“Cassiopée” a software to bridge the gap between researchers and engineers in hydraulic calculations

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"Cassiopée" Software: a Tool to Assist in the Hydraulic Dimensioning of Upstream and Downstream Fish Passage Devices

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Abstract

Engineers always need convenient calculation tools on the field or at the office for evaluating hydraulic characteristics and designing solutions while researchers develop scientific software in most cases non-reusable, invisible, and in the worst case, faulty and unreliable. Funded by the French Biodiversity Office, "Cassiopée" software has first been developed for the design and the verification of upstream and downstream fish passage facilities aggregating multiple tools required for dimensioning: pool-type fishways, pre-barrages, baffle fishways, nature-like fishways, and fish-friendly intakes. "Cassiopée" also includes numerous tools for open flow and pipe flow hydraulics for agriculture and environment. Based on calculation modules, which can be independent or linked in order to carry out complex operations, "Cassiopée" allows an iterative design approach ranging from the definition of the geometric characteristics of the devices to hydraulic simulations of their operating conditions. In a simple and user-friendly interface, it presents the calculation results as clear tables and graphs. Contextual documentation provides detailed information on the different tools and hydraulic formulas used for the calculations. Available in French and English, "Cassiopée" is an open source and free software accessible online (https://cassiopee.g-eau.fr) or as an offline application for Windows, Linux, macOS and Android. An R package is currently under development for advanced users who need to perform intensive calculations without a graphical user interface. Designed as a practical tool resulting from the transfer of research products, it is intended to be widely used by the hydraulic engineering community as a working and educational tool.

Keywords: Software; Hydraulics; Fishway; Ecohydraulics

1. INTRODUCTION

1.1. From a software for fish passage designs…

The laboratory Pôle R&D écohydraulique, OFB-IMFT-PPRIME at Toulouse, France, has a long experience in fish passage design. This starts in the late 70's with studies on Denil Baffle fishways (Larinier, 1978), chevron-type baffle facilities for both fishes and canoes-kayaks (Larinier 1984), and other baffles fishways (Larinier 1992, 2002). At the time, the French government commissioned the laboratory to define construction standards for fish passes. As a result, the laboratory published fish passage design guides to state services, engineering offices and construction companies (Larinier 1983, Larinier et al. 1994). More recently, the laboratory published technical guides for dimensioning nature-like fishways (Larinier et al., 2006) and fish-friendly intakes (Courret et Larinier, 2008).

From the 1980s, the laboratory also disseminated its expertise through software (Larinier and Porcher, 1986) and in 1993, it released the first version of "Cassiopée" (Larinier and Porcher 1996). This latter allows the determination of flow and water level for dimensioning and verifying correct operation for:

- pool-type fishways (with plunging or streaming flow notches, submerged orifices, single or double vertical slots);
- baffle fishways (with Denil type, Fatou type, super-active type or chevron type baffles);
- pre-barrages (with rectangular weir, triangular weir or semi-triangular weir).

"Cassiopée" is since widely used in France and is the reference for dimensioning and verifying fishways design. Despite the release of a third version for Windows in 2012, the software is affected by several shortcomings:

- equations and algorithms used in the software are not well documented;
- types and combinations of hydraulic structures of pool-type fishways doesn't cover all current field situations;
- nature-like fishways and fish-friendly intake devices are not implemented.

The lack of documentation is an important point to raise. Indeed, as the software is used by the state services to check the conformity of fish passes, the results of the calculations must therefore be documented and reproducible so that they cannot be contested.

To cope with these issues, the French Biodiversity Agency (OFB) has worked in partnership with the UMR G-EAU at INRAE since 2016 to develop a new version of "Cassiopée". This was an opportunity to work on new interfaces based on the last standards of user experience adapted to modern communication devices.

1.2. To a general tool for hydraulic engineering calculations

The team "Hydraulic management, optimization and water transfer supervision" at G-EAU, Montpellier is focused on all aspects of 1D surface hydraulics modeling. The team is specialized in irrigation canal modelling and automatic regulation (Malaterre et al., 1998) and has developed the SIC² software for 30 years which is widely used by engineering offices for modeling irrigation canals and their controls (Baume et al., 2005). Stage discharge equations of hydraulic structures is also one of their concern (Belaud et al, 2009, 2012). The require of the French Biodiversity Agency was an opportunity to spread the knowledge of the team with tools useful for both operational or student hydraulic engineers.

