METHODOLOGY

WATER AND EROSION IMPACT ASSESSMENT OF SUSTAINABLE AGRICULTURAL LAND MANAGEMENT PROJECTS

Sustainable Development Goal #2 End hunger, achieve food security and improved nutrition and promote sustainable agriculture

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DEFINITIONS AND ABBREVIATIONS

Abbreviations

RUSLE	Revised Universal Soil Erosion model
USLE	Universal Soil Erosion model
GHG	Greenhouse Gas
DEM	Digital Elevation Model
HWSD	Harmonized World Soil Database
SDG	Sustainable Development Goals
SALM	Sustainable Agricultural Land Management
ABMS	Activity and Baseline Monitoring Survey
CDM	Clean Development Mechanism
LUF	Land Use and Forestry
HSG	Hydrological Soil Group

Definitions

Crop Parcel: A tract or plot of land with a specific area given to different types of crops grown (Oxford Dictionary 2004).

Field Capacity: The amount of water remaining in the soil a few days after having been wetted and after free drainage has ceased (FAO 2016).

Permanent Wilting Point: The water content of a soil when most plants (corn, wheat, sunflowers) growing in that soil wilt and fail to recover their turgor upon rewetting (FAO 2016).

Runoff: Runoff or overland Flow occurs when the soil cannot infiltrate water fast enough or when infiltration ceases, and there is no further capacity to store the water near the soil surface (NRCCA, Cornell University 2010).

Saturated Zone: The layer or depth of soil, which has become saturated with water that has infiltrated down through surface soil layers (FAO 2016).

Soil Erodibility: An indicator of a soil's susceptibility to raindrop impact, runoff, and other erosive processes (FAO 2016).

Rainfall erosivity: The erosive force of rainfall is expressed as rainfall erosivity (Panagos, 2015c). It is commonly expressed as the erosive force a rainfall event can have during 30 minutes.

Tillage: Is the agricultural preparation of soil by mechanical agitation of various types, such as digging, stirring and overturning (FAO 2016).

Cover crops: Crops that are specifically grown for covering the soil during seasons of otherwise no or little soil cover. These crops are usually not utilized directly but serve mainly the covering and sometimes a fertilizing effect (If legumes are grown, which also bind atmospheric nitrogen).

Residues: The leftovers of crops left on the field for decomposition. The process is similar to mulching.

Contour farming: Contour farming is a farm practice where the crops are always grown perpendicular to the height lines (isolines) of a slope. The practice requires good knowledge of the terrain.

Total Available Water (Holding) Capacity: The amount of water available, stored, or released between field capacity and the permanent wilting point water contents (NRCCA, Cornell University 2010).

Water Infiltration: The entry of water into soil as a result of gravity and soil water tension forces (NRCCA, Cornell University 2010).

Prevailing farm practice: It is defined as the farm practice, which is applied on the majority of area, and included in the project as operational boundary.

Sustainable Agricultural Land Management: It is defined as any kind of land management, which is not deteriorating the state of land resources. This can be either the maintenance or enhancement of the land resources and opposes the process of degradation. Degradation processes are for instance soil erosion and nutrient degradation/leaching/overuse.

Groundwater recharge: It is defined as the infiltrating water surplus (above field capacity), which is percolating below the rooting zone.

1. INTRODUCTION

The following table describes the key elements of the methodology:

Table 1: Methodology Key elements

Typical project(s)	Project activities that ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, and that progressively improve land and soil quality through adoption of sustainable land management practices (SALM) in the agricultural landscape. Examples of SALM are (but are not limited to) manure management, use of cover crops, enhancing/ maintaining agricultural biodiversity, and returning composted crop residuals to the field and the introduction of trees into the landscape.
Type of GHGs emissions mitigation action	Not applicable
Primary SDG contribution	Sustainable Development Goal 2 - End hunger, achieve food security and improved nutrition and promote sustainable agriculture *Target 2.4 - Ensure sustainable food production systems and implement resilient agricultural practices that increase productivity and production, that help maintain ecosystems and agricultural biodiversity, that strengthen capacity for adaptation to climate change, extreme weather, drought, flooding and other disasters and that progressively improve land and soil quality*

2. SUMMARY AND APPLICABILITY OF THE METHODOLOGY

2.1 BRIEF DESCRIPTION OF THE METHODOLOGY

Water is a necessity for plant growth and human survival. All agricultural activities and therefore the livelihoods of humans depend on farming and thus soils, as the primary provider of plant nutrients and water storage. Topsoil erosion is one of the main drivers of land degradation. In agricultural lands with declining soil organic matter, topsoil erosion will lead to reduction in the water infiltration capacity of a soil, leading to increased runoff and further erosion by washing away fertile topsoil.

This methodology links the impacts of adopting sustainable agricultural land management (SALM) practices including agricultural biodiversity on soils and water (Figure **1**) and uses soil erosion as a proxy to quantify water benefits (

Figure **2**).

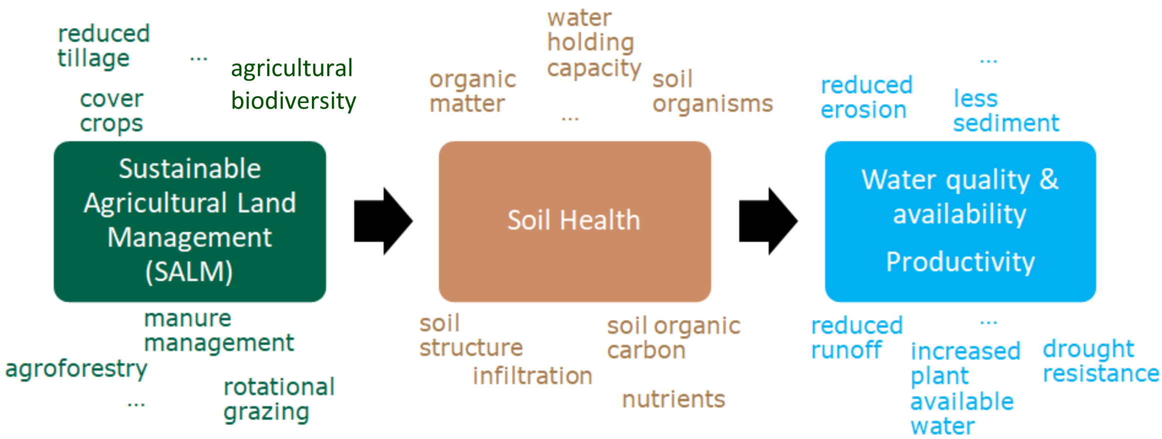

Figure 1: Overview of the links between SALM, soil health and water impacts

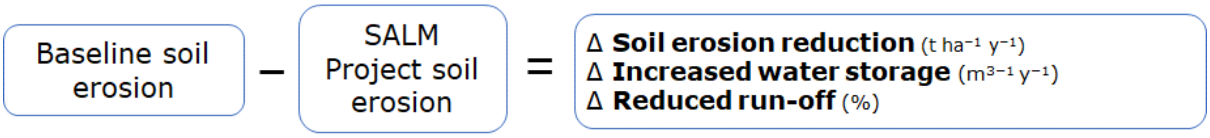

Figure 2: Water Impact Assessment Methodology for SALM Projects

The methodology compares the impact of current land use and farming practices (baseline) and the adoption of sustainable land management practices (project) on soil erosion which is then used to identify benefits of a project in terms of soil erosion reduction, increased water storage, and reduced water runoff.

Info Box: Sustainable Agricultural Land Management Practices (SALM)
SALM is a concept for farmers to adopt agricultural practices that preserve and enhance productive capacities of land to meet the food needs of the growing population, stop and reverse land degradation, and adapt to as well as mitigate the impacts of climate change and achieve increased environmental resilience in different climate or agro-ecological zones. Thereby the enhancement and maintenance of agricultural biodiversity is of key importance to world food supply ensuring food security for the approximately 1.3 billion small farmers in developing countries and emerging economies dependent on traditional agriculture practices (BMEL 2010). The following list summaries the varieties of SALM practices:

NUTRIENT MANAGEMENT

- Mulching
- Composting
- Cover / nitrogen-fixing crops
- Manure
- Restricted chemical fertilizers and chemical management

SOIL & WATER CONSERVATION

- Terraces
- Contour bunds
- Broad beds and furrows
- Semi-circular bunds
- Trash lines
- Diversion ditches and cut-off drains
- Retention ditches
- Pitting
- Trenches
- Tied ridges
- Grass strips
- Irrigation
- Roof catchment
- Ground surfaces and rocks
- Irregular surfaces
- Tanks
- Birkas
- Pans
- Ponds
- Dams
- Wells and boreholes
- Ecological sanitation
- Kitchen water

AGRONOMIC PRACTICES

- Crop rotation
- Intercropping
- Green manure
- Contour strip cropping
- Relay cropping
- Use of improved crop varieties

AGROFORESTRY

- Plant trees amongst crops
- Trees and livestock
- Trees, crops and livestock
- Trees and insects
- Trees and water animals
- Woodlots
- Boundary planting
- Dispersed interplanting
- Fruit orchards

TILLAGE AND RESIDUE MANAGEMENT

- No-tillage/zero-tillage
- Reduced tillage
- Pitting systems
- Stubble and residue mulch tillage
- Dibble stick planting
- Strip and spot tillage
- Ripping
- Ridge and furrow tillage
- Residue management

LAND RESTORATION AND REHABILITATION

- Natural regeneration
- Assisted natural regeneration
- Enrichment planting
- Fire management
- Agroforestry

INTEGRATED LIVESTOCK MANAGEMENT

- Improved feeding and watering
- Housing, stall management systems
- Improved waste management
- Pest and disease control
- Improved breeding practices

SUSTAINABLE ENERGY

- Biomass
- Biogas
- Farm residues
- Energy-efficient stoves
- Sustainable charcoal production

INTEGRATED PEST MANAGEMENT

- Biological pest control
- Use of crop-resistant varieties
- Alternative agricultural practices (spraying, use of fertilizers, pruning)
- Mechanical pest control
- Pesticides
- Cultural methods
- Pest management plan

Source: We Effect & Vi Agroforestry 2014

Methodologically, the Universal Soil Loss Equation (USLE) and the Revised Universal Soil Loss Equation (RUSLE) is applied, which has been established over 50 years ago and became globally one of the most widely applied empirical soil erosion models (Renard et al., 1997; Panagos, 2015c). The USLE model incorporates the main components of soil loss from sheet and gully erosion, which once parameterized can predict changes in soil erosion. The USLE and RUSLE are empirical model-based approaches used to assess long-term average soil erosion risk, quantified in tonnes per hectare per year. The model is designed to estimate long-term annual erosion rates on agricultural fields because of the considerable variation of the input parameters to varying weather conditions.

The model was selected because of its large adaptation rate among scientists, its relative simplicity and robustness (Kinnell, 2010) as well as representing a standardized approach. A combination of existing secondary data and project specific primary data can be used:

Table 2: **Key input information required for the RUSLE model**

Primary Data	Secondary Data
(Prevailing) farm practices Crop data	Precipitation and climate data Soil data Terrain (Slope inclination and length)

The methodology outlines two main impact quantification approaches; i. a generic approach which applies average farm values gathered from a representative sample group of project farms, ii. a spatial explicit approach, which allows to model individual farm level estimation of soil erosion and water impacts using to model (
Figure **3**).

The project developer needs to decide between one of the two main approaches - average or spatial explicit.

