PHISHES

PHysically-based Integrated Soil HEalth Simulation platform

Predicting soil health to protect ecosystems

D 5.4. Implementing the EU Soil Monitoring Law:

How PHISHES Supports Member State Obligations

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Executive Summary

Over 60% of EU soils are currently degraded, costing the European economy an estimated 50 billion euro annually. The EU's Soil Monitoring and Resilience Law, adopted in November 2025, establishes (for the first time) a comprehensive framework requiring Member States to monitor and report against defined soil health descriptors and to transpose obligations into national legislation within three years. Yet, legislation alone is insufficient without the scientific tools to translate policy into action.

The PHysically-based Integrated Soil HEalth Simulation platform (PHISHES) addresses this gap. By coupling established hydrological and biogeochemical models, it generates 30-year predictive simulations of how land use changes and nature-based solutions affect soil health, displayed through a decision support platform benchmarked against SML thresholds. The methodology is validated across four test cases, covering agricultural basins (Czech Republic, Poland), a PFAS contaminated site (Sweden), and urban soils (Rotterdam).

PHISHES directly supports several SML descriptors, including soil organic carbon, water retention, contamination by pesticides and PFAS and soil sealing, as well as key legal provisions: its predictive outputs could enable Member States to invoke Article 9(10) monitoring derogations after PHISHES model validation, its platform supports Article 11 advisory obligations, and its contamination modelling informs the risk-based approach required under Articles 13 and 16.

PHISHES represents a significant and deployable step toward the scientific infrastructure the SML demands, empowering stakeholders to assess compliance trajectories and make evidence-based decision for soil health.

Keywords

Soil Monitoring Law, PHISHES.

List of acronyms and abbreviations

DSS	Decision Support System
EU	European Union
LUCAS	The Land Use and Organic Coverage Area frame Survey
MS	Member State
NBS	Nature-Based Solution
OTV	Operational Trigger Value
PDP	PHISHES Digital Platform
SML	Soil Monitoring and Resilience Law
SOC	Soil Organic Carbon

STV	Sustainable Trigger Value

POLICY BRIEF

Implementing the EU Soil Monitoring Law:

How PHISHES Supports Member State Obligations

1 The Soil Crisis and the Case for Action

More than 60% of soils across the European Union (EU) are currently experiencing some form of degradation.[1] Overexploitation, the accelerating effects of climate change, and widespread pollution are placing extraordinary pressure on one of Europe's most vital and under-protected natural resources. Healthy soils sustain food production, regulate the hydrological cycle, sequester carbon, support vast biodiversity, provide clean groundwater, and underpin human wellbeing. They are thus essential for the provision of ecosystem services.

Despite novel and cutting-edge EU funded research in the field of pedology, soil degradation has continued at an alarming rate, with the annual economic cost of degradation currently estimated at €50 billion[2] in the EU alone. Although the costs are known, political willingness to deal with soil health has yet to crystalize. This development is exacerbated and engendered by a lack of legal protections afforded to soil as compared to water and air and underpinned by a fragmented legal landscape where soil is often relegated and subjected to anthropocentric needs instead of being understood as intrinsically valuable.

Since the early 2000s[3], soil health has gained increasing salience in European policy discourse and imaginaries, as evidenced by the recently adopted Soil Monitoring and Resilience law (SML) which marks a significant step forward in establishing a comprehensive framework for soil monitoring, assessment, and remediation across Member States (MS).

Notwithstanding these laudable efforts, legislation alone is often insufficient without the scientific tools to translate policy obligations into local, evidence-based action. The EU Soil Mission-funded project PHysically-based Integrated Soil HEalth Simulation platform (PHISHES) aims to contribute to bridge the missing link between data on soil health and actions for the safeguarding of soils. This policy brief will delineate what PHISHES is, what it can do and explore how it can service the SML by highlighting entry points.

2 What is PHISHES?

PHISHES develops predictive capability that shows the consequences of actions, land use management changes and nature-based solutions (NBS), on the provision of soil functions and associated ecosystem services. Crucially, it offers a 30-year predictive window, enabling stakeholders to visualise not just immediate outcomes but the sustained trajectory of soil health under various scenarios.