Besides the helper tools for designing fish passages facilities, we decided to propose some tools linked to surface hydraulics inspired by Canal9 (Albert et Alain, 1993).

2. OVERALL CHARACTERISTICS OF THE NEW VERSION OF "CASSIOPÉE"

2.1. An application to use anywhere on any devices

We've made the choice of developing a single page web application with a responsive design adapted to all screens from smartphones to large computer screen. This solution allows to use directly the application online via the "Cassiopée" web site (https://cassiopee.g-eau.fr) with any recent web browser (Dorchies et al., 2020). The same source code is also compiled and deployed as a stand-alone application for Windows, Linux, MacOS, and Android operating systems for those who need to run the application without Internet connection. Figure 1 shows the look of the Android stand-alone application on a small screen.

2.2. An application organized into nested and linkable calculation modules

The application is organized into calculation modules. Each module consists in the resolution of an equation or a set of equations used to solve a dedicated problem. Every parameter of the equations can be either fixed to a single value or a series of values or set to be calculated (analytically or by numerical resolution). The calculation results show the set parameters, the calculated parameter and possibly additional results in tables and charts that can be exported in Excel or image format. This allow the user to answer to every situation considering known and needed parameters to be calculated.

The modules are based on a framework providing a genericity that both facilitates the development of new modules and offers a homogeneous user experience between the different modules. A working session of the application, which can be load or saved on the user terminal in json format, can contain as many calculations modules as needed. Some modules are nesting other modules such as the "Fish ladder" module that is made up of a series of "Fish ladder: Cross walls" themselves made up of one or several hydraulics structure equation modules which are also used in other modules (Pre-dams, Free flow weir stage-discharge laws…).

Calculation results or input parameters of one module can feed other module input parameters thanks to a link mechanism through the session. The application also provides a multi-module solver, which allows calculating through several linked modules where there is no direct computable solution. Figure 2 shows the diagram of several linked modules where one try to calculate the discharge passing by one submerged rectangular gates, a portion of a rectangular canal and a free flow rectangular weir with only knowing the upstream water level.

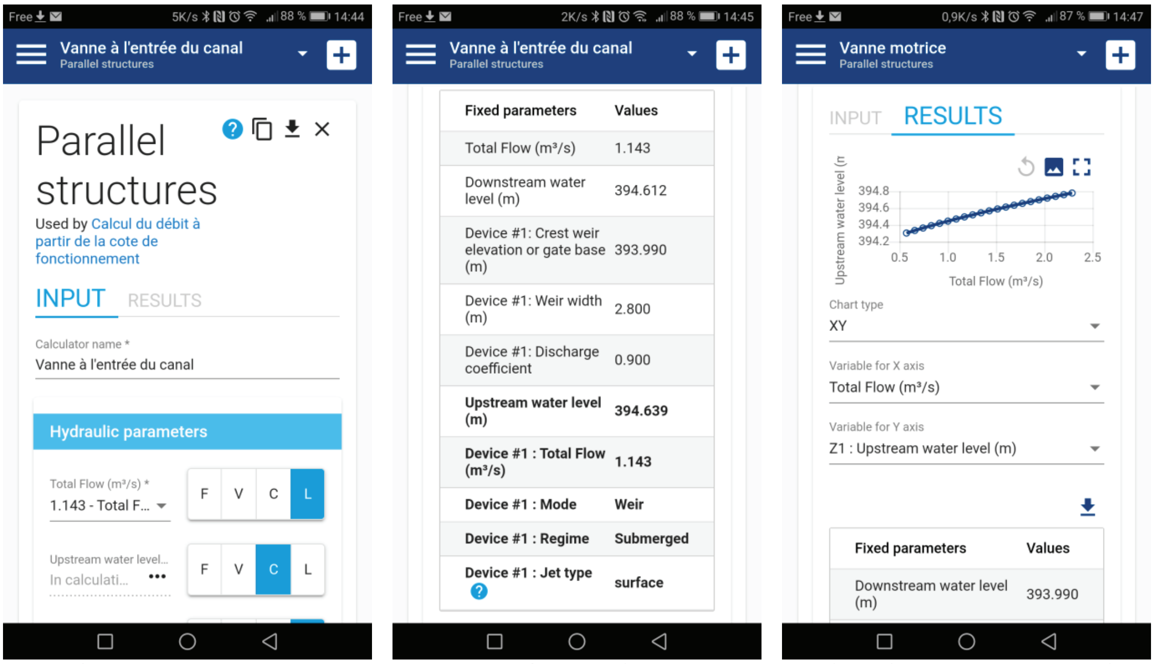


Figure 1. Screenshots on an Android smartphone (From left to right: an input form for the calculation of an hydraulic structure, the table result of the calculation, a chart of the evolution of the flow function of the upstream water level on an hydraulic structure.

