ASES ON-CHAIN PROTOCOL

METHODOLOGY FOR THE ISSUANCE OF VERIFIED WATER CREDITS

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INTRODUCTION

The enhancements of groundwater recharge through Nature-Based Solutions (NBS) projects and its assessment play a vital role in sustainable water resource management. To effectively evaluate the impact of these projects, the aOCP provides a methodology that leverages digital technology, including satellite images and water balance modeling. This innovative approach enables a detailed monitoring of land cover changes and provides valuable insights into the evolution of ecosystem restoration projects as they mature.

The methodology incorporates digital tools to calculate the Curve Number (CN), a key parameter used to estimate infiltration and surface runoff, which directly influences groundwater recharge. By utilizing satellite images, the CN can be determined with improved accuracy, capturing the land cover characteristics and their spatial distribution within the project area. This satellite-based assessment enhances the precision of recharge estimations, enabling a more comprehensive understanding of groundwater dynamics.

Moreover, the integration of the CN calculation with a water balance model strengthens the methodology's analytical capabilities. The water balance model considers various hydrological components such as precipitation, evapotranspiration, surface runoff, and groundwater recharge, providing a sound framework to assess the impacts of NBS projects on groundwater resources. One notable advantage of this methodology is its ability to monitor and track land cover changes as reforestation projects progress. By regularly analyzing satellite images, the evolution of vegetation cover and related land surface modifications can be closely monitored.

This document's goal is to outline the requirements and provide rationale for the aOCP's use of the methodology and baseline monitoring for the calculation of Verified Water Credits (VWCs). This methodology outlines the steps to follow to assess both projects’ potential to generate VWCs prior to its registration and changes in ecological functions due to projects’ once they are implemented, which trigger issuance of VWCs under the aOCP.

I. DEFINITIONS

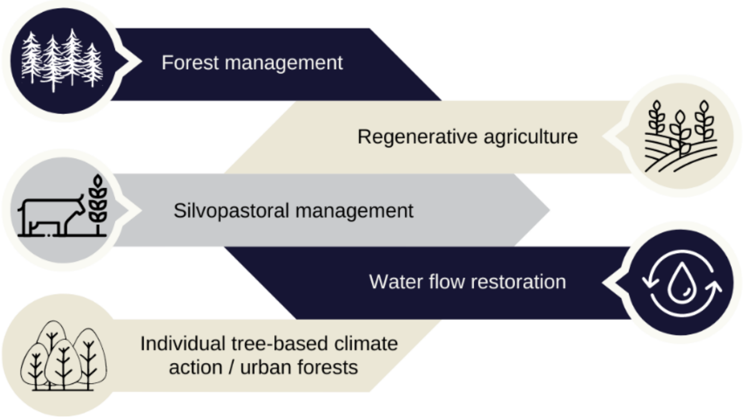
The following definitions also apply to this technique in addition to those in the most recent edition of the Program Definitions:

- **Erosion:** Process in which the top layer of soil, which provides plants with most of the nutrients and water they need, is lost. When this fertile layer is displaced, the productivity of the land decreases.
- **Evapo-transpiration:** combined process of water evaporation from the Earth's surface, including soil, water bodies, and vegetation, as well as the transpiration of water through plant stomata. It represents the loss of water from the land surface and vegetation to the atmosphere.
- **Groundwater recharge:** process by which water infiltrates into the subsurface and replenishes the groundwater reservoir. It is the amount of water that enters the aquifer system through natural or artificial means, such as precipitation, surface runoff, or irrigation.
- **Infiltration rate:** the rate at which water penetrates or seeps into the soil surface.
- **Initial Abstraction:** parameter that accounts for all losses prior to runoff and consists mainly of interception, infiltration, evaporation, and surface depression storage
- **Potential maximum storage:** maximum amount of water that a watershed can retain or store before generating any runoff. It represents the storage capacity of the watershed's soil and vegetation to absorb and retain rainfall.
- **Precipitation:** process by which water in the atmosphere condenses and falls to the Earth's surface in various forms, such as rain, snow, sleet, or hail.
- **Runoff:** Physical process that consists of the runoff of rainwater through the drainage network until it reaches the fluvial network.

II. APPLICABILITY CONDITIONS

This methodology is applicable under the following conditions:

a) The type of Project belongs to one of the following types:



b) The Project complies with the standards of the aOCP Program;

c) The Project was developed less than 24 months ago;
d) The Project area has not been degraded, deforested or burned in the last 24 months;
e) If a project area does not meet requirement "d," the project proponent must provide a technical reason arguing that ecological restoration is necessary because the area's biodiversity and environmental services are vulnerable.
f) The Project is likely to produce an increase in groundwater recharge of at least 1 m^3 in the first 5 years.

II.1 ELIGIBLE ACTIVITIES

The Ases On-Chain Protocol is a voluntary program of the Nature Market applicable on a global scale for the certification of biodiversity conservation and restoration projects. Activities eligible for certification can be applied by individuals, non-governmental organizations (NGOs), government organizations, private companies and/or communities.

The identification of the main activity within the list of eligible activities of the aOCP is crucial for the success of a water balance project. This main activity will be the core of the project, while other additional eligible activities may complement it and strengthen its impact as well as mitigate the identified threats. It is important that all eligible activities, both core and additional, conform to the standard's certification guidelines presented in Table 1.

The classification of activities is an essential element to determine the applicability of the Project to the aOCP certification, as well as for the correct quantification of water credits since the activities or measures implemented, as well as its geographical location and the habitat in where they are located, are determining factors in the evaluation process.

TABLE 1. ELIGIBLE ACTIVITIES

Sector	Code	Eligible Activities	Habitat						
			B	S	M	Q	H	D	AT
Adaptation of ecosystems to climate change	AD-1	Reforestation/restoration with Native species	✓	✓	✓	✓	✓	✓	✓
	AD-2	Promotion of natural regeneration	✓	✓	✓	✓	✓	✓	
	AD-3	Green infrastructure	✓		✓			✓	✓
Spatial connectivity	CON-1	Establishment, improvement, or restoration of corridors ecological	✓	✓	✓	✓	✓	✓	✓
	CON-2	Creation of wildlife passages	✓	✓	✓	✓	✓		✓
	CON-3	Increased connectivity within urban environments							✓
Water Balance Enhancement Water	WB-1	Planting of trees, shrubs, or grasses	✓	✓	✓	✓	✓	✓	✓
	WB-2	Management to enhance natural regeneration	✓	✓	✓	✓	✓	✓	
	WB-3	Use of cover crops during off-season	✓	✓	✓	✓	✓	✓	✓
	WB-4	Installation of fencing to protect vegetation	✓	✓	✓	✓	✓	✓	
	WB-5	Rotational grazing to allow vegetation recovery	✓	✓	✓	✓	✓	✓	
	WB-6	Erosion controls measures i.e. terracing, contour planting, and mulching	✓	✓	✓	✓	✓	✓	✓
	WB-7	Afforestation of non-forested land	✓	✓	✓	✓	✓	✓	✓
	WB-8	Agroforestry practices	✓	✓	✓	✓	✓	✓	✓
	WB-9	Establishment or restoration of riparian buffers	✓	✓	✓	✓	✓	✓	✓
	WB-10	Restoration of degraded wetlands					✓		

Habitat classification according to the Red List scheme, version 3.1***

B: Forest; S: Savannah; M: Thicket; Q: Grasslands; H: Wetlands; C: Caves and underground (non-aquatic) habitats; D: Desert; MI: Intertidal Marine; MN: Neritic marine; MO: Oceanic marine: AT: Artificial – terrestrial; AA: Artificial – aquatic; VI: Introduced vegetation.

