ARMINES / ECOLE DES MINES DE PARIS / MINES PARIS PSL

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FLUMY™ Project
Version 8.0

User's guide
February 2025

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1 Introduction: the model

1.1 Fluvial Systems

This FLUMY™ software is a modeling tool, both process-based and stochastic, for a meandering channel system and its associated deposits at the scale of the reservoir. The model is based on the evolution in time of the channel by migration, cut-off and avulsion, and on the deposition of point-bar sand, mud plug, crevasse splays, overbank alluvium and organic matter.

In the FLUMY working space (after a possible 2D rotation around an origin from the geographical space), the domain (i.e. the floodplain) is discretized as a rectangular 2D grid. The channel can flow in any direction. The flow direction is parallel to a slightly deeping reference plane with a given global domain slope. Time is discretized into iterations, or time steps. At every time step, e.g. 1-2 year for Fluvial systems (and except for a few singular events), **migration** is performed. This is favored by the erodibility, either constant over the domain, or defined as a map on the discretized grid (optionally 3D). Sand and mud plugs are deposited inside abandoned channels after a cutoff or an avulsion.

When overbank flow occurs, alluvium is deposited on the domain, with thickness and grain size decreasing exponentially from the channel. The **aggradation** (or on the contrary the incision) may be constrained by the distance between the elevation of the domain, and an equilibrium profile parallel to the reference plane and also varying in time. Peat (or any pond deposits) may be deposited in the lowlands, the lower parts of the domain with respect to the reference plane.

At some times (coinciding with overbank flow or not), a levee breach may occur within the domain, producing either a chute cut-off, or a crevasse splay of type I, that may evolve into a crevasse splay of type II and crevasse splay channels, and possibly into an **avulsion**. In addition to such local avulsions, regional avulsions may be caused by levee breaching upstream of the domain, resulting in a change of the channel entry point.

All this meandering fluvial sedimentation may take place within given sedimentary units defined by **topographic surfaces** (possibly planes with given elevation). Lithofacies other than resulting from meandering fluvial sedimentation may be deposited between two topographic surfaces. Imported surfaces may be used to replace, erode, or aggrade the current topography. An imported surface may also correspond to an upper stratigraphic surface, to which the deposition will tend.

A **conditioning process** is used to honor vertical wells data. It aims at reproducing at each iteration the local conditions of deposition (assuming that the system is aggrading, or at least not incising), so that the process deposits preferentially (but not yet 100%) what is expected at data points. The process is thus expected to provide plausible realizations of the model when the density of the wells is reasonable.

1.2 Turbidites Systems

The FLUMY model in turbidites context is presently based on the analogy with the planform of the fluvial meandering systems. It is devoted to model middle-fans deposits onto the domain (i.e. the abyssal plain). It makes use of the same equations for the evolution of the meandering channel than in fluvial systems (which assumes steady state when no aggradation is required) taking into account relationship specific to the turbidites systems. The main difference (except the scale) results in the default wavelength which is 2.5 times less than in fluvial context.

At each iteration, e.g. ~7 years for Turidites system, the channel migrates and deposits LAPs (Lateral Accretion Packages, presently corresponding to the fluvial Point Bar lithofacies). Upon request it can be aggradational giving channel lag deposits and overbank sediments during overbank flows, or, on the contrary be erosive, resulting in no deposition, or simply migrating. Levee and overbank sediments are deposited at a given period of iteration (random or constant). Super-elevation is capable to reproduce dissymmetrical levees.

Ghost migration process (only for turbidites systems) corresponds to a low energy filling of the channel, during which there is no apparent migration or levee deposition. When ghost migration stops, the channel has moved and migration starts again: this corresponds to “migration by avulsion” (which is not a natural process obviously).

Hemipelagic Plug lithofacies is also deposited inside abandoned channels after a cutoff or an avulsion (in place of Mud Plug from fluvial systems).

Pelagic lithofacies (absent from fluvial context) permits to reproduce periodically the pelagic sedimentation (very fine sediments like carbonate or terrigenous) all over the domain except onto the channel path.

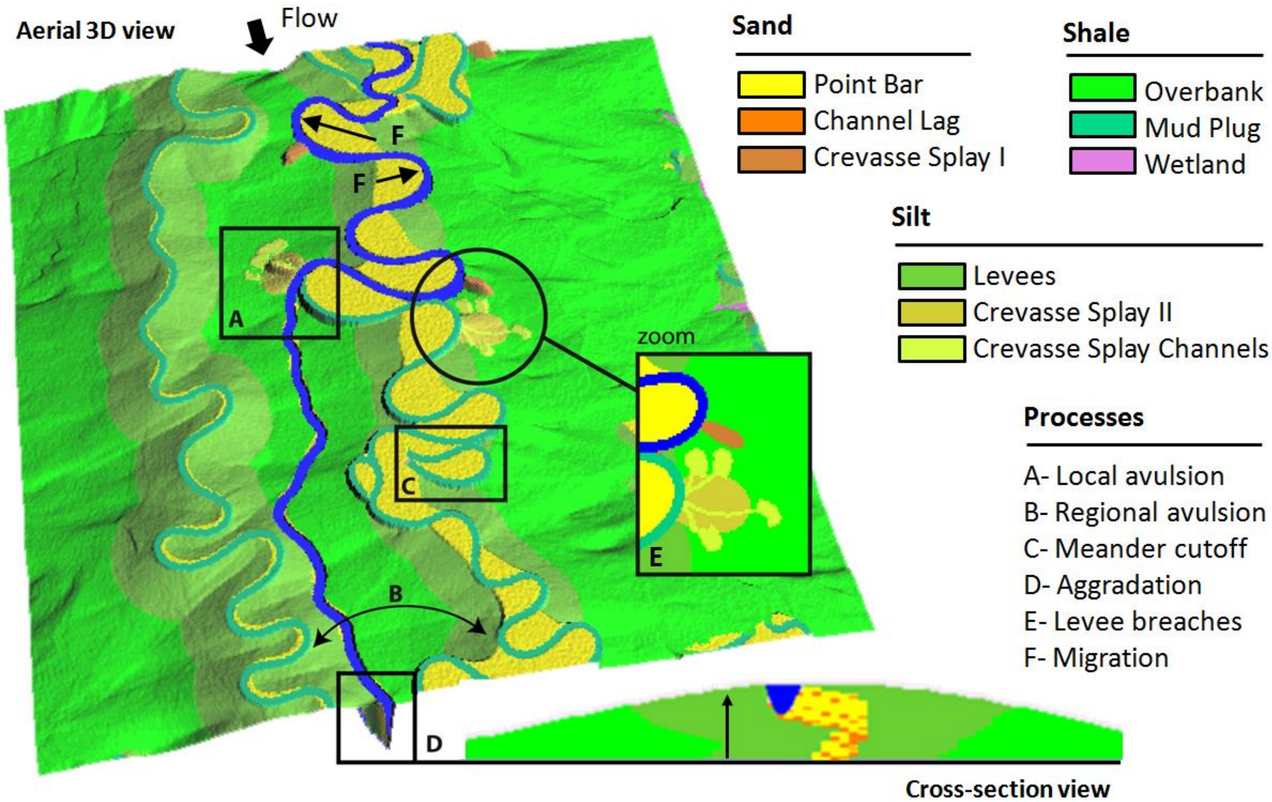
1.3 Outputs

The basic output block model consists, at each node of the 2D grid, in successive deposition units with variable height, informed in lithofacies, age and grain size (irregular pillars).

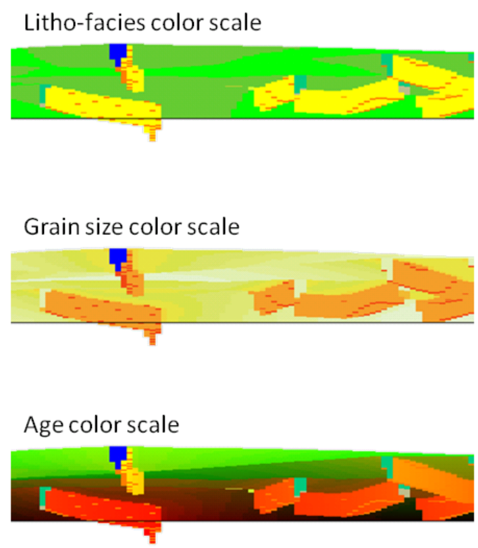
This block could be exported in text files with a regular 3D grid format. (after a vertical discretization done by sampling). Two ASCII output formats are known by FLUMY: The F2G format and the GSLIB format. GSLIB text files can be imported into Petrel© (look at §0).

Such reservoir models are sound inputs for fluid flow simulations and could be used as training images for pixel-based simulation or deep learning methods.

Important Note: The terms “Lithofacies” and “Facies” when applying to FLUMY output property are equivalent to “Depositional Element” in the literature. Indeed, deposition units generated by FLUMY are created with respect to the geometry of sediment bodies. The full detail and complexity of each facies are further represented by the **grain size** property also generated by FLUMY (see §3.8).



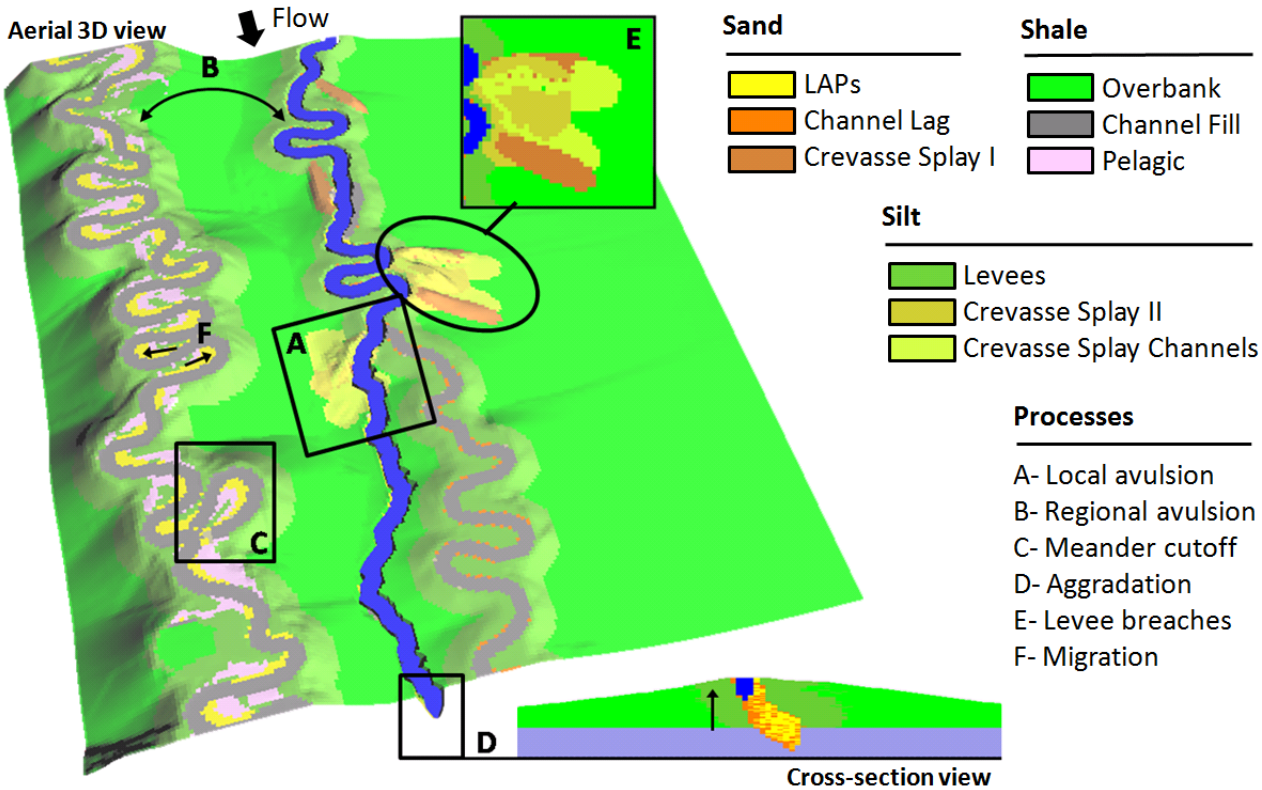
Related process	Facies	Litho-facies	
Migration	Point bar Channel lag	Sand Gravel	PB CL
Cutoff	Abandoned meander (plug and loop)	Sand Shale	SP MP
Aggradation	Levees Overbank flood	Silt Shale Wetland	LV OB WL
Levee breaches	Crevasse splay 1 Crevasse splay 2 Crevasse channels	Sand Silt Sand	CS1 CS2 CCH
Avulsion	Abandoned channel	Sand Shale	SP MP
Marine incursion	Draping	Shale	DR



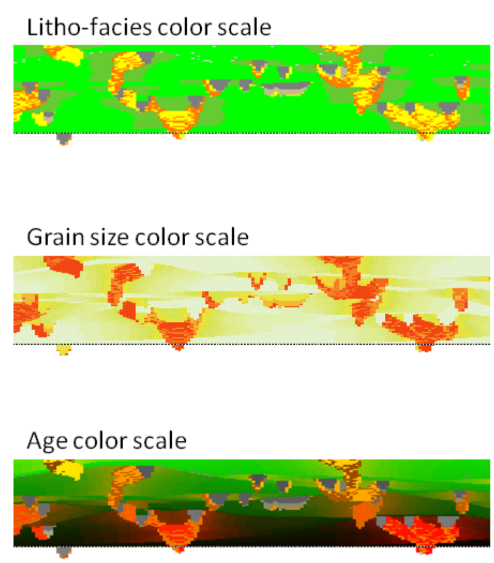
Fluvial Litho-facies sorted in increasing grain size order

Facies	DR	WL	MP	OB	LV	CS2	CCH	CS1	SP	PB	CL
Classes	Shale				Silt		Sand				

Figure 1 : Outputs description (Fluvial systems)



Related process	Facies	Litho-facies	
Migration	Lateral Accr. Packs. Channel lag	Sand Gravel	LAP CL
Cutoff	Abandoned meander (plug and loop)	Sand Shale	SP CF
Aggradation	Levees Overbank flood	Silt Shale Pelagic	LV OB PL
Levee breaches	Crevasse splay 1 Crevasse splay 2 Crevasse channels	Sand Silt Sand	CS1 CS2 CCH
Avulsion	Abandoned channel Channel Fill	Sand Shale	SP CF
Pelagic Sedim.	Pelagic	Shale	PL



Turbidites Litho-facies sorted in increasing grain size order

Facies	PL	CF	OB	LV	CS2	CCH	CS1	SP	LAP	CL
Classes	Shale			Silt		Sand				

Figure 2 : Outputs description (Turbidites systems)

2 Preamble

2.1 Software distributions

Several distributions of FLUMY software are currently available:

	FREE packages	**FREE standalone**	**PREMIUM standalone**	**RESEARCH standalone / packages**
Fluvial environment	X	X	X	X
Turbidites environment		X	X	X
Non-expert user parameters	X	X	X	X
Full set of parameters		X	X	X
Batch mode / Scripting	X (Python/R)		X (Batch)	X (All)
Conditioning (Well/Seismic)			X	X
New JIP developments				X
Technical customer support				X (included)
Additional plugin				On demand

The Premium version (which allows conditioning to wells and seismic data) need to be unlocked with a valid serial number. A trial period of 3 months is possible by registering the software (Look at §2.3).

The Research version (which implements all last developments) is only available to our research partners and need also a valid serial number (§2.3).

The Python and R FREE packages are provided to the following URLs and can be used for training images generation:

Python Package: https://pypi.org/project/flumy

R Package: https://soft.mines-paristech.fr/cran/flumy.html

When using our software, you must cite Flumy (see §2.5) and accept our End-User License Agreement (see §2.4)

2.2 Download and install the software

The last standalone version of the Flumy software is available from our "Download" page of the Flumy web site: https://flumy.minesparis.psl.eu.

After reading and accepting our End-User Freeware License Agreement, download the Flumy archive file to your local computer: windows 64 bits or linux 64 bits.

Extract the contents of the archive file in a directory of yours, ex: C:\Users\user\flumy_W.XYZ (windows), /home/user/flumy_W.XYZ (linux) (where W.XYZ is the Flumy software version number). You will find in this directory the following folders:

- **bin**: executable files
- **data**: sample files for importation features (batch files, centerline, well, topography and erodibility map) and color palettes
- **doc**: this user guide, the tutorials and the End-User Freeware License Agreement

To start the program, double-click on the file **flumy** (or **flumy.exe** depending on your Windows Explorer settings) into the bin directory.

The program will tell you whether a valid serial number has been found or not. If not, the Free version is automatically launched. Otherwise, the Premium or the Research version is launched according to the registered serial number.

Under Linux (Ubuntu) you may have to install additional libraries:

Ubuntu < 18.04	Ubuntu ≥ 18.04
apt-get install -y libwxgtk3.0-dev apt-get install -y freeglut3-dev	apt-get install -y libwxgtk3.0-gtk3-dev apt-get install -y freeglut3-dev

Download page: https://flumy.minesparis.psl.eu/download

2.3 Registering the software

To get a valid Serial Number and registering the **Premium or Research** version, the user has to click on the “Help / Register the Software” menu. The following window is opened:

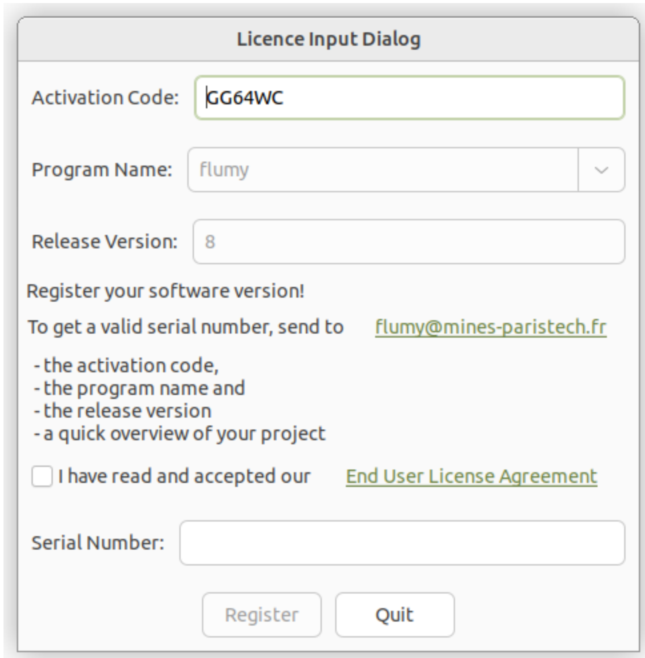


Figure 3 : Registering the software

To get a valid Serial Number, send us by email (flumy@mines-paristech.fr) the following information:

- your name and your institute or company (if any);
- the Activation Code displayed;
- the program name and the release version displayed;
- a quick overview of the project (PhD, training, classes, research topics, field study...);
- the name of the academic or industrial supervisor if the Licensee is a student or a trainee;
- the topic of the project;

and we will send back to you the corresponding Serial Number. Each [Activation Code, Serial Number] pair is unique for each operating system. Once the software is unlocked the “Help / About Software” window indicates details of the current running version. The full set of parameters is only available in the Research confidential version (for Research Program members, see our website for more details).

Note: There is no need to register the Free standalone or packages version.

2.4 Credits and Copyright

The Flumy software is the property of ARMINES / MINES-Paris - PSL. The Flumy software can be used for any legal academic, research or commercial purpose. For instance, it could be used to generate non conditional reservoir simulations (training images). The Flumy standalone software is given without any guarantee. ARMINES / MINES-Paris – PSL is not responsible of any damage that this software could do to your data or to your computer.

By using all or any portion of the Flumy Software you accept the terms and conditions of the End-User Freeware License Agreement (look at LICENSE.txt file in 'doc' directory)

By using all or any portion of the Flumy Software, you must acknowledge FLUMY by following instructions at §2.5.

Flumy™ is a registered trademark in France, UK, Canada, Benelux and Australia.

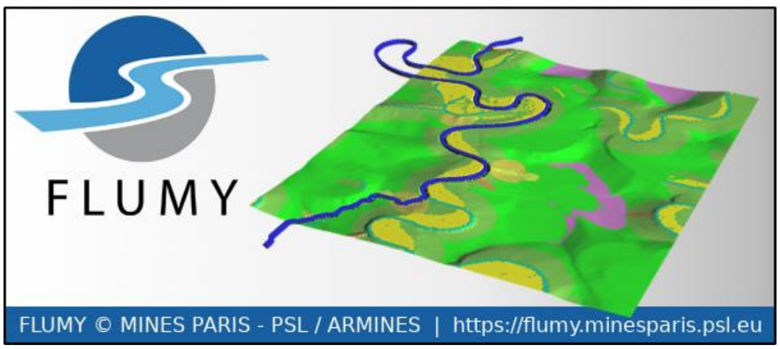
Figure 4 : About the software

2.5 How to Cite?

When using Flumy in your publications, your work or any other communications, you must acknowledge FLUMY by using the following reference:

```
-----------------------------------------------
FLUMY™
Process-based channelized reservoir models
Copyright © MINES PARIS - PSL / ARMINES
Free download from https://flumy.minesparis.psl.eu
-----------------------------------------------
```

You can also freely use the following graphical material:



2.6 Terminology

Nexus: Non-expert user calculator (see $3.2.1)

EP: Equilibrium Profile (see §3.7.1)

OBF: Overbank Flow

VPC: Vertical Proportion Curve (see $4.4.3.1)

LAPs: Lateral Accretion Packages

LADs: Lateral Accretion Deposits

See §6.5 for lithofacies identifiers (CL, PB, MP, …)

3 Input parameters

3.1 Overview

When running the program, a **graphical interface window** opens. **Parameter values**, and names of possible **data files**, are to be entered through the tabs of the interface window: these are described in this Section 3. Alternatively, they can be entered by launching the **journal file** from a previous simulation (see Section 4.1.2), by launching a **batch file** from the command line (see Section 4.1.3), or by opening an existing **project** to re-use a previous simulation (see Section 4.4.1). Note that when running the program, all the inputs, as well as the saved simulation results are stored within a Project Folder, including the journal files.

At startup, Flumy automatically loads a temporary unsaved project. The user can choose to directly launch a simulation then save the project, or open an existing project by using the File menu.

Remark: The subdirectory *data* initially contains examples of channel centerline and erodibility maps, as well as examples of journal or batch files and well files.

Parameters units are:

- *Lengths*: in meters
- *Time*:
    - either in seconds (ex: velocity in m/s)
    - or in iterations, assuming 1 iteration ≈ 1 year (Fluvial) and 7 years (Turbidites).

In the interface window, decimal numbers must be entered with a decimal dot, or a decimal comma, according to the environment (in ASCII files, only decimal point is to be used, see chapter 5).

The interface window contains several tabs described below.

Each tab (except the *Summary* tab which gives a summary of the key parameters) contains several fields corresponding to the parameters to be informed.

For some fields, a choice of options is proposed by using the Edit button.

A table giving possible values for key parameters is provided in chapter 6.1.

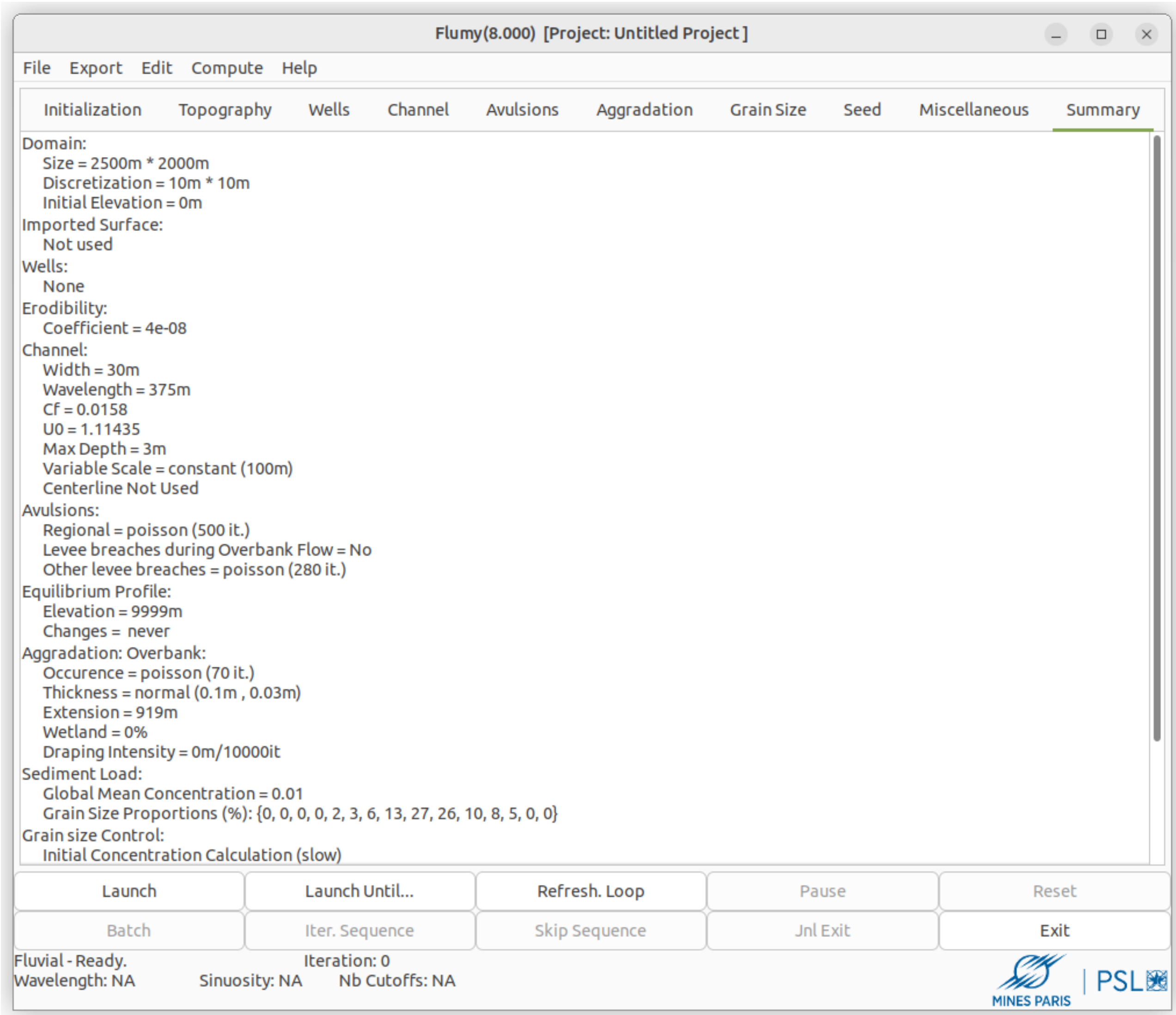


Figure 5 : Summary tab

3.2 Initialization

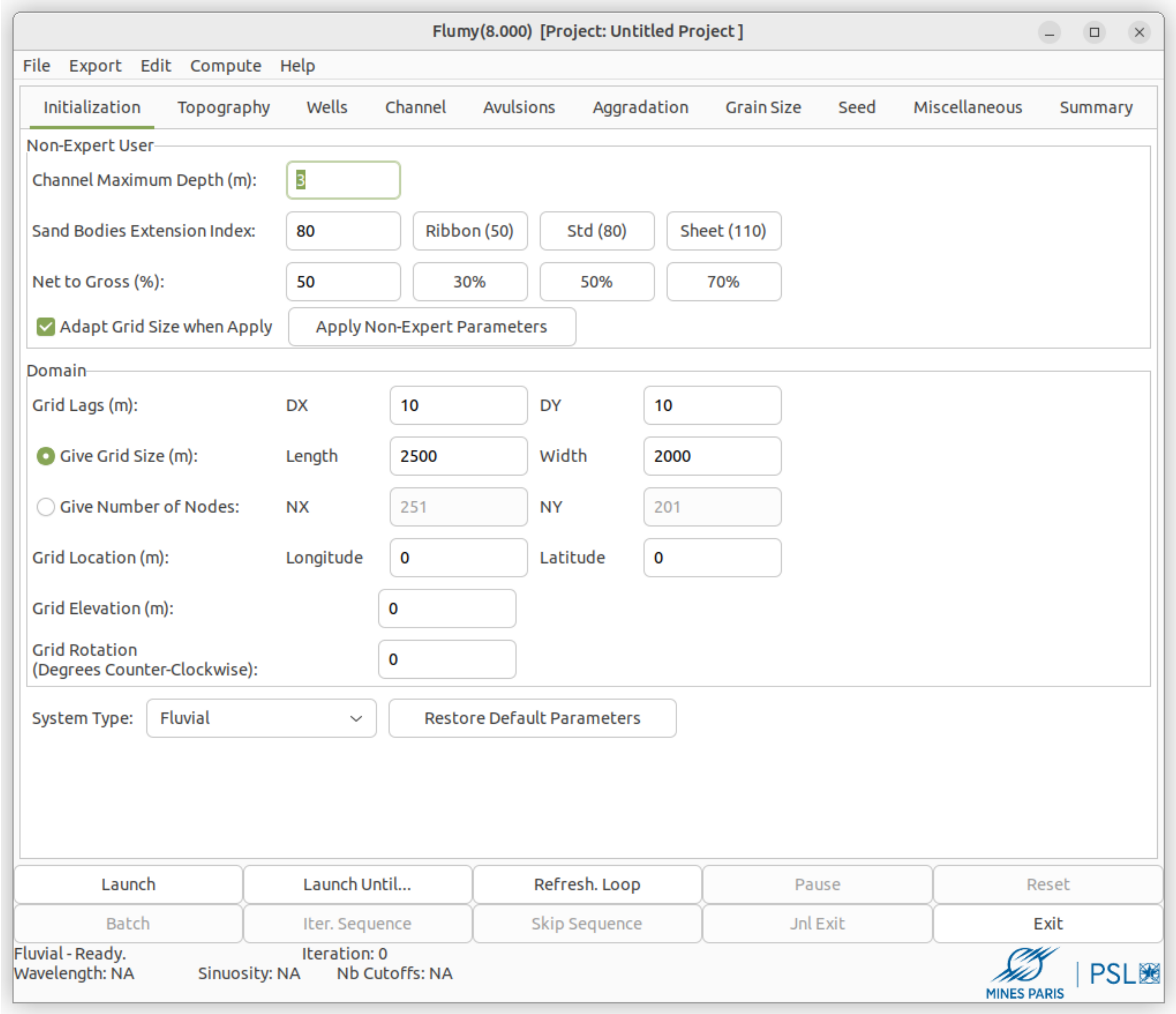


Figure 6 : Initialization tab

3.2.1 Non-expert user

The non-expert user pre-calculator is the easiest way to start with Flumy. It uses 3 input key parameters which are used to automatically deduce all other simulation parameters:

* The **Channel Maximum Depth** (in m) (see §3.5.2 for the description of this parameter)

* The horizontal **Sand Bodies Extension Index** (between 20 and 160 with no units) (characterizing the amplitude of generated channel meanders and thus the type of sand bodies, from 20 for ribbon-type, through 80 for standard, to 100 for sheet-type and 160 for sheet-type with large lateral connectivity)

* The **Net-to-Gross** % (i.e. the required sand proportion)

Default values are proposed. When applying these 3 parameters, the values of all main Flumy parameters are computed automatically by a pre-calculator.

The user has the possibility to compute/update also the **grid size**:

- The cell mesh is set to one third or one fourth of the channel width (which is deduced from channel maximum depth),
- The number of nodes are restored to their default values,
- The grid location and the grid rotation are not changed.

Note:

- If wells are used and the new grid doesn't enclose all the wells, an error message will be displayed when launching the simulation.
- If a topography or a centerline file is used, the user must check that this new grid is compatible and should modify the location, the rotation and/or the number of nodes if necessary.

The user always keeps a direct access to the usual Flumy parameters. In particular he can use the non-expert user facilities for a first guess of the parameters.

