

WetSpass-M Modern

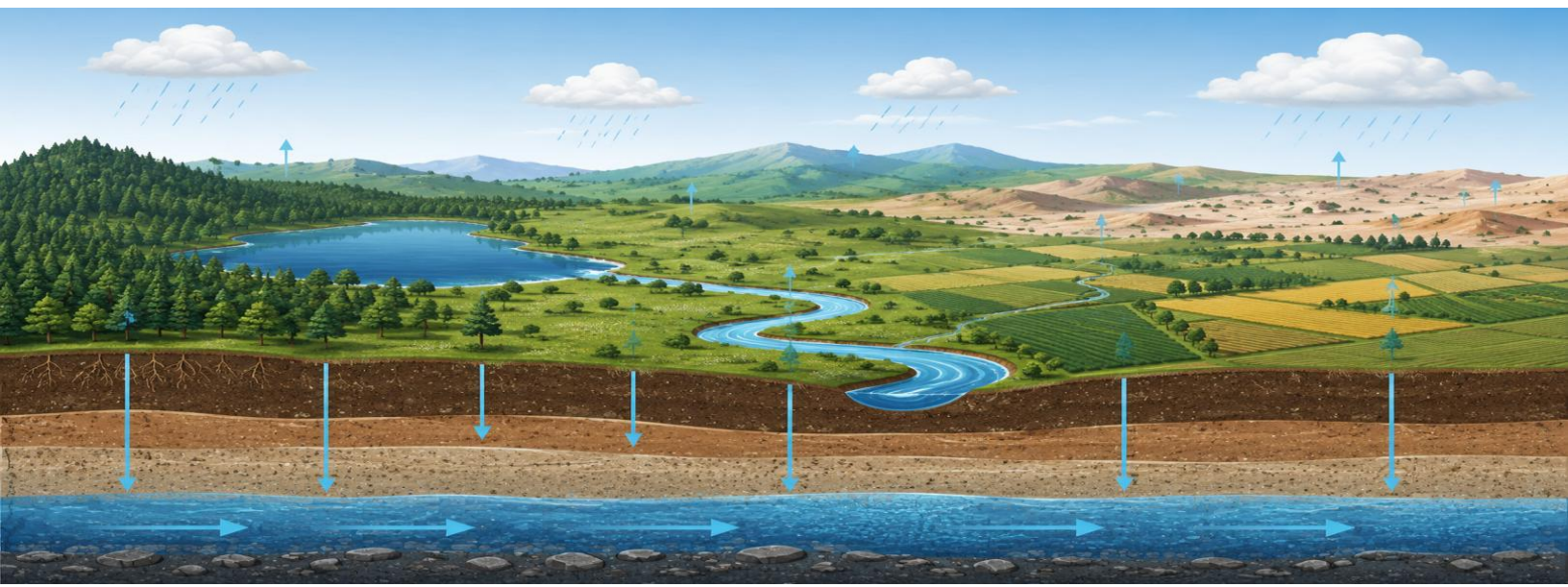
User Guide



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Preface

This document is the user guide for **WetSpass-M Modern**, a modernization of the original **WetSpass-M 2016** model developed by K. Abdollahi, I. Bashir, and O. Batelaan at the Vrije Universiteit Brussel. WetSpass-M is one of the most widely used spatially distributed water-balance models for estimating groundwater recharge at catchment and basin scale, particularly in data-scarce regions where simpler lumped models are insufficient and full physically based models are impractical. WetSpass-M Modern preserves the original model's physics, equations, and lookup-table structure; what it changes is the way the soil column is treated over time, the way the annual mass balance is defined, and the way the model is delivered to the user. The improvements documented in this manual are:

- **A dynamic soil-water bucket** replacing the original quasi-steady-state assumption. Soil moisture is carried as an explicit state variable from one month to the next, so the seasonal redistribution of water through the root zone is preserved. This matters most in seasonally concentrated rainfall regimes — monsoonal, Mediterranean, semi-arid, and arid climates — where the original assumption of monthly reset can distort the seasonal timing of recharge and the dry-season supply for evapotranspiration.
- **An ET cap consistent with mass balance.** Soil-derived evapotranspiration is capped at the water physically available after runoff ($P - SR$), not at rainfall alone. This prevents the model from producing negative recharge on high-runoff cells and ensures the catchment-scale balance closes.
- **A separate diagnostic for groundwater-fed ET.** Transpiration and evaporation drawn from a shallow water table are computed explicitly and reported as `Cell_gw_discharge`, outside the precipitation balance, instead of being folded back into AET where they would double-count water in the closure test.
- **Integration with QGIS via GeoTIFF I/O.** Inputs and outputs are GeoTIFF rasters. The plugin runs inside QGIS, uses QGIS's own raster and vector libraries, and writes outputs that can be inspected, symbolised, and analysed directly in the QGIS map canvas. Legacy ASCII .asc grids are still accepted for backward compatibility.
- **Robust checkpointing and resume for long runs.** The workflow saves its state after every completed month and after every completed spin-up cycle. A power loss, an external drive disconnection, or an unexpected shutdown no longer means starting over — the next time the plugin is opened, the Run tab offers a **Resume run** button that continues from the last completed month. Only one month of computation is ever at risk.
- **Sample data included.** A small example dataset ships with the plugin so you can verify the installation, run the model end-to-end, and inspect the outputs without first having to assemble your own inputs. The sample

dataset uses a small semi-arid catchment and is intentionally limited in size so it runs to completion in a few minutes on any modern laptop.

