Documentation of *SWASHES*
v1.04.02 (2024-11-25)

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Contents

1 Presentation of the *SWASHES* software

SWASHES is a library of Shallow Water Analytic Solutions for Hydraulic and Environmental Studies. A significant number of analytic solutions to the Shallow Water equations is described in a unified formalism. They encompass a wide variety of flow conditions (supercritical, subcritical, shock, etc.), in 1 or 2 space dimensions, with or without rain and soil friction, for transitory flow or steady state. The goal of this code is to help users of Shallow Water based models to easily find an adaptable benchmark library to validate numerical methods.

2 Software distribution

2.1 How to download *SWASHES*

The *SWASHES* software Delestre et al. (2011) can be downloaded on the website https://sourcesup.renater.fr/projects/swashes/.

Alternatively, if you are using the Conda package manager, the *SWASHES* package is available at https://anaconda.org/lrntct/swashes (contribution of Laurent Courty). *Note: You need to check that the conda version corresponds to the current* SWASHES *version.*

SWASHES is also available as a Python library named *pyswashes* (contribution of Laurent Courty). With it you can obtain the selected analytic solution in the form of a csv, Pandas dataframe, NumPy array or ASCII Grid format. See https://pyswashes.readthedocs.io/en/latest/. *Note: You need to check that the Python version corresponds to the current* SWASHES *version.*

2.2 How to cite *SWASHES*

The *SWASHES* software must be referred as:

> Delestre, O., Lucas, C., Ksinant, P.-A., Darboux, F., Laguerre, C., Vo, T. N. T., James, F., and Cordier, S. (2013). SWASHES: a compilation of shallow water analytic solutions for hydraulic and environmental studies. *International Journal of Numerical Methods in Fluids*, 72(3):269–300, DOI: `10.1002/fld.3741`, https://hal.science/hal-00628246. https://www.idpoisson.fr/swashes/.

If you use one of the solutions added to *SWASHES* by Rougier (2022), you should also cite:

> Rougier, M. (2022). Addition of 8 analytical solutions to the SWASHES software. Research report, Institut Denis Poisson - Université d'Orléans, https://hal.science/hal-03762587.

If you use the solute solutions, please also cite:

> Bey-Zekkoub, M., Tassi, P., Lucas, C., and Chhim, N. (2024). Analytical and numerical solutions for one-dimensional solute transport in rivers: advection, adsorption, degradation, and bed accumulation. https://hal.science/hal-04801276.

2.3 License

This software is distributed under CeCILL-V2 (GPL compatible) free software license. So, you are authorized to use the Software, without any limitation as to its fields of application.

If you make changes to *SWASHES* code, you are welcome to **contribute your changes to the main repository**, directly through the website (https://sourcesup.renater.fr/projects/swashes/) or by contacting its main developers (swashes.contact@listes.univ-orleans.fr). You may prefer to distribute yourself the *Modified Software.* In such a case, we ask you to **change its name** in order to avoid confusion between your software and the original one. In such a case, pay attention to the text that follows.

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- a copy of the Agreement,
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For further explanation about this free software license, you should read the following links:

- https://www.cecill.info/licences/Licence_CeCILL_V2-fr.html
- https://www.cecill.info/licences/Licence_CeCILL_V2-en.html

2.4 Installation

Remark 1 *To windows' users: please, look at the application note entitled "Using Cygwin to compile and run* FullSWOF_1D*,* FullSWOF_2D *or* SWASHES *under windows".*

First unzip the archive of the software. When you are in the *SWASHES* directory, write the following lines:

```
make clean
make
```

and run the executable located in the *bin* directory:

```
bin/swashes PARAMETERS
```

Remark 2 *If you are on a multi-core machine, you can speed up the compilation by adding* `-j N` *to your make command (where* `N` *is the number of cores you want to use), like* `make -j 4` *for using up to 4 cores.*