In PHISHES, climate change, soil contamination and soil use are considered in predicting the potential impact certain actions can have. To do so, the project builds upon several pre-existing modelling tools such as Hydrus-PHREEQC, Daisy, MIKE SHE, and MIKE ECO Lab, MODFLOW-2005 and MODFLOW-6. The coupling of these modelling softwares will allow scenario modelling to go beyond merely the soil-unit but also address processes at the watershed scale, thus showing a

[1] Cristina Arias-Navarro, R. Baritz, and A. Jones, "The state of soils in Europe: Fully evidenced, spatially organised assessment of the pressures driving soil degradation," *European Environment Agency* (2024): 10.
[2] Pieper et al., "The upcoming European Soil Health Law – chances and challenges for an effective soil protection," *German Environment Agency* (2023): 9.
[3] Cristina Arias-Navarro et al., "Forty years of soil research funded by the European Commission: trends and future. A systematic review of research projects," *European Journal of Soil Science* 74, no. 5 (2023).

larger picture of the impact varying measures can have on soil health. The project will produce model trains, which consist of combining the aforementioned modelling tools with each other. The project will also result in the development of a digital platform that provides access to data and the tools developed. This ensures that while the PHISHES methodology is validated through four specific test cases, it can be applied anywhere across the EU, contingent on the availability of data for the compound on retention, degradation and precipitation, as well as technical expertise.

All outputs are displayed through the PHISHES Digital Platform (PDP), a Decision Support System (DSS), where they are benchmarked against soil health descriptors and their thresholds, as well as the sustainable target and operational trigger values as articulated in the SML. To that end, "a key objective of the PHISHES project is to translate the results of the scenario simulations into evidence-based recommendations for policy making and for various stakeholders (farmers, planners, authorities)."[4]

2.1 The Five Test Cases

The assumptions about land use management changes and NBS impact on soil functions and soil ecosystem services built into the PHISHES methodology are validated through research in the test sites. The four test cases were selected based on their different nature, and their varying spatial and temporal scales. The laboratory in France further expands on the PFAS and contamination research done in the Örnsköldsvik airport and is thus not counted as a separate test case. The textbox below highlights each test case and the land use management techniques and NBSs that are applied in each. In the case of the Zelivka River Basin, several different types of local stakeholders have been consulted in devising the land use management techniques. Further stakeholder engagement will be completed for the Koprzywianka Basin, and is currently being pursued with government stakeholders in the Rotterdam Urban area and the Örnsköldsvik airport.

As research on agricultural soil and agricultural land use management techniques has been predominant in the field, PHISHES broadens the scope to also include a PFAS contaminated site and an urban site in its analysis. As a result, PHISHES is able to support policy makers facing these challenges as well.

- **Zelivka River Basin, Czech Republic**: point source and aerial pollution in an agricultural river basin, analysing scenarios including spatial reduction in agricultural activity, shifts to conservational agriculture, no-till farming, crop rotation and diversification (more legumes), decreased pesticide usage, permanent soil coverage, and enhanced water retention.
- **Koprzywianka Basin, Poland**: a typical agricultural landscape examining spatial reduction in agricultural activity, shifts to conservational agriculture and no-till agriculture, permanent soil organic cover, reduction of chemical fertilizer use, crop rotation and diversification, decreased pesticide usage, increased retention, sludge recycling, and reducing of atmospheric emissions.
- **Örnsköldsvik Airport, Sweden**: analysing Europe's growing PFAS contamination challenge (in particular a point source contamination) by analysing the injection of non-Newtonian fluid, increased greening and biochar application.
- **Rotterdam Urban Area, Netherlands**: testing urban soil health through indicators of soil sealing, implementing blue/green infrastructure and greening.
- **BRGM Soil Laboratory, France**: a controlled laboratory environment that can calibrate key parameters such as partition coefficients and dispersion coefficients to model the fate and transport as well as soil functions in a PFAS contaminated site in Sweden, focusing on remediation efforts.

[4] European Research Executive Agency, "Grant agreement project 101157438 – PHISHES," 7.