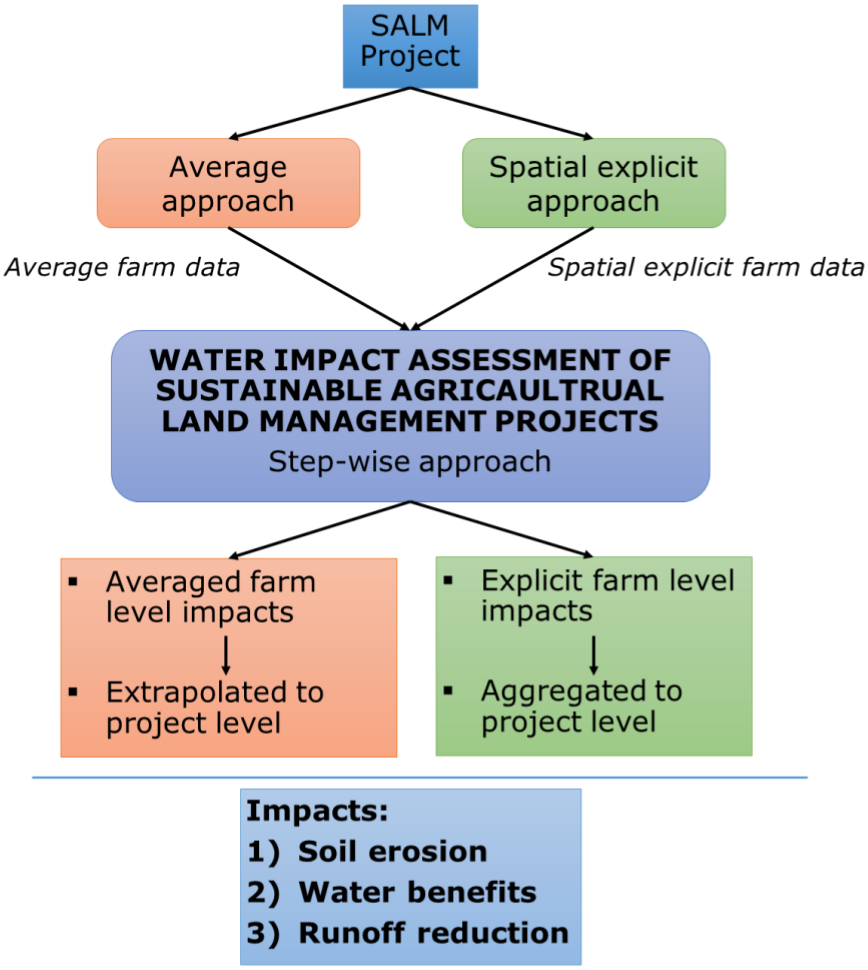

Figure 3: Overview of methodologic approaches

This methodology provides a stepwise approach guiding the project developer through the application of the model and also explaining how to source and process the input data. Figure 4 shows the overall flow of the stepwise approach of the methodology, which data inputs are required, and which deliverables and products will be expected after each step.
A generic overview of the steps required for baseline and project assessment is presented in Figure 4, below. The detailed assessment and calculation approach for each step is outlined in a corresponding Tool in Section 5. The relevant tool number is referred to under each step.

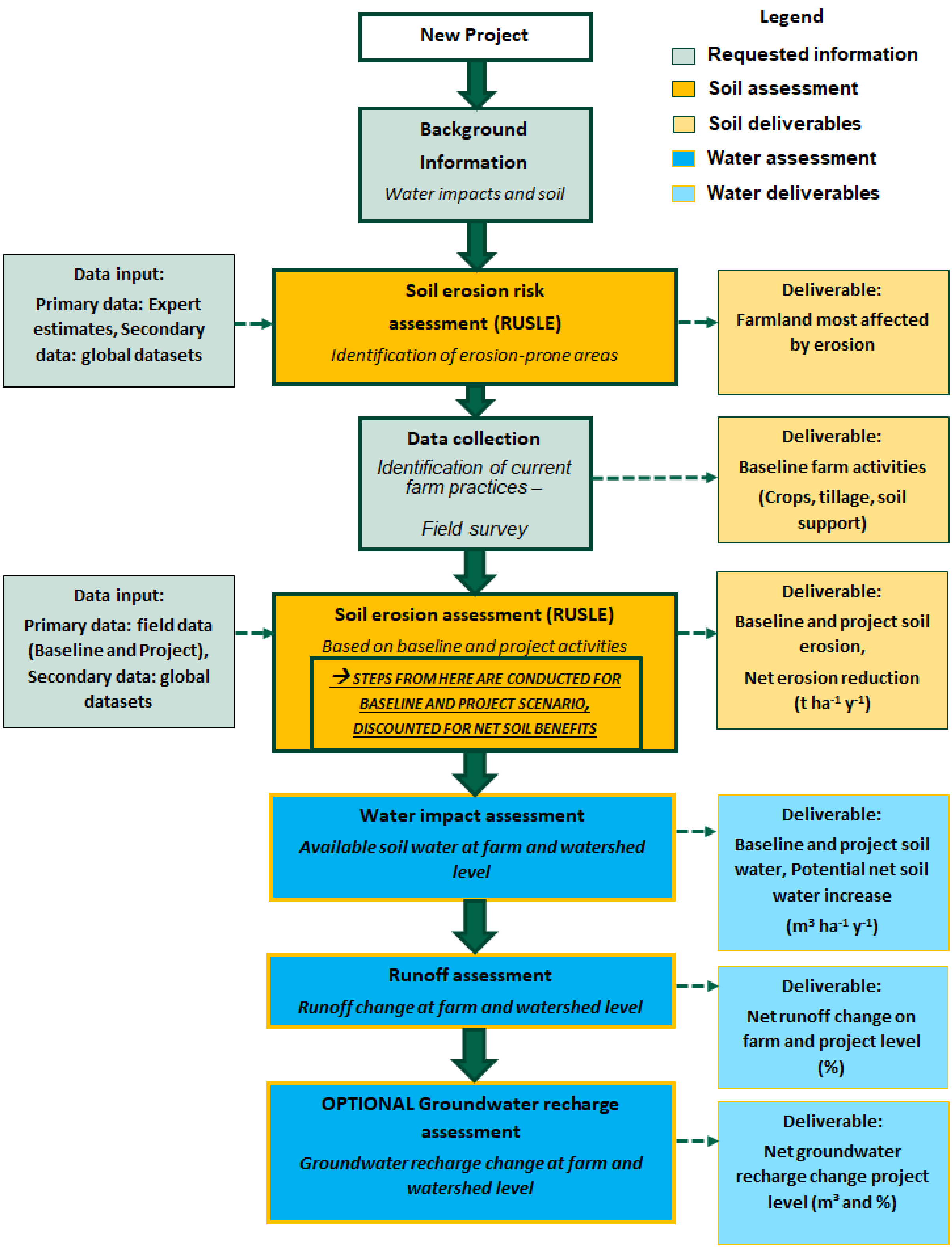

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Figure 4: Schematic overview of the stepwise approach

2.2 APPLICABILITY

Geographic Location - Projects are eligible in all countries.

Project area - The project area on which the baseline management systems are implemented shall be the same area of land on which the sustainable agricultural land management (SALM) practices are implemented in the project.

Land use system - The project shall not lead to a land use change. The agricultural land has been in place for at least 5 years prior to the implementation of the project.

Food security - No reduction in crop yield which can be attributed to the project activity shall be allowed. Activities in the project area shall deliver a yield at least equivalent to the baseline yield i.e., five year average, prior to project start. If regional crop productivity changes (e.g. due to climatic factors), yield in project area shall not decrease significantly more than regional yield.

3. BASELINE METHODOLOGY

3.1 IDENTIFICATION OF HIGH EROSION RISK AREAS (RUSLE)

To assess erosion and water impacts for new and existing projects at the farm and watershed level, areas more prone to sheet and gully erosion and where project activities would have the highest impact will be identified.

This step can be conducted in particular for new projects, where the final project boundary is not set yet, to identify areas which would likely have most significant project impact; or existing projects, in order to identify a rough estimate of soil erosion risk within the existing project boundary and where project activities should focus on. This section explains how to map erosion risk for project areas and identify the most vulnerable areas, to establish a new project or to identify the areas most vulnerable to erosion within an existing project.

At this point, refer to **TOOL 1 – The RUSLE equation** in Section 5. After reading Tool 1, this chapter continues with the required input data and other specifications needed to continue for the application of this tool, especially the input data requirements for the erosion risk mapping.

3.1.1 Erosion risk mapping information

As this step only requires a low degree of detail and certainty, the primary data inputs can be derived from expert estimates or literature to identify only prevailing land use and soil conservation practices to simplify the mapping. However, secondary data can also be derived from global or local databases. Table 3 below suggests available generic global databases, which provides sufficient detail to conduct the modelling with the RUSLE approach.

Table 3: Data input suggestions for soil erosion risk mapping

Data input	RUSLE Factor	Database suggestions
Secondary data		
Precipitation	R	- Worldclim.org
Soil properties	K	- Harmonized World Soil Database (
Terrain (slope length and inclination)	LS	- ASTER DEM(global; NASA, 2011) - other DEM's
Primary data		
Crop type and management	C	Prevailing farm practices (dominating or average crop types and tillage methods) from expert estimates and recent studies.
Soil conservation practices	P	Prevailing farm practices (dominating or average crop types and tillage methods) from expert estimates recent studies.

Once calculated, the soil erosion in tons per ha and year can be categorized into different soil loss tolerance classes. These classes are as follows for Ontario, Canada, however, can be different for different regions (Omafra, 2015).

Very low	<6.7	tons/ha yr.
Low	6.7 - 11.2	tons/ha yr.
Moderate	11.2 – 22.4	tons/ha yr.
High	22.4 – 33.6	tons/ha yr.
Severe	>33.6	tons/ha yr.

The farms/ areas assessed can be mapped according to the erosion classes, and new or ongoing projects can determine where sustainable land management interventions will create the largest impact.

Identification of these areas within the project will provide an overview of where SALM is best suited to increase water storage by reducing annual soil loss. These impacts can broadly be categorized as; a) farm level impacts measured in increased soil available water and b) impacts at the watershed level which can be seen as reduced rainfall runoff and sedimentation.

3.2 PROJECT BOUNDARY

The spatial boundary encompasses the results of SALM activities that are under the 'project owner's control' by ownership or legal contract of the impact rights by farmers. SALM activities in the project area resulting in increased water benefits (decreased runoff, increased water storage in the soil) and reduced erosion are compared to the baseline.

The SALM project activities may contain more than one discrete area of land.

Any areas leaving the project during the project duration are conservatively considered full reversals (i.e. loss of all water and soil erosion benefits). According to the Gold Standard LUF requirements Section 7, Requirements 1 and 2, the project owner is responsible for maintaining or compensating losses, which are already issued. If new areas are added to the project, they have to be documented and audited according to procedures described in the Gold Standard LUF Requirements for the 'New Area Certification'.

3.3 SELECTION OF BASELINE SCENARIO

The baseline scenario is identified as the existing or historical agricultural land management practices (BAU scenario), which would continue to exist in the absence of the project activities. The project owner can use the most recent version of the Additionality section in the Gold Standards "LUF Requirements" as reference to identify the baseline scenario.

To justify the baseline scenario the following procedure shall be followed:

Step 1) the project owner shall gather data to identify existing or historical agricultural land management practices using one of the two approaches below. The choice of the approach shall be justified.

Approach a) Field survey

- Establish a baseline survey using the Activity Baseline and Monitoring Survey (ABMS) protocol (see chapter 4). ABMS is a field-based assessment designed to gather data on farm level activities and prevailing practices. Using such information will allow for assessment of the baseline soil and water conditions. The same survey is also required to estimate the baseline soil erosion and water impacts and to monitor project impacts over time.

Approach b) Existing survey

- Use of existing survey data to identify existing or historical agricultural land management practices in the farming systems in the project area. The existing data shall be current, and in no case be older than 5 years form the project start.

Step 2) Validate the identified existing or historical agricultural land management practices by cross-checking with one or all of the following:

- Peer-reviewed publications from the project region;
- Publications of authoritative government agencies and research organizations;
- Independent Expert judgement

3.4 ESTIMATION OF BASELINE SOIL EROSION AND WATER IMPACTS

The estimation of baseline soil erosion and water impacts shall be set-up using stratified baseline input data applied with the different Tools presented below, such as RUSLE, soil water storage, runoff and, optional, groundwater recharge.

The input data entered into the models should represent area-weighted mean parameters of farm activities for the average approach, e.g. average area coverage of crops and soil conservation practices or specific farm activity data for the spatially explicit approach.

These parameters shall be obtained from:

A. A survey conducted specifically for the project
B. Existing data sources from available databases

STEP 1 Estimate baseline annual soil erosion (RUSLE)

The baseline soil erosion is assessed using the RUSLE TOOLS 1-6 and applying this model to assess the long-term average annual rate of soil erosion in the baseline based on rainfall pattern (R factor), soil texture (K factor), cover vegetation (C factor), slope (LS factor) and soil conservation practices (P factor).