3 Input and output values

If you run the code with unsuitable parameters, the available solutions will be printed:

```
USE: swashes dimension type domain choice NumberCellx [NumberCelly]

Available solutions:
DIMENSION = 1
 ******* type = 0 Inclined plane ***************************************************
 - - - - domain = 1 L=10 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: supercritical flow
 - - - - domain = 2 L=20 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: transient solution
    2: periodic wave
 ******* type = 1 Bumps ************************************************************
 - - - - domain = 1 L=25 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: subcritical flow
    2: transcritical without shock (sub- to super-critical)
    3: transcritical with shock (sub- to super- to sub-critical)
    4: lake at rest with an immersed bump
    5: lake at rest with an emerged bump
 ******* type = 2 MacDonald ********************************************************
 - - - - domain = 1 Long channel: L=1000 m - - - - - - - - - - - - - - - - - - - - -
    1: subcritical flow (Darcy-Weisbach)                   2: (Manning)
    3: supercritical flow (Darcy-Weisbach)                 4: (Manning)
    5: sub- to super-critical flow (Darcy-Weisbach)        6: (Manning)
    7: super- to sub-critical flow (Darcy-Weisbach)        8: (Manning)
 - - - - domain = 2 Short channel: L=100 m - - - - - - - - - - - - - - - - - - - - -
    2: smooth transition and shock (Manning)
    4: supercritical flow (Manning)
    6: sub- to super-critical flow (Manning)
 - - - - domain = 3 Very long, undulating, periodic channel: L=5000 m - - - - - - - -
    2: subcritical flow (Manning)
 - - - - domain = 4 Long channel: L=1000 m with rain - - - - - - - - - - - - - - - - -
    1: subcritical flow (Darcy-Weisbach)                   2: (Manning)
    3: supercritical flow (Darcy-Weisbach)                 4: (Manning)
 - - - - domain = 5 Long channel: L=1000 m with diffusion - - - - - - - - - - - - - -
    1: subcritical flow
    2: supercritical flow
 ******* type = 3 Dam breaks *******************************************************
 - - - - domain = 1 L=10 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: dam break on a wet domain without friction (Stoker's solution)
    2: dam break on a dry domain without friction (Ritter's solution)
    3: dam break on a dry domain with friction (Dressler's solution)
 - - - - domain = 2 L=20 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: self-similar dam break on a flat bottom with a laminar friction
    2: self-similar dam break on an inclined plane with a laminar friction
 ******* type 4 = Oscillations *****************************************************
 - - - - domain = 1 L=4 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: planar surface in a parabola without friction (Thacker's solution)
 - - - - domain = 2 L=10000 m - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: planar surface in a parabola with a linear friction (Sampson's solution)
 ******* type 5 = Bedload (Exner) **************************************************
 - - - - domain = 1 L=15 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: Grass eq.
    2: Meyer-Peter & Muler eq.
 ******* type = 6 Sluice gates *****************************************************
 - - - - domain = 1 L=10 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: sluice gate opening on a dry domain
    2: sluice gate opening on a wet domain with free flow and low h_right = 0.01 * gate_size
    3: sluice gate opening on a wet domain with free flow and h_right = gate_size
```

```
 ******* type = 7 Dam break with a step ********************************************
 - - - - domain = 1 L=20 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: dam break problem with a discontinuous topography
 ******* type = 8 Solute model ******************************************************
 - - - - domain = 1 L=1000 m  - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: no degradation with initial dissolved concentration
    2: no degradation with boundary dissolved concentration
    3: degradation with initial dissolved concentration
    4: degradation with boundary dissolved concentration

DIMENSION = 1.5 (pseudo 2D)
 ******* type = 1 MacDonald PSEUDO 2D **********************************************
 - - - - domain = 1 Rectangular short channel, shape B1: L=200 m - - - - - - - - - -
    1: subcritical flow
    2: supercritical flow
    3: smooth transition
    4: hydraulic jump
 - - - - domain = 2 Trapezoidal long channel, shape B2: L=400 m - - - - - - - - - - -
    1: subcritical flow
    2: smooth transition and hydraulic jump

DIMENSION = 2
 ******* type 1 = Oscillations *****************************************************
 - - - - domain = 1 L=l=4 m - - - - - - - - - - - - - - - - - - - - - - - - - - - - -
    1: radially-symmetrical paraboloid (Thacker’s solution)
    2: planar surface in a paraboloid (Thacker’s solution)
 ******* type 2 = Dam in 2D *********************************************************
 - - - - domain = 1 L=25 m  l=10 m - |!| Use at least 50 points
    1: dam with a parabolic shape
 - - - - domain = 2 L=10 m  l=10 m - |!| Use at least 20 points
    1: cross shaped dam with a higher central ring
 ******* type 3 = Spherical geometry************************************************
 - - - - domain = 1 Earth like parameters with alpha=0 rad  - - - - - - - - - - - - -
    1: global steady state nonlinear zonal geostrophic flow
 - - - - domain = 2 Earth like parameters with alpha=0.406 rad - - - - - - - - - - -
    1: global steady state nonlinear zonal geostrophic flow
--------------------------------------------------------------------------------------

(for more details, see
‘SWASHES: a compilation of Shallow Water Analytic Solutions for Hydraulic and Environmental Studies’,
   O. Delestre, C. Lucas, P.-A. Ksinant, F. Darboux, C. Laguerre, T.N.T. Vo, F. James, S. Cordier
   International Journal of Numerical Methods in Fluids, 2013, 72(3): 269-300.
   DOI: 10.1002/fld.3741 . URL: https://hal.archives-ouvertes.fr/hal-00628246
and other references listed in the documentation.
```