*** Only terrestrial habitats are considered for VWCs.

III. METHODOLOGICAL CONSIDERATIONS

III.1. APPLICATION OF METHODOLOGY

The projects that are eligible to the application of this aOCP methodology are listed in the following table. These projects correspond to those that will directly or indirectly benefit ecosystems, improving infiltration and hence increasing groundwater recharge.

TABLE 2. APPLICATION OF METHODOLOGY BY PROJECT

Type of project	Use of methodologies				
	Carbon in vegetation	Carbon in soil	Biodiversity	Soil conservation and restoration	Water
Regenerative agriculture					✓
Forest management					✓
Silvopastoral					✓
Urban forest					✓
Water flow restoration					✓

III.2. PROJECT BOUNDARY

The physical delineation and/or geographic area of the project activity shall include adjoining polygons that allow for comparison of project impacts and consideration of natural variation beyond the Project area (figure 1). These polygons are:

- Microbasin where the Project is located,
- Limits of the parcel with land ownership,
- Project area: site of implementation of Project activities, includes restoration and conservation areas,
- Areas where restoration is needed (regardless of if it is inside or outside of the land ownership polygon), within the microbasin,
- Counterfactual: area with ecological and topographic characteristics similar to the Project area, within the microbasin, without project activities.

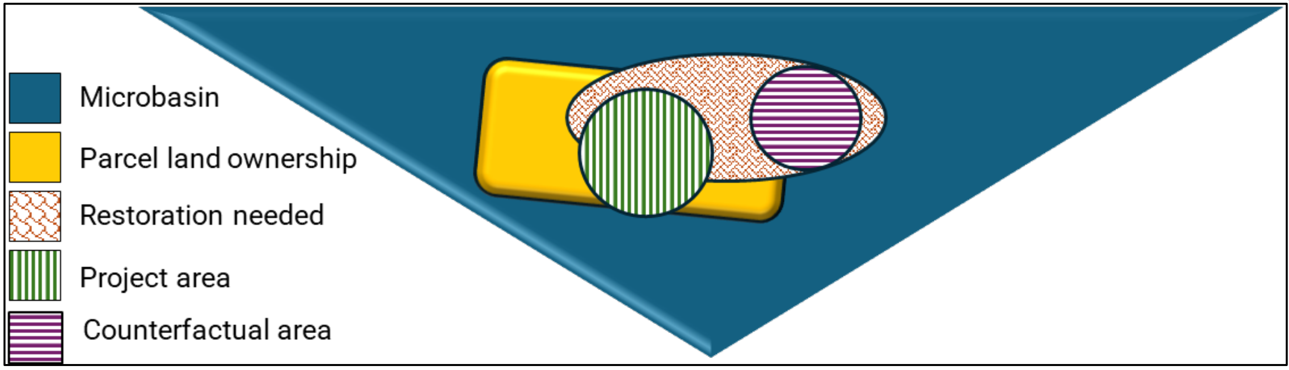


FIGURE 1. POLYGONS TO INCLUDE AS PART OF THE PROJECT BOUNDARY

IV. BASELINE SCENARIO

The baseline scenario represents the expected outcome if the Project activities were not implemented. This baseline scenario should consider factors such as existing land use practices, regulatory requirements, and environmental conditions. It serves as a reference against which the project's impact can be measured.

Prior project registration, the baseline assessment is conducted for the following periods:

Period	Explanation
Pre-project	One year before the start of project activities
1st year monitoring	Only applicable for Modality B projects. One year after implementation of project activities.
Year 10 projection	Ten years after implementation of project activities.
Year 40 projection	Last year of project's life, usually at 40 years after implementation of project activities.

A counterfactual analysis is conducted to assess what would have happened in the absence of the project. Baseline will be surveyed synchronically via the remote monitoring approach along the life of the project. This will be done in areas within the microbasin with similar ecological and topographic conditions at the beginning of the project and which do not undergo anthropogenic land use/land cover change. This will allow the comparison of the natural evolution of the ecosystem hydrologic conditions in the absence of restoration activities.

Counterfactual polygons are automatically computed in GEE, one microbasin at a time, as follows:

1. Compute mean and standard deviation of NDVI, elevation, aspect and slope at the project area. When the project area has more than 1 polygon in the same microbasin, these are considered together.
2. For each of the 4 parameters, select areas within the microbasin with values within the range *mean* ± *std.dev.*
3. Select areas that are within the selected range in ALL the 4 parameters.

This approach results in multiple independent polygons distributed along the microbasin, which guarantees that changes in land cover in any area of the counterfactual have a little impact in the overall condition. This is particularly important, as Project developers have no influence or control over the counterfactual areas.

ADDITIONALITY

Additionality of nature-based solution projects consist in the determination of the genuine environmental benefits resulting from the project's implementation. This assessment ensures that the project's impacts are accurately measured, providing a solid basis for evaluating its effectiveness and supporting Verified Nature Positive Credits issuance.

Additionality can be evidenced by combining the applying the following approach:

- The first step is to establish the baseline scenario.
- By comparing the expected outcomes of the counterfactual scenario with the actual project outcomes, the additional environmental benefits brought about by the nature-based solution project can be determined.
- Additionality assessment can include both quantitative and qualitative indicators. Quantitative indicators may involve measuring changes in groundwater recharge rates, land cover, or other relevant environmental parameters. Qualitative indicators can include social and economic considerations, such as community engagement, job creation, or ecosystem services provided. These indicators help capture the multifaceted impacts of the project and determine if the achieved benefits go beyond what would have occurred naturally or through other interventions.
- Engage with stakeholders and experts to gather their perspectives and insights regarding the additionality of the project. This may involve conducting consultations, expert reviews, or third-party evaluations. Stakeholder input and expert opinions provide valuable perspectives on the project's uniqueness, its contributions to environmental goals, and the extent to which the project goes beyond business-as-usual practices.

IV.1. QUANTIFICATION

The *aOCP Methodology for groundwater recharge assessment* encompasses two components. The first one leverages remote sensing techniques and utilizes the Curve Number method derived from satellite imagery, coupled with the Thornthwaite-Mather water balance method. By employing these remote assessment tools, it becomes possible to estimate groundwater recharge based on parameters such as land cover, precipitation, and evapotranspiration. This approach enables a cost-effective and efficient assessment of groundwater recharge changes across large areas, facilitating effective monitoring and evaluation of projects' impacts on groundwater resources.

