# Deliverable 4.2.1

# Technical validation of the WATDEV toolbox

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| Funding source: | EU Initiative on Climate-relevant Development Smart Innovation Through Research in Agriculture in developing countries – DeSIRA |
| Project Acronym: | WATDEV |
| Project Full Title: | Climate Smart WATer Management and Sustainable DEVelopment for Food and Agriculture in North-East Africa |
| CRIS Ref.: | FOOD/2021/425-767 |
| Project duration: | 54 months |

Published by the WATDEV Consortium
Dissemination Level : Public

Responsible partner : Finnish Environment Institute (SYKE)
Contributing partners : International Soil Reference and Information Center (ISRIC)
Version : Final

This project has received funding from the European Union's
DeSIRA Initiative (Development Smart Innovation through Research in Agriculture)

## WATDEV CONSORTIUM

The project consortium is comprised of:

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| **ETHIOPIA** | Water and Land Resources Institute (WLRI) |
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## DOCUMENT INFORMATION

| | | | |
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| **Project number** | FOOD/2021/425-767 | **Acronym** | WATDEV |
| **Full title** | Climate Smart WATer Management and Sustainable DEVelopment for Food and Agriculture in North-East Africa | | |
| **Project URL** | www.watdev.eu | **Document URL** | |
| **Implementation Agency** | AICS (Italian Agency for Development Cooperation) | | |

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|---|---|---|---|---|
| **Deliverable** | **Number** | 4.2.1 | **Title** | Technical validation of the Toolbox |
| **Project Activity** | **Number** | A 4.2 | **Title** | Technical validation of the Toolbox platform |

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| **Date of delivery** | **Contractual** | M40 | **Actual** | M54 |
| **Status** | Final | | Final | |
| **Final review** | 29/06/2026 | **AICS check** | 30/06/2026 | |
| **Type of document** | ☐ prototype<br>☐ **report**<br>☐ demonstration<br>☐ other | | | |
| **Dissemination level** | ☐ **public**<br>☐ confidential | | | |


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| **Abstract (for dissemination)** | This deliverable presents the technical validation of the WATDEV Toolbox, a web-based platform for visualising and analysing integrated modelling results. It assesses the conceptual design, model linkages, usability, source code, and reliability of analysis tools. The Toolbox enables comparison of management scenarios, supports participatory decision-making, and includes Multi-Criteria Analysis (MCA). Key strengths include flexibility and visualization, while limitations relate to integration and complexity, with recommendations for improvement. |
| **Keywords** | Toolbox, Integrated model, technical validation |

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## Acronyms and Abbreviations

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|---|---|
| AICS | Italian Agency for Development Cooperation |
| ASARECA | Association for Strengthening Agricultural Research in Eastern and Central Africa, Uganda |
| AU-EU | Africa-Europe |
| BMP | Best Management Practice |
| CIHEAM | Centre International de Hautes Etudes Agronomiques Mediterranéennes, Italy |
| CNR- | Consiglio Nazionale delle Ricerche, Italy |
| DG DEVCO | The Commission's Directorate-General for International Cooperation and Development |
| DSSAT | Decision Support System for Agrotechnology Transfer |
| EU | European Union |
| FAO | Food and Agricultural Organization of the United Nations |
| HRU | Hydrological Response Unit |
| HU | Heliopolis University, Egypt |
| ISRIC | International Soil Reference and Information Center, The Netherlands |
| KALRO | Kenya Agricultural & Livestock Research Organization, Kenya |
| KPI | Key Performance Indicator |
| MCA | Multi-Criteria Analysis |
| MODFLOW | Modular Groundwater Flow Model |
| R&I | Research and Innovation |
| STI | Science, Technology and Innovation |
| SWAT | Soil and Water Assessment Tool |
| SYKE | Finnish Environment Institute, Finland |
| UI | User Interface |
| WRC | Water Research Centre, Sudan |
| WATDEV | Climate Smart WATer Management and Sustainable DEVelopment for Food and Agriculture in North and East Africa |
| WLRI | Water and Land Resources Institute, Ethiopia |

# Executive Summary

This deliverable presents the technical validation of the WATDEV Toolbox, a web-based decision-support platform integrating modelling outputs with visualization and post-processing tools. It assesses the conceptual design, model linkages, source code, usability for non-expert users, and reliability of analysis functions.