This means that you have to specify 5 or 6 parameters depending on the case you consider.

- First, you have to give the **dimension** of the solution you want, that is:
  - 1 for one-dimensional cases,
  - 2 for two-dimensional cases,
  - and 1.5 for the pseudo 2d solutions developed by Mac Donald (MacDonald, 1996).
- The second parameter is the **type** of the solution *e.g.* inclined plane, bumps, dam breaks, oscillations and Mac Donald’s solutions.
- Then, you must specify the **domain** you want for the solution, among those available for the type you chose.
- To complete the choice of your solution, you must choose the value of the parameter **choice** corresponding to the configuration you want (sub- or super-critical, Manning or Darcy Weisbach friction coefficient for example).
- Last, enter the **number of cells** for the discretization in space. If you run a two-dimensional

case, do not forget to add the number of cells in the y direction.

Once you selected an existing solution, the result is printed in the terminal. As usual, you can redirect it in a file using the syntax of the following form:

```
bin/swashes 1 1 1 1 100 > sol.dat
```

Thus, the file `sol.dat` is created, with a summary of the parameters of the solution in the header, and the values of the solution in the file. More precisely, the file contains several columns with:

- the values of the discrete space $x_i = (i - 0.5)dx$ (and eventually y in two dimensions),
- the values of the water height h,
- the values of the velocity u (and eventually v, $\sqrt{u^2 + v^2}$ in two dimensions),
- the values of the bottom (the topography),
- the values of the flux $q = q_x = hu$ (and eventually $q_y = hv$, $\sqrt{q_x^2 + q_y^2}$ in two dimensions),
- the values of the free surface,
- and the values of the critical surface, that is the surface where the Froude number (defined by Fr$= u/\sqrt{gh}$) is equal to 1.

(Note that some of these values may not be available for each solution).

For more details, we refer to Delestre et al. (2013) where most of the solutions are described. For solutions on an inclined plane, one can read Delestre et al. (2012). The swash solutions have been programmed by Noémie Gaveau during her internship (see Gaveau (2015)) from Carrier and Greenspan (1958). Self-similar solutions have been added from Bodjona (2013) (see also *Self-similar_solutions.pdf* file in the *doc* folder and Huppert (1982)): note that these solutions are obtained from an approximation of the Shallow Water system and are not valid for small times.