In addition, to improve the accuracy and precision of recharge estimates, the second part of the methodology integrates field observations into a machine learning model for infiltration estimation. By collecting field data, such as infiltration rates and soil characteristics, and training the machine learning model using these inputs, groundwater recharge estimates obtained via the remote approach can be evaluated.

IV.1.1. REMOTE SENSING APPROACH

The data analysis uses the SCS-CN (Soil Conservation Service-Curve Number) method (Mishra & Singh, 2003) to evaluate surface runoff volume, the Penman-Monteith logic for evaporation (Monteith, 1965), and the Thornthwaite-Mather water balance method (Pranoto et al., 2019) to evaluate groundwater recharge. The recommended satellite images are from Sentinel-2, since these offer the best spatial resolution available at open source; higher spatial resolution images are also accepted. This method assumes that groundwater recharge is equal to evapotranspiration and surface runoff subtracted from precipitation. The procedure to compute delta groundwater recharge (dGWR) at a given year is the following:

Linear Spectral Mixture Analysis

Obtain V-I-S proportions

Use the LSMA method (Wang et al., 2017) to generalize urban land use types into three basic elements based on the V-I-S model, vegetation, impervious surface, and bare soil. The proportion of impervious surface, vegetation and soil of each pixel will be used to calculate the CN values.

Assess accuracy

The accuracy of the proportions of vegetation, impervious surface and soil components, shall be verified by selecting 50 random points within an area of 300 m × 300 m.

For each sample point, visually interpret on high-resolution images from Google Earth the vegetation, impervious surface and soil. Accuracy of the vegetation, impervious surface and soil maps is assessed by comparing the visual interpretation proportions from Google Earth and LSMA results. Root mean square error (RMSE) is computed to evaluate the accuracy of the un-mixing results. RMSE is a commonly used method for evaluating the difference between simulated and measured values. RMSE can be expressed by:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(Xi - Yi)^2}{N}} \quad [1]$$

where *Xi* represents the estimated impervious surface, vegetation, and soil fractions of sample *i* from Sentinel-2 by LSMA; *Yi* is the digitized proportion of *i* from the high-resolution image; and *N* is the number of samples.

Alternative to the LSMA method

The percentage of bare soil, vegetation, and impervious surface at each pixel can be obtained using the *Dynamic World V1* dataset (Brown et al., 2022), retrieved from the GEE catalog. For bare soil, the band “*bare*” is selected, for impervious, the band “built”, and for vegetation, the sum of the bands *trees, grass, flooded_vegetation crops,* and *shrub_and_scrub.*

CN determination

Curve number (CN) is an index developed by the Natural Resource Conservation Service (NRCS), to represent the potential for storm water runoff within a drainage area. The CN method proposed by Fan et al. (2013) is used to calculate composite CN. Each 10 m × 10 m pixel was assumed to be an independent drainage area comprising impervious surface, vegetation and soil. The composite CN value for each pixel is determined as the area-weighted average of the CN values associated with the impervious surface, vegetation, and soil. The calculation of the composite CN is carried out using the following formula:

$$CNc = Si \times CNi + Sv \times CNv + Ss \times CNs \quad [2]$$

where *CNc* is the composite CN value; *Si* , *Sv,* and *Ss* are fractions of impervious surface, vegetation and soil extracted by the LSMA, respectively; and *CNi* , *CNv*, and *CNs* are the initial CN values of impervious surface, vegetation and soil, respectively.

The composite CN was calculated under the dry antecedent moisture condition (AMC-I).

CNi : a unique value of 98 is assigned to impervious surfaces, according to the lookup table of Technical Release 55 (TR-55) (USACE Hydrologic Engineering Center, n.d.).

CNs: the soil is classified into four hydrologic soil groups (A, B, C, and D) based on the proportion of sand and clay, as shown in Table 2.

TABLE 3. SOIL TEXTURE CLASSIFICATION AND VALUES OF SOIL CURVE NUMBER (CNS) IN AMC-I (CHUNLIN ET AL., 2018).

Soil type	Soil texture	CNs
A	Sand ≥ 50% and clay ≤ 10%	59
B	Sand ≥ 50% and clay > 10%	72
C	Sand < 50% and clay ≤ 40%	80
D	Sand < 50% and clay > 40%	85

CNv : First, calculate the NDVI (Normalized Difference Vegetation Index). Second, vegetation is classified into four categories according to values of NDVI, as shown in Table 3. Select CN for the hydrologic soil group defined in Table 2.

TABLE 4. CURVE NUMBER FOR VEGETATION (CNV) CLASSIFICATION (BERA ET AL., 2021).

Vegetation	NDVI	Vegetation health (% cover)	CNv			
			A	B	C	D
Forest	NDVI > 0.62	Poor (V < 50%)	45	66	77	83
		Fair (50% < V < 75%)	36	60	73	79
		Good (V > 75%)	25	55	70	77
Orchards	0.55 < NDVI < 0.62	Poor (V < 50%)	57	73	82	86
		Fair (50% < V < 75%)	43	65	76	82
		Good (V > 75%)	32	58	72	79
Grass and farmland	0.31 < NDVI < 0.55	Poor (V < 50%)	68	79	86	89
		Fair (50% < V < 75%)	49	69	79	84
		Good (V > 75%)	39	61	74	80
Non vegetated / open space	NDVI < 0.31		69	84	88	91

If the study region is situated in a hilly terrain, besides the LULC, slope is also a driving factor for surface runoff. Slope correction is performed using the following equation as defined by (Huang et al., 2006)

$$CNsc = \frac{CNc \times (322.79 + 15.63 \times SL)}{SL + 323.52} \quad [3]$$

Where *CNsc* is slope corrected composite curve number, *CNc* is composite curve number and *SL* is slope rise (in percentage).

Calculate surface runoff (Q) and infiltration (F)

Once curve number is determined, proceed to calculate surface runoff (Q) and infiltration rate (F) by SCS-CN method. The equations used are as follows:

$$Q = \frac{(P - 0.2S)^2}{P + (0.8S)} \quad [4]$$

$$S = \frac{25400}{CNcs} - 254 \quad [5]$$

$$Ia = 0.2S \quad [6]$$

$$F = (P - Ia) - Q \quad [7]$$

According to SCS-CN method, *Q* is estimated as zero if $P \leq Ia$.

S: groundwater storage, which depends on land cover and soil hydrologic group, using CNsc calculated in the previous section.

Ia: initial abstraction, which is water held up in soil granules at the beginning of rain before infiltration and runoff take place.

F: infiltration rate, which is the addition of water to the soil that occurs after the initial abstraction process.

CALCULATE EVAPOTRANSPIRATION (ET)

ET is the second largest component (after precipitation) of the terrestrial water cycle at the global scale, since ET returns more than 60% of precipitation on land back to the atmosphere and thereby conveys an important constraint on water availability at the land surface. In addition, ET is an important energy flux since land ET uses up more than half of the total solar energy absorbed by land surfaces (Mu et al., 2013).