RUSLE equation: $$A = R * K * LS * C * P \qquad (1)$$

Table 4: RUSLE factors

RUSLE factor	Description
A	long term average annual soil loss [$t \cdot ha^{-1} \cdot y^{-1}$]
R	Rainfall factor [$MJ\ mm\ ha^{-1} h^{-1}\ yr^{-1}$]
K	Soil erodibility [$t\ ha\ h\ ha^{-1}\ MJ^{-1} mm^{-1}$]
LS	Slope length and inclination factor [dimensionless]
C	Crop vegetation and management factor [dimensionless]
P	Support practice factor [dimensionless]

Table 5: Input data for the baseline assessment

Data category	Data
Secondary data **(R, K and LS factor)**	Available databases, literature and other sources
Primary data **(C and P factor)**	Project area specific existing survey data (existing or new survey)

Step 1a Derive Rainfall Erosivity Factor (R factor)

Use **Tool 2 Rainfall Erosivity Factor** to derive the erosivity factor for the baseline

Step 1b Derive Soil Erodibility Factor (K factor)

Use **Tool 3 Soil Erodibility Factor** to derive the erodibility factor for the baseline

Step 1c Derive Slope Length and inclination Factor (LS)

Use **Tool 4 Slope Length and inclination Factor** to derive the factor LS for the baseline

Step 1d Derive Crop vegetation and management factor (C factor)

Use **Tool 5 Slope Crop vegetation and management factor** to derive the factor C for the baseline

Step 1e Derive Support Practice Factor (P factor)

Use **Tool 6 Support Practice Factor** to derive the factor P for the baseline

By applying the RUSLE equation (1) the long-term average annual soil loss in $t{\cdot}ha^{-1}{\cdot}y^{-1}$ is estimated for the baseline.

STEP 2 Estimation of soil available water in the fraction of soil loss in the baseline

Every soil, due to its physical properties, can hold a specific quantity of water, which is mainly dependent on the particle size and the size of soil pores. Reducing soil loss due to soil erosion will automatically enhance the soil water storage by maintaining more soil on the site, which can hold a higher amount of water on site. The annual soil loss in the baseline is converted into soil volume and the water holding capacity of the particular soil is applied as a percentage. This estimates the water loss in m^3/ ha/ yr for the baseline.

Use **Tool 7 Estimation of soil available water** to derive soil available water in the fraction of soil loss in the baseline

STEP 3 Estimate baseline annual water runoff

The water runoff is estimated using the runoff curve number method together with the runoff coefficient as percentage runoff reduction. The runoff estimations are best suited for larger areas, due to the importance of runoff for catchments than for smaller areas such as fields. The specific input data for this step is defined by the preceding steps and by the CN number (Tool 8), which depends on the soil type and uses qualitative input data from crop type and soil support factors. In addition, annual precipitation data is needed.

Use **Tool 8 Runoff calculation** to derive water runoff in the baseline

This step determines the baseline runoff coefficient as a percentage based land use and cultivation practices.

Optional STEP 4 Estimate baseline annual groundwater recharge

The annual groundwater recharge in the baseline is calculated using the annual soil water balance, using input data, such as rainfall and runoff from the preceding steps. Further input data is needed and described in Tool 9. Although recharge rates are calculated on the basis of square meters it should be always kept in mind that groundwater recharge is a complex process, occurring only on larger areas. Therefore, groundwater recharge can be estimated as an optional assessment on the project (e.g. watershed) level.

Use **Tool 9 Groundwater recharge modelling** to derive total annual groundwater recharge in the baseline

3.5 ESTIMATION OF PROJECT SOIL EROSION AND WATER IMPACTS

Undertake an Activity Baseline and Monitoring Survey (ABMS) to identify the adoption of sustainable agricultural management practices in the project. The ABMS should estimate or record details of each management practice.

STEP 1 Estimate project annual soil erosion (RUSLE)

The project soil erosion is assessed using the RUSLE TOOLS 1-6 and applying this model to assess the long-term average annual rate of soil erosion in the baseline based on rainfall pattern (R factor), soil texture (K factor), cover vegetation (C factor), slope (LS factor) and soil conservation practices (P factor).

The project SALM activities mainly affect the C and P factor, due to changed land use practices, such as different crop factors, because of changed tillage applications and different soil conservation practices.
Therefore, for the estimation of project annual soil erosion, the C and P factor have to be adapted and recalculated to the project activities, while the R, K and LS factor can be used from the baseline, as these factors does not change and are stable.

Step 1a Derive Crop vegetation and management factor (C factor)

Use **Tool 5 Slope Crop vegetation and management factor** to derive the factor C for the project

Step 1b Derive Support Practice Factor (P factor)

Use **Tool 6 Support Practice Factor** to derive the factor P for the project

By applying the RUSLE equation (1) the long term average annual soil loss in $t \cdot ha^{-1} \cdot y^{-1}$ is estimated for the project.

STEP 2 Estimation of soil available water in the fraction of soil loss in the project

Follow the same procedure as used already in the baseline and calculate the soil available water in the fraction of soil loss in the project by converting the soil loss from weight into volume and apply the same soil-dependent water holding capacity that has been already used for the baseline.

Use **Tool 7 Estimation of soil available water** to derive soil available water in the fraction of soil loss in the project

STEP 3 Estimate project annual water runoff

The annual runoff in the project is calculated following the same procedure as in the baseline. Differences compared to the baseline will occur due to the reduced soil erosion rates.

Use **Tool 8 Runoff calculation** to derive water runoff in the project

This step determines the project runoff coefficient as a percentage based on SALM practices.

Optional STEP 4 Estimate project annual groundwater recharge

The annual groundwater recharge is calculated following the same procedure as in the baseline. Differences compared to the baseline will occur due to reduced runoff rates resulting from SALM practices.

Use **Tool 9 Groundwater recharge modelling** to derive total annual groundwater recharge in the project

3.6 NET ANTHROPOGENIC SOIL AND WATER IMPACTS

In order to estimate the net benefits of the project compared to the baseline the project soil erosion benefits have to be deducted from the baseline.

STEP 1 Estimate net soil erosion reduction

In order to estimate the net benefits of the project compared to the baseline the project soil erosion benefits have to be deducted from the baseline.

$$\Delta C_{\mathrm{SEro,t-0}} = (SEro_t - SEro_0) * (1 - UD) \qquad (2)$$

➔ Please use as input data the results from Tool 1-6.

$\Delta C_{SEro,t-0}$ *change in soil erosion in the calculation period [t soil]*
$SEro_t$ *soil erosion at the end of the calculation period [t soil]*
$SEro_0$ *soil erosion at the beginning (e.g. baseline) of the calculation period [t soil]*

UD *Uncertainty deduction [dimensionless]*

STEP 2 Estimate net potential soil water retention

The same procedure as in the preceding chapter has to be followed for estimating the net water benefits.

$$\Delta C_{SW,t-0} = (SW_t - SW_0) * (1 - UD) \quad (3)$$

➔ Please use as input data the results from Tool 7.

$\Delta C_{SW,t-0}$ *change in soil water in the calculation period [m³ water]*
SW_t *soil water at the end of the calculation period [m³ water]*
SW_0 *soil water at the beginning (e.g. baseline) of the calculation period [m³ water]*
UD *Uncertainty deduction [dimensionless]*

STEP 3 Estimate net annual runoff reduction

The same procedure as in the preceding chapter has to be followed for estimating the net annual runoff reduction.

$$\Delta C_{AR,t-0} = (AR_t - AR_0) * (1 - UD) \quad (4)$$

➔ Please use as input data the results from Tool 8.

$\Delta C_{AR,t-0}$ *change in annual runoff in the calculation period [%]*
AR_t *annual runoff at the end of the calculation period [%]*
AR_0 *annual runoff at the beginning (e.g. baseline) of the calculation period [%]*
UD *Uncertainty deduction [dimensionless]*

Optional STEP 4 Estimate net annual groundwater recharge

The same procedure as in the preceding chapter has to be followed for estimating the net annual groundwater recharge.

$$\Delta C_{GW,t-0} = (GW_t - GW_0) * (1 - UD) \quad (5)$$

➔ Please use as input data the results from Tool 9.

$\Delta C_{GW,t-0}$ *change in annual groundwater recharge in the calculation period [%]*
GW_t *annual groundwater recharge at the end of the calculation period [%]*
GW_0 *annual groundwater recharge at the beginning (e.g. baseline) of the calculation period [%]*
UD *Uncertainty deduction [dimensionless]*

3.7 DATA AND PARAMETERS NOT MONITORED OVER THE CREDITING PERIOD

Table 6: Data and parameters not monitored over the crediting period

Data/Parameter	Abbreviation	Data unit	Source of data	Purpose of data
Soil type per stratum y	ST_y	[dimensionless]	Project owners records, particle size distr.	Tool 3
Mean monthly temperature	T_m	°C	Project owners records OR existing databases, e.g. worldclim.org; 5 year average values	Tool 9
Mean monthly precipitation	P_m	mm	Project owners records, OR existing databases, e.g. worldclim.org; 5 year average values	Tool 2 & Tool 9
Mean monthly day length	N	12 hours	Project owners records	Tool 9
Field capacity	FC	mm	Project owners records	Tool 9
Rooting depth	Zr	mm	Project owners records	Tool 9
Soil particle distribution	$F_{Clay/Silt/Sand}$	%	Project owners records	Tool 3
Soil structure index	P_{ermI}	[dimensionless]	Project owners records	Tool 3
Soil permeability index	S	[dimensionless]	Project owners records	Tool 3
Cover rocks (if available)	f_{rf}	%	Project owners records	Tool 3

4. MONITORING METHODOLOGY

4.1 DATA AND PARAMETERS MONITORED

The project owner shall refer to the CDM sampling and surveys guideline for guidance on monitoring. Further, the project owner shall submit a monitoring report annually, containing at least the information listed in the LUF Activity Requirements and those in Table 8.

The project owner shall undergo a verification audit and performance review as stated in the Principles and Requirements.

4.1.1 Assessment of data and model applicability

The project owner shall document the impacts on SDG 2 to demonstrate the applicability of parameters and models in the used approaches based on field assessments at the project beginning. Due to the wide range of data used for this model the stratification process has to be designed conservatively. Strata have to be designed in a way depicting the wide range of different landscape conditions, but not to create too complex stratification.

The stratification of the project area and the farms or farming practices into similar strata is part of the design of the project specific ABMS survey. Stratification of the project region or project area should be based on agro-ecological reasoning, i.e., combining areas of the project with similar growing or site conditions, or similar farming systems, which would otherwise lead to significant differences in terms of soil erosion and water impacts from one stratum to another. Where there are important organizational or institutional stratification criteria such as benefit sharing among certain farmer groups, project layout of the extension system, etc., these criteria can be also used to define the strata, however, significant differences in ecological criteria needs to be always taken into account (differences in soil characteristics and management practices)

Criteria for the stratification are soil type, precipitation, terrain, land management or soil conservation practices.

Each stratum should be reflected by a representative amount of sample sites, where the requested parameters (Table 7) shall be measured to allow for the error range within the confidence interval according to the LUF Activity Requirements Annex A.

4.1.2 Activity Baseline and Monitoring Survey

The Activity Baseline and Monitoring Survey is a sample survey, which is used to derive area-weighted averaged farm parameters that are used as input data to calculate project related soil and water impacts. For guidance on conducting the survey for both baseline and project monitoring purposes, refer to the CDM Sampling and Survey Guideline. Project owners can use their own tools/data management systems as long as they can be transparently verified.