3 The Soil Monitoring and Resilience Law: A New Framework for Member States

The SML, recently adopted after previously failed legislative attempts, disinformation campaigns[5], and years of advocacy, is a landmark Directive establishing legally grounded soil monitoring, assessment, and management obligations across the European Union. Although weak on direct obligations for landowners and land managers, the SML signals the growing recognition of the importance of soil and can work as a stepping stone for future legislation.

Member States now have three years to transpose the Directive into national legislation. While some will need to adapt national soil protection laws, others will need to set up completely new frameworks. Some provisions however represent novel obligations for all Member States: the representative monitoring according to certain rules, the assessment of diffuse soil pollution and the creation of a soil health portal with reporting obligations.

The SML defines a set of soil health descriptors against which Member States must monitor and report. These are divided into four tiers:

- three mandatory Part A descriptors, for which Union-level non-binding sustainable target values (STVs) have been established;
- a set of Part B (non-mandatory) descriptors for which Member States are expected to set their own thresholds for non-binding sustainable target values and operational trigger values (OTV). Both of these values can be set at the same threshold[6];
- a set of Part C (non-mandatory) descriptors with no criteria provided;
- and a set of Part D (non-mandatory) descriptors on soil sealing and soil removal indicators.

Furthermore, beyond monitoring obligations, the SML establishes contaminated site management requirements[7] and obligations to advise and support landowners[8]. In order to meet these obligations, it could be beneficial for Member States to use reliable scientific tools.

The following sections showcase what the entry points of the SML are for PHISHES, highlighting the scientific descriptors of soil health it addresses and how PHISHES can be used by Member States to meet their obligations under the articles of the SML when transposing the Directive into national legislation.

4 Soil Health Descriptors: What Can PHISHES Address?

A chief contribution of the SML is that it provides a definition of soil health in article 3(5), namely that “soil health means the physical, chemical and biological condition of soil, determining its capacity to function as a vital living system and to provide ecosystem services.”

The SML also provides a definition of soil health assessment, based on “the estimation of the values of soil descriptors”.[9] If and how these descriptors are addressed by PHISHES, is elaborated upon in the tables below.

[5] Bartosz Brzezinski, “How to pass a green law in an anti-green age in 6 easy steps,” *Politico* (24 October 2025), https://www.politico.eu/article/how-to-pass-green-law-in-anti-green-age-6-easy-steps-soil-health/.
[6] SML article 7(6).
[7] SML articles 13 – 17.
[8] SML article 11.
[9] SML article 3(11).

4.1 Part A: Mandatory Descriptors (Union-level STVs)

Salinisation | Electrical Conductivity (dS per m⁻ ¹)	**PHISHES STATUS: NOT ADDRESSED**
SML Threshold: < 4 dS m^{-1} (saturated paste extract method), or equivalent. **Exemptions**: Naturally saline land areas, areas with regular flooding from marine submersion, areas subject to sea spray.	PHISHES does not currently address salinisation as no test case provides validation data for this descriptor. Without validated assumptions, including this descriptor would undermine scientific credibility. Technical users and policy makers are invited to build their own model trains addressing the issue of salinisation by applying the PHISHES methodology.
Loss of Soil Organic Carbon | SOC Concentration (g per kg)	**PHISHES STATUS: ADDRESSED**
SML Threshold: • Mineral soils: SOC/Clay ratio > 1/13. • Organic soils: national targets per Regulation (EU) 2024/1991, Art. 4(2), 4(4), and 11(4). **Exemptions**: Non-managed soils in natural land areas.	PHISHES addresses loss of soil organic carbon in all test cases. The agricultural test cases in particular model the impact of land use management changes on SOC dynamics. PHISHES can model 30-year SOC trajectories under different scenarios, enabling MS to assess which soil management interventions are most effective in maintaining or improving the SOC/Clay ratio against the SML threshold.
Subsoil Compaction | Bulk Density in Subsoil (g per cm³)	**PHISHES STATUS: IN DEVELOPMENT**
SML Threshold: The threshold varies by soil texture: Sand, loamy sand, sandy loam, loam: < 1.80 Sandy clay loam, loam, clay loam, silt, silt loam: < 1.75 Silt loam, silty clay loam: < 1.65 Sandy clay, silty clay, clay loam with 35 – 45% clay: < 1.58 Clay: < 1.47 **Exemptions**: Non-managed soils in natural land areas and areas with naturally compacted soils.	PHISHES is actively developing subsoil compaction modelling, expected to be finalized in the first version of the PDP. Critically, through the usage of Daisy and MIKE-SHE, PHISHES already models saturated hydraulic conductivity (Ksat), one of the SML´s optional metrics for compaction assessment. This gives PHISHES a meaningful foothold in compaction assessment even ahead of full bulk density modelling. Soil air capacity modelling is also within the hydrological framework.