Note that the pre-calculator (like the forecast tool, section 0) is based upon formula developed for Flumy that aim at giving only orders of magnitude. The template values for Sand Bodies Extension Index and Net to Gross and their different combination, offer the possibility to generate all kinds of reservoir model:

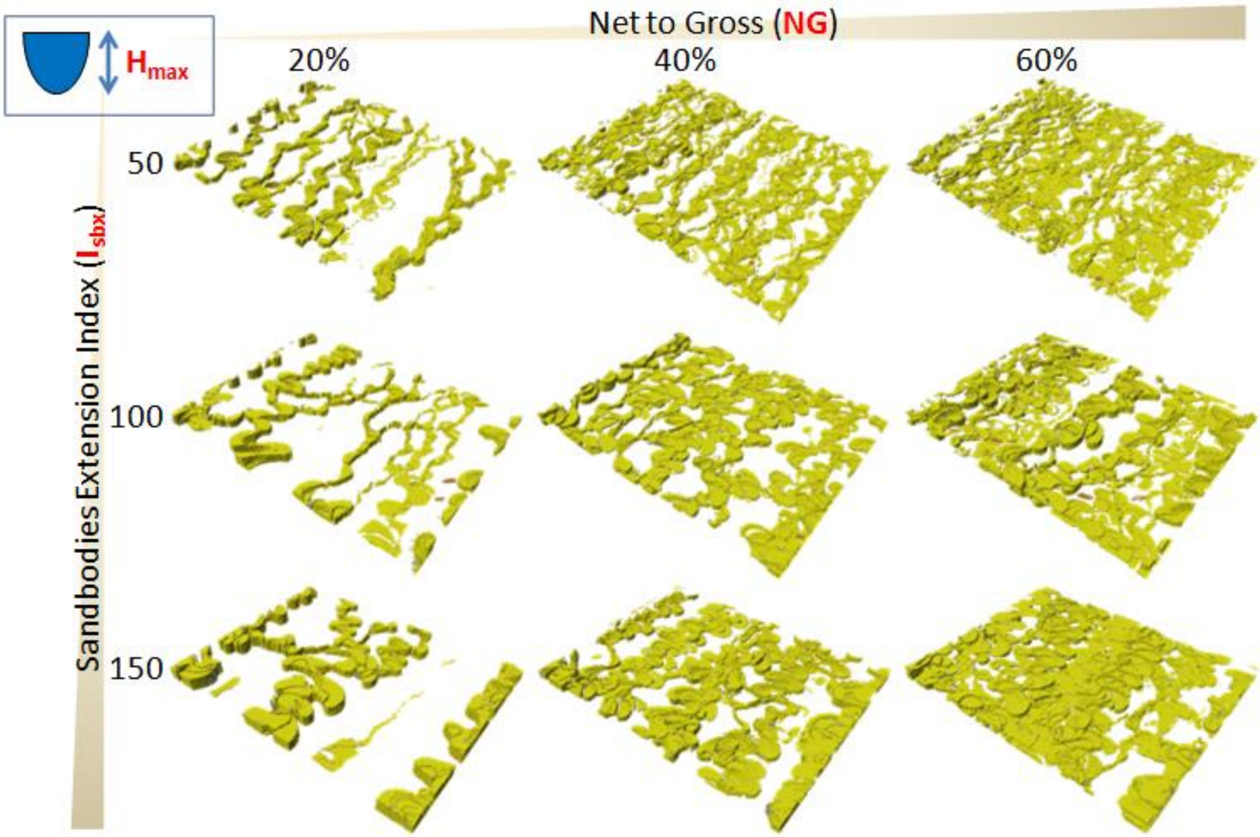


Figure 7 : Point bars / LAPs deposits variability

3.2.2 Domain

* **Grid Lags** (mesh size) of the grid along Flumy Ox and Oy axes (real numbers, in meters)

* <u>Size of the 2D grid</u>: the user has the possibility to enter the size, through one of the two options:

- **Give Grid Sizes** (in meters) along Ox and Oy axes. This is not the domain size (see later),
- **Give Number of Nodes** along Ox and Oy axes.
  - ***Note***:
    - When choosing one option, the data of the other option will be automatically calculated and displayed on the dialog window.
    - Simulations with a number of nodes (nx*ny) above 1 000 000 may be slow. The maximal number of nodes (nx*ny) is 25 000 000.

* **Grid Location (in m)**: real numbers in meters giving the Longitude and the Latitude coordinates of the origin of the 2D grid (standard way: southwestern point of the grid - equivalently cell center).

* **Grid Elevation** (in m) at the origin, giving the elevation reference level. This is displayed as a dashed black horizontal line in vertical section views. See Figure 39 in section 4.3.6.1 for more details.

* **Grid Rotation**: angle in degrees, counted anticlockwise, giving the rotation around the grid location origin to be applied to go from the geographical x-axis (West to East) to the new x-axis of the working space.

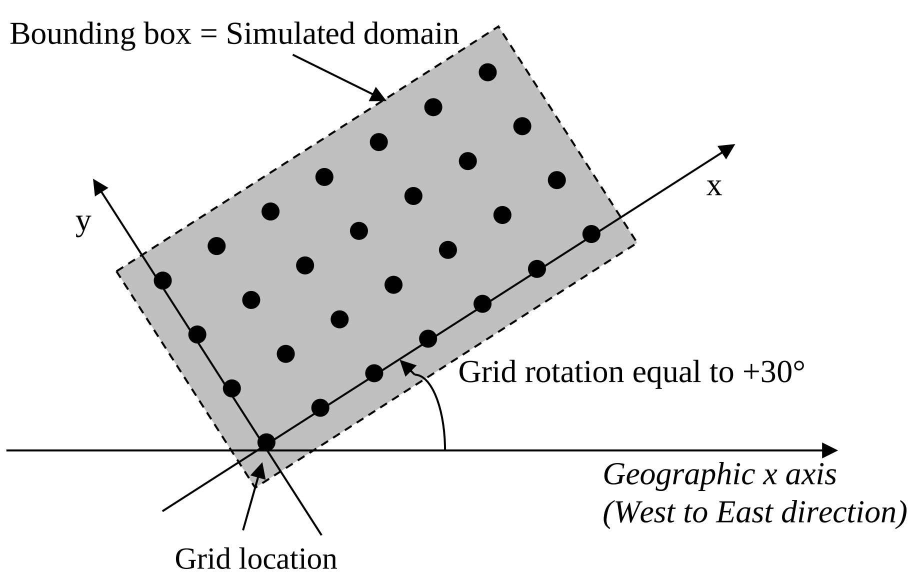


Figure 8 : Grid convention

Determination of the domain 2D grid in the geographical space

- ***Note*:**
  - Numbering corresponds to the numbering of x or y sections (visible in section views) (origin of the 2D grid is at the intersection between x-section 1 and y-section 1.)
  - For x- and y-lags equal to 100m, the previous 2D **grid size** is 600m (along x) and 300m (along y) and the simulated **domain size** 700m (along x) and 400m (along y). Number of nodes nx = 7, ny = 4

3.2.3 System type

The system type defines the environment at deposition time. If you are simulating a continental fluvial reservoir, the "**Fluvial**" option must be selected. If you are simulating a submarine reservoir, the "**Turbidites**" system option must be selected. When changing option, all parameters will be restored to the appropriate default values. These options must be defined at the beginning (before the first iteration).

Please, look at the chapter §6 to see the differences between fluvial and turbidites systems in Flumy.

3.2.4 Default parameters

All Flumy default parameters (for the given system type) can be restored by the button "Restore default parameters" (= "Factory settings"). Please refer to §6.1 to see the default values for all parameters.

3.3 Topography

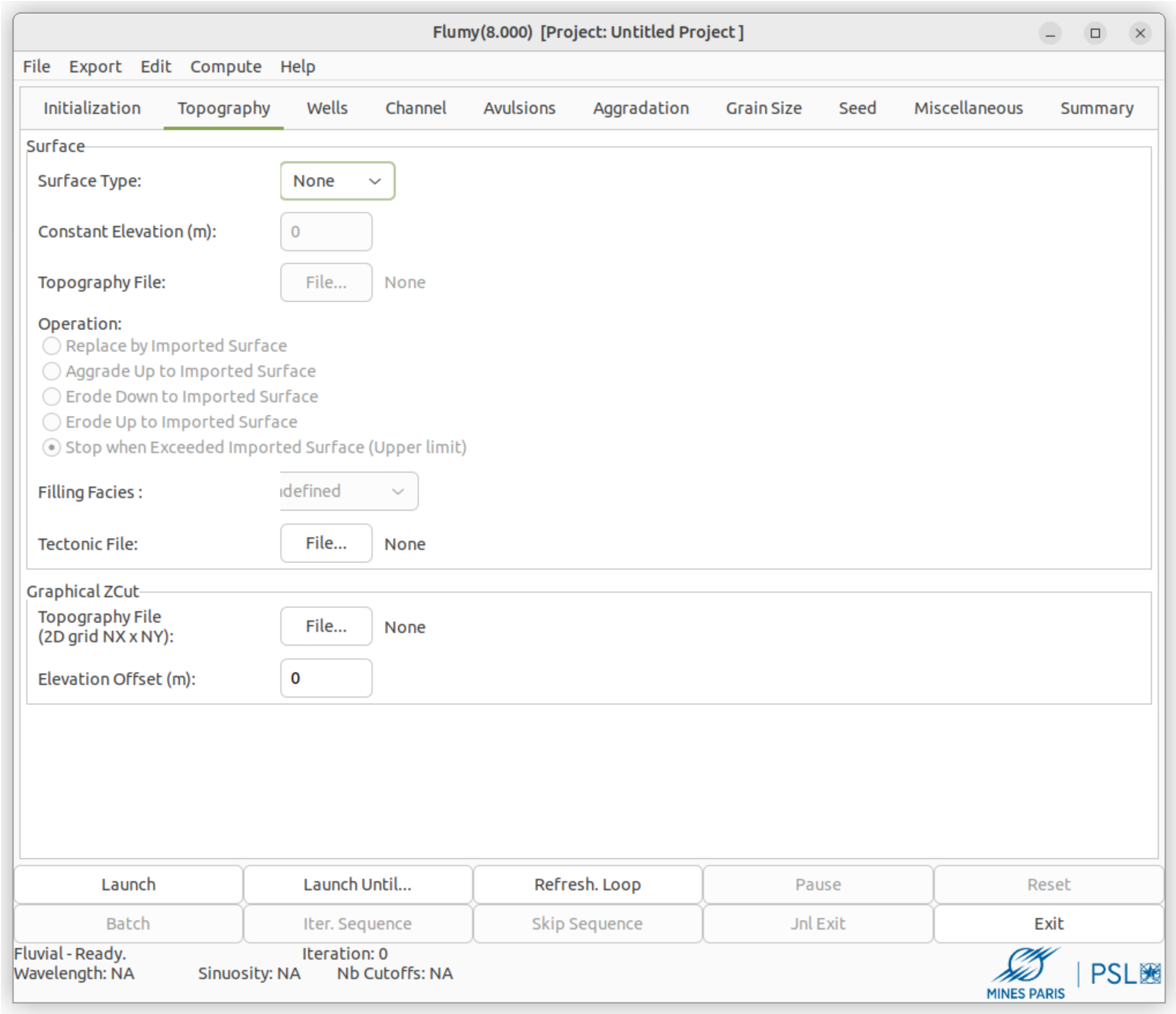


Figure 9 : Topography tab

3.3.1 Surface

* Whenever he wants, the user can choose to use a surface (topography), defining its **Surface type**:

- **None** (No input surface is used)
- either as a **Constant Elevation**, with the **Elevation** in m (including grid elevation – see section 3.2.2);
- or as a **File** (ASCII file at F2G Format, see chapter 5.2.2)

* Then the user has to choose between one of these **Operations**:

- **Replace** the current topography **by the Imported Surface**;
- **Aggrade** the current topography **up to the Imported Surface**;
- **Erode** the current topography **down to the Imported Surface**;
- **Erode** the lower part of the simulation **up to the Imported Surface**;
- **Stop** simulation **as soon as the topography exceeds the Imported Surface** (Upper limit).

The first 4 cases correspond to **one-time operations** (the program runs 1 iteration, and the user has to switch off this operation to be able to do something else, see section 4.1.1).

The fifth option **is not a one-time operation**. The user can display the upper limit topography in 2D aerial view and vertical section views by pushing the Key “u” (See Figure 39 in section 4.3.6.1 for more details). The upper limit is used as long as the user doesn’t change the Surface Type parameter to *None*.

* The **Filling Facies** is used to fill possible empty spaces up to the imported surface for the two first options. The user has the choice between: **Undefined**; **Draping** (see §6.5) or **Pelagic** (see §6.5).

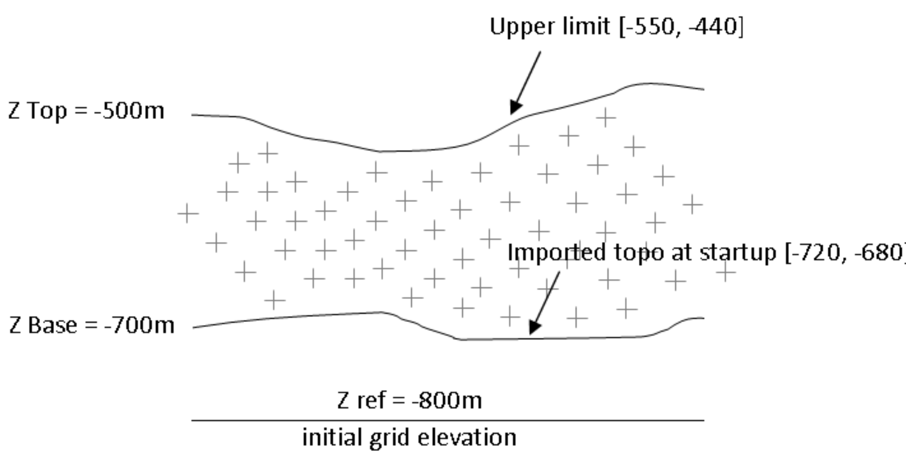


Figure 10 : Imported topography and upper limit

In the above example, at startup, the user replaces the topography to load initial basement, then setup the upper limit during the simulation run. See Figure 39 in section 4.3.6.1 for more details.

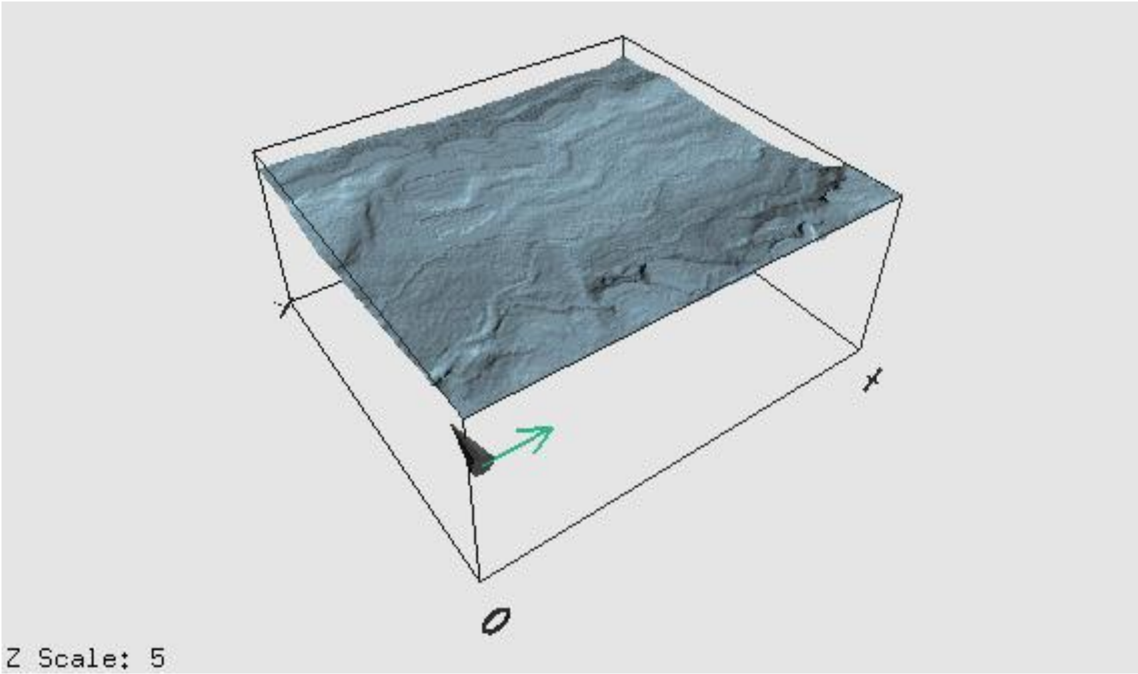


Figure 11 : Imported basement topography filled with draping

* **Tectonic File**: 2D grid ASCII file which has the same structure (mesh and number of nodes) than the domain grid. Each cell contains the vertical substratum deformation (positive or negative distance in meters) to be applied every 1000 iterations.

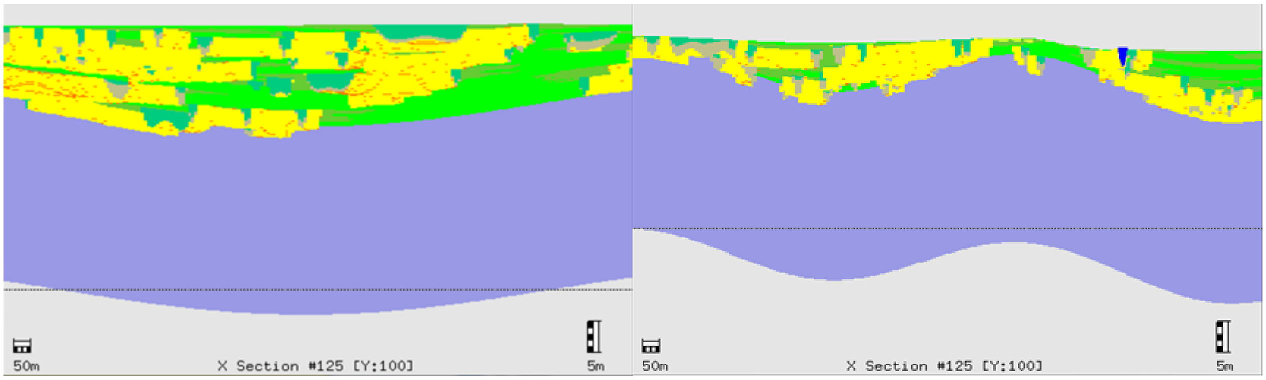


Figure 12 : Tectonic deformation

Note: This feature is still under development and is available only for our Research Partners.

3.3.2 Graphical ZCut option

* **Graphical ZCut option**: this is a purely visual tool (not recorded in the journal file) that allows displaying the simulation as intersected by a given surface, when using the key "/" or the icon: .

- **File**: contains the intersection surface (ASCII at F2G format, see chapter 5.2).
- **Elevation offset** (m): value to be added to the elevation values of the intersection surface (including grid elevation – see section 3.2.2).

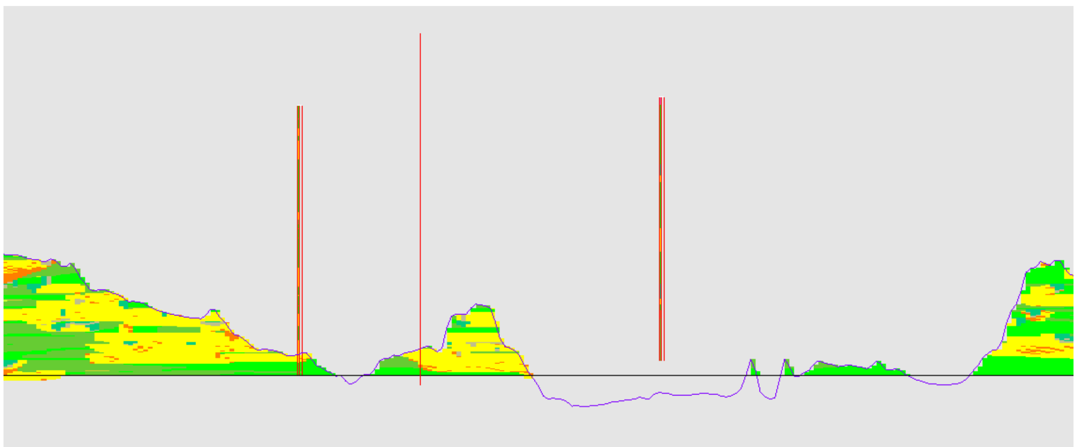


Figure 13 : Vertical section view with ZCut option

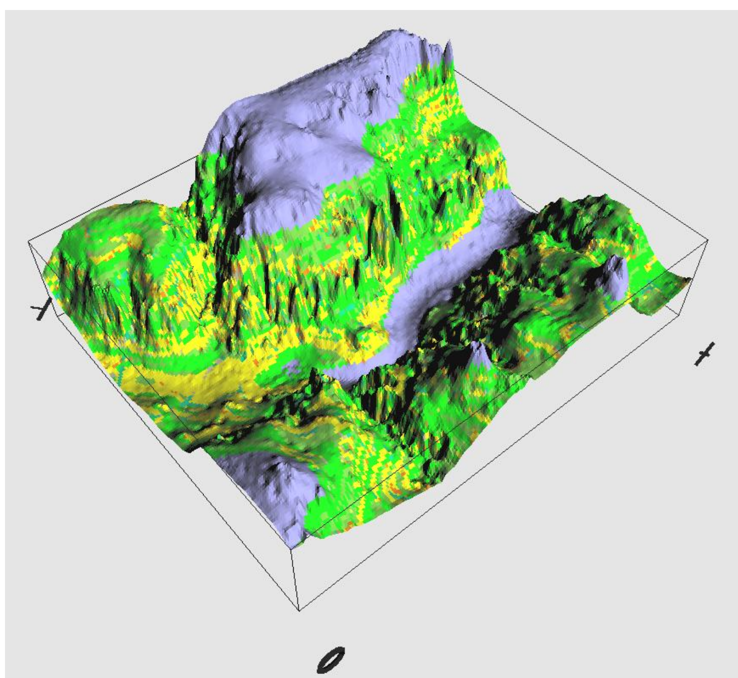


Figure 14 : 3D view with ZCut option (vertical scale exaggerated)

This option is the best tool to understand the outcrops on a fossil reservoir analog.

3.4 Wells

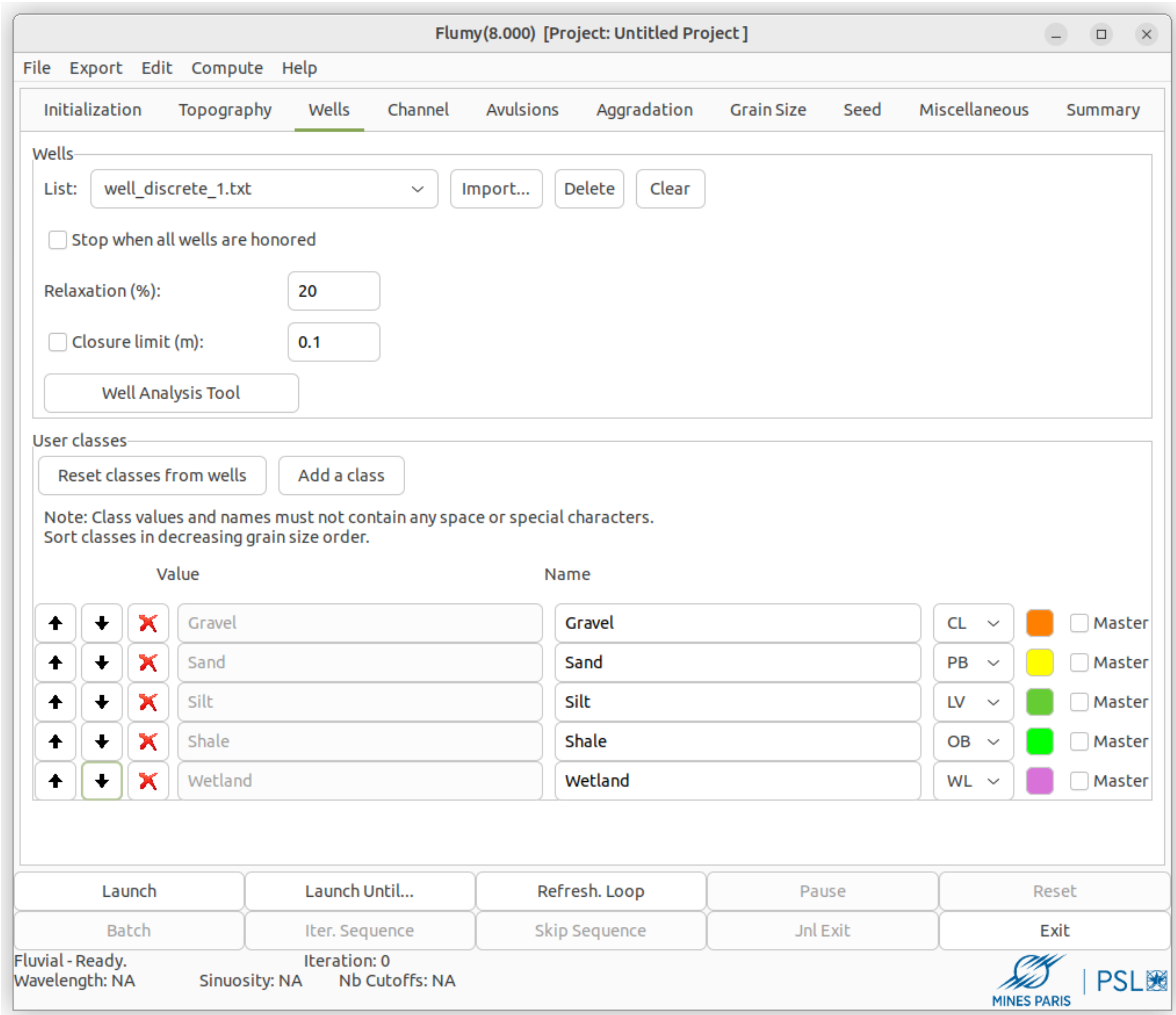


Figure 15 : Wells tab

This tab is not active in the Free version. Conditioning is only available within the Premium or Research version (see Section 2.3 for registering the software and getting a valid Serial Number)

3.4.1 Input Wells

Wells can be added before the first iteration (before simulation has started). Each well should be described in one ASCII file. The format of a well ASCII file is given in the section 5.4.

* **Well list:** list of the wells loaded for the conditional simulation. The user can *Import* well(s) to the list, *Delete* well(s), or *Clear* (delete all wells from the list). In the case a well is not vertical, it will

be kept as a single well, but will be split automatically into pseudo-vertical bits corresponding to the intersections of the well with the cells of the 2D Flumy grid (grid points being centered in cells).

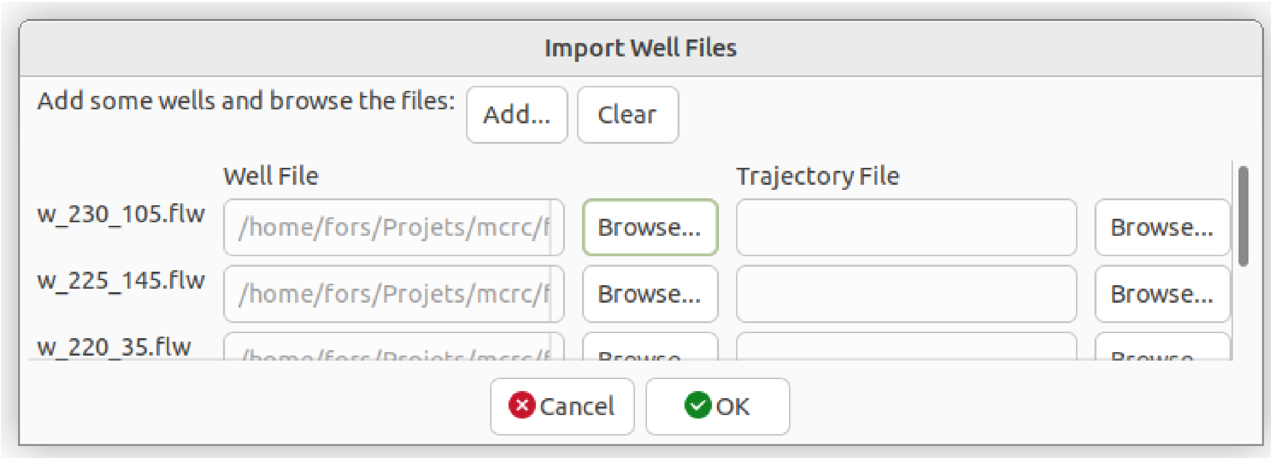


Figure 16 : Import wells dialog

Note: For importing wells from Petrel© (see §0 about LAS files), the trajectory file is mandatory. Wells must be regular-discretized (non null STEP keyword).

*** Stop when all wells are honored**: When checked, the simulation will automatically stop once the current topography has reach the top of all wells.

* **Relaxation** (in %, between 0 and 100):

- a high relaxation will result in a more rapid simulation, less constrained by the deposition of sand exactly at sand data
- a low relaxation will be constrained by the deposition of sand exactly at sand data, but may deposit too much sand globally.

In details:

> Relaxation = probability of unlocking aggradation in the conditioning process. Aggradation is being blocked when for instance Point Bar / LAPs sand must be deposited at a well location, and when channel elevation is getting too high. While attraction of the channel to the well is simultaneously favored, the process may run for too long and deposit far too large layers of sand at this level, before sand data at the well is honored. A compromise between exactness at well data and better reproduction of lithofacies Vertical Proportion Curves can then be obtained by relaxing the process, i.e. allowing aggradation with a given probability. Aggradation is never blocked if relaxation = 100%.

* The **Closure limit** (in m) can be defined to allow Flumy ignoring a thin non-sandy interval. If used, Flumy will ignore each non-sandy interval whose vertical thickness is less than the Closure limit. This is a way to improve the conditioning process by grouping successive sand intervals all together.

- ***Note***: Another transparent operation is dynamically applied by Flumy to improve conditioning process. It consists in virtually replacing all small sandy intervals (where thickness is less than half the maximum channel depth) by a less constraining lithofacies CS1. It implies that small sand intervals will not be honored by Flumy. Use 'n' key in section views to display/hide interpreted little sand lithofacies of a well.

* The **Well analysis tool** button is a way to automatically guess the three Nexus parameters deduced from the wells data analysis (see Section 3.2.1).

3.4.2 Well analysis tool

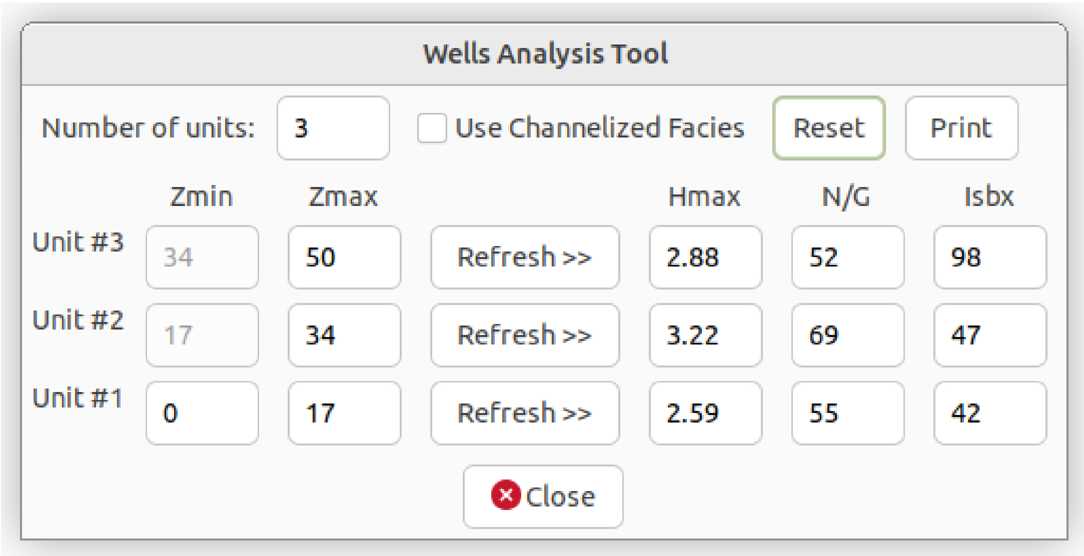


Figure 17 : Wells analysis tool dialog

The aim of this tool is to help the user in defining the Nexus key parameters (see §3.2.1) for each sedimentary unit (the simulation runs up to the top of a unit using a constant set of parameters). This is a way to introduce some vertical non stationarity in the resulted bloc.

First, the well data files are analyzed in order to determine the best number of sedimentary units. An automatic value is proposed by applying the method described in Bubnova et al (2019). The frontier between each unit (horizontal constant elevation) is automatically calculated.

Then, the values of the three Nexus key parameters is inferred automatically by analyzing the well data between each unit limits (not published). This gives an order of magnitude of the key parameters. The inference of Isbx (sand body extension index) is still under development (please ignore).

The user can change the number of units he wants and adapt their thickness.

Then, by clicking on the "Refresh" button, the user can reapply the automatic inference for each unit.

3.4.3 User classes

* The **User classes** feature is a way to convert non standard wells into Flumy lithofacies well. Either discrete or continuous well can be used. In case of discrete well, the user must associate each discrete attribute observed into the well (the value) to the corresponding Flumy lithofacies (see section 5.6). In case of continuous well (i.e. conductivity property for example), the user must defines for each interval (min/max) the corresponding Flumy lithofacies. The user can choose a name and a color for each class.

These information are used by the Histogram and Vertical Proportion Curves features in Attribute mode (see section 4.4.3).

The classes must be ordered in decreasing grain size (see §6.5).

The Master check box indicates which class will be used when converting back the simulation Flumy lithofacies into a User Class (see exporting the simulation result at section 4.4.2). The Master check box is not yet used in Flumy.