The manual assumes you are familiar with QGIS, raster GIS concepts, and basic hydrology (rainfall, runoff, evapotranspiration, recharge). If you are new to any of those, work through the **Quick Start** in Chapter 3 first — it walks you from a clean QGIS install to a valid annual water balance in about five minutes using the sample data. Consult the **Physics and equations** chapter only when you need to understand a specific flux or make a calibration decision. The **Troubleshooting** chapter at the end collects the errors most commonly reported by users, together with their causes and fixes.

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1. Introduction and scope

1.1 What WetSpass-M Modern does

WetSpass-M Modern computes, on a regular grid and at monthly time steps:

- Interception by vegetation
- Surface runoff, split by land-cover fraction
- Actual evapotranspiration (transpiration + soil evaporation + open-water evaporation + impervious-surface evaporation)
- Diffuse recharge to the saturated zone
- (Optionally) focused recharge along ephemeral stream networks

The output is a set of GeoTIFF rasters at monthly, seasonal, and annual resolution, together with a text summary file (Simulated.tbl) and a convergence report (spinup_convergence.csv).

1.2 Who should use it

The model is designed for:

- Regional groundwater recharge estimation
- Water-balance studies at catchment to basin scale
- Long-term average annual and seasonal water budgets
- Climate-change impact assessment (via substituting future climate inputs)
- Land-use change scenario analysis (via substituting land-use maps)

It is not designed for event-scale flood modelling, sub-monthly routing, or transient groundwater simulation. For those, use a physically-based rainfall-runoff model coupled to a groundwater model.

1.3 Model type

Two operating modes are available:

- Dynamic bucket mode (default). Soil moisture is an explicit state carried from month to month. Mass balance: $P = AET + SR + R + \Delta S$. At the annual scale, after spin-up, $\Delta S \approx 0$.
- WetSpass-M 2016 compatibility mode. Soil moisture is reset to zero every month ($\Delta S \equiv 0$). This reproduces the original 2016 physics exactly and is intended for validation against legacy results.

1.4 What changed from the 2016 original

Aspect	WetSpass-M 2016	WetSpass-M Modern (default)
Soil moisture	Reset every month ($\Delta S \equiv 0$)	Dynamic bucket, carried forward
ET cap	At rainfall	At (rainfall – runoff)
Groundwater-fed ET	Folded into AET	Reported separately as Cell_gw_discharge
Time integration	Monthly, one pass	Monthly, spin-up + reported pass
I/O	ASCII grids	GeoTIFF with ASCII fallback
Aggregation	Simple sum	Nodata-preserving sum
Environment	Standalone GUI	QGIS plugin

The original physics remain available through the compatibility mode.

2. Installation

2.1 Requirements

- QGIS 3.28 or newer (tested through 3.44 and listed for QGIS 4.x via `qgisMaximumVersion=4.99`)
- Python 3.9 or newer (comes bundled with QGIS)
- Python packages: `numpy`, `rasterio`. Both are commonly available in QGIS's Python environment.

2.2 Installing the plugin

Locate your QGIS plugin directory:

Windows: `%APPDATA%\QGIS\QGIS3\profiles\default\python\plugins\`

Linux: `~/.local/share/QGIS/QGIS3/profiles/default/python/plugins/`

macOS: `~/Library/Application Support/QGIS/QGIS3/profiles/default/python/plugins/`

Copy the entire `wetpass_modern` folder into that directory.

Open QGIS. Go to Plugins → Manage and Install Plugins → Installed. You should see WetSpass-M Modern listed. Ensure its checkbox is ticked.

A toolbar icon and a WetSpass-M Modern menu entry appear. If the icon is missing, verify that `icon.png` is present in the plugin folder.

2.3 Verifying dependencies

If `rasterio` is missing:

Windows: open the OSGeo4W shell (installed with QGIS) and run: `pip install rasterio`

Linux/macOS: use the same Python interpreter QGIS uses; run: `pip install --user rasterio`

2.4 Shipping the user guide

The Help tab looks for this PDF in the plugin folder. Place it at:

`wetpass_modern/help/WetSpassM_UserGuide.pdf`

If it is not present, the Help tab shows a message with the expected path, but the quick-reference material remains available.