4.2 Part B: Non-Mandatory Descriptors (Member State-level thresholds)

The overview of the following Part B descriptors follows the structure of the SML Annex I and for each descriptor defines how PHISHES addresses it.

Excess nutrient content in soil | Extractable phosphorus (mg per kg)

Addressed: The agricultural test cases model pesticide and fertilizer dynamics, which in turn allows for an analysis of the total sum of phosphorus in both water and in topsoil.

Soil Erosion | Erosion Rate (tonnes per hectare per year)

In Development: A dedicated erosion rate modelling is currently not part of the PHISHES methodology but is being developed by the team. Although it is not a mandatory descriptor in the SML, erosion is a pressing issue for many MS and thus addressing this in the PHISHES methodology is of paramount importance for the replicability of the methodology across MS.

Soil Contamination | Concentration of Heavy Metals and Organic Contaminants

Addressed: The agricultural test cases model pesticide dynamics and concentration of the heavy metals copper and zinc. The laboratory in France also analysis arsenic contamination in an old mine. The PDP can display whether interventions bring contamination levels within Member State-defined STVs and OTVs, directly informing the risk-based approach required under Articles 13 and 16. Although PHISHES' contamination focus is currently strongest on PFAS and pesticides, the methodology is generalisable to other contaminant types where input data and specificities are known. No exemptions are provided for in the SML.

Soil Water Retention and Infiltration | Water Holding Capacity, Ksat (cm per day), Air Capacity (%)

Addressed: Water retention and infiltration are central to the PHISHES hydrological model architecture. Daisy, MIKE SHE and MODFLOW are specifically designed to simulate saturated hydraulic conductivity and soil water dynamics in the soil profile and MIKE-SHE and MODFLOW across the watershed scale. The Rotterdam urban test case directly models the effect of soil sealing on the regulation of water flows and stocks, while the agricultural test cases model the impact of land use changes on these parameters. The Zelivka test case directly models the impact of soil cover, changed land use and soil tillage on water balance in the agricultural soil-plant system. The SML notably allows this descriptor to be assessed at river basin or sub-basin scale, which PHISHES can precisely address with its capability to model the watershed-scale. No exemptions are provided for in the SML.

Loss of SOC Stocks (Part B version) | SOC stocks (tC per ha^{-1})

Addressed: Complementing the Part A SOC concentration descriptor, Part B requires MS to set minimum SOC stock values linked to Land Use, Land Use Change and Forestry (LULUCF) targets. PHISHES' agricultural test cases model SOC stock trajectories under different land use scenarios, enabling Member States to assess long-term stock development.

4.3 Part C: Soil descriptors without criteria

Excess nutrient content in soil | Total nitrogen content in soil (mg per g^{-1}), SOC to nitrogen ratio

Addressed: Nitrogen content will be analysed in the agricultural test cases, which showcases the potential environmental impact of Nitrogen levels when using conservation agriculture land use management techniques. Through this validation exercise, PHISHES

users outside of the test cases will also be able to model the impact on nitrogen content in the soil profile and water leaching to groundwater and freshwater streams.

Acidification | Soil acidity (pH)

Not currently addressed: Acidification is currently not addressed in any part of the PHISHES model trains. Similar to salinisation, technical users and policy makers are invited to build their own model trains addressing the issue of acidification by applying the PHISHES methodology.

Topsoil Compaction | Bulk Density in topsoil (g per cm^{-3})

In Development: Similar to subsoil compaction, the modelling of topsoil compaction is being developed by PHISHES.