3.5 Channel

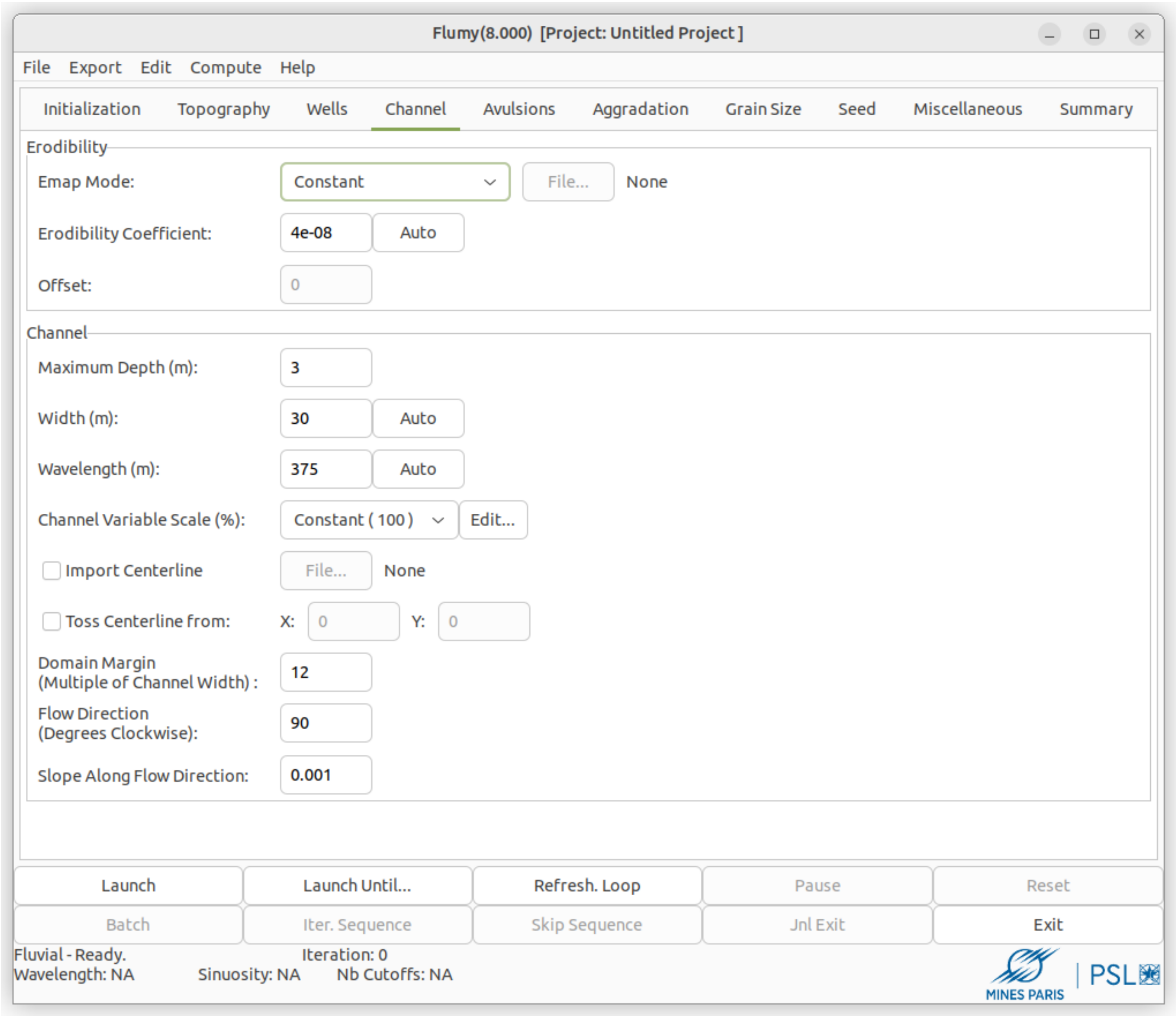


Figure 18 : Channel tab

3.5.1 Erodibility

The higher the erodibility, the more rapid the migration of the channel and the thickener the Point Bar / LAPs deposits. Hence the erodibility is used to control (eg favoring or slowing down) the channel migration (the migration of the channel at a given location is proportional to the velocity perturbation at its outer bank and to the erodibility). The erodibility can be constant over the domain, or variable (2D or 3D map).

Note: Using erodibility maps is the way to perform conditional simulations to seismic data. This option is only available in the Premium or the Research version.

Seismic block can be input into Flumy as erodibility map (assuming that sand probability property coming from the seismic block can be assimilated to an erodibility coefficient):

- low probability => low erodibility => less sand to be deposited
- high probability => high erodibility => more sand to be deposited

The user can give:

* **Emap (Erodibility map) mode:**

- **Constant**: the erodibility is constant over the domain, equal to the erodibility coefficient
- **Loaded from file** (**absolute values** – possibly an Erodibility map built from the centerline, see section 4.4.2)
- **Loaded from file** (**relative values** – each value is converted into absolute value, see further)
- **Dynamic (upper limit)** (the upper limit is used as a conditioning stratigraphic top surface – this option really slow down the simulation)

* **Erodibility coefficient**: (real positive number), the default value was found to produce a realistic channel evolution (look at section 6 for default and usual range of values according system environment). This value has an automatic state (“Auto” button) which permits to automatically calculate a good value to this coefficient which only depends on the channel wavelength.

- ***Note***: Negative erodibility values will be set to 0. Values larger than the maximum are set to this value. An erodibility value of 0 corresponds to locations where no migration is desired.

* The “**Auto**” buttons permit to automatically calculate the Erodibility Coefficient from the current Wavelength parameter.

E_0 and λ_0 are the default values for the current system environment. The Automatic state is deactivated when using non expert user estimator (see section 3.2.1), restoring default parameters or switching to a different system environment.

* Emap **File**:

For the 3 last options, the Emap is read from an ASCII file. The file must have the F2G format (see section 5.2.3).

* Emap with **absolute values**:

In this case, absolute values of erodibility are read. The Erodibility coefficient parameter is ignored.

* Emap with **relative values**:

This option is to be used when the input values are not absolute erodibility values (i.e. seismic block assumed as sand probability). The user then can input:

- The **Erodibility Coefficient**
- The **Offset**

The relative values on the domain $\mathbf{e_i}$ will be transformed into absolute values $\mathbf{E_i}$, first by subtraction of the offset $\mathbf{e_0}$, then by rescaling their mean to the Erodibility Coefficient.

Hence the offset corresponds to 0 erodibility, and the Erodibility Coefficient corresponds to the mean erodibility over the domain (unless resulting values smaller than 0 or larger than $2.E^{-7}$ are found, that are set to these).

An offset equal to (or larger than) the minimum of the input relative values corresponds to a very high confidence in the input Emap, as strictly 0 erodibility values will be present.

$$E_i = E\ \frac{e_i - e_0}{mean\ of\ (e_i - e_0)}$$

* Emap **"Dynamic (Upper limit)"**

In Flumy, it is possible to introduce an imported surface so that the simulation will stop when this is exceeded everywhere (see section 3.3.1). In the case the imported surface represents an upper limit to be approximately reached by the sedimentation (i.e. a **stratigraphic surface**), an Emap "Dynamic" is to be used during the simulation, to favor at any time new location of channel (and so deposition) preferentially where the imported surface to be reached is the highest above the current topography. In the case this imported surface represents an erosional surface, this option should not be used.

When this option is used, the Emap conditioning from an external file is no more possible.

3.5.2 Channel

Channel cross-section: is parabolic, defined by its width and mean depth. Recommended values are given in section 6.

*** Maximum Depth** (in meters): maximum channel depth over a normal cross-section. The maximal depth is 1.5 the mean depth for a parabolic cross-section. In turbidites system, the depth doesn't include the turbidity cloud thickness above the channel (three time higher than the channel). This parameter controls the maximal thickness of a single laterally deposited body (Point Bar / LAPs).

* **Width** (in meters): width of the channel.

* **Wavelength:** (in meters): mean meander wavelength reached before first meander cutoff. The current channel wavelength is echoed into the status bar (see section 0). See section §3.6.2 to look how abandoned meanders are filled.

* The "**Auto**" buttons permit to automatically calculate the Width parameter from the Maximum Depth and the Wavelength parameter from the Width.

* **Channel Variable Scale** (in %): at each regional avulsion (see §3.6), this channel scale size ratio (in percent) is applied to all provided scalable parameters (i.e.: Maximum depth, Width, Wavelength, Erodibility coefficient, Levee width, Aggradation thickness intensity and exponential decrease). This ratio can be constant or follow a probability distribution whose parameters are to be chosen: uniform (between a min and a max), normal (with given mean and standard deviation), lognormal (with mean and standard deviation of this, not of its log).

* **Import Centerline**: unless a centerline data file is given, a centerline will automatically be generated (similarly to a regional avulsion, see section 3.6). The user has the possibility to load a given channel centerline (ASCII file including discretization points of the channel centerline in 2D in geographical coordinates; see format in section 5.3). The first point must be upstream of the domain; the last point must be downstream of the domain according the current Flow Direction. Loading a centerline corresponds to a **one-time operation** (the program runs 1 iteration, and the user has to switch off this operation to be able to do something else, see section 4.1.1).

The Channel Centerline is saved within the Project Folder, when using *Save Project* in the menu *File* at the current iteration. Further running of the simulation will use the 3 coordinates to locate the channel on top of the previously saved simulation.

When importing a pre-existing Channel Centerline, the z coordinate of centerline channel points is not used. The channel centerline is placed at the surface of the domain topography and the channel cuts through the underlying volume.

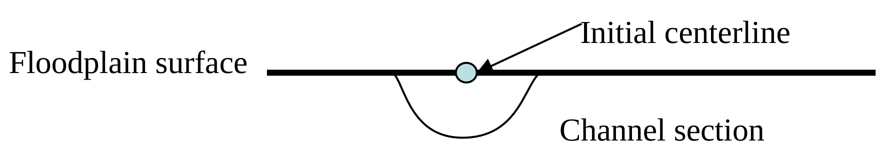


Figure 19 : Channel section

The channel is vertically positioned by the elevation of its centerline. **Changing the width and the depth** of the channel cross-section does not change this elevation. An important exception is when reducing both width and depth to less than ¼ of their previous values. Then the elevation of the new centerline corresponds to the bottom of the previous channel: this allows building **nested channels**, with the small channel located at the bottom of the previous large channel.

* **Toss Centerline from**: This option is similar to the “Import Centerline” from file, except that instead of loading the path from a file, a new path is automatically tossed starting from the given geographical 2D point (X, Y). The point must be located into the domain. The path is automatically completed upstream and downstream using the same algorithm than the regional avulsion (see section 3.6). It could be used to ensure that the first channel will be located into the valley and not in the domain margins for example.

Note: Each time a new channel is imported, the previous one (if exists) is abandoned and filled using Sand Plug and Mud Plug (or Hemipelagic Plug for turbidites system) (See §3.6.2)

* **Domain Margin:** longitudinal and lateral extensions of the domain, used to remove artificial border effects within the domain when the channel migrates or aggrades, given as a multiple of the channel width. The default value corresponds to the development at least of one meander.

* **Flow Direction:** direction of the slope of the reference plane, given in degrees clockwise from South to North direction. 0° is South to North direction, 90° is West to East. (See next figure)

* **Slope along Flow Direction:** value of the slope of the reference plane, dipping in the direction of the Flow Direction.

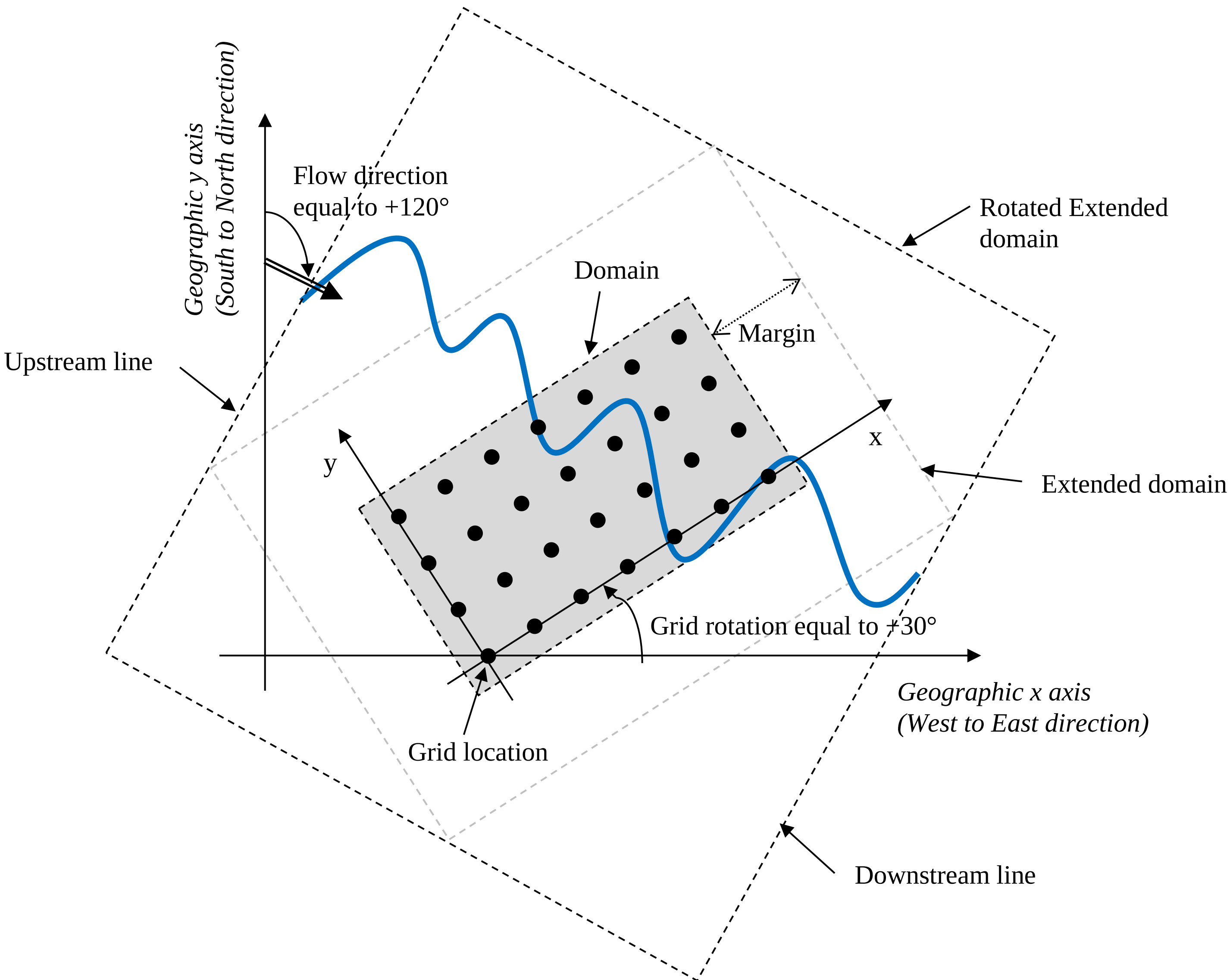


Figure 20 : Flow direction toward grid rotation

3.6 Avulsions

3.6.1 Avulsion Parameters

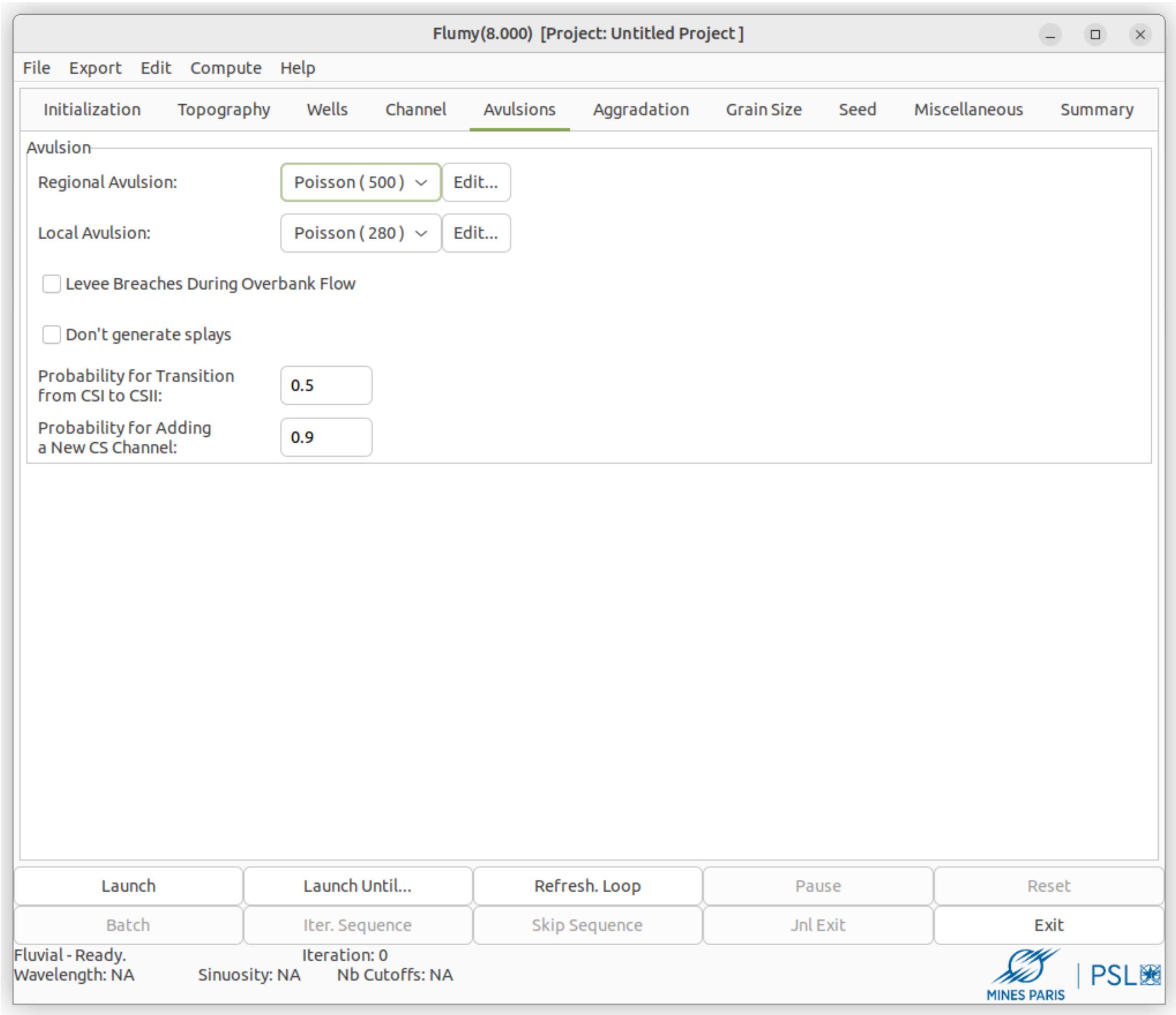


Figure 21 : Avulsions tab

* **Regional Avulsion** (upstream of the domain): four options are offered for its period (never, always, periodic or Poisson). These avulsions can be considered to be caused by successful levee breaches upstream of the domain, and result in a new path within the domain (extended with its lateral margins to avoid border effects, see previous section). Period expected to be longer than for local avulsion.

* **Local Avulsion** (within the domain): four options are offered for the period of levee breaches that occur independently from overbank flow (never, always, periodic or Poisson).

The user has to click on the **Edit** button to customize the period value.

* **Levee Breaches During Overbank Flow:** select this option to make levee breaches during overbank flow.

In the model, a levee breach occurs preferentially at banks where the velocity and erodibility are higher. It produces:

- either a chute cut-off (reconnecting the channel at a distance less than 10 times the channel width),
- or a **Crevasse Splay** of type I "CSI" (erosive and elongated). CSI may evolve into a CSII (non-erosive Crevasse Splay of type II), on which CS Channels may be automatically and iteratively added. The user can specify:

* The **Don't generate splays** checkbox is a way to prevent Flumy from depositing splays during levee breaches. In that case, following parameters are ignored.

* The **Probability for transition from CSI to CSII**

* The **Probability for adding a new CS Channel** on CSII

Finally CSII may lead to a successful local avulsion (new path), with the following probability where S_1 and S_0 are the slopes of the old path and new path downwards:

$$S = \frac{S_1}{(S_0 + S_1)}$$

Here is a little summary of the local avulsion process (step-by-step and ordered):

1- Levee breaches attempts are performed during:
- Local avulsions (for a given avulsion period)
- At each overbank flood (for a given overbank period if "Levee Breaches During Overbank Flow" is checked)

2- If the levee breach attempt is a success:

2.1- A chute cut-off attempt is performed. In case of success, some channel parts will be abandoned AND

2.2- The Crevasse Splay Type 1 facies is deposited in an elongated thin shape next to the levee breach point. This cannot be avoided.

3- Then,

3.1- A new downslope channel path attempt is performed. If the new downstream path is accepted, the previous downstream path is abandoned. AND

3.2- Some additional Crevasse Splay facies can be deposited next to the levee breach point:

3.2.1- According to the probability AV_LOC_PROB1* parameter, the Crevasse Splay Type II is deposited with a circular shape. This can be avoided by setting AV_LOC_PROB1 = 0.

3.2.2- Otherwise, if AV_LOC_PROB1 is not null, some Crevasse Splay Channels are added accordingly to the AV_LOC_PROB2* probability. This can be avoided by setting AV_LOC_PROB2 = 0.

If levee breaches are activated (local avulsions or during overbank floods), Crevasse Splay Type 1 will be necessarily deposited. On the other hand, Flumy won't generate Crevasse Splay Type II and Crevasse Splay Channels by setting probabilities AV_LOC_PROB1 and AV_LOC_PROB2 to 0.

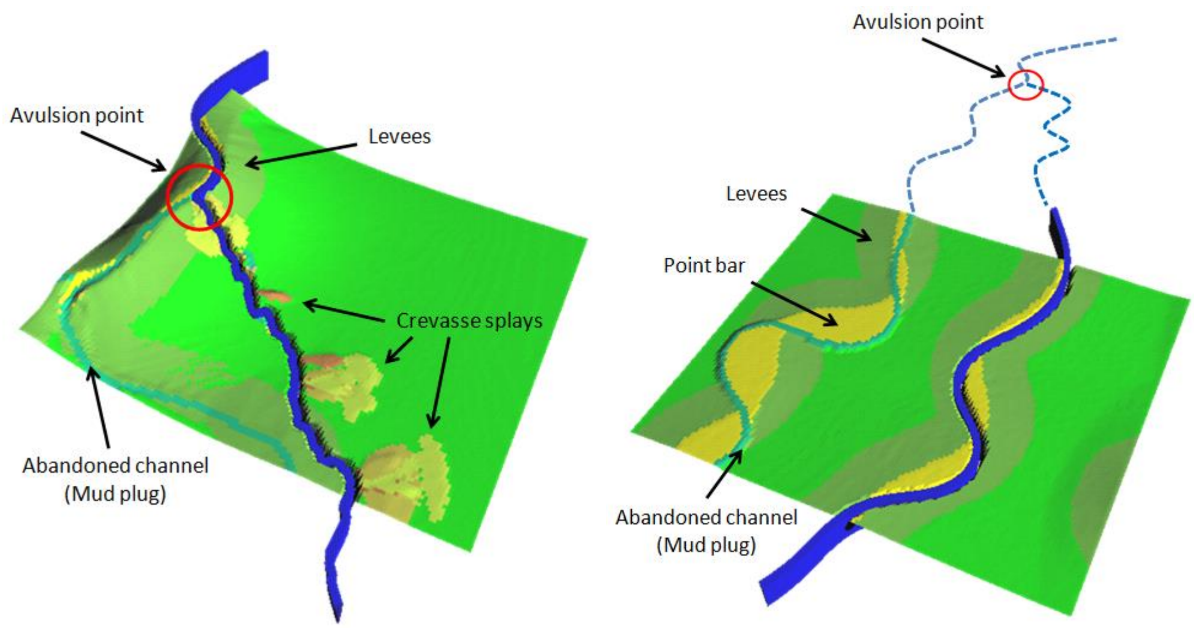


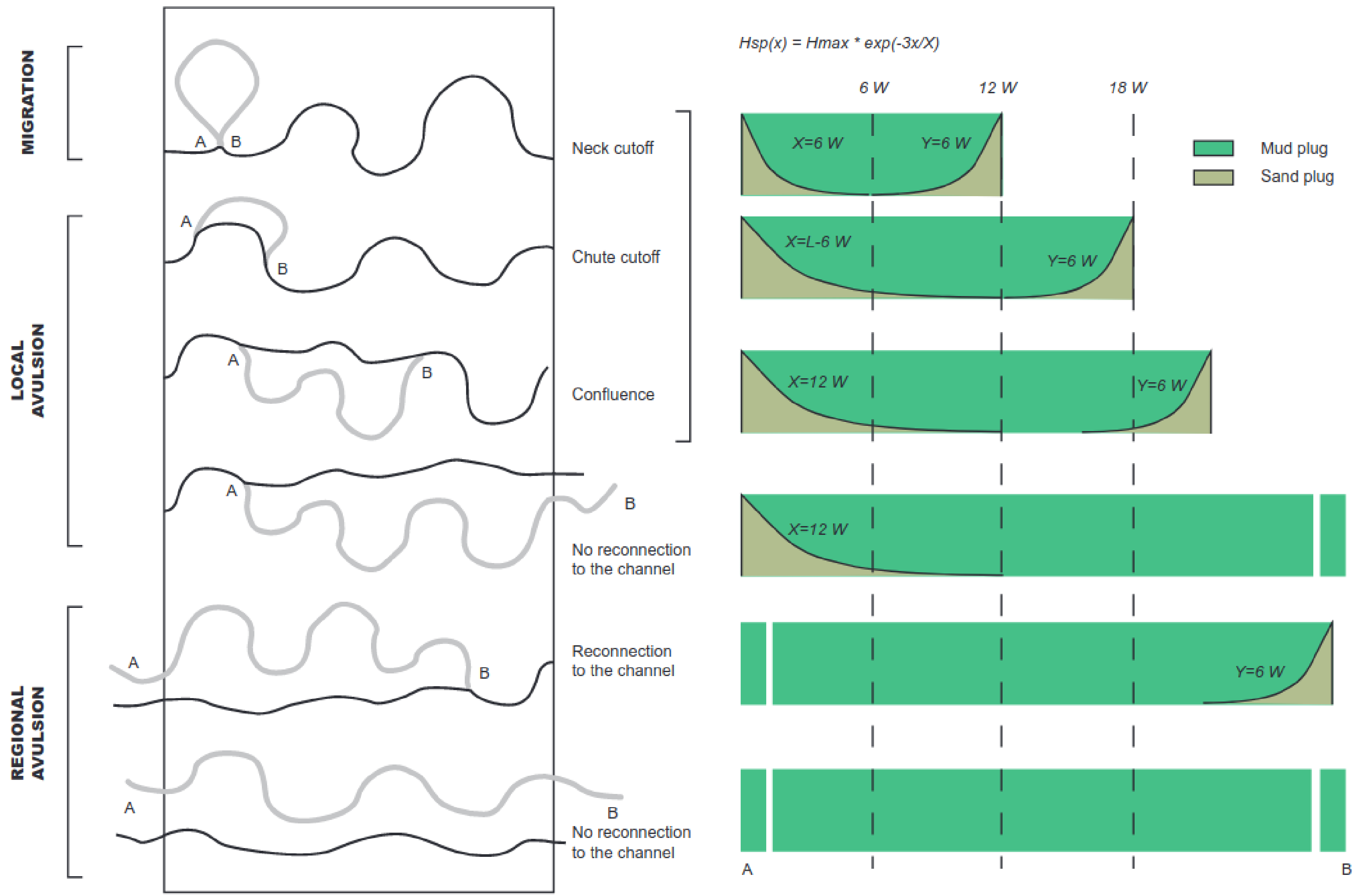
Figure 22 : Local and Regional Avulsions

The avulsions in Flumy are simulated by tossing a new path on the current topography by looking for the steepest path. This algorithm takes into account:

- The existing topography
- The global domain slope in the given flow direction
- The erodibility map
- The conditioning wells influence
- Some randomization

3.6.2 Abandoned Channels

Each time a channel or a part of a channel is abandoned, it is instantly filled with Sand Plug and Mud Plug (fluvial) or Hemipelagic Plug (turbidites). The following rules are applied in order to know the proportion between both lithofacies deposited (Here is an example for Fluvial systems (filling with Sand and Mud Plugs), Hmax = Channel Maximum Depth, W = Channel Width, X is the longitudinal distance from/to connection point):



3.7 Aggradation

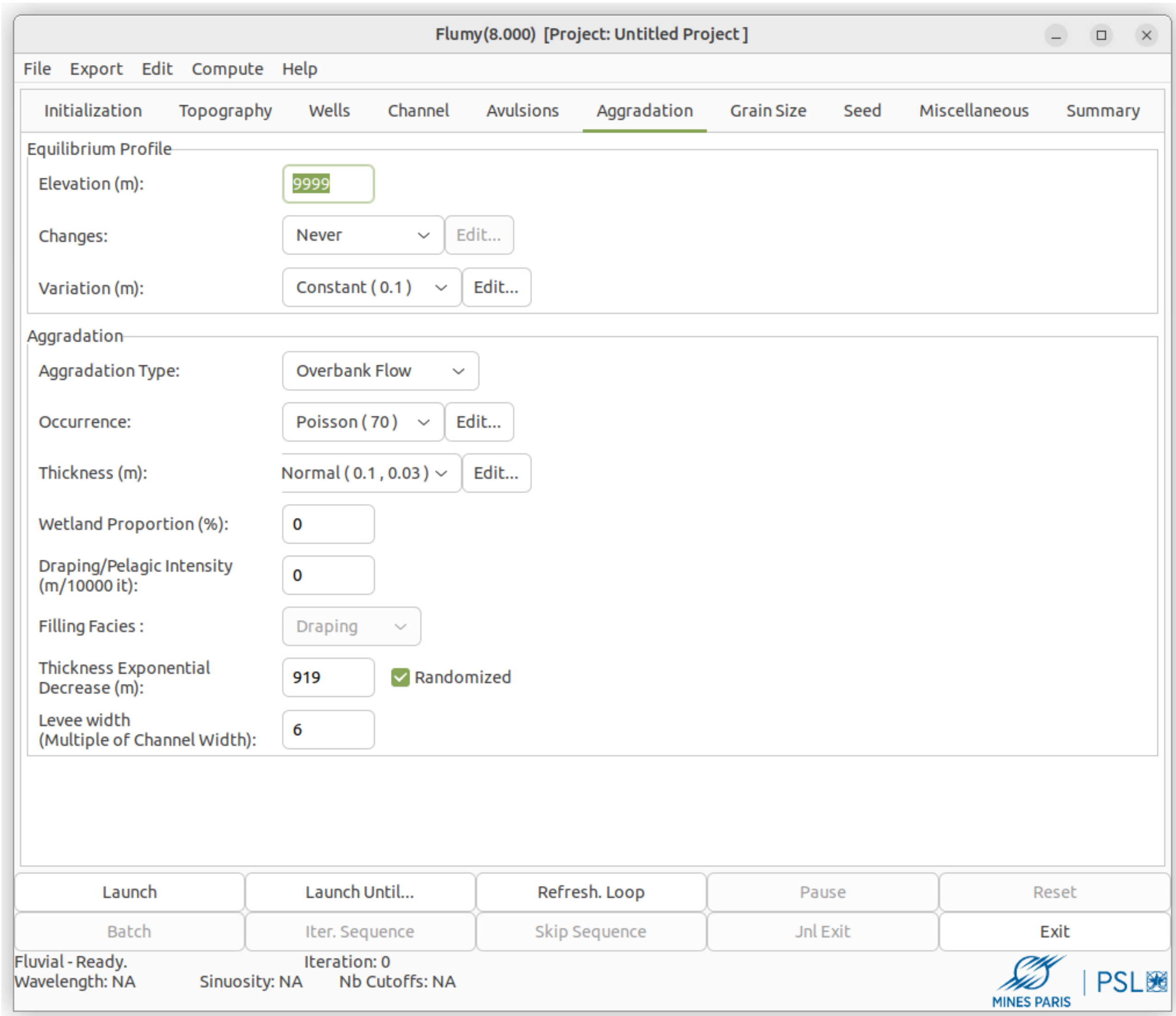


Figure 23 : Aggradation tab

3.7.1 Equilibrium Profile

The equilibrium profile corresponds to a plane parallel to the reference plane and its elevation can vary in time.

The equilibrium profile controls the rate of aggradation/incision. Test on the potential aggradation/incision is made at every overbank flow. Then, the aggradation will be limited by the distance of the equilibrium profile above the domain topography (the system is free if the distance exceeds the overbank flow intensity - see section 3.7.2). Incision will occur if the equilibrium profile is lower than the domain topography. Incision in turbidites context can also be done by using Erosive aggradation mode (see §3.7.2).

* **Elevation** (in meters): elevation (including grid elevation – see section 3.2.2) of the equilibrium profile above the reference plane, at the beginning of the sequence of iterations. By default it is inherited from the elevation of the Equilibrium Profile at the end of the previous sequence, if any.

* **Changes** (in number of iterations): changes of the equilibrium profile elevation can occur: never, at each iteration, periodically, or randomly following a Poisson process.

* **Variation** (in meters): variations of the elevation when changes occur can be constant or follow a probability distribution whose parameters are to be chosen: uniform (between a min and a max), normal (with given mean and standard deviation), lognormal (with mean and standard deviation of this, not of its log).

- ***Note*:** Variations can be positive or negative.

To deactivate the equilibrium profile, set a very high elevation and never change its value.

3.7.2 Aggradation

* The options for **Aggradation type** are:

- **None**
  No aggradation.

- **Draping (fluvial) / Pelagic (turbidites)**
  At each occurrence a constant draping (or pelagic) thickness is deposited everywhere on the domain:
    - to build a basement at the beginning of the simulation (with a thickness exceeding the maximal channel depth) or
    - to protect a (imported) topography surface from being incised by the channel (with a thickness exceeding the maximal channel depth)
    - to simulate external sediment deposition

  - ***Note***:
    - Draping is not affected by the Equilibrium Profile
    - Overbank sedimentation is interrupted
    - Wetland Proportion is inactive
    - Draping or pelagic could also be deposited during sedimentation (see below)

- **Overbank Flow**
  At each occurrence, alluvium (fluvial) or fine-grained sediments (turbidites) levee and overbank deposits are deposited on the domain starting from the channel to the maximal distant. If option used, a draping (fluvial) or pelagic (turbidites) constant thickness could be deposited before overbank sediments (See Draping / Pelagic Intensity parameter below). In turbidites environments:
    - overspill levees are deposited leading in dissymmetrical levee heights. The super elevation intensity is calculated according the channel velocity and the sediment concentration.