The Toolbox connects hydrological models, a spatial database, analysis modules, and an interface. It enables users to explore environmental, agricultural, and socio-economic indicators, compare scenarios, and create custom combinations without rerunning models. The system is mainly based on SWAT-driven modelling, with additional components linked through an interface.

The Toolbox supports decision-making through scenario comparison and Multi-Criteria Analysis (MCA) with user-defined indicators and weights. Its open-source, web-based design improves accessibility.

Strengths include flexibility, usability, and visualization. Limitations include partial integration and system complexity. Recommendations focus on improving usability, completing integration, and strengthening documentation.

# 1. Introduction

This deliverable discusses the technical validation aspects of the WATDEV Toolbox.

The Toolbox is the combination of the WATDEV integrated model (SWAT and DSSAT) and a user interface (the Toolbox properly said) to visualise and further analyse ("post-process") the model results.

This deliverable assesses the conceptual model, model linkages, source code, usability for non-expert users, and the reliability of visualization and analysis tools, highlighting strengths, limitations, and recommendations.

## 1.1. Purpose, context and scope of this deliverable

This deliverable describes conceptual model of toolbox and integrated model within.

It also assesses source code issues, toolbox usability for non-expert users, and the reliability of visualization and analysis tools. Strengths and limitations of toolbox are discussed as well as recommendation are given.

# 2. Conceptual model

## 2.1. Toolbox

The WATDEV Toolbox is a web-based decision-support platform that enables users to explore, compare, and analyse the results of hydrological, agricultural, and socio-economic modelling activities carried out within the WATDEV project. Rather than functioning as a modelling system itself, the Toolbox acts as an interface between model outputs and end users, providing visualisation, scenario comparison, and post-processing capabilities.

The conceptual architecture of the Toolbox consists of four main components: (1) external modelling systems, (2) a central database, (3) post-processing and analysis modules, and (4) the user interface (Figure 1).

Model outputs generated by SWAT, DSSAT, and related modelling workflows are imported into a PostgreSQL/PostGIS database. The Toolbox stores both the original model outputs and a set of derived indicators that are used for visualisation and analysis.

To support efficient exploration of results, model outputs are aggregated to annual indicators where appropriate. These indicators can represent hydrological, agricultural, environmental, or socio-economic performance metrics. Examples include crop yield, irrigation water use, nutrient balances, river discharge, sediment export, and indicators derived through economic post-processing.

The Toolbox allows users to compare alternative management scenarios and Best Management Practices (BMPs) across different study areas. Users can visualise results spatially through maps of study areas, subbasins, and river reaches, and temporally through graphs and charts. Comparisons can be made between baseline scenarios and intervention scenarios to evaluate potential impacts on water resources, agricultural productivity, and economic performance.

A novel feature of the Toolbox is the ability to create customized scenarios. Instead of requiring a new model simulation for every scenario combination, users can construct custom scenarios by combining results from different model runs within the same study area. For example, one subbasin may use results from a baseline simulation while other uses results from an irrigation or agroforestry intervention scenario. This enables rapid exploration of alternative management portfolios without requiring additional computationally intensive model runs.

The Toolbox also includes a Multi-Criteria Analysis (MCA) framework. The MCA combines model-derived indicators with user-defined weights, economic assumptions, and crop-specific parameters. Users can evaluate trade-offs between environmental, agricultural, and economic objectives by assigning relative importance to different indicators. MCA calculations are performed as a post-processing step using stored model outputs and user-supplied parameters, allowing users to experiment with alternative weighting schemes without rerunning the underlying models.