Table 7: Data and parameters collected for the baseline and calculation

Parameter	Abbreviation	Data unit	Recording frequency	Source of data
Total project area	A	ha	Project start	Project owners records
Area per stratum y	A_y	ha	Project start	Project owners records

Area per watershed	A_w	ha	Project start	Project owners records
Crop yield	Crop	t/ha	Project start	Project owners records
Crop/vegetation type in stratum y	C_y	[dimensionless]	Project start	Project owners records
Land use mixture, as the mixture of crops with trees per farm and stratum	$LUmix_y$	%	Project start	Project owners records
Crop/vegetation management(tillage, residues, cover crops)	$C_{management}$	[dimensionless]	Project start	Project owners records
Soil conservation practice per farm and stratum (grass margins, stone walls, contour farming, terrace)	P_y	[dimensionless]	Project start	Project owners records
Soil organic content per farm and stratum y	SOC_y	t C/ ha	Project start	Project owners records
Soil type per stratum y	ST_y	[dimensionless]	Project start	Project owners records, particle size distr.
Mean monthly temperature	T_m	°C	Project start	Project owners records
Mean monthly precipitation	P_m	mm	Project start	Project owners records
Mean monthly day length	N	12 hours	Project start	Project owners records
Field capacity	FC	mm	Project start	Project owners records
Rooting depth	Zr	mm	Project start	Project owners records
Soil particle distribution	$F_{Clay/Silt/Sand}$	%	Project start	Project owners records
Soil structure index	S	[dimensionless]	Project start	Project owners records
Soil permeability index	P_{ermI}	[dimensionless]	Project start	Project owners records
Cover rocks (if available)	f_{rf}	%	Project start	Project owners records

Table 8: Data and parameters monitored

Parameter	Abbreviation	Data unit	Recording frequency	Source of data
Total project area	A	ha	Annual	Project owners records
Area per stratum y	A_y	ha	Annual	Project owners records
Area per watershed	A_w	ha	Annual	Project owners records
Crop yield	Crop	t/ha	Annual	Project owners records

Crop/vegetation type in stratum y	C_y	[dimensionless]	Annual	Project owners records
Land use mixture, as the mixture of crops with trees per farm and stratum	$LUmix_y$	%	Annual	Project owners records
Crop/vegetation management(tillage, residues, cover crops)	$C_{management}$	[dimensionless]	Annual	Project owners records
Soil conservation practice per farm and stratum (grass margins, stone walls, contour farming, terrace)	P_y	[dimensionless]	Annual	Project owners records
Soil organic content per farm and stratum y	SOC_y	t C/ha	Annual	Project owners records
Soil type per stratum y	ST_y	[dimensionless]	Annual	Project owners records
Soil erosion per stratum y	$SEro_y$	t soil/ha/a	Annual	Project owners records
Runoff per watershed (farm and stratum y)	AR_y	mm	Annual	Project owners records
Groundwater recharge per watershed (farm and stratum y)	GW_y	mm	Annual	Project owners records

4.2 UNCERTAINTY

Uncertainty calculations follow the same approach as given by the Gold standard CDM sampling and surveys guideline. The project owner shall use a precision of 20% of the mean at the 90% confidence level as the criteria for reliability of sampling efforts. This target precision shall be achieved by selecting appropriate parameters, sampling and measurement techniques.

This uncertainty calculation can be done for all impact models, as well as all input factors of the RUSLE model. While the formulas show in this example the uncertainty calculation for the soil erosion impact, the same uncertainty calculation has to be calculated for water benefits and runoff reduction as well as all input parameters of the RUSLE model.

Step 1: Calculate the upper and lower confidence limits for all input parameters

Calculate the mean $\bar{X}_p$ and standard deviation σ_p, for each parameter used in stock calculations[5]. The standard error of the mean is then given by

$$SE_p = \frac{\sigma_p}{\sqrt{n_p}} \qquad (6)$$

SE_p	*standard error in the mean of parameter p*
σ_p	*standard deviation of the parameter p*
n_p	*number of samples used to calculate the mean and standard deviation of p*

If SE_p (mean standard error) is available directly from the parameter source (e.g. literature, metadata) it may be used directly in the following calculations (without the use of equation 6).

Example Info Box – Standard error:

A project of several thousand smallholder farmers apply sustainable agricultural practices and thus reduce soil erosion and increase water impacts on their farms. In order to assess the uncertainty of the model a sample of 650 farmers was selected and all parameters were measured using the project ABMS.

The uncertainty has to be calculated for the major model steps (soil erosion, soil water and runoff reduction, but also for the RUSLE input factors, e.g. for the R factor, etc. Here we calculate the overall soil erosion uncertainty derived from RUSLE.
For these 650 farmers is the standard error calculated using the standard deviation as follows:

$$0.29 = \frac{7.59}{\sqrt{650}}$$

Assuming that values of the parameter are normally distributed about the mean, values for the upper and lower confidence intervals for the parameters are given by

$$\text{Lower}_p = \bar{X}_p - t_{np} \times SE_p \qquad (7)$$
$$\text{Upper}_p = \bar{X}_p + t_{np} \times SE_p$$

$Lower_p$	*value at lower end of the 90% confidence interval for parameter p*
$Upper_p$	*value at upper end of the 90% confidence interval for parameter p*
$\bar{X}_p$	*mean value for parameter p*
SE_p	*standard error in the mean of parameter p*
t_{np}	*t-value for the cumulative normal distribution at 90% confidence interval for the number of X samples of parameter p (* Figure **5***).*

Example Info Box – Confidence interval:

The standard error is used to calculate the lower and upper confidence interval of the soil erosion at 90% confidence. The t value is retrieved from Figure **5**, multiplied with the standard error and added or subtracted from the mean soil erosion.

Upper:	17.67 + (1.6525 * 0.29) = 18.17	t/ha yr
Lower:	17.67 – (1.6525 * 0.29) = 17.18	t/ha yr

Step 2: Calculate the change of the soil erosion input parameters (RUSLE), soil erosion, soil water retention or runoff (ΔC_{RUSLE}, ΔC_{SEro}, ΔC_{SW}, ΔC_{AR}; t-0) with the lower and upper confidence interval values of the input parameters. Continue the steps with either of the main outputs.
From here onwards the uncertainty is demonstrated for the parameter ΔCSEro.

Apply the *Lower* and *Upper* parameter values in the models for a parameter change, e.g. $\Delta C_{SEro,\, t\text{-}0}$, for the time steps of $SEro_0$ and $SEro_t$, to achieve a lower and upper value for ΔC_{SEro}.

$$\text{Lower}_{\Delta CSEro} = \text{Model}_{SEro}\,\{\text{Lower}_p\} \qquad (8)$$
$$\text{Upper}_{\Delta CSEro} = \text{Model}_{SEro}\,\{\text{Upper}_p\}$$

$Lower_{\Delta CSEro}$	*lower value of soil erosion (SEro) change at a 90% confidence interval*
$Upper_{\Delta CSEro}$	*upper value of soil erosion (SEro) change at a 90% confidence interval*

$Model_{SEro}$	*calculation models for $SEro_t$, $SEro_0$ and $SEro_{BL}$*
$Lower_p$	*values at the lower end of the 90% confidence interval for all parameters p*
$Upper_p$	*value at the upper end of the 90% confidence interval for all parameters p*

n_p	t_{np}	n_p	t_{np}	n_p	t_{np}	n_p	t_{np}
		51	1.6759	101	1.6602	151	1.6551
		52	1.6753	102	1.6601	152	1.6550
3	2.9200	53	1.6747	103	1.6599	153	1.6549
4	2.3534	54	1.6741	104	1.6598	154	1.6549
5	2.1319	55	1.6736	105	1.6596	155	1.6548
6	2.0150	56	1.6730	106	1.6595	156	1.6547
7	1.9432	57	1.6725	107	1.6593	157	1.6547
8	1.8946	58	1.6720	108	1.6592	158	1.6546
9	1.8595	59	1.6715	109	1.6591	159	1.6546
10	1.8331	60	1.6711	110	1.6589	160	1.6545
11	1.8124	61	1.6706	111	1.6588	161	1.6544
12	1.7959	62	1.6702	112	1.6587	162	1.6544
13	1.7823	63	1.6698	113	1.6586	163	1.6543
14	1.7709	64	1.6694	114	1.6585	164	1.6543
15	1.7613	65	1.6690	115	1.6583	165	1.6542
16	1.7530	66	1.6686	116	1.6582	166	1.6542
17	1.7459	67	1.6683	117	1.6581	167	1.6541
18	1.7396	68	1.6679	118	1.6580	168	1.6540
19	1.7341	69	1.6676	119	1.6579	169	1.6540
20	1.7291	70	1.6673	120	1.6578	170	1.6539
21	1.7247	71	1.6669	121	1.6577	171	1.6539
22	1.7207	72	1.6666	122	1.6575	172	1.6538
23	1.7172	73	1.6663	123	1.6574	173	1.6537
24	1.7139	74	1.6660	124	1.6573	174	1.6537
25	1.7109	75	1.6657	125	1.6572	175	1.6537
26	1.7081	76	1.6654	126	1.6571	176	1.6536
27	1.7056	77	1.6652	127	1.6570	177	1.6536
28	1.7033	78	1.6649	128	1.6570	178	1.6535
29	1.7011	79	1.6646	129	1.6568	179	1.6535
30	1.6991	80	1.6644	130	1.6568	180	1.6534
31	1.6973	81	1.6641	131	1.6567	181	1.6534
32	1.6955	82	1.6639	132	1.6566	182	1.6533
33	1.6939	83	1.6636	133	1.6565	183	1.6533
34	1.6924	84	1.6634	134	1.6564	184	1.6532
35	1.6909	85	1.6632	135	1.6563	185	1.6532
36	1.6896	86	1.6630	136	1.6562	186	1.6531
37	1.6883	87	1.6628	137	1.6561	187	1.6531
38	1.6871	88	1.6626	138	1.6561	188	1.6531
39	1.6859	89	1.6623	139	1.6560	189	1.6530
40	1.6849	90	1.6622	140	1.6559	190	1.6529
41	1.6839	91	1.6620	141	1.6558	191	1.6529
42	1.6829	92	1.6618	142	1.6557	192	1.6529
43	1.6820	93	1.6616	143	1.6557	193	1.6528
44	1.6811	94	1.6614	144	1.6556	194	1.6528
45	1.6802	95	1.6612	145	1.6555	195	1.6528
46	1.6794	96	1.6610	146	1.6554	196	1.6527
47	1.6787	97	1.6609	147	1.6554	197	1.6527
48	1.6779	98	1.6607	148	1.6553	198	1.6526
49	1.6772	99	1.6606	149	1.6552	199	1.6526
50	1.6766	100	1.6604	150	1.6551	≥200	1.6525

Figure 5: t-values (t_{np} -) applicable in equation (4). Select appropriate tnp value depending on the number of samples (np) measured for parameter p.

Example Info Box – Model difference:

As we calculated the confidence interval for the baseline, we apply the same for the project scenario and calculate the difference between both.

Upper Baseline:	18.17	Upper Project:	7.93
Lower Baseline:	17.18	Lower Project:	7.34

Upper ΔSEro: 10.23 t/ ha yr
Lower ΔSEro: 9.84 t/ha yr

Step 3: Calculate the uncertainty in the model output

The uncertainty in the model output is given by

$$UNC = \frac{Upper_{\Delta CSEro} - \mathrm{Lower}_{\Delta CSEro}}{2x\Delta C_{SEro}} \tag{9}$$

UNC	*model output uncertainty [%]*
Lower$_{\Delta CSEro}$	*lower value of soil erosion (SEro) change at a 90% confidence interval [t soil/ ha yr]*
Upper$_{\Delta CSEro}$	*upper value of soil erosion (SEro) change at a 90% Confidence interval [t soil/ ha yr]*
ΔC_{SEro}	*change in soil erosion stocks between the baseline and project scenario [t soil/ ha yr]*

Example Info Box – Uncertainty calculation:

The uncertainty of the soil erosion is calculated using the confidence intervals of project and baseline scenario.

$$\frac{10.23 - 9.84}{10.03 * 10.03} = 2\%$$

Step 4: Adjust the estimate of soil erosion change (*ΔC_{SEro}*) based on the uncertainty in the model output

If the uncertainty of soil erosion change models is less than or equal to 20% of the mean soil erosion change value then the project owner may use the estimated value without any deduction of uncertainty. If the uncertainty of the model is greater than

20% of the mean value, the project owner shall use the estimated value subject to an uncertainty deduction (UD).

$$UD = UNC - 20\% \qquad (10)$$

UD	*uncertainty deduction [%]*
UNC	*model output uncertainty (>20%) [%]*

Example Info Box – Uncertainty deduction:

The overall model uncertainty defines, if an uncertainty deduction has to take place. In case the model is too uncertain, credits have to be deducted to stay conservative.
In the case of our example, the model uncertainty is below 20% and therefore no uncertainty deduction has to be taken into account.
However, if the uncertainty is above 20%, the full uncertainty minus 20% has to be deducted from the calculated model impacts.

5. TOOLS

TOOL 1: The RUSLE equation

The Revised Universal Soil Loss Equation (RUSLE) predicts the long-term average annual rate of soil erosion on a piece of land based on rainfall pattern (R factor), soil texture (K factor), cover vegetation (C factor), slope (LS factor) and soil conservation practices (P factor). It is one of the most widely used soil erosion models and has been refitted and readapted since its creation in the late 50's (Renard et al., 1997; Panagos et al., 2015c). Each factor is the numerical estimate of a specific condition that affects the severity of soil erosion. The values obtained represent long-term averages. It is crucial to understand how the data has to be stratified in order to receive reasonable results, depending whether the model has to be spatial explicit or is generic.

