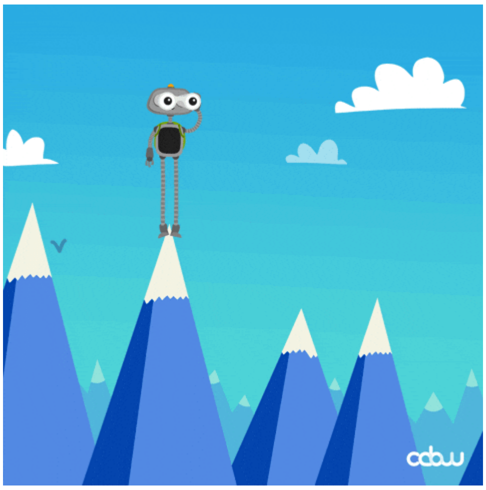
🏔️ Avalanche Scenario Model Chain (2025-11 Update)



⚠️ Handle with care — work in progress

Overview

- The Avalanche Scenario Model Chain is developed with in EUREGIO Project CAIROS
- The Avalanche Scenario Model Chain steps are the preprocessing for the Avalanche Scenario Mapper
- The Avalanche Scenario Model Chain is a orchestrates the full automated avalanche modelling workflow — from raw terrain data to structured delineation of potential release areas (PRAs) and size dependent avalanche simulations.
  - Main entrypoint: cairosModelChain/runCairos.py
  - Orchestrates 15 workflow steps (Step 00–15)
  - Integrates AvaFrame (FlowPy engine) in editable mode via Pixi
  - Manages directory trees, inputs, and processing configurations automatically

---

Cairos/ Repository layout

```
../Cairos/
├── .git/                 # Git version control data (do not edit manually)
├── .pixi/                # Local Pixi environments & virtual dependencies
├── .virtual_documents/   # Temporary Jupyter virtual document links
├── .vscode/              # VS Code project configuration (settings, tasks)
├── __init__.py           # Marks this directory as a Python package (optional)
├── cairosMapper/         # Scenario mapping, visualization, and post-processing tools
├── cairosModelChain/     # Main CAIROS model chain — full automated workflow (Steps 00–15)
├── docs/                 # Project documentation, specs, and design notes
├── notebooks/            # Jupyter notebooks (experimental workflows, testing)
├── pixi.lock             # Pixi environment lockfile (exact dependency versions)
├── pyproject.toml        # Pixi + Python project manifest (dependencies, tasks)
└── testData/             # Sample or test datasets for development and validation
```

