Environment
Agroscope Science | No. 26 / 2015

Locating Organic Soils for the Swiss Greenhouse Gas Inventory

Authors
Chloé Wüst-Galley, Andreas Grünig and Jens Leifeld,
Agroscope, Zürich

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Federal Department of Economic Affairs,
Education and Research EAER
Agroscope

Agroscope good food, healthy environment

Impressum

Editor:	Agroscope Reckenholzstrasse 191 8046 Zürich www.agroscope.ch
Information:	Chloé Wüst-Galley
Layout:	Chloé Wüst-Galley
Photos:	Front cover, from top-left, clockwise: A flooded organic soil (potato) field following heavy rain in the Seeland region, BE, in 2015, source: Jeanne Woodtli, BauernZeitung; Organic farmed soil in the Seeland region, BE © Gabriela Brändle, Agroscope; Damage of natural peatland vegetation and subsequent release of CO_2 due to cattle trampling, in the Glaubenberg region, LU, © Andreas Grünig, Agroscope; An example of a landscape-covering bog incorporating a gradient from reed-bed fen to raised bog vegetation in the Glaubenberg area, OW – heavily grazed for centuries, this land use practice was abandoned here in the last decades © Andreas Grünig, Agroscope; L'Ar du Tsan floodplain and fen (2200 masl) in Nax, VS, © FOEN; A thick peat layer found within a residential area in the Sihl plain, SZ © Andreas Grünig, Agroscope. Back cover: Panorama of a part of the Rothenthurm mire landscape (SZ emitting large amounts of CO_2 due to lasting effects of drainage and previous exploitation © Margrit von Euw.
Download:	www.agroscope.ch/science
Copyright:	© Agroscope 2015
ISSN:	2296-729X
ISBN:	978-3-906804-12-5

The project was mandated by the section Climate Reporting and Adaptation, Federal Office for the Environment, FOEN (A. Schellenberger);
contract numbers: 06.0091.PZ/K435-1876, 06.0091.PZ/N314-1819

Table of Contents

Definitions

Mire	A peat-building fen or a raised or transitional bog
Peatland	A site of an intact or drained mire containing peat

Abbreviations

FOEN	Federal Office for the Environment (= Bundesamt für Umwelt, BAFU; Office fédéral de l'environnement, OFEV)
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
IPCC	Intergovernmental Panel on Climate Change
LULUCF	Land Use, Land-Use Change and Forestry
UNFCCC	United Nations Framework Convention on Climate Change

Throughout the report, cantons are referred to by a two-letter abbreviation, as described in the table nelow. The English, German and French names were obtained from the Swiss Federal Statistical Office, SFSO (Bundesamt für Statistik, BFS / Office fédéral de la statistique, OFS).

Abbreviation used	English name	German name	French name
AG	Aargau	Aargau	Argovie
AI	Appenzell Innerrhoden	Appenzell I.Rh.	Appenzell Rh.-Int.
AR	Appenzell Ausserrhoden	Appenzell A.Rh.	Appenzell Rh.-Ext.
BE	Bern	Bern	Berne
BL	Basel-Landschaft	Basel-Landschaft	Bâle-Campagne
BS	Basel-Stadt	Basel-Stadt	Bâle-Ville
FR	Fribourg	Freiburg	Fribourg
GE	Geneva	Genf	Genève
GL	Glarus	Glarus	Glaris
GR	Graubünden	Graubünden	Grisons
JU	Jura	Jura	Jura
LU	Lucerne	Luzern	Lucerne
NE	Neuchâtel	Neuenburg	Neuchâtel
NW	Nidwalden	Nidwalden	Nidwald
OW	Obwalden	Obwalden	Obwald
SG	St. Gallen	St.Gallen	Saint-Gall
SH	Schaffhausen	Schaffhausen	Schaffhouse
SO	Solothurn	Solothurn	Soleure
SZ	Schwyz	Schwyz	Schwytz
TH	Thurgau	Thurgau	Thurgovie
TI	Ticino	Tessin	Tessin
UR	Uri	Uri	Uri
VD	Vaud	Waadt	Vaud
VS	Valais	Wallis	Valais
ZG	Zug	Zug	Zoug
ZH	Zurich	Zürich	Zurich

Summary

Peat soils are formed and persist in the waterlogged conditions of bogs and many fens, where organic matter is stored in the form of peat. The drying-out of these soils, through drainage for peat extraction, agriculture or forestry, causes, in the short term, soil collapse and subsidence of the drained peat layers, and in the long-term, oxidation and the associated loss of the organic matter. This oxidation releases large quantities of carbon dioxide (CO_2) and nitrous oxide (N_2O) into the atmosphere; these emissions need to be accounted for in the Land Use, Land-Use Change and Forestry (LULUCF) sector of the UNFCCC greenhouse gas inventory (GHGI). This accounting requires an improved estimate of the extent and location of organic soils in Switzerland that is as objective and reproducible as possible.

This report describes the production of a digital map showing new estimates of the surface of organic soils in Switzerland. As there is no single data set from which the location of organic soils across the country could be adequately deduced, numerous spatial and non-spatial data sets were evaluated and combined to produce these improved estimates, using data sets providing information on geology, soils, habitats and vegetation.

Several estimates of organic soil surfaces in Switzerland are presented. The estimate of organic soils recommended for the GHGI covers ca. 28,000 ha, or ca. 0.7 % of the country's land surface. The extensive surfaces of organic soils that were previously recognised in the large valley bottoms are more fragmented in this new estimate of organic soils. Furthermore, many new small surfaces in the pre-Alps and the central plateau are recognised. The incorporation of many different data sets resulted in heterogeneous coverage of the country. One source of this heterogeneity is the fact that many cantons have few modern data sets available concerning organic soil. This is reflected by the large surface area of organic soil for which only historical documentation of bogs, fens and peat extraction exists. A consequence of this incomplete and uneven data coverage is that the estimates of organic soil surface are probably net under-estimates.

Zusammenfassung

Moorböden werden unter wassergesättigten Bedingungen von Hoch- und Übergangsmooren und vielen Niedermooren gebildet. Dabei speichern sie langfristig organische Substanz in Form von Torf. Das Trockenlegen dieser organischen Böden durch Drainage für Torfabbau, Land- oder Forstwirtschaft bewirkt kurzfristig Sackung sowie Schrumpfung der entwässerten Torfschichten und langfristig den Schwund bzw. die Oxidation der organischen Substanz. Dabei werden grosse Mengen Kohlendioxid (CO_2) und Lachgas (N_2O) in die Atmosphäre freigesetzt. Gemäss Rahmenübereinkommen der Vereinten Nationen über Klimaänderungen (UNFCCC) sind diese Emissionen im Sektor Landnutzung, Landnutzungsänderung und Forstwirtschaft / Wald (LULUCF) des Treibhausgasinventars auszuweisen. Dies ruft nach möglichst objektiver Identifikation, nachvollziehbarer Beurteilung bzw. verbesserter Schätzung von Lage, Zustand und aktueller Fläche der organischen Böden in der Schweiz.

Der vorliegende Bericht beschreibt die Erstellung einer digitalen Karte, welche neue Schätzungen der Flächen organischer Böden in der Schweiz zeigt. Da es keinen einzelnen Datensatz gab, mit dem sich organische Böden mit hinreichender Vollständigkeit und Genauigkeit lokalisieren liessen, wurden zur verbesserten Schätzungen zahlreiche räumliche und nicht räumliche Datensätze aus den Bereichen Geologie, Boden, Habitate und Vegetation ausgewertet und zusammengetragen.

Es werden verschiedene Schätzungen zu den Flächen der organischen Böden in der Schweiz hergeleitet. Gemäss der für das schweizerische THGI empfohlenen Schätzung bedecken die organischen Böden noch rund 28‘000 ha oder ca. 0.7 % der Landesfläche. Einerseits erweisen sich heute die ausgedehnten zusammenhängenden Flächen, welche früher für die grossen Täler angegeben worden waren, meistens

als ziemlich stark fragmentiert. Andererseits sind im Mittelland und in den Voralpen zahlreiche neue Flächen hinzugekommen, welche bisher nicht berücksichtigt worden sind. Von grossen Flächen mit organischen Böden ist lediglich historische Information über Hoch-, Übergangs- und Flachmoore sowie zum Torfabbau vorhanden. Infolge der Berücksichtigung vieler unterschiedlicher Datensätze resultiert landesweit ein inhomogenes Ergebnis. Eine wichtige Quelle für diese Inhomogenität ist die Tatsache dass viele Kantone nur wenige aktuelle Datensätze zum Thema „Organische Böden" zur Verfügung stellen konnten. Diese lückenhafte und inhomogene Datenlage führt wahrscheinlich zu einer systematischen Unterschätzung der Gesamtfläche der organischen Böden in der Schweiz.

Résumé

Les sols organiques se forment dans les conditions de saturation en eau caractéristiques des hauts-marais et marais de transition ainsi que de bien des bas-marais. Ce faisant, ils accumulent durablement la matière organique sous forme de tourbe. L'assèchement de ces sols organiques, par drainage pour l'extraction de tourbe ou l'exploitation agricole ou sylvicole, entraîne à court terme le tassement ainsi que la contraction des couches de tourbe drainées et, à long terme, la disparition respectivement l'oxydation de la matière organique. En conséquence, de grandes quantités de dioxyde de carbone (CO_2) et de protoxyde d'azote ou gaz hilarant (N_2O) sont libérées dans l'atmosphère. Selon la Convention-Cadre des Nations Unies sur les Changements Climatiques (United Nations Framework Convention on Climate Change, UNFCCC), ces émissions doivent être prises en compte dans le secteur « Utilisation des terres, changements d'affectation des terres et foresterie » (Land Use, Land-Use Change and Forestry, LULUCF) de l'inventaire des gaz à effet de serre (IGES). Il est donc nécessaire d'identifier aussi objectivement que possible les surfaces de sols organiques en Suisse, de les évaluer de manière reproductible, respectivement d'en améliorer l'estimation de la situation, de l'état et de la surface actuelle.

Le présent rapport décrit la réalisation d'une carte numérique représentant les nouvelles estimations de la surface des sols organiques en Suisse. Comme il n'existait pas un jeu unique de données qui eut permis une localisation suffisamment complète et précise des sols organiques, l'amélioration des estimations repose sur l'assemblage et l'analyse de plusieurs jeux de données spatiales et non spatiales issus des domaines de la géologie, des sols, des habitats naturels et de la végétation.

Diverses estimations des surfaces de sols organiques en Suisse ont été effectuées. Selon la méthode d'estimation recommandée pour l'IGES de Suisse, les sols organiques couvrent encore quelque 28'000 ha, soit environ 0.7% de la superficie du pays. D'une part, les surfaces étendues d'un seul tenant qui étaient autrefois indiquées dans les grandes vallées apparaissent aujourd'hui assez fortement fragmentées. D'autre part, de nombreuses nouvelles surfaces, qui n'avaient pas été répertoriées jusqu'à présent, ont été identifiées sur le Plateau et dans les Préalpes. La prise en compte de beaucoup de sources de données différentes a conduit à un résultat hétérogène à l'échelle du pays. Cela est dû entre autre au fait que peu de cantons disposent de jeux de données actuels sur le thème « sols organiques », respectivement que seules des informations historiques sur les hauts-marais et marais de transition, sur les bas-marais ainsi que sur l'extraction de tourbe ont pu être récoltées à propos de vastes surfaces de sols organiques. En raison du caractère lacunaire et hétérogène des données, il faut s'attendre à ce que la surface totale des sols organiques en Suisse soit vraisemblablement systématiquement sous-estimée.

1. Introduction

1.1. The Formation of Peat and the Destruction of Peat and Organic Soil

Peatlands play a key role in the global Carbon (C) cycle. Although they cover only ~4 million km^2 (or 3 % of the world's land surface area), their very high C density means that they contain over 550 gigatonnes of C, approximately the same amount as is stored in the total global terrestrial biomass (Parish *et al.*, 2008), or between 30 % and 50 % of the world's soil C (Bussell *et al.*, 2010). The accumulation of organic C as peat is a result of long-term water saturation in raised and transitional bogs, and many types of fens. Decomposition of organic C from dead organisms by aerobic decomposition requires considerable amounts of oxygen. In the water-logged conditions of these wetlands, the rate of diffusion of oxygen through water is much lower than the rate at which it is used up in aerobic decomposition, meaning that decomposition of organic C here is impeded. Instead, organisms capable of decomposition in anaerobic conditions decompose the organic matter, but do so at a much lower rate; this rate is lower than that at which matter from dead organisms is added to the system, resulting in a build-up of organic C as peat over time (Clymo, 1984).

The C stored in peat is however not necessarily stable: Disturbance of the hydrological conditions, either through drainage, through significant reduction of the water influx, through the addition of sand in an attempt to maintain or increase pore space, or a combination of these processes, reverses the net effect of C accumulation. The aeration of the peat allows oxygen to reach peat that was until then water-saturated, leading to rapid aerobic decomposition and removal of C from the system as CO_2 (IPCC, 2014) which is emitted to the atmosphere. The aeration of the peat is accompanied, in the short term, by its compaction due to loss of hydrostatic uplift, and in the medium term, consolidation due to removal of interstitial water, as well as increased removal of C from the system as dissolved organic C (Freeman *et al.*, 2001; Tranvik & Jansson, 2002; Holden, 2005).

Whilst a mire, as a habitat, will change or disappear following drainage, the peat may persist at the site for decades or centuries or even millennia, until so much C has left the system that it is no longer considered peat. The consequence of this is that peatlands that were converted into farmland or forests decades or centuries ago will still emit CO_2 into the atmosphere, as long as they remain drained and as long as high levels of organic C occur. Soils containing a thick organic-C-rich layer are classified as organic, rather than mineral soils. Section 1.4 gives the definition of organic soils used throughout this project.

1.2. Relevance for Switzerland

In Switzerland it is estimated that ~90 % of fens and bogs in terms of surface area have been drained or have otherwise disappeared, for example, by peat extraction for fuel since the first half of the 18th century (Grünig, 1994, 2007; Gimmi *et al.*, 2011). Many sites were also converted to agricultural or forested land, especially during the first half of the 20th century, or urban space, following the Second World War. Many of these sites however probably still contain peat – although sites from which peat was extracted are less likely to do so, depending on how much peat was removed. The C emissions from organic soils are considerable: It is estimated that the rate of C loss through CO_2 emissions from organic soils used for intensive agriculture in Switzerland is ca. 9.5 t C ha^{-1} $year^{-1}$ (Leifeld *et al.*, 2003), compared to an estimate of no emissions from mineral soils (Anon, 2014). This means that the estimated 5.5 Mt CO_2 equiv. yr^{-1} emitted by the Agriculture sector (for 2012, Anon, 2014) needs to be increased by an amount in the order of magnitude of 0.6 Mt CO_2 equiv. yr^{-1} (2012 values, using C emissions from ~18,000 ha organic soil under Cropland and Grassland, calculated from Anon, 2014), in addition to the share of the 120,000 to 150,000 t of peat imported annually to Switzerland (Swiss Federal Customs Administration, SCA, 1988-2015; Knecht,

2009) that is used in commercial horticulture[1], to complete the picture of emissions from Swiss agriculture. Furthermore, C emissions due to organic soils cancel out a substantial proportion of the C sink due to Forests in Switzerland: The latter is estimated to be 1.6 Mt CO_2 equiv. yr^{-1} (for Kyoto Protocol 3.3. and 3.4. activities reforestation, afforestation and deforestation, and forest management, mean value from 2008-2014, calculated from Anon, 2014), whereas the current estimate of C emissions from organic soils is ca. 0.81 Mt CO_2 equiv. yr^{-1} (mean emissions from organic soils under Cropland, Grassland and Wetlands for 2008-2012, calculated from Anon, 2014). In short, the C emissions from organic soils are significant, often neglected or under-estimated and need to be accounted for in the national GHGIs.

1.3. Greenhouse Gas Inventory

As a party to the United Nations Framework Convention on Climate Change, Switzerland submits an annual inventory of all greenhouse gas emissions and removals (Anon, 2014). One of the seven sectors for which emissions and removals are calculated is Land Use, Land-Use Change and Forestry (LULUCF). Different land use types are associated with different greenhouse gas emission factors. Switzerland uses a spatially-specific approach to represent Land-Use and Land-Use Change (tier 3 approach). The territory's surface is partitioned into a 1 ha grid and each hectare is assigned to a land use type for a given reporting period; these hectares are then summarised in a Land Use and Land-Use Change matrix. Additionally, rates of C stock changes (in the soil and in dead and living biomass) are assigned to each cell in this matrix. C stock changes across the whole country are then calculated by multiplying these rates by the occurrence of the Land Use and Land-Use Change combinations.

In addition to land use, there are further aspects which are associated with different C stocks and C stock changes. The following are considered in Switzerland's GHGI: forestry production regions, altitude zones and whether a surface occurs on organic or mineral soil. Each hectare of Switzerland's surface is therefore additionally classified by these characteristics; this spatial stratification of the Land Use and Land-Use Change categories should improve the precision and accuracy of the estimate of greenhouse gas emissions. Thus, forests are classified according to the 5 forestry production regions; permanent grassland, copses, shrub vegetation and forests are classified according to the 3 altitude zones; and all land use types (except buildings and construction, surface waters and 'other land') are classified according to whether they occur on organic or mineral soil (Anon, 2014). In order to apply this additional spatial stratification, it is necessary to define these regions. With regards to soils, it is therefore necessary to know where Switzerland's organic and mineral soils are.

1.3.1. Justification / Mandate

An estimate of the location of Switzerland's organic soils is needed for the GHGI. The current estimate of the location of organic soils for the inventory is based upon two sources of information: Switzerland's Soil Suitability Map (Swiss Federal Statistics Office, SFSO, 2000) and the Federal Inventory of Raised and Transitional Bogs (Grünig *et al.*, 1986). This estimate is however insufficient for several reasons. Firstly, the Soil Suitability Map (SFSO, 2000), for the purpose of producing an organic soil map, is imprecise, both in terms of geographic scale (1:200,000) and in terms of its attribute information. The Soil Suitability map was not produced with the aim of locating soil types, rather with the aim of classifying surfaces by their suitability for agriculture and forestry. A consequence of this is that the mapping units that were until now used to represent organic soil for the GHGI include gleys ("Gleysol humic"), fluvisols ("Fluvisol humic") and impervious alluvial soils ("Grundnasse Alluvionen"), as well as bogs and fens ("Moore"), or peat ("Torf"). Secondly, there is a general knowledge gap regarding organic soil under forests – a point already highlighted by Rihm (2011); this is partly a consequence of the bias of the Raised Bog Inventory towards

[1] The share of peat used in commercial horticulture in Switzerland is unknown. The share of peat consumed in the EU that is used for professional and hobby horticulture is ~95 % (excluding energy, which corresponds to the Swiss situation where peat is no longer used as an energy source), and an estimated 65 % - 75 % of this is used in the professional horticulture sector (calculations based on data from Altmann, 2008).

open spaces but is also an outcome of the tendency of soil maps to focus on agriculturally-relevant land, rather than forests.

1.4. Organic Soils in the GHG Inventory

Organic soils as considered for the GHG inventory are defined as follows (IPCC, 2006):
“Organic soils are found in wetlands or have been drained and converted to other land-use types (e.g., Forest Land, Cropland, Grassland, Settlements). Organic soils are identified on the basis of criteria 1 and 2, or 1 and 3 listed below (FAO, 1998):

1. Thickness of organic horizon greater than or equal to 10 cm. A horizon of less than 20 cm must have 12 percent or more organic carbon when mixed to a depth of 20 cm.
2. Soils that are never saturated with water for more than a few days must contain more than 20 percent organic carbon by weight (i.e., about 35 percent organic matter).
3. Soils are subject to water saturation episodes and have either:
   a) At least 12 percent organic carbon by weight (i.e., about 20 percent organic matter) if the soil has no clay; or
   b) At least 18 percent organic carbon by weight (i.e., about 30 percent organic matter) if the soil has 60 % or more clay; or
   c) An intermediate, proportional amount of organic carbon for intermediate amounts of clay.”

This report deals with organic soils formed under water-saturated conditions, i.e. peaty organic soils; we exclude the freely drained organic soils that form in aerobic conditions.

1.5. Project Aims

The over-arching aim of this project is to improve the estimate of the distribution of peaty organic soils (hereafter ‘organic soils’) or peatlands in Switzerland for the GHGI, and to do this in the form of a digital map which will be converted to a 1 ha grid for the GHGI. Specifications and other considerations are as follows:

1. Integrated in this map should be an indication of the certainty that each site contains organic soil.
2. The system should be efficient, by using available data sets or information sources; however, it should be possible to add additional data sets to the map in the future to improve the estimate of organic soils, leading to either an increase or a decrease in the estimate of organic soils.
3. The map should be transparent and reproducible.
4. As part of the quality assessment of the map, an assessment of regions or cantons for which significant data sets are missing should be made.
5. Lastly, recommendations for how to improve this estimate of organic soils in the future need to be made.

2. Methods

The strategy used to locate organic soils for the GHGI in this project was to utilise existing data sets and information sources that indicate the presence of organic soil. Sites that potentially contain organic soil include sites that were once mires but have since been destroyed, as well ‘living’ mires; the occurrence of organic soil can therefore be derived from information about the soil or about the vegetation. Because there is no single data set available for Switzerland that reliably demarcates organic soil surfaces, an approach of combining multiple information sources was used.

Once the individual data sets had been assessed and processed, an automated workflow was developed to produce the map. Such a workflow meets the first three project aims (see previous page, section 1.5) and plays an important role in quality control of this map. More specifically, it means that the assessment of ‘certainty’ of surfaces (project aim number 1) was automated. This is important as tens of thousands of surfaces were produced in creating this map and it would be impossible to assess these manually. This workflow means the map could be reproduced in a standard manner, with reduced chance of human error (project aim number 3) and will allow newly acquired data sets to be easily and quickly added to the map (project aim number 2). The assessment of regions for which there are few relevant data sets (project aim number 4) is dealt with in sections 4.4 and 4.5.1, and recommendations for future work (project aim number 5) are given in section 5.

2.1. The Information Sources

Information sources were targeted based on the following three principles:

Firstly, because the final map should show national **coverage**, information sources that were either available for the whole country, or that were created at the canton level and that were available for most cantons were prioritised. Local high-quality data sets were sought for regions or cantons that were otherwise sparsely covered by data sets.

Secondly, data sets had to contain **precise mapping unit(s)**, which should enable a surface to be unambiguously classified as organic soil or not. A mapping unit incorporating, for example, peat-building as well as non-peat-building vegetation, was considered too imprecise.

Thirdly, the maps had to be of a **sufficiently large scale**. Although digital data do not have a scale in the sense of paper maps (a representative fraction), they do not have unlimited resolution, meaning there is a scale beyond which a given digital map is unsuitable for use (Goodchild, 2011). For a map created from other maps, this scale is determined by the scale at which the component maps were digitised (if appropriate) and by the scale(s) of the component data sets or maps. For the GHGI, the completed map of organic soils will be converted to a 100 m x 100 m grid, which corresponds to a detection size of 100 m to 200 m. These detection sizes require component maps to be of scale at least 1:100,000 to 1:200,000 (Tobler, 1988). In addition, the heterogeneity of the landscape and the size of the surfaces in question need to be considered: the geometry-based generalisation that is introduced during the map-making process and that increases as the mapping scale is reduced is especially important to consider when mapping organic soil surfaces, as these tend to occur as relatively small patches in the landscape (Fell *et al.*, 2014); this is certainly the case in Switzerland, a topographically very heterogeneous country. The majority of data sets chosen for the organic soil map of Switzerland have a scale 1:25,000 or larger (i.e. more detailed), with exceptions being maps that cover regions for which there is otherwise little information available.

In the following sections, the data sets or information sources that were used to construct the new estimates of organic soils are described. It is mentioned throughout that surfaces were scored to represent their reliability as evidence of organic soil; the scores are displayed in square brackets (as [A], [B] or [C]). It is also stated which data sets or information sources were considered ‘historical’ and which were considered ‘modern’ (where it is not mentioned, the information source was considered as ‘modern’). Sections 2.3.3 and 2.3.4 describe these characteristics, as well as the general attribute information captured for each data set. It is recommended to refer to this section first to understand the meanings of these scores.

Metadata regarding the coverage of maps and some information relevant to their use in this project are given in the following parts of this section. Other information, including the scale, data source, survey dates (where known) and publication date are given in appendix I. All data sets were obtained and processed as vector data models. The Swiss Reference System CH1903 (Anon, 2008) was used throughout.

2.1.1. Spatial Datasets

The majority of information sources considered for the map of organic soils were maps, from which relevant surfaces were directly digitised or extracted.

2.1.1.1. Soil Maps

Several local or regional soil maps exist for Switzerland; these have been produced either at the canton scale, at the community scale or for 1:25,000 map sheets. The soil maps that were obtained and used in this project are shown in Table 1 and Figure 1.

Table 1: Soil maps used in the project

<table>
<tr><th>Canton, map sheet (M.S.) or region</th><th>Coverage</th><th>Comment</th></tr>
<tr><td>GE</td><td>13,360 ha (~47 % of canton)</td><td>Pedological map, avoiding forests</td></tr>
<tr><td>GL</td><td>751 ha (~1 % of canton)</td><td>Predominantly in agricultural areas of the main valley bottom (Linth), avoiding forests</td></tr>
<tr><td>LU</td><td>15526 ha (~10 % of canton)</td><td>Altbüron and Wauwil regions, catchment area of the Sempachersee</td></tr>
<tr><td>SO</td><td>15,966 ha (~20 % of canton)</td><td></td></tr>
<tr><td>SG</td><td>46,593 ha (~25 % of canton)</td><td>Predominantly in agricultural areas, avoiding forests</td></tr>
<tr><td>SZ</td><td>Parts of the communities Schübelbach, Tuggen, Wangen and Reichenburg</td><td>Predominantly in agricultural areas, along the main valley bottom (Linth)</td></tr>
<tr><td>TG</td><td>Covers all of canton</td><td></td></tr>
<tr><td>VD</td><td>157,095 ha (~56 % of canton)</td><td>Work in progress</td></tr>
<tr><td>ZG</td><td>11,013 ha (~46 % of canton)</td><td>Predominantly in agricultural areas, avoiding forests</td></tr>
<tr><td>ZH</td><td>76,064 ha (~44% of canton)</td><td>Predominantly in agricultural areas, avoiding forests</td></tr>
<tr><td>M.S. Baden</td><td rowspan="8"></td><td rowspan="8">Covering all non-urban surfaces</td></tr>
<tr><td>M.S. Davos</td></tr>
<tr><td>M.S. Grindelwald</td></tr>
<tr><td>M.S. Hochdorf</td></tr>
<tr><td>M.S. Hitzkirch</td></tr>
<tr><td>M.S. Hörnli</td></tr>
<tr><td>M.S. Laufenburg</td></tr>
<tr><td>M.S. Luzern</td></tr>
</table>

M.S. Lyss		
M.S. Murten		
M.S. Rheinfelden		
M.S. Uster		
M.S. Wohlen		
M.S. Zürich		
M.S. Zurzach		
Seeland, BE, FR	4,670 ha	
Moosseetal, BE	3,500 ha	

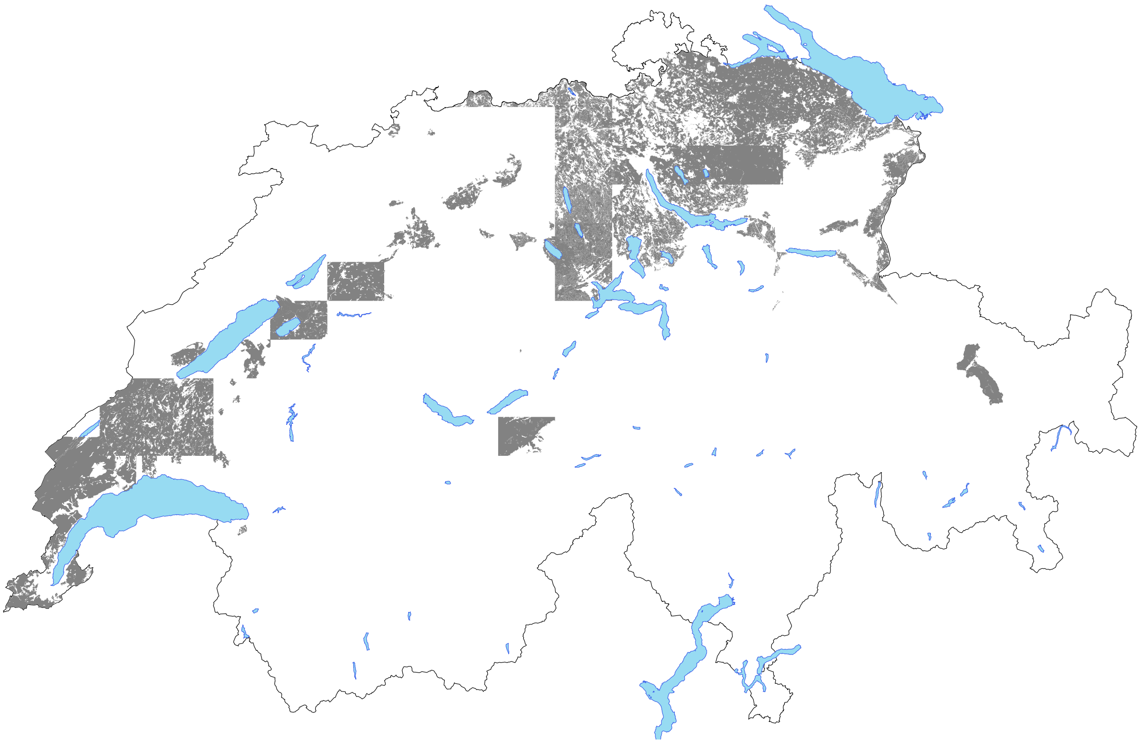


Figure 1: Distribution of soil maps used in the project; national boundary and lake boundaries © Swisstopo; sources and / or proprietors of original data (soil maps) listed in appendix I

Additional maps are available digitally for BS / BL (1:5,000) but no organic soils were identified from these maps.

With the exception of one map (the pedological map of canton Geneva), all but the last two soil maps listed in Table 1 follow the nomenclature and classification schemes of the Swiss soil classification system (Peyer & Frei, 1992; Brunner *et al.*, 1997; Brunner *et al.*, 2002; Brunner *et al.*, 2010). In this system, the soil types "Moor" and "Halbmoor" (French: moor and semi-moor) are classified as organic damp soils (organische Nassböden or sols humides) and meet the requirements of organic soils from the IPCC (2006) (section 1.4).