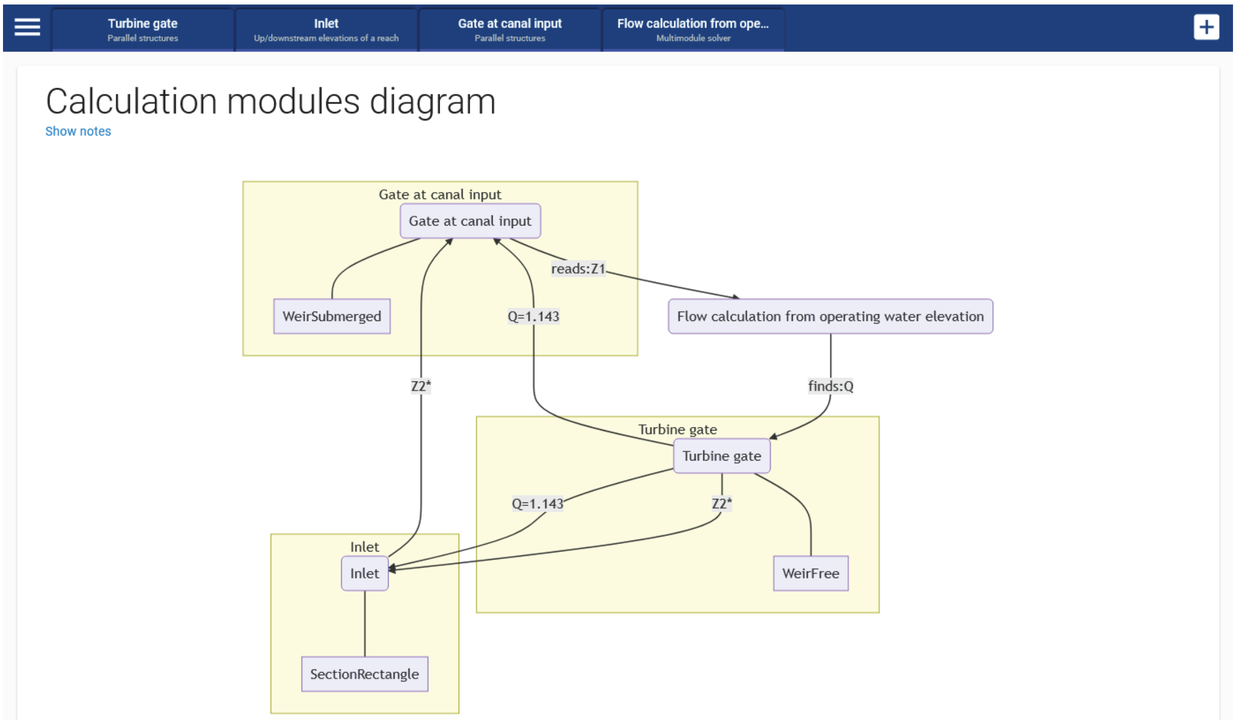


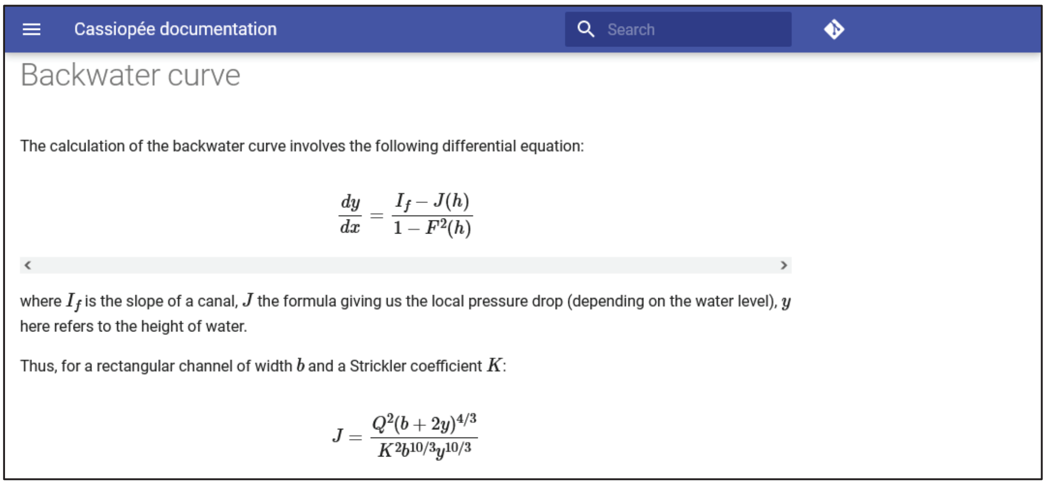
Figure 2. Example of a calculation diagram of chained modules.

