ATHLAS VERITY

Nature-based Solution Calculation Methodology

Satellite, Soil-Peat & AI-Powered Ecological Carbon Quantification

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Reference Standards: [('vm0033', 'Verra (2023). VM0033 Methodology for Tidal Wetland and Seagrass Restoration (applicable pools).'), ('vm0027', 'Verra (2019). VM0027 Rewetting Drained Tropical Peatlands.'), ('ipcc-2013-wetlands', 'IPCC (2014). 2013 Supplement to the 2006 Guidelines: Wetlands.'), ('ipcc-2006', 'IPCC (2006). 2006 Guidelines - AFOLU Volume 4.'), ('iso-14064-2', 'ISO 14064-2:2019. Quantification, monitoring and reporting of GHG removals.'), ('sentinel-2', 'European Space Agency. Sentinel-2 MSI Level-2A products (10 m).'), ('sar-peat', 'Sentinel-1 SAR + InSAR for peatland hydrology & disturbance monitoring.'), ('carbon-fraction', 'IPCC default carbon fraction 0.47 +/- 0.03 for vegetation.')]
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Engine: Nature-based Solution (NbS) Verifier Engine · **Project:** Athlas Verity Carbon Verification Engine

1. Purpose & Scope

This document establishes the standardized, fully transparent mechanism for quantifying the net carbon removals and ecological outcomes (tonnes CO2e) of nature-based solution projects verified by Athlas Verity — including peatland restoration, degraded-land remediation and mixed ecosystem restoration. It integrates carbon accounting with quantified co-benefits into a single auditable pipeline.

It aligns with Verra VM0033/VM0027, the IPCC 2013 Wetlands Supplement and ISO 14064-2, and is prepared for compliance, verification, reporting and carbon-standard publication.

Scope — Forest Project Types

- **Peatland restoration** — Rewetting drained peat; avoid oxidation & promote accumulation
- **Degraded-land remediation** — Restore vegetation/soil carbon on degraded or bare land
- **Mixed ecosystem restoration** — Forest-grassland-wetland mosaics; unified pool accounting
- **Wetland / riparian NbS** — Coastal and freshwater wetlands with quantified outcomes

Aligned Standards

- **Verra VM0033 / VM0027** — Tidal wetland / peatland restoration methodologies
- **IPCC 2013 Wetlands Supplement** — Soil, peat and wetland carbon accounting
- **IPCC 2006 Guidelines** — AFOLU Volume 4 — vegetation and soil pools
- **ISO 14064-2:2019** — Quantification, monitoring and reporting of GHG removals
- **CEOS / Cal/Val practices** — Satellite product calibration and validation

2. Satellite Data Acquisition

The engine ingests multi-sensor, multi-temporal NbS satellite data. Peatland and degraded-land accounting requires optical vegetation signal, radar/hydrology context and terrain; no single sensor is sufficient. The table below defines the operational data stack.

Sensor	Type	Retrieved Variables	Resolution / Revisit	Temporal Coverage	Role in Pipeline
Sentinel-2 (MSI)	Passive optical	Multispectral bands: NDVI, MNDWI, red-edge, SWIR — vegetation & wetness	10 m, 5-day revisit	Continuous	Ecosystem classification & vegetation indices
Sentinel-1 (C-band SAR)	Active radar	VH/VV backscatter — soil moisture, hydrology, disturbance; works through cloud	10 m, 6-12 day revisit	Continuous	Peatland wetness & disturbance monitoring
Landsat 8/9 (OLI)	Passive optical	Long time-series spectral indices for baseline & change	30 m, 16-day	1984-present	Historical baseline & degradation detection
SRTM / Copernicus DEM	Radar interferometry	Terrain, slope, aspect, drainage - peat dome structure	~30 m	Static	Hydrological & peatland terrain normalization
GEDI (NASA, ISS)	LiDAR full-waveform	Canopy height & vertical structure over restored/wooded areas	25 m footprints	2019-present	Vegetation AGB scaling & structure
Hydrology + field plots (aux)	Ground truth	Water table depth, peat depth, SOC cores, allometric plots	Plot / core level	Survey campaign	Peat carbon, hydrology & model validation