- **Ghost Migration (turbidites)**
  While Ghost Migration is active, there is no more levee/overbank deposits nor pelagic. The channel stops its migration. Within the model however, a ghost migration is computed which will be used to set the new location of the channel after changing the aggradation mode. This is the way to mimic an "avulsion by migration" but this process is absolutely not natural.

- **Erosive (turbidites)**
  At each occurrence, the channel will erode its substratum according to the given thickness intensity.

* **Occurrence** (in number of iterations): draping, pelagic or overbank flow can occur: never, periodically, or randomly following a Poisson process.

- ***Note*****:** This period also rules the control on aggradation as well as incision when Equilibrium Profile (§3.7.1) is used (see previous section) or Erosive mode is activated (for turbidites systems).

* **Thickness** (in meters): maximum thickness deposited on levees during an overbank flow. It can be constant or follow a probability distribution whose parameters are to be chosen: uniform (between a min and a max), normal (with given mean and standard deviation), lognormal (with mean and standard deviation of this, not of its log).

* **Wetland Proportion (fluvial)** (in percentage): extension of lowlands, to be covered by wetland lithofacies (peat, mud…) in between two successive overbank flows, entered as a maximal proportion of the domain area. This option is only available in fluvial systems.

- ***Note*****:** In aerial views, wetland lithofacies may be partly covered by the overbank sediment deposited just afterwards.

* **Draping/Pelagic Intensity** (in m / 10000 iterations): thickness rate (calculated according last overbank occurrence) to be deposited before overbank sediments all over the domain except onto the channel path.

- ***Note*****:** In aerial views, draping (fluvial) or pelagic (turbidites) lithofacies may be partly covered by the overbank sediment deposited just afterwards.

* **Draping Facies:** only active when using Draping / Pelagic aggradation mode. Indicates which lithofacies (“Draping” / “Pelagic” or “Undefined”) will be deposited (see §6.5)

* **Thickness Exponential Decrease** (in meters): scaling distance of the negative exponential distribution which rules the decreasing of deposits thickness (and grain size) away from the channel. The deposited thickness (and grain size) is thus 37%, 14% and 5% of the maximum thickness (maximum grain size), respectively at one, two or three times this scaling distance from the channel. The maximum thickness of the aggradation is the “Thickness” parameter above. The maximum grain size is the coarsest class used for the Levee lithofacies (see §3.8)

* **Randomize Overbank Extension:** If activated, this option adds a small random distance delta (having Gaussian distribution) to the Thickness Exponential Decrease parameters. This option prevents Flumy from thresholding sediment extension at a constant distance (leading to border effects using high aggradation rates).

* **Levee Width** (as a multiple of channel width): define the distance from the channel centerline of the frontier between Levee and Overbank lithofacies based on grain-size. Look at section 6.5 to see grain size distribution for Levee and Overbank lithofacies.

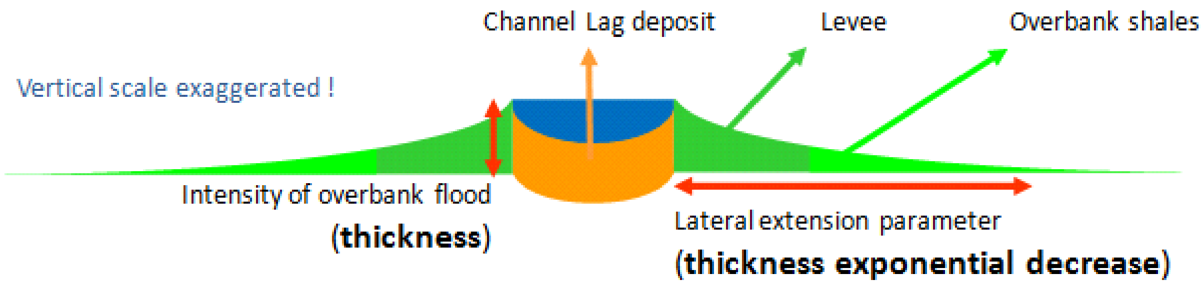


Figure 24 : Aggradation process

3.8 Grain Size

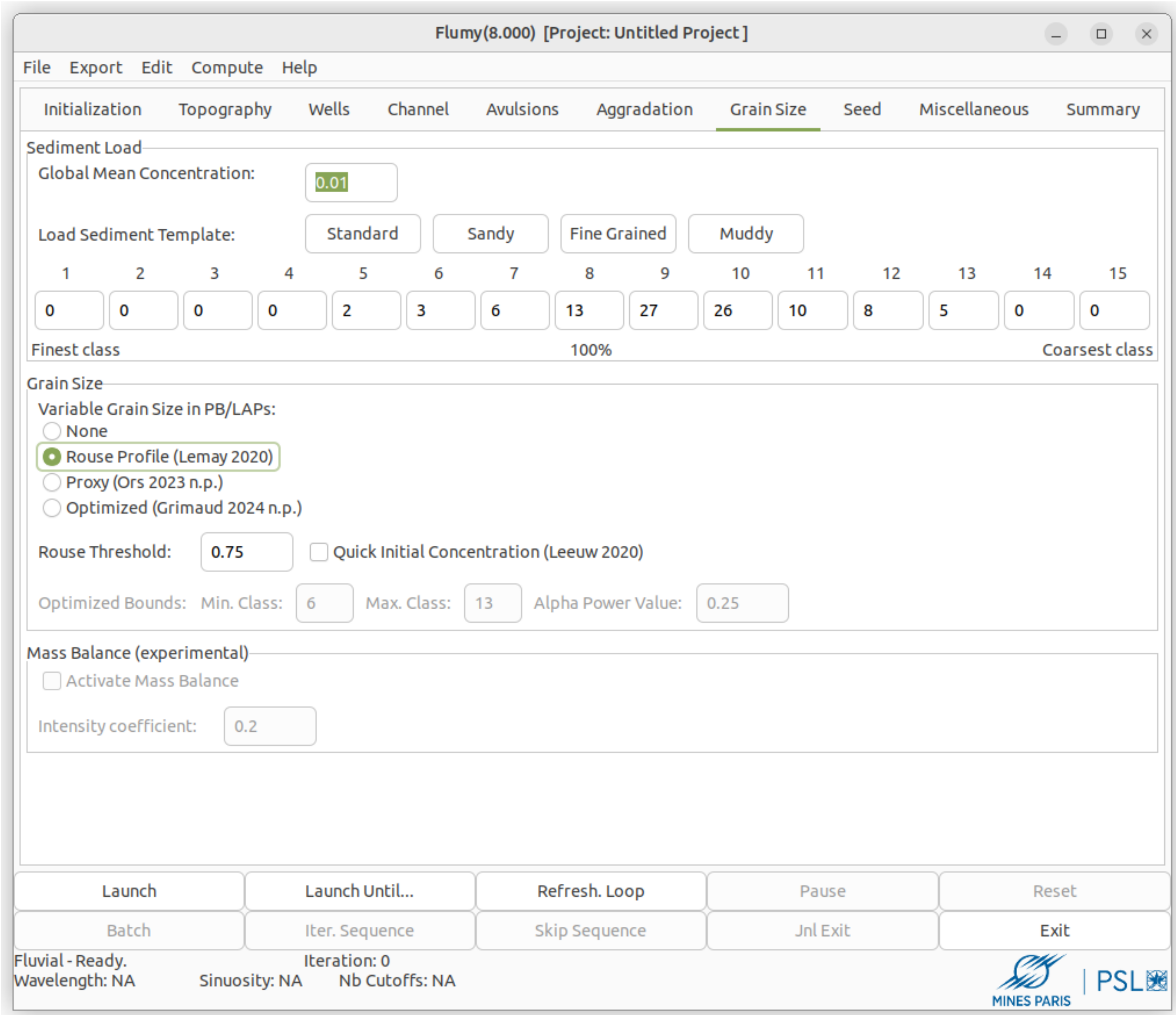


Figure 25 : Grain Size tab

This tab is active for our research partners only. However, the grain size in Flumy is calculated using all these parameters (whatever the software distribution) and all users should refer to the following paragraphs for details. Only our research partners can customized the parameters from this tab.

It exists 15 classes of grain size in Flumy. Deposit grain size classes are calculated depending on the type of the deposited lithofacies, the distance between the deposit and the channel (vertically and horizontally) and the local shape of the channel like the curvature (for sand bodies):

- Grain size classes for the following lithofacies (fine grained) are always fixed: Mud Plug (MP), Hemipelagic Plug (HP), Draping (DP), Pelagic (PL) and Wetland (WL) (see §6.5).

- Grain size classes for the three types of crevasse splays lithofacies (Crevasse Splay I (CSI), Crevasse Splay Channels (CCH) and Crevasse Splay II (CSII)) are lying between fine sand and silt classes as described in the table of the section 6.5. Coarser grain size are deposited at the bottom of the splay and finer ones at the top.

- Grain size classes for levees and overbank deposits decrease exponentially from the channel. For fluvial systems, the grain size values for the Levee and Overbank lithofacies are lying in the interval defined in the table of the section §6.5. For turbidites systems, the maximum Levee grain size is deduced from the local channel curvature, the global sediment concentration and the grain size template proportions using the Rouse profile (see below).

- Grain size classes for sand bodies deposits (Sand Plug (SP), Point Bar/Lateral Accretion Packages (PB/LAPs) and Channel Lag (CL)) is fixed by default. For our research partners, when activated, the grain size of sand bodies depends on the algorithm chosen for “Variable Grain Size in PB/LAPs (see below).

Example of a fluvial vertical cross-section:

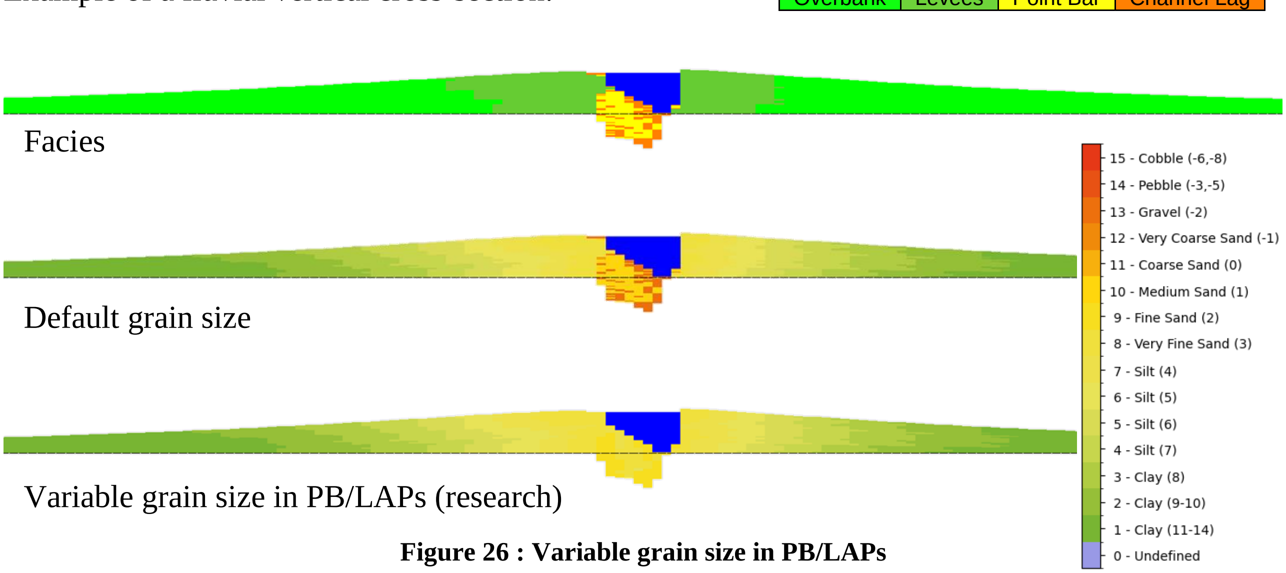


Figure 26 : Variable grain size in PB/LAPs

In the previous example, we see that the grain size for Channel Lag lithofacies* (orange) is too coarse (especially in the top of the sand body). More progressive and consistent grain size values for sand bodies are calculated using several different algorithms that are currently under development.

* **Note**: Remind that lithofacies (as “Channel Lag”) should be more considered as a “Depositional Element” which is linked to the channel geometry.

3.8.1 Sediment Load Parameters

* **Global Mean Concentration**: The global mean sediment concentration is used to control a lot of physical processes simulated in Flumy:

- Calculation of the Froude number for channel migration (Ikeda 1982)
- Calculation of the turbidites flow velocity (see additional hints in §6.4)
- Initialization of the Rouse profiles for grain size variability in levees and sand bodies
- Initialization of the volumes of the Mass Balance (see below)

This parameter is always active.

* **Sediment distribution templates**: The sediment template defines the concentration (percentage) of each of the 15 grain size classes. The sum of all concentrations must be equal to 100%. Four templates are predefined for each systems: “Standard”, “Sandy”, “Fine Grained” and “Muddy”. The user can load each of them by clicking on the corresponding button. The template is used to:

- Calculate the grain size distribution in PB/LAPs when using Rouse Profile algorithm for making grain size variable in sand bodies (see below)
- Calculate the maximum grain size class of the Levee (LV) lithofacies (for turbidites systems)
- Initialize the volumes of the Mass Balance (see below)

This parameter is active for fluvial systems when using Rouse Profile or Mass Balance. It is always active for turbidites systems.

Important Note: Let us recall that sediment transport is not physically modeled. Flumy never runs out of sediments to deposit.

3.8.2 Grain Size Parameters

* **Variable Grain Size in PB/LAPs**:

- **None** (default): Grain size value is constant in each lithofacies of the sand bodies: Point Bars/Lateral Accretion Packages (PB/LAPs), Sand Plug (SP) and Channel Lag (CL) (see §6.5).

- **Rouse Profile** (Lemay 2020): Grain size values in sand bodies (PB/LAPs and CL) are calculated by using the current sediment template (see above) and the Rouse profile curves for each class of sediment (see Lemay 2020). Grain size values decrease away from the channel bottom to top. Grain size value for SP is the median of the current template.

- **Proxy** (Ors 2023 not published): Grain size values in sand bodies (PB/LAPs and CL) are calculated by using a multi-linear regression as a function of the two following variables: the local velocity perturbation of the meander and the deposit elevation. The regression has been trained using the predefined "Standard" sediment template in fluvial and turbidites systems. The "Proxy" algorithm is a quicker way to add some grain size variability in PB/LAPs but it gives results less realistic. Grain size value for SP is fixed to the default one (see §6.5).

- **Optimized** (Grimaud 2024 not published): When checked, grain size values for sand bodies is calculated using a parametric function of the deposit elevation (see below). The sediment template is no more considered.

Rouse parameters: The following parameters are active only when using the Rouse Profile algorithm for variable grain size in PB/LAPs:

* **Rouse Threshold** (proportion): This parameter control the selected grain size class for each PB/LAPs deposit while using the Rouse Profile algorithm. The higher the threshold, the coarser the class selected in the template distribution. Here is an example of the Rouse Threshold using a very simple template (2 grain size classes, the coarsest class color has been turned into brown):

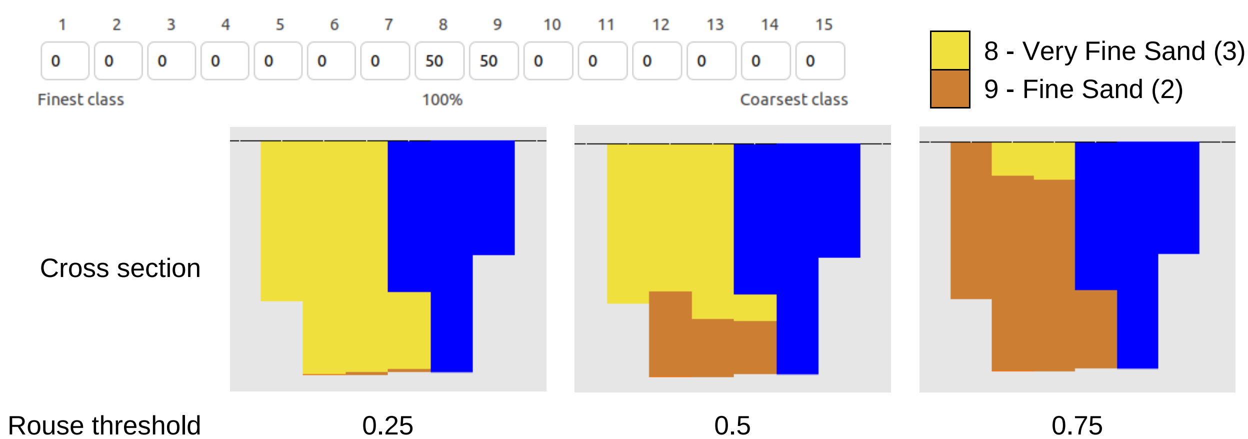


Figure 27 : Impact of the Rouse Threshold

* **Quick Initial Concentration** (Leeuw 2020): When checked, the initial local concentration for each grain size class is approximated using an equation from Leeuw et al. (2020). This is a quicker way to calculate the initial concentration instead of integrating the Rouse Profile curve.

Optimized parameters: The following parameters are active only when using the Optimized algorithm for variable grain size in PB/LAPs.

* **Optimized Bounds**: Grain size classes for PB/LAPs and CL lye between the provided min/max bounds.

* **Alpha Power Value**: The smaller Alpha Power Value, the more vertical the curve, the sharper is the transition between the grain size classes (according deposit elevation relative to the channel bottom).

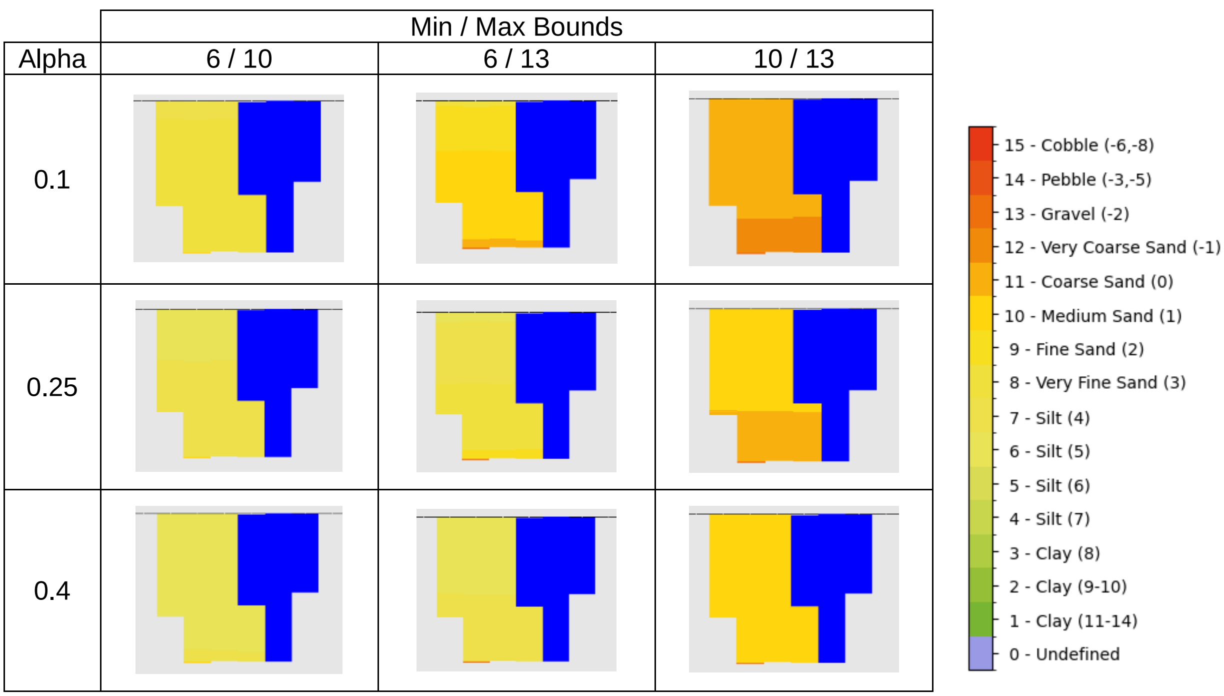


Figure 28 : Optimized variable grain size in PB/LAPs

3.8.3 Mass Balance (experimental)

This feature is under development and has no documentation yet.

3.9 Seed

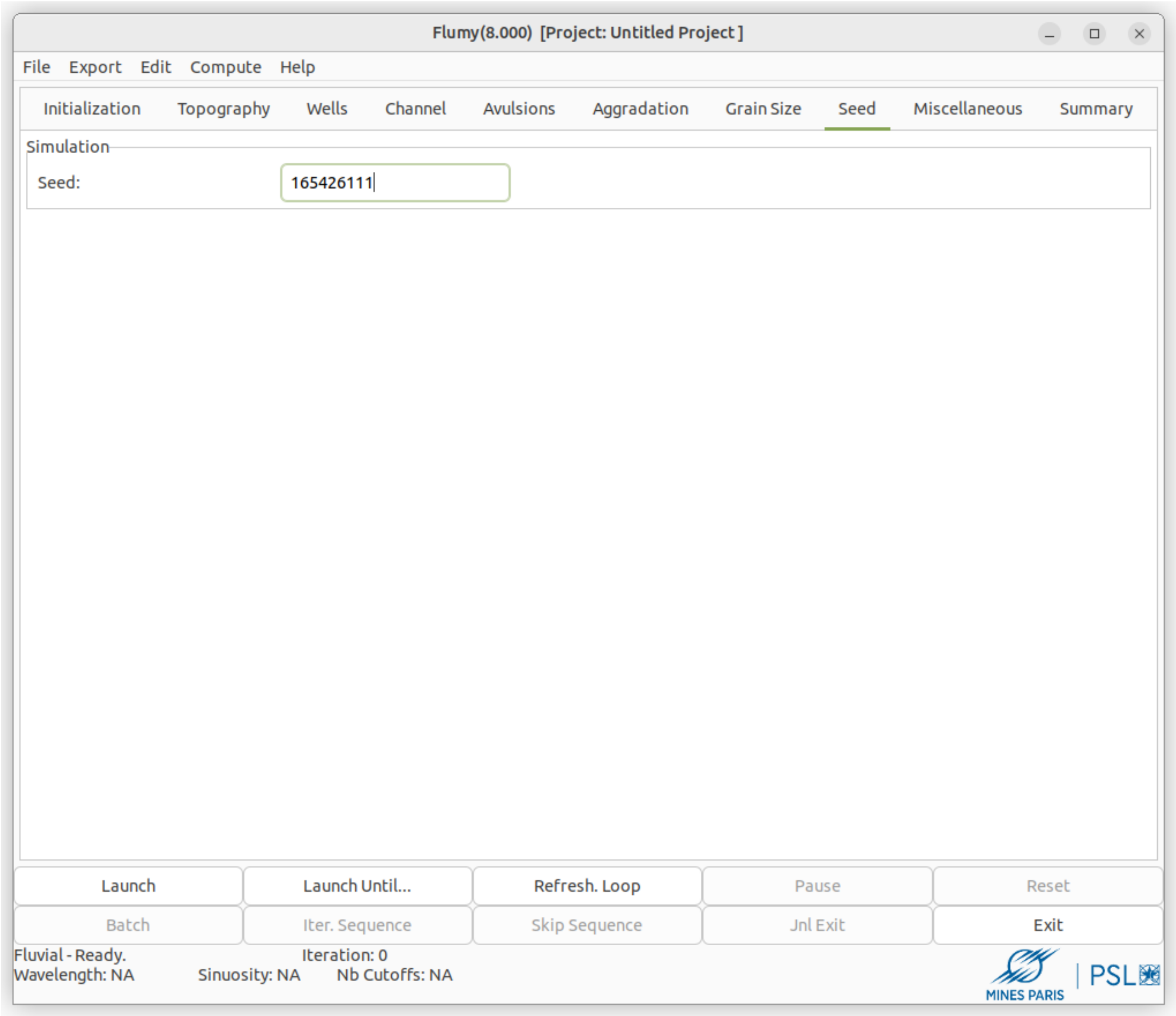


Figure 29 : Seed tab

* **Seed**: the simulation is stochastic and the seed value (typically a natural number with several digits) is used to generate the series of random numbers that are used. 0 is forbidden.

A given simulation can be reproduced by taking the same seed value at the beginning of the simulation (while keeping the other parameters unchanged). On the contrary, changing the seed value while keeping all other parameters unchanged results in a different, **equiprobable**, simulation.

3.10 Miscellaneous

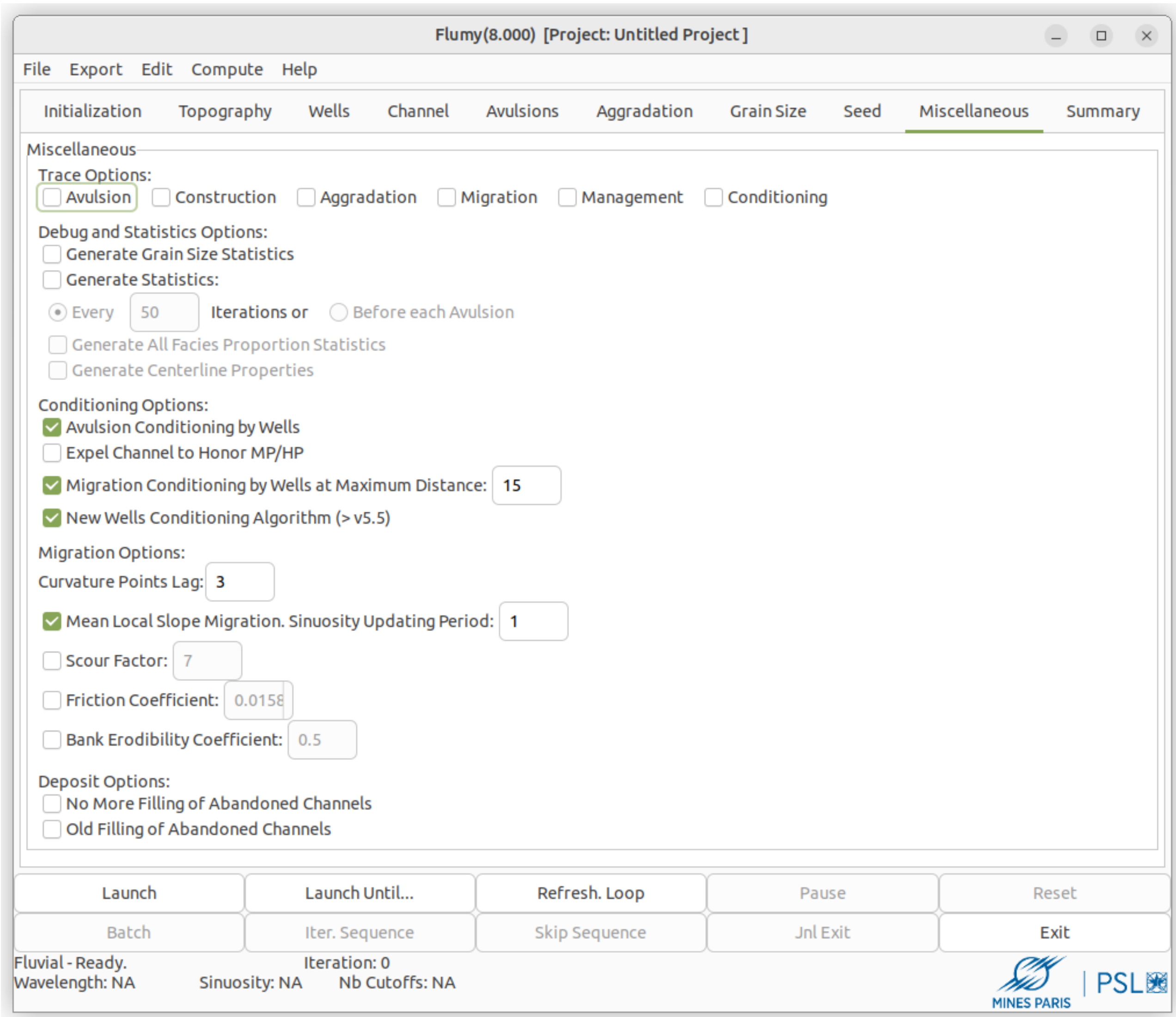


Figure 30 : Miscellaneous tab

This tab is reserved to our research partners only. This tab offers the capability to activate the generation of debugging information and generate a lot of statistics.
In this tab are shown the default values of the advanced parameters. Only our research partners can tune their values.

There is no documentation in this user guide regarding these parameters.

3.11 Status bar

The status bar located at the bottom of the interface window shows several launching options for the simulation (see section 4.1)

Under the control buttons, the following parameters are output:

- status (system environment / ready, simulating),
- current iteration (updated at every refreshment loop),
- the next sequence number to be run if a journal file is loaded,
- the current channel wavelength (Allen),
- the current channel sinuosity,
- the number of meander cutoffs since the simulation beginning
- the current mean topography or when using an upper limit, the percentage of the topography surface that is above this upper limit,
- the forecast of sand proportion in %, aggradation rate in m/10000 iterations and migration rate in m/iteration (these are supposed to give an order of magnitude for Net to Gross, for aggradation rate and for global mean lateral migration rate, according to heuristic formulas; the values are updated using the current parameters only when the simulation has been launched).

4 Simulation: visualization and results

Outputs are available:

- through the status bar at the bottom of the interface window (see section 0)
- as text, giving the list of simulated events and actions (on Linux, in the terminal from which the software is run; on Windows or Linux, in the *Messages Window of the File menu*);
- in one or several graphic windows;
- as output files.

4.1 Launch

4.1.1 Direct launch

Directly from the interface window (lower tool bar), or from the *File* menu, the user can:

- *Launch* the simulation
- *Pause* the simulation
- *Launch until* a given iteration number (default: the next iteration). The window opens, giving the elapsed time and the remaining time for the launched simulation.
- use *Refreshment loop* to launch the simulation for a number of iterations equal to the *Refreshment period* (which can be modified in Settings, default 100 iterations)
- *Exit* from the program.
- ***Note****: this procedure combined with a Refreshment period of 1 allows to see every step of the simulation. However, it is slowing down the calculations.*

Remark: some operations are **one time events**, each one being performed exclusively from all other operations in 1 iteration only. After this iteration, the program pauses whatever was asked and the user has to switch off the operation just performed to do something else. These one time events are, in the order they are to be performed:

- *import topo* in order to *replace (or aggrade or erode) current topography by the imported surface* (then a new channel is generated);
- *import a centerline* or *toss a centerline from a point* (a new channel is also generated).

4.1.2 Reset and journal file

Each Launch (Launch, Launch until, or Refreshment loop) corresponds to a sequence of 1 or more iterations. The simulation is thus processed by sequences of time iterations (make a distinction between: - a sequence of iterations; - and a geological sequence, which can for instance be simulated with several sequences of iterations). Some of the parameters, *sequence parameters*, can be changed at every sequence. The other parameters are *initial parameters*, and will be valid all along the simulation (typically the domain to be simulated and conditioning wells). The list of the operations performed (initial parameter values and the different sequences of iterations with their parameter values) is automatically recorded in a *journal file*, stored in the *Project Folder* (see section 4.4.1).

From the interface window (lower tool bar), or from the *File* menu, the user can also:

Reset the simulation to start a new simulation. Then the user has the possibility to replay the sequences that were automatically recorded in the old journal file. The options are the same than when launching a journal file, see just further.

- ***Note:*** When using the *Reset* button, the saved results within the Project Folder are deleted.

From the *File* menu, the user can also:

- *Launch journal file* to launch a simulation according to the parameters stored in a previous journal file.

Then, from either the interface window (lower tool bar), or the *File* menu, the user can:

- Choose *Batch* to execute the journal file with no stop
- Choose *Iter*. *Sequence* to execute the next sequence of iterations of the journal file
- *Skip sequence* of the journal file, and
- *Jnl Exit* from the journal (jnl) file.

Of course, the user can also introduce additional *Launch* between the sequences that were recorded in the journal file. Note that Journal Files and Batch Files have different format.

4.1.3 Batch mode in command line

The Flumy program can be launched by a command line by using the -b (or --batch) option and giving the full path of a batch file:

flumy –b path_to_your_batch_file

In the current version, the batch file has a particular format which is different from the Project Journal File. Please, look at the section §5.7 for the batch file format description.

This mode permits to automatically (and without any graphical interface), launching Flumy by a command line and generating:

- instantaneous statistics of the current running processes (Net-to-Gross, Aggradation rate…)
- a regular 3D block (in an ASCII file) of the simulation deposits at the end of the sequence
- horizontal slices or virtual wells from the resulting simulation
- histograms deposited thicknesses of the resulting simulation

This batch mode is suitable for generating Training Images (for Multi-Points Statistics or Machine Learning) for instance, performing sensitivity analysis (by changing only one parameter between each simulation and getting statistics or proportions) or testing the Flumy model variability (by executing several identical simulations and modifying only the seed).

This feature is not active in the Free version. It is only available within the Premium or Research version (see Section 2.3 for registering the software and getting a valid Serial Number).