Remark 3 (Bedload case) *If you consider bedload transport (with Exner equation) see Berthon et al. (2012), you will also save the (discrete) initial topography (and the initial free surface). The boundary conditions are the values on the boundaries (more precisely the mean value over the cells centered in $x = -dx/2$ and $x = L + dx/2$ respectively). Note that, to be validated through this solution, your code should not simulate a coupling between Shallow Water and Exner equations, but it must solve the whole system (on h, q and z_b), with no friction in the momentum equation.*

In version 1.04.00, 8 new solutions were added by Maxime Rougier during its internship. Please, refer to the update note "Addition of new analytical solutions to the SWASHES software" at https://sourcesup.renater.fr/www/swashes/ for more details:

- There are two steady solutions in 2d with dam-like topographies. The number of points N_x and N_y should be superior to $L/2$ and $l/2$ respectively to guarantee the shape of the topography.
- There are two solutions in spherical geometry. For those solutions, and unlike the other ones, the functions are computed at the points of the mesh, and not the center of each cells.
- There are three solutions for the case of the sluice gate opening. In those solutions, we look at a problem similar to the dam break problem, but where only the bottom part of the dam opens.
- There is one solution for the case of the dam break with a step. For those solutions, the resolution of a nonlinear system is required. The resolution was done outside of SWASHES. Thus, the given solution only works for the set value of initial water heights, and one should be cautious if they wish to change them.

From version 1.04.02, another type of solution gives the analytic concentrations of dissolved and adsorbed solute, see Bey-Zekkoub et al. (2024). These are not strictly speaking Shallow water solutions, but it can be useful to validate models that contain suspended sediment.

For these solutions, the output file contains:

- the values of the discrete space $x_i = (i - 0.5)dx$,
- the values of the dissolved solute concentration ϕ (in kg/m^3) at the final time,
- the values of the adsorbed solute concentration ψ (in kg/m^3) at the final time,
- the values of the dissolved solute concentration ϕ (in kg/m^3) at the initial time,
- the values of the adsorbed solute concentration ψ (in kg/m^3) at the initial time.

4 For developers: Doxygen

You may wish to add some functionalities to *SWASHES* to suit your needs. Always comment the files, at the beginning of the file, using Doxygen syntax (www.doxygen.org). Then, you will be able to create the doxygen documentation of the whole code, with Doxygen 1.8.0.

HTML documentation. In order to generate the Doxygen html file, the **Doxygen_config_file_html** file is saved in the *doc* directory. To run Doxygen, from the *SWASHES* directory, use the command:

```
doxygen doc/Doxygen_config_file_html
```

Warning: Graphviz (www.graphviz.org) must be in your PATH to generate HTML diagrams. If not, change the HAVE_DOT parameter of the Doxygen_config_file_html file. In the *doc/html/* directory, **index.html** is created.

PDF documentation. To generate the Doxygen LaTeX (pdf) file, you must use the **Doxygen_config_file_latex** file and compile the .tex file:

```
doxygen doc/Doxygen_config_file_latex
cd doc/latex
make
```

In the *doc/latex* directory, **refman.pdf** is created.

References

Berthon, C., Cordier, S., Delestre, O., and Le, M.-H. (2012). An analytical solution of the Shallow Water system coupled to the Exner equation. *C. R. Acad. Sci. Paris, Ser. I*, 350(3–4):183–186, DOI: `10.1016/j.crma.2012.01.007`, https://hal.science/hal-00648343.

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Bodjona, S. H. (2013). Etude d'exemples simples d'écoulements, comparaison Saint-Venant et Navier-Stokes. Master's thesis, Université P. & M. Curie. (In French).

Carrier, G. F. and Greenspan, H. P. (1958). Water waves of finite amplitude on a sloping beach. *Journal of Fluid Mechanics*, 4:97–109, DOI: `10.1017/S0022112058000331`, http://journals.cambridge.org/article_S0022112058000331.

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Huppert, H. E. (1982). Flow and instability of a viscous current down a slope. *Nature*, 300:427–429, DOI: `10.1038/300427a0`.

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