2.3. An open-source project with a complete theoretical documentation

To guaranty its stability and robustness, the application is developed following high standards in term of unit testing, regression tests, continuous integration and continuous deployment. As an example, at each modification in the source code, more than 1900 tests are executed.

One pitfall of the previous versions of “Cassiopée” was the lack of documentation and references. In order, to provide a total transparent tool, which anyone can check and understand, all the source code is released under the GNU Affero General Public license and is available on a public repository[1].

For the same reason, we produced a complete documentation of the calculation modules available in English and French with figures, equations and bibliographic references. All modules and all documented parameters and results are provided with a link to a contextual documentation, which deeply explain the hydraulics concepts and formulas used (Figure 3).


Cassiopée documentation

Search

Backwater curve

The calculation of the backwater curve involves the following differential equation:

$$\frac{dy}{dx} = \frac{I_f - J(h)}{1 - F^2(h)}$$

where I_f is the slope of a canal, J the formula giving us the local pressure drop (depending on the water level), y here refers to the height of water.

Thus, for a rectangular channel of width b and a Strickler coefficient K:

$$J = \frac{Q^2(b+2y)^{4/3}}{K^2 b^{10/3} y^{10/3}}$$

Figure 3. Screenshot of the documentation concerning backwater curve calculation.

3. A COMPLETE TOOL FOR DESIGNING AND VERIFYING FISH PASSAGES

The installation of fish passage devices at weirs and dams is a measure to reduce their impact on the free movement of migratory fish. Their design must comply with a certain number of criteria in order to guarantee flow conditions in these devices that are favorable to their attractiveness and their passability by the target species identified. This new version of “Cassiopée” brings tools to help in design and verification of almost all kind of fishways (Figure 4). The tools allow the fishway designer or auditor to compute key hydraulic indicators for fish passage with all target hydraulic conditions by varying the flow crossing the device and upstream/downstream water elevations.

Figure 4: Examples of fishways; from left to right: pool-type fishway, baffle fishway, nature-like fishpass (credit: Sylvain Richard, OFB)

3.1. Pool-type fishways

Several modules are dedicated to the design of pool-type fishways also called “fish ladders”. It starts from the calculation of the number of falls to allow the target fish species to swim upstream, the calculation of the dissipated power in each pool and finally the simulation of the entire fishways. Figure 5 shows a calculation result example of the effect of varying the downstream water elevation on the water surface within the pools.

[1] https://gitlab.irstea.fr/cassiopee

Each wall of each pool can be equipped with any kind and any number of weirs and orifices with polyvalent stage-discharge equations taking into account transition between free or orifice flow and different levels of submergence.