3. Dataset Inventory

Dataset / Product	Source	Resolution	Frequency
Sentinel-2 MSI reflectance	ESA	10 m (20/60 m bands)	5 days
Sentinel-1 VH/VV backscatter	ESA	10 m	6-12 days
Landsat 8/9 OLI SR	USGS	30 m	16 days
NDVI / MNDWI / red-edge indices	Derived (Sentinel-2, Landsat)	10-30 m	5-16 days
Canopy height & structure	GEDI L2A + UAV-LiDAR	25 m / plot	Campaign-dependent
Terrain / slope / drainage	SRTM / Copernicus DEM	~30 m	Static
Peat depth & extent	Field coring + ground-penetrating radar	Core / survey	Campaign-dependent
Water table depth	Piezometers / InSAR proxy	Point / 10 m	Continuous / periodic
Soil Organic Carbon (SOC)	Field cores	Core interval	Campaign-dependent
Hydrology / disturbance index	Sentinel-1/InSAR + precipitation	10 m / regional	6-12 days / daily

Preprocessing note: All products are pre-processed to a common 10 m grid: radiometric/BRDF normalization, cloud/shadow and open-water masking, geometric co-registration, and spatial gap-filling (kriging / RF imputation). Peat depth and SOC are handled at core resolution, interpolated within classified habitat strata, and validated against independent surveys.

4. AI Engine Architecture (Satellite → Soil/Peat Carbon → Credit)

The Nature-based Solution (NbS) Verifier Engine is a satellite-and-soil-to-credit inference pipeline. Each stage is deterministic, logged, and reproducible from raw inputs to final credits.

1. **Ingestion & Preprocessing**
   Reproject and resample satellite/terrain to a 10 m grid; radiometric normalization, cloud/shadow and water masking.
2. **Feature Engineering**
   Spectral indices (NDVI, MNDWI, red-edge, SWIR), SAR backscatter, terrain, water-table proxy, temporal aggregates.
3. **Ecosystem Classification**
   AI classifier (Random Forest / CNN) maps pixels to vegetation, wetland, peatland or degraded class; strata validated against field survey.
4. **Vegetation Carbon**
   Ensemble regressors estimate AGB+BGB from canopy height + spectral + SAR features per class.
5. **Soil & Peat Carbon**
   SOC from measured cores scaled by classified habitat; peat depth + bulk density interpolated to pixels.
6. **Hydrological & Disturbance Baseline**
   InSAR/SAR wetness and historical degradation establish baseline; water-table proxy informs oxidation risk.
7. **Unified Carbon-Pool Accounting**
   Combine AGB + BGB + SOC + peat into a project pool; annual flux from restoration trajectory.
8. **Uncertainty Quantification**
   Quantile ensembles emit P10/P50/P90; Monte Carlo (N=1000) propagates vegetation, soil, hydrology, disturbance.
9. **Baseline, Additionality & Risk**
   Baseline scenario vs counterfactual; leakage, risk-weighted buffer, integrity and risk discounts applied.
10. **On-chain Verification**
    netVerifiedRemovalTCO2e with co-benefit metrics serialized and written to the registry under AURA consensus.

5. Machine-Learning Models

The AI engine is a stacked ensemble. Cross-model disagreement is treated as a source of uncertainty, not ignored. Models are trained on satellite features and validated against field plots and peat cores.