Other soil types (mostly gley soils) can be classified in the Swiss soil classification as "anmoorig" (à anmoor) or "antorfig" (para-tourbeux). Such soils possibly meet the IPCC requirements of organic soils; however, the overlap between these soils and organic soils (as defined by the IPCC) is only partial, meaning that some anmoorig or antorfig soils should be classified as mineral soil. Anmoorig soils contain 10-30 % organic matter (Peyer & Frei, 1992; Brunner *et al.*, 2002); the IPCC requires > 20 % or > 30 % organic matter, depending on clay content. Thus, some but not all anmoorig soils are organic soils according to the IPCC classification. Antorfig soils have an organic layer with > 30 % organic matter that is < 40 cm thick (BGS, 1996; Brunner *et al.*, 2002); the IPCC requires the organic horizon to be > 10 cm (and an organic horizon < 20 cm must contain > 12 % organic C when mixed to a depth of 20 cm). Likewise, some, but not necessarily all antorfig soils can therefore be classified as organic soil. The decision as to whether or not to include antorfig or anmoorig soils in the organic soil map is relevant because it is likely that these soils cover a substantial area of Switzerland; they include ex-peatlands that were once deep peaty soils but that through peat oxidation resulting from drainage and intensive land use (e.g. for vegetable cultivation) have a reduced organic C content and / or a thinner C-rich layer. Furthermore, it has been shown that such soils have C emissions comparable to other deeper, C-richer organic soils (Leiber-Sauheitl *et al.*, 2014). It is indicated in section 4.5.2 how much of an under-estimate of organic soil surface the omission of anmoorig and antorfig soils might cause.

For this project, it was chosen not to explicitly include antorfig or anmoorig soils, for two reasons. Firstly, only two data sets mention antorfig or anmoorig soils explicitly: the soil maps and possibly the forest habitat maps (unit 44, section 2.1.1.3), although the inclusion of the latter data set would first require ground-truthing to assess this. Including the anmooring or antorfig soils from the soil maps would therefore result in a very incomplete picture of their distribution. Secondly, and more importantly, as outlined above not all anmoorig or antorfig soils as defined in the Swiss soil classification are indeed organic soils, and it is unknown what proportion of them are.

The soil maps were used in this project as follows. The surfaces containing Moor or Halbmoor soil type were digitised (or where already digitised, extracted) and were considered as organic soil [A] for this project. Some of the 1:25,000 map sheets additionally contain ‘combination categories’ where a mix of soil types was identified. Combinations comprising either all organic soil types [A] or combinations where the dominant soil type is Moor or Halbmoor were considered [B]. Very occasionally, Moor or Halbmoor soils are mentioned as being covered (“überschüttet”) by alluvial material; these surfaces were also included [B]. In the pedological map of canton Geneva, one surface (a gley soil) with peat as the parent material was included in the map [B].

Soil maps were additionally used to create surfaces representing mineral soil, which in a final step were overlaid with the organic soil surfaces (see section 2.4.2), serving as a negative control. Mineral soil surfaces were generated by extracting or digitising the extent covered by each map, *minus* Moor and Halbmoor soil types as well as surfaces with “anmoorig”, “sapro-organisch” or “antorfig” hydromorphic organic substance.

For a few regions, soils have been mapped as part of map sheets (Zürich, Hörnli or Uster) and as part of a canton soil map (ZH or SG). There are some differences between the soil maps from the map sheets and from the cantons. Some of these can be explained by different survey dates (i.e. organic soils that have over time changed to the extent that they were recognised as mineral soils in subsequent surveys), but not all. Where one map defines a surface as organic and another map the same surface as mineral, this was identified as a conflicting surface and dealt with as described in section 2.4.2.5. In the majority of cases, the surveying of the map sheets predates that of the canton maps and as a result, the soil type indicated by the latter was used.

Two additional soil / geological maps were also included. Firstly, a map of the Seeland region (Bern / Fribourg / Neuchâtel) from Lüdi (1935), scale 1:50,000. This contains the following relevant units: “Torf”, “Torf über Lehm”, which were considered peat [A]. Secondly, a map of the Moosseetal (Bern) from König and Rufer (1920; in Nussbaum, 1926) containing the following relevant units: “Torfboden” and “Torf über Seekreide”, which were considered peat [A]. Both these maps were considered historical information sources; all other soil maps were considered modern.

The soil maps used in this project represent ca. 13,400 ha of organic soil.

2.1.1.2. Habitat Inventories

The inventories used in this project refer both to vegetation that is peat-building and to vegetation that typically grows over peat. Using vegetation as a proxy for organic soil assumes that the vegetation has been persistent at a site long enough that the peat layer has accumulated to be thick enough that it can be considered organic soil. Cases where this is unlikely to be the case were dealt with as discussed in section 2.4.2.

Federal inventory of raised and transitional bogs of national importance (Bundesinventar der Hoch- und Übergangsmoore von nationaler Bedeutung (Hochmoorinventar) / Inventaire fédéral des hauts-marais et des marais de transition d'importance nationale (Inventaire des hauts-marais), reported in Grünig *et al.*, 1986)

This inventory was carried out to provide baseline information regarding the location and status of raised and transitional bogs (Hoch- und Übergangsmoore, or haut-marais and marais de transition), habitats that have had their distribution in Switzerland severely curtailed, and that are often endangered by human activity. Such baseline information is necessary for the planning of nature protection; prior to this inventory, Swiss-wide information about bogs was mostly available from older material (Früh & Schröter, 1904; Lüdi, 1973a-j, surveying from 1943-1951) which lacked systematic vegetation surveys. Surveying for the inventory took place during 1978-1984 (Grünig *et al.*, 1986), with revised data sets from 1999, 2003 and 2007, as indicated in the data set. The minimum mapping size was 625 m^2. Alterations made in the framework of the 2014 revision of the Biotope-inventories act were not included.

Each contiguous bog surface comprises one to several compartments; each compartment has one mapping unit. The mapping units are classified into three groups: The first group is primary vegetation and comprises the six raised or transitional bog vegetation types; the second group is secondary vegetation and comprises the same six bog vegetation types. The former were considered to be in a near-natural state whereas the latter were degraded and deviated significantly from this. These two vegetation types occur over peat. The third group of mapping units does not consist of bog vegetation; these mapping units represent a buffer zone deemed necessary for the maintenance of the bog habitat. Some of these indicate the original extent of the raised bog (e.g. many of the purple moor-grass grasslands that surround the raised bog surfaces) and some of these do or might contain peat (e.g. naked peat surface, some of the unit "forests", "woodland pasture" or "fen"), but for the other ten mapping units it is unclear whether they contain peat or organic soil.

The Federal Inventory of Raised and Transitional Bogs was used for this project as follows. Surfaces comprising primary and secondary bog vegetation of the following types were extracted: bog hummock vegetation (Bultgesellschaften / végétation de buttes, mapping units [MUs] 1 and 21), bog hollow vegetation (Schlenkenvegetation / végétation de gouilles, MUs 2 and 22), treed bog with *Pinus mugo* (Bergföhrenhochmoor / pinède de tourbière, MUs 3 and 23), bog furrow vegetation (Rüllengesellschaften / végétation de combe d'écoulement, MUs 4 and 24), wooded bog with birch or spruce (Birken- und Fichtenmoore / boulaie et pessière de tourbière, MUs 5 and 25) and mixed raised bog vegetation (Hochmoormischvegetation / végétation mixte de tourbière, MUs 6 and 26). Naked peat surfaces (MU 13) were also considered to contain peat [A] and were extracted directly for use in the digital map. The buffer zone units (MUs 7 to 20, except MU 13) were not considered further. It is possible that many of the "fen" (Flachmoor or bas-marais, MU 11), "forest" (Wald or fôret, MU 7) and "woodland pasture" (Waldweide or pâturage boisé, MU 8) surfaces of these buffer zone units indeed contain peat, but it was assumed that the relevant surfaces would be selected for the map or organic soils based on other information sources.

Using the above-described interpretation of the mapping units, this inventory represents ca. 1,600 ha of organic soil.

Federal Inventory of fens of national importance (Bundesinventar der Flachmoore von nationaler Bedeutung (Flachmoorinventar) / Inventaire fédéral des bas-marais d'importance nationale (Inventaire des bas-marais) Inventar der Flachmoore von nationaler Bedeutung, reported in Broggi, 1990) and inventory of fens of regional importance

The aim of this inventory was to map fens of national and regional importance, documenting a single set of characteristics for fens throughout the country. As for the raised and transition bogs, baseline information in Switzerland was at the time lacking, yet nationally important fens needed to be recognised for the new nature protection act that had been passed following the Rothenthurm Initiative of 1987[2]. The main surveying was carried out 1987-1988 (Broggi, 1990) with updated data sets from 2000, 2004 and 2007, as indicated in the data set; the survey scale was 1:25,000. Nomenclature of fen types mentioned in this section and in section 2.2.2 follow Delarze and Gonseth (2008). Alterations made in the framework of the 2014 revision of the Biotope-inventories act were not included.

Seven vegetation types are distinguished in the fen inventory. These range from sedge- and reed-dominated vegetation types, to wet meadows. An additional vegetation type “transitional bog”, comprised sites that were not included in the Federal Inventory of Raised and Transitional Bogs. Each contiguous fen surface comprised one to several compartments; each compartment could contain several vegetation types and for each compartment the cover of each of the vegetation types (to the nearest 10 %) was recorded. Sites greater than 1 ha, with considerable vegetation diversity or / and in good condition (lightly-, barely- or not damaged) were considered as sites of national or regional importance (Broggi, 1990, 1994a).

Not all fens, as defined in Switzerland, are peat-building and it is unclear which of the seven vegetation types are. The report “Zustand und Entwicklung der Moore in der Schweiz” (Klaus, 2007) considered the following groups of vegetation types to be peat building: i. the three sedge-dominated vegetation types (Caricion fuscae[3], or Saures Kleinseggenried or Parvocariçaie acidophile; Caricion davallianae, or Kalkreiches Kleinseggenried or Parvocariçaie neutro-basophile; and Magnocaricion, or Grossseggenried or Magnocariçaie), ii. the “reed” dominated vegetation type (Phragmition, or Stillwasser-Röhricht or Roselière lacustre) and iii. transitional bogs (Scheuchzerietalia palustris / Caricion lasiocarpae, or Übergangsmoor or marais de transition, cf. Zimmerli, 1996). This decision was based on the abundance of species indicative of humus and peat (from Landolt, 1977) in each of the surveyed sites. While this gives an estimate of the presence / absence of peat for these vegetation types, it would seem that peat is not always present at these sites, suggesting a possible mismatch between vegetation type and soil type (Broggi, 1994b; Leupi, 1994): Two small studies have tested this for two fen vegetation types and question whether the use of vegetation type alone can be used as a proxy for the occurrence of peat.

Firstly, a meta-analysis by Leupi (1994) of the Caricion davallianae fen vegetation type, by far the most abundant fen vegetation type in Switzerland, shows that the soil from only 6 to 9 of the 18 considered sites meet the IPCC criteria of organic soils. This brings into doubt the use of this fen vegetation type as an indicator of organic soil. For this project, fen compartments comprising ≥ 80% Caricion davallianae fen vegetation, totalling almost 3,000 ha, were therefore considered as potentially containing organic soil [C].

A second vegetation type, Caricion fuscae, was chosen for ground-truthing as part of this project (see 2.2.2). This is the second most common potentially peat-building fen vegetation type. While the results of this ground-truthing show that the relationship between vegetation type and soil type is unclear, this fen vegetation type *tends* to grow on organic soil in Switzerland. For this project, surfaces that contained ≥ 80% of this vegetation type (or a combination of ≥ 80% Caricion fuscae and transitional bog vegetation), totalling ca. 1,200 ha, were selected for this project and were considered as probably containing organic soil [B].

[2] Eidgenössische Volksinitiative 'zum Schutz der Moore – Rothenthurm-Initiative', 1987, Art. 24sexies Abs. 5 und UeBest. BV / Initiative populaire fédérale 'pour la protection des marais - Initiative de Rothenturm', 1987, Art. 24sexies 5e al. et disp. trans.const.

[3] Accepted name; referred to also as Caricion nigrae; the accepted scientific name of the common sedge (=Braune Segge) is *Carex nigra* (L.) Reichard (syn. *Carex fusca* auct.).

Surfaces containing ≥ 80% transitional bogs (total <10 ha), were also extracted and included in this project [A].

Vegetation sub-types of both Magnocaricion and Phragmition are known to grow over mineral as well as organic soils (Leuthold, 1996). For this project, fen compartments comprising ≥ 80% Magnocaricion or Phragmition (or ≥ 80% of a combination of these and any of the three vegetation types described so far) were included, considered as surfaces potentially containing organic soil [C]. In spite of the large surface area represented by fen compartments dominated (≥ 80%) by these two vegetation types (ca. 1,500 ha), their addition to the estimates of organic soil results in an increase of less than 400 ha.

In summary, fen vegetation type would appear not to be an ideal proxy for the occurrence of organic soil in fens, but given available information it is at the moment the best proxy we have. Surfaces representing organic soil, i.e. those dominated (≥ 80%) by Caricion fuscae and transitional bog vegetation represent, ca. 1,200 ha of organic soil.

Federal inventory of alluvial zones (Bundesinventar der Auengebiete von nationaler Bedeutung (Aueninventar) / Inventaire fédéral des zones alluviales d'importance nationale (Inventaire des zones alluviales), reported in Kuhn & Amiet, 1988; Gallandat *et al.*, 1993; Gerber *et al.*, 1999; Thielen *et al.*, 2002)

The inventory was carried out to offer a planning tool to the cantons for the protection of the flood-prone areas of (probable) national importance, in view of the deteriorating state of these sites. Surveying began in 1987, with a mapping scale of 1:10,000.

Of the twenty-two vegetation types identified in this inventory, the potentially relevant one for this project is the unit "fen". The spatial precision and accuracy of this inventory appears to be better than that of the federal fen inventory and in addition, several sites can be identified in this dataset that are not included in the latter. This would at first glance suggest that for these sites, this information source provides an improved estimate of fen locations. However, the inventory of alluvial zones was not included in this project for two reasons: Firstly, no detail is given regarding the vegetation type present in the fens meaning it is impossible to distinguish between non-/ and peat-building vegetation. Secondly, fens in alluvial zones that are subject to frequent flooding events tend to contain much sediment material (Steiner & Grünig, 1997) and are therefore unlikely to be organic soil.

Other regional or local inventories

For cantons Zürich and Graubünden, canton inventories were used to identify additional surfaces of organic soils. The inventories from the Zürich inventory identified a significant number of sites; the Graubünden inventory is important as this canton is otherwise poorly covered by relevant data sets.

Canton Graubünden, Nature and Landscape Protection Inventory (Natur- und Landschaftsschutzinventar). Surveying from 1980 to 2006. „Core" areas of raised bogs (as opposed to surrounding areas or buffer zones) not included in the national inventory were extracted from this data set and were considered as containing organic soil [A]. This inventory represents ca. 20 ha of organic soil.

Canton Zürich, Wetland Inventory (Feuchtgebietkartierung, part of the Lebensraum- und Vegetationskartierungen – habitat and vegetation mapping – of the canton). Fen vegetation types, raised bogs [A] and Birken-Föhrenbruchwald [A] not included in the national inventories were extracted from this data set. The fens were mapped using the same vegetation types as the federal inventory. Surfaces of Caricion fuscae vegetation were used in this project, scored as for the federal fen inventory. Surveying from 1976/77 (Burnand & Züst, 1979) to 2008. This inventory represents ca. 100 ha of organic soil.

2.1.1.3. Vegetation and Habitat Maps

Forest habitat maps

The forest habitat maps ("Waldstandortkarten" or "cartes des stations forestières") of the cantons were identified as possibly indicative of organic soils under forest. These maps are produced to describe and categorise the near-natural forest habitat which would occur at a given site. Understanding processes of the (would be) natural forest at a given site is vital for good forest management, for example the stocking of forests with site-appropriate species. The habitat types are differentiated from one another based on a combination of vegetation (indicator plant species groups), soil and physiognomy, including relief, and external factors such as the occurrence of avalanches or rock-falls (Stocker *et al.*, 2002; von Wyl *et al.*, 2003; Frey & Bichsel, 2005; Zuber, 2006). Although the larger tree species of a site might often have been planted, it is expected that a site's ground flora represents a simplified 'résumé' or a summary of a site's characteristics. A consequence of this is that vegetation is an important aspect in defining a forest habitat type. For most cantons, delimitation of the main forest habitat types therefore followed the scheme of Ellenberg and Klötzli (1972) (hereafter E & K) which identifies 71 forest communities. Several cantons have added sub-habitat types to the main ones, to account for rare or unusual habitat types. A few cantons used a different classification system of habitat or vegetation types (see Table 2), but in all cases except two, consistency between the cantons was upheld as a 'translation' from the canton's classification system to the E & K system was supplied by the canton. The two exceptions to this are described at the end of this section.

Five forest habitat types that might be indicative of organic soil were initially identified (Table 2). These were selected based on either the mention of peaty soils by some or all cantons, or a combination of the mention of *Sphagnum* and water-logged soil. From these five types, three forest habitat types were chosen for ground-truthing – E & K units 45, 56 and 71 – based on the mention of peaty soil by some or all cantons.

Table 2: The forest habitat types that possibly grow over peat; E & K = Ellenberg and Klötzli (1972)

Name (German / French)	E & K unit number	Comment, according to canton descriptions of the habitat types	Considered for ground-truthing?
Seggen-Schwarzerlen-Bruchwald / Aulnaie marécageuse à Laiches	44	No *Sphagnum* in moss layer; often on ground gained from water bodies; 'anmoorig' soil mentioned in some of the descriptions	No
Föhren-Birkenbruchwald / forêt marécageuse à Bouleau pubescent	45	No *Sphagnum* in the moss layer; peaty soil mentioned in the descriptions from some of the cantons	Yes
Heidelbeer-Tannen-Fichtenwald mit Torfmoos / Pessière-sapinière à myrtille avec sphaignes	Subunits 46S (LU), 46s (BE/FR), 46* (SG)	*Sphagnum* in the moss layer, water-logged soil; peaty soil types not mentioned in descriptions	No
Typischer Torfmoos-Fichtenwald / Pessière à Sphaignes typique	56	*Sphagnum* in the moss layer; peat mentioned in the descriptions from some cantons	Yes
Torfmoos-Bergföhrenwald / Pineraie de montagne à Sphaignes	71	*Sphagnum* in the moss layer; peat mentioned in the descriptions of all cantons; probably raised bog	Yes

Through ground-truthing, the occurrence of an organic layer thick enough to meet the IPCC criteria of organic soil was checked (see section 2.2.2). Based on the results of this ground-truthing it was decided to use these three units for this project [A]. Forest compartments of mixed habitat types were only included in the map if both units are indicators of organic soil (e.g. a compartment with units 71 / 56).

Table 3: Forest habitat data sets containing relevant habitat types used in the project; spatial coverage (as a percentage of the forested area in that canton) and the units used for surveying are indicated

Canton	Coverage	Survey units
AG	> 95 %	Used E & K units
AI	> 95 %	Used own units
AR	> 95 %	Used E & K units
BE	10-15 %	Used E & K units
FR	> 95 %	Used E & K units
GL	> 95 %	Used E & K units
LU	> 95 %	Used E & K units
NE	> 95 %	Used own units; translation to E & K supplied by the canton
NW	70-75 %	Used E & K units
OW	> 95 %	Used E & K units
SG	> 95 %	Used E & K units
SO	> 95 %	Used E & K units
SZ	10-15 %	Used E & K units
TG	> 95 %	Used E & K units
UR	30-35 %	Used E & K units
VS	> 95 %	Used own units
ZG	20-25 %	Used E & K units
ZH	> 95 %	Used E & K units

Table 3 and Figure 2 show from which data sets surfaces were extracted for this project. For the cantons Basel-Landschaft, Basel-Stadt, Geneva and Schaffhausen no relevant forest habitat types were identified. This was also the case for canton Jura and Vaud, though the maps here are incomplete. There is no suitable forest habitat map for canton Ticino. Lastly, Canton Graubünden has used a model-based approach to produce an 'indicative' forest habitat map ("Standort-Hinweiskarte"), which predicts the most likely habitat type to occur at a site. It is noted by the Amt für Wald und Naturgefahren (roughly translated as the Department of Forest and Natural Hazards) that this map is useful for large-scale planning but for more precise applications (i.e. identification of small sites) and for identifying sites that are regionally scarce, it is unsuitable. An extract of this map covering the northern flank of Piz da Staz, where treed bogs are known to occur, was obtained to test its suitability for this project. These treed bogs were not identified in the forest map and it was therefore decided not to use the map for this project.

Figure 2: Availability and relevance of forest habitat maps as used in the project, by canton; pale grey = relevant habitat units not found in canton; mid-grey = relevant habitat units found in canton; dark grey = appropriate map not available for canton; P = forest habitat maps available for parts of canton only (see main text for details); canton and lake boundaries © Swisstopo

For the majority of cantons, E & K mapping units were provided and could be used directly to identify relevant surfaces; for two cantons, Valais and Appenzell Innerrhoden, this was not the case. For Valais, the relevant mapping unit is "Sphaignes". This mapping unit is noted as occurring on very damp acidic soils and as being associated with peat bogs. *Sphagnum* spp. are indicator species though other species (*Pinus mugo*, *Pinus sylvestris*, *Betula* sp.) are associated with this vegetation type (Werlen, 1994). Based on this description and the similarity of the associated species with those of Torfmoos-Bergföhrenwald (E & K unit 71), it was decided to score these surfaces as organic soil [A]. The mapping units of the forest habitat map of Appenzell Innerrhoden are characterised by the following relevant properties: soil type, according to Peyer and Frei (1992), and habitat type (a synthesis of site characteristics). Surfaces with Halbmoor or Moor soil types as well as surfaces with habitat type "Moorböden" were scored as organic soil for this project [A].

Surfaces from the forest habitat maps represent ca. 3,000 ha of organic soil. Forest compartments of mixed habitat types where only one habitat type is indicative of organic soil (E & K units 45, 56 or 71) were not used for this project as such habitats were not ground-truthed; their surface comprises ca. 1,000 ha.

Other Vegetation Maps

Several other local vegetation maps, both historical and modern, were consulted. Modern maps were considered for regions where we otherwise have little information or where the vegetation map identifies potential peatlands that were otherwise not captured by other data sets, namely the inventories of raised bogs or fens. Local historical vegetation maps were also consulted. These are useful for two reasons. Firstly they identify potential peatlands that, as mires, have disappeared. Secondly, certain maps indicate not only the vegetation or past vegetation of a site, but also the use of the site at the time e.g. "cultivated land over peat". Such information is important because it offers a minimum date for the destruction of a mire, which is important to interpret historical information (see section 2.4.2). The maps consulted and used in this project are indicated in Table 4; their distribution is indicated in Figure 3.

Table 4: Vegetation maps used in the project

Map title	Region	Map description
Wauwilermoos	Wauwilermoos, LU	Location of agricultural land and occurrence of peat
Eigenthal – Pilatus	Eigenthal bei Malters, LU	Location of agricultural land, fens, raised bogs and peat-cutting surfaces
Les Ponts – La Sagne	Vallée des Ponts, NE	Location of agricultural land, occurrence of peat, raised bogs remains and peat-cutting faces
Altmatt, Kanton Zug und Schwyz	Altmatt, ZG and SZ	Location of agricultural land, fens, raised bogs and peat-cutting surfaces
Das Isenriet	Rheintal, SG	Shows location of the original fen
Teufemattalp bei Flühli	Teufimatt, OW	Shows location of forest over peat
Vegetationskarte des Walensee-gebietes	Walensee and area south thereof	Vegetation map, including raised bogs
Vegetationskarte des Rhone-gebietes zwischen den Dents de Morcles und dem unteren Entremont	Rhone area between the Dents de Morcles and lower Entremont valley, VS	Vegetation map, including fens and raised bog vegetation
Carte phytogéographique du Haut-Jura neuchâtelois nord-occidental	NE	Vegetation map including pasture land over peat
Pflanzengeographische Karte des Sihltales bei Einsiedeln	SZ	Vegetation map, including the current and former extent of raised bogs and fens, as well as exploited peatlands
Carte de la végétation du Pays-d'Enhaut et de La Place de Tir du Petit-Hongrin	North-east VD	Vegetation map, including fen and raised bog vegetation
Upper Engadine vegetation map	GR	Vegetation map, including fens and raised bog vegetation

For all maps, raised bog vegetation was considered to grow over organic soil [A], as was any other vegetation specified as growing over peat (or 'Moorboden' or 'Moorgrund'); Caricion fuscae vegetation was also considered to grow over organic soil, but with less certainty [B]. The last two maps listed ("Carte de la végétation du Pays-d'Enhaut et de La Place de Tir du Petit-Hongrin" and the "Upper Engadine vegetation map") were considered modern maps; all other maps were considered historical. The map "Teufemattalp bei Flühli" was obtained from a modern publication (Hahn, 2011) but itself dates to 1880.

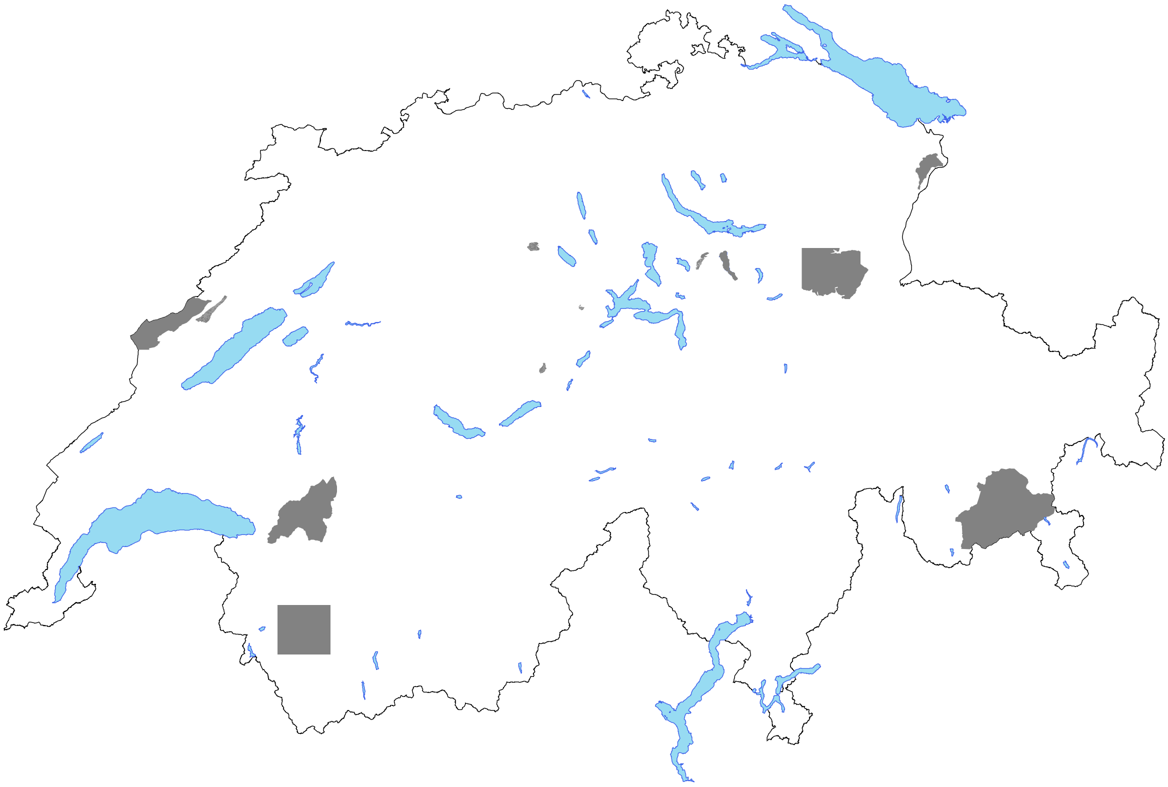


Figure 3: Distribution of local vegetation maps used in the project; national boundary and lake boundaries © Swisstopo; sources and / or proprietors of original data listed in appendix I

Agricultural Surfaces

Ecological compensation areas (ökologische Ausgleichsflächen / surfaces de compensation écologique) are surfaces that form part of farms but that are managed in a way to increase structural and biological diversity in the agricultural landscape. Because their management might not be profitable and in order to ensure their continuation, such surfaces are the subject of subsidies or 'direct payments' (Direktzahlungen / paiements directs). One type of compensation area is straw-meadows (Streuwiesen / prairies à litière) which are often damp areas or fens. These meadows were mown for the production of bedding material for animals, following the collapse of cereal production in Switzerland in the second half of the 19th century coinciding with increased cattle ownership (especially dairy cows for cheese-making) and the ensuing deficit of animal bedding (Mühlethaler, 1994). The repeated cutting over many years alongside the late mowing time combined with the lack of fertilisation means that this traditional management precludes scrub encroachment and benefits fens vegetation (Broggi, 1990; Mühlethaler, 1994).

Because the management of these sites is centrally financed, their location in the landscape is documented (digitally), making them potentially very useful for this project. Where available, the spatial data sets can be obtained from the cantons.

It was decided however not to use straw-meadows for this project. As discussed in the section dealing with the fen inventories, not all fens grow over peat. Without further investigation of these sites, it cannot be assumed that litter-meadows are indicative of organic soil.

2.1.1.4. Geological and Hydrogeological Maps

GeoCover

This digital data set, published by Swisstopo, encompasses the most up-to-date digital geological maps of Switzerland. The component geological maps were surveyed by different people, over the last 130 years (although the vast majority were surveyed in the last 80 years). It comprises 1) the GeoAtlas map sheets (scale 1:25,000); 2) compilations of geological maps and sometimes unpublished geological maps, of various spatial scales “compilation geological maps”. The latter cover regions not covered by the GeoAtlas data set. Lists of the currently-available base maps for these compilation maps, and of the published GeoAtlas map sheets are available from the Swisstopo website[4], under the heading “GeoCover”. Data from 124 sheets of the Geological Atlas (covering ~56 % of the country) and from the compilation map – covering a further 46 sheets – were obtained for this project (total coverage = ~75 % of the country, see Figure 4). Details of the sheets used are given in appendix I. Maps published before or in 1945 were considered ‘historical’ for this project, those published since 1945 (or comprised of maps published since that date) were considered ‘modern’ (see section 2.3.4).