The FAO Penman-Monteith method is FAO's recommended as the sole ETo method for determining reference evapotranspiration. The algorithm used for the MOD16 data product collection is based on the logic of the Penman-Monteith equation, which includes inputs of daily meteorological reanalysis data along with MODIS remotely sensed data products such as vegetation property dynamics, albedo, and land cover. The total daily ET is the sum of evaporation from the wet canopy surface, the transpiration from the dry canopy surface and the evaporation from the soil surface. Google Earth Engine provides access to this dataset, identified as *The Terra Moderate Resolution Imaging Spectroradiometer (MODIS) MOD16A2GF Version 6.1 Evapotranspiration/Latent Heat Flux (ET/LE) product.*

When MOD16 data is not available or accessible, real evapotranspiration can be calculated from Turc (Gudulas et al., 2013), with the formula:

$$ET = \frac{P}{\sqrt{0.9+\frac{P^2}{L^2}}} \qquad [8]$$

Where; ET: annual actual evapotranspiration (mm/year), P: annual rainfall (mm/year), t: mean annual temperature (°C), L: thermal indicator, defined by the following equation:

$$L = 300 + 25t + 0.05t^3 \qquad [9]$$

CALCULATE CHANGE IN GROUNDWATER STORAGE (S)

The model used to calculate change in ground water recharge is the Thornthwaite-Mather water balance method (Pranoto et al., 2019) with the following equation:

$$P = Q + ET \pm \Delta R \qquad [10]$$

Which is derived into:

$$\Delta R = P - Q - ET \qquad [11]$$

Where ΔR is the change of groundwater storage (mm), *P* is rainfall (mm), *Q* is runoff (mm) and *ET* is evapotranspiration (mm).

A negative ΔR indicates deficit, i.e. loss of groundwater, while a positive ΔR indicates surplus, i.e. recharge.

This procedure has been automated by ASES to be executed in the Google Earth Engine JavaScript platform, which allows the quick computation of dGWR for the 4 periods mentioned above.

TIME SCENARIOS

NDVI, land cover fractions, precipitation and ET are the independent variables considered to significantly change over time. Table 4 and 5 show the combination of these factors used to compute dGWR for the assessed periods.

TABLE 5. COMBINATION OF DATASETS USED TO REPRESENT THE FOUR SCENARIOS FOR DELTA GROUND WATER STORAGE (DGWS) MODELLING, PART 1.

Scenario	NDVI	Land cover fractions (LCF)
Before Project	Mean annual NDVI from pre-project period	Unmixing on S-2 image from 2021-09-10
After Project Year 1	Mean annual NDVI from monitoring period	Unmixing on S-2 image from 2023-09-05
Year 10 projection	Monitoring & Maximum*	Based on LCF from monitoring: • Impervious: unchanged • Vegetation: Multiplied 2x and limited to 1.0 • Soil: computed as 1-impervious-vegetation
Year 40 projection	Same as Year 10	Same as Year 10

* Mean annual NDVI for future scenarios was assumed to remain the same as in the monitoring period for the rest of the microbasin, while in the project area it would reach up to the maximum (mean annual) NDVI value found in the microbasin.

TABLE 6. COMBINATION OF DATASETS USED TO REPRESENT THE FOUR SCENARIOS FOR DELTA GROUND WATER STORAGE (DGWS) MODELLING, PART 2.

Scenario	Precipitation	ET
Before Project	Yearly rain in pre-project period from CHIRPS	ET from pre-project period
After Project Year 1	Yearly rain in monitoring period from CHIRPS	ET from monitoring period
After Project Year 10	Yearly rain in year 10 after implementation from NASA *NEX-GDDP-CMIP6*	ET from monitoring period
Project's last year	Yearly rain in year 40 after implementation from NASA *NEX-GDDP-CMIP6*	ET from monitoring period

FIELD OBSERVATIONS AND MACHINE LEARNING

This procedure integrates field measurements of infiltration rates and other soil parameters (table 6) with machine learning (ML) models to evaluate infiltration in the study area. To calibrate and train machine learning models and more precisely estimate infiltration rates, data from field observations are essential.

In order to predict infiltration rates, the machine learning (ML) models implemented combine the acquisition of remote sensing indexes as well as various soil physical and chemical properties influencing soil infiltration capacity, including soil moisture index (SMI), normalized difference vegetation index (NDVI), bulk density, among others. The soil properties incorporated in the model and their sources are listed in Table 7.. Parameters other than remote sensing indexes shall be determined through analysis performed by a certified laboratory. The Soil Grids data can be used as a reference only, but for the calculation of credits, field measurements shall be used.

TABLE 7. REMOTE SENSING INDEXES AND SOIL PHYSICOCHEMICAL PROPERTIES INCLUDED IN ML MODELS.

No.	Soil property	Units	Source
1	Soil Moisture Index (SMI)	Unitless	Remote Sensing Derived
2	Topographic Wetness Index (TWI)	Unitless	Remote Sensing Derived
3	Normalized Vegetation Index (NDVI)	Unitless	Remote Sensing Derived
4	Bulk Density	cg/cm^3	SoilGrids / Field Observation
5	Sand Content	g/kg	SoilGrids / Field Observation
6	Silt Content	g/kg	SoilGrids / Field Observation
7	Clay Content	g/kg	SoilGrids / Field Observation

8	Coarse Fragment Content	cm^3/dm^3	SoilGrids / Field Observation
9	Cation Exchange Capacity (CEC)	mmol(c)/kg	SoilGrids / Field Observation
10	Organic Carbon Density	cg/kg	SoilGrids / Field Observation
11	Soil Organic Carbon Content	%	SoilGrids / Field Observation
12	Nitrogen Content	cg/kg	SoilGrids / Field Observation

SoilGrids: global predictions for standard numeric soil properties (Poggio et al., 2021).

FIELD MEASUREMENT OF INFILTRATION RATES

Soil Sampling

Semi-stratified sampling technique is used to select sampling locations within the study area. While there is no ideal number of sample size for any given area as it depends mainly on heterogeneity of the study area with respect to soil physico-chemical characteristics, topography and purpose of study, however as a rule of thumb, a minimum of 20 samples per hectare is recommended.

It is important to note the higher the number of soil samples, the higher accuracy in results obtained.

Infiltration Assessment

The mini-disc infiltrometer or ring infiltrometer can be used for infiltration rate assessment. The choice of assessment device however depends on the objective of the study and resources available. Refer to annex 1 for detailed method of infiltration measurement with ring and mini-disc infiltrometer.

Infiltration Rate Computation from Ring Infiltrometer Measurements

To compute infiltration rates from the experiment, the volume of water used will have to be converted to water depth (h), and then divided by the elapsed time of infiltration.

Calculate the area of the infiltrometer used.

$$AI = \pi \times r^2 \qquad [12]$$

Where, AI: area of infiltrometer (cm^2); r: radius of infiltrometer (cm);

Calculate the depth (h) of water in cm.

$$h = \frac{V}{AI} \qquad [13]$$

Where; h: depth of water (cm); V: =Volume of water infiltrated (cm^3)

Infiltration Rate (cm/sec)* is then computed.

$$Ir = \frac{h}{t} \qquad [14]$$

Where; Ir: infiltration Rate (cm/s); t: recorded time for the water to infiltrate (s).