3. Quick start in five minutes

This is the fastest path from zero to a valid annual water balance. Details for each step follow in later chapters.

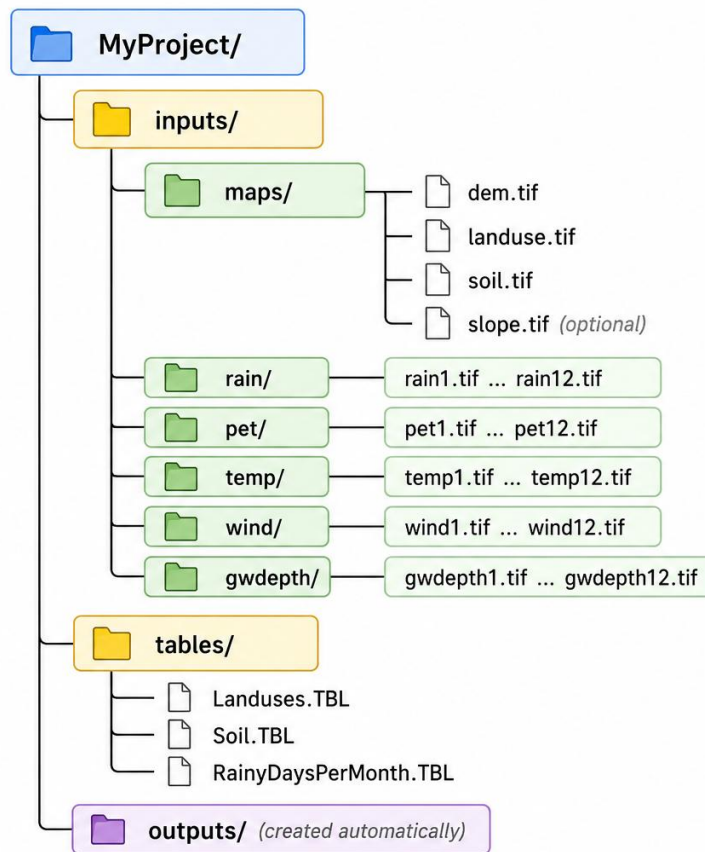
- Prepare your input folder using the standard layout shown in section 4.
- Open the plugin: WetSpass-M Modern → Open.
- Inputs tab. Set the working directory. Click Auto-load. Confirm the DEM, land use, and soil paths are filled.
- Check Inputs tab. Press Check Inputs. Every row should be green. Fix any red rows before continuing.
- Parameters tab. Leave the defaults ($LP = 0.85$, $Alfa = 1.5$) unless you have local calibration data.
- Run tab. Set the output directory. Leave Spin-up cycles = 2 and Compatibility mode = OFF.

- Press Run. Watch the Progress tab. The workflow reports convergence after each spin-up cycle and exits early when the bucket is stable. If you are satisfied that the bucket has converged and do not want to wait for the spinner count, press Skip to final cycle.
- Water Balance tab. Click Load from output folder. The closure error should be close to zero.

4. Input data requirements

4.1 Standard folder layout

All inputs live inside the working directory. The recommended layout is:



The Auto-load button in the plugin scans this layout and fills the paths for you.

Alternative layouts are also recognised (maps/ + tables/, Inputs/Maps/ + Inputs/Tables/, and Maps/ + Tables/). The Check Inputs tab tells you which layout it detected.

4.2 Grid alignment

All raster inputs must share exactly the same grid as the DEM: CRS, pixel size, origin, width, and height. Resolution alone is not enough — two 30 m grids with different origins are still misaligned.

To align rasters in QGIS: Raster → Projections → Warp. Set the target CRS and extent to the DEM, use bilinear for continuous variables (rain, temperature, wind, PET, gwdepth) and nearest for categorical variables (land use, soil).

The Check Inputs tab runs this alignment test automatically.

4.3 Raster formats

GeoTIFF is preferred. Legacy ASCII .asc grids are accepted for backward compatibility. Output is always GeoTIFF.

4.4 Units

Variable	Unit	Typical range
Rainfall	mm/month	0 – 500
PET	mm/month	0 – 300
Temperature	°C	–30 – 45
Wind speed	m/s	0 – 15
Groundwater depth	m below surface	0 – 200
DEM	m	project-dependent
Slope	percent	0 – 100

All fluxes are monthly totals, not intensities. Do not supply daily rates.

4.5 Monthly file naming

The model expects a 12-file pattern per climate variable:

rain1.tif ... rain12.tif

pet1.tif ... pet12.tif

temp1.tif ... temp12.tif

wind1.tif ... wind12.tif

gwdepth1.tif ... gwdepth12.tif

Prefixes are configurable on the Settings tab.

