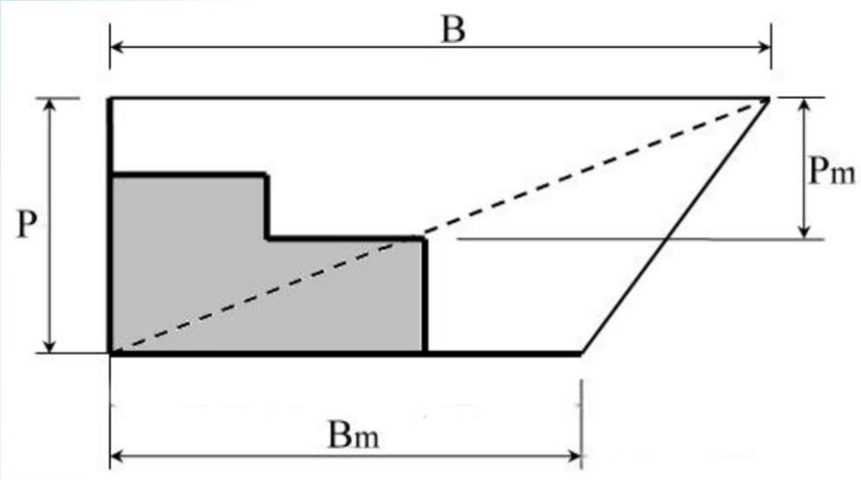
Model A1

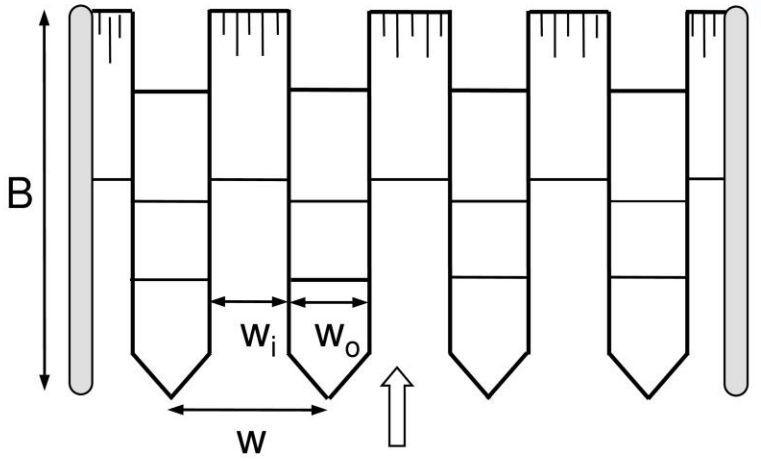






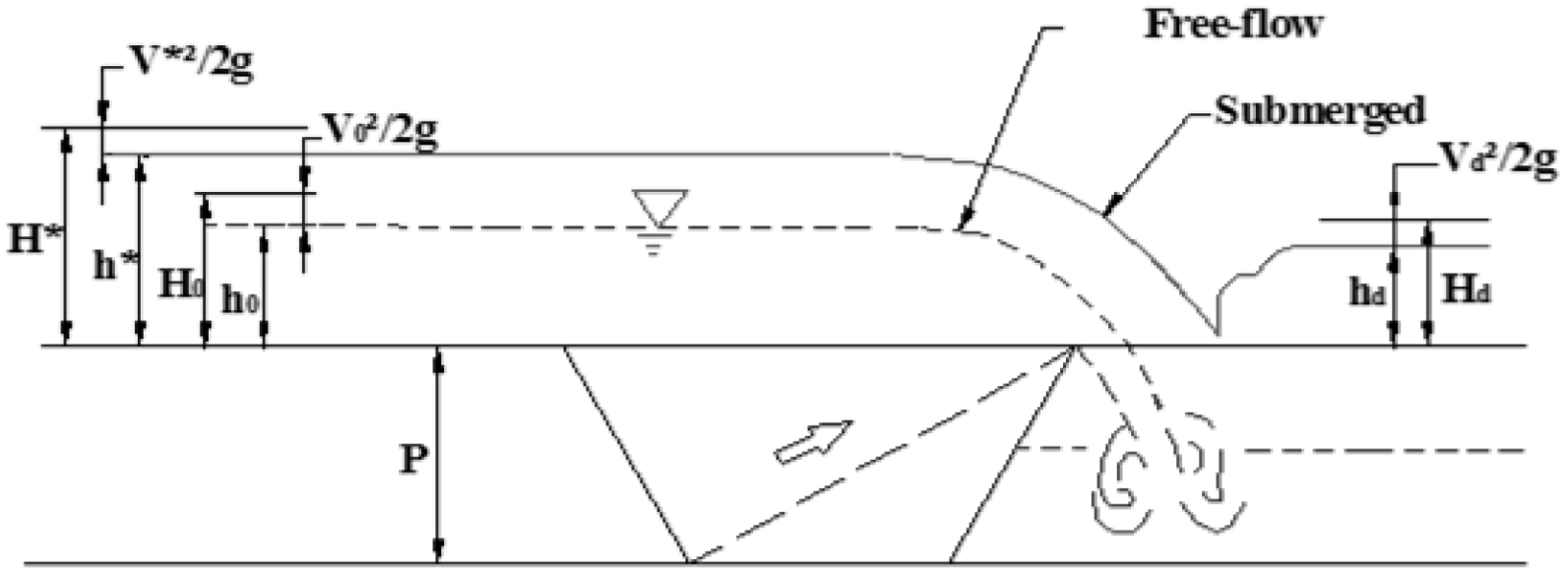
Model B1





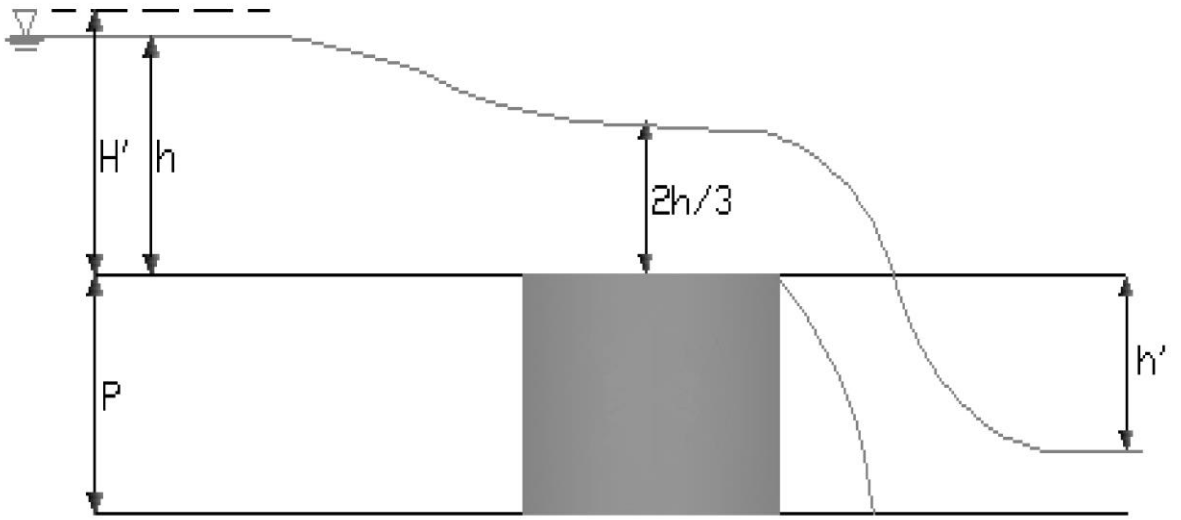
Model C1

Several studies related to the labyrinth and PK-Weir have been the subject of magister thesis themes such as the study of the PK-Weir model B (Noui, 2008), the optimization of the labyrinth weir (Ben Said, 2008), The effect of downstream flow conditions on the performance of the PK-Weir (Belaabed, 2011), Impact of the approach conditions on the performance of the weir piano (Bouredji, 2012), Experimental and numerical analysis of weir piano weir (Athmani, 2014), Optimization of labyrinth weirs (Ben Said, 2018), Study of the flow on the Piano Key Weir in absence of lateral contraction, (Laiadi, 2018) Optimization of the Piano Key Weir shape by numerical and experimental modeling (Athmani, 2018), Study of non-rectilinear weirs submerged by the downstream (Belaabed, 2019).