Cairos/cairosModelChain Repository layout

```
Cairos/
└── cairosModelChain/           # Main Python package (modular CAIROS workflow)
    │
    ├── cairosCfg.ini           # Default configuration (global)
    ├── local_cairosCfg.ini     # Local project override (preferred for runs)
    │
    ├── runCairos.py            # Main driver (Steps 00–15, orchestrates workflow)
    ├── runInitWorkDir.py       # Step 00 – Initialize project directory + logs
    ├── runPlots.py             # Optional plotting entrypoint (not in main workflow)
    │
    ├── com1PRA/                # Step 01–08: Potential Release Area (PRA) workflow
    │   ├── praDelineation.py           # Step 01 – Derive PRA field from DEM + forest
    │   ├── praSelection.py             # Step 02 – Apply thresholds, aspect + region masks
    │   ├── praSubCatchments.py         # Step 03 – Delineate subcatchments (WhiteboxTools)
    │   ├── praProcessing.py            # Step 04 – Clean and polygonize PRA masks → GeoJSON
    │   ├── praSegmentation.py          # Step 05 – Intersect PRAs with subcatchments → GeoJSON
    │   ├── praAssignElevSize.py        # Step 06 – Classify PRAs by elevation + area size
    │   ├── praPrepForFlowPy.py         # Step 07 – Prepare PRAs for FlowPy simulation
    │   ├── praMakeBigDataStructure.py  # Step 08 – Build aggregated FlowPy input tree
    │   ├── bottleneckSmoothing.py      # Not used ATM
    │   └── __init__.py
    │
    ├── com2AvaDirectory/       # Step 09–15: FlowPy & Avalanche Directory chain
    │   ├── avaDirBuildFromFlowPy.py    # Step 13 – Convert FlowPy results to AvaDirectory
    │   ├── avaDirType.py               # Step 14 – Build scenario type structure (dry/wet)
    │   ├── avaDirResults.py            # Step 15 – Aggregate final scenario results/maps
    │   └── __pycache__/
    │
    ├── in1Utils/               #Core utilities (shared across all modules)
    │   ├── cfgUtils.py          # Config handling, GDAL/PROJ setup, manifest writers
    │   ├── dataUtils.py         # Raster/vector I/O, compression, helper functions
    │   ├── plottingUtils.py     # Plotting helpers (matplotlib/geopandas)
    │   ├── workflowUtils.py     # Workflow flag parsing, discovery of FlowPy leaves
    │   └── __pycache__/
    │
    ├── in2Parameter/           # Parameterization + FlowPy integration
    │   ├── compParams.py        # Step 09/11 – Compute size-dependent FlowPy parameters
    │   ├── sizeParameters.py    # Parameter range management for simulation inputs
    │   ├── muxi.py              # Additional parameter computation utilities
    │   └── __pycache__/
    │
    ├── outPlots/               # Optional plotting layer
    │   ├── out1SizeParameter.py # Plot FlowPy parameter outputs (alpha/umax/etc.)
    │   ├── plotFunctions.py     # Common plotting logic
    │   └── __pycache__/
    │
    ├── helpBash/               # Bash-level helpers
    │   └── printIni             # Quick print of current INI (for terminal debugging)
    │
    ├── helpPy/                 # Python-level diagnostic helpers
    │   ├── showDir.py           # Pretty-print project folder tree
    │   ├── tifDiff.py           # Compute raster difference between runs
    │   └── __pycache__/
    │
    └── __pycache__/
│
└── jupyterLaps/                # Jupyter Lab notebooks (manual & prototype workflows)
    ├── 12-0_makeScenarioDirFromFlowPy.ipynb # Step 12 prototype – Scenario directory builder
    ├── 13-0_makeScenarioDir.ipynb           # Step 13 prototype – Scenario directory builder
    ├── 14-5_makeScenarioMapsRobo.ipynb      # Step 14 automation – Avalanche Scenario Roboter
    ├── WIN-14-5_makeScenarioMapsRobo.ipynb  # Windows-compatible variant
    ├── 90-5_prepForest.ipynb                # Preprocessing – Forest raster generation
    └── ...                                 # Other utility notebooks from CAIROS legacy
```

Quick start (Linux)

1. Minimal system prerequisites

- Install only the flexible, OS-level tools system-wide.
- All project dependencies (AvaFrame, CAIROS, GDAL, NumPy, etc.) will live inside Pixi-managed environments.
- System Python (python3.10 or 3.11 on Ubuntu) is kept minimal — used only for tools like VS Code, Pixi bootstrap, etc.
- CAIROS and AvaFrame never touch system Python → they live in isolated .pixi/envs/* environments.
- Optional:
  - Install VS Code for editing, debugging, and integrated terminals: https://code.visualstudio.com/download

```
# System-wide basics
sudo apt update
sudo apt install -y git python3 python3-pip

# Install Pixi (recommended via installer script)
curl -fsSL https://pixi.sh/install.sh | bash
# restart your shell so `pixi` is in PATH
```

2) Install AvaFrame (temporary: dev branch)

```
# choose your workspace directory, e.g. ~/Documents/Applications
cd ~/Documents/Applications

# clone AvaFrame
git clone https://github.com/avaframe/AvaFrame.git
cd AvaFrame
# checkout branch until next release (ATM)
git checkout PS_FP_outputRelInfo
```

Two options from here:

Option A: Use AvaFrame via CAIROS

- Nothing else required — CAIROS links AvaFrame in editable mode automatically through Pixi.
- Skip the manual build step.