4.6 Lookup tables

Three tables are read from inputs/tables/.

Landuses.TBL

Tab-delimited. One row per land-use class code.

Column	Meaning
1	Land-use code (integer)
4	Vegetated fraction (0–1)
5	Bare-soil fraction (0–1)
6	Impervious fraction (0–1)
7	Open-water fraction (0–1)
8	Rooting depth (m)
9	Leaf area index (LAI)
10	Minimum stomatal resistance (s/m)
11	Vegetation roughness height z_0 (m)
13	Land-use factor for runoff coefficient

14	Aerodynamic resistance at 1 m/s wind (s/m)
----	--

Soil.TBL

Column	Meaning
1	Soil code
3	Field capacity (fraction)
4	Wilting point (fraction)
6	Residual water content (fraction)
7	Soil moisture parameter a
8	Evaporation depth (m)
9	Tension height at air-entry (m)
12	Soil factor for runoff coefficient

RainyDaysPerMonth.TBL

Two columns: month number (1–12), mean number of rainy days per month.

4.7 Optional inputs

- Snow cover (snowcover1.tif ... snowcover12.tif): fraction 0–1. Enable on the Run tab.
- Irrigation (irrig1.tif ... irrig12.tif): additional water applied to the soil.
- LAI per month in inputs/maps/LAI/.

5. Tab-by-tab reference

5.1 Inputs tab

Sets the working directory and the primary rasters. The Auto-load button scans the standard folder layout and fills the paths automatically.

Fields:

- Working Directory — root of the project, contains inputs/ and outputs/
- DEM map, Land use map, Soil map, Slope map — paths to the static rasters. If Slope is left empty and "Create slope map from DEM directly" is ticked, the model computes slope internally.
- No of time steps — usually 12 for a full year.
- Starting / Final time step — usually 1 and 12.
- Initial discharge — initial surface and subsurface flow values for the surface-water interaction option. Only used if the model is configured with basin area > 0.

5.2 Check Inputs tab

Runs a full validation:

- Every required lookup table exists and has enough columns.
- Every monthly raster exists for every requested month.
- Every raster shares the DEM's CRS, transform, width, and height.

Results are colour-coded. Red rows block the run — fix them first. Orange rows (grid mismatch) are warnings that usually indicate the model will produce garbage, so they should be fixed too.

Only explicit Check Inputs clicks write to the run log. Auto-checks triggered by switching tabs stay silent, so the log is not filled with duplicate lines.

5.3 Settings tab

Configures file-name prefixes for each variable. If your files are named precip1.tif instead of rain1.tif, change the prefix here. Also configures the nodata value (default -9999).

5.4 Parameters tab

Calibration coefficients.

Parameter	Default	Notes
"a" interception	4.5 mm/day	Interception threshold
Alfa	1.5	Priestley-Taylor coefficient
LP	0.85	Soil-moisture limitation
Average intensity	4 mm/h	Used in runoff formula
Slope factor	0.4	Weight in runoff coefficient
Land-use factor	0.3	Weight in runoff coefficient
Soil factor	0.3	Weight in runoff coefficient
Basin area	10 km ²	For surface-water interaction
"x" coefficient	0.5	Surface-water interaction
Beta	0.75	Baseflow coefficient
Contribution factor	0.5	Recharge contribution

5.5 Output Period tab

Choose which temporal aggregations to write:

- Monthly — 12 files per variable.
- Seasonal — wet-season and dry-season files.
- Annual — one file per variable.

Season definitions are preloaded for several climate regions; the Ethiopian preset uses Kiremt (June–September) as wet season and the rest as dry season.

5.6 Run tab

- Output Directory — where rasters and reports go.
- Model version — compatibility mode checkbox (see section 11).
- Spin-up cycles — number of extra warm-up passes before the reported pass (see section 7). Default 2.
- Save final soil moisture — writes soilwater_storage_initial.tif for use as the starting state in future runs.
- Reset soil moisture state — deletes the state file, forcing the next run to start from a dry profile.
- Enable automatic checkpointing — writes a checkpoint after every completed month, so a power loss or drive disconnection resumes where it stopped.
- Create simulation file — writes Simulated.tbl with per-month mean fluxes.

- Include snow processes — enables the snow module.

5.7 Progress tab

Live log and progress bar. Controls:

- Skip to final cycle — abandons the remaining spin-up cycles and jumps straight to the final output cycle. Use this once the bucket has essentially converged and you do not want to wait for the spinner count. The current cycle finishes cleanly, then the workflow moves to the final pass.
- Pause — stops at the next block write and saves a checkpoint. The next run can resume from it.
- Cancel — stops at the next block write without saving a checkpoint. Partial output remains on disk until the next fresh run.
- Close dialog — hides the window; the run continues in the background.