* other units can be used, such as mm/h.

INTERPRETATION OF INFILTRATION RATES

Infiltration Rates obtained after calculation may be compared with literature references based on soil texture category.

MACHINE LEARNING MODELS FOR INFILTRATION RATES PREDICTION

Three machine learning models; Random Forest Regressor, Support Vector Machine, and Artificial Neural Network were developed and tested on the data for prediction of infiltration rates based on 12 input parameters listed in table 6 above. Figure 2 below shows a flowchart of the methodology used.

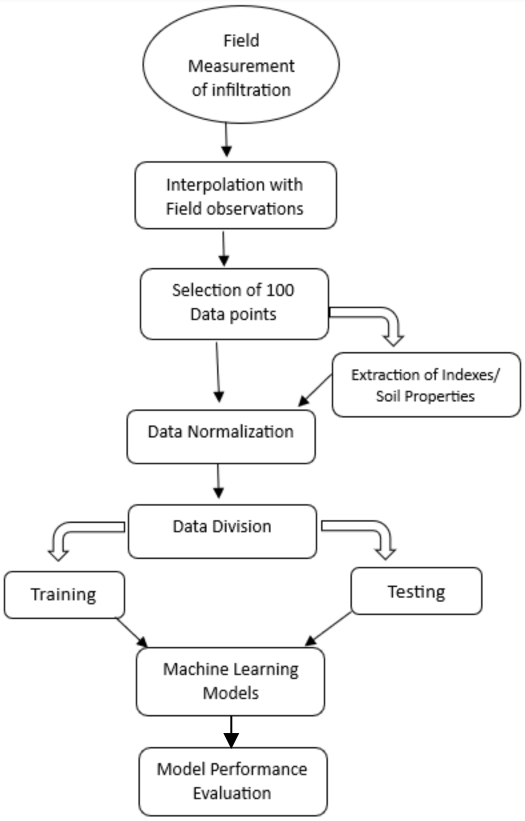


FIGURE 2. FLOWCHART OF INFILTRATION ASSESSMENT METHODOLOGY

Inverse Distance Weighting (IDW) interpolation is carried out with the field observation data to obtain infiltration rates across the entire study area including unsampled points. A total of 100 sample points in addition to the field observations is extracted from the interpolated surface for infiltration rates. For each sample point, the corresponding NDVI, TWI, SWI, as well as the other soil properties listed in table 6 were extracted. Data were then transferred to an excel file for treatment after which it was converted to a comma separated value (.csv) before importation into the models. Data normalization was executed on the data set to eliminate any bias by transforming the variables to give them the same order of magnitude. The data was then divided with 60% used for model training and 40% for model testing. All three models are fitted on the data set and their prediction accuracy is assessed with four main error metrics: Root Mean Square Error (RMSE), Mean Square Error (MAE), Mean Absolute Error (MAE), and Coefficient of Determination (R^2).

Model development was conducted with python programming language. Annex 2 contains the python codes used to develop and execute the model commands.

MODEL PERFORMANCE ASSESSMENT

Four main methods of assessment were implemented in this study. The Root Mean Square Error (RMSE), Mean Square Error (MAE), Mean Absolute Error (MAE), and Coefficient of Determination (R2).

Root Mean Square Error (RMSE)

RMSE measures the average magnitude of the difference between predicted values and the actual values. It is calculated by taking the square root of the average of squared differences between the predicted and actual values. RMSE values range from 0 to infinity where lower values indicate better predictive accuracy and 0 represents a perfect prediction.

Mean Square Error (MAE)

MSE is the average of squared differences between predicted values and actual values. It is calculated by taking the average of squared errors. Similar to RMSE, value ranges from 0 to infinity where lower values of MSE indicate better predictive accuracy.

Mean Absolute Error (MAE)

MAE measures the average absolute difference between predicted values and the actual values. It is calculated by taking the average of absolute differences between the predicted and actual values. The resulting values range between 0 and infinity where lower values of MAE indicate better predictive accuracy.

Coefficient of Determination (R^2)

R^2 measures the proportion of the variance in the dependent variable that can be explained by the independent variables in a regression model. It ranges from 0 to 1, where 0 indicates the model does not explain any variance, and 1 represents a perfect fit. It is important to note that R^2 does not determine the model's accuracy in making predictions. It primarily assesses the goodness-of-fit of the model to the observed data.

CROSS-CHECK OF FIELD DATA-MACHINE LEARNING MODEL WITH REMOTE SENSING MODEL

This stage consists of using the infiltration rates obtained from the machine learning model derived from field observations to calculate runoff, in substitution of the curve number method derived from satellite images. The formula used is:

$$Q = P - I \qquad [15]$$

The accuracy of the calculations obtained through the SCS-CN modified method can be assessed using the RMSE as described in section 2.1.1.

V. MONITORING

DATA AND PARAMETERS USED IN BOTH VALIDATION AND MONITORING

Parameter	*Ss*
Data unit	%
Description	Soil cover percentage
Equations	2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	LMSA performed on a composite Sentinel-2 image (median of the monitoring period)
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	*Sv*
Data unit	%
Description	Vegetation cover percentage
Equations	2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	LMSA performed on a composite Sentinel-2 image (median of the monitoring period)
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so

QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	*Si*
Data unit	%
Description	Impervious cover percentage
Equations	2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	LMSA performed on a composite Sentinel-2 image (median of the monitoring period)
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	NDVI
Data unit	Unitless
Description	Normalized Difference Vegetation Index
Equations	Table 3
Source of data	Calculated for each monitoring period. The least cloudy image within a 2-week window at the end of each season will be selected, i.e. days 7-21 in March, June, September and December.

Calculation method or default value applied	NDVI performed on a composite Sentinel-2 image.
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of vegetation curve number
Comments	

Parameter	CNv
Data unit	Unitless
Description	Vegetation Curve Number
Equations	Eq.2 and Table 3
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Classification according to tables 2 and 3.
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	CNs
Data unit	Unitless
Description	Soil Curve Number

Equations	Table 1 and Eq.2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Classification according to table 2.
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	CNi
Data unit	Unitless
Description	Impervious Curve Number
Equations	Eq.2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Default value of 98, according to the SCS TR-55 Table 2-2a – Runoff curve numbers for urban areas[1]
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

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[1] https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables

Parameter	CNi
Data unit	Unitless
Description	Impervious Curve Number
Equations	Eq.2
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Default value of 98, according to the SCS TR-55 Table 2-2a – Runoff curve numbers for urban areas[2]
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of composite curve number
Comments	

Parameter	S
Data unit	Millimeters (mm)
Description	Maximum potential storage
Equations	Eq. 4, 5 and 6
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Equation 5.
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so

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[2] https://www.hec.usace.army.mil/confluence/hmsdocs/hmstrm/cn-tables

QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of runoff (Q)
Comments	

Parameter	Ia
Data unit	Millimeters (mm)
Description	Initial abstraction
Equations	Eq. 6 and 7
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Equation 6.
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of infiltration (Q)
Comments	