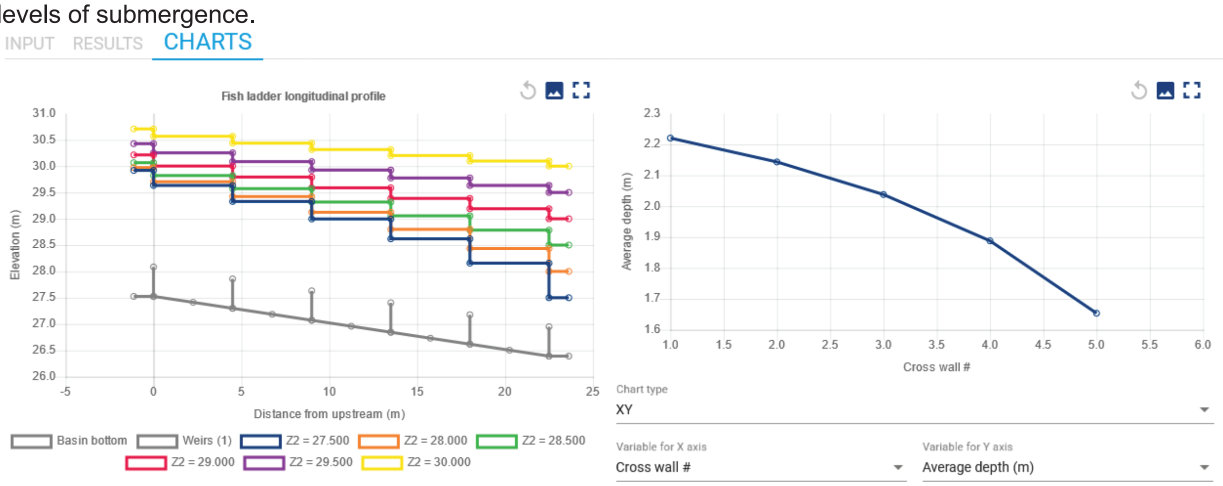


Figure 5: charts of the water surface in a fish ladder for several downstream water elevation and a chart showing the average water depth in each pool for one downstream water elevation.

3.2. Baffle fishways

This part is divided into two modules: one used to design new fishways and the other to simulate hydraulic conditions for existing fishways, taking into account structural engineering specifications. It implements the equation developed by Larinier (2002) for plane baffles (Denil), “Fatou” baffles, superactive baffles, chevrons baffles (mixed use for canoes-kayaks).

3.3. Nature-like fishpasses

The nature-like also called rock-ramp fishpass modules calculate hydraulic characteristics of a rock-ramp pass made up of uniformly distributed blocks (emergent or submerged and of various shapes). A module helps for the calculation of the block concentration, another one is adapted for calculation over a single not inclined apron fishpass, and a last one stands for inclined or multiple apron fish pass. These modules implement formulas and numerical resolution developed by Cassan et Laurens (2016), and Cassan et al. (2017, 2014).

3.4. Crossability verification

Migratory fish species have different abilities to cope with fishway hydraulic conditions, which depends on the type of fishway. On pool-type fishway, the following criteria are checked: jet type (surface or plunging), maximum fall between pools depending on the jet type, minimum slot width, minimum orifice surface, minimum head on weir, minimum water depth in the basins, and maximum dissipated power. On baffle fishways, the only criteria is the minimum water depth in the pass. On nature-like fish passes criteria are minimum water depth and maximum flow velocity.

Based on these criteria, the verification module allows to check the passability of a modeled fish pass for one or several fish species. “Cassiopée” implements the fish species criteria provided by the working group “Informations sur la Continuité Ecologique” (Baudoin et al, 2014) as well as any user defined species criteria.

3.5. Fish-friendly intake devices

To cope with the issue of fish mortality caused by turbines at hydroelectric plants during their downstream migration, fish-friendly intakes, combining low bar-spacing rack and bypasses, can be installed. “Cassiopée” proposes a set of tools to dimension these devices. A first module is used to size the rack and to calculate head losses, in respect with equations developed by Raynal et al. for angled racks (2013a) and inclined racks (2013b). Then, different modules are used to size the weir which control the downstream flow (“Free flow weir stage-discharge laws”), to calculate hydraulic conditions in the downstream transfer canal (“Uniform flow calculation”) and finally to check the jet trajectory and the fish reception conditions downstream (“Jet trajectory and impact”).

4. TOOLS FOR EXPERIENCIED AND APPRENTICE HYDRAULIC ENGINEERS

4.1. Calculation in Open channels

"Cassiopée" implements several calculation tools related to open channel flow useful for rivers or canals. For all these modules, available section shapes are rectangular, trapezoidal, circular, or parabolic. The "Parametric section" module explores all possible hydraulic characteristics (head, flow velocity, head losses, critical and normal depths…). The "Uniform flow calculation" module allows to calculate any missing hydraulic parameter for a given uniform flow configuration. The "backwater curves" modules calculates supercritical, subcritical water surface as well as the water jump position if any. The "Upstream/downstream elevations of a reach" calculates, given an expected type of water surface (respectively subcritical or supercritical) any relevant hydraulic parameter (respectively upstream or downstream water elevation, flow, or roughness coefficient) of an homogeneous portion of river or canal through the calculation of the backwater curve.