5.8 Results tab

Choose which intermediate rasters to keep on disk. By default the model keeps monthly recharge and AET rasters; the rest are deleted after aggregation to save space.

5.9 Water Balance tab

See section 10.

5.10 Focused Recharge tab

See section 9.

5.11 About tab

Scientific justification, equations, references. See section 6 for a summary.

5.12 Help tab

Opens this PDF and provides a quick-reference of the workflow, output folder structure, and common errors.

6. Physics and equations

6.1 Water balance at a cell, per month

The model partitions precipitation into four fluxes and one storage change:

$$P = AET + SR + R + \Delta S$$

where:

- P = precipitation (rainfall plus snowmelt)
- AET = actual evapotranspiration to the atmosphere
- SR = surface runoff
- R = recharge to the saturated zone
- ΔS = change in soil-water storage during the month

6.2 Interception

$$a_{aii} = a - LAI$$

$$V_a = P - (1 - 1/\exp(0.463 - LAI))$$

$$DIT = a_{aii} - a_{aii} / (1 + V_a / a_{aii})$$

$$I_{total} = vegarea \cdot P \cdot (1 - \exp(-DIT \cdot nr / P))$$

$$I_{\text{total}} = \min(I_{\text{total}}, \text{PET})$$

$$I = I_{\text{total}} - (0.04 + 0.067 \cdot \text{LAI})$$

where nr is the number of rainy days in the month, a is the interception parameter (default 4.5 mm/day), and vegarea is the vegetated fraction of the cell.

The factor $(0.04 + 0.067 \cdot \text{LAI})$ splits total interception into a portion that evaporates directly (which is the flux I that enters AET) and a remainder that drips back to the soil.

6.3 Surface runoff

Runoff is computed with a modified runoff-coefficient method:

$$C_{\text{per}} = w_{\text{lu}} \cdot \text{LU_factor} + w_{\text{soil}} \cdot \text{Soil_factor} + w_{\text{slope}} \cdot \text{slope} / (10 + \text{slope})$$

$$C_{\text{imp}} = 0.09 \cdot \exp(2.4 \cdot (\text{imp} + \text{ow}))$$

$$C_{\text{wp}} = (1 - \text{imp} - \text{ow}) \cdot C_{\text{per}} + (\text{imp} + \text{ow}) \cdot C_{\text{imp}}$$

$$C_{\text{sr}} = (C_{\text{wp}} \cdot P_d) / (C_{\text{wp}} \cdot P_d - I_{\text{coef}} \cdot C_{\text{wp}} + I_{\text{coef}}) \text{ if } I_{\text{coef}} < P_d$$

$$C_{\text{wp}} \text{ otherwise}$$

$$Q = Ch \cdot C_{\text{sr}} \cdot (P - I_{\text{total}})$$

where $P_d = P / \text{nr}$ is the average daily rainfall, $I_{\text{coef}} = 24 / I_{\text{avg}}$ is the inverse of the average rainfall intensity, and Ch is a soil-moisture-driven runoff modifier.

6.4 Actual evapotranspiration

AET combines four precipitation-derived components:

$$\text{AET} = I + E_{\text{transp}} + E_{\text{bare}} + E_{\text{imperv}}$$

Each component is computed with a soil-moisture limitation:

$$E_{\text{transp}} = \text{PET}_{\text{veg}} \cdot (1 - a \cdot (\text{awc} / \text{PET}_{\text{veg}})) \cdot \text{evap_rate}$$

$$E_{\text{bare}} = \text{PET} \cdot (1 - a \cdot (\text{awc} / \text{PET})) \cdot \text{evap_rate}$$

where awc is available water capacity plus soil storage, and a is the soil moisture parameter from Soil.TBL.

In dynamic mode, the soil-water supply is $S_{\text{prev}} + P - I - \text{SR} - E_{\text{imperv}}$, not just the current month's rainfall. This is the key difference from 2016.

Groundwater-fed transpiration and bare-soil evaporation are computed separately and reported as Cell_gw_discharge, outside the precipitation balance.

6.5 Recharge

Recharge is the overflow from the soil bucket:

$$S_{\text{max}} = (\text{fc} - \text{wp}) \cdot \text{rootdepth} \cdot 1000 \text{ [mm]}$$

$$A = S_{\text{prev}} + P - I - \text{SR} - E_{\text{imperv}}$$

$$E_{\text{s}} = \min(E_{\text{s_potential}}, A) \text{ [tp + bare]}$$

$$S_{\text{new}} = \text{clamp}(A - E_{\text{s}}, 0, S_{\text{max}})$$

$$R = \max(0, A - E_{\text{s}} - S_{\text{max}})$$

fc and wp come from Soil.TBL, rootdepth from Landuses.TBL.