Model	Input	Validation	Rationale / Output
Random Forest (RF)	Tabular NbS features (spectral indices, SAR, terrain, wetness); quantile variant for P10/P50/P90	Spatially-separated folds vs plots; OOB error	Robust; ecosystem classification & carbon regression
XGBoost	Non-linear interactions among spectral, radar & hydrological features	Held-out cores & plots; RMSE / R2 / bias	Handles interactions; strong tabular baseline
Deep CNN Regressor	3D feature cubes (multi-band, multi-temporal); learns spatial & disturbance context	Independent holdout scenes; interval coverage	Spatial context; robustness across NbS strata
Ensemble Stacker	Outputs of RF, XGBoost, CNN as meta-features; ridge/GBM meta-model	Ensemble spread tracked as uncertainty budget	Final consensus estimate; spread → uncertainty margin

Training & Calibration Blocks

1. Target definition: vegetation C, SOC density and peat depth from cores + plots as training labels.
2. Spatially-separated folds by ecosystem stratum & region; strict no-geographic-leakage split.
3. Quantile regression forests + MC dropout for calibrated P10/P50/P90 intervals.
4. Validation metrics: RMSE, R2, bias, and 95% interval coverage vs held-out cores & plots.
5. Empirical residual calibration on independent field campaigns before inference.
6. Annual re-training as new scenes, hydrology and survey data arrive.

> **Integrity safeguard:** spatially separate folds prevent geographic leakage; held-out field plots independently validate every prediction before any credit is issued.

6. Step-by-Step Calculation Procedure

1. **Ecosystem Classification**
   AI maps each 10 m pixel to vegetation/peatland/wetland/degraded class; compute area per class.
2. **Vegetation Carbon (AGB+BGB)**
   veg_p10 = min(agb_p10, cap) per class; add BGB via root-to-shoot ratio.
3. **Soil & Peat Carbon**
   soc_stock = sum(SOC_density × depth) per stratum; peat depth & bulk density interpolated.
4. **Hydrological Baseline**
   Establish water-table and disturbance baseline from InSAR/SAR + historical degradation.
5. **Unified Carbon Pool**
   total_C = AGB + BGB + SOC + peat; annual flux from restoration trajectory over crediting period.
6. **CO2e Conversion**
   total_C × carbon_fraction × 44/12 → tCO2e per pool.
7. **Baseline & Additionality**
   Baseline = counterfactual degraded pool % (e.g. 40%); additionality verified.
8. **Deductions**
   Apply leakage (%), risk-weighted buffer (%), integrity discount (%), risk adjustment (%) in sequence.
9. **Conservatism & Net Credit**
   net = deterministic_net - uncertainty_margin; capped at CI-95% lower bound; result = netVerifiedRemovalTCO2e.

7. Uncertainty & Conservatism

The engine reinforces structural conservatism with Monte Carlo simulation (N = 1000). Vegetation, soil/peat carbon, hydrological and disturbance uncertainty are drawn from distributions defined by their mean and standard deviation. The crediting boundary is the lower bound of the 95% confidence interval.

```
uncertainty_margin = max(deterministic_net - lower_crediting_bound, 0)
```

```
net_verified = deterministic_net - uncertainty_margin
```

Each calculation carries an equation trace linking every input to final output, so auditors can reproduce every figure. Because NbS faces disturbance and reversal risk, an evidence-weighted buffer pool is applied. Issuance never exceeds the CI-95% lower bound.

8. Numerical Example (End-to-End, Pixel to Credit)

Inputs (500 ha restoration, conservative):

- **Project:** 200 ha Peatland restoration (rewetting drained peat)
- **Satellite stack:** Sentinel-2 MNDWI/NDVI + Sentinel-1/InSAR wetness + SRTM terrain + GEDI, 10 m grid
- **Vegetation carbon:** 45 t C/ha (AGB+BGB)
- **Soil + peat carbon:** 320 t C/ha (SOC + peat)
- **Baseline:** degraded to 40% of project pool (previous drainage/oxidation)
- **Deductions:** leakage 10%, buffer 25%, integrity IC-B (10%), risk_adjustment 12%
- **Carbon fraction:** 0.47; CO2e ratio 44/12