Parameter	F
Data unit	Millimeters (mm)
Description	Infiltration
Equations	Eq. 7 and 14
Source of data	Calculated for each monitoring period

Calculation method or default value applied	Equation 7
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of runoff (Q)
Comments	

Parameter	P
Data unit	Millimeters (mm)
Description	Rainfall
Equations	Eq. 4, 7, 8, 10, 11 and 15
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Calculated on Google Earth Engine from the “CHIRPS Daily: Climate Hazards Group InfraRed Precipitation With Station Data (Version 2.0 Final)” dataset (Funk et al., 2015).
Frequency of monitoring/recording	Calculate once and use the same value for the project lifecycle. The period shall be the 30 years before the start of the project. For instance, if the project starts on June 2023, the dataset will comprise 01-01-1992 to 31-12-2022.
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of runoff (Q), infiltration (F) and groundwater recharge (ΔR)
Comments	

Parameter	Q
Data unit	Millimeters (mm)

Description	Runoff
Equations	Eq. 4, 7, 10, 11 and 15
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Equation 4
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of infiltration (F) and groundwater recharge (ΔR)
Comments	

Parameter	ET
Data unit	Millimeters (mm)
Description	Evapotranspiration
Equations	Eq. 8, 9, 10 and 11
Source of data	Calculated for each monitoring period
Calculation method or default value applied	Equation 8
Frequency of monitoring/recording	Quarterly, or different if the monitoring plan establishes so
QA/QC procedures to be applied	Technical verification by repetition of the calculation
Purpose of data	Input for the calculation of change of groundwater storage (ΔR)
Comments	

DESCRIPTION OF THE MONITORING PLAN

- **SAMPLE DESIGN**

The remote sensing approach implies the assessment of the whole Project area and the comparison with the whole microbasin given that GIS are used to analyze the satellite images and other layers in raster format.

Sampling for the field measurement approach is explained in section 7.2.1.

- **MONITORING PLAN**

Remote sensing monitoring is to be conducted quarterly in alignment to the aOCP strategy for close follow up of the evolution of projects and quick decision making in case of unintended events.

Field measurements will be performed on a yearly basis in order to run the machine learning model and compare with the results issued from the remote sensing approach.

VI. CALCULATION OF WATER CREDITS

The potential for generation of water credits is calculated based on the expected change in groundwater recharge or infiltration (ΔR). Assuming that the project leads to the restoration of the Project area to optimal conditions, the potential improvement in ΔR, is calculated as the difference between ΔR before project implementation and ΔR when the project reaches the expected results and comparing it to the expected outcome in the absence of Project activities. One way to forecast the expected results is using the values of ΔR in areas within the region where ecosystem is in optimum condition and/or the state of the Project area before it was degraded. The following section presents an example of calculation of water credits for a project.

As the project develops year after year and monitoring campaigns take place, the real impact of the project is calculated as the difference between calculated dGWR for the last year and dGWR modelled for the *no-project scenario*.

EXAMPLE OF CALCULATION OF WATER CREDITS FOR A SPECIFIC PROJECT

Δ GroundWater Recharge and percent change over the years in the microbasin and the Project area are depicted in Tables 7 and 8, respectively. Between pre-project and monitoring periods, infiltration in the Project area increased 23.2%, from -212 to -163 mm. In the same period, the counterfactual area also experienced an increase, from -278 to -213 mm, equivalent to 23.1%. Infiltration in the rest of the microbasin also increased, from -185 to -126 mm, equivalent to 32.0%, similar to the Project area. Negative values indicate that the area is subject to water deficit, where the volume of water that is lost due to runoff and evapotranspiration is higher than the volume of precipitation. This situation is leading to depletion of the aquifer, jeopardizing ecosystem functions and peoples' vital needs satisfaction.

At this first year after project implementation, its effects are not so notorious. However, when observing the results expected at year 10 and 40, project's impacts on rainfall water infiltration are more evident. The change in dGWR from the pre-project period up to year 40 is a 60.2% increase in the Project area, 35.0% increase in the counterfactual area and 38.6% increase in the rest of the microbasin. The difference between the counterfactual and the rest of the microbasin, considering both remain "unchanged", can be due to vegetation types, soil texture and slope. On the other hand, the difference between the Project area and the counterfactual, where both have similar ecological characteristics, can be attributed to the implementation of Project activities. It is expected that, as planted trees grow and natural regeneration takes place, vegetation will reduce runoff, increasing the volume of water being infiltrated underground. According to the modelling results, it is expected that when the restoration reaches maturity, the Project area will infiltrate an additional volume of 10,279 m^3 per year, compared to the pre-project period, depending also on the volume of rainfall for each given year.

TABLE 8. ESTIMATED DGWR IN THE PROJECT AREA (8.05 HA), COUNTERFACTUAL (8.03 HA) AND MICROBASIN (827.03 HA) AT THE ASSESSED PERIODS.

	dGWR (mm = L m^{-2})			Total Infiltration (m^3)		
Period	**Project area**	**Counterfactual**	**Microbasin**	**Project area**	**Counterfactual**	**Microbasin**
Pre-project	-212	-278	-185	-17,075	-22,293	-1'528,301
Monitoring	-163	-213	-126	-13,110	-17,140	-1'038,896
Year 10	-84	-181	-114	-6,799	-14,527	-939,376
Year 40	-84	-181	-114	-6,793	-14,500	-938,314

TABLE 9. PERCENTAGE CHANGE IN INFILTRATION AND DGWR IN THE PROJECT AREA (8.05 HA), COUNTERFACTUAL (8.03 HA) AND MICROBASIN (827.03 HA) OVER THE ASSESSED PERIODS.

Period	Percent change (%)			dGWR change (m^3)		
	Project area	**Counter-factual**	**Microbasin**	**Project area**	**Counter-factual**	**Microbasin**
Pre-project to Monitoring	23.2	23.1	32.0	3,961	5,150	489,056
Pre-project to Y10	60.2	34.8	38.5	10,279	7,758	588,396
Pre-project to Y40	60.2	35.0	38.6	10,279	7,803	589,924

VI.1. WATER CREDITS CALCULATION

The modelled change in the project scenario from year 0 to 40 is: 60.2 %, whilst in the control area with a BAU scenario it is 35.0 %. Pre-project dGWR in the Project area is: -212.1 mm, according to the modelled Project scenario trajectory, its dGWR at year 40 will be -84.4 mm. Contrastingly, if the Project area follows the modelled BAU trajectory, its dGWR at year 40 will be -137.9 mm.

Two project scenarios were computed: conservative and optimistic. The conservative scenario assumes that the full impact of the project will be achieved until year 40. It is represented as a lineal progression from the Pre-project (year 0) until the Future (year 40) infiltration. The optimistic scenario assumes that planted trees will mature and reach the maximum impact since year 10, maintaining the benefits until the end of the project.

Therefore, 3 scenarios were computed as follows:

- Conservative scenario: linear change from year 0 until 40.
- Optimistic scenario: linear change from year 0 until 10, then linear change from year 11 until 40.
- No project scenario: linear change from year 0 until 40.