The following descriptions below shows the RUSLE factors (Tools 2 - 6) and how they are weighted and calculated for assessing soil loss and soil loss reductions (baseline and project scenarios) in $t \cdot ha^{-1} \cdot y^{-1}$ for increased water storage within the soil. Given that the RUSLE is the most widely used soil erosion model, many regional values for the model are available. The Global Land Degradation Information System (GLADIS) by FAO provides a database with all factors that are used within the RUSLE model.

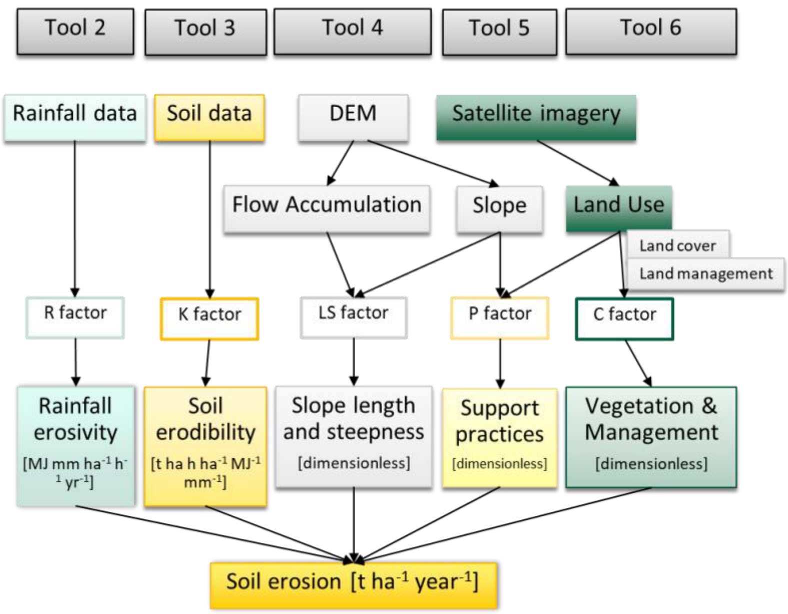

Figure 6: The RUSLE equation and rough outline of intermediate steps

$$A = R * K * LS * C * P \tag{1}$$

Table 9: RUSLE factors

RUSLE factor	Description
A	Long term average annual soil loss [$t \cdot ha^{-1} \cdot y^{-1}$]
R	Rainfall factor [$MJ\ mm\ ha^{-1} h^{-1}\ yr^{-1}$]
K	Soil erodibility [$t\ ha\ h\ ha^{-1}\ MJ^{-1} mm^{-1}$]
LS	Slope length and inclination factor [dimensionless]
C	Crop vegetation and management factor [dimensionless]
P	Support practice factor [dimensionless]

- ➔ The RUSLE model is applied for the entire project area, but accounted only for the farm level impacts.
- ➔ Each of the following factors that are used to calculate the RUSLE model represents a separate tool, which are described in the tools 2-6.
- ➔ The tool can be applied in a generic or a spatial explicit approach.

Example:
Project X and Y both want to estimate soil erosion losses and lost soil water. Both of them work with several thousand of smallholder farmers. Both projects know the total amount of farmers and their field area that participate in the project. They know precisely what kind of land management the farmers do and what changes they apply to their land.

The only difference is that project X has no digital file of the farm boundaries with GPS locations of each farmer, while project Y has. Project X can calculate soil erosion and soil water losses as well as project Y, however without pinpointing the effects to a specific area. The total amount of fields and farmers force the project to categorize farmers into strata of similar environmental and management conditions. Therefore, only average effects of management change can be calculated and thus only average values of the calculated benefits can be assigned to each farmer. Project Y however, can follow the spatial explicit approach and can calculate the soil erosion and lost soil water as well as its reversals due to sustainable agricultural management for each farmer in a GIS environment. This enables project Y to exactly assess all losses and benefits on a specific field of a farmer. Project Y knows exactly how many tones of soil get eroded in the northern corner of the field of farmer A, where he grows maize, while less soil get eroded in the southern part of his field, where he grows beans. The advantage is to pinpoint benefits to each farmer.

(a) Generic approach

$$SEro = \sum_{n=i}^{n} (area_i * A_i) \tag{11}$$

SERo	*Total Soil erosion (t/ ha yr)*
A	*Soil erosion*

i	*Stratum*

(b) Spatial explicit approach

$$SEro = \sum_i^n(\sum(Farea_i * A_i)) \quad (12)$$

SERo	*Total Soil erosion (t/ ha yr)*
A	*Soil erosion*
Farea	*Farm area*
i	*Stratum*

Example:
The following table is an example how the factors would aggregate.

Table 10: Example Baseline, project and net soil loss

	Factors					
	R	K	LS	C	P	soil loss t/ha^{-1} yr^{-1}
Baseline	8527	0.016	0.35	0.5	1	23.87
Project	8527	0.016	0.35	0.37	0.5	8.83
Benefit						**15.04**

In the example and on average approximately **15.04 t·ha^{-1}y^{-1}** of soil loss would be reduced.

TOOL 2: RAINFALL EROSIVITY FACTOR (R FACTOR)

R is the rainfall and runoff factor (MJ mm ha^{-1}h^{-1} yr^{-1}) given by geographic location based on long-term cyclical rainfall patterns. It is derived from E, the kinetic energy of a rainfall event and I30, the maximum intensity of rain in 30 minutes expressed in cm per hour.

Detailed information on both rainfall and rainfall intensity are needed for a direct estimation of the R-factor. Since this data is in most of the cases difficult to obtain, a simplified approach, based on empirical formula can be used to estimate R.

The simplified approach uses average annual or monthly precipitation data to determine the erosivity index. Empirical equations are available for different countries. This methodology will provide a basic set of different equations for a wide variety of different agro-ecological zones, which can be retrieved from Table 11. The project developer is recommended to check, if the equations used are up to date, or even to introduce and use new equations, published in a peer-reviewed journals. The scientific literature can serve as justification for the application of empirical equations. In case no equation can be retrieved for a specific country, equations with for countries of the same AEZ can be used to calculate the R factor.

Note that the R factor is unlikely to change between baseline and project scenario[1].

(a) Spatial explicit calculation:

Suggestions, how a spatial explicit calculation could look like can be retrieved from a publication by Millward and Mersey, 1999, even though the formulas might not be exactly the same. Furthermore, the scientific community undertook efforts to model global erosivity, which are publicly available (Panagos et al., 2017).

[1] The source of underlying data and calculation approach should remain for entire CP and for baseline and project scenario calculation.

Table 11: Rainfall erosivity factor equations

Country	Formula	AEZ	Source	Comment
Spain/ Morocco	$R = 1.05 * MFI_5$ $MFI = \frac{\sum_{i=1}^{12} P_i^2}{P}$	warm temperate dry	Arnoldus (1977) Hernando and Romana (2015)	
Ethiopia/ Egypt	$R = 0.55 * MAP - 24.7$	warm temperate moist	Hurni, H. (1985)	
Thailand	$R = 38.5 + 0.35 * MAP$	tropical moist	Harper (1987)	
Indonesia	$R = \frac{2.5 * P^2}{100 * (0.073P + 0.73)}$	tropical wet	Bols (1978)	
India	$R = 0.4043 * MAP_{10}^{1.112}$	warm temperate moist	Tiwari et al. (2015)	
Kenya	$R = 117.6 * (1.00105^{MAP})$	tropical dry	Kassam et al. (1992)	For regions < 2000mm precipitation
Côte d’Ivoire/ Burkina Faso	$R = P * 0.5$	tropical moist/dry	Roose, In: Morgan Davidson (1991)	

Notes: MAP, Mean Annual precipitation (mm);MAP_{10}, Mean Annual precipitation – 10 year average P, Annual Rainfall (mm); Pi, Average monthly precipitation; MFI_5, Modified Fournier index for 5 years; MFI, Modified Fournier index

TOOL 3: SOIL ERODIBILITY FACTOR (K FACTOR)

K is the average soil loss (t ha h ha^{-1} $MJ^{-1}mm^{-1}$) for a particular soil in cultivated, continuous fallow with an arbitrarily selected slope length of 22.13 m and slope steepness of 9%. K is a measure of the susceptibility of soil particles to detachment and transport by rainfall and runoff. Soil texture is the principal factor affecting the K factor. However, soil structure, organic matter and permeability also affect the potential soil erodibility significantly.

The K factor was always calibrated using the soil nomograph developed by Wischmeier and Smith (1978). It was further converted to metric units by Renard et al. (1997). The formula used here by Auerswald (2014) is based on the widely used nomograph and very similar to the formula used by Panagos et al. (2014), who modelled soil erosion for the entire continent of Europe.

$$K = \frac{K_1 * K_2 + 0.043 * (S-2) + 0.033 * (P_{ermI} - 3)}{10} \tag{13}$$

$$K_1 = 2.77 * M^{1,14} * 10^{-5} \tag{14}$$

$$K_2 = \left(\frac{12 - OM}{10}\right) \tag{15}$$

$$M = f_{\%silt + \%very\ fine\ sand} * \left(100 - f_{\%clay}\right) \tag{16}$$

$$OM = 1.72 * C_{org} \tag{17}$$

$f_{\%silt/clay/very\ fine\ sand}$	*Fraction (%) of the respective soil particle group* *Note: the very fine sand fraction is estimated to be 20% of the entire sand fraction (Panangos et al., 2015).*
OM	*Organic matter content (%); Max: 4%*
C_{org}	*Organic carbon content (%)*
S	*Soil structure index: 1 - 4, very fine granular (1) - blocky (4)*
P_{ermI}	*Permeability index: 1 -6, rapid (1) – very slow (6)*

Table 12: Permeability Indices (Panagos et al., 2015c)

Permeability class		Soil Texture	Saturated hydraulic conductivity, mm h^{-1}
1	fast and very fast	Sand	>61.0
2	moderate fast	Loamy sand, sandy loam	20.3 – 61.0
3	moderate	Loam, silty loam	5.1 – 20.3
4	moderate low	Sandy clay loam, clay loam	2.0-5.1
5	slow	Silty clay loam, sandy clay	1.0-2.0
6	very slow	silty clay, clay	<1.0

Table 13: Soil structure index (Huang et al., 2012)

Soil structure index	Soil structure	Particle size (mm)
1	Very fine particles	<1.0
2	Fine particles	1 - 2
3	Medium or coarse particles	2 – 10
4	Blocks, shales or coarse particles	>10

The nomograph or the equation by Auerswald (2014) is valid for most of the soil conditions, however limitations occur in soils with high silt contents (silt+very fine sand fraction >70%), soils with low erodibility (K<0.2) and soils with rock fragments covering the ground (>1.5%).
Auerswald (2014) suggests the following equations to apply in either of the conditions:

(18)

High silt contents:

$$K = 0.631 * 2.77 * 10^{-5} * \left(\left(f_{Si+vfSa}\right) * (100 - f_{Cl})\right)^{1.14} + 0.0024 * f_{Si+vfSa} + 0.161$$

Low erodibility:

(19)

$$K = 0.091 - 0.34 * K_1 * K_2 + 1.79 * (K_1 * K_2)^2 + 0.24 * K_1 * K_2 * S + 0.0033 * (P_{ermI} - 3)$$

Rock fragment cover:
The rock fragment cover adds another component to the C factor instead of directly addressing rock fragments to the K factor. This C factor amendment has to be applied after the initial C factor has been calculated.

(18)

$$C = 1 \qquad \text{for } f_{rf} < 1.5\%$$

$$C = 1.1 * \exp\left(-0.024 * f_{rf}\right) - 0.06 \qquad \text{for } f_{rf} > 1.5\%$$

f_{rf} *fraction (%) of soil surface covered with rocks*

In case no information is available, the rock cover amendment equation might be neglected.

Data sources can be global soil databases (including parent material and soil texture) for soil classification. Major soil properties won't change over time (Angima, 2003). Soil tests, which are conducted on site, can be used to validate the results from global databases or can be used to increase the accuracy of the modelling (Tier approach). Scientific literature will be needed to assess the measurement results.