Soil Biodiversity | DNA metabarcoding for fungi and bacteria

Partly addressed: Soil biodiversity is modelled in the Daisy model through the average leaf area index or average soil cover, number of days without LAI<0.5 or soil cover, biomass development, Net Carbon incorporated with bio-incorporation, and the soil microbial biomass pools.

The SML suggests that soil biodiversity should be measured through: DNA metabarcoding for fungi and bacteria; metabarcoding of archaea, protists and animals; phospholipid fatty acid analysis (PLFA); abundance and diversity of nematodes; abundance and diversity of earthworms; abundance and diversity of springtails; abundance and diversity of native ants; soil biological quality based on arthropods (QBS-ar); presence of invasive alien species and plant pests; and soil basal respiration.

While the Daisy model measures of soil biodiversity through proxies are practical and applicable at scale, it falls short in that it cannot identify which organisms are present and soil fauna, thus not showing a complete picture of soil biodiversity. On the other hand, Daisy's key advantage in modelling soil biodiversity is that it can model 30 years into the future and does not just provide a snap-shot that DNA metabarcoding would.

Soil Contamination | Concentration of PFAS

Addressed: The PFAS test cases will be able to model contaminant distribution and transport in soil profiles, leaching to freshwater streams via artificial drainpipes, and leaching to the groundwater as influenced by land use and soil management, and assess the effect of remediation measures including biochar application, non-Newtonian fluid injection, and phytostabilisation.

4.4 Part D: Soil Sealing and Soil Removal Indicators

Soil Sealing and Soil Removal | Total sealed soil and areas that underwent soil removal (km^2 and % of MS surface), soil sealing and soil removal, de-sealing and net-sealing (average per year in km^2 and % of MS surface), total settlement area (km^2 and % of member state surface), land use change to and from settlement area (average per year in km^2 and % of MS surface)

Partly addressed: The issues of soil sealing is addressed in the urban test site in Rotterdam.

A Note on the 2027 Descriptor Submission Deadline

By June 2027, Member States must submit their own soil health descriptors and operational trigger values under Articles 7(5) and 7(6). Only once these are submitted can the PDP be fully adjusted for country-specific threshold assessment. This is a systemic constraint of the transposition timeline, not a PHISHES limitation: the PDP remains flexible to integrate newly defined thresholds by Member States once available or be able to be updated to remain in line with new scientific findings.

5 Legal Article Entry Points

Beyond addressing the scientific descriptors of soil health, PHISHES can also aid in the implementation of the SML as it can be used to fulfil some of the binding and non-binding provisions[10] in the SML.

5.1 Binding Provisions

Article	Obligation	PHISHES Contribution
Article 9(10): Monitoring Derogation	MS may waive new soil measurements for a soil descriptor if it is reasonable to expect, based on prior data and predictive soil models supported by statistically significant field data, that values have not changed significantly since the last monitoring cycle. This derogation cannot happen over two consecutive sampling campaigns.	Once PHISHES outputs have undergone the data validation process necessitated for regulatory uptake, its 30-year predictive capability, validated through multiple test cases at different scales, could be the 'predictive soil model' this derogation envisages. MS can use PHISHES outputs to justify skipping costly sampling campaigns while maintaining scientific defensibility of their actions for soil health.
Article 11: Supporting Landowners and Land Managers	MS must provide impartial, science-based advice; promote awareness of long-term benefits of soil health practices; and provide local-level information on suitable measures to increase soil health and resilience based on soil health assessments.	The PDP translates complex modelling into accessible, locally contextualised recommendations for the test cases. Furthermore, by modelling on a 30-year horizon, PHISHES can show the concrete long-term impact of soil health practices as opposed to short-term fluctuations. It can thus support land owners and land managers in making decisions for soil health.
Article 12: Soil Sealing	MS must avoid or reduce loss of ecosystem service capacity, minimise soil sealing and soil removal, and offset losses through de-sealing. Where soil sealing and land take is not preventable, MS are advised to utilise areas where loss of ecosystem services would be minimal.	The Rotterdam urban test case directly models soil sealing and urban greening scenarios, and highlights ecosystem service impacts. The PDP can visualise how sealing decisions affect indicators against SML thresholds for this test case.
Articles 13 & 16: Contaminated Sites	MS must establish a risk-based, stepwise approach to contaminated sites and ensure appropriate risk reduction measures are implemented.	The agricultural and PFAS test cases demonstrate PHISHES' capacity to model contamination risk and remediation outcomes. In addition, its methodology would allow for additional forms of contamination to be considered, if input parameters and data are available. Once MS submit their STVs and OTVs, the PDP can display for the test site locations