4.1.4 Saving a Project

The user can save the project at the current iteration using the menu option *File / Save Project.* Each time the user saves a project, a “simulation snapshot” is stored into the project folder (see section 4.4.1).

The user can save the current project to a new one using the *Save Project As* option in the *File* menu.

The user can navigate forward or backward step by step (snapshot to another snapshot) using the corresponding options in the *File* menu.

Finally an existing project can be reloaded to continue a previous work using the *Open Project* menu option. Flumy automatically loads the last available snapshot in the project folder (see section 4.4.1).

4.1.5 Messages window

The *File* menu contains also a check box which permits to open/close a *Messages Window* containing information about simulated events, warnings and errors. This window can be emptied using the *Clear* button.

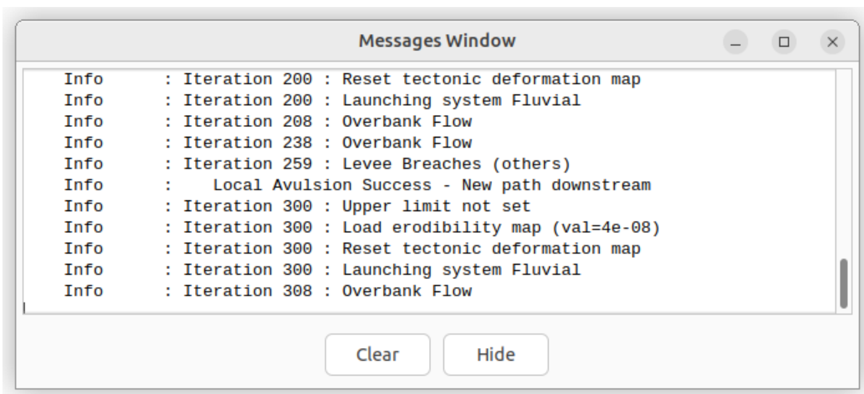


Figure 31 : Messages window

4.2 Settings menu

4.2.1 Lithofacies and Grain Size Colors

Use the menu *Change facies colors* to display the different lithofacies or the different grain size classes with their default colors, and possibly to change these. The user can also *Load facies colors* or *Save facies colors*. (see file format section 5.6)

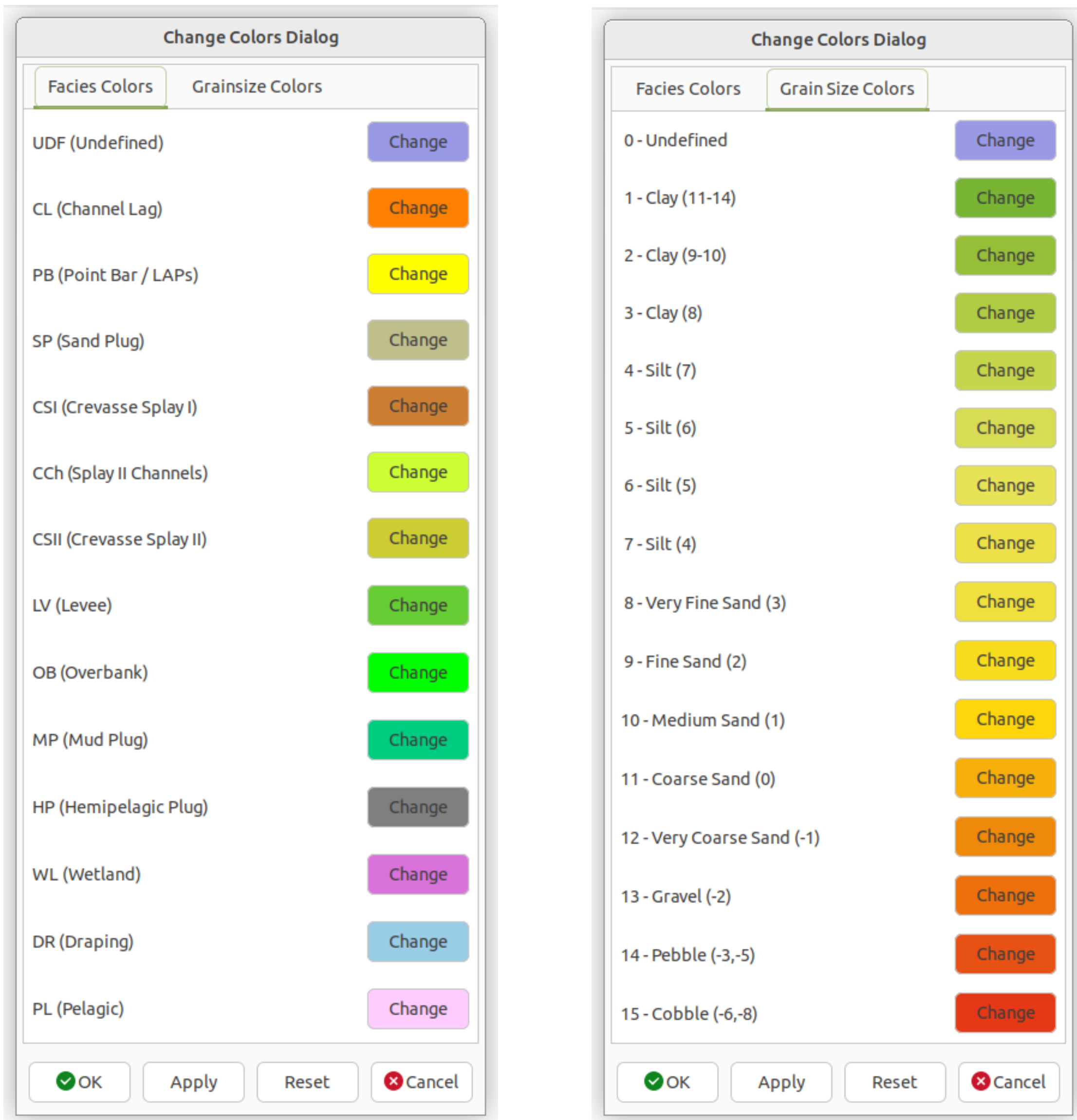


Figure 32: Flumy Lithofacies and Grain Size Classes

Look at section 6.5 to see more details on the lithofacies and grains size classes handled by Flumy.

4.2.2 Refreshment period

All graphical views are refreshed every N iterations where N is the *Refreshment period*. Default is N = 100 iterations. Choosing N = 1 enables to see each iteration.

- ***Note***: A low value may increase considerably computation time.

4.3 Visualization of simulation

When running the program, a first graphic window opens at the same time as the interface window. More *New graphic window* can be opened with the *File* menu. This allows visualizing simultaneously different views of the simulation at the same time.

- ***Note***: Each window is independent from the others. However, closing the first graphical window, will close all others.

The key ‘h’ permits to display in the Message Window (look at *File* menu) all the keyboard shortcuts available in graphical views.

- ***Note***: Capital letters for shortcuts must be done using the left or right “Shift” key. The “Caps Lock” state is not taken into account for shortcuts.

4.3.1 Graphical views

The different graphical views and associated shortcuts are the following:

Key a  To display the 2D aerial view

Key x  To display the vertical cross section in the (y,z) plane (Looking in x decreasing direction)

Key y  To display the vertical cross-section, in the (x,z) plane (Looking in y increasing direction)

Key d  To display a 3D aerial view of the top topography

4.3.2 General operators

These operators are available in all graphical views:

Key r To reset the view to the default graphical parameters

Key f To display current deposits using lithofacies colors (see section 6.5)

Key g To display current deposits using grain size colors (see section 6.5)

Key G To display current deposits using lithofacies color darkening with grain size increasing

Key A To display current deposits using lithofacies color darkening with old age and grain size increasing. The colors for PB, LV and OB change with grain size and age of deposits. The PB deposit is yellow, getting red when older. The LV/OB deposits vary from yellow to red away from the channel, becoming red to black when older.

Key E To display the age of the deposits (darker is older)

Initial age (0) Maximum simulation age

Figure 33 : Age color scale

Key c To display or to hide the grid-discretized channel within the modelled domain

Key C To display or to hide the real channel.

Key s To display or to hide the location of the red cursor (vertical sections)

Key / To display the simulation eroded from the top by a ZCut surface, see section 3.3

Key p To make a screenshot of the graphic window (tiff file)

Key X To choose the number of the vertical cross section in the (y,z) plane

Key Y To choose the number of the vertical cross-section in the (x,z) plane

The arrows keys can be used to move the red cursor location (vertical sections)

4.3.3 2D Aerial view

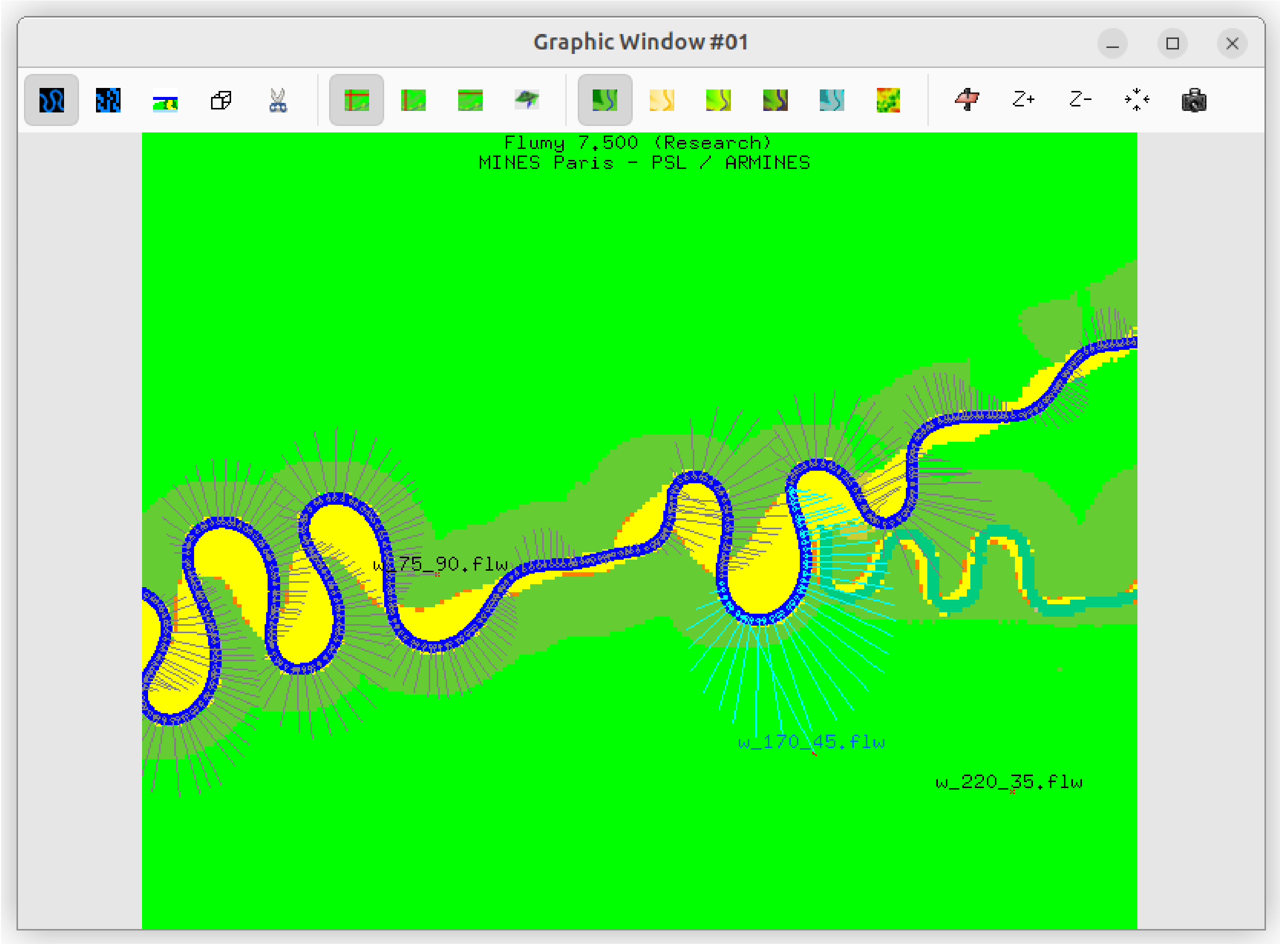


Figure 34 : 2D aerial view

Keys used to control the **2D aerial view** within a window:

Key e  To display the erodibility map. When displaying the erodibility map, the lithofacies are hidden. The erodibility has the following color scale:

Figure 35 : Scale of erodibility, from 0 (black) and low values (red) up to 2.E^{-7} (dark green)

Key $  To display an horizontal section (Z-slice). The user must indicate the elevation of the horizontal section in the popup Window. Press Close to return to 2D aerial view.

Key u To display the current upper limit. The deposited parts of the simulation above this topography are displayed brighter. See section 3.3.

Key w To display the well labels (Well locations are always displayed as a red cross)

Key l To display velocity perturbation vectors for each centerline point (only when real channel is displayed). Grey arrows at centerline points indicate 500 times the migration assuming an erodibility equal to 2.E^{-8}. In presence of conditioning wells, blue arrows are increased by a factor of 2, corresponding to forced migration. Red arrows are reduced, corresponding to forced repulsion. See also section 4.3.6.1.

The LMB (Left Mouse Button) can be used in 2D aerial view to zoom on a rectangular area.

4.3.4 Vertical section view

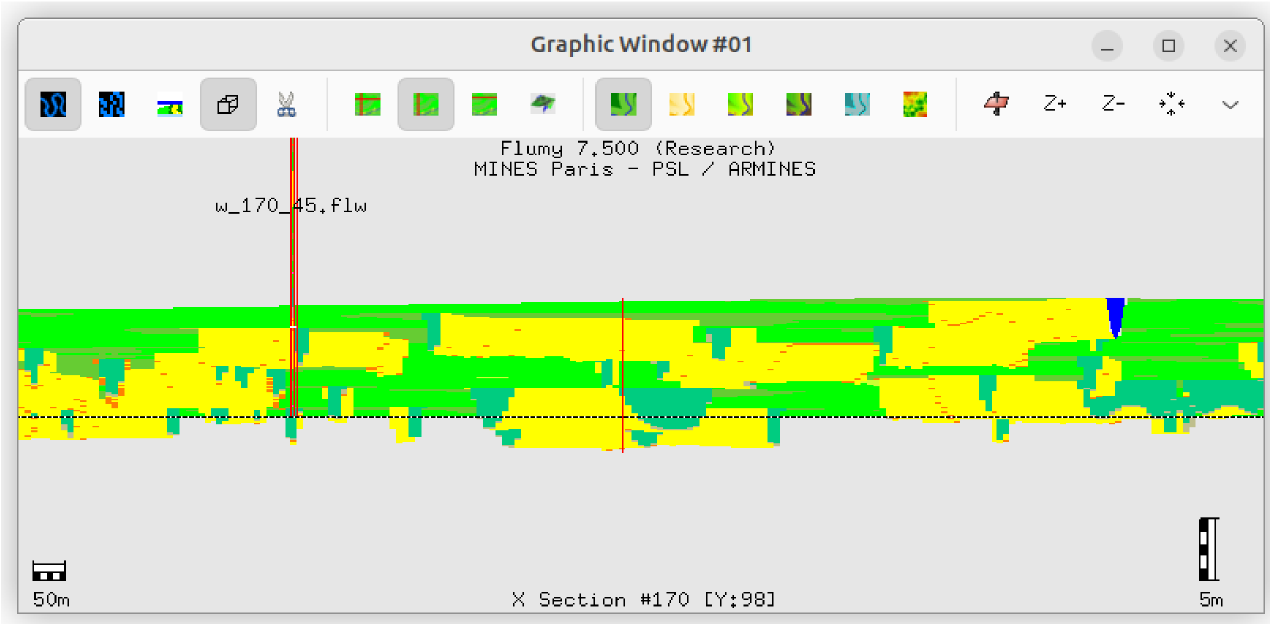


Figure 36 : Vertical X section

The elevation reference level is displayed as a horizontal dashed black line in vertical sections. See Grid Elevation in section 3.2.2.

The 0 absolute elevation is displayed as a horizontal red plain line. If the initial Grid Elevation is kept to 0m, then the reference level dashed black line overlap the red line which is not shown. See Figure 39 in section 4.3.6.1.

- ***Note*:** For convenience the global domain slope of the reference plane is not shown in the different visualizations.

Keys used to control the **vertical section view** within a window:

Key z Z- To decrease the vertical exaggeration

Key Z Z+ To increase the vertical exaggeration

Key u To display as a black line the upper limit topography

Key q To display the equilibrium profile as a blue line on the section

Key w To display the well labels (see section 4.3.6 for specific well description in vertical section views)

Key n To display the interpreted lithofacies for well data (see Closure limit in section 3.4.1)

The LMB (Left Mouse Button) can be used in vertical section views to zoom on a rectangular area.

The RMB (Right Mouse Button) can be used to change the section displayed.

4.3.5 3D aerial view

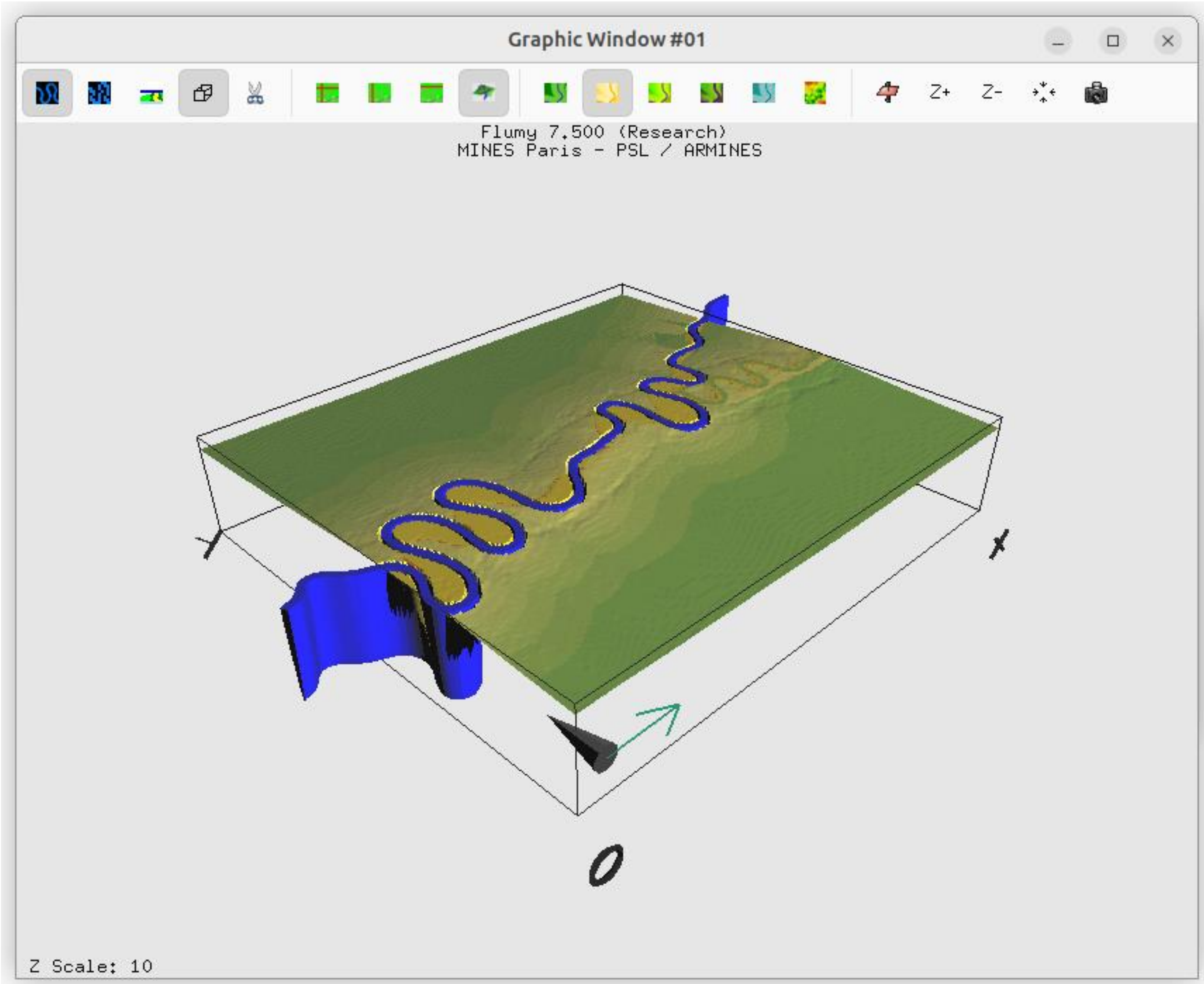


Figure 37 : 3D aerial view

Keys used for **3D aerial** viewing within a window:

Key z Z- To decrease the vertical exaggeration

Key Z Z+ To increase the vertical exaggeration

Key v To display the xOy base as a 3D empty cube, the North (black cone) and flow (water green arrow) directions.

Key C To display or to hide the real channel. In 3D aerial view the whole channel is displayed as it goes inside *and* outside the domain.

Key u To display the current upper limit. The deposited parts of the simulation above this topography are displayed brighter. See section 3.3.

Key V To display the extended domain limits and upstream channel entry points

Key t To display the virtual modified topography which takes into account the domain slope and the well influence during conditioning (Research Partners only)

Key o To activate the automatic screenshot process which exports in the project folder a screenshot of the graphical window at each refreshment step (Research Partners only)

The LMB (Left Mouse Button) to vary the 3D point of view and the RMB to zoom in/out.

The numerical pad keys 8 – 5 – 4 – 6 can be used to move the camera (front, back, left right).

The numerical pad keys 7 – 9 – 1 – 3 can be used to rotate the camera (left, right, down, up).

The keys minus ‘-‘ and plus ‘+’ can be used to move up / down the camera.

The numerical pad key 0 can be used to reset the camera position.

4.3.6 2D views in conditioning

When well labels is activated (Key w) a grey label means that the well is inactive (no impact on the processes); a blue label means that the well is currently attracting the channel (sand is requested at well); a red label means that the well is repulsing the channel (all but the sand is to be deposited at the well); a pink label means that the well is totally honored (no more impact).

4.3.6.1 Cross-sections

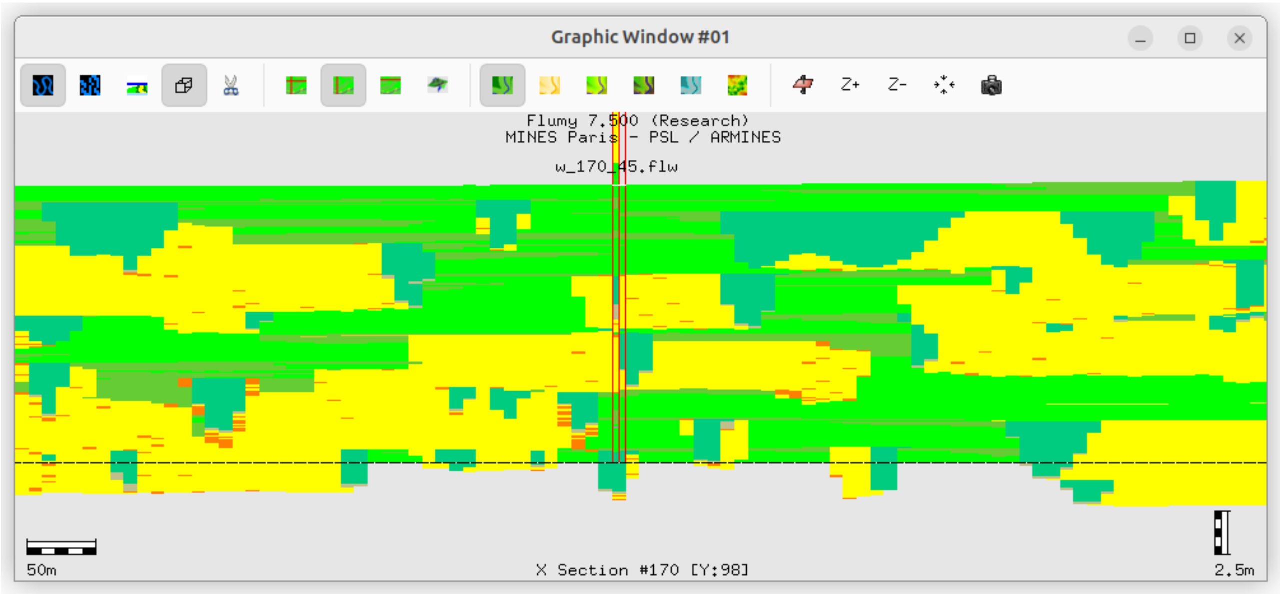


Figure 38 : Vertical section with a well

In the relevant vertical cross-sections, each vertical conditioning well is pictured with two columns delimited by vertical red lines. The right column represents the current simulation that is being represented in the cross-section. The left column (actually graphically superimposed on the current simulation) pictures the well data.

The horizontal white line across the well indicates the "active level" under which all data have been validated. One desirable reason for a lithofacies data to be validated is its being honored by the deposition of the same lithofacies or of an **equivalent lithofacies**:

- Channelized: Point Bar / LAPs, Channel Lag, Sand Plug, Mud Plug and Hemipelagic Plug
- Levees: Levee, Crevasse Splays I and II and Crevasse Channel
- Shale or clay: Overbank, Wetland, Pelagic
- Neutral: Draping or Undefined

However, though the conditioning process aims at reproducing at best the local conditions of depositions, it is not 100% exact. This results in some lithofacies data to be validated while not being honored. For instance, an Overbank sediment deposit where a different lithofacies would have been deposited is automatically validated (for not being a replacement lithofacies, Overbank cannot be any further honored). Similarly, when the active level is becoming too deep (in practice at more than 80% of the maximum channel depth from the current topography at the well), it is updated by validating the corresponding data. But the data is possibly “misfit”, i.e. not honored.

Here is an example which illustrates the vertical location of well:

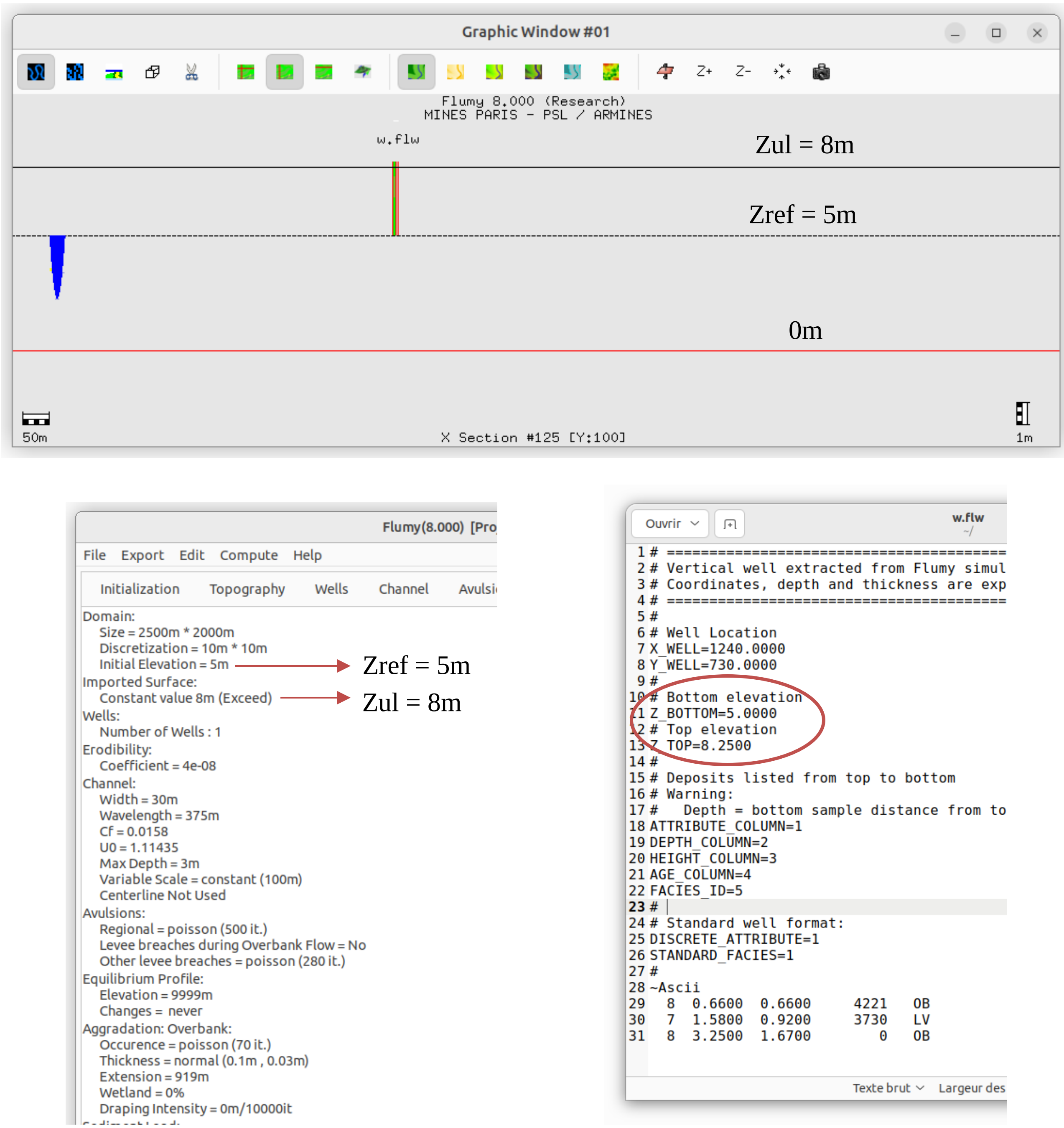


Figure 39 : Well vertical location, reference level and upper limit

4.3.6.2 Aerial view

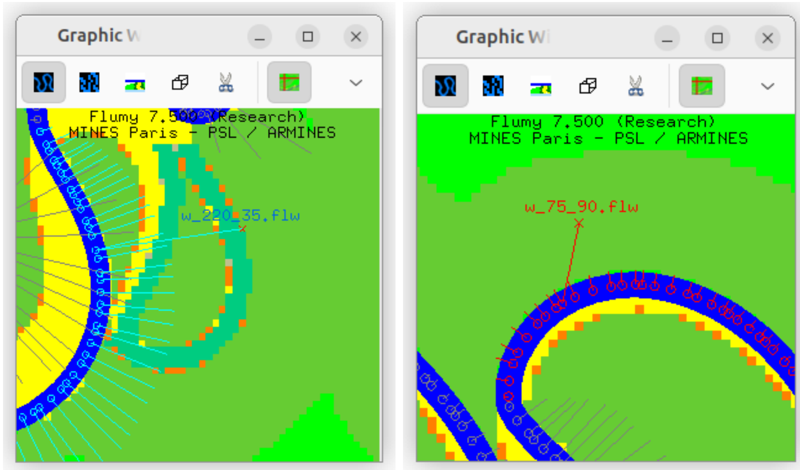


Figure 40 : Attractive well (left) and repulsive well (right)

The conditioning process is essentially based on temporary modifications of parameters like the erodibility, in order to attract (in migration or avulsion) the channel to well data where for instance sand should be deposited, or to “repulse” the channel, keeping it away from well locations where shale should be deposited.

Lithofacies data (at each well active level) considered as attractive:

- Channelized and equivalent lithofacies, when the channel elevation is becoming too high (channel bottom getting higher that the active level, or channel top reaching the level of non replacement lithofacies such as shale). Then the aggradation is also blocked to favor deposition of sand (though not completely, see **Relaxation** section 3.4.1)
- Levees and equivalent lithofacies data, if too far from channel.

Lithofacies data considered as locally repulsive:

- Shale and equivalent lithofacies;
- Levees and equivalent lithofacies if very close to channel;

A well which is completely honored is repulsive. Neutral lithofacies have no effect.

In the aerial view, a red cross indicates the location of each well. When representing the velocity perturbations (see §4.3.3), a line joins each well to its closest channel point (in term of Von-Mises distance d/exp(-dx/d) when flow direction is along Ox axis, favoring upstream points). If the distance between the well and the closest meander is more than 15 times the channel width, the well has no impact on migration.

The color of this line gives the status of the well in term of migration:

- **blue** when the well is attractive;
- **red** when the well is repulsive (the distance is limited to 6 times the channel width for shale and equivalent lithofacies and 2.5 times it for levees and equivalent lithofacies;
- **grey** when the well is inactive.

4.4 Output

Different types of output are available:

- output files of the parameters and the simulation saved within the Project Folder, through *Save Project* in the menu *File*;
- output files generated through *Export…* in the menu *File*;
- general statistics about the simulation

4.4.1 Project Folder

All the inputs, as well as the states of the simulation that the user has saved at different iterations are stored within the Project Folder.

The user can define a *New Project,* or *Open Project* in the case he wants to continue a previously saved simulation.

The user can *Save Project* to save the results at the current iteration (simulation snapshot), and thus can save the results at different iterations. The user can navigate within the sequence of saved results using *Project Navigate Backward* and *Project Navigate Forward.* Thus the user can for instance go back to a previously saved simulation, and rerun the simulation with a new choice of parameters (note that the sequence of saved results will be updated only by a further *Save Project*).

The Project Folder is a directory which includes several directories and files.

- **centerline** directory: this includes the channel centerline files used.
- **erodibility** directory: this includes the erodibility map files used.
- **tectonic** directory: this includes the tectonic files used.
- **topography** directory: this includes the topography files used.
- **wells** directory: this includes the well files used.