6.6 Snowmelt

Snow is tracked as snow water equivalent (SWE):

$$\text{SWE} = \text{SWE}_{\text{prev}} + P / (1.61 - 1.35 \cdot T + 1)$$

C_m = melt factor if $T >$ base temperature, else 0

$Melt = \min(C_m \cdot \text{degree_days} \cdot T, SWE)$

$SWE = SWE - Melt$

degree_days is read from DegreeDaysPerMonth.TBL.

7. Spin-up and convergence

7.1 Why spin-up is needed

Because soil moisture is now a state variable, the model needs to run the same 12 monthly input maps several times before the bucket reaches a repeating annual cycle: S at the start of year N equals S at the start of year $N+1$ at every cell.

Only then does the reported year have a well-defined mass balance and a ΔS that can be compared against P .

7.2 Recommended spin-up counts

Climate	Cycles
Maritime temperate	1
Continental / Mediterranean	2
Monsoon (Ethiopia, India, West Africa)	2–3
Arid / semi-arid	3–5

The spinner on the Run tab sets extra warm-up passes before the reported pass. Set to 2 (default) → three passes total.

7.3 Automatic convergence check

After every spin-up cycle the workflow computes:

$\text{mean } |S_{\text{end}} - S_{\text{start}}| \text{ [mm/yr]}$

If this falls below a tolerance, the bucket has converged and the remaining warm-up cycles are skipped automatically. The default tolerance is:

$\text{tolerance} = \max(1.0 \text{ mm}, 0.5 \% \times \text{mean annual } P)$

For $P = 1170 \text{ mm/yr}$, the tolerance is 5.86 mm/yr . A 5 % margin is applied on top, so values within 5 % of the tolerance also count as converged. This prevents the workflow from running an extra cycle when the residual is sitting on the numerical noise floor.

7.4 Convergence report

Every run that has at least one spin-up cycle writes spinup_convergence.csv:

```
Spin-up convergence report
mean_annual_P_mm,1171.6800
tolerance_mm,5.8584
tolerance_frac,0.005000
converged_after_cycle,3
cycle,mean_abs_dS_mm,mean_dS_mm,pct_of_P,tol_mm,converged
1,47.210314,41.305442,4.031023,5.858400,no
```

2,8.417295,7.441808,0.718202,5.858400,no

3,1.208741,0.918376,0.103163,5.858400,yes

Interpretation:

- `mean_abs_dS_mm` — the convergence metric for that pass.
- `pct_of_P` — the metric as a fraction of mean annual P.
- `converged` — yes if the metric fell below the tolerance (with margin).

If `converged_after_cycle` equals the spinner value, the bucket was still drifting at the last allowed pass. Add 1–2 cycles and re-run.

When spin-up is set to 0, no spin-up cycle runs and the CSV is not written. The final cycle runs directly from the state stored in `soilwater_storage_initial.tif`.

7.5 Manual verification

Two independent checks confirm convergence:

- In the Water Balance tab, ΔS is close to zero — within the tolerance reported in the Progress log.
- The last row of `spinup_convergence.csv` has `converged = yes`.

If both checks pass, the reported mass balance is trustworthy.

8. Outputs and interpretation

8.1 Output folder structure

outputs/

Lookups/ static lookup rasters

Interception_1.tif ... _12.tif monthly outputs

Cell_runoff_1.tif ... _12.tif

Cell_evapotranspiration_1.tif ...

Recharge_diffusive_1.tif ...

Recharge_diffusive_annual.tif annual aggregate

Recharge_diffusive_wet_season.tif seasonal (if enabled)

Recharge_diffusive_dry_season.tif seasonal (if enabled)

Recharge_focused_annual.tif (after Focused Recharge tab)

Recharge_Total_annual.tif (after Combine button)

soilwater_storage_initial.tif bucket state for next run

soilwater_storage_delta_annual.tif ΔS over the reported year

spinup_convergence.csv spin-up report (when spin-up > 0)

wetpass_checkpoint.json resume state (deleted on completion)

Simulated.tbl per-month mean fluxes

8.2 Output variables

Name	Meaning	Units
Interception	Interception of the cell	mm/month

total_Interception	Interception before the $0.04 + 0.067 \cdot \text{LAI}$ factor	mm/month
evap_rate	Evaporative efficiency factor (0–1)	–
Ch	Soil-moisture runoff modifier	–
Cell_runoff	Total surface runoff	mm/month
Csr	Runoff coefficient	–
vegrunoff	Runoff from vegetated area	mm/month
barerunoff	Runoff from bare soil	mm/month
imperrunoff	Runoff from impervious area	mm/month
owrunoff	Runoff from open water	mm/month
Cell_evapotranspiration	Precipitation-derived AET	mm/month
Cell_gw_discharge	Groundwater-fed ET (diagnostic)	mm/month
Cell_actualtranspiration	Vegetation transpiration	mm/month
Cell_actual_baresoil_evapo	Bare-soil evaporation	mm/month
Cell_ow_evaporation	Open-water evaporation	mm/month
Cell_imper_evaporation	Impervious-surface evaporation	mm/month
Cell_gw_transpiration	Groundwater-fed transpiration	mm/month
Cell_gw_evaporation	Groundwater-fed soil evaporation	mm/month
recharge	Diffuse recharge	mm/month
soilwater_storage	Bucket state at end of month	mm
wb_error	Cell-level mass balance residual	mm/month
penmann_coefficient	Penman coefficient	–