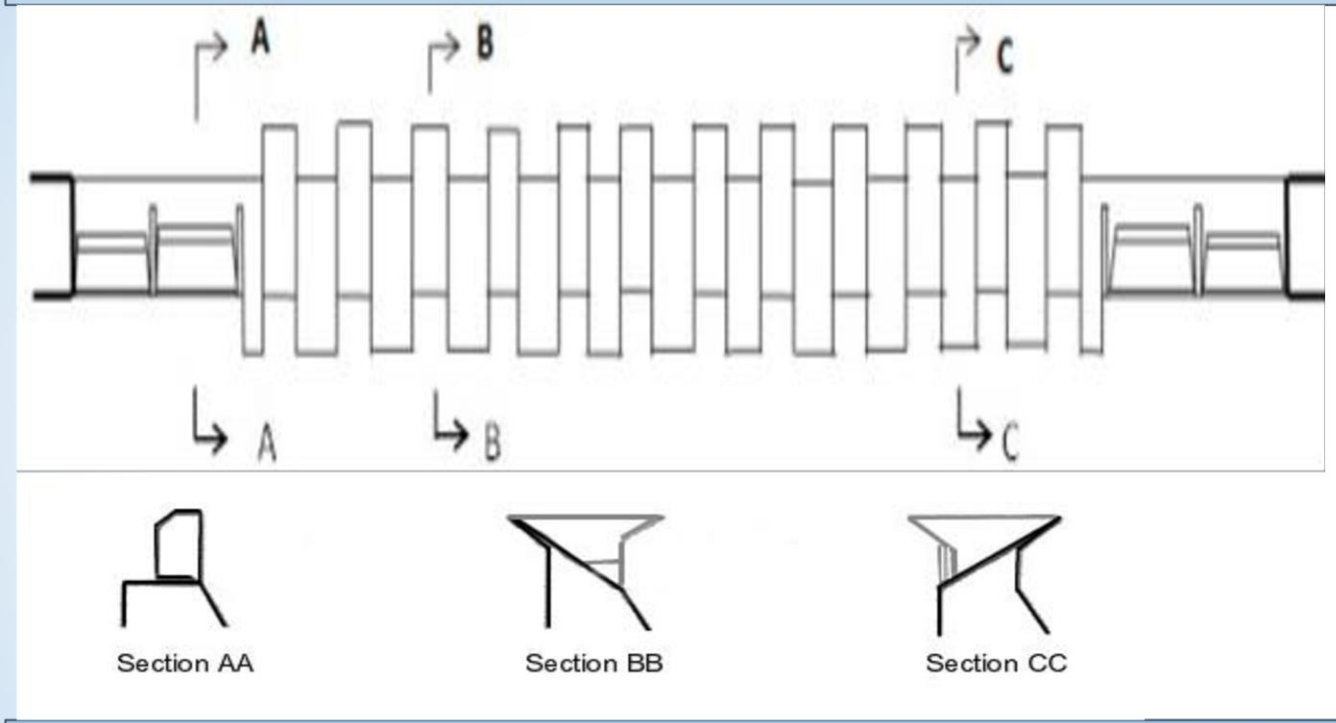
FUSE PLUGS

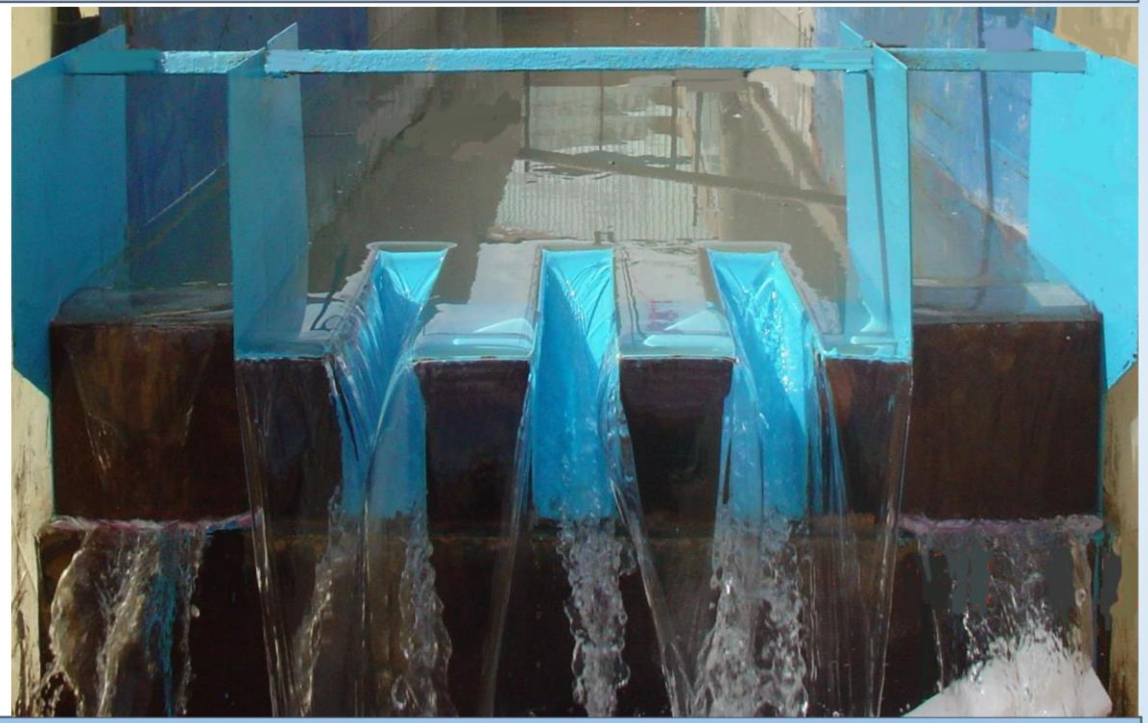
A new solution of very simple concrete fuse plugs has been proposed by Hydrocoop in 2004 which are overtopped by usual floods and may tilt for exceptional flood. Biskra University laboratory has been deeply associated with the optimization of these solutions by theoretical studies and physical model tests (Bedjouti, 2004), (Sekkour, 2015)



Combining Innovative systems

An interesting solution has been studied from 2015 by theoretical and experimental ways: it consists in the combination of PK-Weirs on half the length of a weir and fuse plugs on the other half. Tests show that it is possible to discharge five times the flow of a traditional Creager weir.





Combining PK-Weirs and concrete fuse plugs on the same weir and adapting them accordingly provides the specific advantages of both devices: Higher flow from the PK-Weirs for typical floods before tipping of the fuse plugs and higher flow from the adapted fuse plugs after tipping for large flows. While delaying the first overturning until the 100-year or 1000-year flood, such a combination makes it possible to either increase the maximum flow, or to reduce the length of the weir or the depth of the water table.

Existing Labyrinth Weir and Piano Key Weirs in Algeria

EXISTING LABYRINTHS WEIR IN ALGERIA

Algeria has 83 dams with a total storage capacity of about nine billion cubic meters. Several of these dams are equipped with a labyrinth spillway.

Dam		Discharge (m^3/s)	Nappe Depth (m)	Type de Labyrinthe
Beni Bahdel	1934/1946	1200	0,5	Labyrinth with only outlet alveoli
Bakhadda	1936/1960	2000	1,25	Labyrinth in curvilinear alignment with inclined outlet invert
Harezza	1984		1,90	Labyrinth in rectilinear alignment
Kedarra	1986	750	2,32	Labyrinth in rectilinear alignment
Fontaine des Gazelles	2000	3000	4,0	Labyrinth in curvilinear alignment
Sekkak	2004	1477	2,4	Labyrinth in rectilinear alignment
Ouljet Mellegue	2018	3500	4,5	PK-Weir

The Beni Bahdel and Bakhadda dams are equipped with labyrinth type spillways with a particular design, it is interesting to present them.