Directories "ite_#" include the snapshot of the simulation as saved at iteration no #. Each such directory includes in particular:

- Centerline (current centerline at this iteration)
- Current parameters:
  SEED (current seed)
  EP (equilibrium profile elevation)
- Journal file Journal_#.jnl
- Simulation

The project folder includes also three (or four) files:

- the current journal file Flumy.jnl and its backup (if so)
- the Flumy version number
- the graphical parameters for each views

4.4.2 Exported files

These are:

- individual **well**
  vertical well, located at the intersection of the X and Y cross-sections of the main graphical view (Number #01)
- **topography**
  current topography including the channel top surface
- **erodibility map**
  current 2D erodibility map
- **centerline**
  current real centerline (successive X,Y,Z centerline points)
- **discretized centerline**
  current discretized centerline projected on the domain grid (with a decreasing sediment load along the channel path)
- **simulation block**
  a 3D regular (sub)grid for each variable (lithofacies, grain size and age) with a given vertical discretization step, that can be directly imported into any software that import ASCII files (i.e. Petrel©, Gocad©…)
- **erodibility map built from the centerline**
  to reproduce the channel belt. The Emap is obtained by locating anisotropic bumps at channel centerline points, making use of the input Extension from channel points (as multiple of channel width) along X and along Y and around the given mean value.
- **age horizon**
  the topography at a given previous age

Formats of these export files are given in chapter 5.

- ***Note*****:** The global domain slope is not taken into account in the output files (nor in the input files), as it is easier to go directly between the horizontally flat reference system of Flumy simulation and the geographical system of the actual reservoir.

4.4.3 General statistics

These are available through the menu *Compute.* Graphical statistics can be computed on input wells or on the whole simulation. Wells statistics are not available the Free version.

4.4.3.1 Simulation Vertical Proportion Curve (VPC)

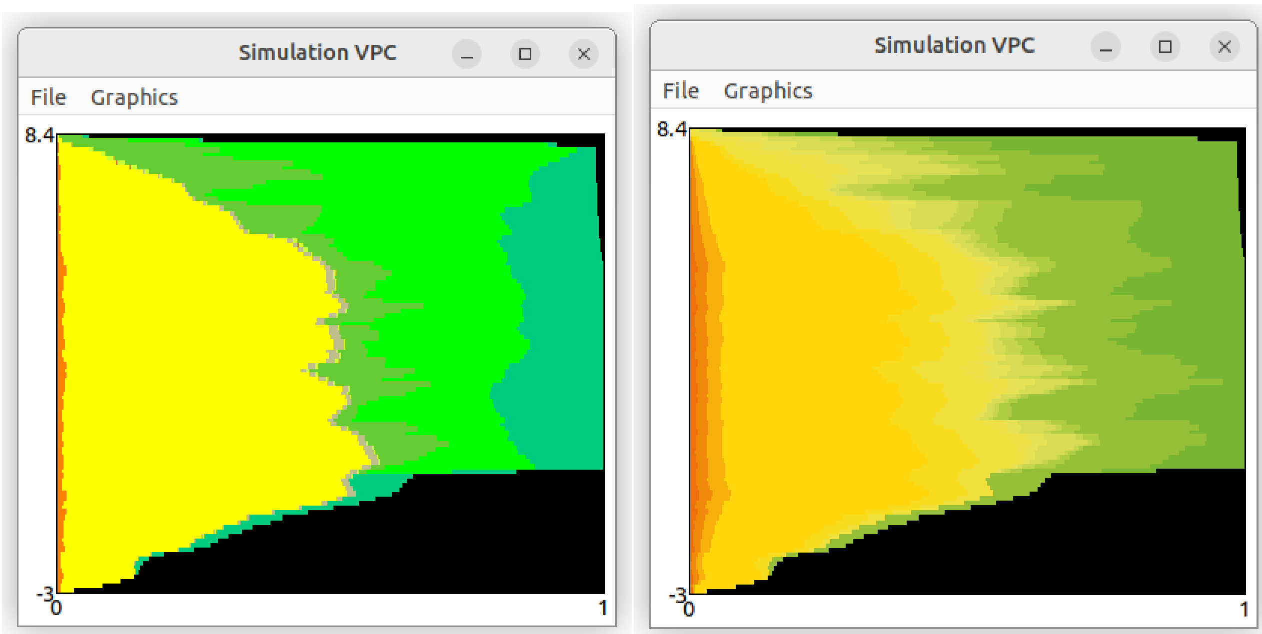


Figure 41 : Vertical Proportion Curve (left: lithofacies, right: grain size)

It corresponds to a cumulative histogram of the proportions of the different lithofacies (or grain size classes), calculated level by level (parallel to the reference plane).

Several options are available on the window *Vertical proportion curve*. The VPC is computed over a given interval (default - overall thickness of deposits), specifying:

- Either *number of levels*: discretization of the interval
- or *thickness*: thickness of each unitary level
- and *use elevation limits*: to give the limits of the selected interval (can be used with the option *number of levels* or *thickness*)

By default, the graphic window displays VPC including all lithofacies (or grain size classes) present in the simulation, with same colors as in the simulation.

Note: The grain size VPC view has been reverted (coarser grain at the left) (see classify option below). Variable grain size in PB/LAPs using Rouse Profile algorithm (Lemay 2018) was activated (see §3.8).

On the graphic window *Vertical Proportion Curve*:

Through the menu *Graphics* one can:

- *Remove data* - to remove a lithofacies (or a grain size class) from the histogram,
- *Concatenate data* - then a new name has to be given to the new lithofacies (or the grain size class),
- *Classify data* - opens the window *Classify Dialog*, where lithofacies (or grain size classes) order can be changed or reverted by using the buttons at the bottom of the dialog,
- *Switch orientation* - vertical <=> horizontal (the proportions are still calculated vertically)
- *Show removed data* - removed data are displayed in white
- *Show unavailable data* - by default in black - VPC is presented as 100% of the present lithofacies (or grain size classes), including the possible proportion of level which is not informed
- *Change data colors* - new lithofacies (or grain size classes) colors do not apply to simulation (only VPC),
- *Background color* - color of the background on which the diagram is displayed.

Through the menu *File*, one can:

- *Save* the proportions in a text file
- *Update the proportions*
- *Cancel* previous operations made by using 3 first *Graphics* menu options (operations remove / concatenate / classify are cancelled one by one)
- *Change parameters* go back to the parameters window *Vertical proportion curve*
- *Proportion slices* save a slice ASCII file giving the VPC of each grid cell for a given vertical interval
- *Statistics* display the proportions for each VPC level where user can then saves it into an ASCII file
- *Print* print or save the image in postscript format.

The global statistics (whole simulation) can be edited by choosing a number of levels equal to 1 through the overall thickness of the deposits.

The bottom and top elevation can be used to crop the VPC so that a full filled block will be considered. In the previous example, setting bottom to 0m and top to 21m will remove all unavailable data from the VPC (black).

Another way to obtain a cropped simulation without any empty space, is to erode the simulation with a constant surface from the bottom to 0m, and from the top to 21m using the *Surface* erosion one time operations (see section 3.3.1).

4.4.3.2 Simulation Proportion Matrix

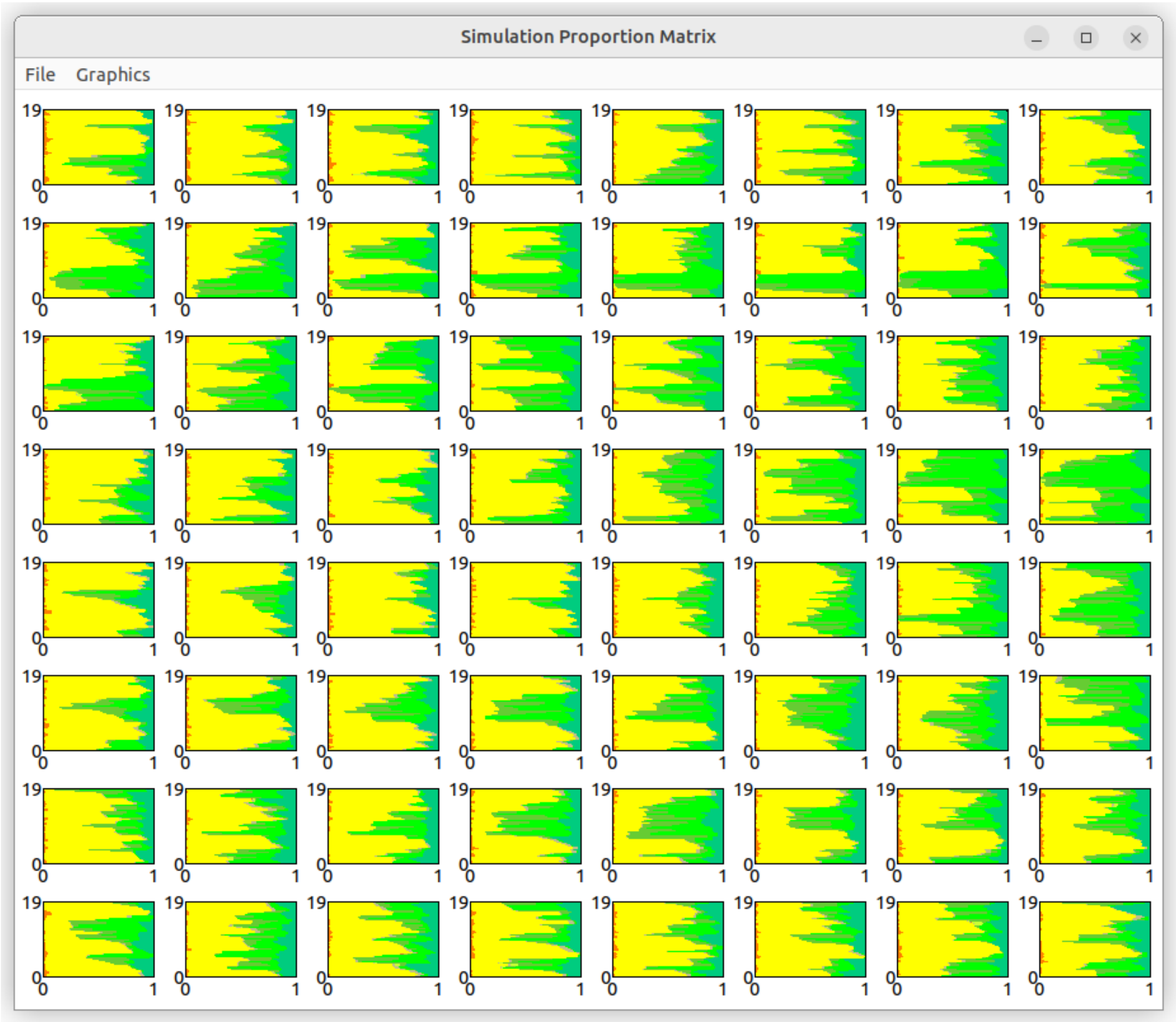


Figure 42 : Vertical Proportion Matrix (Domain split in 8x8)

The overall 2D domain can be divided along Ox and Oy axes. VPC is then computed within each sub-domain. Options are similar to *Vertical proportion curve* (see section 4.4.3.1).

4.4.3.3 Wells Vertical Proportion Curve

Figure 43 : Wells Vertical Proportion Curve

When input wells have been added (see section 3.4.1), the user can calculate VPC onto well data. If the wells are non standard (discrete or continuous), the data displayed are interpreted Flumy lithofacies. Options are similar to *Vertical proportion curve* (see section 4.4.3.1).

This tool can be used:

- to identify the different geological units if so, and
- to analyze the lithofacies proportions along wells

4.4.3.4 Simulation or Wells Facies-Crossing Histogram

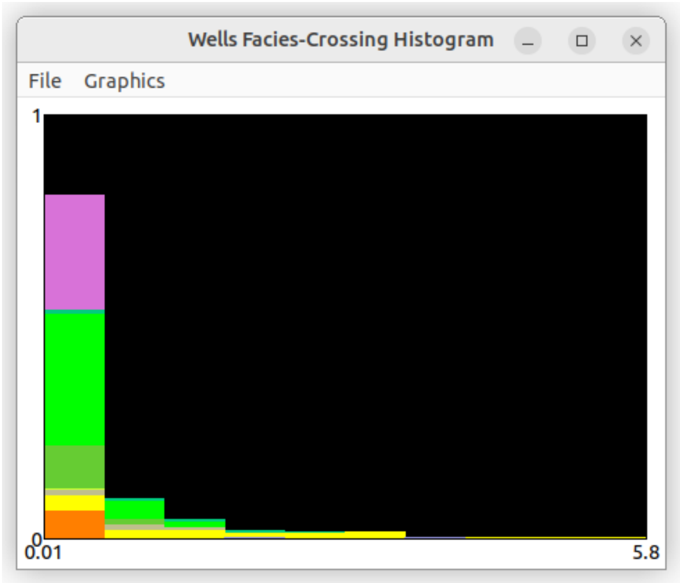


Figure 44 : Wells facies-crossing histogram

When input wells have been added (see section 3.4.1) (resp. a simulation has started), the user can build the samples facies-crossing histogram. Options are similar to *Vertical proportion curve* (see section 4.4.3.1). The difference with VPC is that the orientation is switched and the user cannot show the removed data and hide the unavailable data (which corresponds here to the empty black space).

The well (resp. simulation) histogram is a way to analyze the distribution of the samples according their height. In the example above (of fluvial context), there is very few samples of Point Bar (yellow) which height are greater than 4m. These samples are probably amalgamated Point Bar channel deposits. Most Wetland (purple) samples have a really thin thickness.

When computing the histogram on input wells, the closure limit option from the Wells tab is a way to see the impact of the closure feature (see section 3.4.1). The histogram is then recalculated using the limit set by the user.

4.4.3.5 Simulation or Wells Sand-Crossing Cumulative Histogram

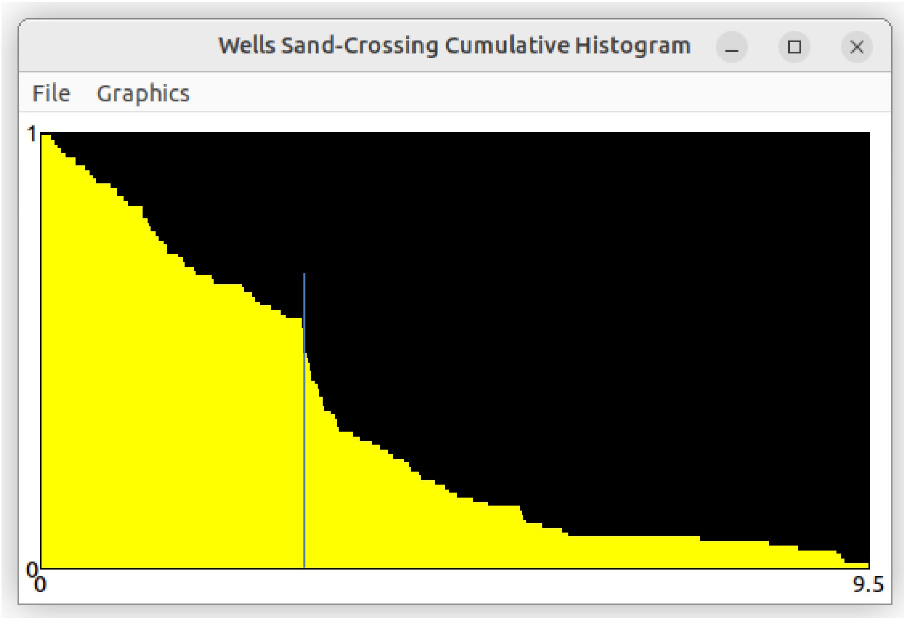


Figure 45 : Simulation sand-crossing cumulative histogram

This feature offers the possibility to display the inverse cumulative histogram of sand-crossing intervals (either computed from the input wells or the whole simulation).

This tool is used for inferring key parameters from wells data.

The slope break in this histogram is a good clue to infer the channel maximum depth parameter (here is 3m)

4.4.3.6 Conditioning Statistics

Statistics are computed on the part of well(s) that has been simulated (possibly including undefined lithofacies). They give, out of this part, the proportion of a given lithofacies: on data (“Data”), on simulated values (“Simu”), as well as the proportion of the same part where the lithofacies is both present on data and on simulation (“Matching”) (hence the “Matching” proportion cannot exceed the “Data” proportion, nor the “Simu” proportion).

The proportion of exactly honored data is then given by the “Matching” proportion when considering all lithofacies. The listed lithofacies represent the families of the lithofacies considered as equivalent for the conditioning process (see section 4.3.6.1).

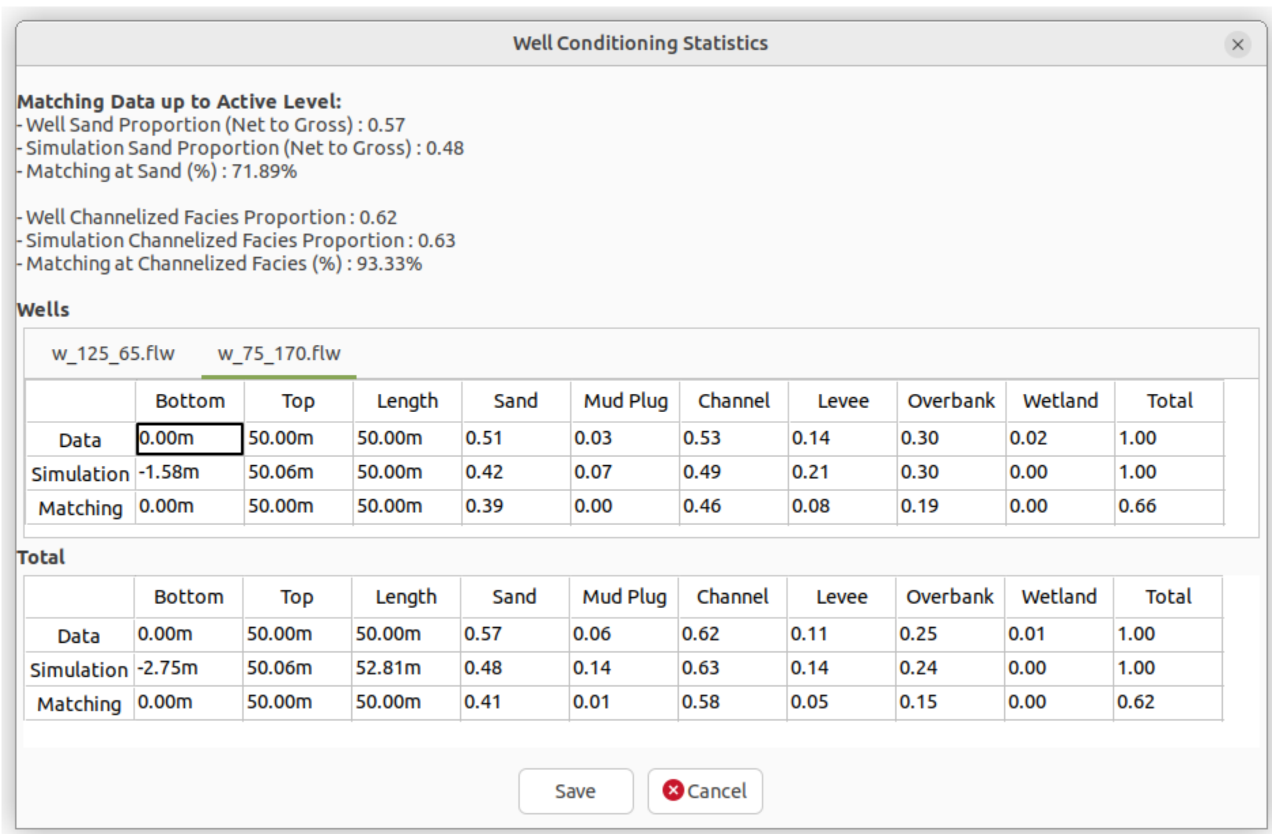


Figure 46 : Well Conditioning Statistics

In the example above, Channelized Facies in the two wells have been honored at 93.33%. The proportion of Channelized Facies in the simulation is equal to the one in the wells (0.62≈0.63).

4.4.4 Petrel© and Flumy

Here is the procedure to run a Flumy conditional simulation (with wells coming from Petrel) and then, import it into the Petrel© model. Let's take the following example.

- ***Note:*** All geographical coordinates in the imported files (topographies, centerlines, erodibility maps and wells) must be expressed in the same projection system!

Usually, the simulation domain grid is not oriented according West to East and South to North directions (constrained by faults for example).

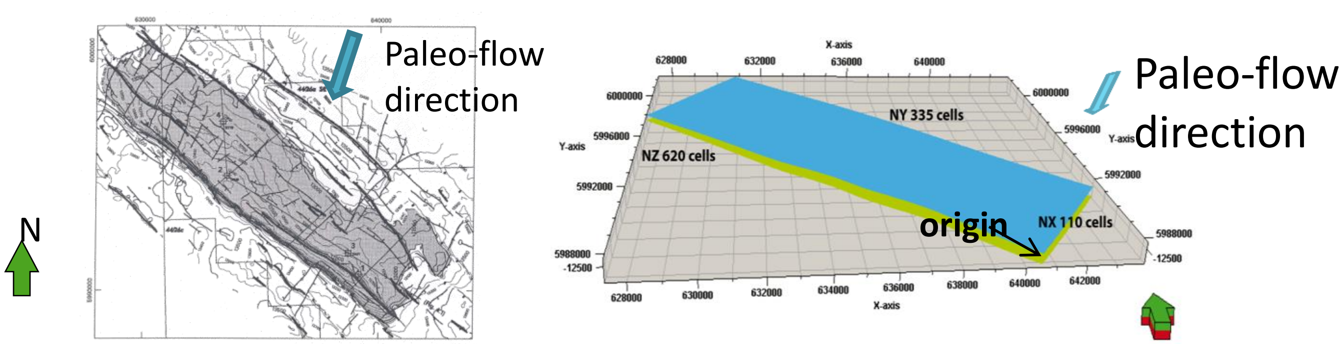


Figure 47 : Rotated domain in Petrel©

To ensure that Flumy and Petrel© can exchange files, user has to determine the following Flumy parameters before running the Flumy simulation.

4.4.4.1 Identify the appropriate Flumy initialization parameters

- In your Petrel 3D regular grid, create a fancy constant property
- Export this property into an GSLIB ASCII file (with the coordinates)
- Look at the GSLIB text file using a text editor:
    - The first node coordinates indicate the Flumy Grid Location (Initialization tab, see §3.2.2).
    - Deduce the Grid Rotation (mathematical convention, Initialization tab, §3.2.2)
    - Deduce the Paleo-Flow Direction (geologist convention, Channel tab, §3.5.2)
    - Identify how I and J grid indices are increasing:
        - I increases faster than J: assume that the cells order is **+X +Y**
        - J increases faster than I: assume that the cells order is **+Y +X**

4.4.4.2 Export wells from Petrel© and import them into Flumy

- Export your regular discretized wells in the LAS format. You should obtain 2 files per well: (i) one LAS file with your data (ii) one trajectory file
- Launch Flumy and fill Initialization tab (§3.2.2) with appropriate parameters:
  - The Grid size and the Grid mesh (same as Petrel©)
  - The Grid location, Grid rotation and Flow direction deduced from first step
- Import your wells from the Wells tab (§3.4.1)
- Use the “Well Analysis Tool” to guess appropriate simulation non-expert user parameters (look at §3.4.2)

4.4.4.3 Launch and export a simulation with Flumy

- Fill the Non-Expert user parameters or Advanced parameters from other tabs
- Execute your Flumy simulation up to the top of your reservoir
- Export one of the three Flumy properties (lithofacies, grain size or age) in a GSLIB ASCII file by using the "Export 3D Simulation Block" menu option (use the correct “Cells order” deduced from the first step)

4.4.4.4 Import the file into Petrel©

- Under Petrel©, import this GSLIB text file as a new property into your grid.

5 Files formats

In, the following, we are giving some general comments on the built-up of the files and examples of all file formats used by Flumy. These are intended to help the user in building its own files and in exchanging these with other software.

5.1 General comments

Important note:

- **All ASCII files must be encoded with either UTF-8 or ANSI (ISO8859).**

- Flumy can export two types of grid ASCII files format (2D or 3D):
  - Flumy Generic Grid (F2G – see §5.2)
  - GSLIB format (suitable for **Petrel**©)

- Flumy can import three types of grid ASCII files format (2D or 3D):
  - Flumy Generic Grid (F2G – see §5.2)
  - GSLIB format (suitable for Petrel©)
  - CPS3 format (suitable for Petrel©)

- **For exchanging grid files between Petrel© and Flumy, you should use the GSLIB ASCII Format (see §0)**

- **Flumy can import regular discretized wells exported by Petrel© with the LAS format. Regular LAS wells must have a non null STEP keyword value.**

- **(x, y) coordinates:**
  In all imported or exported data files (except imported surfaces or imported erodibility maps when using the simple ASCII file format), the (x,y) coordinates correspond to the geographical coordinates, not the coordinates in the Flumy system related through an origin and a rotation around it, see Section 3.2.2.

- **z coordinate:**
  In imported or exported data files, z is consistent with the input elevation of the reference level (which does not take into account the global domain slope), as it is easier to go directly between the horizontally flat reference system of Flumy simulation and the geographical system of the actual reservoir.

Some rules have to be strictly followed otherwise there might be some problems during the file exchange with other software.

- Symbol #: any line starting with this symbol corresponds to a comment line
- Decimal numbers: to be entered with a decimal point
- Field name: to be exactly as in the model (capital letter, underscore, ….)
- The thickness of each deposition unit is rounded to the cm.

In the different output files, the Flumy lithofacies deposits are represented by abbreviation or numbers . Lithofacies other than NA correspond to the different units that are iteratively deposited at each point of the 2D grid. As the beginning and the end elevations of the deposited material may vary with the 2D grid point, lithofacies NA is added below and above, in the 3D regular grid outputs.

Similarly, the exported grain size classes are represented by their float value which lies in the interval]0, 1] (not the class integer number).

See the section §6.5 for more details regarding the lithofacies and grain size class list.

The age property is an integer representing the iteration number at which the deposition unit has been deposited.

5.2 Flumy Generic Grid format

Grid files are used to import/export surfaces and erodibility map (2D grid) and to export simulation regular block (3D Grid).

5.2.1 Overview

The Flumy Generic Grid format handles regular discretization grid localization (3D location as Longitude, Latitude and Elevation in the geographical system) and rotation (2D rotation around vertical axis). This format indicates the order description in which the grid cells are dumped. It permits also to dump more than one variable column by column. An ASCII file with the Flumy Generic Grid Format is composed first by a header with several keywords in the appropriate order (see below), then, all grid cell values (one grid cell by line where different variable values are separated by the space character on the same line).

Keyword	**Value**	**Comment**
F2G_DIM	2 or 3	2D or 3D grid
F2G_VERSION	1 or more	F2G format version
F2G_LOCATION	X Y Z (m)	Grid location of the first cell center in the geographical system (Z is ignored for 2D grid)
F2G_ROTATION	Rotation (°)	Rotation in degrees counter clockwise around vertical axis (West => East direction is 0°)
F2G_ORIGIN	Ox Oy Oz (in m)	Offset of the origin of the grid (**Keep it to 0, 0, 0**) (Oz is ignored for 2D grid)
F2G_NB_NODES	Nx Ny Nz	Number of node along X-axis, Y-axis and Z-axis (Nz is ignored for 2D grid)
F2G_LAGS	Dx Dy Dz	Lag between nodes along X-axis, Y-axis and Z-axis (Dz is ignored for 2D grid)
F2G_ORDER	±A ±B ±C	The order in which cells are dumped. A B C must be replaced by ±X or ±Y or ±Z. For example, the order +Y +X +Z means that the cells first are dumped along increasing Y-axis (faster index), then along increasing X-axis, finally increasing Z-axis. (+Y +X +Z is the default when exporting F2G files). All three axes must be defined even for 2D grids (±Z is ignored in that case).
F2G_NB_VARIABLES	Nb variables	Number of variables… and for each variable…
F2G_VARIABLE_#	Name	Name of the variable
F2G_UNDEFINED_#	Undefined value	Value to be considered as undefined
F2G_VALUES		Indicates that next line is the first grid cell values

The ‘#’ above as to be replaced by the variable index starting from 1 for the first variable.

5.2.2 Topography (IN/OUT)

The topography file must use the F2G format. The topography values are in meters. Such file has only one variable: the Elevation.

The topography must cover the domain area entirely. The topography values must include the grid elevation (see section 3.2.2).

Here is an example of a 2D topography file using the F2G format:

```
F2G_DIM 2
F2G_VERSION 1
F2G_LOCATION 447100 -527300 0
F2G_ROTATION 0
F2G_ORIGIN 0 0
F2G_NB_NODES 211 166
F2G_LAGS 20 20
F2G_ORDER +Y +X +Z
F2G_NB_VARIABLES 1
F2G_VARIABLE_1 Z Elevation
F2G_UNDEFINED_1 NA
F2G_VALUES
81.74
81.78
…
79.64
```

The file above has 35026 lines (211x166 cell values) plus 12 header lines (compulsory keywords).

Cells are dumped columns by columns (Y is the faster index and X the slower)

Even for 2D grids, the +Z flag must be present in last position of F2G_ORDER value

5.2.3 Discretized centerline (OUT)

The discretized centerline file uses the F2G format. The dumped variable is the wet cell's sediment load of the domain grid. Its values are decreasing along the channel path from 1 (upper free surface elevation) to 0 (lower free surface elevation). The free surface elevation used for this calculation is the sum of the real topography, the water depth and the global negative slope. Outside the channel path the values are set to -1.

Note: There is no guarantee that the sediment load values are decreasing monotonically along the channel path.

Here is an example of a 2D discretized channel centerline file using the F2G format:

```
F2G_DIM 2
F2G_VERSION 1
F2G_LOCATION 0 0 0
F2G_ROTATION 0
F2G_ORIGIN 0 0
F2G_NB_NODES 268 201
F2G_LAGS 15 15
F2G_ORDER +Y +X +Z
F2G_NB_VARIABLES 1
F2G_VARIABLE_1 Centerline Disc
F2G_UNDEFINED_1 NA
F2G_VALUES
-1
-1
-1
-1
…
-1
```

The file above has 53880 lines (268x201 cell values) plus 12 header lines (compulsory keywords).

Cells are dumped columns by columns (Y is the faster index and X the slower)

Even for 2D grids, the +Z flag must be present in last position of F2G_ORDER value

5.2.4 Erodibility map (IN/OUT)

The erodibility map (Emap) file must use the F2G format. Input Emap values can be *Absolute* ($E=[0,2.E^{-7}]$) or *Relative* (any value) (see section 3.5.1). Output Emap values generated by Flumy are Absolute. The Emap file has only one variable: the Erodibility.

The grid of the Emap file could partially cover the domain area. Missing values are automatically calculated from proximal erodibility values found into the Emap file.

Here is an example of a 2D erodibility map file using the F2G format with absolute values:

```
F2G_DIM 2
F2G_VERSION 1
F2G_LOCATION 447100 -527300 0
F2G_ROTATION 0
F2G_ORIGIN 0 0
F2G_NB_NODES 211 166
F2G_LAGS 20 20
F2G_ORDER +Y +X +Z
F2G_NB_VARIABLES 1
F2G_VARIABLE_1 Erodibility
F2G_UNDEFINED_1 NA
F2G_VALUES
2e-08
2e-08
…
2e-08
```

The file above has 35026 lines (211x166 cell values) plus 12 header lines (compulsory keywords).

Cells are dumped columns by columns (Y is the faster index and X the slower)

Even for 2D grids, the +Z flag must be present in last position of F2G_ORDER value

5.2.5 3D block (OUT)

The simulation ASCII file uses the F2G format. This is a 3D regular grid (vertically discretized at a given discretization step). The user must indicate the following fields before exporting the simulation:

* The **Minimum/Maximum X/Y grid indices** (starting from 1): This is a way to export a sub-block of the simulation (not the whole grid)

* The **Minimum/Maximum elevation** (in m): This is a way to export a horizontal slice of the simulation (and remove the channel bottom footprint below reference plane for example)

* The **Vertical discretization step** (in m): because Flumy internally stores vertical irregular pillar in each domain cell, the exportation procedure must upscale the simulation content at a regular discretization step. Values are sampled at cell centers.

* The **Cells Order**: Indicate in which order grid cells are dumped (Look at F2G_ORDER in §5.7)

* The **properties** the user wants to export:

- The **Facies** variable is an integer (see section 6.5).
- The **Grain Size** variable is a float value between 0.125 (finest grain) and 1 (coarsest grain) (see section 6.5),
- The **Age** variable is an integer indicating the date of the deposit (number of iterations)

Here is an example of a 3D sub block of the simulation exported into a file using the F2G format with the 3 variables:

```
F2G_DIM 3
F2G_VERSION 1
F2G_LOCATION 449100 -525300 0.48
F2G_ROTATION 0
F2G_ORIGIN 0 0 0
F2G_NB_NODES 10 10 79
F2G_LAGS 20 20 1
F2G_ORDER +Y +X +Z
F2G_NB_VARIABLES 3
F2G_VARIABLE_1 Facies
F2G_UNDEFINED_1 255
F2G_VARIABLE_2 Grain Size
F2G_UNDEFINED_2 0
F2G_VALUES
2 0.6875
2 0.6875
…
9 0.125
```

The file above has 7900 lines (10x10x79 cell values) plus 14 header lines (compulsory keywords).