TOOL 4: SLOPE LENGTH AND INCLINATION FACTOR (LS)

The LS factor represents a ratio of soil loss under given conditions to that at a site with the "standard" slope steepness of 9% and slope length of 22.13 m (Wischmeier and Smith, 1978). The steeper and longer the slope, the higher the risk for erosion. Therefore, the units, which have to be used for this formula need to be in meters (m) for slope length and in percent gradient (%) for slope steepness.
Quantifying the LS factor can be seen in the formula below:

$$LS = (0.065 + 0.0456 * \text{slope} + 0.006541 * \text{slope}^2) * \left(\frac{\text{slope length}}{22.1}\right)^{NN} \tag{20}$$

Where

Slope	*Slope inclination in [%]*
Slope length	*Slope length in meters [m]*
NN	*representative of slope as:*

Table 14: NN values for different slope gradients

S	< 1	1 ≤ slope < 3	3 ≤ slope < 5	≥ 5
NN	0.2	0.3	0.4	0.5

Spatial explicit calculation:
The spatial explicit calculation can be retrieved from various scientific publications. However, mostly the chronology of DEM processing the easy approach of filling the DEM and applying the flow direction and flow accumulation calculations in order to retrieve the flow path (length) and feed the result with the slope inclination into the above mentioned formula (Millward and Mersey, 1999).

TOOL 5: THE CROP VEGETATION AND MANAGEMENT FACTOR (C FACTOR)

The C-factor is for the project developer one of the most important factors with regards to land use decisions. It represents the ability of vegetation to reduce erosion, when compared to bare fallow areas (Renard et al., 1997). Therefore, different land use management systems will have different cover vegetation types, which can be changed in a relative short time. A C factor of 1 signifies high erosion and low vegetation and 0 means low erosion and high vegetation cover. The variety of different plants used in agriculture have therefore different C factors, which furthermore depend strongly on the management. For ~~In~~ example, a C factor of 0.5 (corn) signifies, that 50% of the erosion compared with bare area conditions will occur, not incorporating the management.
The aim for a project developer is to reduce the C (and P) factor, in order to reduce soil erosion. This is done applying different sustainable agricultural land management practices, such as agroforestry, conservation tillage, keeping residues and cover crops or simply to plant trees.
C factor are calculated using default values for the crop itself and multiplying it with a specific crop management factor, as proposed by Panagos et al.(2015a). Note that arable and non-arable land have different ways to calculate the C factor:

C factor – arable land

$$C_{arable} = C_{crop} * C_{management} \tag{21}$$

C_{crop}	*Default crop and vegetation value*
$C_{management}$	*Crop management value*

$$C_{management} = C_{tillage} * C_{residues} * C_{cover} \tag{22}$$

$C_{tillage}$	*Tillage management*
$C_{residues}$	*Residue management*
C_{cover}	*Cover crop management*

Table 15: Tillage options and values

Tillage type	C tillage value
Conventional tillage	1
Conservation tillage	0.35
No tillage	0.25

If different tillage types are applied on one farm the equation is as follows:

$$C_{tillage} = (F_{conventional} * 1) + (F_{conservation} * 0.35) + (F_{No-till} * 0.25) \quad (22)$$

$F_{conventional/conservation/no\text{-}till}$ *Fraction of tillage application (%)*

Various studies, revised in Panagos et al. (2015a) have shown that residues kept on the site reduce erosion, reduce runoff and increase infiltration. Several studies reported reductions of up to 30%, however a qualified estimation is at 12% reduction:

$$C_{residues} = 1 * (0.88 * F_{res}) + (1 - F_{res}) \quad (23)$$

F_{res} *Fraction of residue coverage (%)*

Cover crops reduce the velocity of raindrops and help thus to reduce loss of soils and nutrients. It is common agricultural practice to keep the soil bare during winter or seasons of low plant activity. This factor is used for crops solely grown for the purpose of soil and nutrient protection during seasons of low or no plant growth, such as winter. Cover crops grown in between the main crop should be addressed in the crop default factor. Be aware that this factor should not be applied, if there is no non-vegetation season (moist tropics) or if the C_{crop} factor already covers most of that period, e.g. wet rice with several cycles, etc. The soil erosion is approximately 20% less than without cover crops.

$$C_{cover} = 1 * \left(0.8 * F_{crop-cover}\right) + (1 - F_{crop-cover}) \quad (24)$$

$F_{crop\text{-}cover}$ *Fraction of crop-coverage during the non-vegetation period (%)*

The calculated crop factors of several studies are compiled for arable and non-arable land in Table 16 and Table 17. Due to the ongoing utilization of the RUSLE method new C values might get published, which are not covered by the tables. We therefore recommend the project developer to check the peer reviewed scientific literature for key crop factors.

Table 16: Arable land crop factors

ICC group name	ICC crop group	Crop	C factor	Source	Study area country
Cereals	1	Cereals (spring & winter)	0.35	Omafra (2015)	CA
		Corn Average	0.15	Vezina, 2005; Hurni, 1985; Omafra (2015)	VN, ET, CA
		Millet	0.10	Hurni, 1985	ET
		Rice Average	0.25	Kuok, 2013; Vezina, 2005	VN, MY
		Silage corn	0.50	Omafra (2015)	CA
		Teff	0.25	Hurni, 1985	ET
		Wheat and Barley	0.15	Hurni, 1985	ET
		Average Cereals	0.25		
Vegetables	2	Seasonal Horticultural crops	0.50	Omafra (2015)	CA
		Average Vegetables	0.50		
Fruits and Nuts	3	Banana	0.09	Angima, 2003	KE
		Berry plantations	0.15	Panagos, 2015a	EU
		Fruit trees	0.10	Omafra (2015)	CA
		Grapes/Wineyards	0.30	Panagos, 2015a	EU
		Oranges	0.13	Shi, 2004	CN
		Average Fruits and Nuts	0.12		
Oilseed crops	4	Canola	0.50	Omafra (2015)	CA
		Oil palm	0.20	Kuok, 2013	MY
		Olive	0.15	Panagos, 2015a	EU
		Soy	0.69	Vezina, 2005	VN
		Average Oilseeds	0.35		
Roots and Tubers	5	Cassava	0.54	Vezina, 2005	VN
		Average Roots and tubers	0.54		
Beverage and spice crops	6	Cocoa	0.20	Kuok, 2013	MY
		Coffee	0.30	Kuok, 2013; Angima, 2003	MY, KE
		Tea	0.20	Kuok, 2013	MY
		Average Beverage and spice crops	0.25		
Leguminous crops	7	Beans	0.40	Kuok, 2013; Omafra (2015)	MY, CA
		Pulses	0.16	Hurni, 1985; Hurni, 1988	ET
		Average Leguminous crops	0.24		
Sugar crops	8	-	-		
Other	9	Cotton	0.20	Nyakatawa, 2007	US
		Rubber	0.20	Kuok et al., 2013	MY
		Average Other	0.20		

Note: This table compiled published C factor values from various scientific publications and geographical regions. But the table imposes no claim to be complete. The project developer is recommended to check whether the required C factor values of a crop not mentioned here has been published in a more recent publication.

C factor - Non-arable land

Non-arable C factors do not require the management factor, but might be applied if the management applies, e.g. tillage in a pasture.

Table 17: Non-Arable land crop factors

Land use group	Land use	C factor	Source	Study area country
Forests	Broadleaved Forest	0.002	Panagos, 2015a	EU
	Coniferous	0.002	Panagos, 2015a	EU
	Mixed	0.002	Panagos, 2015a	EU
	Degraded Forest	0.05	Hurni, 1985	ET
	Open Woodland	0.06	Eweg and van Lammeren, 1996	ET
	Mixed Dipt. Forest	0.002	Kuok, 2013	MY
	Average Forest	0.002		
Grass- and Rangeland	Natural grassland	0.045	Panagos, 2015a	EU
	Mixed Shrub and Grassland	0.18	Ranzi, 2012	VN
	Savanna	0.18	Ranzi, 2012	VN
	Average Grassland	0.035	Hurni, 1985; Ranzi, 2012; Eweg and van Lammeren, 1996; Kuok, 2013; Omafra (2015)	ET, VN, MY, CA
Mixed Crop and pasture	Dryland cropland and pasture	0.5	Ranzi, 2012	VN
	Irrigated cropland and pasture	0.18	Ranzi, 2012	VN
	Mixed dryland, irrigated cropland and pasture	0.5	Ranzi, 2012	VN
	Agroforestry	0.08	Panagos, 2015a	EU
Shrub and herbaceous lands	Mires and heathland	0.055	Panagos, 2015a	EU
	Sclerophyllous veg.	0.055	Panagos, 2015a	EU
	Transitional woodland shrub	0.027	Panagos, 2015a	EU
	Afro-Alpine	0.01	BCEOM, 1998	
	Average Shrub and Herbaceous vegetation	0.0455		
Wetlands	Herbaceous Wetland	0.18	Ranzi, 2012	VN
	Wooded wetland	0.003	Ranzi, 2012	VN
Open spaces, little or no vegetation	Tundra	0.1	Panagos, 2015a	EU
	Badlands, Steppes	0.45	Panagos, 2015a	EU
	Bare rocks	0	Panagos, 2015a	EU
	Beaches, Dunes, Sands	0	Panagos, 2015a	EU

	Burnt areas	0.325	Panagos, 2015a	EU
Open water		0		
Glaciers		0		
Urban and Settlement	Settlement, Cleared	0.25	Kuok, 2013	MY
	Urban, Settlement	0	Ranzi, 2012	VN

Note: This table compiled published C factor values from various scientific publications and geographical regions. But the table imposes no claim to be complete. The project developer is recommended to check whether the required C factor values of a crop not mentioned here has been published in a more recent publication.

Spatial explicit calculation

Spatial explicit crop and tillage values can be assigned, using a land use map and delineating/separating it into the different watersheds/strata of the project, depending on the grown crops and the mixture with trees on the site.

TOOL 6: SUPPORT PRACTICE FACTOR (P FACTOR)

The P-factor expresses the overall effect of soil conservation practices on agricultural soils. It is the ratio (dimensionless) how much soil erosion occurs, if certain soil conservation practices are applied in comparison to no adoption of such practices.
Because soil conservation measures are ultimately a matter of cost, less efficient but also cheaper practices are adopted first, before more efficient, but also costlier practices are adopted. Therefore, the P factor is dependent on the topology of the area and mostly just used on agricultural areas, e.g. terraces make less sense on flat terrain. Additionally, recent studies have shown that soil conservation practices are also used on non-arable land, however less often.

A widely recognized study by Panagos et al. (2015b) estimated P factors for the European Union. He estimated the P factor based on 3 important soil conservation practices: Contour farming, grass margins and stone walls. The steeper the slope, the less efficient are the practices. Contour farming efficiency is directly linked with the slope gradient, while Stone walls and grass margin P factors were estimated based on the observed frequency. The reference transect is 250m long. Therefore, the project developer has to observe the frequency of these measures on the project area. Other studies apply only default values, which are not linked to the slope and scientific debate about their accuracy is ongoing.
However, a mixture of calculation and default values is proposed for calculating the P factor of all non-terraced fields (Panagos et al., 2015b). For **terraced fields** a **default factor of 0.15** is applied (Kuok et al., 2013), without the option to use additional erosion reductions deriving from the P factor calculation by Panagos et al. (2015b). This assumes that the slope gradient on a terraced field is reduced to less than 9%. In case higher slope percentages on a terraced

field occur the P calculation by Panagos et al. (2015b) applies and no terrace default value can be applied.

The P factor according to Panagos et al. (2015b) is calculated for common agricultural fields as follows:

$$P = P_c * P_{sw} * P_{gm} \tag{25}$$

P_c *P factor - contour farming*
P_{sw} *P factor - stone walls*
P_{gm} *P factor - grass margins*

Table 18: Contour support practice factor

Slope %	P_c - value
9-12	0.6
13-16	0.7
17-20	0.8
21-25	0.9
>25	0.95

Table 19: Stone wall and grass margin support practice factor

No. of features	P_{sw} - value	P_{gm} - value	Length to next feature (m)
0	1	1	0
1	0.707	0.853	250
2	0.577	0.789	125
3	0.5	0.75	83.3
4	0.448	0.724	62.5
5	0.408	0.704	50
6	0.378	0.689	41.7
7	0.354	0.677	35.7
8	0.334	0.667	31.25
>8	0.317	0.66	< 31

Note: The frequency of stone walls or grass margins reduces the effective slope length. Therefore, these P values are connected to slope, but not to the inclination according to Panagos et al. (2015b).The length to the next feature depends on the 250m transect.