[10] The articles are summarised for the sake of brevity in this policy brief. For the authoritative text, please find the full article in the official Soil Monitoring and Resilience Law as published in the Journal of the European Union.

		whether interventions bring sites within these thresholds, thus providing the base information for a risk-based and step-wise approach.
Article 24(1)(k): Knowledge Repository	The Commission shall, with MS, develop a repository of knowledge on soil resilience containing practical information on soil management practices that is regularly updated and locally applicable.	PHISHES' validated land management scenarios and modelled outcomes across agricultural, urban, and PFAS-contaminated contexts could constitute the kind of evidence base this repository requires. Beyond test site specific results, PHISHES also provides a non-context specific overview of good practices for soil health and soil resilience, helping to improve access to independent science-based advice, and promoting the impact of soil health measures.

5.2 Non-Binding Provisions[11]

By including many of the non-legally binding provisions in its methodology, PHISHES helps to ensure that MS are working in a manner compatible with the SML and the suggestions made by the European Commission, even when they are not legally binding. The following table delineates specific suggestions for analysis or datasets made by the Commission in the preamble of the SML and shows if PHISHES accounts for this.

Preamble Paragraph	Provision	PHISHES Contribution
Paragraph 16	The Parliament and the Council call on MS to prepare a system to monitor soil carbon stocks, using the land use/cover area frame statistical survey (LUCAS) datasets.	The LUCAS database is already being integrated into the PHISHES methodology.
Paragraph 28	When establishing their soil units, MS can draw on additional available data on climate, environmental zones or river basins. In this context, the Alterra Report 2281 on 'Descriptions of the European Environmental Zones and Strata' of January 2012 is especially relevant as it provides datasets on generic classification of environmental stratification of Europe, aggregated into environmental zones, which can be used for the establishment of soil units by MS.	The European environmental zones and strata defined in the Alterra report will be added to the data repository of PHISHES.
Paragraph 35	To visualise soil sealing and soil removal, the COPERNICUS data is suggested to be used to form a common understanding on soil sealing and soil removal across the Union.	The data on soil sealing and soil removal does not come from COPERNICUS, thus decreasing compatibility of PHISHES with the SML. PHISHES will primarily use physical-based, deterministic models. These models not only allow for the assessment of the current situation, but also can showcase underlying processes driving soil sealing.
Paragraph 39	Cognizant of the importance of urban soils to ecosystem services, it is suggested that issues to focus on are: a	The Rotterdam test case does consider contamination, in particular contamination arising from increased infiltration of runoff

[11] The paragraphs are summarised for the sake of brevity in this policy brief. For the authoritative text, please find the full preamble in the official Soil Monitoring and Resilience Law as published in the Journal of the European Union.

	higher rate of contaminated sites due to past industrial activities, a higher risk of flooding because of soil sealing, a higher prevalence of heat islands and more limited access to green areas essential for mental and physical well-being.	when soil is sealed. It also analyses urban greening, but does not focus on flooding, a higher prevalence of heat islands and access to green areas directly.
Paragraph 42	Essential mitigation principles to focus on in regards to soil sealing and soil removal are: minimising soil sealing, de-sealing, and reconstructing previously sealed soils, rational densification of urbanised areas while safeguarding green spaces, including urban green spaces, and natural terrains, revitalisation of brownfields, privileging time-limited land take and performing land rehabilitation upon the termination of the land take.	The Rotterdam test case focuses the mitigation efforts of urban greening and soil de-sealing.
Paragraph 51	States the importance of gathering data on the presence of contaminants such as pesticides, their metabolites, and PFAS and other emerging soil contaminants.	The agricultural and PFAS test cases extensively address these contaminants.
Paragraph 52	The Directive deems it essential to include microplastics and nanoplastics in the monitoring of soil contaminants.	PHISHES does not address microplastics or nanoplastics.
Paragraph 68	The Directive states that the best risk reduction measures are sustainable, and taken through a decision-making process that considers environmental, social and economic impact.	PHISHES cannot quantify the socio-economic impact of the measures it proposes for soil health. It only informs users of the environmental benefits of the measures it proposes.