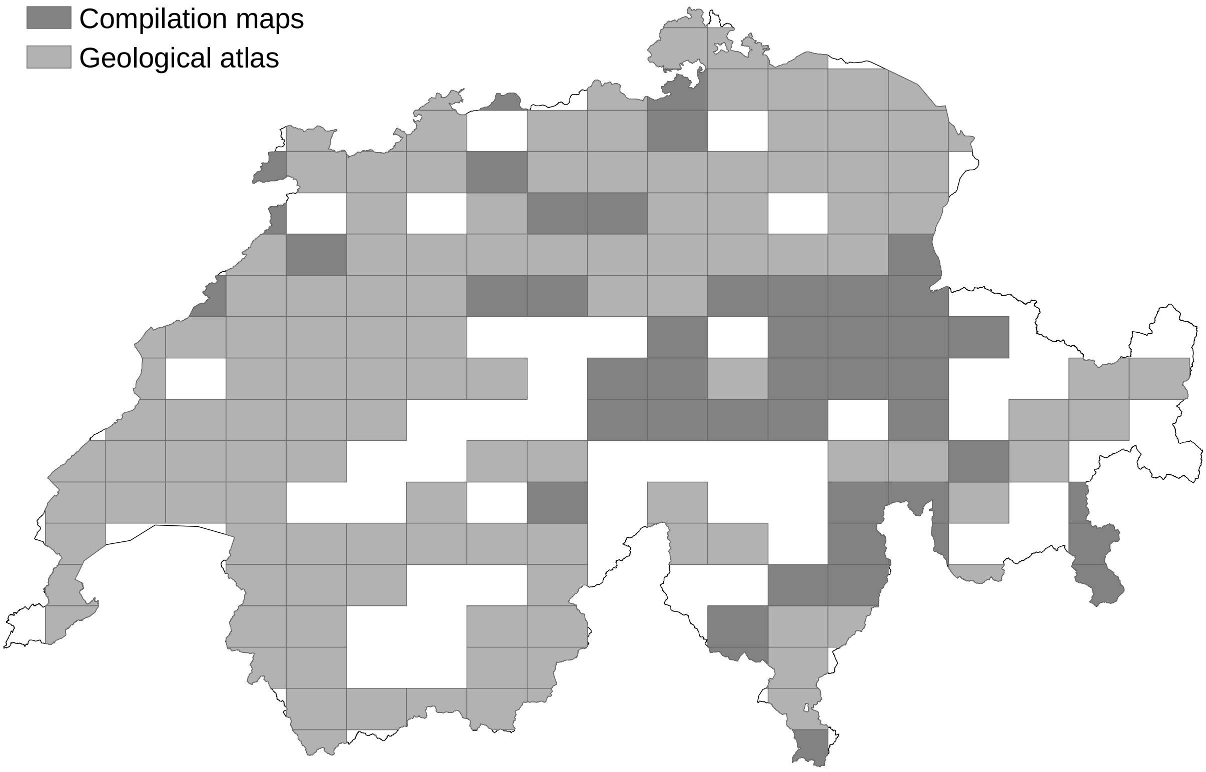


Figure 4: Distribution of geological maps (GeoCover) used in the project; GeoCover maps, map sheet outlines and national boundary © Swisstopo

Considered a sedimentary rock type, peat is usually encapsulated in geological maps as a Holocene deposit. One drawback of the GeoCover data set for this project is that the mapping units relevant to peatlands vary between the map sheets and while a clear distinction is made between peatlands and non-

[4] www.swisstopo.ch

peatlands in some map sheets (e.g. “Tourbières, Marais tourbeux”, from map sheet La Chaux- Les Verrières; “Torfmoor” vs. “Sumpf”, from map sheet Beggingen), this is not the case in others: For example, some mapping units contain both peaty and non-peaty sites (e.g. “Ried, Sumpf, vernässter Boden, Hoch- und Flachmoor” from the Rigi map sheet). For such mapping units, it is impossible to distinguish peaty sites (in this example, the raised bogs, or Hochmoore) from sites that may or may not be peaty from the information available. Ground-truthing is an unrealistic option for the GeoCover data sets as each relevant mapping unit *of each map sheet* would need to be investigated.

The suitability of GeoCover was additionally judged by comparing it to other datasets, leading to the following observations: Firstly, GeoCover identifies many sites that are indicated in historical information sources as peatlands, and that also appear on aerial photographs as very dark brown to black surfaces when covered by cropland (typical of peaty soils), yet which are in regions not covered by modern soil or hydrogeology maps. Because GeoCover has good coverage compared to other data sets pertaining to soil or rock, i.e. soil and hydrogeology maps, it possibly brings a lot of new information regarding organic soils. Secondly, the overlap between sites identified as peatlands by GeoCover and by the hydrogeological maps (described in the following section) where peat cover is stipulated explicitly, is moderate; in the region where the two datasets overlap, only 57% of surfaces identified as peat by GeoCover are also identified as such by the hydrogeological maps – although the much coarser scale of the latter (1:100,000) must be kept in mind. Thirdly, in the few areas where a suitable comparison between the GeoCover data set and soil maps could be made, the GeoCover data set appears to slightly over-estimate the surfaces of organic soil relative to the soil maps. As described in section 2.1.1.1, inconsistencies between soil maps themselves however suggest that conflict between the GeoCover and soil maps should itself be treated with caution. In conclusion, it was decided to use GeoCover for this project, but to explicitly account for the possibly that it over-estimates the extent of organic soil.

Surfaces indicating peaty soils or potentially peaty soils were extracted from the GeoCover data set. The surfaces were coded according to their reliability as indicators of organic soil. In cases where the mapping unit cannot distinguish between peatlands and non-peatlands (e.g. as the Rigi map sheet described above), the surfaces received a score [C]. Surfaces with only superficial layers of peat, or surfaces labelled “sometimes peat” (“z.T. Torf”) were also scored as such [C]. In cases where peatlands could be distinguished unambiguously, the surfaces were considered as organic soil [B]. A ‘B’ score, rather than an ‘A’ score was used for the GeoCover data set in the light of comments in the previous paragraph. The consequence of this for the final map of organic soils is that surfaces represented *only* by GeoCover will be identified as organic soil, but will represent surfaces in the less conservative estimate of organic soil only (see section 2.6 for the meaning of ‘conservative’ in this project).

Surfaces from the GeoCover data set represent ca. 13,000 ha of organic soil.

Hydrogeological Maps

The hydrogeological maps of Switzerland map the permeability of bedrock and unconsolidated rock, as well as the presence of a peaty cover layer. The scale of the hydrogeological maps is coarse (1:100,000) but the coverage of these maps in combination with the fact that a peat layer is specifically mentioned makes these maps worth incorporating into this project. Seven maps have been published so far (Bözberg - Beromünster, Jäckli & Kempf, 1972; Bodensee, Kempf, 1980; Panixerpass, Jäckli, 1985; Biel / Bienne, Hauber & Pfirter, 1991/1992; Toggenburg, Haering *et al.*, 1993; Saane / Sarine, Pasquier *et al.*, 1998; Vallorbe - Léman nord, Pasquier *et al.*, 2006). The vector data currently available for three of these the map sheets (Vallorbe-Léman nord, Biel / Bienne and Saane / Sarine, including part of Besançon, see Figure 5), were used for this project. Surfaces with a cover layer “peat” were assumed to be organic soil and were extracted and used for this map [B]; a ‘B’ score was assigned rather than an ‘A’ score because information could not be found regarding the minimum thickness of peat required for a cover layer to be assigned as ‘peat’. Surfaces described as “Wechsellagerung von Kies, Sand, Ton und Torf” (~alternating sediment of gravel, sand, clay and peat) were also extracted and used for this map [C].

Surfaces from the Hydrogeological maps represent ca. 12,000 ha of organic soil.

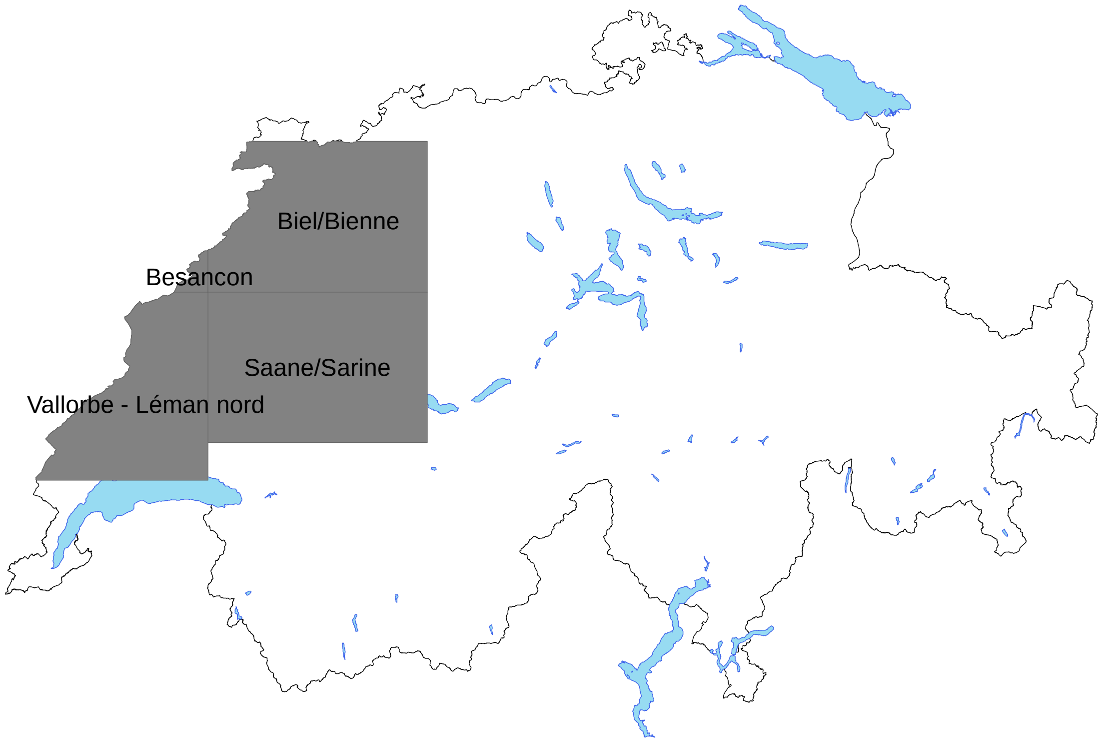


Figure 5: Distribution of hydrogeological maps used in the project; national boundary, lake outlines and map sheet outlines © Swisstopo; the proprietor of the hydrogeological maps is listed in appendix I

Quaternary Maps of the Linth Region

These geological maps cover the Linth Plain and the valley bottom between Luchsingen, lake Klöntal and lake Walen (Schindler, 2004). The relevant mapping unit of the surfaces is: "Vorwiegend Lehm bis Feinsand, oft mit organischen Resten" (predominantly loam to fine sand, often with organic remains). Core drillings throughout the region show that the organic remains are peat (Schindler, 2004) and these surfaces were therefore digitised for this project [C].

2.1.1.5. Historical Topographical Maps

Surfaces derived from all of the following information sources were considered historical.

Dufour Maps

The earliest official map covering the whole of Switzerland is the Dufour map (1:100,000) published between 1845 and 1865. It was coordinated by Guillaume-Henri Dufour who was appointed Head Quartermaster of the Swiss Confederation in 1832 (Locher, 1953-1954). The 'basic' data sets for this map were topographical surveys in the scale of 1:25,000 (in the Jura and Midlands) or 1:50,000 (in the Alps). Several cantons had already been or were surveyed by the cantons themselves, and these surveys were adopted by Dufour for the national map. These were for the cantons of Aargau, Basel-Stadt, Bern, Fribourg, Geneva, Luzern, Neuchâtel, Solothurn, St. Gallen, Appenzell Innerrhoden, Appenzell Ausserrhoden, Thurgau, Vaud, Zug and Zürich; the survey dates and mappers of these maps are listed in appendix I. The remainder of the territory was surveyed under Dufour's instruction between 1837 and 1861 and the map 1:100,000 map sheets were published between 1845 and 1865 (Locher, 1953-1954). Under the instruction of Dufour, lakes, ponds and "Sümpfe" (or marais, translated here as non-littoral wetlands, referred to hereafter simply as wetlands), as well as peatlands ("Torfmoore" or tourbières), mines and quarries were to be surveyed precisely (Anon, 1896).

Wetlands (dark-gray or blue stippling) and peatlands (brown stippling) from these ‘basic’ maps were incorporated into this project. Wetlands were considered as potentially containing organic soil [C]; peatlands were considered as containing organic soil [A].

Siegfried Maps

The next important map series covering the whole country was the topographic atlas of Switzerland, or the “Siegfried maps”. The first edition of this atlas was produced from 1870 to 1900 (with a few map sheets of the first edition published in the early 20th century, Swisstopo, 2005). The aim of the atlas was to produce maps of Switzerland at the scale of the original surveys, i.e. 1:25,000 (midlands, Jura and southern Ticino) or 1:50,000 (Alp region). Two of the mapping units are relevant for this project: wetland (“Sumpf”, or marais, represented by blue stippling) and peatland (“Torfland”, or tourbière, represented by small brown right-angled lines). All sheets were surveyed with the same mapping instructions, namely that surfaces that could not be crossed by a horse should be recognised as wetlands (Anon, 1888). This consistent surveying across the whole country, in combination with the improved spatial accuracy (Imhof, 1927), makes the Siegfried map a very important information source for this project.

There are however limitations to the Siegfried maps that must be considered: Firstly, many wetlands are shown in later editions of the Siegfried map but not in the first edition; assuming that the wetting of sites has not be prevalent in Switzerland’s landscape history, this implies that the first edition under-represents wetlands. This is important because many mires were destroyed between the first and last editions of the atlas, meaning that some wetlands may never have been documented. Secondly, the wetland legend item is not necessarily an indication of a peatland: Comparison with other historical and modern information sources shows that some wetlands (with no indication of peat extraction on the Siegfried maps) indeed contain peat, whereas for others there is no such evidence. Such surfaces are still useful for this project as they indicate the previous extent of wetlands which is useful information if it can be combined with other descriptive historical information regarding peat.

Three editions of the Siegfried map series were used in this project: the first edition (ca. 1880), the edition from 1910 (or closest to this date) and the last edition (ca. 1940). Wetlands were digitised as surfaces, and for each wetland surface it was recorded whether or not peatland symbology was present or not. The few sites are indicated only as peatlands (brown symbols, no blue symbology) were also digitised as surfaces. Wetlands were considered as potentially containing peat [C]; peatlands were considered to contain organic soil [A].

Surfaces from the Siegfried and Dufour maps represent ca. 10,000 ha of organic soil.

Other Historical Maps

Several historical maps covering local areas were additionally identified as relevant for this project (Table 5 and Figure 6). These contain symbology indicating wetland and / or peatland and were published before the first edition of the Siegfried map. Some of them post-date the Dufour map but contain wetlands not mapped in the latter. All maps have a scale of less than 1:60,000 and were deemed to be sufficiently accurate to be useful for the project. The relevant surfaces of these maps were digitised and were scored in the same manner as the Siegfried maps.

Table 5: Other historical regional or local maps used in the project

Map title	Canton, region	Mapper	Publication date	Relevant legend items
General Charte der Jura Gewässer / Plan Général des eaux de Jura et des inondations qu'elles produisent pendant les grandes cruës	FR, NE, BE Seeland	Trechsel, F	1816-1817	Stippling, interpreted as wetland
Karte der Umgebungen von Bern	BE, surroundings of Bern	Beck, E.	1858	Blue stippling, interpreted as wetland
Carte général de la Plaine de l'Orbe	VS, Orbe plain	Gonin, L.	1862	Blue marking, interpreted as wetland
Veränderungen von Wald-Reben-Sumpfareal ca. 1700-1930	ZH, Glattal	Winkler, E.	1936*	Wetland surface

* This map contains the outline of wetlands in 1930 and in 1700; the former based on the Siegfried maps, the latter based on the Zehntenpläne of canton Zürich and the Gyger map of 1667 (Winkler, 1935-1936).

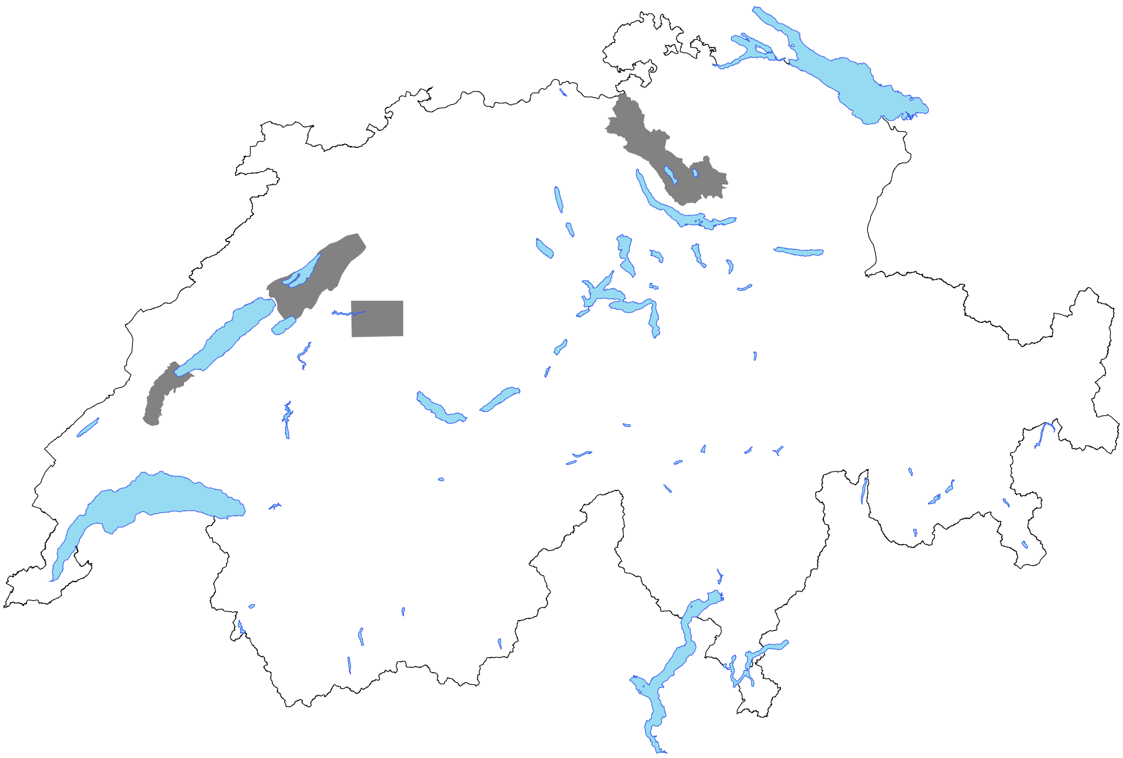


Figure 6: Distribution of other historical regional or local maps used in the project; national boundary and lake boundaries © Swisstopo

2.1.1.6. Other Data Sets

Vector 25

The Vector25 data set[5] was used to identify surfaces currently recognised as wetlands. The surfaces relevant to this project are all wetlands ("Sümpfe" / "marais") and therefore were considered to not necessarily occur over organic soil [C]. They were however included in the project as they might be important in combination with historical information regarding peat. Surfaces of the following categories were used: wetland, wetland and shrubs, wetland in forest, wetland in open forest (Sumpf, Sumpf und Gebüsch, Sumpf in Wald, Sumpf in offenem Wald / marais, marais et buissons, marais en fôrets, marais en fôrets clairsemée).

Peat Extraction Maps

Maps showing the location of sites from which peat was extracted with machinery during the late 1910's to the early 1920's were included in this project [A]. These nine maps are from the manuscript of Probst *et al.* (1923) and were considered historical information sources. Together they represent ca. 700 ha of organic soil.

2.1.2. Non-Spatial Data Sets

A number of documents contain important texts describing the location and status of mires and / or peatlands. The majority of these documents are old, containing information from observations that were carried out before the middle of the 20th century. All relevant localities were geo-referenced as points and attribute information from these sources was captured as described in section 2.3. In a subsequent step, the points were converted to surfaces (polygons) as described in section 2.4.2.2.

2.1.2.1. Expert Observations and Descriptions of Fens and Bogs

Two of the most important and comprehensive texts describing mires and peatlands that have mostly disappeared from modern documentation are: Früh and Schröters' "Die Moore der Schweiz" (1904) and Lüdi's series "Moore der Schweiz" (Lüdi, 1973a-j, surveying from 1943-1951). These texts each contain descriptions of hundreds of bogs and fens from across Switzerland, from the late 19th to the mid-20th century. These information sources were considered historical. The value of these texts is two-fold. Firstly they document the locations of fens and bogs that have often since disappeared (or in the case of Früh and Schröter, they also mention fens and bogs that had already disappeared). Secondly, the status of the fens and bogs is documented, including, in the case of destroyed fens or bogs, the land-use e.g. cultivation, peat extraction, or forestry. This information is relevant for this project because it offers an approximate date (or minimum date) for the drainage and / or extraction of peat at a site. This was in turn important to interpret historical information (see section 2.4.2.2). The fens, bogs and peatlands described in these texts were geo-referenced initially as points. All raised and transitional bogs, as well as fens or used surfaces (such as agricultural surfaces) occurring over peat, were scored as organic soil [A].

Two additional texts, Grossenbacher (1980) and Gerber (1925) also describe the location and state of destroyed or intact peat bogs in local areas. Grossenbacher (1980) gives an overview of the raised and transitional bogs of canton Bern. The fieldwork for this was carried out in 1974 to 1976, though older texts are frequently referred to within this text, allowing an understanding of the change (mostly decline) in the state of bogs since the late 19th century. All bogs that could be located and that are not sites included in the raised- and transitional-bog inventory were located and used in this project [A]. Fifteen sites were incorporated into this project, of which 14 were already destroyed. In spite of the relatively recent field surveying, this information source was considered a historical one for those sites described as already destroyed or as already destroyed by the early 20th century. Gerber (1925) describes eight peatlands (all

[5] http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/landscape/vector25.html, accessed 17th June 2014

destroyed mires) south east of the city of Bern, which were scored for this project as organic soil [A]. This information source was considered historical.

2.1.2.2. Sites Suitable for Peat Extraction

Another extensive source of information about historical peatlands is from the manuscript “Die Torfausbeutung in der Schweiz in den Jahren 1917 bis 1921” (Peat extraction in Switzerland from 1917 to 1921; Probst *et al.*, 1923). This report contains information obtained from questionnaires that attempted to quantify the amount of potential peat fuel in the country. The results of the questionnaires (from 1917 and 1918) include information about the location, extent and peat thickness of peatlands that would be suitable for peat extraction. In total 503 and 413 localities, respectively, were identified (although many localities appear in both tables). From the two questionnaires, 466 and 354 localities, respectively, were geo-referenced, corresponding to approximately 795 sites overall (see Figure 7). All sites were scored as containing organic soil [A].

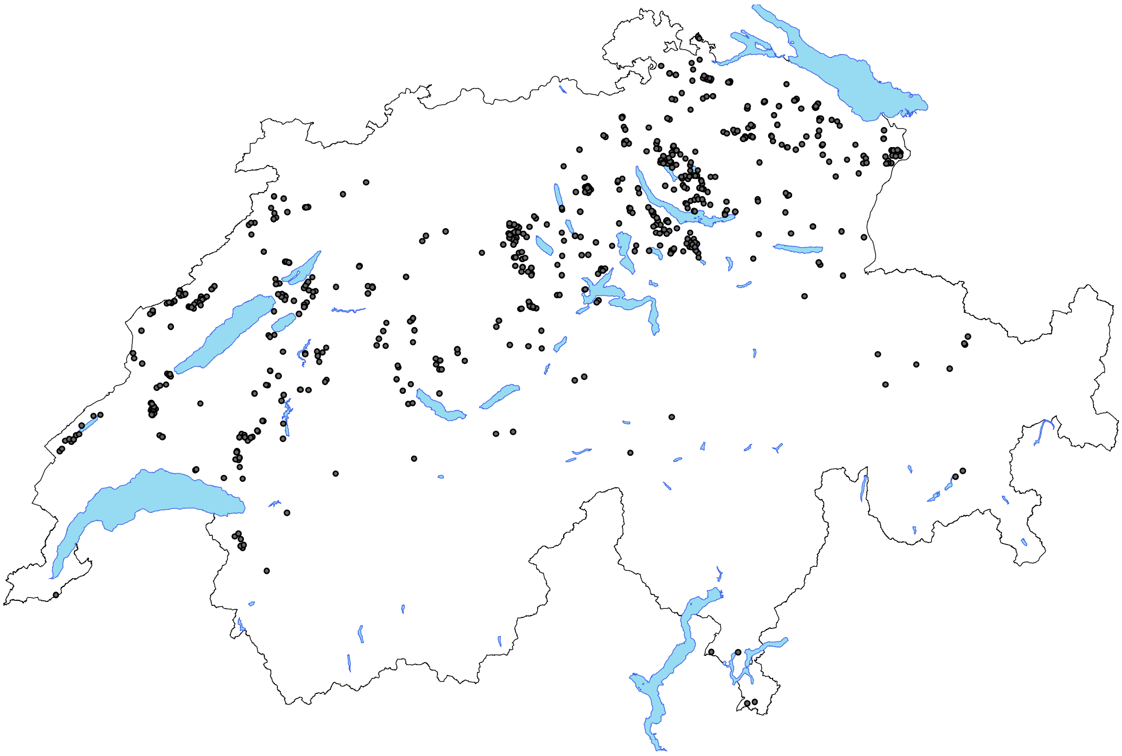


Figure 7: Sites reported by Probst et al. (1923) as suitable for peat extraction, as geo-referenced in this project, including peat extraction maps as described in section 2.1.1.6; national boundary and lake boundaries © Swisstopo

2.2. Checking Suitability of the Datasets for this Project

2.2.1. General

Information sources and data sets were initially assessed on the three principles described in section 2.1. They were additionally assessed as follows:

Firstly, descriptions explaining the contents of data sets were consulted. These included technical reports, theses, technical descriptions (as in the case of geological maps and soil maps) or map legends (as in the case of most vegetation maps), the latter sometimes with associated species lists. Such documents provided meta-data required for this project (e.g. survey dates and mapping scale) and, importantly, allowed mapping units to be checked, to ensure that these can unambiguously distinguish surfaces that represent organic soil from those that do not.

Secondly, the spatial accuracy of inventories and historical maps was determined by comparing these with current maps. Where spatial accuracy was not particularly good, this was recorded in the attribute table of the data set (section 2.3.1), or where it was very poor – as is the case for a few historical maps – these were not used.

Thirdly, data sets were assessed by comparison with other data sets, to judge whether they systematically over- or under-estimate the occurrence of organic soil. Because there is no single data set which documents all organic soil surfaces across the country, it was not possible to use a single data set against which to compare the rest. Data sets were therefore compared to the multiple other data sets – historical as well as modern – used in this project. Additionally, a number of data sets that were otherwise *not* considered as information sources for this project were also used to judge the reliability of each information source. These include: orthophotos (Swissimage), where, for cultivated surfaces, it is often possible to identify the very dark soil typical of soils with high C content; a detailed elevation model (Alti3D), where thin, regular depressions indicative of drainage pipes can often be seen on cultivated or grassy surfaces; and place names (from the historical Siegfried maps and modern topographic maps) which can indicate the location of previous wetlands or peatlands, traces of which have otherwise disappeared.

2.2.2. Ground-Truthing

In addition to the checking of data sets as described in the previous section, two data sets were ground-truthed: forest habitat maps (three habitat units) and the fen inventories (one vegetation type). These were chosen using the following criteria: Firstly, the ground-truthing had to be deemed necessary, i.e. data sets were chosen for which it was unclear whether or not mapping units were indicative of organic soil. Secondly, the data set had to have standard mapping units across the country. This criterion ruled out the GeoCover data set.

2.2.2.1. Forest Habitat Maps (“Waldstandortkarten” or “cartes des stations forestières”)

Three forest habitat types (Föhren-Birkenbruchwald / forêt marécageuse à Bouleau pubescent, E & K unit 45; Typischer Torfmoos-Fichtenwald / Pessière à Sphaignes typique, E & K unit 56; Torfmoos-Bergföhrenwald / Pineraie de montagne à Sphaignes, E & K unit 71) were selected for ground-truthing. The use of E & K units 56 and 71 as indicators of organic soil was tested by Rihm (2011), by comparing their distribution with that of raised bogs of national importance; although the potential usefulness of these two vegetation units was mentioned, the habitat maps were not included in subsequent GHGIs. For several reasons however, it was decided to reassess the usefulness of the forest habitat maps as an indicator of organic soils: Firstly, the raised bog inventory did not cover all wooded bogs, especially those without a treeless centre, meaning this inventory is insufficient to test the usefulness of the forest habitat maps. Secondly, comparison of the species lists of the E & K vegetation units with those of the raised bog inventory indicates that E & K units 56 and 71 are very similar to two vegetation units of the raised bog inventory (Birken- und Fichtenmoore / boulaie et pessière de tourbière and Bergföhrenhochmoor / pinède de tourbière). Thirdly, it is quite possible that a forest growing over peat might not be a treed bog (with the typical bog species) and would therefore not be included in the raised bog inventory. Many drained forests of E & K unit 45 potentially fit this category.

Ground-truthing was carried out at 18 sites across four cantons (see Figure 8): Fribourg (E & K units 45, 2 sites, 56, 3 sites, and 71, 2 sites), Lucerne (E & K units 45, 3 sites, 56, 2 sites and 71, 2 sites), St. Gallen (E & K units 56, 1 sites and 71, 2 sites) and Zurich (E & K unit 45, 1 site). The sites were chosen to represent a variety of elevations and the geographical range of the sites. Sites for which we have evidence that peat had been extracted were not selected. At each site, three 1 m soil cores were extracted using an Eijkelkamp peat sampler with a 6 cm gouge, sampling 50 cm deep at a time. Samples were stored in airtight conditions at 4°C until processing, where they were cut into 10 cm intervals for analysis. For many samples the amount of material extracted in the upper 10 cm was insufficient for analysis therefore the upper 10 cm were additionally sampled using a 10 cm shallow-soil auger (gouge diameter 4.5 cm) adjacent to the main soil probe. Field work was carried out between March and May 2013. The fieldwork and the analysis of C content were carried out as part of a Master's thesis (Mössinger, 2013). The C content was measured from soil probes from 17 of the 18 sites by elemental analysis.