If a field is terraced the following formula applies:

(26)

$P = P_c * P_{sw} * P_{gm}$ For terraced slope > 9%

$P = 0.15$ For terraced slope < 9%

TOOL 7: ESTIMATION OF SOIL AVAILABLE WATER

This tool estimates the effect of topsoil stabilization on the availability of soil water in $m^3\ ha^{-1}\ y^{-1}$. Soil can hold a specific quantity of water, which is mainly dependent on the particle size and mixture as well as soil pores. Reducing soil loss due to soil erosion will automatically enhance the soil water storage by maintaining more soil on the site, which is able to hold a greater amount of water on site.
Sustainable agricultural land management practices will affect only the uppermost 30cm of the soil. However, only water that is between the permanent wilting point (unsaturated soil water) and the field capacity (soil water saturation) is plant available and called "total available soil water" (TAW).

Generic approach

(27)

$$SW = \sum_{i=1}^{n} (SW_i * area_i)$$

SW	*Total annual soil water*
SW_i	*Annual soil water per stratum*
$area_i$	*Area in ha per stratum*

Spatial explicit approach

The spatial explicit approach does not need any strata. However, of course a farm will have different management practices, which will be treated as strata per farm. All mentioned steps in Tool 7 are applied pixel wise in a GIS software and can be aggregated spatial explicit per farm/project area.

(28)

$$SW = \sum \sum_{i=1}^{n} (SW_i * farm\ area_i)$$

SW	*Total annual soil water*
SW_i	*Annual soil water per stratum*
Farm $area_i$	*Area in ha per stratum*

General steps

(29)

$$\mathrm{SW} = V_{soil} * \mathrm{TAW}$$

SW_i	*Soil water (m^3/ ha yr)*
Vsoil	*Soil retention volume (m^3/ ha yr)*
TAW	*Total available soil water capacity (%)*

(30)

$$TAW = FC - PWP$$

TAW	*Total available soil water capacity (%)*
FC	*Field capacity (%)*
PWP	*Permanent Wilting Point (%)*

Identify the FC and PWP by entering the specific soil texture class into Figure 7 and retrieve the data from the soil moisture range chart. The soil texture class can be identified entering the known soil fraction shares from Factor K into Figure 8 (Tool 2).

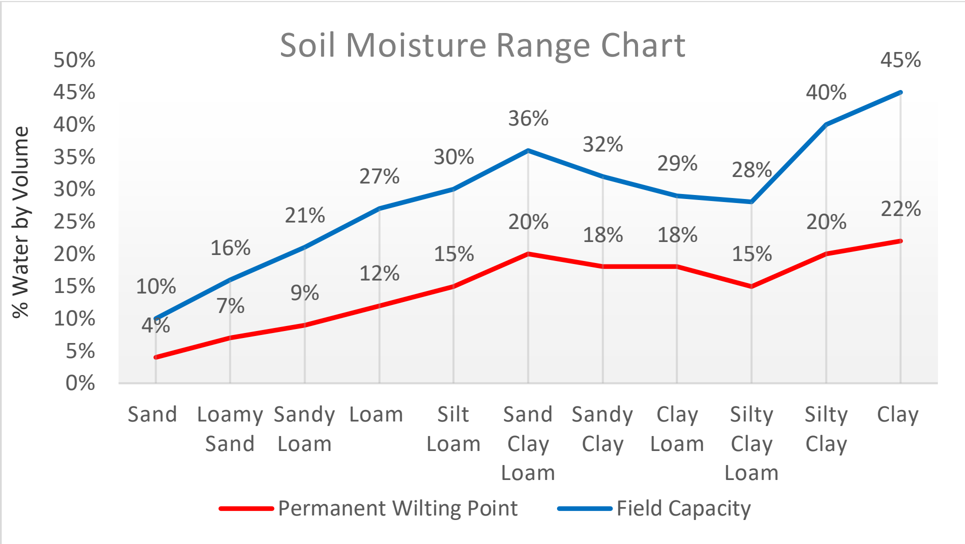

Figure 7: Soil moisture range based on soil type (Omafra, 2015; Based on data from Ratliff et al., 1983)

Texture classes:

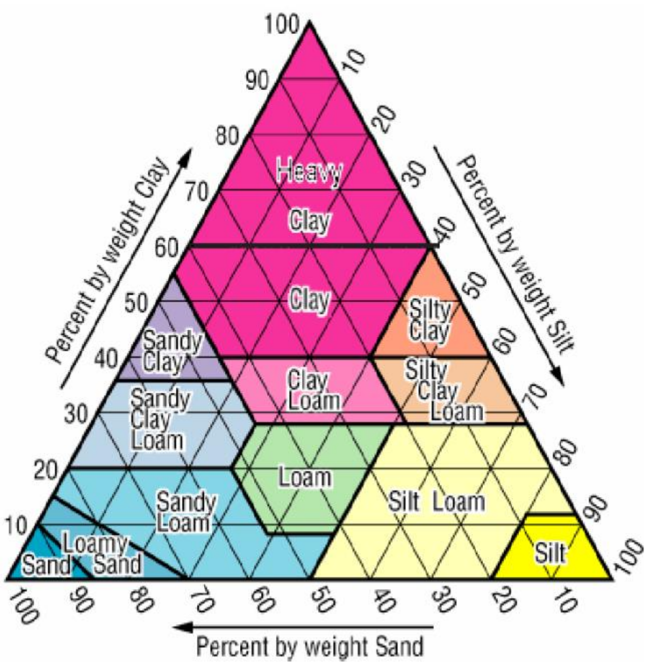

Figure 8: Soil texture class distribution according to soil fraction distribution, FAO, 2009

Convert soil erosion loss into volume using the bulk density of the soil texture class. The Bulk density from Figure 9 can be used or spatial explicit data can be applied.

$$V_{soil} = W_{soil} * BD \tag{31}$$

V_{soil}	*Soil volume (m^3/ ha yr)*
W_{soil}	*Soil weight (t/ ha yr)*
BD	*Bulk density (kg/m^3)*

Texture Class	Bulk Density (g cm^{-3})
Sand	1.65
Loamy sand	1.6
Sandy loam	1.55
Loam	1.5
Sandy clay loam	1.5
Silty clay loam	1.5
Silty loam	1.5
Clay loam	1.45
Silty clay	1.45
Sandy clay	1.4
Clay	1.35

Figure 9: Average Bulk densities for soil texture classes (Zeri et al., 2018)

TOOL 8: RUNOFF CALCULATION AND COEFFICIENT

Runoff Curve-number method

The runoff curve number method calculates the runoff originally at the watershed level, based primarily on factors related to soil and soil cover (Cronshey, 1986). For Urbanized watersheds would apply different factors according to Lim et al. (2006), however this methodology focuses on agriculture.

Generic approach

The methodology was originally designed to be applied at the watershed level. This encompasses forest, meadows, agriculture and other land uses. Therefore, the project area and watershed has to be stratified according to the land use and project activities, e.g. Agriculture: corn with intercropping, etc. The average values of all areas apply for the calculation. The baseline or project AR is calculated as the sum of all strata.

$$AR = \sum_{i=1}^{n} (AR_i * \ area_i) \tag{32}$$

AR	*Total Annual runoff*
AR_i	*Annual runoff per stratum*
$area_i$	*Area in ha per stratum*

Spatial explicit approach

The spatial explicit approach does not need any strata. However, of course a farm will have different management practices, which will be treated as strata per farm. All mentioned steps in Tool 8 are applied pixel wise in a GIS software and can be aggregated spatial explicit per farm/project area.

$$AR = \sum \sum_{i=1}^{n} (AR_i * \ farm\ area_i) \tag{33}$$

AR	*Total Annual runoff*
AR_i	*Annual runoff per stratum*
Farm $area_i$	*Area in ha per stratum*

General steps

$$AR = \frac{(P - 0.2S)^2}{P + 0.8S} \tag{34}$$

AR	*Runoff in [mm]*
P	*Rainfall in [mm]*

S *Potential maximum retention after rainfall begins [mm]*

S is the potential maximum retention after the beginning of a rainfall event. It is related to soil and cover conditions within the watershed through a curve model (CN). It was initially developed from agricultural watersheds, in order to simplify a more detailed approach using initial abstraction (I_a). However, I_a is difficult to calculate and thus S is commonly used. CN is a value ranging between 0-100. The entire formula is expressed in inches.

$$S = \frac{25400}{CN} - 254 \tag{35}$$

CN Runoff curve number

The values for CN are empirically derived based on soil and vegetation cover and have been listed in Table 21 and 22. In order to determine the correct CN value based on the project activities the hydrological soil group has to be identified in table 20, based on the soil texture class known from Tool 7 (Figure 8).
The original CN method uses daily precipitation rates. However, it is likely to derive the input data from average monthly precipitation rates, which can be divided to the average daily rainfall rates. We propose to use 5 year average values. The CN method estimates the runoff of this average, assuming it would be one rainfall event. Daily average rates assume that soil water storage does not dry out in times of a water surplus and thus more runoff can be generated. This leads to the assumption that this method also can be used with monthly average values (Cronshey, 1986).

Table 20: Runoff curve number method important facts

Fact	Description
Factor	AR as an expression of runoff
Data Unit	original in Inches (in), here it has been converted to mm already
Level of application	Watershed/Catchment
Source of Data	Soil Conservation Service Curve Number (SCS-CN) Methodology Handbook

Project activities, such as changes in land use and management will change CN values accordingly. Because these are the main affecting project activities, the CN value is the changing part in the runoff calculation between Baseline and Project Runoff.

However, the hydrologic soil group (HSG) has to be determined for each soil present in the project. The HSG indicates the minimum rate of infiltration for bare soil after prolonged wetting. Table 21 shows the HSG according to soil texture classes.

The HSG are classified into 4 different categories (Cronshey, 1986):

Group A: soils have low runoff potential and high infiltration rates even when thoroughly wetted. They consist chiefly of deep, well to excessively drained sand or gravel and have a high rate of water transmission (greater than 0.30 in/hr).

Group B: soils have moderate infiltration rates when thoroughly wetted and consist chiefly of moderately deep to deep, moderately well to well drained soils with moderately fine to moderately coarse textures. These soils have a moderate rate of water transmission (0.15-0.30 in/hr).

Group C: soils have low infiltration rates when thoroughly wetted and consist chiefly of soils with a layer that impedes downward movement of water and soils With moderately fine to fine texture. These soils have a Low rate of water transmission (0.05-0.15 in/hr).

Group D: soils have high runoff potential. They have very low infiltration rates when thoroughly wetted and consist chiefly of clay soils with a high swelling potential, soils with a permanent high water table, soils with a Claypan or clay layer at or near the surface, and shallow Soils over nearly impervious material. These soils have a very low rate of water transmission (0-0.05 in/hr).

Table 21: Hydrological soil groups, Cronshey (1986)

HSG	*Soil textures*
A	Sand, loamy sand, or sandy loam
B	Silt loam or loam
C	Sandy clay loam
D	Clay loam, silty clay loam, sandy clay, silty clay, or clay

Table 22: Tables used to determine CN value; Cronshey (1986)

Cover description			Curve numbers for hydrologic soil group			
Cover type	Treatment [2]	Hydrologic condition [3]	A	B	C	D
Fallow	Bare soil	—	77	86	91	94
	Crop residue cover (CR)	Poor	76	85	90	93
		Good	74	83	88	90
Row crops	Straight row (SR)	Poor	72	81	88	91
		Good	67	78	85	89
	SR + CR	Poor	71	80	87	90
		Good	64	75	82	85
	Contoured (C)	Poor	70	79	84	88
		Good	65	75	82	86
	C + CR	Poor	69	78	83	87
		Good	64	74	81	85
	Contoured & terraced (C&T)	Poor	66	74	80	82
		Good	62	71	78	81
	C&T+ CR	Poor	65	73	79	81
		Good	61	70	77	80
Small grain	SR	Poor	65	76	84	88
		Good	63	75	83	87
	SR + CR	Poor	64	75	83	86
		Good	60	72	80	84
	C	Poor	63	74	82	85
		Good	61	73	81	84
	C + CR	Poor	62	73	81	84
		Good	60	72	80	83
	C&T	Poor	61	72	79	82
		Good	59	70	78	81
	C&T+ CR	Poor	60	71	78	81
		Good	58	69	77	80
Close-seeded or broadcast legumes or rotation meadow	SR	Poor	66	77	85	89
		Good	58	72	81	85
	C	Poor	64	75	83	85
		Good	55	69	78	83
	C&T	Poor	63	73	80	83
		Good	51	67	76	80

[1] Average runoff condition, and I_a=0.2S
[2] Crop residue cover applies only if residue is on at least 5% of the surface throughout the year.
[3] Hydraulic condition is based on combination factors that affect infiltration and runoff, including (a) density and canopy of vegetative areas, (b) amount of year-round cover, (c) amount of grass or close-seeded legumes, (d) percent of residue cover on the land surface (good ≥ 20%), and (e) degree of surface roughness.