6 What Makes PHISHES Unique?

Several other decision-support tools exist for soil health. PHISHES' value rests on a combination of features that are individually available elsewhere but rarely combined:

- **Watershed scale modelling:** Most soil health tools operate at the soil-unit level. PHISHES connects soil-unit modelling with hydrological models to illustrate how land management decisions propagate through the catchment. This shows the actual impact of land use management techniques and NBSs in the relevant physical spaces.
- **Long-term foresight:** PHISHES' scenario simulations over a 30-year window allow stakeholders to distinguish short-term fluctuations (as captured by mere probing) from genuine directional trends. Upon request, the simulation horizon could be expanded to 100 years, although weather trends become harder to model on such a timeline. This is particularly useful as the SML necessitates long-term monitoring. Policy makers can use the PDP to demonstrate compliance trajectories in the long term and offer evidence-based decision-making support. Upon data validation and regulatory uptake, the PHISHES predictive methodology could allow stakeholders to exonerate themselves from probing responsibilities for one cycle as per article 9 of the SML.
- **Agricultural, urban, and contaminated soils:** Existing Commission-funded research[12] has focused predominantly on agricultural soils. PHISHES builds on this corpus while extending it to urban environments and PFAS contamination – both explicitly referenced in the SML preamble, paragraphs 39 and 51.

[12] Cristina Arias-Navarro et al., "Forty years of soil research funded by the European Commission: trends and future. A systematic review of research projects," *European Journal of Soil Science* 74, no. 5 (2023).

- **Stakeholder legitimacy:** Land management scenarios and the PDP are developed in a process of co-creation with local stakeholders through roundtables, consultations and PDP workshops.[13] A large-scale stakeholder questionnaire will also be conducted to gauge current stakeholder practices in regard to soil health and stakeholder needs for the PDP. By engaging with local stakeholders in this way, the PHISHES methodology can be amended to its users' needs.
- **Replicability across the EU:** While the PHISHES outputs are aimed at policy makers to inform their regulatory actions for soil health, technical users will be best suited to using the tools available for download from the digital platform on a day-to-day basis. Although policy makers from the test sites will be able to directly see scenarios and suggested land use management changes in the PDP, policy makers of other areas will need to find which model train is most appropriate for their (pollution) problem and build a model train themselves with their own data. Then, the simulation results must be interpreted by the user to reach relevant policy recommendations. The list of necessary input data required from users is compiled by PHISHES and accessible via the PDP. Preferably, users have location specific data available in their own databases, but when that might not be available, PHISHES recommends general databases where users can find the relevant information to build their model trains.
- **Increasing Soil Salience Amongst Stakeholders:** PHISHES' efforts to map soil functions to SML descriptors and ecosystem services does not just help transcend the food security paradigm but helps policy makers make more informed decisions by considering the broader value of ecosystem services. Moreover, as Breure et al. argue, "the concept of ecosystem services in policy making can be a powerful tool for evaluating different management strategies of natural resources because it gives [...] a quantifiable incentive for environmental protection, biodiversity conservation and sustainable societal behaviour."[14]

7 Limitations of the PHISHES Methodology

A credible scientific tool must be transparent about its limitations. The following gaps are relevant for policy makers assessing PHISHES' fitness for purpose:

- **Salinisation:** The mandatory descriptor of salinisation is not modelled, thus decreasing PHISHES' compatibility with the SML. For monitoring purposes, especially for those Member States facing salinity challenges, it is possible to build a model train to add onto the PHISHES methodology to tackle this problem.
- **Non-mandatory descriptors:** PHISHES does not address the non-mandatory descriptor of acidification, and is in the process of developing the modelling of erosion and topsoil compaction, which are significant drivers of soil degradation in the Union. Furthermore, it also does not consider several elements of soil biodiversity as articulated in Part C descriptors, contamination by some heavy metals as articulated in Part B descriptors, and microplastics and nanoplastics as per the preamble of the SML.
- **Socioeconomic dimensions:** Socioeconomic analysis is absent despite the SML[15] and its stakeholders requiring an understanding of the socio-economic implications of land management changes.
- **Urban climate dynamics:** PHISHES addresses sealing and de-sealing impacts on infiltration; however, direct flood modelling and urban heat island effects are outside of its scope.
- **Measuring bias:** naturally, one cannot model what one does not measure. As such, a limitation of PHISHES is that the scenario modelling and the resulting recommendations will not include the impact on elements (such as those earlier identified) that it cannot measure. If a land use

[13] To be organized in the following years after the release of the first draft of the PDP.
[14] Breure et al., "Ecosystem services: a useful concept for soil policy making!" *Current Opinion in Environmental Sustainability* 4, no. 5 (2012): 584.
[15] SML article 11(1)(b).

management action proposed by PHISHES were to have a certain (positive or negative) impact on salinisation, for example, PHISHES could not predict such an effect on salinisation.

- **Technical Difficulty:** policy makers outside of the test cases are required to build their own model trains with their local soil data to use the PHISHES methodology. As such, technical modelling expertise is required. Whereas technical users might have this expertise, it is not widespread amongst local policy makers, possibly creating a barrier for users.
- **Model validation:** if policy makers want to benefit from PHISHES and its methodology and use it to meet their SML obligations, PHISHES must undergo data validation for regulatory uptake in the decades after 2028 following the conclusion of this research project. This process entails "careful vetting of selected parameter values, model code and structure, and methods of model evaluation, by others to build confidence that PHISHES can be applied for regulatory purposes."[16]
- **Ecosystem services links:** The links between soil characteristics, soil functions and ecosystem services and drivers such as climate change and land management practices are difficult to establish, and as a result PHISHES will be developing these links through the use of a fuzzy logic approach. While this approach can strengthen the understanding of stakeholders by showcasing the variety of interlinkages, it could be ill-suited as an approach to meet specific targets for soil health.[17]

8 Conclusion

The recently adopted Soil Monitoring and Resilience Law aims to "establish a unified framework for systematic soil health monitoring in the EU."[18] It does so by requiring Member States to report against mandatory and non-mandatory descriptors of soil health and demands remediation action for contaminated soils. As the SML is transposed in the following years, there is space for the uptake of practical, science-based support tools such as PHISHES, which aims to bridge the missing link between data on soil health and actions for the safeguarding of soils.

PHISHES' watershed-scale architecture, 30-year predictive horizon, and transferable model-train methodology position it as a capable tool for implementing Art. 9 monitoring derogations, informing Art. 11 advisory obligations, and supporting the contaminated site management framework of Articles 13 and 16. By including several soil health descriptors in its predictive modelling of the impact of land use management changes and NBSs on soil health, and comparing these actions against threshold values, it empowers stakeholders to see whether they are on track to meet SML obligations.

While areas of improvement continue to exist, PHISHES provides a solid foundational methodology for users to build upon, expand and apply to their local contexts. Therefore, PHISHES represents a significant and deployable step towards the scientific infrastructure the SML demands.

Once PHISHES results are formulated, the update of this policy brief[19] will take into consideration the extent to which PHISHES results can also address other pieces of EU legislation such as the EU Regulation on Nature Restoration, the Common Agricultural Policy, and the EU's Zero-Pollution Action Plan amongst others.

[16] Paini et al., "Investigating the state of physiologically based kinetic modelling practices and challenges associated with gaining regulatory acceptance of model applications," *Regulatory Toxicology and Pharmacology* 90 (2017): 113.
[17] Qiu et al., "Evidence-based causal chains for linking health, development, and conservation actions," *Bioscience* 68, no. 3 (2018): 182 – 193.
[18] Eloise Mason, "Monitoring Systems of Agricultural Soils Across Europe Regarding the Upcoming European Soil Monitoring Law," *European Journal of Soil Science* 76 (2025): 1.
[19] Foreseen for May 2028.

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