Option B: Use AvaFrame standalone

- If you want to run AvaFrame directly (outside CAIROS), you need to compile the Cython parts:

```
# set the avalanche dir in local_avaFrameCfg.py and apply your settungs to
local_com4FlowPyCfg.ini
cd AvaFrame
pixi shell
python setup.py build_ext --inplace
# checkout branch until next release (ATM)
git checkout PS_FP_outputRelInfo
pixi shell --environment dev
cd AvaFrame/avaframe
python runCom4FlowPy.py
```

- Repeat this step whenever Cython code changes or after pulling new updates.

3) Install CAIROS repo

```
# choose your workspace directory next to AvaFrame
cd ~/Documents/Applications
git clone <your-cairos-repo> Cairos    # !!!!!!
cd Cairos
```

4) Setup CAIROS ModelChain env

```
# Clean any old envs if something is corrupted
rm -f pixi.lock
pixi clean -e dev || true
#pixi clean cache || true
rm -rf .pixi

# Install dev env (with local AvaFrame)
pixi install -e dev

# Check that CAIROS uses your local AvaFrame
pixi shell -e dev
python -c "import avaframe, pathlib; print(pathlib.Path(avaframe.__file__).resolve())"
> .../Documents/Applications/AvaFrame/avaframe/__init__.py
```

5) Configure

Copy the defaults and edit the **local** copies:

```
# CAIROS ModelChain config
cd Cairos/cairosModelChain
cp cairosCfg.ini local_cairosCfg.ini

# AvaFrame config
cd ../AvaFrame/avaframe
cp avaframeCfg.ini local_avaframeCfg.ini

# AvaFrame FlowPy config
cd ../AvaFrame/avaframe/com2FlowPy
cp flowPyAvaFrameCfg.ini local_flowPyAvaFrameCfg.ini
```

Running cairos ...

- Fill in `local_cairosCfg.ini` → `[MAIN]` with your project info and input filenames (the files must exist in the run's `00_input/` folder once the project is initialized).
- Adapt your local_*Cfg.ini's
- Details TBA....

```
cd Cairos/cairosModelChain #location of runCairos.py
pixi run -e dev cairos
```

- after first initialzation run you see:

```
INFO:__main__:

       ============================================================================
          ... Start main driver for CAIROS model chain (2025-11-06 13:11:24) ...
```

```
    ============================================================================

INFO:__main__: Config file:
/home/christoph/Documents/Applications/Cairos/cairosModelChain/local_cairosCfg.ini
INFO:__main__: Step 00: Initializing project...
INFO:runInitWorkDir: cairosDir:
/media/christoph/Daten/Cairos/ModelChainProcess/cairosTutti/pilotSellaTest/alpha32_3_umax8_18_ma
xS5_
INFO:runInitWorkDir: ...cairosDir: ./.
INFO:runInitWorkDir: ...inputDir: ./00_input
INFO:runInitWorkDir: ...praDelineationDir: ./01_praDelineation
INFO:runInitWorkDir: ...praSelectionDir: ./02_praSelection
INFO:runInitWorkDir: ...praBottleneckSmoothingDir: ./03_praBottleneckSmoothing
INFO:runInitWorkDir: ...praSubcatchmentsDir: ./04_praSubcatchments
INFO:runInitWorkDir: ...praProcessingDir: ./05_praProcessing
INFO:runInitWorkDir: ...praSegmentationDir: ./06_praSegmentation
INFO:runInitWorkDir: ...praAssignElevSizeDir: ./07_praAssignElevSize
INFO:runInitWorkDir: ...praPrepForFlowPyDir: ./08_praPrepForFlowPy
INFO:runInitWorkDir: ...praMakeBigDataStructureDir: ./09_flowPyBigDataStructure
INFO:runInitWorkDir: ...flowPySizeParametersDir: ./09_flowPyBigDataStructure
INFO:runInitWorkDir: ...flowPyRunDir: ./09_flowPyBigDataStructure
INFO:runInitWorkDir: ...flowPyResToSizeDir: ./10_flowPyOutput
INFO:runInitWorkDir: ...flowPyOutputDir: ./10_flowPyOutput
INFO:runInitWorkDir: ...avaDirDir: ./11_avaDirectoryData
INFO:runInitWorkDir: ...avaDirTypeDir: ./12_avaDirectory
INFO:runInitWorkDir: ...avaDirResultsDir: ./12_avaDirectory
INFO:runInitWorkDir: ...avaDirIndexDir: ./12_avaDirectory
INFO:runInitWorkDir: ...avaScenMapsDir: ./13_avaScenMaps
INFO:runInitWorkDir: ...avaScenPreviewDir: ./14_avaScenPreview
INFO:runInitWorkDir: ...plotsDir: ./91_plots
INFO:runInitWorkDir: ...gisDir: ./92_GIS
INFO:__main__: Step 00: Project initialized in 0.01s
INFO:__main__: Step 00: Log file: runCairos_20251106_131124.log
ERROR:__main__: Step 00: Required input files are missing in ./00_input:
ERROR:__main__:    - DEM=10DTM_pilotSellaTest.tif
ERROR:__main__:    - FOREST=10nDOM_binAgg_100_pilotSellaTest_forestCom.tif
ERROR:__main__:    - BOUNDARY=regionPilotSella.geojson
ERROR:__main__:

          ... Please provide the required input files and run again ...
```