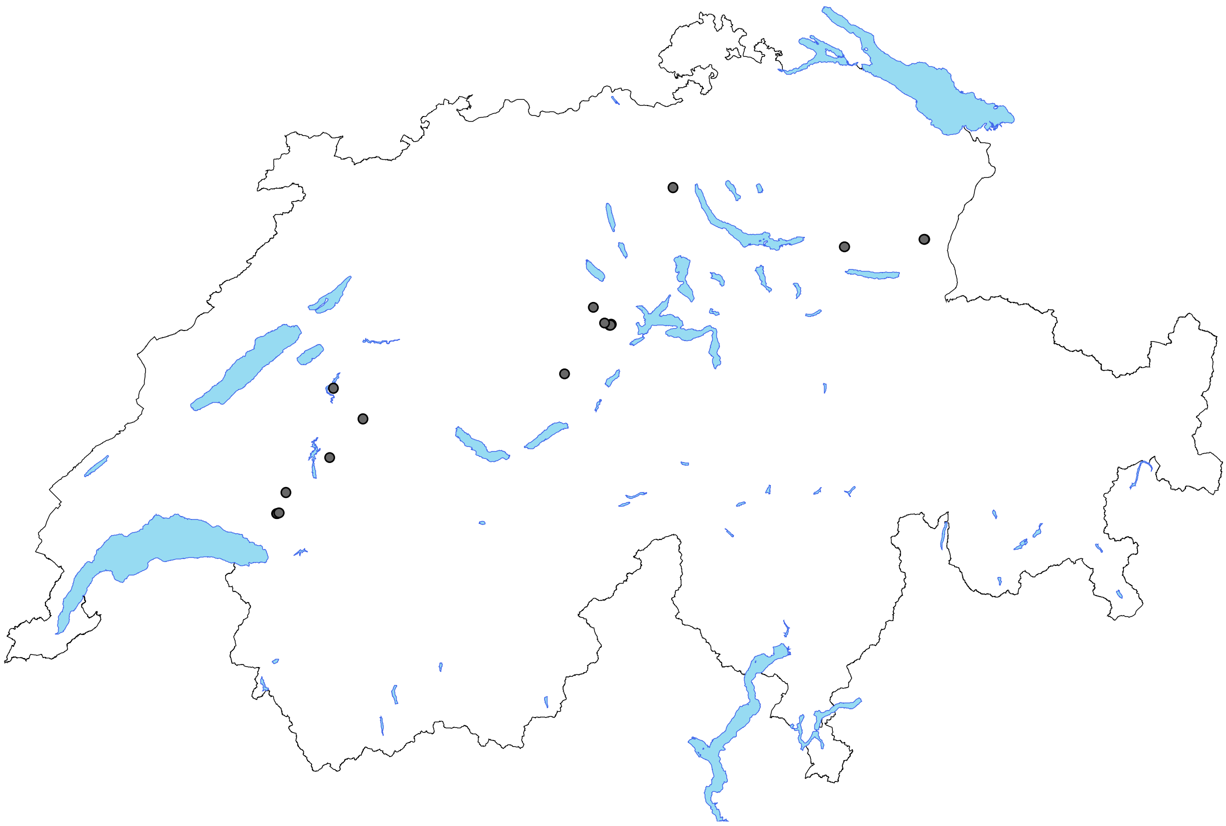


Figure 8: Locations of the sites sampled in ground-truthing of the forest habitat maps (not all 18 sites can be distinguished as points representing closely-occurring sites overlap); lake and canton boundaries © Swisstopo

Results All probes from 17 sites met the requirements of organic soil (IPCC, 2006) and the organic C content for the majority of the soil samples was between 40 % and 55 % (Mössinger, 2013). For one site (the 18th site whose probes were not analysed, a Torfmoos-Bergföhrenwald in FR), a peat layer thick enough to be considered organic soil could only be found in the centre of the site; this site is however very small (~80 m x ~30 m). Based on the results, the three forest habitat types tested were considered to be reliable indicators of organic soil, and surfaces corresponding to these habitat types were extracted and used in this project as described in 2.1.1.3.

2.2.2.2. Fen Inventory

The Caricion fuscae vegetation type (Kalkarmes Kleinseggenried or Parvocariçaie acidophile) was selected for ground-truthing. This vegetation type is the second most abundant fen vegetation type in Switzerland expected to be peat-building (Klaus, 2007; Delarze & Gonseth, 2008).

Ground-truthing was carried out at 11 sites in two regions (Figure 9): Seven sites in the Alpthal and Sihltal areas of SZ; secondly in the Glaubenberg area of OW (2 sites) and LU (2 sites). The sites were chosen to represent the variety of elevations across which this fen type tends to be found and included compartments with a minimum of 80 % (10 sites) or 70% (1 site) coverage of Caricion fuscae. At each site, four to six 1 m soil cores were taken from a single fen compartment (four cores taken from 9 sites, five and six cores taken from 1 site each). Soil cores were taken using utility borers. The micro-topography and vegetation tended to be very variable within each site; the soil cores were therefore taken across each site to attempt to sample this local heterogeneity. Field work was carried out in July 2013. Soil cores were analysed from 10 of the sites, for organic C content, using the same methodology as that used for the ground-truthing of forest habitat maps (c.f. Mössinger, 2013). At an eleventh site, one of the LU sites, cores were taken but not collected (and hence not analysed); at this site, a mosaic of fen and raised bog vegetation, >1 m of peat was found in each of these four soil cores.

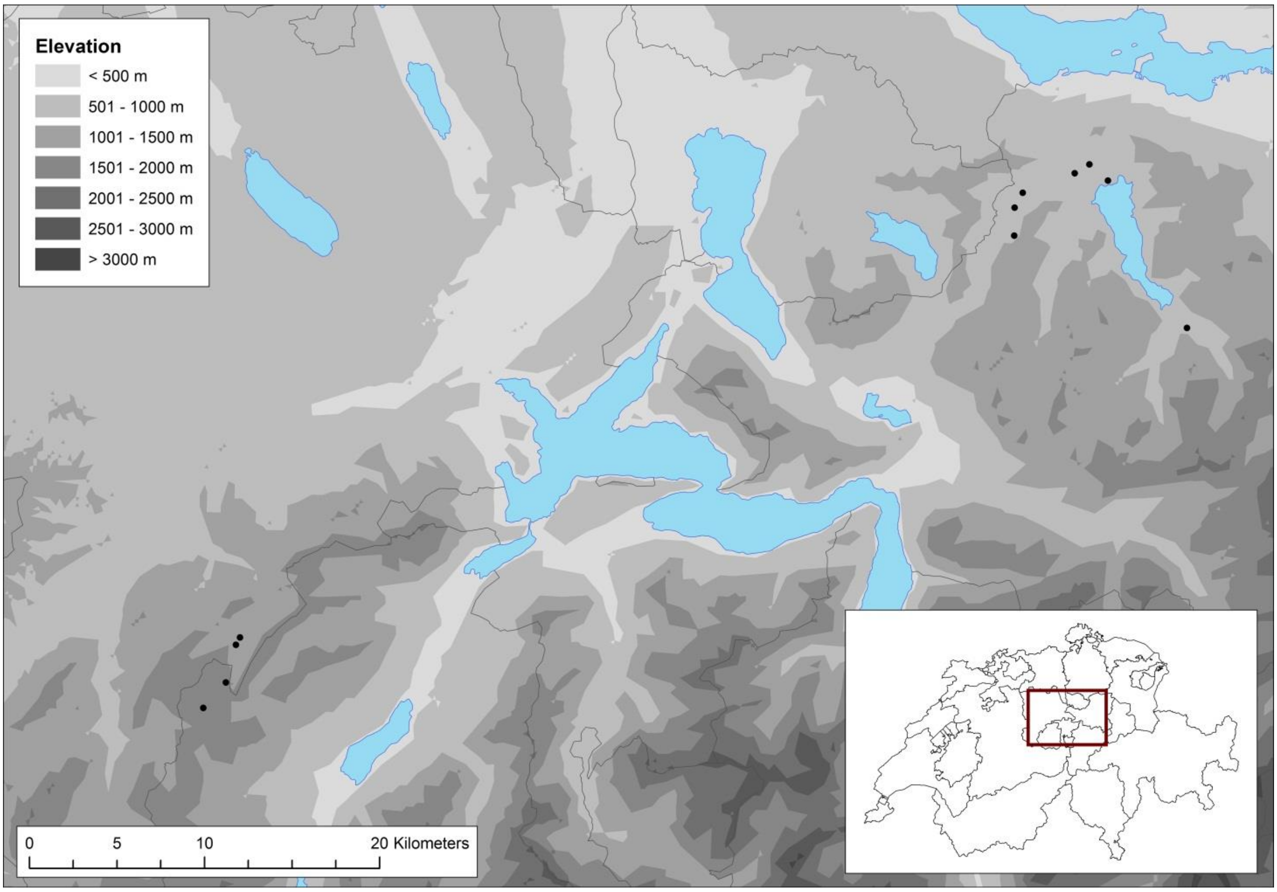


Figure 9: Locations of the sites sampled in ground-truthing Caricion fuscae fens; lake, national and canton boundaries © Swisstopo; elevation derived from data from Swisstopo

Results For eight of the eleven sites, more than half of the soil cores met the IPCC criteria of organic soil (Figure 10) and for three of these, all of the cores did. The heterogeneity of soil C amount (both between and within sites) supports the idea proposed by Leupi (1994) and Broggi (1994b) that for fens, vegetation alone cannot necessarily be used to predict the occurrence of organic soil. The sample sites were distributed between two regions: half of them were in a relatively flat, low-lying area (the north-easterly sites, in canton SZ) and half were in a region that is topographically more heterogeneous and at higher-elevation (the south-westerly sites, in cantons OW / LU). The occurrence of organic soil was however mixed with respect to these differences, i.e. cores containing organic soil were taken from sites located in both regions; regional topography therefore does not seem to improve predictability.

It was however decided to include Caricion fuscae fens in this project, as described in section 2.1.1.2. Although not all sites contained organic soils, the majority of cores in the majority of sites did. Including this data set probably causes a small over-estimation in the organic soil surface, but omitting this fen vegetation type would have caused a larger under-estimation of organic soil.

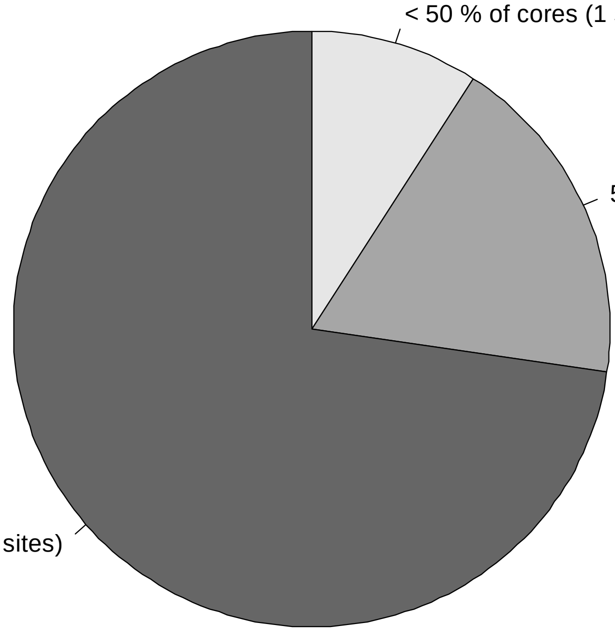


Figure 10: Results of the ground-truthing of the Caricion fuscae fens, showing the proportion of soil cores at each of the sites that are organic soil; four to five cores were taken from each site; total number of sites = 11

2.3. Documenting the Properties of the Data Sets in the GIS Database

Each information sources listed in section 2.1 that was deemed suitable for this project needed to be assessed for its quality in terms of (i) spatial accuracy and precision; and (ii) its reliability in informing us whether or not there was peat at the site (at the time that the dataset was compiled). One challenge of working with so many data sets is that the information gathered when all data sets are brought together might easily become too much and thus unwieldy. For this reason, a reductionist approach was taken, namely the scoring of each surface of each data set, according to the two criteria listed above. These 'quality categories' are described in sections 2.3.1 to 2.3.3, below. Data sets were additionally classified as 'historical' or 'modern', described in section 2.3.4. All scores were incorporated into the attribute table of each GIS dataset meaning that this information was carried through to the 'combined dataset' following the combination of the individual data sets (section 2.4.2.3).

Additional information captured in the attribute table of each spatial data set included: the author and date of publication, date of survey (given as a range, if necessary) and the name of the data set. Where surveying date could not be obtained, the publication date of the map or accompanying report was used. A complete list of information recorded for each data set is given in appendix II.

2.3.1. Spatial Quality (of Extent) of Surfaces

Each surface of each data set was scored for its spatial accuracy, following the criteria shown in Table 6. Additionally, the scale of the map was recorded in the GIS attribute table of each data set.

Table 6: Categories of the spatial quality of data sets represented by surfaces

Category	Description
W	Very good. If: (1) peatlands outlined or symbology detailed enough to infer outline; and (2) surveying targeted towards vegetation / soils; and (3) no apparent survey error
X	Good. If: (1) no apparent survey error; but: (2) mapping was not targeted towards vegetation / soils; or/and (3) outline of peatlands unclear (e.g. symbols on symbology are too far apart)
Y	Poor. If: (1) apparent survey error; or (2) problems apparent in the geo-referencing of the analogue map

2.3.2. Spatial Quality (of Location) of Points

This score is relevant for non-spatial data, i.e. texts, that were geo-referenced as part of this project. Each point of each data set was scored for its spatial accuracy and precision, following the criteria shown in Table 7.

Table 7: Categories of the spatial quality of data sets represented by points

Category	Description
W	Very good. (1) Certain that the object described is here; and (2) location is precise (< 100 m)
X	Good. (1) Certain that the object described is here; and (2) location is less precise (100 m-200 m)
Y	Moderate. (1) Certain that the object described is here; and (2) location is based on the place name (Flurname / toponyme) only; or (3) location is less precise than 200 m
Z	Poor. (1) Location less precise than 200 m; or (2) potentially inaccurate

2.3.3. Quality of Attribute Information

Each surface or point of each data set was scored for whether or not it contains peat (yes, no, maybe). This score was supplemented by a score indicating the reliability of this information (Table 8), as follows: Surfaces or points scored an ‘A’ where there was evidence of peat and where the mapping unit or description unambiguously described peat. In contrast, surfaces derived from mapping units where peaty and non-peaty surfaces could not be differentiated (e.g. “Torf oder Sumpf”, peat or wetland / tourbe ou marais) scored a “C”. Certain legend items scored a “B”, a score that was introduced to deal with data sets or mapping units where peat was inferred, but where its presence was unclear. The most important data sets that scored a “B” were the Caricion fuscae vegetation type (because field work suggested that the presence of organic soil is not ubiquitous), and the GeoCover data set (because these maps possibly over-estimate peatlands). A description of how surfaces were scored for each data set is given in section 2.1 and a summary is given in Table 9. Both modern and historical information sources were scored as shown in Table 8; for historical sources this ‘evidence of peat’ refers to the evidence that peat was present at the time of surveying. Surfaces derived from historical information sources were however re-scored and dealt with as described in section 2.4.2.2.

Table 8: Categories of the attribute quality of data sets, indicating certainty that there is peat at a site (at the time of survey)

Category	Description
A	Conclusive. (1) There is direct mention or evidence of peat or of a vegetation type that is a reliable indicator of peaty soil; e.g. raised bog vegetation, soil type “Moor”, “Torfland” signature in a Siegfried map
B	There is probably peat. (1) There is inference of peat but no direct mention of it; or (2) the vegetation type is a less reliable indicator of peat soil; e.g. Caricion fuscae vegetation
C	Inconclusive. It is unable to differentiate between peat / not peat from this information source; e.g. wetland signature on a map, base-rich Davall sedge fen

Table 9: Summary of the attribute quality score assigned to surfaces and points of the individual data sets; for details see main text (this section) and descriptions of individual data sets

Data set and category	Score
Soil maps (2.1.1.1)	
Halbmoor	A
Moor	A
Complex with Moor / Halbmoor as dominant soil type	B
H / M covered by alluvial material	B
Peat as parent material	B
Inventories of raised- and transitional bogs, and fens, other vegetation or habitat maps (2.1.1.2 and 2.1.1.3)	
Raised bog vegetation	A
Transitional bog vegetation	A
Naked peat surface	A
Fen vegetation dominated by base-rich Davall sedge fen	C
Fen vegetation dominated by Caricion fuscae	B
Fen vegetation dominated by Magnocaricion	C
Fen vegetation dominated by Phragmition	C
Fen vegetation dominated by Molinion	C
Vegetation or crops specified as growing over peat	A
Forest habitat maps (2.1.1.3)	
Föhren-Birkenbruchwald (E & K unit 45)	A
Typischer Torfmoos-Fichtenwald (E & K unit 56)	A
Torfmoos-Bergföhrenwald (E & K unit 71)	A
Geological maps (2.1.1.4)	
(exclusively) Peaty surfaces	B
Mention of peaty and non-peaty surfaces	C
Surfaces with a superficial peat layer	C
Predominantly loam to fine sand, often with organic remains	C

Hydrogeology maps (2.1.1.4)	
Surfaces with a peaty cover layer	B
Historical topographical maps (2.1.1.5)	
Peatlands	A
Wetlands	C
Vector25 (2.1.1.6)	
Wetlands	C
Peat extraction maps (2.1.1.6)	
Surfaces from which peat was extracted	A
Expert Observations and Descriptions of Fens and Bogs (2.1.2.1)	
Raised and transitional bogs	A
Fens or used surfaces occurring over peat	A
Drained mires (often used for peat extraction)	A
Sites suitable for peat extraction (2.1.2.2)	
Sites suitable for peat extraction	A

2.3.4. Age of Data Set

Historical ("H") and modern ("M") data sources were considered differently for the evaluation of how likely there (still) is organic soil at a site (see section 2.4.2). Data sets stemming from surveys carried out before or during 1945 were considered historical and those surveyed after 1945, modern (if the survey date was not available, the publishing date was used). Although the cut-off date, 1945, is 70 years prior, it corresponds to the end of one of the major periods of soil drainage and melioration (Maurer, 1985; Mühlethaler, 1995; Seitz, 2013, pg. 42), and it is therefore assumed that mires that had until this point in time not been destroyed, are likely to have survived either as wetlands or, if they were destroyed, as peatlands. However, it must be borne in mind that drainage activity of a considerable surface area continued after this time with continued subsidies (Béguin & Smola, 2010), that private drainage projects – not accounted for in many official calculations – occurred (Béguin & Smola, 2010) and still continue, and that effects of drainage tend to persist decades after the drainage system is laid. The assumption that all sites described as peatlands since 1945 still are peatlands, is therefore not completely correct; however, given the survey dates of data sets available to us, it is probably the optimal date to use. Table 10 shows which data sets were considered modern and which were considered historical.

Table 10: Summary showing which data sets were considered modern or historical

Data set	Date(s) of survey start, or publication if unknown	Considered historical or modern
Soil maps	Various, those post 1971	Modern
Soil maps	Lüdi, 1935 and König and Rufer, 1920	Historical
Inventories (fens of national and regional importance, raised and transitional bogs of national importance, canton nature inventories)	Various, post 1978	Modern
Forest habitat maps	Various, most post 1990, one beginning 1951	Modern
Vegetation map: Carte de la végétation du Pays-d'Enhaut et de La Place de Tir du Petit-Hongrin	1981	Modern
Vegetation map: Upper Engadine vegetation map	2007	Modern
All other vegetation maps	1880 to 1932	Historical
Geological maps (GeoCover)	Various	All those published before and in 1945 = historical; those published post-1945 = modern
Hydrogeological maps	Various, all post 1991	Modern
Historical topographical maps	Various, 1700s to ~1910	Historical
Modern topographical maps	2008-2014	Modern
Maps showing peat extraction (from Probst et al. 1923)	1916 and 1918	Historical
Descriptions from Lüdi (1973)	1943-1951	Historical
Descriptions from Früh and Schröter (1904)	1881-1903	Historical
Descriptions from Grossenbacher (1980)	1974-1976 and earlier	Historical* and modern
Descriptions from Gerber (1925)	1925	Historical

* = In spite of the recent date of this publication, descriptions of most of the sites used in this report are either based upon old descriptions (mostly late 19^{th} and early 20^{th} centuries) and / or describe sites that were at the time already destroyed.

2.4. Bringing Together the Information

2.4.1. Background

The outcome of the project is a digital map (and associated geodatabase) showing the surfaces of organic soil in Switzerland, including an indication of strength of evidence for how certain it is that each surface contains organic soil. Two different types of data were dealt with: Surface data (polygons), indicating organic or mineral soil, and historical descriptions containing a variety of information, which were georeferenced as points. These data types were brought together to create the map displaying surfaces of organic soils.

2.4.2. Combining the Datasets

2.4.2.1. Approach

The flowchart in Figure 11 outlines the steps taken in combining the information sources to produce the map of the distribution of the estimates of organic soils. An overview of the process is given below and details are given in the remainder of this section.

The data sets were digitised, and surfaces representing organic soil or mineral soil were extracted. Generally speaking, each data set or 'theme' (e.g., vegetation maps) was represented by one layer, as long as no overlapping polygons occurred within a given layer. Each polygon of each layer was assigned information regarding survey date, and spatial and attribute quality (section 2.3 and appendix II). Information from texts (mostly historical texts) was initially digitised as points. For each site identified, this attribute information was subsequently attached to a polygon representing that site (section 2.4.2.2).

Using a GIS (ArcGIS, ESRI Inc. 1999-2013), these layers were then combined (in this first step, only layers concerning *organic* soil were combined). The information associated with the layers regarding survey date, spatial quality and quality of attribute information was also combined, meaning that a polygon represented by, for example, three data sets, would now have three sets of information (section 2.4.2.3). This combination of information was then used to assign each of the polygons to a category using a set of rules (section 2.4.2.4). Implicit in this set of rules is that once the presence of organic soil at a site is indicated, the more data sets associated with a site, the better the score that site obtains. This assumes that the presence of peat or peat-building vegetation at a site was determined *for each data set*; this is not to say that the data sets need to be independent – surveyors will almost certainly have consulted existing records or maps of a region whilst compiling a map or description – rather, for each survey or map, independent observations of the vegetation or soil were made.

In a subsequent step, information regarding the occurrence of mineral soil was also incorporated (section 2.4.2.5). Polygons representing mineral soil were overlaid with those representing organic soil. Where apparent conflict occurred, the spatial quality and the survey dates of mineral and organic data sets were compared. A decision matrix was used to decide whether to consider surfaces organic or mineral based on these characteristics. In a final step, sites that have only recently become wetlands were checked (section 2.5).

The system used to create this map is a modular system, significant parts of which were automated as a series of model tools in ArcGIS (see appendix III). These two aspects – its modular nature and the fact that it is partially automated – mean that a user with access to the component data sets can easily re-create the map, either to suit his / her own needs, or to improve accuracy. There are three main ways in which this could be done: Firstly, changes could be made to the 'scores' assigned to each polygon of each data set regarding the certainty of peat at a site (the [A], [B], [C] scores), and the map re-calculated. This would be sensible to do should more information about a data set come to light (e.g. information regarding conditions under which fen vegetation tends to build peat). Secondly, the rules given in Table 12 representing 'certainty that each site actually contains organic soil', could be altered, and the map re-calculated. This would be necessary if, for example, a map showing old mires were required. Thirdly, the map could be re-calculated if new information sources were incorporated; a list of possibly useful additional data sets is given in section 5.1.

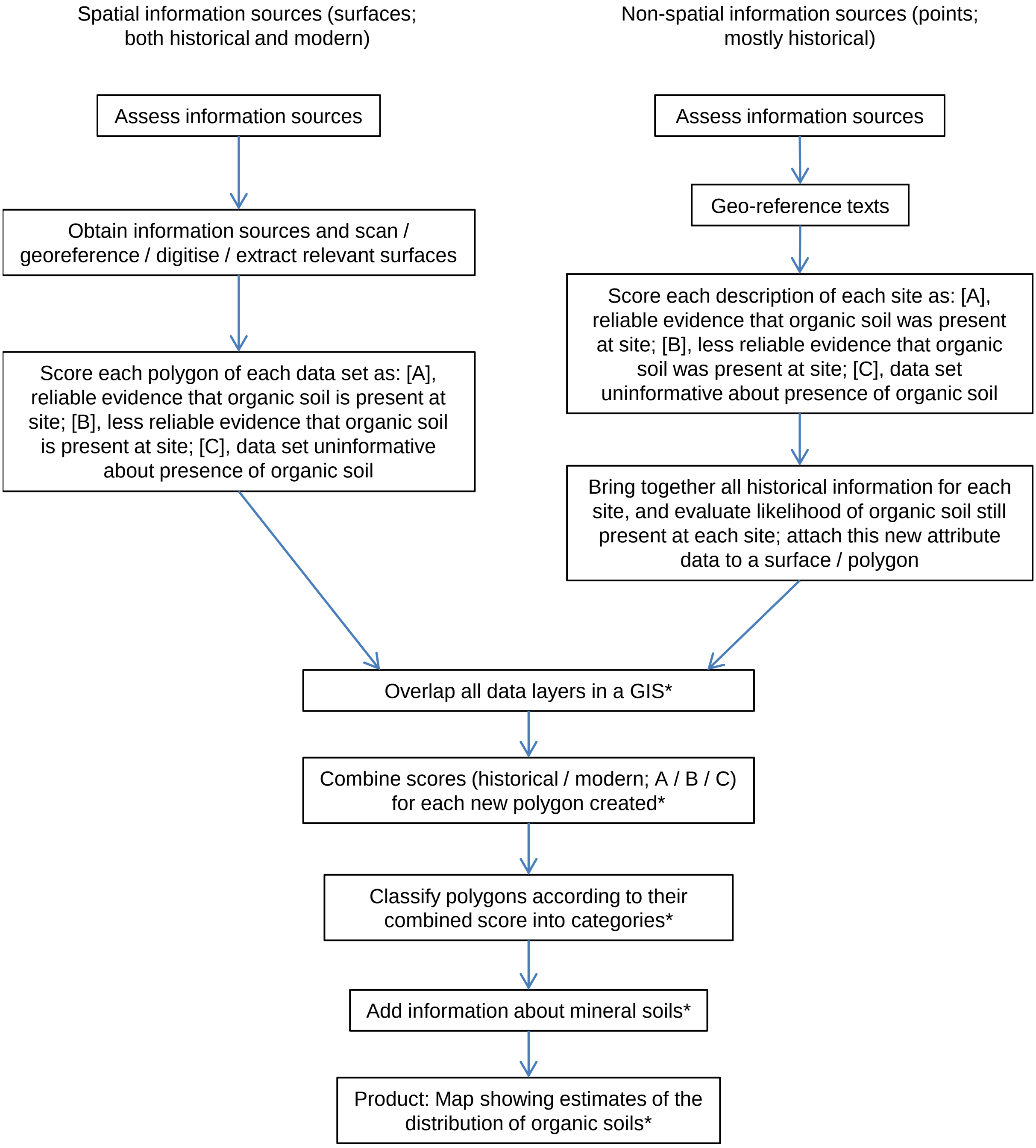


*Figure 11: Flow chart outlining workflow steps for construction of the map; * = steps of the workflow that are incorporated into model tools in ArcGIS (appendix III)*

2.4.2.2. Interpreting Non-Spatial and Historical Information

Information contained in old text documents is important to capture; it is however difficult to work with, in the context of this project, for two reasons: Firstly, locations described in texts tend to be easier to geo-reference as points initially rather than as surfaces, although other data sets used in this project were represented as surfaces. The second more important reason relates to the age of the information. Drainage and peat extraction in Switzerland were intense up to the middle of the 20th century, reaching their peak around the Second World War (Maurer, 1985; Mühlethaler, 1995; Seitz, 2013). This means that sites described over 100 years ago are more likely to have since been destroyed than sites described in the latter half of the 20th century. This effect is compounded by the fact that peat is not a stable C store in a site that is drained: As described in section 1.1, if a mire is destroyed (e.g. drained), the site will only remain a peatland for a limited period of time. A peatland described 100 years ago that has been destroyed might therefore not contain enough organic C to be considered organic soil today. This problem is not restricted to very old descriptions, as sites drained in the 1980s, for example, are also continuously losing organic C. It is however a more serious problem for these older sites, partly because they are more likely to have been destroyed since they were described, and partly because more time has passed since they were destroyed. These issues are amplified by the fact that the majority of peatlands described in these old texts were *already* being intensively used for agriculture and / or peat extraction at the time that they were described; these are exactly those sites most likely to have been transformed into mineral soil.

The two issues outlined in the previous paragraph were dealt with as follows. Individual sites that were described by old non-spatial descriptions (i.e. texts) were assessed by combining all of the information from historical sources for a given site. These include peat extraction records from Probst *et al*. (1923), observations by Früh and Schröter (1904), Lüdi (1973a-j, surveying from 1943-1951), Grossenbacher (1980) and Gerber (1925). With this information, it was attempted to re-construct the history of each site, to estimate whether or not organic soil is likely to still be present. This was possible because many sites were described more than once. Information regarding estimated date of drainage or change to agricultural land, as well as peat extraction was considered. This reconstruction of a site's history was formalised by the application a set of rules (Table 11), which result in the re-scoring of a *site* as historical or modern and as [A], [B] or [C]. These rules incorporate three aspects: firstly, the mention of peat; secondly, the likelihood – based on the thickness of peat and the date of drainage – that there is enough peat remaining at the site that it could be classed as organic soil today, assuming a rate of loss of soil thickness of 1 cm per year (Hoins *et al.*, 1996; 5-30 mm / year, Kasimir-Klemedtsson *et al.*, 1997; 5-16 mm / year, Lienert, 2013; 0->30 mm / year, Weinzierl & Waldmann, in prep.); and thirdly, the mention of peat extraction. For example, a site with noted as having >2 m of peat in the early 1900's, which was drained in 1935, and for which there is no evidence of peat extraction, is likely to still contain organic soil today – such sites were scored as "modern [B]". Peat extraction plays such an important role because it is possible that extraction removed the entire peat layer.