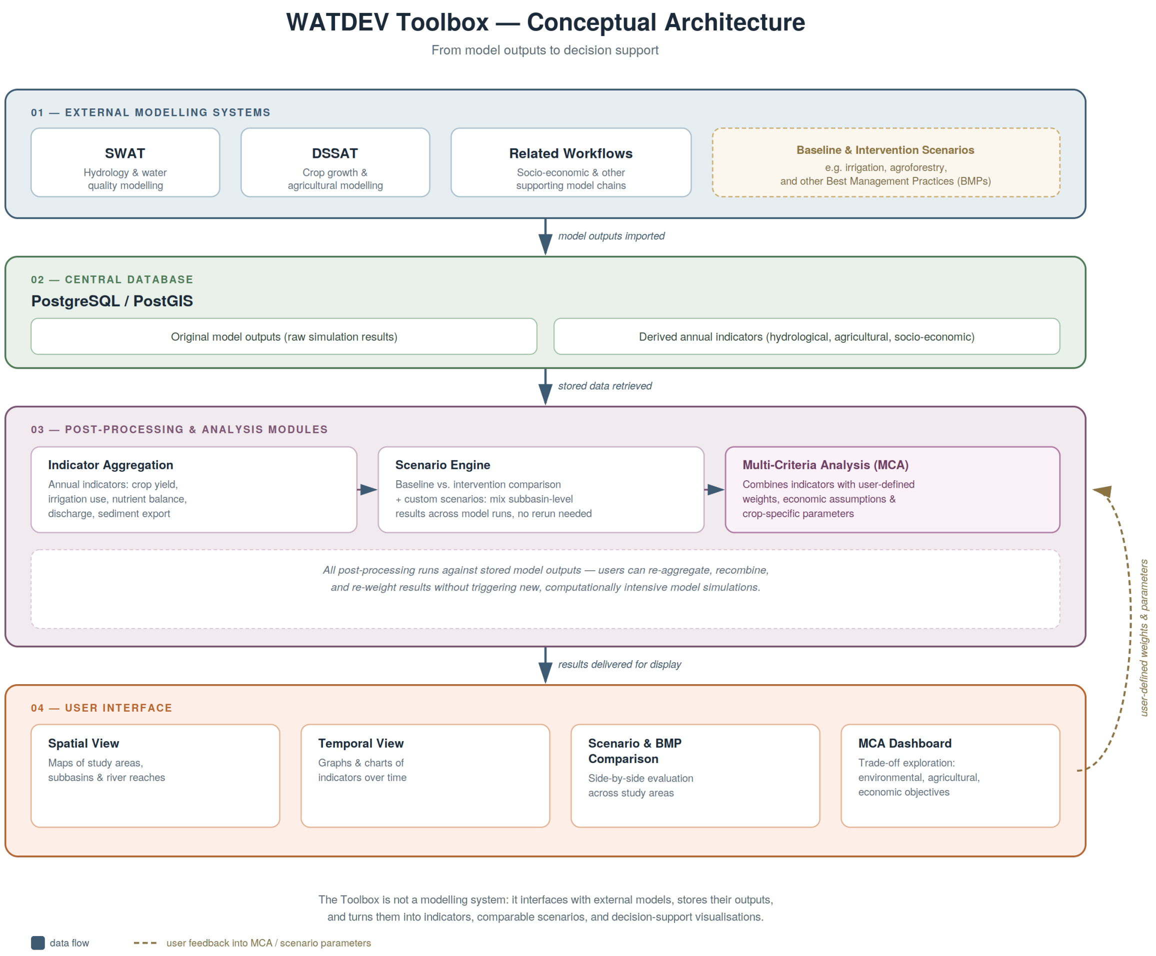


**Figure 1** - Conceptual architecture of the WATDEV Toolbox

## 2.2. Integrated model

The integrated model is based on SWAT-MODFLOW (version 2012/Rev 636_smrt) and DSSAT (version 4.8.0) models. Hereafter SWAT-MODFLOWS is referred to as a SWAT.

Since the integrated model is based on SWAT and DSSAT, quite a lot of the conceptual models of it are inherited from the SWAT (Neitsch et al, 2009) and DSSAT (Hoogenboom, et al, 2019, 2025, Jones et al., 2003) models. They are also briefly discussed in a deliverable D3.1.1 (Report of Modelling strategy with selected models and model combinations defined) of the WATDEV project.

In fact, the used SWAT model is a combination of the three different models: pure SWAT (catchment model), MODFLOW (ground water model) and rt3d, which is particle-based transport model.

The combination of them three is called SMRT, at least in the source code.

SWAT and DSSAT do not directly communicate with each other (i.e. there are no hard coded subroutine calls from SWAT directly to DSSAT side or vice versa). If either side needs some functionality from other side, it is copied to interface. All communication and information change happens through interface as visualized in Figure 1.

Currently SWAT code is modified to allow users to identify by a switch how much land related routines from both models are used. Currently land routines come mainly by DSSAT side but optionally they could be picked one by one, but this functionality is not fully implemented yet.

The parts of the conceptual model that is not inherited from DSSAT or SWAT are presented in Figure 1.