These modules can be used as educational tools to explore and explain hydraulics phenomena. For example, Figure 6 shows that the location of a water jump is linked to the location where the conjugate depth crosses the water depth. Figure 7 shows outputs of the "Parametric section" module where calculation is done on a range of water depth demonstrating the minimum head is obtained at critical flow when the Froude is equal to 1.

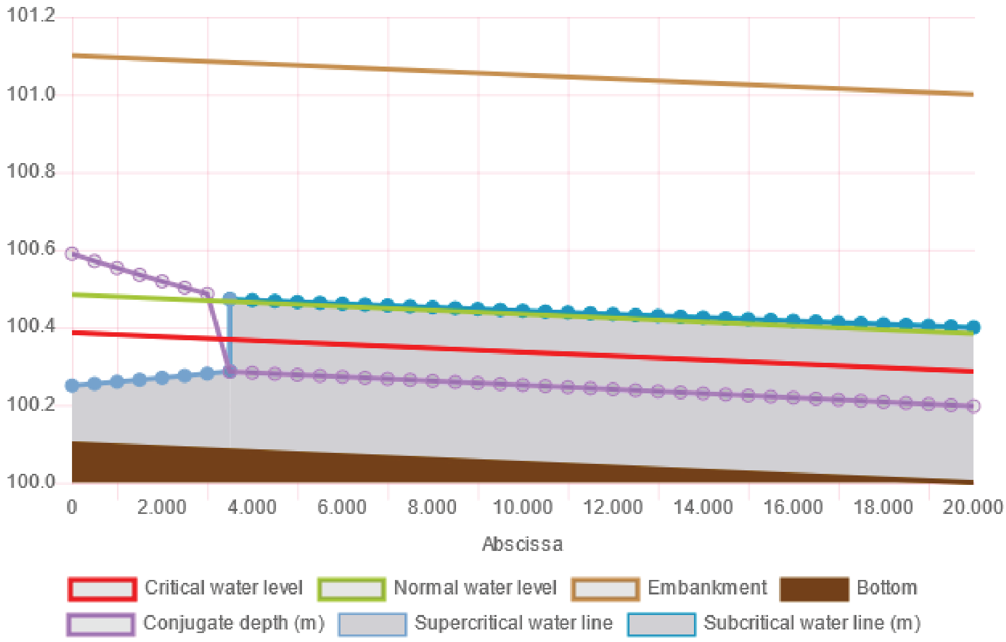


Figure 6: plot of a backwater curve with location of the water jump and the display of the conjugate water curve.

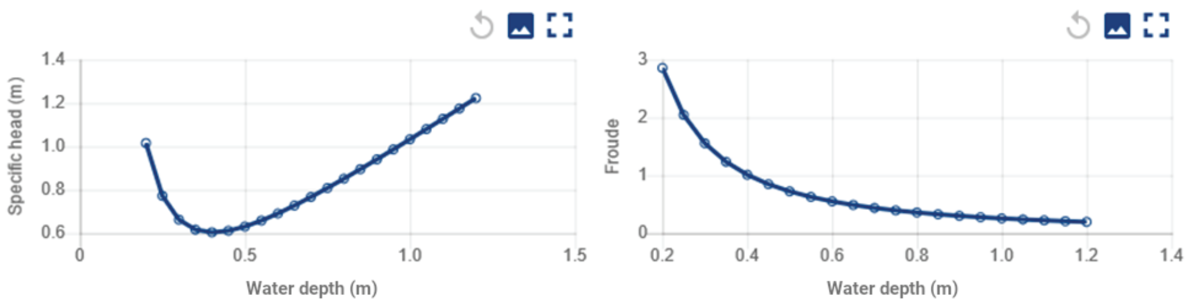


Figure 7: charts of the specific head (left) and the Froude (right) function of the water depth in a rectangular section for a given flow.

4.2. Calculation on hydraulic structures

Several modules are related to hydraulic structures: "Parallel structures", "Free flow weir stage-discharge laws" and "Fish ladder: cross walls". All these modules are based on "Parallel structures" which calculates relationship between upstream and downstream water level with the flow through one or several weirs or orifices layed out in parallel. The derived modules ("Free flow weir stage-discharge laws" and "Fish ladder: cross walls") calculate additional hydraulic parameters such as taking into account the water velocity in the stage-discharge equation or calculating criteria related to fish passability.