Project's impact was calculated, in mm, as the difference between the BAU and the project scenario. Then it was converted into m^3/ha by multiplying by 10 the impact in mm, since mm = L/m^2. The additional water infiltration the Project can potentially lead to was calculated as the sum of each year's impact. Table 9 compares the annual infiltration in the Project area for the 3 assessed scenarios over the 40 years following project implementation.

Figure 3 illustrates Project area’s modelled infiltration for the 3 scenarios. The accumulated additional water infiltration at year 40, attributable to Project activities, is estimated to be between 10968.0 and 30123.0 m^3/ha. Considering the whole Project area (8.05 ha), the volume of water that is expected to be infiltrated due to implementation of Project activities is between 88297 and 242502 m^3. Since 1 water credit equals 1 m^3 of water that is infiltrated due to implementation of Project activities, the number of Water Credits the Project can generate is between 88297 and 242502 (figure 4).

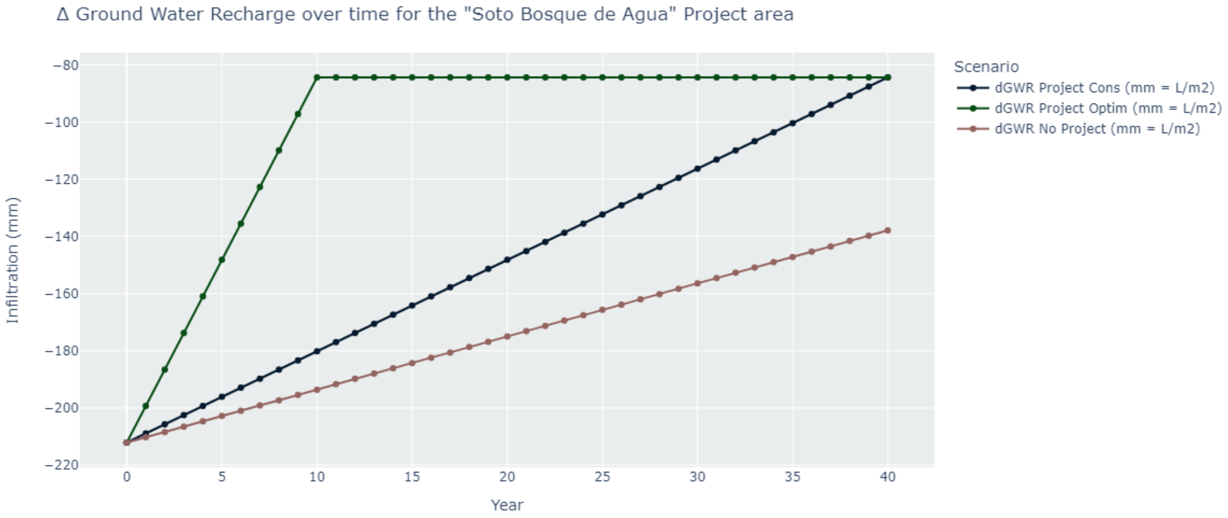
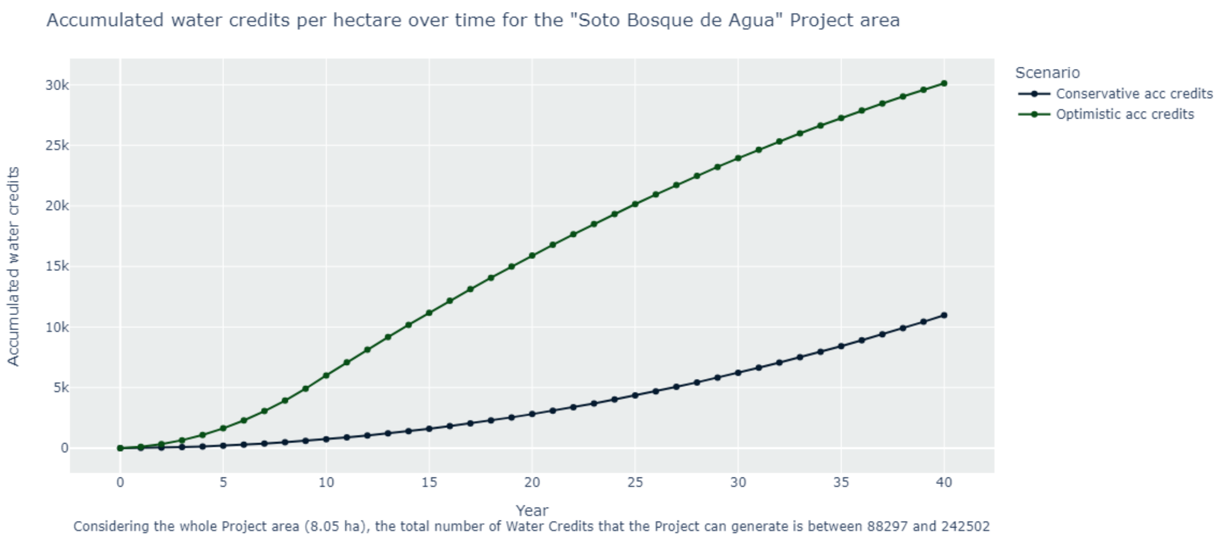


FIGURE 3. PROJECT AREA’S MODELLED INFILTRATION FOR THE 3 SCENARIOS.


Accumulated water credits per hectare over time for the "Soto Bosque de Agua" Project area

Considering the whole Project area (8.05 ha), the total number of Water Credits that the Project can generate is between 88297 and 242502

FIGURE 4. YEARLY ACCUMULATED NUMBER OF WATER CREDITS PER HECTARE FOR BOTH THE CONSERVATIVE AND OPTIMISTIC SCENARIOS.

Table 9 presents the calculation of water credits along the life of the project. Columns *dGWR Project Cons (mm = L/m^2)* and *dGWR Project Optim (mm = L/m^2)* show the modelled evolution in the project area for the conservative and optimistic scenarios, respectively. Column *dGWR No Project (mm = L/m^2)* shows modelled evolution in dGWR at the Project area using expected change in the counterfactual area. Columns *Impact Cons* and Column *Impact Optim* show the difference in water infiltration in the project area between the no-project scenario, and the conservative or optimistic scenarios, respectively. Columns *conservative acc credits* and *Optimistic acc credits* show the volume of water (m^3) infiltration due to project activities, accumulated since the start of the project, for both conservative and optimistic scenarios, respectively; this gives the number of credits to issue each year per hectare.

In this example, the accumulated volume of water (in m^3) and, therefore, the number of credits per hectare along the 40-year period of the Project will be 10,968 in the conservative scenario and 30,123 in the optimistic scenario.