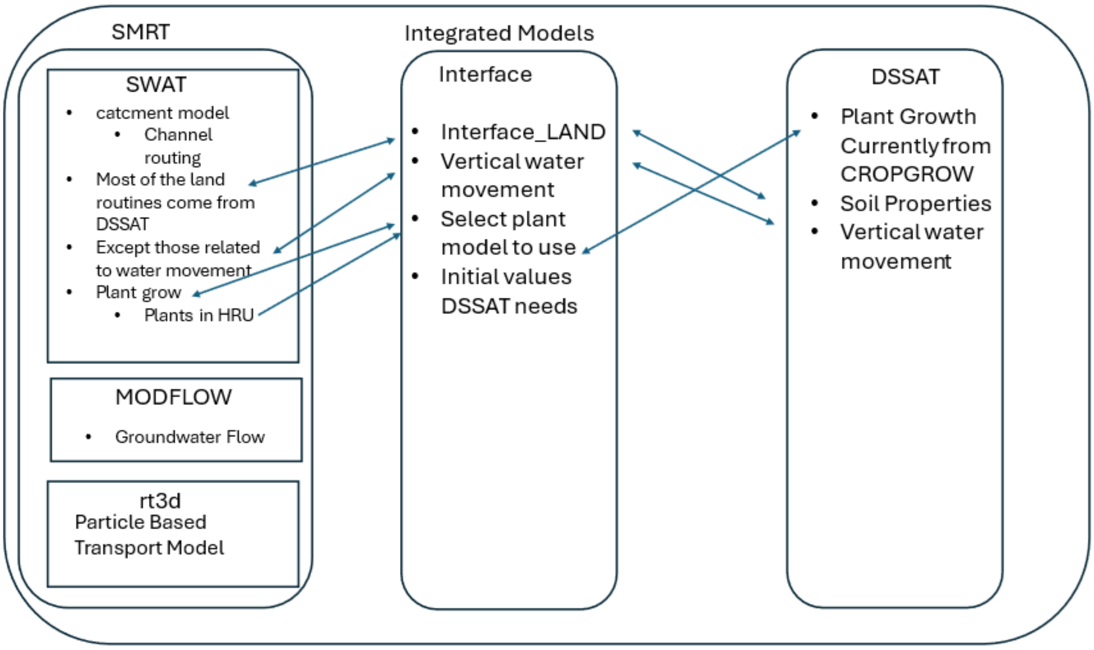


**Figure 2 -** Visual description of schematization of integrated model capturing the essential features of it.

# 3. Toolbox

## 3.1. Usability for non-expert users

The Toolbox is a visualization tool to study the results of an integrated modelling system which combines dynamic catchment-scale model to multicriteria analysis.

The main idea of the Toolbox is to help in discussions between different stakeholder groups and to give option to try different directions in decision making.

The Toolbox - at the moment - is applied to 4 study areas: Sharqia in Egypt, Gezira in Sudan, Koga in Ethiopia, and Hola/Bura in Kenya. The application for these study areas was based on a participatory process between different stakeholder groups in developing scenarios of Best Management Practices (BMPs), selecting Key Performance Indicators (KPIs) and assigning them weights based on development objectives.

## 3.2. Analysis tools

The BMPs for each study site consist of local adaptations of changes to cropping practices such as crop selection and fertilization (Egypt, Ethiopia, Sudan); addition of permanent crops (Egypt, Ethiopia, Kenya); or improved water management at the field and system scales (all sites).

The model can either assume a steady state condition or trees planted as seedlings and grow over time. In the steady state assumption, the user gets the long-term view of the BMP. In the planted assumption, the user's actual income covers the first 10 years in Multi-Criteria analysis.

In the Toolbox there is an option to view the model metadata, which explains basics of the scenario The current version of the Toolbox contains detailed scenarios of BMP application for each project study area. Further details of the modelled scenarios results can be found in D3.2.1.

The Toolbox also includes Multi-Criteria Analysis (MCA), which is a tool to help choose between different adaptation options under complex conditions, and therefore an essential part of the Toolbox. MCA consists of a set of systematic procedures for designing, evaluating, and selecting decision alternatives based on conflicting criteria. Each adaptation option is analysed in relation to agree upon criteria. Criteria can be weighted if some of them are considered more important than others. The MCA included in the Toolbox includes both environmental criteria (for crop growth, soil and water) and economic criteria (investment and operational costs, and income).

## 3.3. Implementation

In the Visualization section, the user can compare the impact of different scenarios on a specific sub-catchment area. To do this, the user must first select the management option scenarios and then click on the desired sub-catchment area on the map. Results can be compared as a line graph over time, or as bar graphs for different crops and metrics in a specific year.