Table 11: Re-scoring of sites using information from historical texts; section 2.3.3 describes the meaning of the [A], [B] and [C] scores

Criteria	Re-scoring of site
Mention of "Sumpf" or "Flachmoor" only	Historical, [C]
Mention of "Torf" or "Hochmoor" only	Historical, [A]
Mention of a peatland (i.e. "Torf" or "Hochmoor") without mention of thickness of the peat layer; *or* there is mention of peat layer thickness but it is probably too little for it to be considered organic soil today	Historical, [A]
Mention of a peatland from which there has been peat extraction	Historical, [A]
Mention of a peatland and the thickness of the peat layer; thickness of its peat is great enough that it is still possible that there could be organic soil there today (assuming loss of 1 cm / year); since the description of peat thickness, no evidence of peat extraction	Modern, [B]

In order to incorporate this derived attribute information into the final map, a surface (polygon) needed to be defined for each site. To do this, a wetland surface that closely matched each site being described was sought in the first (~1880) and subsequent (~1910) editions of the Siegfried maps. Where no suitable surface could be found (for ca. a quarter of the cases), surfaces were sought from the Vector25 data set (wetlands), or from one of the federal inventories. Surfaces from the Siegfried maps were preferred because their publication date most closely matches those of the historical texts. The derived attribute information (Table 11) was then applied to these surfaces.

A new data layer was thus created, containing surfaces whose scores were derived attribute information from a variety of historical texts.

2.4.2.3. Combining Spatial and Attribute Information

The data layers indicative of organic soil were combined in a GIS using the “union” geoprocessing tool. Where polygons from different data layers overlap, the union tool creates new polygons including the attribute information from all component layers. Attribute fields retained in the union output from the individual data layers included: “ShortName”, the dates of publication and surveying, “is peat” (= whether or not peat or organic soil is present at a site), “is peat Q” (= the quality of the information concerning the present of peat or organic soil, on a 3-point scale, A, B, C), “spatial Q” (= the spatial quality of the digital data set, on a 3- or 4-point scale, W, X, Y (Z)) and “Age” (= whether an information source was considered as historical or modern); for details of these attributes, see section 2.3. The outcome of this step was a new feature class containing ca. 103,000 polygons, each polygon represented by between one and eight data layers. Each new polygon was then classified, as described in the following step.

2.4.2.4. Rules for Classifying Polygons

Polygons were classified initially using the evidence regarding organic soil only; evidence of mineral soil was considered in a following step (section 2.4.2.5).

Polygons were classified into eight classes (I to VIII) based upon the attribute information of the information sources representing each polygon (Table 12). Class I contains surfaces for which we have the strongest evidence that there is organic soil; classes II, III and IV contain surfaces with intermediate support for organic soil at a site. Class V contains surfaces for which we have the weakest modern evidence that there is organic soil at a site, but nonetheless modern evidence. More specifically, class V surfaces are represented by single modern ‘B’ data sets and class IV surfaces are represented by one ‘B’ data set alongside additional evidence of peat. Class III contains surfaces represented by one ‘A’ data set and classes II and I contain surfaces represented by one ‘A’ data set and other data sets in addition. The method thus assigns surfaces that are represented by many data sets to a lower (i.e. more certain) category than those represented by few or single data sets.

Classes VI and VII contain surfaces for which there is evidence that they once contained peat but for which we have no modern evidence. Class VI contains surfaces which are, in addition to having once been peatlands, modern-day wetlands. Based on available data we cannot know whether sites in classes VI and VII are organic or mineral soil: They could be either i) organic soil sites in regions not covered by modern data sets; ii) sites that were originally organic soil, but from which all peat was removed through extraction; or iii) sites that were originally organic soil, but which have lost so much organic C over time through oxidation that they no longer can be considered as such. Class VIII comprises sites possibly containing organic soil, but for which we cannot be certain given the available data sets.

The recommendation of which classes should be considered for the GHGI is given in section 2.6.

Table 12: Classification of polygons (classes I to VIII) according to the concatenated scores of their component data sets

	Must contain a minimum of:	**May contain the following additional information (info) sources:**	**May *not* contain these sources in addition (could move the polygon to another class):**
VIII	One historical or modern "C" info source	Additional "C" info sources	Any "A" or "B" info sources
VII	One historical "A" or "B" info source	Additional historical info sources	Any modern info sources
VI	One historical "A" or "B" info source *and* a modern "C" info source	Additional historical info sources *or* additional modern "C" info sources	Any modern "A" or "B" info sources
V	One modern "B" info source	Historical or modern "C" info sources	Any historical "A" or "B" info sources *or* modern "A" info sources *or* additional modern "B" info sources
IV	Two or more modern "B" info sources *or*	Any historical info sources or modern "C" info sources	Any modern "A" info sources
	One modern "B" info source *and* one or more historical "A" or "B" info sources	Any additional historical info sources *or* modern "C" info sources	Any modern "A" info sources
III	One modern "A" info source	Historical or modern "C" info sources	Any historical "A" or "B" info sources *or* modern "B" info sources *or* additional modern "A" info sources
II	One modern "A" info source *and* one historical "A" info source *or*	Modern or historical "C" info sources *or* historical "B" info sources	Additional modern or historical "A" info sources *or* any modern "B" info sources
	One modern "A" info source *and* one modern "B" info source *or*	Modern or historical "C" info sources *or* historical "B" sources	Additional modern "A" or "B" info sources or a historical "A" source
	One modern "A" info source *and* one historical "B" info source	Modern or historical "C" info sources *or* additional historical "B" info sources	Additional modern "A" info sources *or* historical "A" info sources *or* modern "B" info sources
I	Two modern "A" info sources *or*	Any	-
	One modern "A" info source *and* at least two modern "B" info sources *or*	Any	-
	One modern "A" info source *and* at least two historical "A" info sources *or*	Any	-
	One modern "A" info source *and* one historical "A" info source *and* a modern "B" info source	Any	-

2.4.2.5. Adding Information about Mineral Soils

In a subsequent step, the data layers indicative of mineral soil were combined with the initial map of organic soils using the union geoprocessing tool. The same attribute fields were retained as in section 2.4.2.3. The outcome was a map comprising ~130,000 polygons which were processed in two steps, as follows.

Polygons represented by organic data sets *only* (i.e. not overlapping with mineral data sets), remained as before. Polygons represented by mineral data sets *only* were removed; these are of no interest for the final map. Polygons in classes V, VI, VII or VIII overlapping with one or more mineral data set(s), were assigned 'mineral'; the evidence that these polygons represent organic soil is either moderate to weak, or even non-existent. Polygons in classes I, II, III or IV and that overlapped with one or more mineral data sets were considered 'potentially conflicting'; the evidence that these polygons represent organic soil is strong, yet there is conflicting evidence from the mineral data sets.

In a second step, polygons that had been marked 'potentially conflicting' were dealt with. There are several reasons why a polygon might be represented by apparently conflicting data sets. The first is that one of the data sets might be more imprecise than the other, or be of poorer spatial quality, so that a surface is incorrectly indicated as organic or as mineral. The second possibility is related to the disappearance of organic soil at a site over time; if the data set indicative of mineral soil is more recent than that indicative of organic soil it is quite possible that both information sources are correct: the soil might once have been organic but through C-loss over time, for example through drainage, it has been transformed into a mineral soil. The third possibility is that the data sets truly disagree with each other. The fourth possibility is that a site might have only recently accrued its peat-building vegetation, meaning that the use of vegetation maps to indicate organic soil was for this site, incorrect; such sites were dealt with as described in section 2.5.

The first three reasons for conflict were dealt with by classifying all potentially conflicting polygons according to the spatial quality and survey date of their component data sets. For this, only those modern data sets indicative of peat (i.e. scoring an A or a B) were considered. Table 13 shows these 'rules' used to classify polygons. If the organic data set(s) representing a polygon had better spatial quality than the data set(s) representing mineral soil, the polygon was classified as organic, and *vice versa*. An exception to this was a polygon whose organic data sets had better spatial quality than the mineral data sets, but for which the mineral data set(s) was / were more recent than the organic one(s). It is unclear how to deal with such polygons and they were scored as "conflicting"[6]. Where spatial quality was equal, surveying dates of the organic and mineral data sets were compared. Where the data set(s) representing mineral soil had been surveyed more recently than those representing organic soil, the polygon was classified as mineral soil. Where the surveying dates of the mineral data sets were the same as, or earlier than those of the organic data sets (including cases where the surveying periods overlapped), polygons were considered to be truly conflicting[7]; conflicting surfaces were not considered in the final estimates of organic soil but were considered in the uncertainty analysis of the recommended estimate of organic soil (section 4.5.6).

[6] < 1 ha of surface falls into this category.
[7] < 1 % of the recommended estimate of organic soils falls into this category.

Table 13: Rules used to assign potentially conflicting polygons that are represented by data sets indicative of organic soil (class I,II,III and IV) and of mineral soil

		Spatial quality (SQ)		
		Organic SQ is better than mineral SQ	Organic SQ is equal to mineral SQ	Organic SQ is worse than mineral SQ
Age of data sets	Mineral data sets older than organic data sets	No real conflict, → **organic**	?→ **conflict**	No real conflict, → **mineral**
	Organic and mineral data sets are of same age	No real conflict, → **organic**	? → **conflict**	No real conflict, → **mineral**
	Organic data sets older than mineral data sets	Unclear, either mineral soil or conflicting data → **conflict**	No real conflict, → **mineral**	No real conflict, → **mineral**

2.5. Removing Sites that have Recently become Wetlands

Many of the organic soil surfaces identified in this project are based on vegetation data. One assumption of using such information to infer organic soil is that the vegetation has been present at the site long enough for a thick enough layer of peat to accumulate that it can be considered organic soil. Given that Switzerland's landscape history is one of drainage and thus drying out, rather than of (re-)wetting, this is a reasonable assumption to make. There is however another situation in which new wetlands could be formed: the draining of lakes, leading to the exposure of land conducive to the formation of wetland habitat. If this drainage occurred in the last few centuries, assuming a rate of net peat accumulation rate of < 1 mm per year (calculated from Shotyk *et al.*, 1998; Shotyk, 2002), such sites would need to be removed from the map.

Regions where this might have occurred were identified by comparing lake extents in the first edition of the Siegfried map (ca. 1880) with those in current topographical maps. Three relevant regions were identified: the three Jura lakes (lakes Bienne, Neuchâtel and Murten, BE, FR, NE and VD, whose water levels were lowered as part of the Jura water corrections during 1866-1878 and 1962-1973, Vischer, 2003), lake Pfäffikon (ZH) and lake Greifen (ZH). Supposed organic soil surfaces that overlap areas known to have become land since 1880 due to lower water levels were identified. Within this subset of organic soil surfaces, those represented that information sources relating to vegetation *only* were searched for (i.e. surfaces represented by, for example soil maps, were not included). No such surfaces were identified: all surfaces in these previously littoral zones were represented by soil or geological maps (usually in addition to vegetation maps).

2.6. An Estimate of Organic Soils for the GHGI

For the GHGI it is recommended that surfaces in classes I to V should be considered organic soil (Figure 12). The sites in classes I to IV, a sub-set of these surfaces, represent a more conservative estimate of organic soils, an estimate for which it is more certain that the surfaces represent organic soil, but which is certainly an under-estimate. Class V contains surfaces for which there is moderately strong evidence of organic soil (2.4.2.4 and Table 12), including most importantly those identified in GeoCover and as Caricion fuscae fen vegetation. The comparison of GeoCover with other data sets (section 2.1.1.4) and ground-truthing of Caricion fuscae (section 2.2.2.2) both indicate that not including these data sets in the recommended estimate of organic soils would lead to a larger under-estimate of organic soil than an over-estimate resulting from their inclusion. Surfaces in classes I to V therefore form the recommended estimate of organic soils. Uncertainty surrounding this estimate is discussed in section 4.5.6. Surfaces in classes VI, VII and VIII should *not* be considered as organic soil. These three classes are considered as part of the uncertainty analysis (section 2.7). In addition, classes VI and VII are included as interesting sites for further work (section 5).

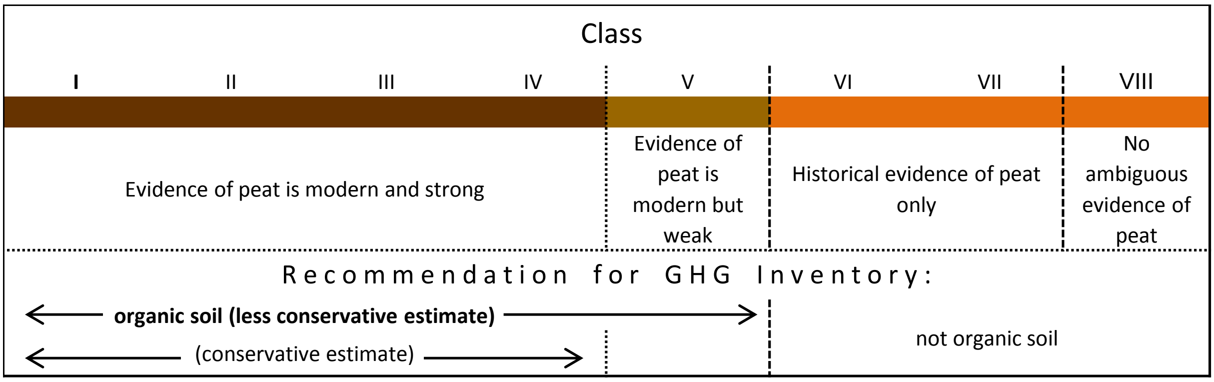


Figure 12: The eight classes into which surfaces were classified and their recommended treatment for the GHGI

2.7. Estimating Uncertainty due to Missing Data

Six cantons were identified for which the data coverage identified for this project is particularly poor (section 4.4): Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri. Two additional cantons, Bern and Schwyz were considered as they have incomplete forest habitat maps and otherwise only moderate data coverage. To estimate the uncertainty due to poor data coverage in these eight cantons, two approaches were used.

The first approach estimates the amount of organic soil missing from the recommended estimate of organic soils due to incomplete forest habitat maps. This method was applied to the cantons Bern, Schwyz and Uri, as they have incomplete forest habitat maps.The amount of organic soil that forest habitat maps contribute to in neighbouring regions with similar climate was calculated. This value (a percentage) was applied to these three cantons, to obtain a percentage increase in the organic soil estimate that would be expected, were forest habitat maps complete. This is decribed in more detail as follows.

The climate regions (Klimaregionen / régions climatiques) from the Federal Office of Meterology and Climatology, Meteoswiss (Schüepp & Gensler, 1980) were used to partition the country into different climate regions; the country was additionally partitioned by canton. Only the climate regions covering Bern, Uri and Schwyz were considered. For each canton section in each climate region, the amount of organic soil with and without information from the forest habitat maps was calculated, following the general methodology used in this project (section 2.4.2). The extra amount of organic soil represented by the forest habitat maps was calculated as a percentage increase, for each canton section occurring in each climate region. The mean percentage increase across all canton sections in a given climate region was calculated (not including that from Bern, Uri or Schwyz) and this percentage increase was then applied to the amount of organic soil calculated – *excluding* forest habitat maps – for the canton section of interest, i.e. Bern, Schwyz or Uri. This procedure was carried out for all climate regions in which the cantons Bern, Schwyz and Uri occur. The amount of organic soil these cantons are expected to have (i.e. using the extrapolated values for these cantons) was added to the amount of organic soil calculated for all other cantons, to give a total score for the country. This method assumes that organic soil under forest forms a similar proportion of organic soil across cantons of the same climate region. This method influences the estimate of uncertainty for organic soil under forests only.

The second approach concerns the cantons Graubünden, Ticino, Uri, Glarus, Nidwalden and Obwalden. The two former cantons do not have suitable forest habitat maps, but their location and distinctive climatic characteristics precluded the use of extrapolation based on data from neighbouring cantons with similar climatic conditions as described in the previous paragraph. The latter three cantons have complete forest habitat maps. For this second (coarser) approach to estimate the amount of organic soil 'missing' due to the lack of modern data, the surfaces in these cantons for which we only have historical information regarding the presence of peat (i.e. polygons classified as classes VI or VII) were simply added to the recommended estimate of organic soil. This method covers all land use types, thus including estimates for forest land, cropland and grassland in the GHGI. It almost certainly produces an over-estimation of the recommended estimate of organic soil, because many of these sites might no longer contain organic soil. This method however offers a reasonable indication of what the upper estimate of organic soil surface area could be (sections 4.5.1 and 4.5.6).

3. Results

The main result of this project is a geodatabase showing estimates of the distribution of organic soils in Switzerland. The surface area assigned to each class is shown in Figure 13 and maps showing the distribution of organic soil estimates are displayed in Figure 14 and Figure 15. A map showing the distribution of the surfaces of individual classes (I to V) can be found in appendix IV. It is recommended that classes I to V form the best estimate of organic soils and that this estimate should be used for the GHGI. The extent of this estimate is 27,813 ha (classes I to V); the more conservative estimate (classes I to IV) covers 18,066 ha (Table 14). There are an additional 7,078 ha for which there is only historical evidence of organic soil (classes VI and VII) and 54,310 ha for which there is evidence only of wetlands or of surfaces potentially containing organic soil, class VIII (section 2.4.2.4). The addition of the mineral data sets – as a negative control (section 2.4.2.5) – resulted in the 'removal' of surfaces from the organic soil estimates (this removal of surfaces is taken into account in the estimates given above). Thus, 1,088 ha (5.6 %) were removed from the more conservative estimate and 3,956 ha (12.4 %) were removed from the recommended estimate. Surfaces were also removed from classes VI and VII (3,068 ha) and VIII (19,367 ha); the removed surfaces are not considered any further. There were an additional 199 ha of 'truly conflicting surfaces' (see Table 13 and Table 14), for which it is unclear whether these surfaces should be considered mineral or organic soil.

Uncertainty around the recommended estimate or organic soils (27,813 ha) is discussed in section 4.5.6.

Table 14: Surface area of the estimates of organic soil, including surfaces deemed 'organic' (i.e. no truly conflicting surfaces from mineral data sets), 'mineral' (i.e. conflicting surfaces from mineral data sets), or 'conflicting'; for details of the three categories see section 2.4.2.5 and Table 13

	Organic (ha)	Mineral (ha)	Conflicting (ha)
I to IV	18,066.3 (93.3 %)	1,088.1 (5.6 %)	199.0 (1.0 %)
I to V	27,813.4 (87.0 %)	3,955.5 (12.4 %)	199.0 (0.6 %)
VI	1,974.9 (70.4 %)	830.2 (29.6 %)	n/a
VII	5,103.3 (69.5 %)	2,237.4 (30.5 %)	n/a
VIII	54,310.4 (73.7 %)	19,367.3 (26.3 %)	n/a

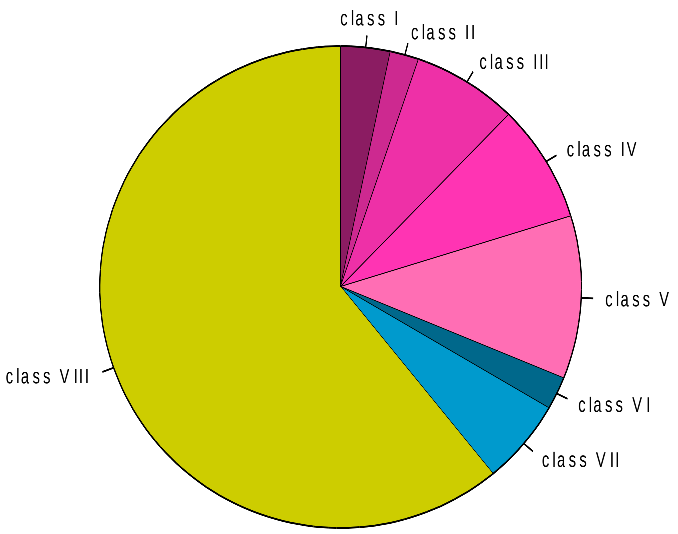


Figure 13: Assignment of surfaces to each class; the total surface area is 89,202 ha

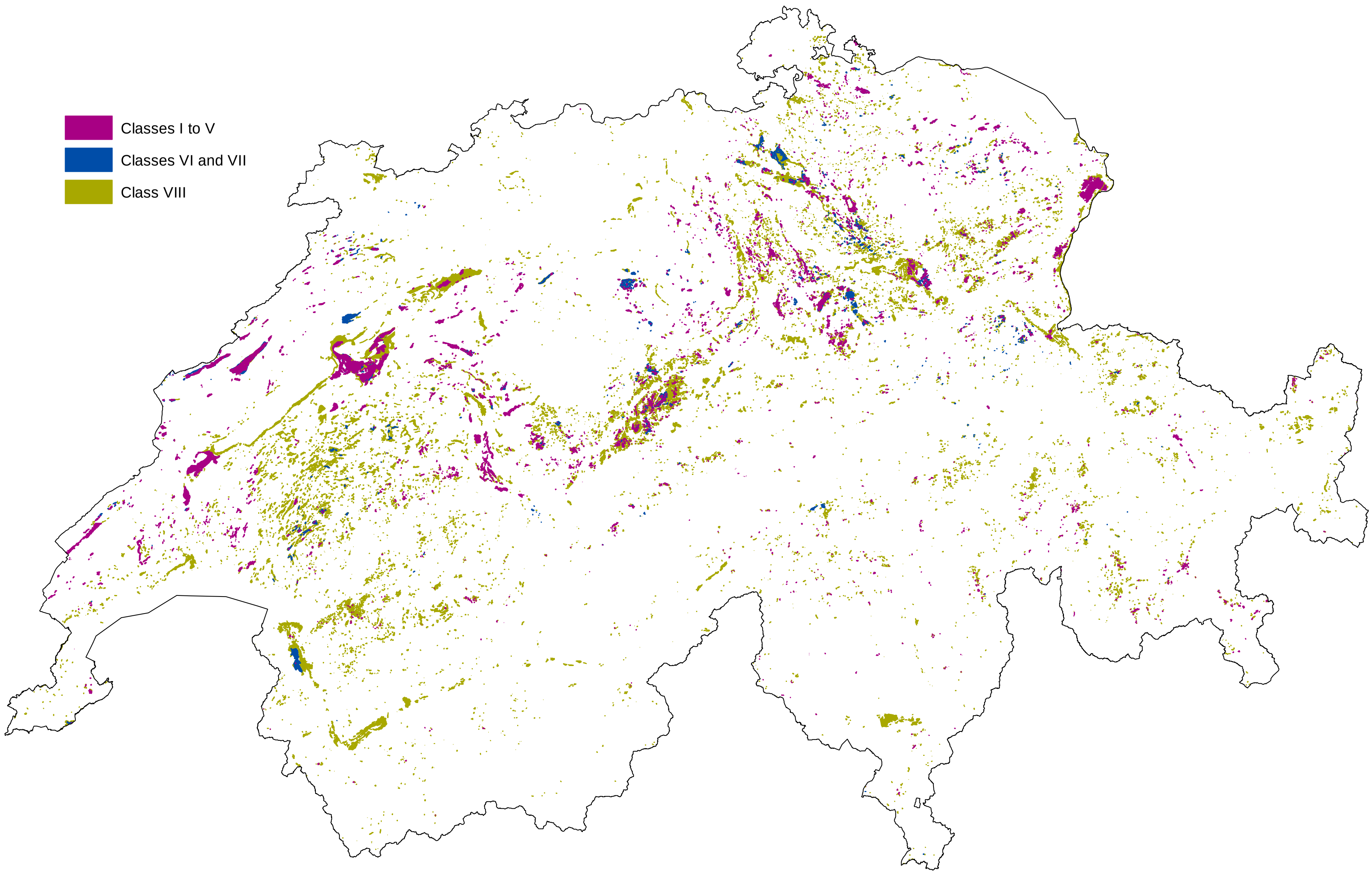


Figure 14: Map showing the distribution of the eight classes; pink surfaces = classes I,II,III,IV,V (recommended estimate of organic soil); blue surfaces = classes VI and VII; dark yellow surfaces = class VIII; surfaces are exaggerated in size for better visibility; the original data sets used to create this map (and their proprietors) are listed in appendix I; national outline © Swisstopo

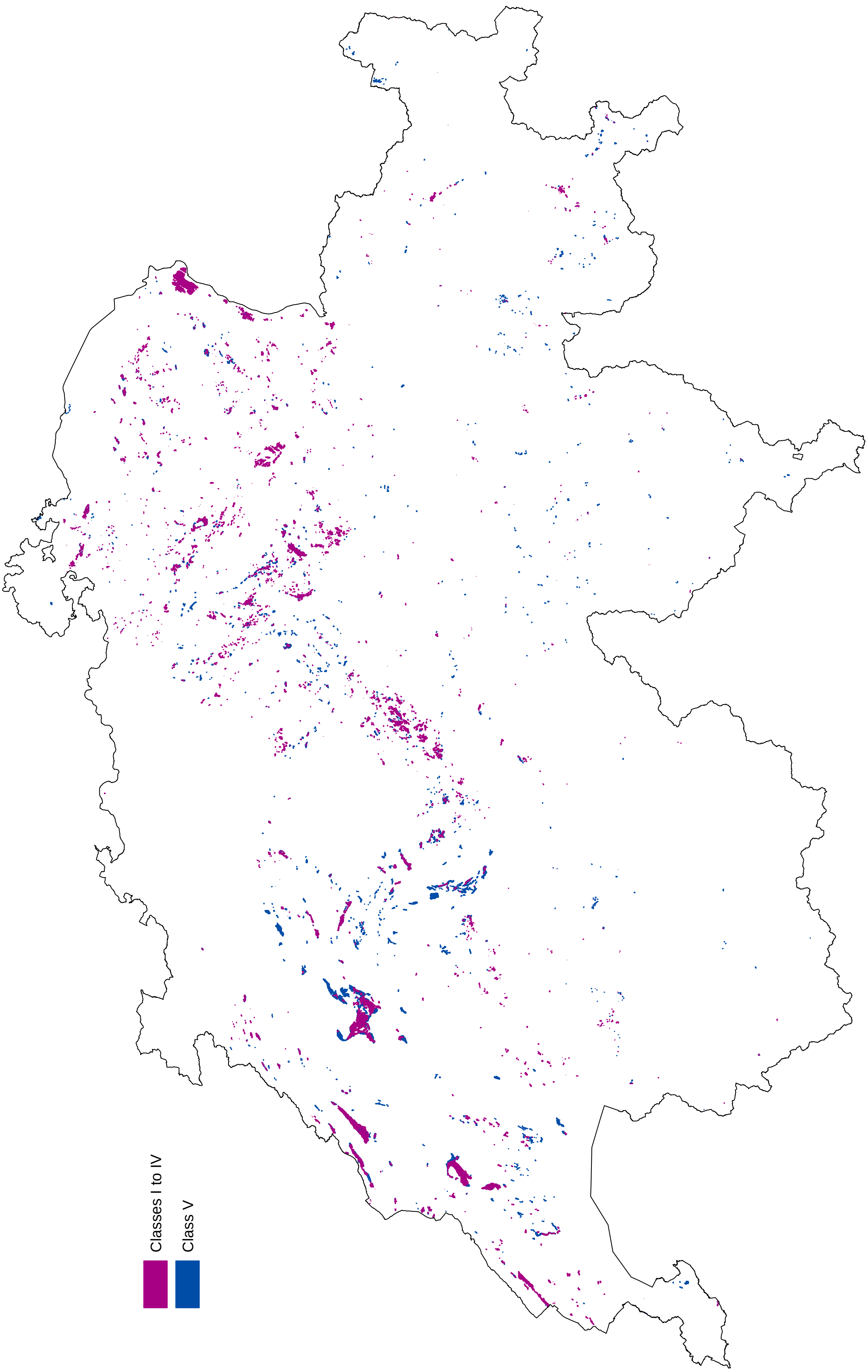


Figure 15: Map showing the surfaces of organic soils recommended for the GHGI (i.e. classes I to V); pink surfaces = classes I to IV (a more conservative estimate); blue surfaces = class V; surfaces are exaggerated in size for better visibility; the original data sets used to create this map (and their proprietors) are listed in appendix I; national outline © Swisstopo

The previous estimate of organic soils for the GHGI comprised a union of the mapping units F3 and Q1 of the Soil Suitability map and the national raised bog inventory; it covered ca. 28,000 ha, similar to the new recommended estimate of organic soil. The locations of the sites of organic soil in the two estimates are however quite different. In the previous estimate, the majority of the organic soil surfaces were large contiguous surfaces in mostly large valley bottoms: the Orbe plain (Orbeebene, Plaine de l'Orbe) in canton Vaud, the Seeland in cantons Bern / Fribourg / Neuchâtel, the Linth plain (Linthebene) in cantons St. Gallen, Schwyz and Glarus, the Rhine valley of St. Gallen (St. Galler Rheintal), the Rhone delta at Lake Geneva in cantons Vaud and Valais (Chablais), and lastly, Drachen-Ried and Grossried near Stans (canton Nidwalden). These surfaces have been substantially reduced in the new recommended estimate of organic soils; these surfaces have either been fragmented, or, as is the case for the Rhone delta and Drachen-Ried and Grossried, have almost completely disappeared. Instead, many new small surfaces have been identified, which are predominantly located in the pre-Alps and in the Central Plateau (see Appendix V). For the GHGI there is a resulting increase in the amount of forest land and unproductive wetlands over organic soil, and a reduction in the surface of settlements over organic soil.

4. Quality Control

4.1. Transparency

This freely-available report describes the information sources and the methodology to produce the new estimates of organic soils of Switzerland. The methods used to derive these estimates, as well as the estimates (maps) themselves should therefore be transparent and reproducible. The data sets or information sources used for the production of the maps are listed in section 2.1 and appendix I, with reference to where they were obtained from. In most cases these data sets remain property of individual organisations (e.g. cantons, research organisations) and must be obtained from these organisations. The methodology described in sections 2.3, 2.4 and 2.5 (including Figure 11) describes the steps taken to create the new estimates of the distribution of organic soils. An important part of this semi-automated workflow is a series of model tools built in ArcGIS which are documented in Appendix III. Their use means that the map can be reproduced relatively quickly, automatically and minimising human-error. Appendix II additionally describes how the input data sets need to be formatted for these Model Tools to function. The estimates of organic soil surfaces as well as the model tools are available from the Air Pollution and Climate Group, Agroscope (Reckenholz), Switzerland.

4.2. Accuracy

The majority of data sets used in this project are published or are available publically as ‘finished’ products, implying that they are of sufficient quality for use as input data for the GHGI. This concerns all national inventories, vegetation, geological and hydrogeological maps, and most soil and forest habitat maps. Data sets were checked for their suitability for this project as described in section 2.2 and two data sets (three E & K units of the forest habitat maps and one mapping unit of the fen inventories) were ground-truthed (section 2.2.2). This ground-truthing indicated the appropriate use of these two data sets as information sources.