8.3 Reading the annual rasters

Annual rasters are the sum of the 12 monthly rasters. For continuous variables (rain, ET, runoff, recharge) this is correct. For state variables (soilwater_storage), annual aggregation is not meaningful and the model writes them as monthly snapshots instead.

8.4 Simulated.tbl

Text file with the catchment-mean fluxes per month:

```
TimeStep AET Runoff Interception Recharge
1 23.4567 12.3456 5.6789 8.9012
2 25.1234 11.2345 6.7890 7.8901
...
```

Useful for calibration against observed annual hydrographs. When a run is resumed, the file is appended to rather than truncated, so months written before the pause are preserved.

9. The Focused Recharge module

9.1 What it computes

Focused recharge is the streambed infiltration along ephemeral or intermittent streams. It is a separate process from diffuse recharge and typically concentrated on a small fraction of the catchment area.

The module:

- Derives a stream network from the DEM (D8 flow accumulation).
- Routes monthly surface runoff downstream.
- Applies an exponential transmission loss on streambed cells.
- Reports the fraction of the network treated as losing vs gaining.

9.2 Parameters

- Stream threshold — accumulation threshold in cells (typical 500).
- K_s — streambed hydraulic conductivity, either from Soil.TBL or a fixed value. Typical clogged values: $1e-7$ to $1e-6$ m/s.
- Channel width — from Strahler order, from a shapefile attribute, or fixed.
- Losing / gaining threshold — depth-to-water-table cutoff. Streambed cells with a shallower water table are treated as gaining and skip loss.
- Flow duration fraction — fraction of each rainy day during which ephemeral streams actually flow. Typical 0.20–0.40.
- Maximum infiltration depth — physical cap, typical 20 mm/day.

9.3 Workflow

- Run the main model first.
- Open the Focused Recharge tab.
- Configure parameters.
- Press Run focused recharge.
- (Optional) Press Combine diffusive + focused → Total to produce Recharge_Total_annual.tif.
- Return to the Water Balance tab and click Update recharge.

10. The water balance panel

10.1 Reading the panel

The panel shows the annual average of each flux and the closure error:

$$\text{Mass balance: } P = AET + SR + R_{\text{total}} + \Delta S$$

$$\text{Closure error} = P - AET - SR - R_{\text{total}} - \Delta S$$

The colour of the closure error is green if $|\text{error}|$ is within the acceptable band ($< 1\%$ of P), amber if 1–5 %, and red above 5 %. A green closure on a spun-up run is the strongest evidence that the model has produced a physically consistent water balance.

10.2 What ΔS means

ΔS is the change in stored soil moisture over the reported year. On a converged run it is close to zero — typically under the tolerance of 0.5 % of P . If ΔS is larger, the bucket has not yet reached a repeating annual cycle. Increase spin-up cycles by 1 and re-run.

ΔS is not a closure-error correction. It is a real, physical flux that belongs in the balance and would be non-zero even in a perfect model run, because the soil column still accumulates or releases some water during the reported year.

10.3 Focused recharge integration

If you have run the Focused Recharge module, the panel reads `Recharge_focused_annual.tif` and adds it to `R_total`. If you have also produced `Recharge_Total_annual.tif` with the Combine button, the panel reads that file directly.

The panel distinguishes these cases in the status line beneath the buttons.

11. Compatibility mode

11.1 What it does

Ticking WetSpaSS-M 2016 compatibility mode on the Run tab disables the dynamic bucket and restores the original physics:

- Soil moisture is reset to zero every month ($\Delta S = 0$ internally).
- Soil-derived ET is capped at rainfall, not ($P - \text{runoff}$).
- Groundwater-fed ET is folded back into `Cell_evapotranspiration`.
- The recharge-driven ET adjustment is reapplied so that the closure error matches the original 2016 formulation.

11.2 When to use it

Use it to validate the modernized code against a legacy WetSpaSS-M 2016 installation on identical inputs. Cell-by-cell differences should be at the level of floating-point round-off. If they are larger, the implementation has diverged and should be investigated.

Do not use compatibility mode for operational studies in seasonally-concentrated rainfall regimes — you will lose the seasonal redistribution that the bucket provides.

12. Troubleshooting

12.1 The Check Inputs tab shows red rows

The tables or rasters listed are missing or malformed. Read the message column — it usually identifies the file path or the missing column.