Poor: Factors impair infiltration and tend to increase runoff.

Good: Factors encourage average and better than average infiltration and tend to decrease runoff.

Table 23: Tables used to determine CN value; USDA (1986)

Cover description		Curve numbers for hydrologic soil group			
Cover type	Hydrologic condition	A	B	C	D
Pasture, grassland, or range—continuous forage for grazing. [2]	Poor	68	79	86	89
	Fair	49	69	79	84
	Good	39	61	74	80
Meadow—continuous grass, protected from grazing and generally mowed for hay.	—	30	58	71	78
Brush—brush-weed-grass mixture with brush the major element. [3]	Poor	48	67	77	83
	Fair	35	56	70	77
	Good	30 [4]	48	65	73
Woods—grass combination (orchard or tree farm). [5]	Poor	57	73	82	86
	Fair	43	65	76	82
	Good	32	58	72	79
Woods. [6]	Poor	45	66	77	83
	Fair	36	60	73	79
	Good	30 [4]	55	70	77
Farmsteads—buildings, lanes, driveways, and surrounding lots.	—	59	74	82	86

1 Average runoff condition, and $I_a = 0.2S$.
2 *Poor:* <50%) ground cover or heavily grazed with no mulch.
Fair: 50 to 75% ground cover and not heavily grazed.
Good: > 75% ground cover and lightly or only occasionally grazed.
3 *Poor:* <50% ground cover.
Fair: 50 to 75% ground cover.
Good: >75% ground cover.
4 Actual curve number is less than 30; use CN = 30 for runoff computations.
5 CN's shown were computed for areas with 50% woods and 50% grass (pasture) cover. Other combinations of conditions may be computed from the CN's for woods and pasture.
6 *Poor:* Forest litter, small trees, and brush are destroyed by heavy grazing or regular burning.
Fair: Woods are grazed but not burned, and some forest litter covers the soil.
Good: Woods are protected from grazing, and litter and brush adequately cover the soil.

Runoff Coefficient

The runoff coefficient is defined as the total runoff observed in a year (or season) divided by the total rainfall in the same year (or season). It expresses, how much of the overall precipitation ends up as runoff in percent and thus considers also rain events that did not produce any runoff. Therefore, this is a good measure to compare runoff and its reduction in larger catchments.

$$K = \frac{AR_{catch}}{P_{catch}} \tag{36}$$

AR_{catch}	*Average runoff in catchment (mm)*
P_{catch}	*Average Precipitation in catchment (mm)*
K	*Total annual runoff expressed as the ratio (%) of catchment to cultivated area runoff.*

Because the coefficient is a ratio either the average values of the watershed or the total amount of precipitation and runoff can be used to calculate the ratio.

Table 24 below shows an example of how much precipitation of a catchment can be reduced due to runoff reduction measures between baseline and project implementation.

Table 24: Example of Runoff coefficient result

	Baseline	Project	Net benefit
Activities	Heavy downstream siltation and sedimentation as a result of soil erosion and runoff	Intercropping Increased crop diversification Trees and vegetative buffers Increased infiltration	
Total Annual Precipitation	1245mm	1245mm	
Total Annual Runoff	149mm	121mm	
K	**12%**	**10%**	**2%**

OPTIONAL TOOL 9: GROUNDWATER RECHARGE MODELLING

Measuring groundwater recharge is ambitious and costly, due to its inaccessibility. Many authors established models to estimate recharge rates, since water scarcity in agriculture can be overcome by irrigation, which is mainly fed by groundwater. The water balance shows how water gets distributed on a specific area.

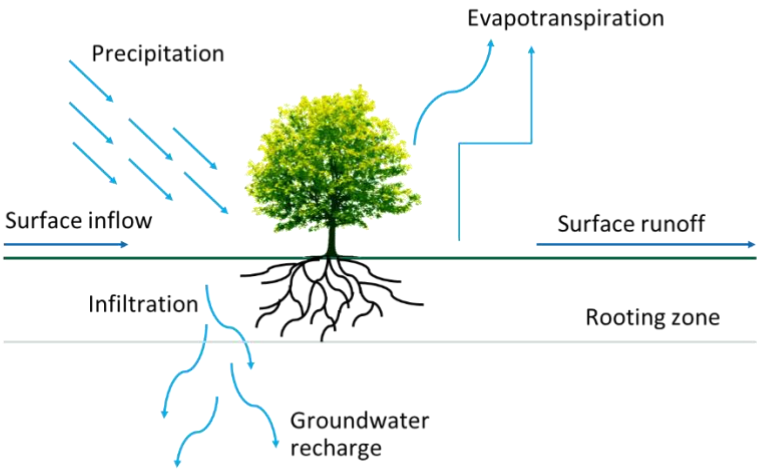

Figure 10: Water balance

Water balance

$$P + In_{surf} = Out_{surf} * ET * Inf * \Delta W_s \quad (37)$$

P	*Precipitation*
In_{surf}	*Surface inflow*
Out_{surf}	*Surface runoff*
ET	*Evapotranspiration*
Inf	*Infiltration*
ΔW_s	*Change in water storage*

Annual soil water budget

Thornthwaite and Mather (1957) established a simplified model to estimate the annual water balance of a given area. It assumes, that water percolating below the rooting zone will eventually reach the groundwater table, since it cannot be evaporated or transpired. Capillary rise is not further considered, as this is difficult to estimate and depends entirely on the specific soil porosity. Furthermore, water can only percolate below the rooting zone in times of a water surplus. Factors which lead to loss of water, such as surface runoff, evapotranspiration, and the change in the water storage have to be discounted before. Thus, the infiltration rate after discounting all other water losses is assumed to be the annual groundwater recharge rate. Surface water inflow is not considered in the Thornthwaite and Mather model, because this model considers processes that occur on the watershed level. It is no model, with which farm level influence can be estimated on a per ha basis. However, the model can be calculated on the watershed level and calculated back towards single farm level impacts, if farms cover a significant area of the watershed. Since daily rainfall data is usually scarce, monthly precipitation data can also be used to calculate the annual soil water budget.

Natural groundwater recharge

A Surplus in water only occurs during the wet season, when more water enters than leaves the area. Water loss parameters are Surface runoff and Evapotranspiration. Thus, the net balance has to be positive. Negative values lead to a water deficit. This deficit accumulates and is noted in the dynamical soil water storage (S_B), which has to be filled again after a dry season, in order to create a net surplus again. A in depth calculation of deficit and Actual Evapotranspiration (AET) can be retrieved from Bakundukize et al. (2011) and Mushtaha et al. (2019).

Overall input parameters for estimating groundwater recharge:

- Mean Monthly temperature
- Mean Monthly precipitation
- Mean monthly day length
- Mean monthly runoff
- Field capacity of soil type
- Rooting depth

Generic approach

(38)

$$R_N = \sum_{i=1}^{n} (R_{Ni} * area_i)$$

R_N	*Total Annual groundwater recharge*
R_{Ni}	*Annual groundwater recharge per stratum*
$area_i$	*Area in ha per stratum*

Spatial explicit approach

The spatial explicit approach does not need any strata. However, of course a farm will have different management practices, which will be treated as strata per farm. All mentioned steps in Tool 9 are applied pixel wise in a GIS software and can be aggregated spatial explicit per farm/project area.

(39)

$$R_N = \sum \sum_{i=1}^{n} (R_{Ni} * farm\ area_i)$$

R_N	*Total groundwater recharge*
R_{Ni}	*Annual groundwater recharge per stratum*
Farm $area_i$	*Area in ha per stratum*

General steps

(40)

$$R_N = SUR_{Net}$$

R_N	*Natural groundwater recharge [mm]*
SUR_{Net}	*Net water surplus [mm]*

(41)

$$SUR_{Net} = SUR_{Pot} - \Delta S_B$$

SUR_{Pot}	*Potential water surplus [mm]*
ΔS_B	*Change in soil water storage [mm]*

(42)

$SUR_{Pot} = (P - Out_{surf}) - PET$; for $(P\text{-}Out_{surf})\text{-}PET > 0$

PET	*Potential Evapotranspiration [*mm day^{-1}*]*

Potential Evapotranspiration – Hamons equation

The potential evapotranspiration is the possible evapotranspiration occurring without shortages in the water supply. Therefore, the PET is not always the actual evapotranspiration (AET), which is the realized evapotranspiration. The AET is the difference between the water demand and supply and differs from the PET in month of water shortages. Hamons PET was suggested to suit the best to the Thornthwaite and Mather method among other PET equations according to

Bakundukize et al. (2011). It is based on very general climate input data, as can be retrieved from the formula below (Lu et al., 2005).

(43)

$$PET = k * 0.1651 * 216.7 * N * (\frac{e_s}{T + 273.3})$$

PET	*potential evapotranspiration [mm day^{-1}]*
k	*proportionality coefficient = 1[1] [unitless]*
N	*daytime length [x/12 hours]*
e_s	*saturation vapor pressure [mb]*
T	*average monthly temperature [°C]*

(44)

$$e_s = 6.108 * e^{(\frac{17.26939*T}{T+237.3})}$$

T average monthly temperature [°C] ; for T > 0

Soil water storage

Soil water storage is the dynamical storage of water, which is suspect to continuous change. The water deficit is the Difference between the potential and the actual evapotranspiration. This deficit can be accounted for in the dynamic water storage, which is drained or filled depending on the water surplus or shortage (Bakundukize et al., 2011).

(45)

$$S_B = AWC * e^{(\frac{-APWL}{AWC})}$$

AWC Available water capacity [mm]
APWL Accumulated potential water loss [mm]

This formula applies only in month during the dry season, or with an active water deficit. If the water surplus meets the exact amount of the water loss parameters: S_B = AWC.

Available water capacity

The available water capacity is the potential soil water storage. It depends on the rooting depth of the particular area, which itself naturally depends on the crop or vegetation growing on this area.

(46)

$$AWC = FC * Z_r * 1000$$

FC	*Field capacity [Vol%]*
Z_r	*Rooting zone [m]*

Rooting zone parameters

The rooting zone depends on the vegetation and crops grown on the area. The following table are taken from Thornthwaite and Mather (1957) and reviewed in

Bakundukize et al. (2011), which show common rooting zones for different crops and vegetation types.

Vegetation	Soil texture	Water holding capacity (% volume) = water content at field capacity	Rooting depth (m)	Water capacity of the root-zone (CAP) (mm)
Shallow rooted crops (spinach, peas, beans, beets, carrots etc.)	Fine sand	10	0.50	50
	Fine sandy loam	15	0.50	75
	Silt loam	20	0.62	125
	Clay loam	25	0.40	100
	Clay	30	0.25	75
Moderately rooted crops (corn, cereals, cotton, tobacco)	Fine sand	10	0.75	75
	Fine sandy loam	15	1.00	150
	Silt loam	20	1.00	200
	Clay loam	25	0.80	200
	Clay	30	0.50	150
Deep rooted crops (alfalfa, pasture, grass, shrubs)	Fine sand	10	1.00	100
	Fine sandy loam	15	1.00	150
	Silt loam	20	1.25	250
	Clay loam	25	1.00	250
	Clay	30	0.67	200
Orchards	Fine sand	10	1.50	150
	Fine sandy loam	15	1.67	250
	Silt loam	20	1.50	300
	Clay loam	25	1.00	250
	Clay	30	0.67	200
Mature forest	Fine sand	10	2.50	250
	Fine sandy loam	15	2.00	300
	Silt loam	20	2.00	400
	Clay loam	25	1.60	400
	Clay	30	1.17	350

Figure 11: Rooting zone parameters, Thornthwaite and Mather (1957), reviewed in Bakundukize et al. (2011)

However, depending on the forest type and site conditions the rooting depth might be a lot deeper (4-6m). Special adjustments can be made to this graph or the rooting depth can be simply measured.

Accumulated potential water loss

In case of dry month or with a water deficit, the accumulated potential water loss accounts for the monthly water deficit. The APWL accounts for potential water losses, due to its relation with the PET, instead of the AET.

(47)

$APWL = PET - (P - Out_{surf})$; for PET >P

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