Cells are dumped horizontal slice by horizontal slice (Y is the faster index and Z is the slower)

5.3 Channel centerline (IN/OUT)

Data for the channel centerline are given as an ASCII file containing the discretization points of the channel in 2D or 3D. The first point must be upstream of the channel; the last point must be downstream of the channel. Comments are not allowed after the "~Ascii" line delimiter.

Coordinates are given in the geographical system.

```
# =====================================================================
#Centerline saved by Flumy
#
# Dimension of points (2D or 3D)
N_DIMENSIONS=3D
# Number of points
N_POINTS=178
# Auxiliary variables
N_VARIABLES=0#
=====================================================================
~Ascii
-4535 -2808.11 0
-4486.97 -2792.14 0
-4437.86 -2779.01 0
-4387.76 -2768.73 0
…
4359.50 1255.74 0
```

The file above has 178 lines (178 channel points) plus 11 header lines (including comments).

5.4 Well file (IN/OUT)

There is one separate file per well to be imported (exported). Imported wells can be vertical or non-vertical but then with an elevation decreasing along hole. Non-vertical wells are automatically identified by the presence of the (x,y,z) of each sample (see below). Only vertical wells can be exported.

The file format is inspired from the well known LAS format. Unfortunately, LAS format does not include well location. The Flumy file header contains well location, the elevation of the top and the bottom of the well. The header contains also additional keywords indicating which columns are to be extracted from the data part.

The data part must follow the separator line (~Ascii).

- ***Note***: to import wells from Petrel©: In Petrel© export logs using LAS format, then for each file remove all the lines before "~Ascii" line and add the compulsory keywords at the beginning.

It is possible to extract vertical wells from the simulated block.

- ***Caution***: the well must be extracted at the intersection of the cross-sections of the **first** window opened by the program (since sections cursors displayed on the different windows are independent).

Keyword	**Value**	**Comment**	
X_WELL=	X	Well location abscissa (longitude) in the geographical system	
Y_WELL=	Y	Well location ordinate (latitude) in the geographical system	
Z_BOTTOM=	Zb	Bottom elevation of the well (including grid elevation – see section 3.2.2)	
Z_TOP=	Zt	Top elevation of the well (including grid elevation – see section 3.2.2)	
ATTRIBUTE_COLUMN=	Attribute column index (Interest variable)	The attribute is the **Lithofacies identifier** for a standard Flumy well, the **custom discrete value** for a non-standard discrete well or the **continuous property** for a non-standard continuous well	
DISCRETE_ATTRIBUTE=	0 or 1	Indicate whether attribute is discrete (1 = Flumy lithofacies identifiers or custom categories) or not (0 = continuous variable)	
STANDARD_FACIES=	0 or 1	If attribute is discrete, indicate if the attribute corresponds to standard Flumy lithofacies identifiers (1) or custom category (0)	
AGE_COLUMN=	Age	Age of the sample (number of iterations since the simulation beginning) (only for extracted well)	
DEPTH_COLUMN=	Depth column index	Depth are defined relative to the top of the well	**Used only in vertical well**
XS_BOT=	X sample bottom column index	Sample bottom abscissa in geographical system	**Used only in non-vertical well**
YS_BOT=	Y sample bottom column index	Sample bottom ordinate in geographical system	
ZS_BOT=	Z sample bottom column index	Sample bottom elevation in geographical system	

5.4.1 Format for a vertical well

The output well file contains one header which describes **in that order**: the well location; the well bottom elevation (bottom elevation of the last sample) and the well top elevation (head); the compulsory column's indices (Attribute and Depth for a vertical well) ; and two flags which indicates whether the well is standard (attribute is Flumy lithofacies identifier) or not (attribute is user defined, see §5.4.3). Then ~ASCII keyword indicates that samples are listed below.

File example of a vertical well:

```
# Well Location
X_WELL=2555
Y_WELL=3050
#
# Bottom elevation
Z_BOTTOM=-100
# Top elevation
Z_TOP=-81.62
#
# Deposits listed from top to bottom
# Vertical well columns order:
#   1-Facies_id 2-Facies 3-Depth 4-Thickness 5-Time
# Warning:
#   Depth = bottom sample distance from top of the pillar (Z_TOP)
ATTRIBUTE_COLUMN=1
DEPTH_COLUMN=3
#
# Standard well format:
DISCRETE_ATTRIBUTE=1
STANDARD_FACIES=1
#
~Ascii
  7   LV    5.68   5.68
  2   PB    8.45   2.77
  1   CL    8.84   0.39
  2   PB   10.57   1.73
  1   CL   10.88   0.31
  8   OB   11.07   0.19
 11   WL   11.10   0.03
...
  8   OB   17.18   0.22
  8   OB   17.38   0.20
  0  UDF   18.38   1.00
```

The third column is compulsory (Depth). The fourth is optional and here, corresponds to the sample thickness. The two red values are always the same, as the first sample thickness corresponds to the first sample cumulative depth from the top. The green value always corresponds to Z_TOP – Z_BOTTOM.

Only the lithofacies identifier and the depth columns are necessary. Other columns are ignored.

5.4.2 Format for a non-vertical well

The format for a non-vertical well is close to the format of a vertical well. A well is identified as a non-vertical well if columns XS_BOT, YS_BOT, ZS_BOT (representing the (x,y,z) of the bottom of each sample) are defined and informed. The values of ZS_BOT must decrease. The last one should equal Z_BOTTOM value.

File example of a deviated well:

```
# Well Location
X_WELL=2450
Y_WELL=2650
#
# Bottom elevation
Z_BOTTOM=0
# Top elevation
Z_TOP=25
#
# Deposits listed from top to bottom
# Deviated well columns order:
#   1-Facies_id 2-Facies 3-X_bottom 4-Y_bottom 5-Z_bottom
# Warning:
#   [X|Y|Z]_bottom = sample bottom geographical location
ATTRIBUTE_COLUMN=1
XS_BOT=3
YS_BOT=4
ZS_BOT=5
#
# Standard well format:
DISCRETE_ATTRIBUTE=1
STANDARD_FACIES=1
#
~Ascii
  7   LV    2460  2645  23
  2   PB    2463  2642  19
  1   CL    2468  2640  18
  8   OB    2487  2625  10.25
  2   PB    2506  2608  5
  8   OB    2527  2588  0
```

The green value (last sample bottom elevation) always corresponds to Z_BOTTOM. Facies short name, depth, thickness and age columns (if present) are ignored.

Samples are considered connected to the previous one (the top one). The first well sample is assume to be connected to the well head. If you have some missing values (gaps or undefined attributes), an undefined lithofacies sample (0 UDF) must be added to fill the gap.

5.4.3 Format for a non-standard well

The format for a non-standard well is almost the same than a standard one. The user must only indicates whether the attribute (the interest variable) is discrete (DISCRETE_ATTRIBUTE=1) or continuous (DISCRETE_ATTRIBUTE=0). A non-standard well has the following keyword set to 0: STANDARD_FACIES=0

Here is an example of a vertical non-standard discrete well:

```
# Well Location
X_WELL=3450
Y_WELL=2650
#
# Bottom elevation
Z_BOTTOM=0
# Top elevation
Z_TOP=25
#
# Deposits listed from top to bottom
# Vertical well columns order:
#   1-Facies_id 2-Facies 3-Depth 4-Thickness 5-Time
# Warning:
#   Depth = bottom sample distance from top of the pillar (Z_TOP)
ATTRIBUTE_COLUMN=2
DEPTH_COLUMN=3
#
# Non-standard well format:
DISCRETE_ATTRIBUTE=1
STANDARD_FACIES=0
#
~ASCII
  1   Silt    2.00   0.005
  2   Sand    6.00   0.006
  3   Gravel  7.00   0.012
  4   Shale   14.75  0.024
  2   Sand    20.00  0.007
  4   Shale   25.00  0.003
```

The green value always corresponds to Z_TOP – Z_BOTTOM (vertical well). The columns number 1 (sample index) and 4 (a sample property) are ignored.

All values of a discrete attribute are collected comparing the characters (case sensitive). In the example above, the different possible categorical values of the discrete attribute are: Silt, Sand, Gravel and Shale.

The user will have to indicate the Flumy lithofacies associated to each categorical value found in the input wells (see section 3.4.2).

For continuous attribute, the user will have to create “user classes” defining which interval of the continuous variable corresponds to a Flumy lithofacies (see section 3.4.2).

5.5 Journal file (IN/OUT)

Each line of the journal (excepting blank lines and lines starting with #) contains a parameter value. A description of the parameter can be found after the # sign (all characters following # are comments). The parameters order is significant and **must not be changed**.

The first section (sections are separated with blank lines) corresponds to initial values of the parameters before the first launch. The other sections correspond to a simulation sequence. The last parameter of the sequence corresponds to the number of iterations.

Note that a journal file stores all successive current project sequences. All sequences can be executed in one mouse click by using the file menu “Launch Journal file”. These files cannot be used for the Batch mode (command line) which uses a particular file format (see §5.7).

Here is an example of a Journal File for a conditional simulation having only one sequence of 111 450 iterations:

```
165426111       # Simulation / Seed Value
Fluvial         # Simulation / System Type
0               # Domain / Origin / X (m)
0               # Domain / Origin / Y (m)
251             # Domain / Dimensions / Number of nodes along X
201             # Domain / Dimensions / Number of nodes along Y
10              # Domain / Lags / Lag X (m)
10              # Domain / Lags / Lag Y (m)
0               # Domain / Grid Direction (degrees)
0               # Domain / Z Reference Level (m)
none            # Surface / Surface type
exceed          # Surface / Import option
0               # Surface / Constant Surface Elevation (m)
none            # Surface / Surface File
undefined       # Surface / Filling Facies
none            # Surface / Tectonic File
11              # Wells / Count
w_225_145.flw   # Wells / Filename
w_220_35.flw    # Wells / Filename
w_175_165.flw   # Wells / Filename
w_170_45.flw    # Wells / Filename
w_130_105.flw   # Wells / Filename
w_125_65.flw    # Wells / Filename
w_80_130.flw    # Wells / Filename
w_75_170.flw    # Wells / Filename
w_75_90.flw     # Wells / Filename
w_70_50.flw     # Wells / Filename
w_25_160.flw    # Wells / Filename
0               # Wells / Nb Classes
20              # Wells / Relaxation Parameter
```

```
false           # Wells / Closure activated
true            # Wells / Stop simulation when all wells are honored
0.1             # Wells / Closure limit
none            # Channel / Centerline file
30              # Channel / Width (m)
3               # Channel / Max Depth (m)
375             # Channel / Wavelength (m)
constant        # Channel / Scale / Distribution type
100             # Channel / Scale / constant distribution value
12              # Channel / Domain Margin (multiple of channel width)
90              # Channel / Flow Direction (degrees)
0.001           # Channel / Slope along flow direction
4e-08           # Erodibility / Coefficient
constant        # Erodibility / From
none            # Erodibility / Erodibility Map File
false           # Avulsions / Levee breach during overbank flow
poisson         # Avulsions / Levee breach / Frequency
280             # Avulsions / Levee breach / Period
poisson         # Avulsions / Regional / Frequency
500             # Avulsions / Regional / Period
false           # Avulsions / No splay at levee breach
0.5             # Avulsions / Probability CSI to CSII
0.9             # Avulsions / Probability CSII to CSIII
9999            # Equilibrium Profile / Initial Elevation
never           # Equilibrium Profile / Frequency / Frequency
constant        # Equilibrium Profile / Intensity / Distribution type
0.1             # Equilibrium Profile / Intensity / constant
distribution value
false           # Grain Size / Calculate initial concentration quickly
0.75            # Grain Size / Threshold for Rouse profile
false           # Grain Size / Activate variable grain size in PB
0.01            # Sediment / Global Concentration
0               # Sediment / Sediment volume for class #1
0               # Sediment / Sediment volume for class #2
0               # Sediment / Sediment volume for class #3
0               # Sediment / Sediment volume for class #4
2               # Sediment / Sediment volume for class #5
3               # Sediment / Sediment volume for class #6
6               # Sediment / Sediment volume for class #7
13              # Sediment / Sediment volume for class #8
27              # Sediment / Sediment volume for class #9
26              # Sediment / Sediment volume for class #10
10              # Sediment / Sediment volume for class #11
8               # Sediment / Sediment volume for class #12
5               # Sediment / Sediment volume for class #13
0               # Sediment / Sediment volume for class #14
0               # Sediment / Sediment volume for class #15
false           # Mass Balance / Activated?
overbank        # Aggradation / Type
919             # Aggradation / Thickness exp. decrease (m)
```

```
6               # Aggradation / Levee width (multiple of channel width)
true            # Aggradation / Randomize lambda ?
poisson         # Aggradation / Frequency / Frequency
70              # Aggradation / Frequency / Period
normal          # Aggradation / Intensity / Distribution type
0.1             # Aggradation / Intensity / Normal distribution / Mean
value
0.03            # Aggradation / Intensity / Normal distribution /
Standard deviation
0               # Aggradation / Peatland proportion (%)
0               # Aggradation / Pelagic/Draping intensity (m / 10000 it)
draping         # Aggradation / Draping Facies

true            # Define a new sequence
165426111       # Simulation / Seed Value
none            # Surface / Surface type
exceed          # Surface / Import option
0               # Surface / Constant Surface Elevation (m)
none            # Surface / Surface File
undefined       # Surface / Filling Facies
none            # Surface / Tectonic File
20              # Wells / Relaxation Parameter
false           # Wells / Closure activated
true            # Wells / Stop simulation when all wells are honored
0.1             # Wells / Closure limit
none            # Channel / Centerline file
30              # Channel / Width (m)
3               # Channel / Max Depth (m)
375             # Channel / Wavelength (m)
constant        # Channel / Scale / Distribution type
100             # Channel / Scale / constant distribution value
12              # Channel / Domain Margin (multiple of channel width)
90              # Channel / Flow Direction (degrees)
0.001           # Channel / Slope along flow direction
4e-08           # Erodibility / Coefficient
constant        # Erodibility / From
none            # Erodibility / Erodibility Map File
false           # Avulsions / Levee breach during overbank flow
poisson         # Avulsions / Levee breach / Frequency
280             # Avulsions / Levee breach / Period
poisson         # Avulsions / Regional / Frequency
500             # Avulsions / Regional / Period
false           # Avulsions / No splay at levee breach
0.5             # Avulsions / Probability CSI to CSII
0.9             # Avulsions / Probability CSII to CSIII
9999            # Equilibrium Profile / Initial Elevation
never           # Equilibrium Profile / Frequency / Frequency
constant        # Equilibrium Profile / Intensity / Distribution type
0.1             # Equilibrium Profile / Intensity / constant
distribution value
```

```
false           # Grain Size / Calculate initial concentration quickly
0.75            # Grain Size / Threshold for Rouse profile
false           # Grain Size / Activate variable grain size in PB
0.01            # Sediment / Global Concentration
0               # Sediment / Sediment volume for class #1
0               # Sediment / Sediment volume for class #2
0               # Sediment / Sediment volume for class #3
0               # Sediment / Sediment volume for class #4
2               # Sediment / Sediment volume for class #5
3               # Sediment / Sediment volume for class #6
6               # Sediment / Sediment volume for class #7
13              # Sediment / Sediment volume for class #8
27              # Sediment / Sediment volume for class #9
26              # Sediment / Sediment volume for class #10
10              # Sediment / Sediment volume for class #11
8               # Sediment / Sediment volume for class #12
5               # Sediment / Sediment volume for class #13
0               # Sediment / Sediment volume for class #14
0               # Sediment / Sediment volume for class #15
false           # Mass Balance / Activated?
overbank        # Aggradation / Type
919             # Aggradation / Thickness exp. decrease (m)
6               # Aggradation / Levee width (multiple of channel width)
true            # Aggradation / Randomize lambda ?
poisson         # Aggradation / Frequency / Frequency
70              # Aggradation / Frequency / Period
normal          # Aggradation / Intensity / Distribution type
0.1             # Aggradation / Intensity / Normal distribution / Mean
value
0.03            # Aggradation / Intensity / Normal distribution /
Standard deviation
0               # Aggradation / Peatland proportion (%)
0               # Aggradation / Pelagic/Draping intensity (m / 10000 it)
draping         # Aggradation / Draping Facies
111450          # Number of iterations for this sequence
```

5.6 Colors file (IN/OUT)

It is used to save the current lithofacies colors from "Settings" menu. Colors are stored as RGB (Red Green Blue) values. Each component is coded between 0 and 1.

- ***Notes***:
  - In the data directory, you can find two files named flumy_xxx_colors. These files can be directly used in Gocad© or Isatis© in order to display Flumy lithofacies, it contains default colors for all lithofacies. Its format is slightly different.
  - There is not yet the possibility to save/load grain size classes colors.

Output Colors File example:

```
# Flumy Facies Colormap
# Number of facies
14
# Color of facies with RGB components
# Undefined (UDF)
0.60 0.60 0.90
# Channel Lag (CL)
1.00 0.50 0.00
# Point Bar / LAPs (PB)
1.00 1.00 0.00
# Sand Plug (SP)
0.75 0.75 0.55
# Crevasse Splay I (CSI)
0.80 0.50 0.20
# Splay II Channels (CCh)
0.80 1.00 0.20
# Crevasse Splay II (CSII)
0.80 0.80 0.20
# Levee (LV)
0.40 0.80 0.20
# Overbank (OB)
0.00 1.00 0.00
# Mud Plug (MP)
0.00 0.80 0.50
# Hemipelagic Plug (HP)
0.50 0.50 0.50
# Wetland (WL)
0.85 0.45 0.85
# Draping (DR)
0.60 0.80 0.90
# Pelagic (PL)
1.00 0.80 1.00
```

5.7 Batch file (IN)

The batch file is an ASCII File which describes the parameter values used to launch several sequences of iterations by command line (see §4.1.3). This feature is only available in Premium and Research version. Each batch file starts with one mandatory global section using [GLOBAL] keyword. Then, the batch file must contain one section for each sequence of iterations using [NEW_SEQ] keyword.

Inside a section, each line is composed by one keyword, followed by an '=' sign and its action or parameter value (numerical or string). Note that the batch file and the journal file (§5.5) have different formats.

All elevations (Z) and locations (X,Y) must take into account the initial grid elevation (DOMAIN_ZREF parameter) and the grid origin location (DOMAIN_OX and DOMAIN_OY parameters). Thus, coordinates are in the geographical referential system.

Existing keywords for a batch file are the following. Some keywords with the "(Research)" label, are only available in the Research version (ex: STATS_IT).

Global parameter keywords:

VERBOSE	If not zero, trace all information of each simulation step (mute by default)	Optional
FORCE_SIMU	If not zero, ignore consistency warnings and errors and launch the simulation	Optional
USE_TURBIDITE	If not zero, use turbidites system (use fluvial system by default): 1 for Public scenario, 2 for Research scenario	Optional
WELL_FILE *	Path to one conditioning well file with a standard format (Flumy lithofacies ID) (see §5.4). User can provide several well files.	Optional
WELL_NAME *	Name of one well (the order must be the same than the well files list)	Optional
BASEMENT_TOPO	Path to an ASCII file with F2G format (see §5.2.2) containing the initial topography to be loaded at startup.	Optional
BASEMENT_FACIES	Facies ID to be deposited between initial reference elevation (look at Grid Elevation parameter: DOMAIN_ZREF in §6.1) and basement topography. (Default is 0 = UDF)	Optional

* These keywords can appear more than one time in the global section

Sequence parameter keywords:

LAUNCH_ZUL	Launch the sequence up to reach a given Upper Limit constant elevation including initial grid elevation (DOMAIN _ZREF parameter) (in m), then stop ⇨ This keyword is **deprecated**. Prefer using LAUNCH_IT=-1 instead (see below)	One of these two keywords was mandatory. **LAUNCH_IT keyword is now mandatory**
LAUNCH_IT	Launch the sequence for a given number of iterations then stop. If the value is equal to -1, then launch the sequence until the upper limit topography ZUL_FILE or ZUL_TOPO is reach. The simulation could stop before the required option when all wells are honored. See COND_WELL_STOP_HONORED parameter below.	
ZUL_FILE	Define the upper limit topography by an irregular topography from the given ASCII file (see §5). When using upper limit topography, you can define the upper limit type by using ZUL_TYPE keyword.	One of them is mandatory if LAUNCH_IT=-1
ZUL_TOPO	Define the upper limit topography by a constant elevation (in meters) When using upper limit topography, you can define the upper limit type by using ZUL_TYPE keyword.	
ZUL_TYPE	Type of upper limit surface: 1 => Neutral (the default): The simulation will stop when the whole topography reach the upper limit surface. 2 => Erosive: Same as Neutral, but then, exceed part of the topography is removed down to the upper limit surface 3 => Stratigraphic: Same as Neutral except that Flumy will try to adapt the processes so that the topography will fit the upper limit surface	Optional
NEXUS_HMAX	Execute Non Expert User Calculator with the given Maximum Channel Depth (in m, 3m by default)	If at least one of this keyword is provided, the

NEXUS_ISBX	Execute Non Expert User Calculator with the given Sand Body Extension Index (80 by default)	Nexus is executed first (see §3.2.1) Then following user defined parameters are overridden.
NEXUS_SAND	Execute Non Expert User Calculator with the given Sand Proportion (Net to Gross) (in %, 50% by default))	
NEXUS_GRID	If not zero, execute the Non Expert User Calculator and update the Grid Size according the Channel Width (update Grid Size by default)	
NEW_TOPO	Define a new topography by (i) a constant elevation (in meters) or (ii) an irregular topography from the given ASCII file (see §5). The new topography is applied before starting the sequence.	Optional
NEW_TOPO_MODE	New topography alteration mode: 1 => Replace (the default): Replace the topography by the new one 2 => Aggrade: Add some material above current topography up to the new one 3 => Erode Down: Erode topography down to the new one 4=> Erode Up: Erode bottom of deposits up to the new topography (useful for removing channel footprints below the reference elevation)	Optional
NEW_TOPO_FACIES	Facies ID (see §5.1) to be added when using a new topography with Replace or Aggrade mode. (Default is 0 = UDF)	Optional
EMAP_FILE	Erodibility map ASCII file (see §5). Erodibility values can be absolute or relative. (see §3.5.1) (default is none). The erodibility map is constant with the EROD_COEF value (see §6.1).	Optional
EMAP_OFFSET	When using erodibility map relative file, offset to be applied in order to convert the file values. (see §3.5.1) (default is 0)	Optional
NEW_CL_FILE	New centerline ASCII file (see §5.3) to be applied before starting the sequence (default is none)	Optional (exclusive with NEW_CL_POINT)
NEW_CL_POINT	Point geographical coordinates from which a new centerline must be tossed (see §5.3) before starting the sequence (default is none).	Optional (exclusive with NEW_CL_FILE)

TECTO_FILE	Tectonic deformation map ASCII file (see §3.3.1) to be used during current sequence (default is none)	Optional
SINUOSITY_INTERVAL	Period (number of iterations) for refreshing the real channel sinuosity used by the mean local slope algorithm (default is 1)	Optional
CURVATURE_PTS_NB	Number of points to be used for curvatures calculation (default is 3)	
SCOUR_FACTOR	Customized scour factor (default is 6)	Optional
FRICTION_COEFF	Customized friction coefficient (default is 0.0168 (Fluvial), 0.0419 (Turbidites), 0.0209 (Turbidites Research)	Optional
CONCENTRATION	Turbidites sediments mean concentration (default is 0.1)	Optional
BANK_EROD_COEFF	Bank erodibility coefficient (default is 0.5)	Optional
SNAP_SAVE_DIR	Directory where to save the simulation snapshot at the end of the sequence	Optional
SNAP_LOAD_DIR (Research)	Directory where to load a simulation snapshot (restore the previous state of a simulation) before starting the new sequence	Optional
<PARAM>	Any authorized parameter keyword (see keywords column in next section §6.1) and its value.	Optional

Global action keywords:

STATS_IT (Research)	Dump statistics into a CSV file (located in the same folder than the batch file) every X iterations (X is given by the user)	
STATS_AV (Research)	If not zero, dump statistics into a CSV file (located in the same folder than the batch file) before each regional avulsion	
SLICE_Z *	Dump a slice of the simulated block into an ASCII file (located in the same folder than the batch file) at the given Z elevation (look at section §5.2.5 for the F2G file format). If the elevation Z is not inside the grid, automatically takes the vertical centered slice.	One of these six keywords is mandatory in the global section All active is possible.
F2G_DZ	Dump the simulated block into an ASCII file (located in the same folder than the batch file) with the given discretization step (look at section §5.2.5 for the F2G file format)	
HISTO_DZ	Dump the sand-crossing cumulative histogram with the given thickness step.	
EXP_WELL *	Right hand value is formatted as follow: ix;iy;z_bot;z_top. Extract one vertical well from the simulation into a well file (§5.4) located at grid cell {ix;iy} (indices lying from 1 to NX or NY) between z_bot elevation and z_top elevation. At the end of the simulation, the Automatic Nexus Inference from all extracted wells is displayed (see "Fill Nexus" option in §3.4.1).	
STATS_FILE (Research)	Path for the output statistics file (default is the batch file name with extension ".csv")	Optional
STATS_PROPS (Research)	If not zero, dump facies proportions into the CSV file. Can be used only if STATS_IT or STATS_AV is used.	Optional
STATS_CL (Research)	If not zero, dump the centerline statistics into a CSV file (see STATS_CL_FILE keyword). Can be used only if STATS_IT or STATS_AV is used.	Optional
STATS_CL_FILE (Research)	Path for the output centerline statistics file (default is the batch file name with extension "_centerline.csv"). Can be used only if STATS_IT or STATS_AV is used.	Optional
SLICE_FILE *	Path for the output slice file (default is the batch file name with extension ".slice.f2g") (the order must match the slices order)	Optional
F2G_FILE	Path for the output simulated block file (default is batch file name + extension ".f2g")	Optional

F2G_IT	Generate the output simulated block periodically into F2G files (every given a number of iterations) (-1 by default means that the feature is not activated). F2G_FILE value is ignored because generated files are automatically named (batch file name + simulation age + extension ".f2g").	Optional
F2G_FACIES	If not zero, dump lithofacies variable in the exported bloc (zero by default)	If F2G export is required, one of these three keywords is mandatory
F2G_GRAIN	If not zero, dump grain size variable in the exported bloc (zero by default)	
F2G_AGE	if not zero, dump age variable in the exported bloc (zero by default)	
F2G_ZBOT	Bottom elevation of the F2G exported block (Initial grid elevation (DOMAIN_ZREF parameter) by default)	Optional
F2G_ZTOP	Top elevation of the F2G exported block (Mean topography by default)	Optional
F2G_ORDER	Order in which cells are dumped in the F2G file (see §5.2.5, +Y +X +Z by default)	Optional
HISTO_NZ	Define the number of required levels for calculating the sand-crossing cumulative histogram	Optional
HISTO_FILE	Path for the output sand-crossing cumulative histogram file. (default is the batch file name with extension "_histo.csv")	Optional

* These keywords can appear more than one time in the global section

5.8 Statistics CSV file description (OUT)

Here is the description of the variables dumped in the CSV statistics file (Research feature). Each line indicates all statistics at a given iteration:

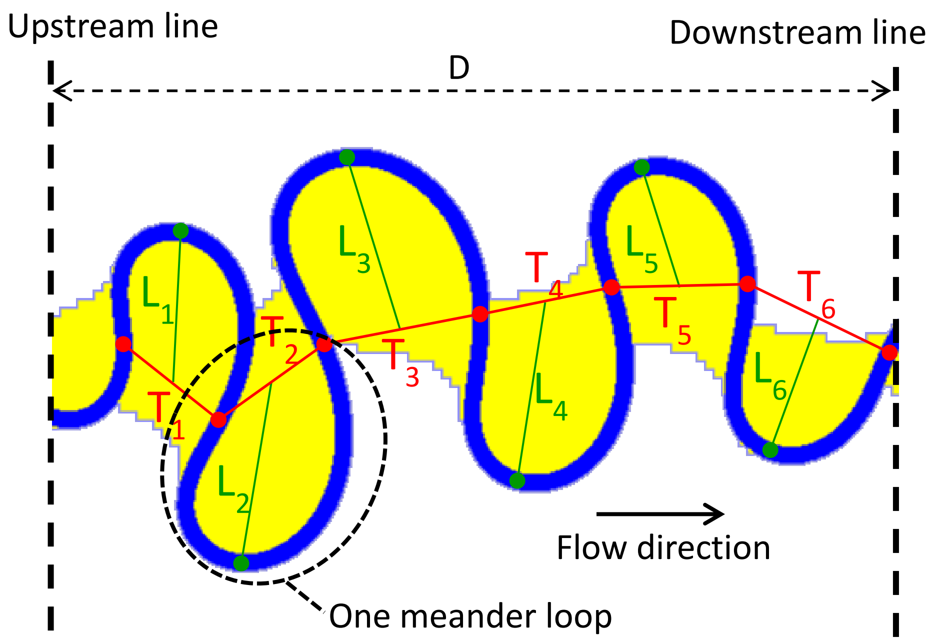


Figure 48: Channel geometric statistics

Definitions:

- N = number of complete meandering loops of the centerline (here, N=6)
- S = total centerline curvilinear length
- D = distance between upstream and downstream line
- T = meander loop segment joining two inflexion points
- L = sand body extension approximated by the distance between the middle of a meander loop segment and the farthest centerline point of the loop.

$$Obsv\_Sinuo = \frac{S}{D} \qquad Obsv\_Sinuo\_Allen = \frac{S}{\sum_{i=1}^{N} T_i} \qquad Obsv\_Tortuo = \frac{1}{D}\sum_{i=1}^{N} T_i$$

$$Obsv\_sb\_ext = \frac{1}{N}\sum_{i=1}^{N} L_i \qquad Obsv\_Wavelength = 2 \times \frac{1}{N}\sum_{i=1}^{N} T_i$$

Time: Age of the statistics calculation (usually used as abscissa for graphical representation)

Abstract_Time: Virtual time which is used for Non-expert user calibration (internal use)

Obsv_Min_topo: Minimum elevation of the topography (including water elevation)

Obsv_Nb_cutoff: Total number of self-cutoff occurred since the simulation beginning

Obsv_Nb_chutecutoff: Total number of chute-cutoff occurred since the simulation beginning

Obsv_Nb_av: Total number of avulsion (regional or local) occurred since the simulation beginning

Obsv_Sinuo_Allen: Sinuosity calculated over the channel centerline using Allen formula

Obsv_Tortuo: Tortuosity calculated over the channel centerline

Obsv_sb_ext: Mean sand body extension calculated over the channel centerline

Obsv_sb_ext_on_wl: Mean sand body extension on wavelength parameter ratio calculated over the channel centerline

Obsv_sb_ext_on_obsv_wl: Mean sand body extension on mean observed wavelength ratio calculated over the channel centerline

Obsv_isbx: Observed sand body extension index recalculated from the previous ratio

Obsv_Min_max_depth: Minimum channel maximum depth (due to local slope migration)

Obsv_Max_max_depth: Maximum channel maximum depth (due to local slope migration)

Obsv_Sand_obj: Sand object volume deposited since the simulation beginning

Obsv_###_prop: Proportion of the lithofacies ### (where ### is the abbreviation of one lithofacies, see section §5.1)

Obsv_Sand_prop: Sand proportion (percentage of total deposited volume)

Pred_Sand_prop: Sand proportion forecast estimated by the non-expert user calculator (constant)

Obsv_Aggrad_rate: Aggradation rate (meters/10000 iterations) calculated from mean topography

Pred_Aggrad_rate: Aggradation rate estimated by the non-expert user calculator (constant)

Obsv_Sinuo: Sinuosity calculated over the channel centerline

Pred_Sinuo: Predicted sinuosity (internally used for Non-expert user calibration)

Obsv_Kob: Observed aggradation coefficient (internally used for Non-expert user calibration)

Pred_Kob: Predicted aggradation coefficient (internally used for Non-expert user calibration)

Obsv_Kmig: Observed migration coefficient (internally used for Non-expert user calibration)

Pred_Kmig: Predicted migration coefficient (internally used for Non-expert user calibration)

Obsv_Max_depth: Observed maximum channel depth (can vary due to local slope migration)

Pred_Max_depth: Maximum channel depth parameter (should be constant)

Obsv_Wavelength: Mean wavelength calculated over the channel centerline

Pred_Wavelength: Wavelength parameter (should be constant)

Obsv_Velocity: Observed mean flow velocity

Pred_Velocity: Predicted mean flow velocity

Obsv_Mean_vp: Mean velocity perturbation of the channel centerline

Pred_Mean_vp: Predicted mean velocity perturbation of the channel centerline

$$\mathbf{Obsv\_isbx} = \frac{\frac{\mathbf{L}}{\mathbf{wl}} - \mathbf{sill}}{\mathbf{offset} - \mathbf{sill}} \times \mathbf{100}$$

5.9 Centerline statistics CSV file description (OUT)

Here is the description of the variables dumped in the centerline CSV statistics file by the batch mode. Each file line corresponds to one channel point for a given iteration:

Iteration: Age of the centerline point. All centerline points are dumped upstream to downstream

Dist_previous: Curvilinear distance (in m) between the previous point and this one (first point has a 0m value)

Curv_abscissa: Curvilinear distance (in m) between the channel first point and this one (first point has a 0m value)

Cart_abscissa: Point coordinate abscissa (in m) in the relative system (not geographical system)

Cart_ordinate: Point coordinate ordinate (in m) in the relative system (not geographical system)

Elevation: Point elevation (in m) in the relative system (not geographical system = ignoring grid elevation) without global domain slope contribution

Curvature: Curvature value at point (clockwise orientation is positive)

Vel_perturb: Velocity perturbation at point

Velocity: Mean velocity at point

Mean_depth: Mean channel depth (in m) at point

True_elevation: True point elevation (in m) in the relative system (not geographical system = ignoring grid elevation) but taking into account the global domain slope

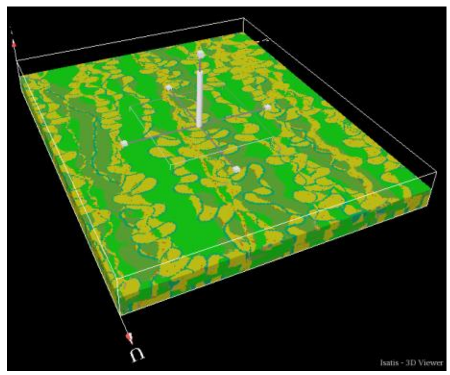
Batch file examples

Here are two examples of batch files and resulted simulated block (Isatis 3D viewer). Look at data directory for more batch file example:

First example:

Launch one sequence of iterations to fill a 3D block of 300x250 nodes up to 10m elevation using the Nexus feature (Fluvial ribbon system with low Net to Gross). Then, generate the lithofacies variable in an F2G ASCII file organized as a 3D grid vertically discretized by 0.2m step with 300x250x150 nodes. **Note**: The grid horizontal mesh (dx=dy=10m) is automatically deduced by the Nexus from the channel width (see section §3.2.1). Here, the user, wants a bigger domain than the default domain size (by setting greater nodes number than the ones proposed by the Nexus).