- Copy or prepare these files into your project's `00_input/` directory.
- Their filenames must match the entries defined in your INI's `[MAIN]` section e.g:

```
[MAIN]
DEM      = 10DTM_pilotSellaTest.tif
FOREST   = 10nDOM_binAgg_100_pilotSellaTest_forestCom.tif
BOUNDARY = regionPilotSella.geojson
COMMISSIONREGION = commRegionExtentPilotSella.geojson
COMMISSIONS = commissionsEuregio.geojson
AVAREPORT = avaReportMicroRegions.geojson
```

- run again...

```
cd Cairos/cairosModelChain #location of runCairos.py
pixi run -e dev cairos
```

- when all input is provided and checked you will see:

```
...
INFO:__main__: Step 00: Project initialized in 0.01s
INFO:__main__: Step 00: Log file: runCairos_20251106_113707.log
INFO:__main__: Step 00: Input DEM validated: nodata + CRS check done.
INFO:__main__: Step 00: Input FOREST validated: nodata + CRS check done.
INFO:__main__: Step 00: All raster inputs validated: DEM + FOREST nodata/CRS checked and safe.
INFO:__main__: All inputs complete:
/media/christoph/Daten/Cairos/ModelChainProcess/cairosTutti/pilotSellaTest/alpha32_3_umax8_18_ma
xS5/00_input

       ============================================================================
               ... LET'S KICK IT - AVALANCHE SCENARIOS in 3... 2... 1...
       ============================================================================
...
```

DEM-driven consistency rule

- **NOTE**: All rasters (REL, RELID, ALPHA, UMAX, EXP, Outputs) must inherit:
  - CRS, transform, and nodata from `[MAIN].DEM`
- identical width/height for raster alignment
- **Any deviation triggers a warning during preprocessing or FlowPy parameterization.**

Running a single leaf

- Instead of enumerating the BigData tree, set in `[WORKFLOW]`:

```
#test only
makeSingleTestRun = False
singleTestDir = pra030secE-1800-2000-4
```

- With this Step 09-15 will parameterize **that** leaf (`pra030secE-1800-2000-4`).

What the workflow does (Steps 00–15)