The metrics that can be visualised consist of the Key Performance Indicators (KPIs) selected for the WATDEV toolbox (see D3.2.1 for more details), which are either aggregation of model results to an annual time-step, or calculations derived from model results.

The Toolbox also performs calculations of economic KPIs, implemented as "post-processing" of integrated model results. Users can define the economic assumptions behind these KPIs, including general information on costs (rent, labour, water use), information per crop (market prices, cultivation costs in money and labour) and implementation and operationalization costs for each management scenario.

Users can perform an MCA using all KPIs, or a subset of their choice. They can also assign different weights to each KPI, and indicate if it is a positive or negative indicator. Normalised results for each indicator are shown as a spider chart, while the overall MCA score is shown underneath.

For the MCA to work, at least one scenario defined as "baseline" should be present.

# 4. Source codes

## 4.1. Toolbox

The WATDEV Toolbox is implemented as a web application using open-source technologies. The backend is primarily developed in PHP and is responsible for data management, authentication, scenario handling, MCA calculations, and communication with the database. The frontend is implemented in JavaScript and provides interactive dashboards, maps, charts, and user interfaces for exploring model results.

The Toolbox uses PostgreSQL as its primary database system, with the PostGIS extension providing support for spatial data storage and analysis. Spatial information such as study area boundaries, subbasins, and river reaches is stored within the database and visualised through the web interface. Interactive visualisations are implemented using modern JavaScript libraries, enabling users to explore model outputs and compare scenarios dynamically.

The software is containerised using Docker, which simplifies deployment and ensures reproducibility across different computing environments. Production deployments typically include additional components such as Keycloak for authentication, Traefik as a reverse proxy, and pgAdmin for database administration.

The Toolbox source code is maintained in a GitHub repository (https://github.com/watdev-eu/) under an MIT open-source licence. The use of open-source technologies and licensing facilitates long-term sustainability, reproducibility, and future extension of the Toolbox by project partners and external contributors.

## 4.2. Integrated model

As indicated in Chapter 2.2 most of the source codes of the integrated model are inherited from the SWAT and DSSAT models. Some changes have been made to some source code files from both sides to utilize all needed functionalities.

One of the biggest changes was to create a spatialization of DSSAT variables because by design DSSAT originally is a single location model without horizontal capabilities. Basically, all modifications done to the source codes of DSSAT files are either changes to read input provided by user via interface or related to spatialization of DSSAT.

Spatialization is created in an interface module by introducing and saving required DSSAT variables for all individual HRUs considered by SWAT model application. Those saved DSSAT variables are collected to a derived type variables of a Fortran collecting certain type variables together to a single variable. Those subroutines that are in an interface are all named as interface_XXXX where XXX is the name of the original subroutine. Clear exception to this naming convention is an interface_LAND subroutine that deals basically almost whole LAND phase of the SWAT model.

In other words, interface_LAND is also where those variables needed by DSSAT routine are initialized correctly in a every time step and where LAND.for subroutine of DSSAT is called.

# 5. Strengths, limitations, and recommendations

The most important strength of the toolbox is its user interface to launch catchment scale model able to calculate not only the crop yield in each area but also the water quality of it.

Currently, usage of the toolbox is limited to the prepared areas; but since the toolbox is mostly built on top of SWAT, adding new areas should be quite straight forward.

Scaling the Toolbox to other areas requires a new application of the integrated model to that area.

At a general level, modeling can be done using global data for weather, soil types, land cover or land use, and elevation map of the area. Global data are available from several open data bases (e.g. https://swat.tamu.edu/data/).

The reliability of the modeling will improve if more accurate local data is available. However, information from local experts is desirable to determine intervention objectives, select appropriate BMPs to achieve these objectives, adjust socioeconomic assumptions to local conditions, and select the importance of different KPIs.

One of the strengths of the toolbox is it connections to sophisticated crop growth model DSSAT, which has the capacity to provide detail information regarding the crop growth. But at the same time, it is its greatest weakness. DSSAT requires huge number of values for parameters that in principle should be measured and currently measurement have been done, or results are collected to few species.

Currently, the integrated part of the model included to the toolbox is not well calibrated to any area even though the pure SWAT model is. Therefore, while WATDEV toolbox applications using the SWAT model alone (even if though the integrated model) are valid, it is recommended to perform re-calibration before activating DSSAT as the crop modelling component.

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