- Missing file → check the file name spelling.
- Missing column → open the .TBL file and compare to the template.
- Grid mismatch → reproject the raster to the DEM grid.

12.2 "Input rasters are not on the same grid as the DEM"

This means CRS, transform, or size differs. Use QGIS → Raster → Projections → Warp to reproject every input to the DEM's grid. Verify the fix with the Check Inputs tab.

12.3 Recharge raster is all zeros

Three possible causes:

- The run did not complete — check the Progress log for errors.
- ET consumes all available water — check the Water Balance panel: if AET is close to P, recharge will be near zero. Adjust the LP or LAI parameters.

- The recharge raster was produced by an earlier buggy run — delete Recharge_diffusive_*.tif and re-run.

12.4 Closure error is large in the Water Balance panel

In order of likelihood:

- ΔS is large — the bucket has not converged. Increase spin-up cycles.
- Rasters are misaligned — Check Inputs will catch this.
- Compatibility mode was toggled between runs — discard the checkpoint and re-run.

12.5 Checkpoint errors on Resume

If a parameter, spin-up count, or compatibility setting changed after pausing, the checkpoint's parameter hash no longer matches. Click Discard checkpoint and start a fresh run.

12.6 Model appears stuck on a spin-up cycle

It is not stuck. Each cycle runs 12 months. Watch the "Month N — block M" lines. The workflow exits early when the bucket converges — look for the CONVERGED line in the Progress log. If you are satisfied with convergence and do not want to wait for the spinner count, press Skip to final cycle.

12.7 Power loss or drive disconnection during a run

Automatic checkpointing is on by default. The workflow saves its state after every completed month. When you reopen QGIS:

- The Run tab shows a "Paused run found" banner.
- The main button reads "Resume run" instead of "Run".
- Click Resume run and the workflow picks up at the exact month and block where it stopped. Only one month of computation is ever at risk.

12.8 "Output device unavailable" warning

The external drive holding the output folder was disconnected. The workflow retried the write a few times and then paused cleanly. Reconnect the drive, then click Resume run on the Run tab. Only the month that was in progress will be recomputed.

12.9 Duplicate "[Check Inputs]" log lines

Fixed as of version 2.0.5. Auto-checks triggered by switching to the Check Inputs tab or changing the working directory no longer write to the run log; only an explicit Check Inputs click does.

13. References and acknowledgements

13.1 Original model

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13.2 Bucket formulation

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13.3 Evapotranspiration

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13.4 Acknowledgements

The modernization effort was carried out by M. G. Gurmu in 2026 (in Ethiopia). The original physics remain the intellectual property of K. Abdollahi, I. Bashir, and O. Batelaan, to whom co-authorship should be given in any publication that uses WetSpass-M or WetSpass-M Modern.

Appendix A — Glossary

AET — Actual evapotranspiration. The sum of transpiration, soil evaporation, open-water evaporation, and impervious-surface evaporation over a period.

Bucket — A simplified representation of the soil column as a single reservoir of plant-available water.

Closure error — The residual in the water balance after all fluxes and storage changes are accounted for. Should be close to zero on a well-posed model run.

DEM — Digital elevation model. A raster of land-surface elevations.

Focused recharge — Recharge concentrated on a small fraction of the landscape, typically streambeds and topographic lows, as opposed to diffuse recharge spread over the whole catchment.

Gaining stream — A stream that receives water from the aquifer along its reach.

Losing stream — A stream that loses water to the aquifer along its reach. Losing reaches are the source of focused recharge.

PET — Potential evapotranspiration. The evapotranspiration that would occur if water were freely available.

Spin-up — The process of running a state-tracking model repeatedly on the same inputs until the internal state reaches a repeating cycle.

ΔS — Change in soil-water storage over a period. Zero in quasi-steady-state models; non-zero in dynamic models.

Appendix B — File listing

Filename	Purpose
init.py	QGIS plugin entry point
metadata.txt	Plugin metadata
icon.png, icon.ico	Icons
LICENSE.txt	Academic-use license
README.md	Short project README
wetpass_plugin.py	Main plugin class
wetpass_provider.py	QGIS Processing provider
wetpass_algorithm.py	QGIS Processing algorithm
core/calculation_engine.py	Core physics
core/workflow.py	Orchestrator with spin-up
core/raster_io.py	Raster I/O with auto-alignment
core/focused_recharge.py	Focused recharge engine
core/stream_derivation.py	D8 hydrology, stream network
core/stream_io.py	Vector rasterization
ui/main_dialog.py	Main GUI
ui/worker.py	Background thread
ui/water_balance_tab.py	Water balance panel

ui/focused_tab.py	Focused recharge GUI
ui/focused_worker.py	Focused recharge thread
help/WetSpassM_UserGuide.pdf	This document

End of document.