The attribute information of each data set – whether it unambiguously represents organic soil or not – was assessed for precision by consulting the technical report or description associated with each data set where available (section 2.2.1), as these generally contain the definition of each mapping unit. Where the attribute information was deemed too imprecise (e.g. certain mapping units of the geological maps, see below under ‘Consistency’), or where it did not always reliably indicate organic soil (e.g. the fen inventories, section 2.1.1.2), polygons were scored as such (section 2.3.3) or were not included in the map. These penalised scores were taken into account to produce a more- or less-conservative estimate of the organic soils (sections 2.4.2 and 3).

Verification of the estimates of organic soil through targeted ground-truthing or through comparison with information from soil probes was not carried out as part of this project and is recommended as future work (section 5).

4.3. Consistency

The consistency of mapping units across the country is important to ensure consistent representation of organic soils across the country. For the majority of data sets used that occur country-wide, standard mapping units – or mapping units that could be translated into standard mapping units – exist. Exceptions are the geological maps, two forest habitat maps and one soil (pedological) map. The different geological maps were surveyed by different geologists over at least 100 years, and peatlands are included in sometimes quite different mapping units across the different map sheets. Some of these mapping units potentially also include non-peaty soils (e.g. “Flachmoore und Hochmoore”, “Verlandungsbildungen, vorwiegend Torf", "Ried, Sumpf, z.T. Torf"), and were not considered as containing organic soil (section 2.1.1.4). This has probably led to an under-estimation of organic soil surfaces. For the forest maps (Appenzell Innerrhoden and Valais) that used different mapping units than standard ones, sufficient information was contained in the data sets to decide whether or not the surfaces represent organic soil (details given in the forest habitat maps, 2.1.1.3).

4.4. Completeness

There is no single data set available for Switzerland which reliably demarcates organic soil surfaces. The approach used in this project was therefore to obtain multiple data sets, which are (physically) scattered across the country. National inventories and maps were available from federal offices. However, surveys dealing with forestry, soil or regional nature protection tend to be the responsibility of the cantons and this has two consequences for the project: Firstly, there are very few cantons for which there are complete modern data sets covering both forested and agricultural land. Secondly, some cantons are covered by very few data sets, leading to significant 'holes' in coverage across the country. This variation in the coverage of modern data sets across cantons means that the completeness of the recommended estimate of organic soil is variable across the country (Table 15).

The lack of data probably led to a net under-estimate of the amount of organic soil across the country. It is however possible that including additional modern data sets for regions where older data sets are already available, would *reduce* the estimate of organic soil, as these data sets might indicate more surfaces of mineral soil. This would be the case where drained peatlands have lost so much organic C over time that they have become mineral soils. Such sites are however probably few compared to the 'holes' in the coverage of data sets, therefore the remainder of this section concentrates on the issue of under-estimation of organic soil due to missing data, rather than over-estimation.

Table 15 shows the availability of the main regional modern data sets by canton. In addition to these, the following data sets cover every canton: the inventory of raised and transitional bogs and the fen inventory. Additionally, surveys recording raised bogs not captured in the national inventories were used for cantons Graubünden and Zurich. Two additional columns are shown in Table 15: Surface area of the peaty surfaces from the inventory of raised and transitional bogs and the total area of organic soil as indicated by historical information (only), i.e. classes VI and VII. This information, in combination with the coverage of data, indicates for which cantons there might be significant amounts of estimated organic soil 'missing', for which the search for additional data sets should be prioritised as future research, and for which cantons it would be useful to estimate the amount of organic soil 'missing' through extrapolation (2.7).

Those cantons most particularly poorly represented by the data sets are Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri (Table 15). Although for Graubünden there is a data set covering raised bogs (Natur and Landschaftsschutzinventar), which was not included in the calculations for Table 15, Graubünden should still be considered poorly represented because there is little information indicative of soil type, e.g. very little coverage by geological or soil maps, meaning that destroyed mires are particularly poorly represented. In addition, based on the extent of raised bogs and historical peatlands in this canton, it potentially contains a lot of organic soil.

Two approaches of extrapolation were used to provide an estimate of the amount of organic soil 'missing' in the cantons Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri due to insufficient data, as described in section 2.7. The surfaces identified through this extrapolation are not included in the recommended estimate of organic soil; the results are however presented in the following section (4.5.1) and form part of the uncertainty around the recommended estimate.

Table 15: Availability of modern data sets by canton as used in this project; cantons ranked by coverage by modern data sets

Canton	Soil maps (%)[1]	Forest habitat maps[2]	GeoCover (%)[3]	Hydro-geology (%)	Area covered (%) by modern data sets[1]	RBI (ha)[4]	Historically peaty (ha)[5]
NE		✓	80.0	100	100	230.2	612.0
ZG	60	20%	100.0		100	87.4	66.9
SO	25	✓	65.0	62	100	0.9	< 1
BS		✓	99.7		100	0	< 1
TG	100	✓	74.8		99	1.2	129.6
JU		✓	59.0	88	99	74.4	110.8
AI		✓	98.1		99	7.9	< 1
ZH	70	✓	74.0		98	46.9	1343.6
AG	50	✓	92.9		98	1.2	20.2
VD	50	✓	77.2	65	97	96.1	91.9
GE	70	✓	62.7		95	0	14.0
SH		✓	94.7		95	0	< 1
FR	5	✓	87.2	86	94	67.1	536.9
LU	30	✓	76.4		86	188.4	706.4
AR	< 5	✓	68.4		78	13.7	11.9
SG	30	✓	50.1		75	124.6	462.4
VS		✓	60.9		71	8.3	597.0
BE	5	6%	52.6	49	70	252.4	992.0
BL		✓	54.3	17	70	0	< 1
SZ	< 5	14%	66.4		67	134.2	777.4
TI		no	55.0		53	14.5	3.2
OW		✓	1.9		45	115.6	375.5
UR		34%	36.0		40	5.6	55.1
GR	< 5	no	32.1		36	77.2	80.4
GL	< 5	✓	10.6		34	9.5	73.1
NW		✓	4.1		25	9.3	16.7

[1] calculated using surface area of cantons minus urban areas and lakes, to nearest 5 %; [2] ✓ indicates > 95 % coverage; [3] map sheets from 1945 or earlier not included; [4] RBI = raised and transitional bog inventory, only peaty surfaces were used for calculation, [5] classes VI and VII

4.5. Sources of Uncertainty

4.5.1. Missing Data

Section 4.4 describes the coverage of data sets for each canton. Six cantons were identified that are poorly-represented by modern data sets: Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri. Two methods were used to estimate the uncertainty in the estimate of organic soil due to missing data in these cantons.

The first, more precise approach, attempted to estimate how much organic soil is missing from the forests of cantons Bern, Schwyz and Uri, due to incomplete forest habitat maps (section 2.7). Although Bern and Schwyz were not identified as having the poorest coverage of data sets, they were also included in this uncertainty analysis because they too have incomplete forest habitat maps and only moderate coverage of other data sets. Extrapolation of organic soil identified by forest habitat maps from cantons with a similar climate, added a total of 1,085 ha of organic soil to the three cantons, corresponding to a 4 % increase of organic soil across the country (Table 16). This increase is assumed to occur under forest.

Table 16: Estimate of the amount of organic soil 'missing' due to incomplete forest habitat maps in the cantons Bern, Schwyz and Uri

Region	Estimate of organic soil (ha)[1]	Estimate of organic soil without forest habitat maps (ha)	Estimate of organic soil using extrapolation (ha)	% increase of surface
Bern	7,161.8	7,083.1	7,880.8	10.0
Schwyz	922.1	711.8	1,265.1	37.2
Uri	56.4	42.1	78.8	39.8
CH	27,813.4	-	28,898.0	3.9

[1] classes I to V, including information from the partial forest habitat data sets for Bern, Schwyz and Uri

For Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri a second, coarser approach was used to provide a maximum estimate for the amount of organic soil that might be 'missing' due to insufficient modern data sets (section 2.7). This method added a total of 604.2 ha of organic soil to these six cantons, corresponding to an extra 2 % of organic soil across the country (Table 17). This increase is assumed to occur across all land-use types.

Table 17: Estimate of the amount of organic soil 'missing' due to missing modern data in the six most poorly-represented cantons

Region	Estimate of organic soil (ha)[1]	Organic soil represented by historical info. only (ha)[2]	Estimate of organic soil *including* historical info. only (ha)[3]	% increase of surface
Glarus	148.8	73.1	221.9	49.1
Graubünden	732.1	80.4	812.6	11.0
Nidwalden	27.9	16.7	44.6	60.1
Obwalden	936.9	375.5	1312.5	40.1
Ticino	154.4	3.2	157.7	2.1
Uri	56.4	55.1	111.5	97.8
Total	2,056.5	604.2	2,660.5	-
CH	27,813.4	-	28,417.6	2.2

[1] classes I to V; [2] classes VI and VII; [3] classes I to VII for the six cantons, classes I to V for other cantons

A combination of these two methods can be used to estimate the surface of organic soil 'missing' due to poor coverage of modern data sets as follows: For cantons Glarus, Graubünden, Nidwalden, Obwalden, Ticino and Uri, the amount due to missing modern data in general is 604 ha (Table 17). This can be added to that 'missing' due to incomplete forest maps in cantons Bern and Schwyz (1,062 ha, derived from Table 16), to give a total of 29,480 ha of organic soil across the country 27,813 ha plus 604 ha plus 1,062 ha).

4.5.2. Anmoorig and Antorfig Soils

Some anmoorig or antorfig soils, as defined in the Swiss soil classification system, fulfil the IPCC definition of organic soils (see section 1.4). Not including them has therefore led to an under-estimation of organic soils. The addition of anmoorig and antorfig soil surfaces, scored as "B" for the attribute quality regarding the evidence of peat, leads to a recommended estimate of organic soil (i.e. classes I to V) that is ca. 20 % higher than the current recommended estimate. This is a significant increase, especially considering that such a small proportion of the country is covered by soil maps from which anmoorig and antorfig soils were identified (the soil map sheets, plus cantons Luzern, St. Gallen, Solothurn, Vaud, Thurgau, Zug and Zürich). It must however be kept in mind that the soil maps identifying the largest anmoorig or antorfig surfaces (the soil map sheets) were surveyed in the 1980s and tend to cover surfaces under intensive agricultural use; many of these surfaces might well have lost so much C in the meantime, that they should no longer be considered organic soil.

Based on the data sets currently available, it is not possible to estimate the amount of organic soil 'missing' due to these soils across the whole country. One potential way to do this would be to extrapolate the amount of additional surface represented by anmoorig or antorfig soils from the soil maps available (i.e. 20 %), to the rest of the country. This would however result in a gross over-estimation of organic soil for two reasons. Firstly, the regions for which we have soil maps tend to contain a lot of surfaces – compared to the rest of Switzerland – that were once peatlands but which due to drainage and conversion to agriculture, are now anmoorig or antorfig soils, i.e. they over-represent these soils. Secondly, as discussed in section 2.1.1.1, not all anmoorig or antorfig soils are organic soils.

4.5.3. Under-estimation of Mineral Soil

For several regions there is information about mineral soil that conflicts with the information about organic soil; the recommended estimate of organic soil was as a consequence reduced by 12 %, and the more conservative estimate by 6 %. Information regarding mineral soil was derived from the soil maps. Because the soil maps only cover ca. 15 % of non-urban land, it is likely that the addition of more mineral soil data would result in a further reduction of the organic soil estimate. The lack of soil maps thus also causes an over-estimate in the final estimate of organic soil. The extent of this over-estimation is impossible to estimate. Extrapolation of this 6 % or 12 % to the remainder of the country for which there are no soil maps would be inappropriate, because, as mentioned above, the area covered by soil maps is not representative of the whole country. Only the addition of more information from soil cores, profiles or maps can help solve this problem.

4.5.4. Treatment of Ambiguous Mapping Units

Several data sets contain mapping units that could not be classified with certainty as containing peat or not. These include, most importantly, many mapping units from the GeoCover data set (section 2.1.1.4) and three fen vegetation types from the fen inventories (Caricion davallianae, Magnocaricion and Phragmition, section 2.1.1.2). Additionally, certain surfaces were omitted altogether, including surfaces from the forest habitat maps that represent mixtures of forest types where only one of the two listed forest types is indicative of organic soil (section 2.1.1.3), or the agricultural surfaces for which the presence of organic soil is unknown (section 2.1.1.3). This omission of surfaces, or the scoring of such surfaces as "C", has probably led to an under-estimate of organic soil in the estimate recommended for the GHGI. This uncertainty could in some cases be reduced in the future by further ground-truthing, targeting particularly these mapping units (section 5.3).

4.5.5. Under-estimation Due to Geometry-based Generalisation

A further source of uncertainty, in this case of under-estimation, is the neglect of surfaces i.e. peatlands, smaller what was been mapped in the individual data sources. Although we tried to minimise this under-estimation by using mostly large scale data sources (section 2.1), such under-estimation can be considerable. For example, this effect was quantified for the national fen inventory, where it was estimated that the minimum mapping area of 1 ha caused an under-estimate of ca. 40 % of the estimated area of fens (Dalang & Fischbacher, 1992).

4.5.6. Uncertainty Around the Recommended Estimate of Organic Soil

It is recommended to use the estimate of 27,813 ha as an initial estimate for the surface area of organic soil GHGI. This estimate can however be revised in the light of missing data. Section 4.5.1 describes two attempts to estimate how much organic soil might be missing due to missing data. Incorporating the results from these increases the estimate of organic soil by 6 % to 29,480 ha. 199 ha could also be added to this – surfaces for which there is truly conflicting evidence from mineral soil (sections 2.4.2.5 and 3) –, bringing the total to 29,679 ha. One of the two methods used to estimate the surface missing due to missing modern data (estimation of organic soil due to incomplete forest habitat maps) used non-spatial extrapolation of surfaces; this part of the estimate can be assumed to occur over forest, but otherwise cannot be located and therefore cannot be used as Activity Data for the GHGI. If a spatially explicit estimate of organic soil is necessary, these latter surfaces need to be omitted, bringing the estimate of organic soils to 28,617 ha (28,418 ha – see Table 17 – plus 199 ha).

A lower estimate of organic soil can be obtained from the more conservative estimate of organic soil, 18,066 ha.

An upper estimate of organic soil surface area can be derived by including all surfaces for which we have historical evidence that they were peatlands, i.e. classes VI, VII, or even including sites for which we are uncertain whether or not they represent(ed) organic soil, i.e. class VIII. These three classes cover 61,389 ha, yielding an upper estimate of 89,401 ha (27,813 ha plus 199 ha plus 61,389 ha). This upper estimate however almost certainly includes sites that are non-peaty wetlands, as well as peatlands from which perhaps so much C has left the soil (through drainage, through peat extraction and / or through oxidation over time, and eventually urbanisation) that they can no longer be considered organic soil. This value therefore offers an over-estimation and is given as an upper estimate of organic soil, but should not, under any circumstances, be used as the estimate for the GHGI without further evaluation (see section 5). A summary of the uncertainty around the recommended estimate of organic soil is given in Figure 16.

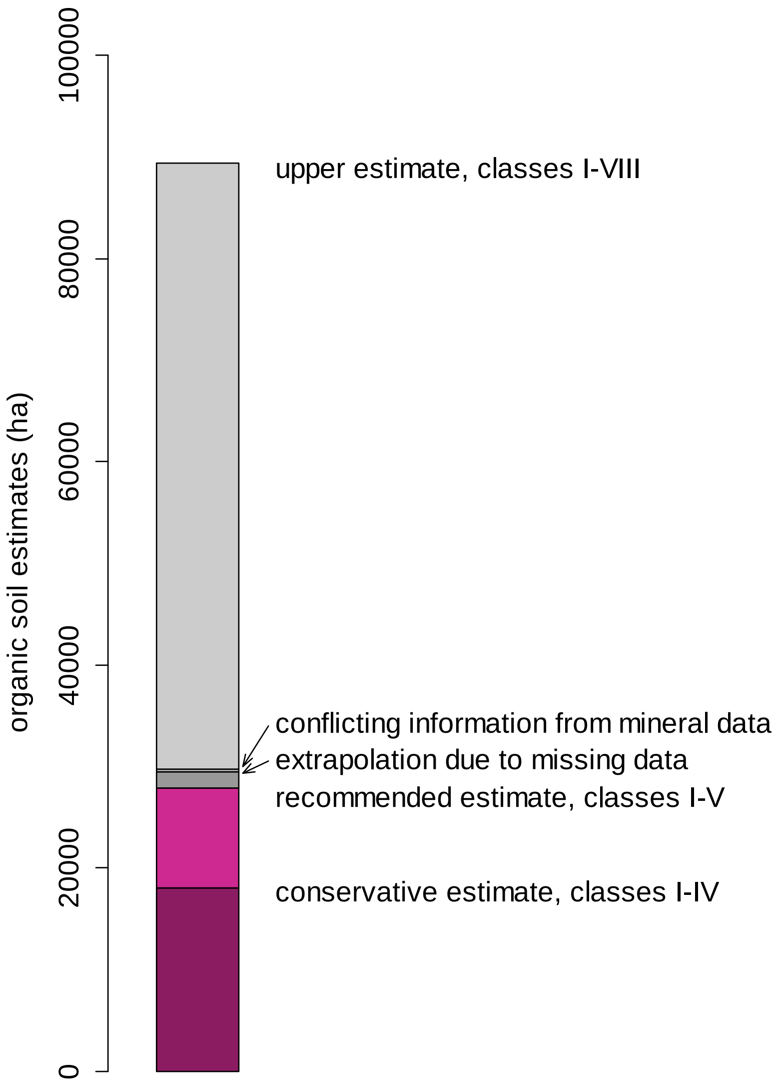


Figure 16: Summary of the uncertainty around the recommended estimate of organic soil

5. Recommendations for Future Work

5.1. Addition of Further Data Sets

Missing data, especially from modern data sets, causes substantial uncertainty in the recommended estimate of organic soils. The inclusion or completion of additional modern data sets (points 1 to 7 of section 5.1.2) should therefore be prioritised, as well as the consideration of other fen vegetation types (5.1.1) and the validation of the new estimates (section 5.3).

5.1.1. The Fen inventory

The occurrence of peat under fens needs to be better understood. The fieldwork carried out as part of this project, as well as the review carried out by Leupi (1994), suggest that vegetation type alone might not be the best proxy for the presence of peat at a fen site. It is likely that other factors such as water regime and topography additionally play a role, and therefore need to be considered in conjunction with vegetation type in order to classify surfaces as peat-building or not.

Another approach to understand which fen sites grow on peat would be the identification, for specific sites – either in exisiting vegetation surveys or in herbarium records of sites – of species that are good indicators of fen peat (e.g. *Carex diandra*, *C. chordorrhiza*, *Eriophorum gracile Schoenus ferruginieus*).

As well as the investigation of the supposedly peat-building fen vegetation types listed in section 2.1.1.2, the investigation of another fen type, Molinion (Pfeifengraswiesen or prairie à molinie), is warranted. Where this fen type occurs in the proximity of a raised bog, it often grows on dry peat, indicating the former extent of the raised bog that has – usually due to hydrological disturbance and possibly additionally peat extraction – shrunk. According to the national and regional fen inventories, ca. 70 ha of fen are dominated (≥ 80 %) by Molinion.

5.1.2. Other Data Sets

1. As well as those **soil maps** that have been digitised and that were used in this project, numerous regional and local soil maps exist. These include over 300 soil-mapping projects that were carried out between 1960 and 1996 by the mapping service of the then Forschungsanstalt für landwirtschaftlichen Pflanzenbau Zürich-Reckenholz, FAP or Eidgenössische Forschungsanstalt für Agrarökologie und Landbau Zürich-Reckenholz, FAL, currently the Agroscope Institute for Sustainability Sciences, ISS. One way to increase the coverage of soil information across the country would therefore be the incorporation of organic surfaces as indicated by these soil maps. It must however be kept in mind that many of these maps are several decades old and where they cover surfaces currently used for intensive agriculture, the classification of soil may no longer be correct: the organic soils here rapidly lose organic matter, becoming mineral soils over time. The availability of digital data is another issue: NABODAT (Switzerland's National Soil Information System, http://nabodat.ch/index.php/de/) is an on-going project which aims to bring together, harmonise and digitise soil data owned by the cantons as well as the federation. This information system would therefore be an appropriate place to locate potential soil maps. It is however foreseen that the harmonisation and digitalisation of surface data, i.e. soil maps, will require several more years[8]. It is anticipated that direct access to NABODAT will be reserved for the cantons and the federation, who also remain the owners of the data.
2. The **GeoCover** data set available from Swisstopo is incomplete. Swisstopo release new geological maps each year, both from the Geological Atlas series (1:25,000, newly surveyed) and from the series of Compilation maps (various scales, compiled from unpublished maps as well as Geological Special

[8] http://nabodat.ch/index.php/de/nabodat/datenzugang; accessed 17th March 2015

Maps). 56 % of the 222 planned Geological Atlas sheets[9] were available for this project. It is estimated that the atlas will be completed in ca. 20 years (pers. comm. Andreas Möri, Head of Geological Mapping, Swisstopo). These sheets, as well as the Compilation maps should be incorporated as they become available.

3. The coverage of the hydrogeological maps is likewise incomplete. Additional maps are being worked on and existing maps are being digitised by the SGTK. The digitisation of the map sheet Toggenburg has recently been completed and that of the map sheet Basel should be complete by 2015 (pers. comm. Doris Reber, Schweizerische Geotechnische Kommission / commission géotechnique suisse).
4. Ideally, the forest habitat maps of Bern, Graubünden, Schwyz, Ticino and Uri should be incorporated as they become available or are completed. From discussion with cantonal foresters, it is unclear whether or not these will be completed in the near future.
5. Not all bogs and fens that were surveyed as part of the federal or regional inventories were included in the associated protection acts and were therefore not incorporated into the inventory data sets used in this project. These sites should be added to the map of organic soils.
6. The government is obliged to regularly revise the designation of biotopes of national importance, as per paragraph 16 of the Ordinance on the Protection of Nature and Cultural Heritage[10]. Such revisions include the correction of perimeters of sites as well as the inclusion of newly surveyed sites. It is recommended that these changes, if relevant to organic soils, should be incorporated into the map of organic soils as they become available.
7. In addition to the sites of the federal and regional inventories, there are potentially many more mires located within mire landscapes. The different biotopes (including mires) that fall within the boundaries of these protected landscapes – which cover 2.1 % of the country – must be *delineated*, designated and protected, a duty of the cantons[11]. As this delineation is carried out, the data should be incorporated into this project.
8. Information from local historical names: Place names (‘Flurnamen’ / ‘toponymes’) often indicate old land-use types or land-cover. The geo-referenced Swissnames (Swisstopo) database could be used to identify sites that were in the past probably bogs, fens or sites used for peat *extraction*. In combination with validation, this database could therefore be used to identify sites that might today contain organic soils. A preliminary search, searching for place names containing *the* partial terms “marais”, “moor”, “moos”, “mosses”, “mouille”, “palu”, “paliu”, “palü”, “sagne”, “saigne” and “tourb”, identified ~1,640 place names that might be relevant (appendix VI). The Swissnames database comprises place names contained only in the current 1:25,000 to 1:200,000 topographical maps and thus omits historical names that have disappeared; geo-referencing of the place names from the Siegfried maps, to create a ‘historical Swissnames’ data set, would also be of use here. Documentation of historical place names at local and regional scales exists for some areas of the country, for example the Luzern Namebook project (http://www.geo.lu.ch/app/namenbuch/), the Namebook of canton Schwyz (Weibel, 2012), or a collection of place names from across the country (https://www.ortsnamen.ch/), and these could be used for this purpose.
9. Another approach to identify ancient raised bogs and fens would be to use **herbarium specimens** or preferably herbarium databases (e.g. Infoflora[12]), to identify sites from which raised bog and fen

[9] http://www.swisstopo.admin.ch/internet/swisstopo/en/home/products/maps/geology/atlas.html, accessed 19.11.2014

[10] Verordnung über den Natur- und Heimatschutz, NHV, SR 451.1 / Ordonnance sur la protection de la nature et du paysage, OPN, RS 541.1

[11] Verordnung über den Schutz der Moorlandschaften von besonderer Schönheit und von nationaler Bedeutung (Moorlandschaftsverordnung) SR 451.35 / Ordonnance sur la protection des sites marécageux d'une beauté particulière et d'importance nationale, (Ordonnance sur les sites marécageux), RS 451.35

[12] http://www.infoflora.ch/

indicator species were repeatedly collected in the past; as ancient raised bogs and fens, such sites might still contain organic soil. These sites could incorporated into this project and treated as the historical “Expert observations and descriptions” were treated (2.1.2.1 and 2.4.2.2), or be the target of further ground-truthing.

10. Information regarding drainage can provide an indication of organic soil – or at least the original extent thereof – especially under croplands. The vast majority of crops grown on organic soils in Switzerland require these soils to be drained, meaning that where organic soils occur (or occurred at the time of the laying of the drains) under croplands, drainage systems should be in place. Because (naturally) poorly-drained mineral soils also need to be drained, this information is only *indicative* of organic soils. The previous estimate of 120,000 ha of drained land in Switzerland was recently increased to at least 192,000 ha (Béguin, 2010). About half of the cantons of Switzerland have digital geographic information on the distribution of drains in agricultural areas and a further eight cantons have analogue information (Béguin & Smola, 2010; Seitz, 2013).

11. Retro SEALS, a server for digitised journals and part of the library of the Swiss Federal Institute of Technology, ETH, systematically scans and indexes journals. A number of journals in this server contain monographs or articles with information relevant to the distribution of state of mires, often with accompanying maps. Although several articles were obtained from Retro SEALS for this project, the relevant journals were not systematically searched through. One strategy to find additional habitat or vegetation maps, or otherwise descriptions of mires in Switzerland would therefore be to systematically search relevant titles, including “Veröffentlichungen des Geobotanischen Institutes der Eidg. Tech. Hochschule, Stiftung Rübel, Zürich“ and „Beiträge zur geobotanischen Landesaufnahme“ / „Matériaux pour le levé géobotanique de la Suisse„ / „Contributi allo studio geobotanico della Svizzera“, pending digitization.

5.2. Anmoorig and Antorfig Soils

It is likely that the new estimates of organic soils already contains some surfaces of anmoorig and antorfig soils, which will have been incorporated through the use of older data sets (namely soil maps from the 1970’s or 1980’s) that depict these surfaces as organic soils. There are however also datasets that portray anmoorig soils explicitly, for example the (same) soil maps and possibly the forest habitat maps – although further ground-truthing of the latter would be needed to test this. The reasons why anmoorig and antorfig soils were not included in the new estimate of organic soils are discussed in section 2.1.1.1. However, given the potentially large surface they cover (section 4.5.2) and the fact that they potentially emit a lot of greenhouse gases compared to other recognised organic soils (Lieber-Sauheitl, 2014), it would be sensible to try and understand how realistic it would be to incorporate these soils into an estimate of organic soils in the future, given the data sets available. Because of the incongruence between the IPCC definition of organic soils and the classification of these soils (section 2.1.1.1), it would be necessary to alter the definition of organic soils for the Swiss GHGI, something encouraged by the IPCC where necessary (IPCC, 2006).

5.3. Validation of the Estimates of Organic Soil

Validation of the new estimates of organic soils is vital to estimate properly the uncertainty associated with them. Such validation could utilise data from either existing soil probes or new soil probes taken as part of a ground-truthing effort. The former approach would require the identification of soil probes from the federation or from cantons that were not used to construct any of the soil maps already used in this project, and obtaining the associated data sets. The information system, NABODAT, will contain an estimated 14,000 soil profiles from both the cantons and the federation (FAP and FAL), some of which might be suitable for this. It is anticipated that direct access to NABODAT will be reserved for the cantons and the federation, who also remain the owners of the data.

The second method, a targeted ground-truthing effort, involves three aspects. The first aspect would be the validation of soil surfaces identified as organic soil, as well as those surfaces subtracted from the estimate of organic soil due to information from the mineral soil data sets. This would allow a better estimate of the uncertainty associated with the current estimates. A second aspect would be the targeted investigation of class VI and VII surfaces, i.e. those surfaces for which we only have historical evidence of peaty soil. This would be a relatively straight-forward way to reduce the uncertainty in the recommended estimate of organic soil, but given the considerable extent of surfaces in the classes VI and VII alone (~7,000 ha in ~4,000 sites), it would also be a large task. A combination of the two approaches – using data from already-existing soil probes where possible, followed by the ground-truthing of the largest sites for which no probes exist – would be a suitable approach. The third aspect involves targeting the underlying data sets, namely the habitat or vegetation units that were deemed ambiguous with regards to presence of peat, for example fen vegetation types or mixed forest habitat types (as discussed in section 4.5.4). This would indicate how much of an under-estimation the current treatment of these surfaces has caused. The results from this part of the validation would in turn be useful to feed into improved estimates of organic soils in the future.

5.4. A Dynamic Approach to Organic Soil Loss

The estimate of organic soil given here offers a static picture of the location of organic soil in Switzerland. Due to on-going oxidation of organic matter, the distribution of organic soil is however dynamic, with a reduction over time following the conversion to mineral soil. This dynamic aspect is also relevant for the GHGI, where not only GHG emissions, but the *changes* in GHG emissions are reported for a given reporting period. As part of the LULUCF sector of Switzerland's GHGI, a dynamic aspect is reflected in the incorporation of land-use *change*; ideally, a dynamic aspect should however also be associated with the change from organic to mineral soil over time. This would lead to a reduction of the calculated emissions from organic soils over decades, as the surface area of organic soil would decrease.

Estimating the change from organic to mineral soils empirically would require information on the following: location of organic soil surfaces, content of organic C and depth of organic layer at each site, as well as rate of loss of organic C. Obtaining such data for Switzerland's organic soils would require a considerable surveying effort. Estimating the rate of loss of surfaces of organic soil might however be more realistic by using a different approach: old and recent soil maps that overlap geographically could be compared to identify surfaces depicted as organic soil in an older map, and mineral soil in a more recent map, allowing a very approximate rate of change to be estimated. The overlap of soil maps that are currently available in digital form is too low for this (5.7 % of coverage of soil maps). Obtaining soil maps or data from soil probes from on-going soil mapping projects or from NABODAT would however increase this overlap, making this approach a reasonable option in the future. This rate of disappearance of organic soils due to oxidation would not be spatially explicit and could therefore not be used in conjunction with other Activity Data; it would however offer an estimate of the decrease in emissions over time due to disappearence of organic soil. As soil maps tend to cover open land, including especially agricultural land, this decrease in emissions would also be limited to cropland and grassland, rather than forest land.