TABLE 10. MODELLED YEARLY INFILTRATION FROM PRECIPITATION IN THE PROJECT AREA AND ACCUMULATED NUMBER OF CREDITS PER HECTARE. (SEE NEXT PAGE)

Year	dGWR Project Cons (mm = L/m^2)	dGWR Project Optim (mm = L/m^2)	dGWR No Project (mm = L/m^2)	Impact Cons (mm = L/m^2)	Impact Optim (mm = L/m^2)	Impact Cons (m^3/ha)	Impact Optim (m^3/ha)	Conservative acc credits	Optimistic acc credits
0	-212	-212	-212	0	0	0	0	0	0
1	-209	-199	-210	1.3	10.9	13	109	13	109
2	-206	-187	-208	2.7	21.8	27	218	40	327
3	-203	-174	-207	4	32.7	40	327	80	654
4	-199	-161	-205	5.4	43.7	54	437	134	1091
5	-196	-148	-203	6.7	54.6	67	546	201	1637
6	-193	-136	-201	8.1	65.5	81	655	282	2292
7	-190	-123	-199	9.3	76.4	93	764	375	3056
8	-187	-110	-197	10.7	87.4	107	874	482	3930
9	-183	-97	-195	12	98.2	120	982	602	4912
10	-180	-84	-194	13.4	109.2	134	1092	736	6004
11	-177	-84	-192	14.7	107.3	147	1073	883	7077
12	-174	-84	-190	16	105.4	160	1054	1043	8131
13	-171	-84	-188	17.4	103.6	174	1036	1217	9167
14	-167	-84	-186	18.7	101.7	187	1017	1404	10184
15	-164	-84	-184	20.1	99.9	201	999	1605	11183
16	-161	-84	-182	21.4	98	214	980	1819	12163
17	-158	-84	-181	22.8	96.2	228	962	2047	13125
18	-155	-84	-179	24.1	94.3	241	943	2288	14068
19	-151	-84	-177	25.5	92.5	255	925	2543	14993
20	-148	-84	-175	26.8	90.6	268	906	2811	15899
21	-145	-84	-173	28	88.7	280	887	3091	16786
22	-142	-84	-171	29.4	86.9	294	869	3385	17655
23	-139	-84	-169	30.7	85	307	850	3692	18505
24	-136	-84	-168	32.1	83.2	321	832	4013	19337
25	-132	-84	-166	33.4	81.3	334	813	4347	20150
26	-129	-84	-164	34.8	79.5	348	795	4695	20945
27	-126	-84	-162	36.1	77.6	361	776	5056	21721
28	-123	-84	-160	37.5	75.8	375	758	5431	22479

Year	dGWR Project Cons (mm = L/m^2)	dGWR Project Optim (mm = L/m^2)	dGWR No Project (mm = L/m^2)	Impact Cons (mm = L/m^2)	Impact Optim (mm = L/m^2)	Impact Cons (m^3/ha)	Impact Optim (m^3/ha)	Conservative acc credits	Optimistic acc credits
29	-120	-84	-158	38.8	73.9	388	739	5819	23218
30	-116	-84	-156	40.1	72	401	720	6220	23938
31	-113	-84	-155	41.5	70.2	415	702	6635	24640
32	-110	-84	-153	42.8	68.3	428	683	7063	25323
33	-107	-84	-151	44.2	66.5	442	665	7505	25988
34	-104	-84	-149	45.4	64.6	454	646	7959	26634
35	-100	-84	-147	46.8	62.8	468	628	8427	27262
36	-97	-84	-145	48.1	60.9	481	609	8908	27871
37	-94	-84	-144	49.5	59.1	495	591	9403	28462
38	-91	-84	-142	50.8	57.2	508	572	9911	29034
39	-88	-84	-140	52.2	55.4	522	554	10433	29588
40	-84	-84	-138	53.5	53.5	535	535	**10968**	**30123**

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ANNEX 1. FIELD TECHNIQUE FOR INFILTRATION MEASUREMENT WITH RING INFILTROMETER

1. At each sample location, clip any plants on the site down to ground level, being careful not to disturb the soil.
2. The soil should typically be pre-wetted to a moisture level throughout the profile prior to conducting the experiment. Pre-wetting the soil ensures that it is at or near field capacity, meaning it is adequately moist but not saturated/waterlogged.
    a. In dry soils, water naturally infiltrates rapidly. This may cause an overestimation of infiltration rates.
    b. This step can be skipped for already moist soils which experienced some irrigation or rainfall prior to conduction of the experiment.
3. The metal ring should be marked at regular intervals (at least 2 markings) on the inside to ensure ease of measuring the drop of water height at each point and a 15 cm. mark from the bottom on the outside of the ring.
4. Insert the ring, until it reaches the 15 cm. depth mark in the soil. If the terrain has slope, the 15 cm mark shall be at the level of the soil on the lowest side of the ring (see figure 5).
    a. This is because flow may move laterally especially if the rings are set only a short depth into the soil.
5. Seal any large gaps along the exterior edges of the ring with soil taking care not to disturb the surface of soil inside the ring.
6. Gently fill the ring with water, being careful not to stir up the soil, until the level reaches the upper line drawn on the inside of the ring.
7. Measure with the help of a stopwatch and record the time taken for the water level to drop to each line marked.
8. Refill the ring with water and repeat the measurements several times until the time of infiltration is the same as on the previous measurement.
    a. At least two infiltration tests should be carried out at each sample point to make sure accurate results are obtained.
    b. As more water replaces the air in the pores, the water from the soil surface infiltrates more slowly and eventually reaches a steady rate from which the basic infiltration rate of the soil can be obtained.

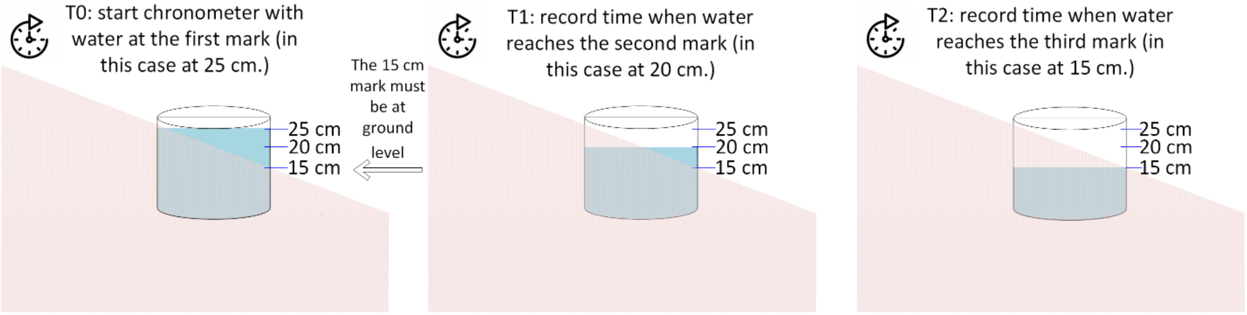

FIGURE 5. PROCEDURE FOR MEASURING WATER INFILTRATION ON THE FIELD.

DOCUMENT HISTORY		
Version	**Date**	**Comments**
V2.3	20/02/2025	Edition of the third version.
V2.2	08/02/2024	Edition to the second version, including an updated example of a project baseline assessment.
V2.0	25/06/2023	Second version released for review by the aOCP Steering Committee under the aOCP Version 2. Machine learning algorithms and Penman-Monteith ET Method were added.
V1.0	15/03/2023	First version Second version released for review by the aOCP Steering Committee under the aOCP Version 1.