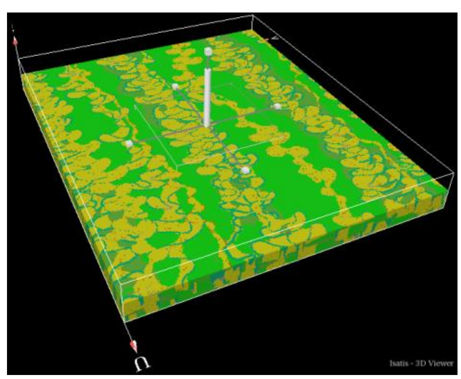
```
[GLOBAL]
F2G_DZ      = 0.2
F2G_FACIES  = 1
[NEW_SEQ]
LAUNCH_IT   = -1
ZUL_TOPO    = 10
NEXUS_HMAX  = 3
NEXUS_ISBX  = 60
NEXUS_SAND  = 30
DOMAIN_NX   = 300
DOMAIN_NY   = 250
```



Second example:

The same as before in verbose mode, but the user wants to override the required maximum channel wave length (which was automatically calculated by the Nexus). Then, he also wants to dump the grain size variable into the F2G ASCII file.

```
[GLOBAL]
VERBOSE          = 1
F2G_DZ           = 0.2
F2G_FACIES       = 1
F2G_GRAIN        = 1
[NEW_SEQ]
LAUNCH_IT        = -1
ZUL_TOPO         = 10
NEXUS_HMAX       = 3
NEXUS_ISBX       = 60
NEXUS_SAND       = 30
CHNL_WAVELENGTH  = 280
DOMAIN_NX        = 300
DOMAIN_NY        = 250
```



If one of the parameter has a wrong value or if there is a consistency warning, a message is displayed in the console. If a parameter is out of its range (section §6.1), the simulation stops.

6 Additional information

6.1 List of parameters (and strict range of values)

When starting a new sequence by using either *launch/launch until/refreshment period/Launch journal file* or the *Batch mode*, an error message may show the parameters out of their range. In that case, the user must change the value of the parameter before launching the new sequence.

Warning: When relevant, fluvial and turbidites ranges are separated by a '/' character). Look at the end of the table for enumerative integer possible values.

Parameters	Keyword	Mini	Default	Max
Non-expert user				
Channel Maximum depth (m)	NEXUS_HMAX	1/10	3/40	$15/10^3$
Sand bodies extension index	NEXUS_ISBX	20	80	160
Net to gross (%)	NEXUS_SAND	1	50/20	99
Update grid size when apply*	NEXUS_GRID	-	1	-
Domain grid **(Except slope, these parameters cannot be changed once the simulation has started)**				
Grid Lags (m) [DX]	DOMAIN_DX	0.01/1.	10/200	+∞
Grid Lags (m) [DY]	DOMAIN_DY	0.01/1.	10/200	+∞
Grid Number of Nodes [NX]	DOMAIN_NX	2	251	5000
Grid Number of Nodes [NY]	DOMAIN_NY	2	201	5000
Grid Location (m) [Longitude]	DOMAIN_OX	-∞	0	+∞
Grid Location (m) [Latitude]	DOMAIN_OY	-∞	0	+∞
Grid Elevation (m)	DOMAIN_ZREF	-∞	0	+∞
Grid Rotation (degrees counterclockwise)	DOMAIN_GRID_DIR	-360	0	360
Slope along Flow Direction	DOMAIN_SLOPE	10^{-4}	$10^{-3}/5.10^{-3}$	0.1
Topography				
Surface Type		-	None	-
Constant Elevation (m)		-∞	0	+∞
Topography File		-	None	-
Operation		-	Upper limit	-
Upper Limit Type******	ZUL_TYPE	0	0	3
Filling Facies		-	UDF	-
Graphical ZCut				
Topography File		-0	None	-
Elevation offset (m)		-∞	0	+∞
Wells				
Relaxation (%)	COND_WELL_RELAX	0	20	100
Closure limit activated*	COND_WELL_CLOSURE_ON	-	0	-
Closure limit (m)	COND_WELL_CLOSURE	0.01/0.1	0.1/1.4	1/10
Stop when all wells honored	COND_WELL_STOP_HONORED	-	0	-

Parameters			**Min**	**Default**	**Max**
Erodibility					
Emap mode			-	Constant	-
Erodibility coefficient (no unit)		EROD_COEF	0	$4.E^{-8}$	$2.E^{-7}$
Offset (no unit)		EMAP_OFFSET	-∞	0	+∞
Channel					
Maximum depth (m)		CHNL_MAX_DEPTH	1/10	3/40	$15/10^{3}$
Width (m)		CHNL_WIDTH	5/100	30/800	$500/10^{4}$
Wavelength (m)		CHNL_WAVELENGTH	10/200	375/4000	$10^{4}/5.E^{4}$
Scale variation distribution***		CHNL_SCALE_DIST	-	0	-
[Constant]	Constant value (%)	CHNL_SCALE _CONST	50	100	150
[Uniform]	Minimum (%)	CHNL_SCALE _MIN	50	80	100
[Uniform]	Maximum (%)	CHNL_SCALE _MAX	100	120	150
[Normal]	Mean (%)	CHNL_SCALE _NORM_MEAN	90	100	110
[Normal]	Standard dev (%)	CHNL_SCALE _NORM_STDEV	0	20	40
[Lognormal]	Mean (%)	CHNL_SCALE _LOGNORM_MEAN	90	100	110
[Lognormal]	Standard dev (%)	CHNL_SCALE _LOGNORM_STDEV	0	20	40
Domain Margin (multiple of the channel width)		CHNL_MARGIN	1	12/5	100
Flow direction (degree clockwise)		CHNL_FLW_DIR	-360	90	360
Avulsions					
Regional Avulsion frequency**		AV_REG_FREQ	-	2	-
[Periodic]	Period (#it)	AV_REG_PERIOD	1	500/470	+∞
[Poisson]	Average period (#it)	AV_REG_POISSON	1	500/470	+∞
Local Avulsion frequency**		AV_LOC_FREQ	-	2	-
[Periodic]	Period (#it)	AV_LOC_PERIOD	1	280/288	+∞
[Poisson]	Average period (#it)	AV_LOC_POISSON	1	280/288	+∞
Levee Breaches During Aggradation*		AV_LV_OB	-	0	-
Probability for transition from Crevasse Splay I to Crevasse Splay II		AV_LOC_PROB1	0	0.5	1
Probability for adding a new Crevasse Splay Channel		AV_LOC_PROB2	0	0.9	1
Don’t generate splays at levee breach*		AV_NO_SPLAY	-	0	-
Equilibrium Profile					
Initial Elevation (m)		AG_EP_INIT_ELEV	-∞	9999	+∞
Change frequency**		AG_EP_FREQ	-	0	-
[Periodic]	Period (#it)	AG_EP_PERIOD	1	24	+∞
[Poisson]	Average period (#it)	AG_EP_POISSON	1	24	+∞

Parameters		**Keyword**	**Min**	**Default**	**Max**
Variation distribution***		AG_EP_DIST	-	0	-
[Constant]	Constant value (m)	AG_EP_CONST	-∞	0.1/1.5	+∞
[Uniform]	Minimum (m)	AG_EP_MIN	-∞	0.07/1.05	+∞
[Uniform]	Maximum(m)	AG_EP_MAX	-∞	0.13/1.95	+∞
[Normal]	Mean (m)	AG_EP_NORM_MEAN	-∞	0.1/1.5	+∞
[Normal]	Standard dev (m)	AG_EP_NORM_STDEV	0	0.03/0.45	+∞
[Lognormal]	Mean (m)	AG_EP_LOGNORM_MEAN	-∞	0.1/1.5	+∞
[Lognormal]	Standard dev (m)	AG_EP_LOGNORM_STDEV	0	0.03/0.45	+∞
Aggradation					
Aggradation type****		AG_TYPE	-	2	-
Occurrence frequency**		AG_OB_FREQ	-	2	-
[Periodic]	Period (#it)	AG_OB_PERIOD	1	24	+∞
[Poisson]	Average period (#it)	AG_OB_POISSON	1	24	+∞
Thickness distribution***		AG_OB_DIST	-	2	-
[Constant]	Constant value (m)	AG_OB_CONST	0.02/0.3	0.1/2	+∞
[Uniform]	Minimum (m)	AG_OB_MIN	0.02/0.3	0.07/1.4	+∞
[Uniform]	Maximum(m)	AG_OB_MAX	0.03/0.4	0.13/2.6	+∞
[Normal]	Mean (m)	AG_OB_NORM_MEAN	0.02/0.3	0.1/1.4	+∞
[Normal]	Standard dev (m)	AG_OB_NORM_STDEV	0	0.03/0.45	+∞
[Lognormal]	Mean (m)	AG_OB_LOGNORM_MEAN	0.02/0.3	0.1/1.4	+∞
[Lognormal]	Standard dev (m)	AG_OB_LOGNORM_STDEV	0	0.03/0.45	+∞
Wetland Proportion (%) **(fluvial)**		AG_OB_PEAT	0	0	99
Pelagic Intensity (m/10^5it) **(turbidites)**		AG_OB_PEL_INT	0	0	100
Draping Facies*****		AG_DRAP	-	DR/PL	-
Thickness Exponential Decrease (m)		AG_EXP_DEC_THICK	1/100	919/29782	+∞
Thickness Decrease Randomized*		AG_RAND_LAMBDA	-	1	-
Levee width (multiple of the channel width)		AG_LV_WIDTH	0.05	6	+∞

****Aggradation type possible values:
- 0 = None
- 1 = Draping or Pelagic
- 2 = Overbank Flow
- 3 = Ghost Migration
- 4 = Erosive

****** Upper limit type possible values:
- 0 = None
- 1 = Neutral
- 2 = Erosive
- 3 = Stratigraphic

** Frequency possible values:
- 0 = Never
- 1 = Periodic
- 2 = Poisson

* Boolean possible values:
- 0 = No
- 1 = Yes

*** Distribution possible values:
- 0 = Constant
- 1 = Uniform
- 2 = Normal
- 3 = Lognormal

***** Draping possible values:
- UDF, DR or PL ID (§5.1)

Parameters	Keyword	Min	Default	Max
Sediment Load (Research partners only)				
Global mean sediment concentration	SED_LOAD_MEAN	0	0.01/0.1	1
Sediment template proportions**	SED_LOAD_VOL	**	**	**
Grain Size (Research partners only)				
Activate variable grain size in PB*	GR_PB	-	0	-
Activate proxy of variable grain size in PB*	GR_PB_PROXY	-	0	-
Activate optimized algorithm of variable grain size in PB*	GR_PB_OPTIM	-	0	-
Calculate initial concentration quickly in Rouse Profile algorithm*	GR_QUICK_C0	-	0	-
Threshold for selecting grain size in Rouse Profile algorithm	GR_THRESHOLD	0.05	0.75	0.95
Minimum grain size class in PB for optimized algorithm	GR_PB_OPTIM_MIN	1	6	15
Maximum grain size class in PB for optimized algorithm	GR_PB_OPTIM_MAX	1	13	15
Power value for optimized grain size formula	GR_PB_OPTIM_ALPHA	0.05	0.25	0.95
Mass Balance (Research partners only) (Experimental)				
Activate mass balance	MASS_BAL_ACTIVE	-	0	-
Mass balance intensity	MASS_BAL_COEF	0	0.2	+∞
Seed (Will change automatically during simulation)				
Seed	SIM_SEED	1	165426	$2^{32} - 1$

Note: To activate Proxy or Optimized algorithm for variable grain size in PB/LAPs, the "GR_PB" parameter must also be set to "1"

* Boolean possible values:
0 = No
1 = Yes

** List of 15 integer values (percentage) separated by ";".
The sum of all values must be equal to 100. Example:

SED_LOAD_VOL = 0; 1; 2; 3; 4; 8;17;25;22; 8; 5; 3; 2; 0; 0

6.2 Usual range of values

When starting a simulation by using either *launch/launch until/refreshment period*, a warning window may show the parameters out of the **usual** range of values. The warning is intended to:

- help the user to choose adequate parameters,
- inform the user that the obtained results may not be realistic. Nevertheless, the simulation can be run with these parameters.

Warning: When relevant, fluvial and turbidites ranges are separated by a '/' character).

<table>
<tr><th colspan="4">Domain slope</th></tr>
<tr><td rowspan="3">Global Domain slope
(Floodplain slope in fluvial context)
(Abyssal plain slope in turbidites context)</td><td colspan="3">Observed values in natural and experimental systems</td></tr>
<tr><td>Warning message if lower</td><td>Usual value</td><td>Warning message if greater</td></tr>
<tr><td>0.0005</td><td>0.001</td><td>0.016/0.05</td></tr>
</table>

<table>
<tr><th colspan="4">Channel geometry</th></tr>
<tr><td rowspan="7">Width to depth relation

From E. Held PhD, 2011 ($w_{bkf} = 10 d_{bkf}$)
W = 10 Hmax = 15 Hmean

Warning if W/Hmean < 12 or > 27
Error if W/Hmean < 10 or > 30</td><td colspan="3">Compiled from natural and experimental observations, the ratio between channel width and depth must be realistic</td></tr>
<tr><td>Width</td><td>Mean depth</td><td>Max depth</td></tr>
<tr><td>30 m</td><td>2 m</td><td>3 m</td></tr>
<tr><td>60 m</td><td>4 m</td><td>6 m</td></tr>
<tr><td>90 m</td><td>6 m</td><td>9 m</td></tr>
<tr><td>900 m</td><td>60 m</td><td>90 m</td></tr>
<tr><td>1800 m</td><td>120 m</td><td>180 m</td></tr>
</table>

<table>
<tr><th colspan="3">Grid size</th></tr>
<tr><td rowspan="3">Grid number of nodes (NX x NY)</td><td colspan="2">Too much grid nodes makes the simulation slow down</td></tr>
<tr><td>Warning message if greater</td><td>Maximum</td></tr>
<tr><td>1 000 000</td><td>25 000 000</td></tr>
</table>

<table>
<tr><th colspan="3">Fluvial Channel wavelength</th></tr>
<tr><td rowspan="7">Width to wavelength relation:

From K. Richards, 1982
$\lambda \approx 12.5$ W (fluvial)
Warning if λ/W < 2.5 or > 16
Error if λ/W < 2 or > 20</td><td colspan="2">Compiled from natural and experimental observations, the ratio between channel width and wavelength must be realistic</td></tr>
<tr><td>Width</td><td>Wavelength</td></tr>
<tr><td>30 m</td><td>375 m</td></tr>
<tr><td>50 m</td><td>625 m</td></tr>
<tr><td>100 m</td><td>1250 m</td></tr>
<tr><td>150 m</td><td>1875 m</td></tr>
<tr><td>200 m</td><td>2500 m</td></tr>
</table>

<table>
<tr><th colspan="3">Turbidites channel wavelength</th></tr>
<tr><td rowspan="7">Width to wavelength relation:

From M. Lemay PhD, 2016
$\lambda = 12.5/2.5\ W = 5\ W$ (turbidites)

Warning if $\lambda/W < 2.2$ or > 9
Error if $\lambda/W < 2$ or > 12</td><td colspan="2">Compiled from natural and experimental observations, the ratio between channel width and wavelength must be realistic</td></tr>
<tr><td>Width</td><td>Wavelength</td></tr>
<tr><td>600 m</td><td>3000 m</td></tr>
<tr><td>900 m</td><td>4500 m</td></tr>
<tr><td>1500 m</td><td>7500 m</td></tr>
<tr><td>2400 m</td><td>12000 m</td></tr>
<tr><td>3000 m</td><td>15000 m</td></tr>
</table>

Relationship between channel width and domain grid	
Channel width / Grid lag	If channel width < lag(x or/and y) Channel discretization will give a dotted line
	Channel width should be ≥ 2 lag (max of x or y)
Channel width / Domain width	If domain is too narrow then meander loops will not be fully displayed on screen.
	Domain width should be ≥ 40 channel width
Channel width / Domain length	If domain is too short then meander loops will not be fully displayed on screen.
	Domain length should be ≥ 50 channel width

Relationship between exponential thickness decrease and levee width	
Exponential thickness decrease / Levee width	To be sure that some overbank will be deposited beyond the levee
	Exponential thickness decrease should be > Levee width / 6

Relationship between domain margin and domain size	
Domain margin / Domain width	If the margin is too big toward the domain width, the simulation will be slow down for nothing (no deposit)
	Domain margin should be ≤ domain width
Domain margin / Domain length	If the margin is too big toward the domain length, the simulation will be slow down for nothing (no deposit)
	Domain margin should be ≤ domain length

6.3 Some sensibility analysis

In the following we are presenting the major role of parameters. As there are many cross influences, the table is just intended to show the influence of the variation of one parameter, the others remaining unchanged.

	Process influenced	Consequence
Global Domain slope	Channel migration, Length of meander loops	Steeper slope slightly increases the velocity of migration and the length of meander loops
Erodibility	Channel migration	Migration is faster with larger erodibility, favoring sand, its horizontal connectivity, sinuosity and mud plug (fluvial systems) or hemipelagic plug (turbidites systems).
Channel width	Channel migration	Migration is faster with larger width, favoring sand, its horizontal connectivity, sinuosity and mud plug / hemipelagic plug.
Channel depth	Channel migration	Channel depth favors sand, its vertical connectivity, wavelength and mud plug / hemipelagic plug
Equilibrium profile (EP)	Aggradation	When EP elevation is just above domain, aggradation is reduced, favoring sand and horizontal connectivity. An EP elevation high above domain favors aggradation, shale, and vertical connectivity of sand.
	Incision	When EP is below domain
Overbank flows (OBF) occurrence	Aggradation	Frequent OBF favor aggradation, shale, and vertical connectivity of sand
	Incision	Frequent OBF favor incision since test on accommodation are made at each OB event.
Overbank flows thickness	Aggradation	High OBF intensity favors aggradation, shale, and vertical connectivity of sand
Overbank thickness parameter	Aggradation	High OBF intensity favor aggradation, shale, and vertical connectivity of sand
Avulsion (regional or local)	Aggradation	High frequency of avulsions decreases the rate of aggradation of the domain
	Meandering pattern & mud plug / hemipelagic plug frequency	High frequency of avulsions gives less time to meander loops to develop (ribbon like channels with small sinuosity, and less mud plugs or hemipelagic plugs).
	Proportion of sand	Avulsion favors sedimentation over the whole domain and increases a little bit the sand proportion as several channel deposits are to be at the same elevation.

6.4 Additional hints

Wavelength:

The wavelength λ of the channel is, in the model, proportional to the channel maximum depth H_{max}, approximately: $\lambda \simeq 125\,H_{max}$ (for fluvial systems) and $\lambda = 50\,H_{max}$ (for turbidites systems). The input parameter corresponds to the maximal wavelength of the channel just before the first meander cutoff.

Sinuosity:

The actual sinuosity (Allen 1984 formula) is output in the Status Bar in the bottom of the Interface Window. When the meanders are developing, the sinuosity increases with:

Fluvial: $\dfrac{w\,E_0}{H^2 f_{av}}\sqrt{\dfrac{g\;I_0}{c_f}}$ Turbidites (more tortuous): $\dfrac{w\,E_0}{H^2 f_{av}}\sqrt{\dfrac{g\,RC\,I_0}{c_f}}$

Where:

- w = channel width
- H = channel mean depth
- E_0 = mean erodibility coefficient
- I_0 = domain global slope
- g = 9.81 (the gravity)
- R = 1.65 (reduce density for quartz) (turbidites only)
- C = global mean sediment concentration (turbidites only)
- C_f = friction coefficient (internally computed)
- f_{av} = frequency of avulsions (not a direct parameter in Flumy, as it must take into account local avulsions in addition to regional ones (see§3.6).

For a given channel geometry, the meanders develop and the sinuosity increases when the avulsion period(s) is larger.

Sand proportion (N/G):

The Net to Gross forecast is computed for Point Bars or LAPs only (not Channel Lag). When applying Nexus parameters, the forecast N/G value displayed is equal to the required N/G. It is output in the Status Bar in the bottom of the Interface Window.

Aggradation rate:

The aggradation rate forecast is output in the Status Bar in the bottom of the Interface Window.

Erodibility and lateral migration:

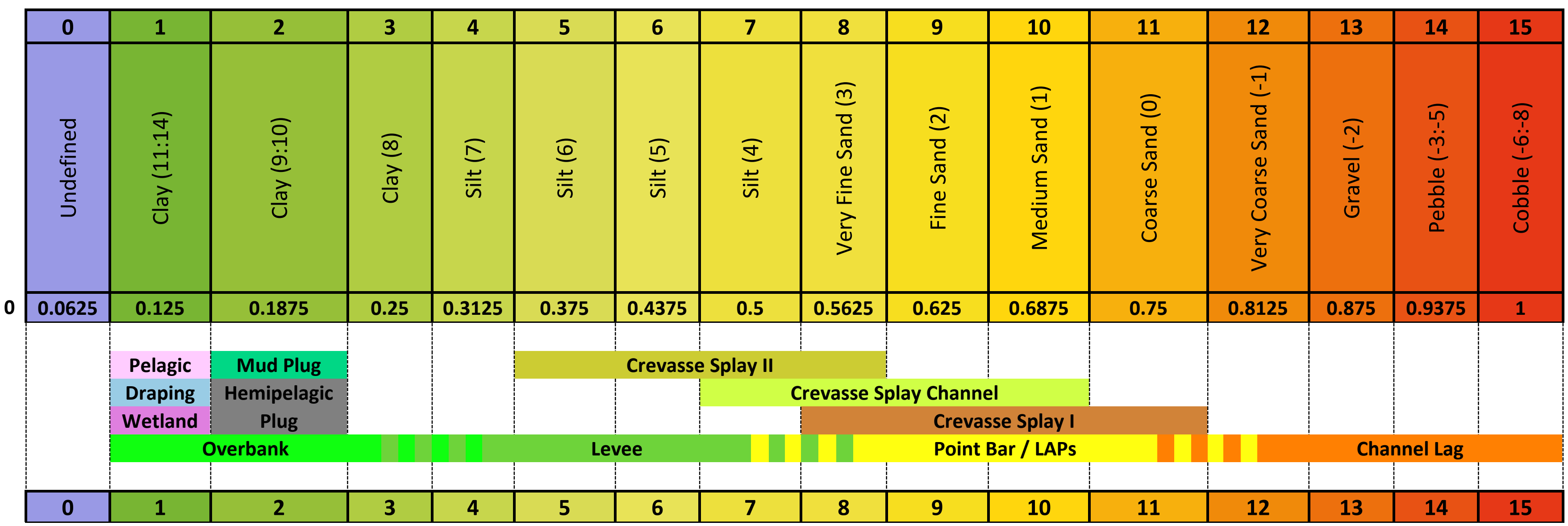
The default erodibility coefficient value of $4.E^{-8}$ has been found to match lateral migration observed on contemporary systems. A velocity perturbation of 1m/s then gives a mean migration of $4.E^{-8}$ meters per second, i.e. 0.6 meters per year at meander apex or 0.32 meters per year for the whole channel (Fluvial).

6.5 Lithofacies and Grain Size

Lithofacies identifiers and their default grain size class:

Lithofacies ID	13	12	11	10	9	8	7	6	5	4	3	2	1	0
Lithofacies	Pelagic	Draping	Wetland	Hemipela. Plug	Mud Plug	Overbank	Levee	Crevass Splay II	Crev. Spl. Channel	Crevasse Splay I	Sand Plug	Point Bar / LAPs	Channel Lag	Undefined
Abbreviation	PL	DR	WL	HP	MP	OB	LV	CS2	CCH	CS1	SP	PB	CL	UDF
Default Grain Size Class	1	1	1	2	2	3	6	7	8	9	9	10	13	0
Default ϕ Class	11:14	11:14	11:14	9:10	9:10	8	5	4	3	2	2	1	-2	NA

Grain size classes and lithofacies ranges:



Note: Overbank, Levee, Point Bar / LAPs and Channel Lag grain size intervals depend on the “Variable Grain Size in PB/LAPs” algorithm and the sediment template chosen by the user (Research Partners only – see §3.8). Sand Plug grain size class is currently fixed. Its value is determined in accordance with the interval of Point Bar / LAPs.

For users who wants to work with less than 13 lithofacies (for post process purpose by instance), the Flumy lithofacies can be regrouped by categories in that way (according the number of groups you want):

<table>
<tr><th>Nb groups</th><th>PL</th><th>DR</th><th>WL</th><th>HP</th><th>MP</th><th>OB</th><th>LV</th><th>CS2</th><th>CCH</th><th>CS1</th><th>SP</th><th>PB</th><th>CL</th></tr>
<tr><td>2</td><td colspan="9">OB</td><td colspan="4">PB</td></tr>
<tr><td>3</td><td colspan="6">OB</td><td colspan="3">LV</td><td colspan="4">PB</td></tr>
<tr><td>7</td><td>PL</td><td>DR</td><td>WL</td><td colspan="3">OB</td><td colspan="3">LV</td><td colspan="3">PB</td><td>CL</td></tr>
<tr><td>10</td><td>PL</td><td>DR</td><td>WL</td><td colspan="2">MP</td><td>OB</td><td colspan="2">LV</td><td>CCH</td><td>CS1</td><td colspan="2">PB</td><td>CL</td></tr>
<tr><td>13</td><td>PL</td><td>DR</td><td>WL</td><td>HP</td><td>MP</td><td>OB</td><td>LV</td><td>CS2</td><td>CCH</td><td>CS1</td><td>SP</td><td>PB</td><td>CL</td></tr>
</table>

Wetland: Only in fluvial context

Hemipelagic Plug: Only for turbidites systems, the **Hemipelagic Plug** lithofacies is deposited within the abandoned channel after a cutoff, an avulsion or during Ghost Migration “aggradation”

Mud Plug: Only for fluvial systems, the Mud Plug lithofacies is deposited within the abandoned channel after a cut off or an avulsion

Draping: Only for fluvial systems, the Draping lithofacies can be used to simulate deposits during a marine incursion for example

Pelagic: Only for turbidites systems, the Pelagic lithofacies can be used to simulate pelagic fine deposits away from the turbidites channel.

Point Bar / LAPs: This lithofacies is named Point Bar in fluvial context and LAPs (Lateral Accretion Packages) in turbidites context. Its abbreviation and its identifier stay PB in both contexts.

Flumy facies and color scales

Hint: Copy this page; cut the image and use it as a bookmark

FLUMY™

ARMINES | MINES PARIS | PSL

Lithofacies			Grain
Id	Abr.	Full Name	ϕ
0	UDF	Undefined	-
1	CL	Channel Lag	-8:0
2	PB	Point Bar / LAPs	-1:4
3	SP	Sand Plug	0:3
4	CSI	Crevasse Splay I	0:3
5	CCH	Crev. Splay II Chan.	1:4
6	CSII	Crevasse Splay II	3:6
7	LV	Levee	3:6
8	OB	Overbank	7:14
9	MP	Mud Plug (flu)	9:10
10	HP	Hemipel. Plug (tur)	9:10
11	WL	Wetland (flu)	11:14
12	DR	Draping (flu)	11:14
13	PL	Pelagic (tur)	11:14

Grain size / ϕ class		
15	-6:-8	Cobble
14	-3:-5	Pebble
13	-2	Gravel
12	-1	Very Coarse Sand
11	0	Coarse Sand
10	1	Medium Sand
9	2	Fine Sand
8	3	Very Fine Sand
7	4	Silt
6	5	Silt
5	6	Silt
4	7	Silt
3	8	Clay
2	9:10	Clay
1	11:14	Clay
0	NA	Undefined

Erod: 0, $2.e^{-8}$, $4.e^{-8}$, $5.e^{-7}$

H_{max}: Channel Maximum Depth

I_{sbx}: Sandbodies Extension Index

NG: Net-to-Gross (Sand Prop.)

6.6 Some references

6.6.1 Articles

Leopold, Wolman, Miller, 1964: Fluvial processes in geomorphology. Freeman and Company.

Sun, 1996: A simulation model for meandering rivers. Water Resources Research 32(9).

Karssenberg, Törnqvist, Bridge, 2001: Conditioning a process-based model of sedimentary architecture to well data. Journal of Sedmientary Research, Vol 71

Bridge, 2003: Rivers and Floodplains, Blackwell Publishing, 491p.

Cojan, Isabelle & Rivoirard, Jacques & Galli, Alain. (2008). Process-Based Stochastic Modelling: Meandering Channelized Reservoirs. International Association of Sedimentologists. 144. 10.1002/9781444303131.ch5.

Bubnova, Anna & Ors, Fabien & Rivoirard, Jacques & Cojan, Isabelle & Romary, Thomas. (2019). Automatic Determination of Sedimentary Units from Well Data. Mathematical Geosciences. 52. 10.1007/s11004-019-09793-w.

Lemay, Martin & Grimaud, Jean-Louis & Cojan, Isabelle & Rivoirard, Jacques & Ors, Fabien. (2020). Geomorphic variability of submarine channelized systems along continental margins: Comparison with fluvial meandering channels. Marine and Petroleum Geology. 115. 104295. 10.1016/j.marpetgeo.2020.104295.

Grimaud, J.-L., Ors, F., Lemay, M., Cojan, I., Rivoirard, J.: Preservation and Completeness of fluvial meandering deposits influenced by channel motions and overbank sedimentation. J. Geophys. Res. Earth Surface, 2021–006435

Martin Lemay, Jean-Louis Grimaud, Isabelle Cojan, Jacques Rivoirard, Fabien Ors, et al.. Submarine channel stacking patterns controlled by the autogenic 3D kinematics of meander bends. The Geological Society, London, Special Publications, 2024, 540 (1), ⟨10.1144/SP540-2022-143⟩. ⟨hal-04082222⟩

Ferdinand Bhavsar, Nicolas Desassis, Fabien Ors, Thomas Romary. A stable deep adversarial learning approach for geological facies generation. *Computers & Geosciences*, 2024, 190, pp.105638. ⟨10.1016/j.cageo.2024.105638⟩. ⟨hal-04751800⟩

6.6.2 PhDs

Lopez, 2003: Modélisation de Réservoirs Chenalisés Méandriformes, Approche Génétique et Stochastique., Ph. D. Thesis Ecole Nationale Supérieure des Mines de Paris, 254 p.

Benjamin Grappe. Modèles d'écoulement à surface libre pour la simulation à long terme de la migration des systèmes méandriformes. Sciences de la Terre. Ecole Nationale Supérieure des Mines de Paris, 2014. Français. ⟨NNT : 2014ENMP0008⟩. ⟨pastel-01038004⟩

Martin Lemay. Transposition à l'environnement turbiditique chenalisé d'un modèle de systèmes fluviatiles méandriformes pour la modélisation de réservoirs. Géomorphologie. Université Paris sciences et lettres, 2018. Français. ⟨NNT : 2018PSLEM033⟩. ⟨tel-03118435⟩

Anna Bubnova. On the conditioning of process-based channelized meandering reservoir models on well data. Earth Sciences. Université Paris sciences et lettres, 2018. English. ⟨NNT : 2018PSLEM055⟩. ⟨tel-02173727⟩

Alan Troncoso. Conditional simulations of reservoir models using Sequential Monte-Carlo methods. Modeling and Simulation. Université Paris sciences et lettres, 2022. English. ⟨NNT : 2022UPSLM055⟩. ⟨tel-04077499⟩

7 User's comments

Any comments are welcome by sending an email to flumy@mines-paristech.fr.

If problems remain, send us an email by joining the Project file (or the set of journal files and input files) and explaining the sequence of operations that permits to reproduce the issue.

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- The FLUMY research team will do all his best to answer you in a correct delay. But remind that the Free and Premium version do not include any technical support guarantee.