6. References

The links to references available from FOEN and from “retro.seals.ch”, the retrodigitized journals service of the Swiss Federal Institute of Technology, as well as other selected publications, are given for ease of access.

Altmann, M. (2008) Socio-economic impact of the peat and growing media industry on horticulture in the EU. Co Concept, Luxemburg.

Anon (1888) Bundesgesetze betreffend das Eidgenössiche topographische Büreau und Instruktionen desselben. Stämpfli'sche Buchdruckeri, Bern, Switzerland.

Anon (1896) Die schweizerische Landesvermessung 1832-1864 (Geschichte der Dufourkarte). Buch-druckerei Stämpfli und Cie, Bern, Switzerland.

Anon (1998a) *Wald-Standortskartierung, Kanton Appenzell Innerrhoden*. Scherrer Ingenieurbüro AG, Nesslau, SG, Switzerland.

Anon (1998b) *Carte phytosociologique des forêts du canton de Neuchâtel*. Service cantonal des forêts, Neuchâtel, Switzerland, unpublished.

Anon (2008) Formeln und Konstanten für die Berechnung der Schweizerischen schiefachsigen Zylinder-projektion und der Transformation zwischen Koordinatensystemen. Bundesamt für Landestopografie Swisstopo, Bern, Switzerland.

Anon (2014) *Switzerland’s Greenhouse Gas Inventory 1990–2012: National Inventory Report 2014*. Federal Office for the Environment FOEN, Bern, Switzerland. 532. www.bafu.admin.ch/ghginv2014.

Beck, E. (1858) *Karte der Umgebungen von Bern*. E. Beck, Bern, Switzerland.

Béguin, J. (2010) Landwirtschaftliche Drainagen der Schweiz: quo vadis? In: *Informationen Ländliche Ent-wicklung 2010* (ed. by: Weber, R.). suissemelio / Bundesamt für Landwirtschaft BLW, Bern, Switzerland.

Béguin, J. & Smola, S. (2010) *Stand der Drainagen in der Schweiz, Bilanz der Umfrage 2008*. Bundesamt für Landwirtschaft BLW, Bern.

BGS (1996) *Schlüssel zur Klassifikation der Bodentypen der Schweiz*. Bodenkundliche Gesellschaft der Schweiz BGS, Switzerland.

Broggi, M.F. (1990) *Inventar der Flachmoore von nationaler Bedeutung*. Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland.

Broggi, M.F. (1994a) Kriterien zur Behandlung von Flachmoor-Singularitäten. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Broggi, M.F. (1994b) Fragen und Antworten zum Flachmoorinventar. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Brunner, H., Jäggli, F., Nievergelt, J. & Peyer, K. (1997) *Kartieren und Beurteilen von Landwirtschaftsböden*. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau FAL, Zürich, Switzerland.

Brunner, H., Nievergelt, J., Peyer, K., Weisskopf, P. & Zihlmann, U. (eds.) (2002) *Klassifikation der Böden der Schweiz*. Bodenkundliche Gesellschaft der Schweiz BGS / Eidgenössische Forschungsanstalt für Agrarökologie und Landbau FAL, Zürich, Switzerland.

Brunner, H., Conradin, H., Gasser, U., Kayser, A., Lüscher, P., Meuli, R., Müller, M., Nievergelt, J., Pazeller, A., Peyer, K., Presler, J., Weisskopf, P. & Zürrer, M. (eds.) (2010) *Klassifikation der Böden der Schweiz*. Bodenkundliche Gesellschaft der Schweiz BGS, Luzern, Switzerland.

Burga, C., A. (2010) Upper Engadin: Samedan - St. Moritz - Bernina - Maloja, Grisons, Switzerland: Vegetation map, Geological map, scale 1:50,000. University of Zurich, Switzerland.

Burger, T. (1996) *Standortskundlicher Kartierungsschlüssel für die Wälder der Kantone Bern und Freiburg*. ARGE Kaufmann+Partner, Solothurn / Burger+Stocker, Lenzburg / WSL, Birmensdorf, Switzerland.

Burger, T. (2003) *Standortskundliche Exkursionen in die Wälder des Kantons Zug*. Kantonsforstamt Kanton Zug, Zug, Switzerland.

Burnand, J. & Züst, S. (1979) Zum Inventar der Feuchtgebiete im Kanton Zürich. *Vierteljahrsschrift der Naturforschenden Gesellschaft in Zürich*, **124**, 313-327.

Burnand, J., Frehner, M. & Rutishauser, U. (2013) *Waldstandorte in Appenzell Ausserrhoden: Beschreibung der Standortseinheiten*. Kanton Appenzell Ausserrhoden, Herisau, Switzerland.

Burnand, J., Frehner, M., Frey, H.-U., Preiswerk, T. & Lüscher, P. (1999) Projekt Waldstandortskartierung St. Gallen-Mittelland: Bericht zum Teilprojekt, Kartierungsschlüssel und Beschreibung der Standorte - Katalog der Standortstypen. Kantonsforstamt St. Gallen, St. Gallen, Switzerland, unpublished.

Bussell, J., Jones, D.L., Healey, J.R. & Pullin, A.S. (2010) How do draining and re-wetting affect carbon stores and greenhouse gas fluxes in peatland soils? *Collaboration for Environmental Evidence Review*, **08-012 (SR49)**, 1-74.

Clymo, R.S. (1984) The limits to peat bog growth. *Philosophical Transactions of the Royal Society of London Series B*, **303**, 605-654.

Dalang, T. & Fischbacher, U. (1992) Fraktale Geometrie der Flachmoore. *Informationsblatt des Forschungsbereich Landschaft, WSL*, **12**, 3.

Delarze, R. & Gonseth, Y. (2008) *Lebensräume der Schweiz*. Ott, Thun, Switzerland.

Düggeli, M. (1903) Pflanzengeographische und wirtschaftliche Monographie des Sihltales bei Einsiedeln von Roblosen bis Studen (Gebiet des projektierten Sihlsees). Zürcher & Furrer, Zürich, Switzerland.

Ellenberg, H. & Klötzli, F. (1972) *Waldgesellschaften und Waldstandorte der Schweiz*. Schweizerische Anstalt für das Forstliche Versuchswesen, Birmensdorf, Switzerland.

ESRI Inc., (1999-2013) *ArcGIS 10.2.1. for Desktop*, ESRI Inc. California, USA.

FAO (1998) *World reference base for soil resources*. Food and Agriculture Organization of the United Nations, FAO, Rome, Italy.

Fell, H., Roßkopf, N. & Zeitz, J. (2014) Impact of the spatial resolution of soils data on climate reporting for organic soils using the example of Germany. *Mires and Peat*, **14**, 1-9.

Freeman, C., Evans, C.D., Monteith, D.T., Reynolds, B. & Fenner, N. (2001) Export of organic carbon from peat soils. *Nature*, **412**, 785.

Frei, E. & Peyer, K. (1985) *Bodenkarte Grindelwald*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich, Switzerland.

Frey, H.-U. (1995) Waldgesellschaften und Waldstandorte im St. Galler Berggebiet. *Veröffentlichungen des Geobotanischen Institutes der Eidg. Tech. Hochschule, Stiftung Rübel, Zürich*, **126a**, 1-280. http://retro.seals.ch/digbib/voltoc?pid=gbi-002:1995:126.

Frey, H.-U. & Bichsel, M. (2005) *Waldgesellschaften und Waldstandorte des Kantons Uri*. Sicherheitsdirektion des Kantons Uri, Amt für Forst und Jagd, Altdorf, Switzerland.

Früh, J. & Schröter, C. (1904) Die Moore der Schweiz mit Berücksichtigung der gesamten Moorfrage. A. Francke, Bern, Switzerland.

Gallandat, J.-D., Gobat, J.-M. & Roulier, C. (1993) *Kartierung der Auengebiete von nationaler Bedeutung*. Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland.

Gams, H. (1927) Von den Follatères zur Dent de Morcles: Vegetationsmonographie aus dem Wallis. *Beiträge zur geobotanischen Landesaufnahme*, **15**, 1-760.

Gerber, B., Gsteiger, P., Leibundgut, M. & Righetti, A. (1999) *Gletschervorfelder und alpine Schwemmebenen als Auengebiete*. Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland.

Gerber, E. (1925) Über die Entstehung der Torfmoore südöstlich Bern. *Mitteilungen der Naturforschenden Gesellschaft in Bern*, 20-23. http://retro.seals.ch/digbib/view?pid=mnb-001:1925:-::69.

Gimmi, U., Lachat, T. & Bürgi, M. (2011) Reconstructing the collapse of wetland networks in the Swiss lowlands 1850-2000. *Landscape Ecology*, **26**, 1071-1083.

Gonin, L. (1862) *Le desséchement de la Plaine de l'Orbe: Cartes*. Imprimerie Georges Bridel, Lausanne, Switzerland.

Goodchild, M.F. (2011) Scale in GIS: An overview. *Geomorphology*, **130**, 5-9.

Grossenbacher, K. (1980) Die Hoch- und Übergangsmoore des Kanton Bern: eine Übersicht. *Mitteilungen der Naturforschenden Gesellschaft in Bern*, **37**, 81-130. http://retro.seals.ch/digbib/view?pid=mnb-002:1980:37::212.

Grunder, K. & Baggenstos, M. (1993) *Die Waldgesellschaften des Kantons Nidwalden*. Oberforstamt Nidwalden, Stans, Switzerland, unpublished.

Grünig, A. (ed.) (1994) *Mires and man: Mire conservation in a densely populated country - the Swiss experience*. Swiss Federal Institute for Forest, Snow and Landscape Research, WSL, Birmensdorf, Switzerland. http://www.wsl.ch/dienstleistungen/publikationen/pdf/420.pdf

Grünig, A. (2007) Moore und Sümpfe im Wandel der Zeit. *Hotspot: Biodiversität in Feuchtgebieten*, **15**, 4-5.

Grünig, A., Vetterli, L. & Wildi, O. (1986) *Die Hoch- und Übergangsmoore der Schweiz*. Eidg. Anst. forstl. Versuchwes. Ber, Birmensdorf. **281**, 62. http://www.wsl.ch/dienstleistungen/publikationen/pdf/448.pdf

Haering, C., Jäckli, H., Kobel, M., Kündig, R., Lienert, O., Philipp, R., Starck, P. & Wyssling, L. (1993) *Hydrogeologische Karte 1:100'000, Blatt 5, Toggenburg*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Hahn, P. (2011) Zeitspuren im Entlebuch: Waldentwicklung und Landschaftswandel im 20. Jahrhundert. Haupt Verlag, Bern Stuttgart Wien.

Hainard, P., Michel, C. & Clot, F. (1992) *Carte de la végétation du Pays-d'Enhaut et de La Place de Tir du Petit-Hongrin*. Division Protection de la Nature Lausanne, Switzerland.

Hauber, L. & Pfirter, U. (1991/1992) *Hydrogeologische Karte 1:100'000, Blatt 4, Biel / Bienne*. Schweizerische Akademie der Naturwissenschaften (1988-2003), Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Hoins, U., Presler, J., Gysi, M. & Hoegger, S. (1996) *Abklärung des Handlungsbedarfs bezüglich der Nutzung von organischen Böden im Kanton Zürich*. Fachstelle Bodenschutz, Kanton Zürich, Zürich, Switzerland.

Holden, J. (2005) Peatland hydrology and carbon release: why small-scale process matters. *Philospohical Transactions of the Royal Society of London Series A*, **363**, 2891-2913.

Imhof, E. (1927) Unsere Landeskarten und ihre weitere Entwicklung. *Schweizerische Zeitschrift für Vermessungen und Kulturtechnik*, **25**, 1-21.

IPCC (2006) Volume 4, Agriculture, Forestry and Other Land Use. In: *IPCC guidelines for national greenhouse gas inventories* (ed. by: Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K.). Institute for Global Environmental Strategies IGES, Japan. http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html.

IPCC (2014) 2013 Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories: Wetlands. (ed. by: Hiraishi, T., Krug, T., Tanabe, K., Srivastava, N., Baasansuren, J., Fukuda, M. and Troxler, T.G.). IPCC, Switzerland. http://www.ipcc-nggip.iges.or.jp/public/wetlands/pdf/Wetlands_Supplement_Entire_Report.pdf.

Jäckli, H. (1985) *Hydrogeologische Karte 1:100'000, Blatt 3, Panixerpass*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Jäckli, H. & Kempf, T. (1972) *Hydrogeologische Karte 1:100'000, Blatt 1, Bözberg Beromünster*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Jozic, M. (1988) *Bodenkarte des Kantons Zug 1:5000*. Baudirektion des Kantons Zug, Amt für Umweltschutz, Zug, Switzerland.

Kasimir-Klemedtsson, A., Klemedtsson, L., Berglund, K., Martikainen, P., Silvola, J. & Oenema, O. (1997) Greenhouse gas emissions from farmed organic soils: a review. *Soil Use and Management*, **13**, 245-250.

Kempf, T. (1980) *Hydrogeologische Karte 1:100'000, Blatt 2, Bodensee*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Klaus, G. (ed.) (2007) *Zustand und Entwicklung der Moore in der Schweiz*. Federal Office for the Environment FOEN, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00067/index.html?lang=de&show_kat=/publikationen/00029

Knecht, M. (2009) Torfimporte in die Schweiz und deren Umwelt- und Klimabilanz. Pro Natura, Basel, unpublished.

König, F. & Rufer, F. (1920) *Land und Leute des Moosseetales*. Verlag der Flurgenossenschaft des Münchenbuchseemooses in Münchenbuehsee, Switzerland.

Krause, M., Buchli, R. & Peyer, K. (1986) *Bodenkarte Davos, Parsenn, Dischma*. Eidg. Anst. forstl. Versuchwes. Ber, Birmensdorf, Switzerland.

Kuhn, N. & Amiet, R. (1988) *Inventar der Auengebiete von nationaler Bedeutung*. Bundesamt für Forstwesen und Landschaftsschutz, Bern, Switzerland.

Landolt, E. (1977) Flora indicativa: Ökologische Zeigerwerte und biologische Kennzeichen zur Flora der Schweiz und der Alpen. Haupt Verlag, Bern, Switzerland.

Leiber-Sauheitl, K., Fuss, R. & Freibauer, A. (2014) High CO2 fluxes from grassland on histic Gleysol along soil carbon and drainage gradients. *Biogeosciences*, **11**, 749-761.

Leifeld, J., Bassin, S. & Fuhrer, J. (2003) Carbon stocks and carbon sequestration potentials in agricultural soils in Switzerland. *Schriftenreiher der FAL*, **44**, 1-109.

Leupi, E. (1994) Kleinseggenriede der Schweiz und ihre Böden. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Leuthold, B. (1996) Beschreibung der Röhrichte (Phragmition) und der Grossseggenriede (Magnocaricion). In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Lienert, B. (2013) Einfluss von Aufforstung auf Kohlenstoffverluste aus organischen Böden (Halbmooren) im Staatswald bei Witzwil (BE). MSc Thesis, Univeristy of Zurich, Switzerland.

Locher, T. (1953-1954) Kurzer Blick auf die Entstehung der Dufourkarte. *Jahresbericht der Geographischen Gesellschaft von Bern*, **42**, 4-6.

Lüdi, W. (1935) Das grosse Moos im westschweizerischen Seelande und die Geschichte seiner Entstehung. *Veröffentlichungen des Geobotanischen Institutes Rübel in Zürich*, **11**, 1-344. http://retro.seals.ch/digbib/voltoc?pid=gbi-001:1935:11.

Lüdi, W. (1944) Moore der Voralpen zwischen der Wald-Emme und der Sarner-Aa [Moore der Schweiz. VI a. Kantone Luzern, Obwalden, Nidwalden]. Geobotanisches Institut der Eidgenössischen Technischen Hochschule, Zürich, unpublished.

Lüdi, W. (1973a) *Moore der Schweiz. I. Kanton Waadt*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973b) *Moore der Schweiz. II. Kanton Neuenburg*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973c) *Moore der Schweiz. III. Kanton Freiburg*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973d) *Moore der Schweiz. IV. Kanton Bern*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973e) *Moore der Schweiz. V. Kanton Aargau*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973f) *Moore der Schweiz. VI. Kantone Luzern, Obwalden, Nidwalden*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973g) *Moore der Schweiz. VII. Kantone Schwyz und Zug*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973h) *Moore der Schweiz. VIII. Kantone St.Gallen und Thurgau*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973i) *Moore der Schweiz. IX. Kantone St.Gallen und Appenzell*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüdi, W. (1973j) *Moore der Schweiz. X. Kanton Graubünden*. Schweizerischer Bund für Naturschutz, Basel, Switzerland.

Lüscher, C. (2013) *Bodenkartierung Kanton Glarus 2006 - 2010*. ARCOPLAN, Ennetbaden, Switzerland.

Maurer, P. (1985) *Anbauschlacht*. CHRONOS, Zürich, Switzerland.

Mössinger, E. (2013) *Zustand und Eigenschaften von Torfböden der Schweiz*. MSc Thesis, University of Basel, Switzerland.

Mühlethaler, E. (1994) Nutzungsgeschichte der Flachmoore in der Schweiz. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Mühlethaler, E. (1995) Nutzungsgeschichte der Hoch- und Übergangsmoore. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Nussbaum, F. (1926) Das Moosseetal, ein diluviales Fluß- und Gletschertal. *Mitteilungen der Naturforschenden Gesellschaft in Bern*, 122-169. http://retro.seals.ch/digbib/view?pid=mnb-001:1926:-::183.

Parish, F., Sirin, A., Charman, D., Joosten, H., Minayeva, T., Silvius, M. & Stringer, L. (2008) *Assessment on peatlands, biodiversity and climate change: Main report*. Global Environment Centre, Kuala Lumpur, Malaysia / Wetlands International, Wageningen, The Netherlands. 179.

Pasquier, F., Bouzelboudjen, M. & Zwahlen, F. (1998) *Hydrogeologische Karte 1:100'000, Blatt 6, Saane/Sarine*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Pasquier, F., Bichet, V. & Zwahlen, F. (2006) *Hydrogeologische Karte 1:100'000, Blatt 7, Vallorbe-Léman nord*. Schweizerische Geotechnische Kommission, Zürich, Switzerland.

Peyer, K. (1984) *Bodenkarte Hörnli, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1986a) *Bodenkarte Murten, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1986b) *Bodenkarte Wohlen, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1988a) *Bodenkarte Luzern, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1988b) *Bodenkarte Zürich, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1988c) *Bodenkarte Zurzach, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1992) *Bodenkarte Laufenburg, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1993) *Bodenkarte Rheinfelden, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K. (1996) *Bodenkarte Baden, 1:25,000*. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau FAL, Zürich-Reckenholz, Switzerland.

Peyer, K. & Frei, E. (1992) *Klassifikation der Böden der Schweiz*. Eidgenössische Forschungsanstalt für Agrarökologie und Landbau FAL, Zürich-Reckenholz, Switzerland.

Peyer, K., Brunner, H. & Wüest, O. (1983) *Bodenkarte Hochdorf, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K., Flückiger, R., Schai, F. & Bonnard, L.F. (1981) *Bodenkarte Uster, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Peyer, K., Flückiger, R., Walther, H.R., Wüest, O. & Zihlmann, U. (1984) *Bodenkarte Lyss, 1:25,000*. Eidgenössiche Forschungsanstalt für landwirtschaftlichen Pflanzenbau FAP, Zürich-Reckenholz, Switzerland.

Preiswerk, T. (1993) Waldgesellschaften und Waldstandorte im Kanton Schwyz. Atragene, Zürich.

Presler, J., Zürrer, M. & Kaufmann, G. (2005) *Bodenübersichtskarte Kanton Thurgau, 1:50'000*. Amt für Umwelt des Kantons Thurgau / Amt für Raumplanung des Kantons Thurgau, Frauenfeld, Switzerland.

Probst, E., Schmidlin, H. & Zimmerli, N. (1923) *Die Torfausbeutung in der Schweiz in den Jahren 1917 bis 1921*. Eidgenössische Inspektion für Forstwesen, Jagd und Fischerei, Bern, Switzerland.

Rihm, B. (2011) *LULUCF Abgrenzung organischer Böden*. Meteotest, Bern, unpublished.

Roth, A. (1919) *Die Vegetationskarte des Walenseegebietes*. Kartographia Winterthur AG, Winterthur, Switzerland.

SCA (1988-2015) Available at: https://www.swiss-impex.admin.ch/ (accessed 6th January 2015).

Schindler, C. (2004) Zum Quartär des Linthgebietes zwischen Luchsingen, dem Walensee und dem Zürcher Obersee. *Beiträge zur geologischen Karte der Schweiz*, **169**, 1-166.

Schmider, P., Winter, D. & Lüscher, P. (2003) *Wälder im Kanton Thurgau: Waldgesellschaften, Waldstandorte, Waldbau* Thurgauische Naturforschende Gesellschaft, Frauenfeld, Switzerland.

Schmider, P., Küper, M., Tschander, B. & Käser, B. (1993) *Die Waldstandorte im Kanton Zürich: Waldgesellschaften, Waldbau, Naturkunde*. Oberforstamt und Amt für Raumplanung des Kantons Zürich, Zürich, Switzerland.

Schüepp, M. & Gensler, G. (1980) Klimaregionen der Schweiz. In: Die Beobachtungsnetze der Schweizerischen Meteorologischen Anstalt. Konzept 1980. Arbeitsberichte der Schweizerischen Meteorologischen Anstalt, Nr. 93, Anhang Ib (ed. by: Müller, G.), Zürich, Switzerland.

Seitz, N. (2013) Drainagen in der Schweiz: Zeitlicher Verlauf, aktuelle Datenlage und Einfluss auf die Landschaftsentwicklung. MSc Thesis, Eidgenössische Forschungsanstalt WSL, Birmensdorf, Switzerland.

SFSO (2000) Digitale Bodeneignungskarte der Schweiz; 1:200,000. Neuchâtel, Switzerland.

Shotyk, W. (2002) The chronology of anthropogenic, atmospheric Pb deposition recorded by peat cores in three minerogenic peat deposits from Switzerland. *Science of the Total Environment*, **292**, 19-31.

Shotyk, W., Weiss, D., Appleby, P.G., Cheburkin, A., Frei, R., Gloor, M., Kramers, J.D., Reese, S. & Van Der Knaap, W.O. (1998) History of Atmospheric Lead Deposition Since 12,370 14C yr BP from a Peat Bog, Jura Mountains, Switzerland. *Science*, **281**, 1635-1640.

Spinner, H. (1932) *Carte phytogéographique du Haut-Jura neuchâtelois nord-occidental*. Art. Institut Orell Füssli Zürich, Switzerland.

Steiner, G.M. & Grünig, A. (1997) Die hydrologischen Moortypen der Schweiz. In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Stocker, R., Burger, T., Elsener, O., Liechti, T., Portmann-Orlowski, K. & Zantop, S. (2002) *Die Waldstandorte des Kantons Aargau*. Finanzdepartement des Kantons Aargau, Abteilung Wald, Aarau, Switzerland.

Swisstopo (2005) Ausgaben_Siegfriedkarten_digital.xls, from: http://www.swisstopo.admin.ch/internet/swisstopo/de/home/products/maps/hist/siegfried.parsysrelated1.94029.downloadList.32777.DownloadFile.tmp/siegfriedausgabende.pdf. Bern, Switzerland.

Thielen, R., Tognola, M., Roulier, C. & Teuscher, F. (2002) *Ergänzung des Bundesinventars der Auengebiete von nationaler Bedeutung*. Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland.

Tobler, W. (1988) Resolution, Resampling, and All That. In: *Building Data Bases for Global Science* (ed. by: Mounsey, H. and Tomlinson, R.), pp. 129-137. Taylor and Francis, London, UK.

Tranvik, L.J. & Jansson, M. (2002) Terrestrial export of organic carbon. *Nature*, **415**, 861-862.

Trechsel, F. (2004) *General Charte der Jura Gewässer (1817)*. Cartographica Helvetica, Murten, Switzerland.

Vischer, D. (2003) *Die Geschichte des Hochwasserschutzes in der Schweiz*. Bericht des Bundesamt für Wasser und Geologie BWG, Bern, Switzerland.

von Wyl, B., Häfliger, P. & Baggenstos, M. (2003) *Pflanzensoziologische Kartierung der Luzerner Wälder - Kommentar Waldbau*. Kantonsforstamt Luzern, Luzern, Switzerland. 227.

Walcher, J. (1984) *Die Waldgesellschaften im Kanton Glarus*. Kantonsforstamt Glarus, Glarus, Switzerland.

Weibel, V. (2012) *Vom Dräckloch i Himel. Namenbuch des Kantons Schwyz*. Druckerei Triner AG, Schwyz, Switzerland.

Weinzierl, W. & Waldmann, F. (in prep.) Programm „Lebensgrundlage Umwelt und ihre Sicherung“ (BWPLUS), Abschlussbericht, Ermittlung langjähriger CO2-Emissionen und Beurteilung der Moore Oberschwabens auf Basis historischer und aktueller Höhennivellements. Landesamt für Geologie, Rohstoffe und Bergbau, Freiburg, Germany.

Werlen, C. (1994) Elaboration de la carte de végétation forestière du Valais. *Schweizerische Zeitschrift für Forstwesen*, **145**, 607-617.

Winkler, E. (1935-1936) Veränderungen der Kulturlandschaft im Zürcherischen Glattal. *Mitteilungen der Geographisch-Ethnographischen Gesellschaft Zürich*, **36**, 1-164.

Zimmerli, S. (1996) Beschreibung der Pflanzengesellschaften der Übergangsmoore (Scheuchzerietalia palustris). In: *Handbuch Moorschutz in der Schweiz 1* (ed. by: Bressoud, B., Broggi, M.F., Gonet, C., Hintermann, U., Grünig, A., Küttel, M., Marti, K., Schlegel, H. and Theis, E.). Bundesamt für Umwelt, Wald und Landschaft BUWAL, Bern, Switzerland. http://www.bafu.admin.ch/publikationen/publikation/00887/index.html?lang=de

Zuber, R. (2006) Waldstandorte. Forstdienst Graubünden, Chur, Switzerland.

7. Appendix I – Data Sets Used in Map

In the following tables, technical details regarding all data sets used in the new estimates of organic soils are given, namely the scale, the technical report or publication associated with the data set, the survey period (if known) and the "shortname", as was used in the GIS database; the data ownership and / or source of each data set is also indicated.