Implemented stage discharge equations span several device geometries (orifices, rectangular weirs, triangular weirs, truncated triangular weirs and rectangular gates) with specific equations adapted to sharp crested or broad crested weirs as well as equations handling transition between free flow and submerged flow as well as free surface and orifice flow on rectangular gate. To help the user in the choice of a stage discharge equation, "Cassiopée" displays warning if some equation parameter is outside the validity domain of the equation. As shown in Figure 8, the interface facilitates the comparison of stage-discharge equations according to different parameters.

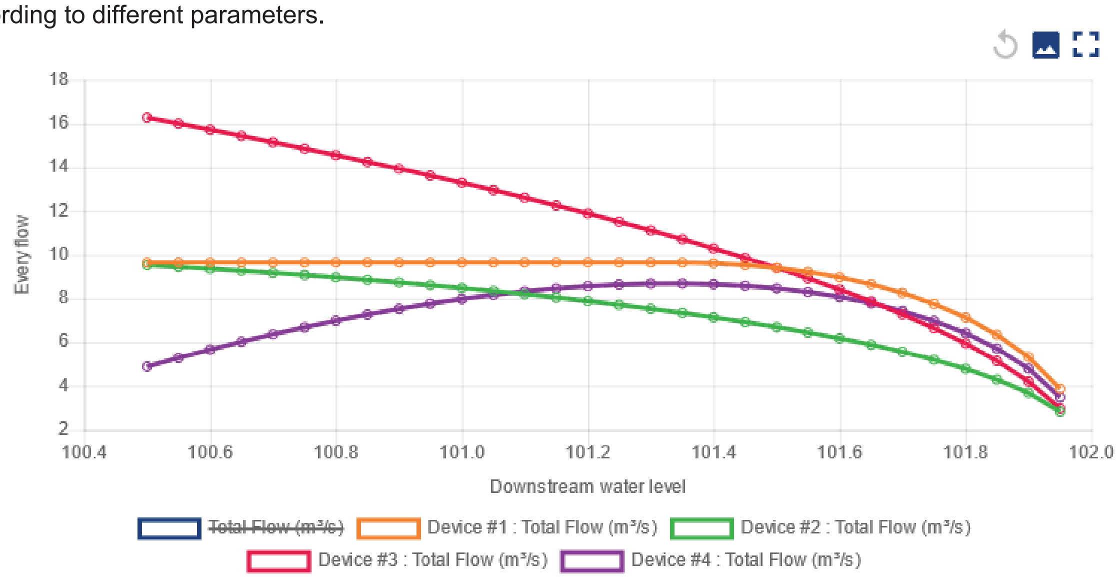


Figure 8: Plot of the flow crossing a rectangular weir depending on variation of downstream submergence for several stage-discharge equations: broad crested-weir (Cunge, 1980) (orange), sharp crested weir (Villemonte, 1948) (green), submerged slot (Larinier, 1992) (red), and deeply submerged sharp-crested weir (Rajaratnam, 1969) (purple).

5. CONCLUSIONS AND ROADMAP

The release of the new version of "Cassiopée" took place in October 2020 with a communication and training sessions towards the French public administrations and engineering offices working on fish-passes. Since then, with more than 50.000 calculations triggered by more than 18.500 visitors during the year 2021, 76% of whom from France (statistics provided by online applications), "Cassiopée" is largely used in France. With more than 10% of the visitors accessing to "Cassiopée" with a smartphone, we can think that the application is actually used in a versatile way to make some quick calculations on the field, as well as at the office to carry out the design and verification of complex devices such as pool-type fishways (18.700 calculation reported in 2021) or pre-dams (5.400 calculations).

Now, the majority of "Cassiopée" users are fish-passes designers but its wide range of hydraulic tools and its ease to use make "Cassiopée" an interesting tool to use in hydraulics education and civil engineering practice. Users can report malfunctions or wishes for the development of new features by e-mail or propose modifications to the code themselves to share with the community as the source code is open and released under AGPL3 license.

The development of a new module for velocity-area streamgauging is planned in 2022, implementing the ISO 748 norm (ISO, 2009) and uncertainty estimators (Despax et al., 2016). An R-package allowing to use "Cassiopée" calculation modules with the R language (R Core Team, 2021) for intensive calculations is also under development.

6. ACKNOWLEDGEMENTS

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The authors want to pay tribute to Michel Larinier, the creator of the first versions of “Cassiopée”, who left us too early in 2020.

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