Stage	Calculation	Result
Total Carbon Pool	`(45 + 320) = 365 t C/ha × 200 ha`	**73,000 t C**
Gross CO2e	`73,000 × 44/12 = 267,667 t CO2e`	**267,667 t CO2e**
Baseline (40% degraded)	`267,667 × 0.40`	**107,067 t CO2e**
Net after baseline	`267,667 - 107,067 = 160,600 t CO2e`	**160,600 t CO2e**
After leakage (10%)	`160,600 × 0.90`	**144,540 t CO2e**
After buffer (25%)	`144,540 × 0.75`	**108,405 t CO2e**
After integrity (10%)	`108,405 × 0.90`	**97,565 t CO2e**
After risk (12%) & conservatism	`97,565 × 0.88 ≈ 85,857 t CO2e`	**85,857 t CO2e**

Conclusion: Of ~160,600 tCO2e gross restoration potential, ~53% passes to 85,857 tCO2e validated credits after baseline degradation, leakage, the risk-weighted permanence buffer, integrity and risk conservatism — with quantified biodiversity and community co-benefits.

9. Verification & On-chain Lifetime

1. The netVerifiedRemovalTCO2e is written to the Athlas Verity registry with a serial number per vintage (AV-NBS001-{serial}) and a provenance hash of all input datasets and model runs.
2. AURA consensus re-checks the arithmetic and conservatism bounds; every credit is traceable to its source polygon, satellite scene set and field/core evidence, with co-benefit metrics attached.
3. On retirement, the credit certificate is minted and the serial is burned on-chain, preventing double claiming of the same ecological removal.

10. Regulatory & Compliance Framework

This section defines the compliance pathway through which AV-NBS001 credits are rendered eligible, additional, monitored, and independently verifiable under recognised carbon standards. It formalises the audit requirements referenced throughout this methodology.

A. Eligibility & Applicability

Project eligibility. A project is eligible for AV-NBS001 crediting only where it demonstrably falls within the applicable scope of this methodology and the governing standards: **Verra VM0033 / VM0027 · IPCC 2013 Wetlands Supplement · IPCC 2006 Guidelines · ISO 14064-2:2019 · CEOS / Cal/Val practices**.

- **Boundary & commencement:** a defined project boundary, a documented start date, and enforceable legal right to the carbon rights being claimed.
- **Land/asset status:** verifiable baseline land-use or asset status at commencement, with no prior registry registration of the same credits (no double counting).
- **Additionally screen:** the activity must not be required by law, regulation, or business-as-usual practice.

B. Additionality Assessment

Additionally is established using a documented, evidence-based procedure consistent with the governing registry (Verra VCS, CDM, ISO 14064-2, or Puro.earth as applicable). The assessment applies a sequential test:

1. **Legal/regulatory test** — confirm no statutory obligation to undertake the activity.
2. **Investment/financial test** — demonstrate the activity is not clearly the most economically attractive course absent carbon revenue (economic analysis against a conservative financial benchmark).
3. **Barrier test** — identify material financial, technological, institutional, or capacity barriers that the carbon revenue overcomes.
4. **Common-practice test** — confirm the activity type is not widespread within the relevant region/asset class.

All assumptions, data, and model outputs supporting the additionality determination are retained in the audit trail for independent review.

C. Monitoring, QA/QC & Sampling Plan

Monitoring plan. A written monitoring plan defines indicators, measurement frequency, instrumentation, and data-retention rules for every crediting interval. All raw inputs (satellite scenes, field records, meter logs, mass-flow data) are time-stamped, georeferenced where applicable, and retained in the auditable registry.

Sampling design. Ground-truth and field sampling follow a stratified random design with documented sample size determined by a target confidence/precision budget, giving statistically valid estimates and defensible uncertainty bounds.