Step 00 — Initialize project folders

- Creates the standardized CAIROS run directory structure based on `[MAIN]` in your `cairosCfg.ini`.
  - Each run lives in its own tree:

```
<workDir>/<project>/<ID>/
├── 00_input/                ← User-provided inputs (DEM, FOREST, BOUNDARY, etc.)
│
├── 01_praDelineation/       ← Step 01: Derived PRA raster field + terrain layers
(slope/aspect)
├── 02_praSelection/         ← Step 02: Filtered PRA rasters by threshold, elevation, and
aspect
│
├── 03_praBottleneckSmoothing/  ← Not used ATM
├── 04_praSubcatchments/     ← Step 03: Subcatchment rasters + polygons (via WhiteboxTools)
├── 05_praProcessing/        ← Step 04: Cleaned & polygonized PRA masks (GeoJSON)
├── 06_praSegmentation/      ← Step 05: PRAs segmented by subcatchments (GeoJSON)
├── 07_praAssignElevSize/    ← Step 06: PRAs classified by elevation bands and size
├── 08_praPrepForFlowPy/     ← Step 07: Prepared PRA inputs for FlowPy (GeoJSON + metadata)
├── 09_flowPyBigDataStructure/  ← Step 08: FlowPy BigData structure (SizeN/{dry,wet}/Inputs
tree)
│
├── 10_flowPyOutput/         ← Steps 09–12: FlowPy results, size aggregation, compression
```

```
│
├── 11_avaDirectoryData/        ← Step 13: Raw AvaDirectory data collected from FlowPy outputs
├── 12_avaDirectory/            ← Steps 14–15: Unified AvaDirectoryType & Results (CSV, GeoJSON,
Parquet)
│
├── 13_avaScenMaps/             ← Step 16 (planned): Automated avalanche scenario map generation
├── 14_avaScenPreview/          ← Optional previews for avalanche scenarios
│
├── 91_plots/                   ← Diagnostic plots, QA visualizations, and size parameter
distributions
└── 92_GIS/                     ← GIS-ready exports (merged shapefiles, GeoPackages, layers)
```

Log file

- Each workflow run automatically creates a timestamped log file:

  ```
  <workDir>/<project>/<ID>/runCairos_YYYYMMDD_HHMMSS.log
  ```

Steps 01–08 — PRA processing (`com1PRA`)

- The PRA chain defines the complete pre-processing stage of CAIROS — from delineating potential release areas to creating structured, FlowPy-ready input datasets.
- Each step builds directly on the previous one, and together they establish the BigData foundation used in later FlowPy and AvaDirectory processing.

Step	Module	Main INI Sections	Description
01	`com1PRA/praDelineation.py`	`[praDELINEATION]`, `[MAIN]`	Detects potential release areas (PRA) from DEM and slope; outputs base PRA raster + aspect layer.
02	`com1PRA/praSelection.py`	`[praSELECTION]`	Applies filtering thresholds (e.g. area, elevation, slope) to select relevant PRA regions.
03	`com1PRA/praSubCatchments.py`	`[praSUBCATCHMENTS]`	Generates subcatchment polygons using WhiteboxTools; prepares catchment delineations.
04	`com1PRA/praProcessing.py`	`[praPROCESSING]`	Cleans, dissolves, and vectorizes PRA rasters; outputs unified PRA GeoJSONs.
05	`com1PRA/praSegmentation.py`	`[praSEGMENTATION]`	Intersects PRAs with subcatchments to segment them into manageable units.
06	`com1PRA/praAssignElevSize.py`	`[praASSIGNELEV]`, `[praSEGMENTATION]`	Assigns elevation bands and size classes to each segmented PRA.
07	`com1PRA/praPrepForFlowPy.py`	`[praPREPFORFLOWPY]`, `[WORKFLOW]`	Converts PRAs into FlowPy input-ready GeoJSONs and ensures consistent CRS and naming.
08	`com1PRA/praMakeBigDataStructure.py`	`[praMAKEBIGDATASTRUCTURE]`, `[WORKFLOW]`	Aggregates all PRA data (rasters + GeoJSONs) into the structured BigData tree.

- **NOTE**: The table lists only the primary INI sections.

- Several steps internally reference additional parameters (e.g. from `[MAIN]`, `[avaPARAMETER]`, or `[praSEGMENTATION]`).