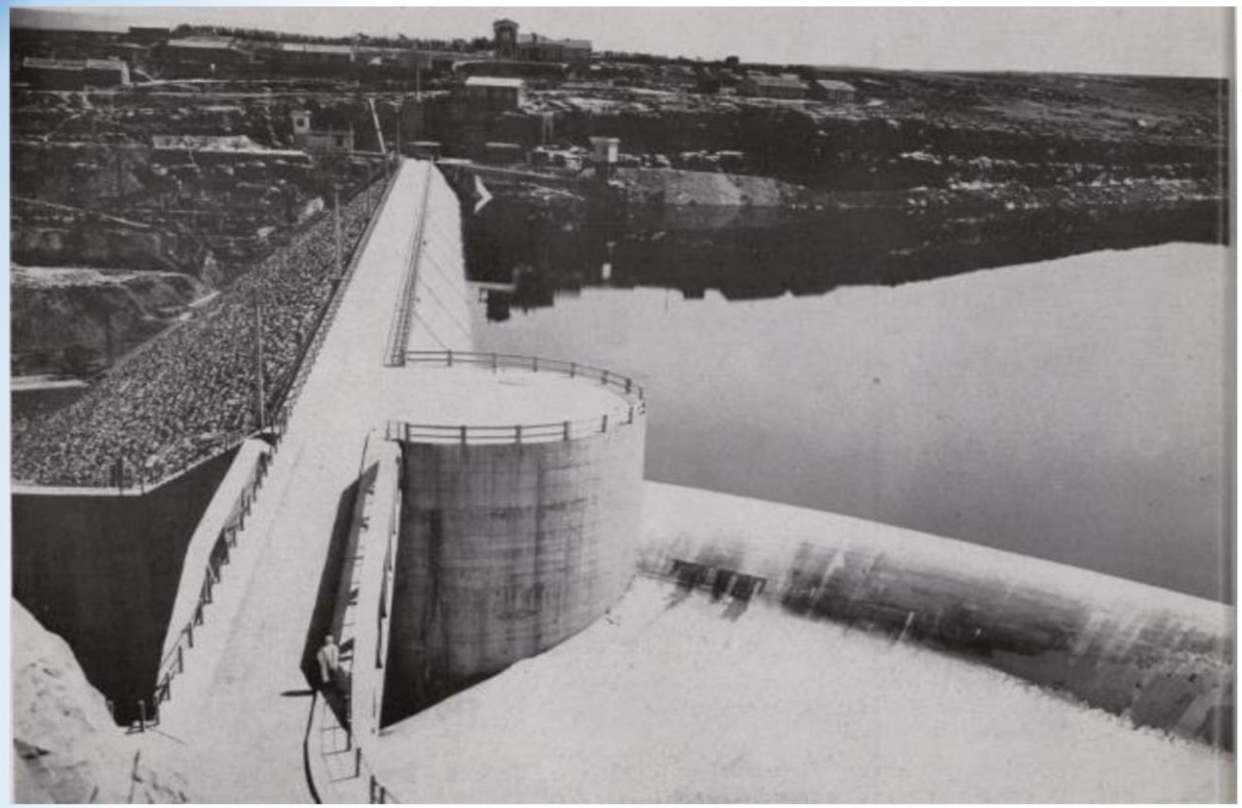
- **Beni Bahdel Dam (Algeria) 1938**

- A multiple arch 55 m high.
- A 1200 m^3/s spillway discharging about 10 $m^3/s/m$ with a 0,5 m nappe depth : instead of 2,8 m for a Creager.
- A rectangular layout.
- The developed length is 15 x spillway length!
- A very long upstream overhangsupported by pillars.
- The area of wall per m^2 depth saving is over 30.
- The gain of wall surface per m^2 of depth is more than 30.

Fig.1

- **Bakhada Dam: Algeria (1936) (1960)**

- A 40 m high rockfill dam.
- A 2000 m^3/s spillway with about 15 $m^3/s/m$ with a 1.25m nappe depth.
- Capacity storage 56 $10^6 m^3$.
- The shape appears more cost effective than Beni Bahdel.
- The layout is rathe similar to the PK-Weir model B1 but with some differences:
- a trapezoidal shape partially connected to a curved base,
- the invert of the inlet is horizontal while that of the downstream outlet is inclined.
- the upstream face wall is slightly inclined to be similar to an upstream overhang.



Creager spillway (before 1960)

Curved labyrinth weir (after 1960)

- A trapezoidal shape partially connected to a curved base,
- The invert of the inlet is horizontal.
- The upstream face wall is slightly inclined to be similar to an upstream overhang.

- The invert of the outlet is inclined.

Conclusion:

- It seems to be a great future for PK-Weirs, labyrinths and fuse plugs for 3 reasons:

- The huge improvement provided by these solutions compared to more traditional spillways

- The increasing discharge of spillways foreseen in the future

- The risk of gates jamming for controlled spillways.

- This future may apply as well to very large and small spillways, existing of futures ones.

- Most or all of the floods discharge is done by a single spillway for most existing dams. In the future it will be usually safer and cost effective to associate PK-Weirs with gates or fuse plugs. However this may be wrongly prevented by traditional design criteria or even by official rules.

- For low dams with huge discharge, PK-Weirs may be cost effective and possibly associated with gates (as in Vietnam). But if there is no rock as foundation, it may be less expensive for long dams to discharge a small nappe depth along hundreds meters of lined embankment.

Thank you

For your attention