QA/QC. Quality-assurance/quality-control procedures include: duplicate and independent re-measurement checks, instrument calibration traceability, outlier screening, and reconciliation against independent data sources. Any data gap or anomaly is logged and conservatively treated.

D. Third-Party Verification & Audit Trail

Independent verification. Issuance is conditioned on independent desk review and, where required, field or on-site verification by a qualified verifier. The verifier re-checks input provenance, calculation logic, uncertainty treatment, and conservatism settings against this methodology.

Audit trail. Every issued unit carries a unique serial (AV-NBS001-[SERIAL]), a provenance hash of all input datasets and model runs, and an immutable on-chain record. On retirement the serial is burned, preventing double counting and enabling independent audit at any time.

Re-verification cycle. Monitoring reports, calculations, and verifier findings are re-assessed at each crediting interval; buffer and risk parameters are re-evaluated against observed disturbance events before further issuance.

E. Permanence, Leakage & Buffer

Permanence & reversal risk. Nature-based solutions sequester carbon with inherent reversal risk from disturbance (fire, harvest, land conversion, climate stress). Units contribute to a **buffer pool** sized by a non-permanence risk (**NPR**) assessment spanning disturbance and governance vectors; change-detection triggers buffer drawdown on verified reversal.

Leakage. Displacement of land-use or biomass activity outside the project boundary is screened and quantified, and any identified leakage is deducted from issuable units.

F. SDG Contribution & Safeguards

SDG contribution. Activities are evaluated against SDG 13 (Climate Action), SDG 15 (Life on Land) and SDG 6/2, with documented biodiversity and livelihood co-benefits. **Safeguards.** FPIC, stakeholder consultation, protection of high-conservation-value areas, and no net harm to communities are enforced.

11. References

ID	Reference
vm0033	Verra (2023). VM0033 Methodology for Tidal Wetland and Seagrass Restoration (applicable pools).
vm0027	Verra (2019). VM0027 Rewetting Drained Tropical Peatlands.
ipcc-2013-wetlands	IPCC (2014). 2013 Supplement to the 2006 Guidelines: Wetlands.
ipcc-2006	IPCC (2006). 2006 Guidelines - AFOLU Volume 4.
iso-14064-2	ISO 14064-2:2019. Quantification, monitoring and reporting of GHG removals.
sentinel-2	European Space Agency. Sentinel-2 MSI Level-2A products (10 m).
sar-peat	Sentinel-1 SAR + InSAR for peatland hydrology & disturbance monitoring.
carbon-fraction	IPCC default carbon fraction 0.47 +/- 0.03 for vegetation.

12. Key Glossary

Term	Definition
Peatland	Organic-soil wetland; drainage oxidizes stored carbon.
Rewetting	Restoring water table to halt peat oxidation & promote accumulation.
AGB / BGB	Above-Ground / Below-Ground Biomass - living vegetation carbon.
SOC / peat C	Soil Organic Carbon / carbon stored in peat deposits.
Water table	Depth of the saturated zone; key driver of peat oxidation.
Co-benefits	Quantified biodiversity and community outcomes of NbS projects.
P10 / P50 / P90	10th/50th/90th percentile of the estimation distribution.
Buffer pool	Risk-weighted reserve covering disturbance & reversal risk.
Additionality	Removals occurring only because of the project.
tCO2e	Tonnes of carbon dioxide equivalent - unit of carbon credit.
Disturbance	Fire, drainage, land-use events that can reverse carbon storage.
VM0027	Verra methodology for rewetting drained tropical peatlands.
InSAR	Interferometric SAR - measures ground/hydrology change.
MRV	Measurement, Reporting and Verification.

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14. Supplementary Notes

14.1 Purpose and Status of This Document

This methodology is provided as an informative, professional reference describing the technical design and calculation approach of the Athlas Verity carbon-verification engine. It is intended to support understanding, compliance readiness, verification, and reporting by project proponents, verifiers, and standard bodies.

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