Output of Step 08 — FlowPy BigData Tree

- Each case (PRA × size × elevation band) is written into a **BigData tree** designed to match AvaFrame's expected input structure for FlowPy runs.

```
09_flowPyBigDataStructure/
└── BnCh2_subC500_100_5_sizeF500/         ← Root: parameterized subcatchment/size case
    ├── pra030secS-2000-2200-3/           ← Case: single PRA scenario (aspect/elev/size)
    │   ├── Size2/
    │   │   ├── dry/
    │   │   │   ├── Inputs/
    │   │   │   │   ├── REL/              ← Rasterized release masks (PRA polygons)
    │   │   │   │   │   ├── pra030secS-2000-2200-3-praAreaM.tif
    │   │   │   │   │   └── pra030secS-2000-2200-3-praBound.tif
    │   │   │   │   ├── RELID/            ← PRA IDs encoded as integer rasters
    │   │   │   │   │   └── pra030secS-2000-2200-3-praID.tif
    │   │   │   │   ├── RELJSON/          ← PRA geometry + metadata (GeoJSON)
    │   │   │   │   │   └── pra030secS-2000-2200-3.geojson
    │   │   │   │   ├── ALPHA/            ← Computed FlowPy input (Step 09)
    │   │   │   │   ├── UMAX/
    │   │   │   │   ├── EXP/
    │   │   │   │   └── DEM.tif           ← Optional local DEM reference (if enabled)
    │   │   │   └── Outputs/
    │   │   │       └── com4FlowPy/       ← FlowPy outputs (Step 10)
    │   │   └── wet/
    │   └── Size3/
    │       └── dry/...
    └── pra030secN-2200-2400-5/...
```

Terminology & Naming Conventions

Term	Description
Root	The main parameter-case folder (defined by `[praPROCESSING]`, `[praSUBCATCHMENTS]`, `[praSEGMENTATION]`). Example: `BnCh2_subC500_100_5_sizeF500` (constructed from default PRA parameters).
Case	A single PRA release scenario, combining PRA ID, elevation range, and size. Formed from `[praDELINEATION]`, `[praSELECTION]`, `[praASSIGNELEV]`, `[avaPARAMETER]`. Example: `pra030secS-2000-2200-3`.
SizeN	Size class folder derived from the case's maximum potential size (`[avaPARAMETER]`.sizeRange). Example: `pra...-4` → `Size2`, `Size3`, `Size4`.
Scenario	Flow regime folder: either `dry/` or `wet/`.
Leaf	The lowest-level folder — `SizeN/scenario/` — containing `Inputs/` and `Outputs/` subdirectories for FlowPy processing.

- **NOTE**: No `Size5` for `wet/` Avalanches!!!

Summary:

- Steps 01–08 create the foundation of the CAIROS workflow.
- They transform raw terrain and PRA data into a fully structured **BigData input tree**, ready for parameterization (Step 09) and FlowPy simulations (Step 10).

Steps 09–15 — FlowPy and AvaDirectory Chain

Step 09 — Parameterization (per leaf)

- Code: `in2Parameter/compParams.py`
- Inputs: DEM + PRA release (`Inputs/REL/pra*.tif`)
- Uses `[avaPARAMETER]` and `[avaSIZE]` to compute `ALPHA`, `UMAX`, and `EXP` once per leaf.
- **Folder rule:** if a leaf path contains `.../SizeN/...`, the computed size is **clamped to** `N` before mapping to ALPHA/UMAX/EXP.
- DEM selection logic (handled via `workflowUtils.demForLeaf(...)`):
  - For BigData leaves (default): use `00_input/<DEM>` from `[MAIN].DEM`
  - For single or manual runs: fallback to `Inputs/DEM.tif` if present

Step 10 — Run FlowPy (per leaf)

- **NOTE**: FlowPy is now executed directly through AvaFrame — there is no `runCairosFlowPy.py` anymore.
- Driver: `cairos/runCairos.py`
- FlowPy INI: `AvaFrame/avaframe/com4FlowPy/com4FlowPyCfg.ini`
  - Copy to `local_com4FlowPyCfg.ini` before editing

Example FlowPy configuration used for CAIROS runs:

```
[GENERAL]
infra = False
previewMode = False
variableUmaxLim = True              # important for CAIROS
varUmaxParameter = uMax             # important for CAIROS
variableAlpha = True                # important for CAIROS
variableExponent = True             # important for CAIROS
forest = False                      # important for CAIROS
...

# computational defaults
tileSize = 12000
tileOverlap = 4000
procPerCPUCore = 1
chunkSize = 50
maxChunks = 500

[PATHS]
outputFileFormat = .tif
outputNoDataValue = -9999
outputFiles = zDelta|travelLengthMax|fpTravelAngleMax|cellCounts|relIdPolygon
useCustomPaths = False
deleteTempFolder = True
useCustomPathDEM = True             # important for CAIROS
workDir =
demPath = ...00_input/10DTM_pilotSellaTest.tif  # important for CAIROS
...

[FLAGS]
plotPath = False
plotProfile = False
saveProfile = True
writeRes = True
fullOut = False
```

Step 11 — Back-map FlowPy outputs to size (optional)

- Description:
  - Writes new size-based results into:

        - `<leaf>/Outputs/com4FlowPy/sizeFiles/res_<uid>/...`
    - where `<uid>` is the FlowPy run identifier created by AvaFrame.
    - Each size file corresponds to a resampled or aggregated result from the original FlowPy output, grouped per PRA and per size class.
- Code:
    - `in2Parameter/compParams.py::computeAndSaveSize`
- Controlled by:
    - `[WORKFLOW].flowPyOutputToSize`
- Writes new size-based results into:
    - `<leaf>/Outputs/com4FlowPy/sizeFiles/res_<uid>/...`
    - where `<uid>` is the FlowPy run identifier created by AvaFrame.

Step 12 — Output management and cleanup (optional)

- TBA

Step 13 — Build AvaDirectory from FlowPy

- Description:
    - Collects all `com4FlowPy` outputs for each scenario and merges them into a structured **AvaDirectoryData** tree.
    - Handles optional `RELJSON` merges, per-PRA splitting, and raster clipping for both **dry** and **wet** flow scenarios.
- Code:
    - `com2AvaDirectory/avaDirBuildFromFlowPy.py`
- Controlled by:
    - `[WORKFLOW].avaDirBuildFromFlowPy`
- Inputs:
    - `09_flowPyBigDataStructure/<caseFolder>/pra*/Size*/dry|wet/Outputs/com4FlowPy/`
- Outputs:
    - `11_avaDirectoryData/<caseFolder>/com4_/praID.geojson` + rasters
    - `11_avaDirectoryData/<caseFolder>/avaDirectory.csv`

Step 14 — Build AvaDirectory Type

- Description:
    - Merges all PRA-level GeoJSONs into a unified avaDirectoryType dataset.
    - Cleans, normalizes, and deduplicates attributes across all dry/wet and rel/res combinations.
    - Provides the master dataset for raster path enrichment in Step 15.
- Code:
    - `com2AvaDirectory/avaDirType.py`
- Controlled by:
    - `[WORKFLOW].avaDirType`
- Inputs:
    - `11_avaDirectoryData/<caseFolder>/com4_*/praID*.geojson`
- Outputs:
    - `12_avaDirectory/<caseFolder>/avaDirectoryType.csv`
    - `12_avaDirectory/<caseFolder>/avaDirectoryType.geojson`
    - `12_avaDirectory/<caseFolder>/avaDirectoryType.parquet`

Step 15 — Build AvaDirectory Results

- Description:

    - Builds the enriched avaDirectoryResults dataset by attaching relative raster paths to each (praID, resultID) combination
    - The .pkl index maps:
    - (praID, resultID) → { rasterType: path, ... } for all available simulation outputs.
    - These results form the foundation for Avalanche Scenario Mapper (scenario mapping, under development).

- Code:

    - `com2AvaDirectory/avaDirResults.py`

- Controlled by:
  - `[WORKFLOW].avaDirResults`
- Inputs:
  - `12_avaDirectory/<caseFolder>/avaDirectoryType.parquet`
  - `11_avaDirectoryData//com4_*/.tif
- Outputs:
  - `12_avaDirectory/<caseFolder>/avaDirectoryResults.csv`
  - `12_avaDirectory/<caseFolder>/avaDirectoryResults.geojson`
  - `12_avaDirectory/<caseFolder>/avaDirectoryResults.parquet`
  - `12_avaDirectory/<caseFolder>/indexAvaFiles.pkl`

Summary:

- Steps 09–15 form the complete FlowPy + AvaDirectory pipeline.
- They parameterize, simulate, post-process, and structure all avalanche scenarios into reusable, indexed datasets — ready for mapping, visualization, and scenario-based analysis.

INI

---

thats it for now - tbc...