Soil maps (section 2.1.1.1); M.S. = map sheet; * survey period unknown; date(s) given refer to either completion of project, publishing of report, or analysis of samples

Canton, map sheet or region	Scale	Technical report / publication	Survey period	Data ownership and source (if different)	Shortname
GE	1:5,000		1985	Système d'information du territoire à Genève (SITG), canton GE; extracted: 27.10.2014	BK_GE
GL	1:5,000	Lüscher (2013)	2006-2010	Departement Volkswirtschaft und Inneres, Kanton GL; original data / source: Geodata, Kanton GL	BK_GL
LU, Einzugsgebiet des Sempachersees	1:10,000	-	1993*	Amt für Umweltschutz, Kanton LU; © GIS Kanton LU / Raumpooldaten; source: Dienststelle Raum und Wirtschaft, Kanton LU	BK_LU1
LU, Wauwiler Moos	1:5,000	-	1976*		BK_LU2
LU, Wauwil, Schötz, Ettiswil	1:5,000	-	1993*		BK_LU3
LU, Flühli, Längenhohwald, Churzenhütten	1:1,000	-	1994*		BK_LU4
LU, Bodenkarte / Wasser-haushalt des Bodens Gelfingen	1:5,000		1991*		BK_LU5
LU, Bodenkarte / Wasser-haushalt des Bodens Rickenbach	1:5,000		1992*		BK_LU6
LU, Bodenkarte / Wasser-haushalt des Bodens Altbüron	1:5,000		1986*		BK_LU7
SG	1:5,000 – 1:10,000	-	1972-1994	Amt für Umwelt und Energie, Kanton SG; © 2012 AFU SG; source: Amt für Raumentwicklung und Geoinformation, Kanton SG	BK_SG

SO	1:5,000	-	1996-2009	Fachstelle Bodenschutz, Amt für Umwelt, Kanton SO	BK_SO
SZ, communities Tuggen, Reichenburg, Schübelbach and Wangen	1:5,000	-	1991	Publication	BK_1 – BK_5
TG	1:50,000	Presler *et al.* (2005)	1974-2004*	Amt für Umwelt, Kanton TG; source: Amt Für Geoinformation, Kanton TG	BK_TG
VD			1971-2009*	Département de la sécurité et de l'environnment, état de Vaud; Géodonnées état de VD	BK_VD
ZG	1:5,000	Jozic (1988)		Amt für Umweltschutz, Kanton ZG; source: GIS-Fachstelle, Kanton ZG	BK_ZG
ZH	1:5,000		1988-1996	Amt für Landschaft und Natur, Kanton ZH; source: Amt für Raumentwicklung, Kanton ZH	BK_ZH
M.S. Baden	1:25,000	Peyer (1996)	1990-1993	Abteilung für Umwelt, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	BK25_1070
M.S. Davos		Krause *et al.* (1986)	1982-1983	Publication	BK25_1197
M.S. Grindelwald		Frei and Peyer (1985)	1981	Publication	BK25_1229
M.S. Hochdorf		Peyer *et al.* (1983)	1981	Amt für Umweltschutz, Kanton LU; © GIS Kanton LU / Raumpooldaten; source: Dienststelle Raum und Wirtschaft, Kanton LU	BK25_1130
M.S. Hitzkirch			1987-1996	Amt für Umweltschutz, Kanton LU; © GIS Kanton LU / Raumpooldaten; source: Dienststelle Raum und Wirtschaft, Kanton LU	BK25_1110
M.S. Hörnli		Peyer (1984)	1983	Publication	BK25_1093
M.S. Laufenburg		Peyer (1992)	1987-1989	Abteilung für Umwelt, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	BK25_1049
M.S. Luzern		Peyer (1988a)	1977-1986	Amt für Umweltschutz, Kanton LU; © GIS Kanton LU / Raumpooldaten; source: Dienststelle Raum und Wirtschaft, Kanton LU	BK25_1150

M.S. Lyss		Peyer *et al.* (1984)	1982	Publication	BK25_1146
M.S. Murten		Peyer (1986a)	1984	Publication	BK25_1165
M.S. Rheinfelden		Peyer (1993)	1985-1990	Abteilung für Umwelt, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	BK25_1048
M.S. Uster		Peyer *et al.* (1981)	1979	Publication	BK25_1092
M.S. Wohlen		Peyer (1986b)	1985	Abteilung für Umwelt, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	BK25_1090
M.S. Zürich		Peyer (1988b)	1978-1986	Publication	BK25_1091
M.S. Zurzach		Peyer (1988c)	1985-1986	Abteilung für Umwelt, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	BK25_1050
Grosses Moos, BE, FR	1:50,000	(Lüdi, 1935)	?	Publication	Lü18
BE, Moosseetal	ca. 1:25,000	König and Rufer (1920) obtained from Nussbaum (1926)	1917-1920	Publication	Kon

Habitat inventories (section 2.1.1.2)

Name	Scale	Technical report / publication	Survey period	Data ownership and source (if different)	Shortname
Federal Inventory of Raised and Transitional Bogs	1:25,000	Grünig *et al.* (1986)	1978-2008	FOEN, CH 3003 Bern	HMI
Federal Inventory of Fens of National Importance	1:25,000	Broggi (1990)	1987-2007	WSL / FOEN © 2012; source: WSL*	FMI
Federal Inventory of Fens of Regional Importance	1:25,000	explained in Broggi (1990)	1987-2007	WSL / FOEN © 2012; source: WSL*	FMIreg
Nature and Landscape Protection Inventory, canton Graubünden	1:10,000		1980-2006	Amt für Natur und Umwelt, Kanton GR; source: GeoGR AG	HM_GR
Wetland mapping – Inventory of canton Zürich	1:5,000		1976-1990	Amt für Landschaft und Natur, Naturschutz, Kanton ZH	FG_ZH

*WSL: Swiss Federal Institute for Forest, Snow and Landscape Research WSL / Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL / Institut fédéral de recherches sur la forêt, la neige et le paysage WSL

Forest habitat maps (section 2.1.1.3)

Canton	Scale	Technical report / publication	Survey period	Data ownership and source	Shortname
AG	1:5,000	Stocker *et al.* (2002)	1990-1992	Abteilung Wald, Kanton AG; data of canton AG; source: Departement Finanzen und Ressourcen, AGIS Service Center, Kanton AG	WG_AG
AI	1:5,000	Anon (1998a)	1997-1998	Oberforstamt, Land- und Forstwirtschafts-departement, Kanton AI	WG_AI
AR	1:5,000	Burnand *et al.* (2013)	2009-2012	Oberforstamt; Daten des Kantons AR	WG_AR
BE	1:5,000	Burger (1996)	1991-1994	Amt für Wald des Kantons BE	WG_BE
FR	1:5,000	Burger (1996)	1991-1994	Service des forêts et de la faune, état de FR; © Staat Freiburg – AWWF – ART 2012_01	WG_FR
GL		Walcher (1984)	1972-1984	Departement Bau und Umwelt, Umweltschutz und Energie, Kanton GL; original data / source: Geodaten Kanton GL	WG_GL
LU	1:10,000	von Wyl *et al.* (2003)	1991-2000	Dienststelle Landwirtschaft und Wald; © GIS Kanton Luzern / Raumpooldaten; source: Dienststelle Raum und Wirtschaft, Kanton LU	WG_LU
NE		Anon (1998b)	1951-1961	Service de la faune, des forêts et de la nature, canton et république de Neuchâtel	WG_NE
NW	1:5,000	Grunder and Baggenstos (1993)	1993-2005	Amt für Wald und Energie, Kanton Nidwalden; source: GIS-Daten AG	WG_NW
OW	1:10,000 - 1:25,000		1977-1980	Amt für Wald und Landschaft, Kanton Obwalden; source: GIS-Daten AG	WG_OW
SG	1:5,000	Frey (1995) mountain areas; Burnand *et al.* (1999, unpublished), lowlands	1992-2010	Kantonsforstamt; source: Amt für Raumentwicklung und Geoinformation, Kanton St. Gallen	WG_SG
SO	1:5,000		1977-1994	Amt für Wald, Jagd und Fischerei; source: Amt für Geoinformation, Abteilung SO!GIS, Kanton Solothurn	WG_SO

SZ	1:5,000	Preiswerk (1993)	1991-1992	© Amt für Wald und Naturgefahren, Kanton SZ	WG_SZ
SZ, OAK[13]	1:5,000		1979	Source: Walter Keller, pers. comm.	WG_OAK
TG	1:5,000	Schmider *et al.* (2003)	1994-2002	© Forstamt, Kanton TG, 2012; source: Amt für Geoinformation, Kanton TG	WG_TG
UR	1:5,000	Frey and Bichsel (2005)	1988-2008	Amt für Forst und Jagd, Kanton UR	WG_UR
VS		Werlen (1994)	?, 1988 – 1997	Service des forêts et du paysage, canton du VS	WG_VS
ZG	1:5,000	Burger (2003)	2004-2012	Amt für Wald und Wild, Kanton ZG	WG_ZG
ZH	1:5,000	Schmider *et al.* (1993)	1982-1987	Amt für Landschaft und Natur, Kanton ZH; source: Amt für Raumentwicklung, Abteilung Geoinformation, Kanton ZH	WG_ZH

[13] OAK = Oberallmeindkorporation Schwyz

Other vegetation maps (section 2.1.1.3)

Source	Scale	Survey period	Publication	Shortname
Wauwilermoos	ca. 1:25,000	1898	Früh and Schröter (1904)	FSreg
Eigenthal – Pilatus	ca. 1:25,000	1893-1895		FSreg
Les Ponts – La Sagne	ca. 1:50,000	1895		FSreg
Altmatt, Kanton Zug und Schwyz	ca. 1:50,000	1894		FSreg
Das Isenriet	ca. 1:100,000	1900		FSreg
Teufemattalp bei Flühli	1:5,000	1880	Hahn (2011)	Flü
Die Vegetationskarte des Walenseegebietes	1:50,000		Roth (1919)	Rot
Vegetationskarte des Rhonesgebietes zwischen den Dents de Morcles und dem unteren Entremont	1:50,000		Gams (1927)	Gam
Carte phytogéographique du Haut-Jura neuchâtelois nord-occidental	1:25,000		Spinner (1932)	Spi
Pflanzengeographische Karte des Sihltales bei Einsiedeln	1:25,000	1901?-1903	Düggeli (1903)	Dugg
Carte de la végétation du Pays-d'Enhaut et de La Place de Tir du Petit-Hongrin	1:25,000	1981-1983	Hainard *et al.* (1992)	Hai
Upper Engadine vegetation map	1:50,000	2007-2009	Burga (2010)	Bur

Geological atlas of the GeoCover data set (section 2.1.1.4). The source and ownership of all these data sets is the Federal Office of Topography Swisstopo. All maps of the geological atlas are of scale 1:25,000. The relevant polygons were combined into a single layer, alongside those of the compilation maps (next table). The shortname of this combined layer is “GC”.

Geographical atlas no.	Geological atlas sheet name	Publication date
1	Movelier – Soyhières – Delémont – Courrendlin	1930
2	La Chaux – Les Verrières	1930
3	Laufen – Bretzwil – Erschwil – Mümliswil	1936
4	Flawil – Herisau – Brunnadern – Schwellbrunn	1930
5	Mont-la-Ville – La Sarraz – Montricher – Cossonay	1935
6	Lauterbrunnen	1933
7	Mönchaltorf – Hinwil – Wädenswil – Rapperswil	1934
8	St-Maurice	1934
9	Scaletta	1935
11	Iorio	1939
13	Grindelwald	1938
14	Ardez	1940
15	Biaufond – Les Bois – La Ferrière – St-Imier	1946
16	Pfyn – Märstetten – Frauenfeld – Bussnang	1943
17	Vallée de Joux	1941
18	Beromünster – Hochdorf – Sempach – Eschenbach	1945
20	Zernez	1948
21	Münsingen – Konolfingen – Gerzensee – Heimberg	1949
22	Fraubrunnen – Wynigen – Hindelbank – Burgdorf	1950
23	St. Gallen – Appenzell	1949
24	Finhaut	1951
25	Les Plats – Marchairuz – La Cure – Arzier – Gimel	1950
26	Neuenegg – Oberbalm – Schwarzenburg – Rüeggisberg	1953
27	Jorat	1952
28	Luzern	1955
29	Zermatt	1955
30	Monte Moro	1954
31	Saas	1954
32	Gemmi	1956
33	Grand Saint-Bernard	1958
34	Basodino	1957
35	St-Léonard	1959
36	Gurnigel	1961
37	Monthey	1960
38	Diessenhofen	1961
39	Tesserete	1962
40	St-Ursanne	1963
41	Lenk	1962

42	Orbe	1963
43	Randa	1964
44	Scuol / Schuls – Tarasp	1963
45	Rorschach	1964
46	Coppet	1964
47	Montreux	1965
48	Genève	1965
49	Rodersdorf	1965
50	Wohlen	1966
51	Val de Ruz	1968
52	Andelfingen	1967
53	Linthebene	1969
54	Weinfelden	1968
55	Bonfol	1969
56	Andeer	1971
57	Hörnli	1970
58	Dt de Morcles	1971
59	Basel	1970
60	Bieler See	1971
61	Simplon	1972
62	Morges	1972
63	Murten	1972
64	Les Mosses	1974
65	Bischofszell	1973
66	Bellinzona	1974
67	Neuchâtel	1974
68	Val Bedretto	1975
69	Lugano	1976
70	Sciora	1977
71	St. Niklaus	1978
72	Solothurn	1977
73	P. Campo Tencia	1980
74	Neunkirch	1981
75	Eggiwil	1980
76	Lyss	1981
77	Sembrancher	1983
78	Säntis	1982
79	Langenthal	1984
80	Arlesheim	1984
81	Albulapass	1987
82	Lötschental	1985
83	Schächtental	1987
84	Sursee	1990

85	Lausanne	1988
86	Wil	1988
87	Adelboden	1993
88	Les Diablerets	1990
89	Zug	1990
90	Zürich	1992
91	Orsières	1992
92	Châtel-St-Denis	1993
93	Brig	1993
94	Yverdon-les-Bains	1994
95	Ste-Croix	1995
96	Moutier	1996
97	Beggingen	1997
98	Fribourg	1996
99	Romont	1995
100	Bern	2000
101	Chanrion	1998
102	Zurzach	2000
103	Moudon	2000
104	Worb	1999
105	Rossens	2002
106	Walensee	2003
107	Matterhorn	2003
108	St-Margrethen – Diepoldsau	2003
109	Büren a. A.	2004
110	Frick - Laufenburg	2005
112	Steckborn – Kreuzlingen	2008
113	Murgenthal	2003
115	Gruyères	2005
116	Rigi	2006
117	Nyon	2004
120	Baden	2006
121	Vals	2007
123	Payerne	2006
124	Bivio	2007
125	Romanshorn	2007
128	Uster	2007
129	Einsiedeln	2009
131	Aletschgletscher	2011
134	Albis	2009
135	Aarau	2011
141	Nesslau	2011
162	Travers	2011

Compilation maps of GeoCover data set (section 2.1.1.4). The source and ownership of all these data sets is the Federal Office of Topography Swisstopo. The relevant polygons were combined into a single layer, alongside those of the geological atlas (previous table). The shortname of this combined layer is “GC”.

Map sheet number	Sheet name	Scale of component map sheets	Survey period*
1048	Rheinfelden	1:100,000	1984
1051	Eglisau	1:100,000	1984
1071	Bülach	1:100,000	1984
1084	Damvant	1:50,000	1985
1088	Hauenstein	1:25,000	2010
1104	Saingnelégier	1:25,000	2005
1109	Schöftland	1:25,000	2005-2010
1110	Hitzkirch	1:50,000-1:100,000	1967-1984
1125	Chasseral	1:25,000	2011
1135	Buchs	1:25,000-1:50,000	1906-1985
1143	Le Locle	1:25,000	1910
1148	Sumiswald	1:25,000	2012
1149	Wolhusen	1:25,000	2002
1152	Ibereregg	1:50,000	1967
1153	Klöntal	1:50,000	1942
1154	Spitzmeilen	1:50,000	1920-1942
1155	Sargans	1:25,000-1:50,000	1917-1985
1171	Beckenried	1:10,000-1:50,000	1909-1995
1173	Linthtal	1:50,000	1942
1174	Elm	1:50,000	1920-1942
1175	Vättis	1:50,000	1920
1176	Schiers	1:12,500-1:50,000	1945-2012
1190	Melchtal	1:5,000-1:100,000	1942-2011
1191	Engelberg	1:25,000-1:100,000	1880-2011
1193	Tödi	1:50,000	1942
1194	Flims	1:50,000	1920-1942
1195	Reichenau	1:50,000	1920-1942
1210	Innertkirchen	1:25,000	1937-1995
1211	Meiental	1:25,000	2005-2008
1212	Amsteg	1:10,000-1:50,000	1926-1999
1213	Trun	1:50,000	1924
1215	Thusis	1:25,000	2011
1236	Savognin	1:10,000-1:200,000	1910-2007
1249	Finsteraarhorn	1:25,000	1928-2011
1254	Hinterrhein	1:25,000-1:50,000	1918-1945
1255	Splügenpass	1:25,000-1:100,000	1926-2006
1258	La Stretta	1:50,000	1946
1274	Mesocco	1:10,000-1:100,000	1923-2012
1275	Campodolcino	1:25,000	2000

1278	La Roesa	1:50,000	1946
1293	Osogna	1:25,000-100,000	2007
1294	Grono	1:25,000-1:100,000	2007-2012
1298	Lago di Poschiavo	1:50,000	1946
1312	Locarno	1:25,000	1990
1332	Brissago	1:10,000-1:25,000	1936-2010
1373	Mendrisio	1:10,000-1:25,000	1956-2012

* in the majority of cases, this is the range of publication dates of the component maps (from which the composite map was created)

Hydrogeological maps (section 2.1.1.4)

Map sheet	Publication	Scale	Data ownership and source	Shortname
Biel / Bienne	Hauber and Pfirter (1991/1992)	1:100,000	FOEN; source: Schweizerische Geotechnische Kommission	HYGEO
Saane / Sarine	Pasquier *et al.* (1998)	1:100,000		
Vallorbe – Léman nord	Pasquier *et al.* (2006)	1:100,000		

Quaternary maps of the Linthebene Region (section 2.1.1.4)

Map	Publication	Scale	Source	Shortname
Linth Plain	Schindler (2004)	1:25,000	published	Schi1
The valley bottom between Luchsingen, lake Klöntal and lake Walen				

Historical topographical maps - the Dufour maps (section 2.1.1.5)

Canton	Survey dates	Mapper where known	Data ownership and source	Shortname
AG	1837-1843	E. H. Michaelis	Swisstopo; maps digitised by the Landscape Dynamics research unit, WSL	SK_DK
BE	1845	H. H. Denzler		
BS	1815-1817	A. J. Buchwalder		
FR	1844-1851	A. Stryienski		
GE	1837-1838	G.-H. Dufour and J.J. Goll		
LU	1864-1867	H. Müllhaupt u. Sohn?		
NE	1838-1845	J. F. Ostervald		
SG, AI, AR	1851-1856	J. Eschmann		
SO	1828-1832	U. J. Walker		
TG	1839	J. J. Sulzberger		
VD	1862-1885?			
ZG	1845-1846	J. Anselmier		
ZH	1852-1865	J. Wild		
rest of cantons	~1837 – 1861	under instruction of G.-H. Dufour		

Information from: from http://www.swisstopo.admin.ch/internet/swisstopo/en/home/topics/geodata/historic_geodata/ma_col/duf_map.html, accessed 5th January 2015; Locher 1953-1954; from maps themselves, where seen

Historical topographical maps – excluding the Dufour maps (section 2.1.1.5)

Canton	Scale	Survey period	Data ownership and source	Shortname
Siegfried Map	1:25,000 and 1:50,000 (see main text)	Ca. 1880 (1st edition), and later edition: 1910	Swisstopo; maps digitised in-house and by the Landscape Dynamics research unit, WSL	SK_DK
FR, NE, BE Seeland	1:50,000	1816-1817	Published, Trechsel (2004)	Tre
BE, surroundings of Bern	1:24 742	1850	Published, Beck (1858)	Bec
VS, Orbe plain	1:50,000		Published, Gonin (1862)	Gon
ZH, Glattal	1:100,000	1700, 1930	Published, Winkler (1935-1936)	Win

Modern topographical map (section 2.1.1.6)

Name	Scale	Data ownership and source	Shortname
V25	accuracy: 3-8 m	Swisstopo	V25

Maps showing peat extraction (section 2.1.1.6)

Title	Scale	Source	Shortname
Vallée de Joux	1:25,000	From manuscript, Probst *et al.* (1923)	PE_1
Obere Orbe-Ebene	1:25,000		PE_2
Moorgebiet zwischen den drei Juraseen	1:25,000		PE_3
Moorgebiet Wauwil – Kaltbach – Uffikon	1:25,000		PE_4
Moorgebiet von Les Ponts – La Sagne und La Chaux-du-Milieu – La Brévine	1:25,000		PE_5
Moorgebiet von Muri – Boswil – Bünzen – Besenbüren – Althäusern	1:25,000		PE_6
Moorgebiet von Châtel-St.Denis, La Rogivue – Le Crêt, Semsales – Vaulruz, Sâles	1:25,000		PE_7
Moorgebiet von Altmatt-Rothenthurm und Einsiedeln – Schwantenau – Willerzell	1:25,000		PE_8
Moorgebiete am Oerlinger-, Hauser-, Nussbaumer-, Steinegger- und Hasensee	1:25,000		PE_9

Non-spatial data sets (sections 2.1.2.1 and 2.1.2.2)

Author	Title or region covered	Survey period	Source	Shortname
Früh J. and Schröter C.	National	1891-1903	Früh and Schröter (1904)	FStext2
Gerber, E.	SE of Bern (city)	?	Gerber (1925)	Gerb
Grossenbacher, K.	Canton Bern	1974-1976	Grossenbacher (1980)	Gros
Lüdi, W.	Kanton Waadt	1943-1951	Lüdi (1973a)	Lü1
Lüdi, W.	Kanton Neuenburg		Lüdi (1973b)	Lü2
Lüdi, W.	Kanton Freiburg		Lüdi (1973c)	Lü3
Lüdi, W.	Kanton Bern		Lüdi (1973d)	Lü4
Lüdi, W.	Kanton Aargau		Lüdi (1973e)	Lü5
Lüdi, W.	Kantone Luzern, Obwalden, Nidwalden		Lüdi (1973f)	Lü6
Lüdi, W.	Kantone Schwyz und Zug		Lüdi (1973g)	Lü7
Lüdi, W.	Kantone St. Gallen und Thurgau		Lüdi (1973h)	Lü8
Lüdi, W.	Kantone St. Gallen und Appenzell		Lüdi (1973i)	Lü9
Lüdi, W.	Kanton Graubünden		Lüdi (1973j)	Lü10
Lüdi, W.	Moore der Voralpen zwischen der Wald-Emme und der Sarner-Aa	1937-1944	Lüdi (1944)	Lü11
Probst E., Schmidlin, H. and Zimmerli, N.	National	1917-1918	Probst *et al.* (1923)	PET
n/a	Compilation of the above data sets (see section 2.4.2)	n/a	n/a	HisText

8. Appendix II – Structure of ArcGIS Tables

All component data sets contain a set of common fields in their attribute table, as shown in the table below. These are necessary for the successful running of the model tools, described in appendix III. Most data sets contain additional fields, as described in the following pages. The component data sets listed are not available from the authors of this report, but can be obtained from their proprietors (or otherwise), as indicated in appendix I.

Fields common to all attribute tables in the geodatabase

Field name	Field type	Description
ShortName	Text	Short name used to identify this data set
AuthorEndnote	Text	Author name of the publication relevant to data set, or, if this does not exist, the department / canton relevant to the data
DateEndnote	Short Integer	Publication date of the publication relevant to data set
DateF	Short Integer	Year of surveying or, if a range, the first year of surveying, if known
DateL	Short Integer	Year of surveying or, if a range, the last year of surveying, if known
IsPeat	Text	Indication of whether this data set represents organic soil (Y = yes) or mineral soil (N = no) at the time of survey
IsPeatQ	Text	Indication of the certainty of the presence of peat (A, B or C); see 2.3.3
SpatialQ	Text	Indication of the spatial accuracy of this data set (W, X or Y; or W, X, Y or Z); see 2.3.1 and 2.3.2.
Age	Text	Whether the data set is considered modern (M) or historical (H)
Scale	Long Integer	Scale of the map (e.g. “5000” means 1:5,000)
SpatialQ2*	Short Integer	Spatial quality (of field “SpatialQ”) converted into integers as follows: W → 3, X → 2, Y, Z → 1
Date* (for organic data sets)	Short Integer	The most recent date (year) of surveying, i.e. the contents of DateL; populated for modern data sets only
DateMin (for mineral data sets)	Short Integer	The oldest date (year) of surveying, i.e. the contents of DateF

* only populated for modern data sets where IsPeatQ = A or B

The following tables list the additional fields (first column) that occur in the attribute tables of the various feature class data sets; the corresponding information on data type (second column) and description (third column) are also given.

Soil maps of the cantons, a compilation of soil maps from cantons GE, GL, LU, SG, SO, TG, VD, ZG and ZH (section 2.1.1.1); short names = BK_GE, BK_GL, BK_LU1, BK_LU2, BK_LU3, BK_LU4, BK_SG, BK_SO, BK_TG, BK_VD, BK_ZG, BK_ZH

SheetName	Text	Name of the map
Description	Text	Description of the soil, as given in map

A compilation of soil maps each covering one 1:25,000 soil sheet, plus two local soil maps (those from canton Schwyz) (section 2.1.1.1); short names = BK_... or BK25_...

SheetName	Text	Name of the map
UnitCode	Text	Mapping unit code
Description	Text	Description of the soil, as given in map

Additional soil maps, compilation of Lüdi's soil map of the Grosses Moos region (Seeland) and König and Rufer's map of the Moosseetal (canton Bern) (section 2.1.1.1); short names = Lü18, Kon

IsIntact	Text	An indication (Y = yes, N = no, ? = unsure) of whether the site was intact at the time of survey, according to the description
Symbology	Text	Brief description of the symbology

Federal inventory of raised and transition bogs of national importance (section 2.1.1.2); short name = HMI

KE	Text	Mapping unit (Karteneinheit or unités cartographiées) from the raised bog inventory; see section 2.1.1.2 for details

Inventories of fens of national and regional importance (section 2.1.1.2); short names = FMI or FMIreg (fens of regional importance)

ScheuchzerietaliaPC	Short Integer	% cover of the vegetation type Scheuchzerietalia (e.g. '8' = 80% cover, '6' = 60% cover)
CaricionNigraePC	Short Integer	% cover of the vegetation type Caricion fuscae
CaricetaliaDavallianaePC	Short Integer	% cover of the vegetation type Caricetalia davallianae
PeatBuildingPC	Short Integer	Sum of the percentages from the vegetation types considered to be peat-building

Nature and landscape inventory, Graubünden (section 2.1.1.2); short name = HM_GR

SiteName	Text	Name of the site
Description	Text	Description of the habitat and / or vegetation

Wetland mapping – inventory of canton Zürich (section 2.1.1.2); short name = FG_ZH: no additional fields

Forest habitat maps (section 2.1.1.3); short name = WG_... e.g. WG_AG for canton Aargau

UnitFull	Text	Full name of the mapping unit used by the canton
UnitEKFull	Text	Full E & K unit name used by the canton
UnitEK	Text	E & K unit name (45, 56 or 71)

Local vegetation maps, a compilation of local habitat or vegetation maps, from: Früh & Schröter (1904), Hahn (2011), Roth (1919), Düggeli (1903), Gams (1927), Spinner (1932), Hainard et al. (1992) and Burga (2010) (section 2.1.1.3); short names = FSreg, Flü, Rot, Dugg, Gam, Spi1, Hai and Bur

MapTitle	Text	Name of the map
Code	Text	Mapping unit code
Description	Text	Description of the habitat and / or vegetation
IsIntact	Text	An indication (Y = yes, N = no, ? = unsure) of whether the site was intact at the time of survey, according to the description

GeoCover (section 2.1.1.4); short name = GC

Description	Text	Name of the mapping unit
SheetName	Text	Name of the 1:25,000 map sheet from the national map (“Blatteinteilung 1:25',000”)
SheetNumber	Text	Number of the 1:25,000 map sheet from the national map (“Blatteinteilung 1:25',000”)
MaxScale	Short Integer	The scale of the map (‘25,000’ = 1:25,000), or the scale of the least detailed map used if the GeoCover map is a compilation of geological maps
Comment	Text	Comments
IsIntact	Text	An indication (Y = yes, N = no, ? = unsure) of whether the site was intact at the time of survey, according to the description

Hydrogeological maps (section 2.1.1.4); short name = HYGEO

Lithology	Text	Lithology
CoverLayer	Text	Description of the cover layer (’Torf’ = peat, or ‘keine’ = none)
Scale	Text	Scale of the map
SheetName	Text	Name of the map sheet (from the 1:100,000 series)

Schindler’s Quaternary maps (section 2.1.1.4); short name = Schi1

Description	Text	Description of the sediment

Wetlands and peat extraction sites from the historical topographic maps, the Siegfried maps and the Dufour maps (section 2.1.1.5); short name = SK_DK

Occurrence	Text	Date of the map (1880 or 1910 or both) containing the wetland or peat symbology
Symbology	Text	Symbology

Other local historical topographical maps from Beck (1858), Gonin (1862), Trechsel (1817) and Winkler (1936) (section 2.1.1.5); short name = Bec, Gon, Tre, Win

MapTitle	Text	Name of the map
Code	Text	Mapping unit code
Description	Text	Description of the habitat and / or vegetation

Vector 25 (section 2.1.1.6); short name = V25

Symbology	Text	Mapping unit

Peat extraction maps from Probst et al. (1923) (section 2.1.1.6); short names = PE_1, PE_2, PE_3, PE_4, PE_5, PE_6, PE_7, PE_8, PE_9

PageNumber	ShortInteger	Page number of each map (of the pdf file)
Description	Text	Description of peat extraction method and / or organisation
IsIntact	Text	An indication (Y = yes, N = no, ? = unsure) of whether the site was intact at the time of survey, according to the description

Historical texts, a product of historical non-spatial information sources (excluding information from peat extraction records from Probst *et al.*, 1923) (section 2.1.2.1); short name = HisText

Sources	Text	The ShortName(s) of the text(s) providing information for each polygon (FStext2, Gerb, Gros, Lü)
Comments	Text	Comments

Peat extraction records from 1917 and 1918 from Probst *et al*. (1923) (section 2.1.2.2); short name = PET

Pe1	Text	Whether or not the site is listed in the 1917 table of sites from which peat could be extracted
Pe2	Text	Whether or not the site is listed in the 1918 table of sites from which peat could be extracted
IsIntact	Text	An indication (Y = yes, N = no, ? = unsure) of whether the site was intact at the time of survey, according to the description

9. Appendix III – Description of the Model Tools

A workflow was designed to create the digital map of organic soils. A large component of this workflow is a series of model tools which were built in ArcGIS and which automate a large part of the production of the map. These model tools are available from the first author and this section describes their use.

9.1. Formatting of Input Data Sets

Successful running of the model tools is dependent on the correct formatting of the input data sets / feature classes, namely the following fields in the attribute tables: “ShortName”, “IsPeat”, “IsPeatQ”, “SpatialQ”, “Age”, “SpatialQ2” and “Date” (other fields may be present). These fields must be correctly named and must have the correct field type and field content, as described in appendix II. Additionally these fields must be visible (i.e. not ‘hidden’). It is recommended that other fields in the attribute tables are however set as ‘hidden’, to avoid an overwhelmingly large attribute table when all layers are overlaid in Step 1 (below).

9.2. Running the Model Tools

Step 1

Run “model tool 1”. Parameter (P)1 = Path and name of the output file (e.g. Union1); P2 = Input features, which should be all layers indicative of *organic* soil (layers indicative of mineral soil are added in a later step).

This model creates a union of all input layers; the resulting attribute table contains all fields that were ‘visible’ in the input data sets. The model tool also adds a number of fields to the output (Union1), which will be populated and used in subsequent steps.

Step 2

Run “model tool 2”. P1 = Name of the input file (e.g. Union1); P2 to P7 = the following expressions: ALL_sources, ALL_is_peat, ALL_age, ALL_is_peatQ, ALL_spatial_Q, ALL_spatial_Q2.

These expressions concatenate the content of the respective fields across all input data sets, writing the data to the fields in the attribute table of Union1. The majority of these concatenated fields are used to carry out the classification of polygons in the next steps. The field “ALL_sources” (a concatenation of the short names associated with a given polygon) can be used to identify the information sources which individual polygons are represented by, in the final map.

Step 3

Run “model tool 3”. P1 = Name of the input file (e.g. Union1). This model has two main roles.

Firstly, for each polygon, it counts the number of data sets of the type “MA”, “MB”, “MC”, “HA”, “HB” or “HC” that each polygon is represented by. M = modern data set, H = historical data set, and A, B and C are as defined as in section 2.3.3, e.g. a polygon represented by, for example, a soil map (MA), the Siegfried map as peat (HA) and as a modern wetland (MC), would receive MA = 1, MB = 0, MC = 1, HA = 1, HB = 0, HC = 0.

Secondly, based on these combinations, and according to a set of rules (see section 2.4.2), this model tool assigns each polygon to a class (1 to 8, referred to as I to VIII in the main text). The rules determining the assigning of polygons to a class can be changed by entering (i.e. ‘editing’) the model tool.

Step 4

Run “model tool 4”. P1 = Path and name of output file (e.g. Union1OrgMin); P2 = path and name of second output file (e.g. Union1OrgMin_No_MinOnly); P3 = input features, which are the names of the layers containing information about mineral soil, as well as the output from steps 1 to 3 (e.g. Union1) which *must be* the upper-most layer listed; P4 = An expression, which is the concatenation of all the fields “IsPeat” from the mineral data sets, as well as “ALL_is_peat” from Union1. This model tool carries out 3 main tasks.

Firstly, it creates a union of the organic soil layer (the output from steps 1 to 3, e.g. Union1) and the layers indicative of mineral soil.

Secondly, the model tool creates and populates a field stating whether a polygon has information regarding organic soil only (field “is_peat” contains only Y’s), mineral soil only (field “is_peat” contains only N’s) or both (field “is_peat” contains Y’s and N’s). Those polygons represented by data sets indicative only of mineral soil are subsequently removed.

Thirdly, the model tool adds and populates a field “verdict 1”. This identifies polygons that are ‘potentially conflicting’ (see section 2.4.2) or not. It additionally adds a number of fields to the output (Union1OrgMin_No_MinOnly), which will be populated and used in the subsequent step.

Step 5

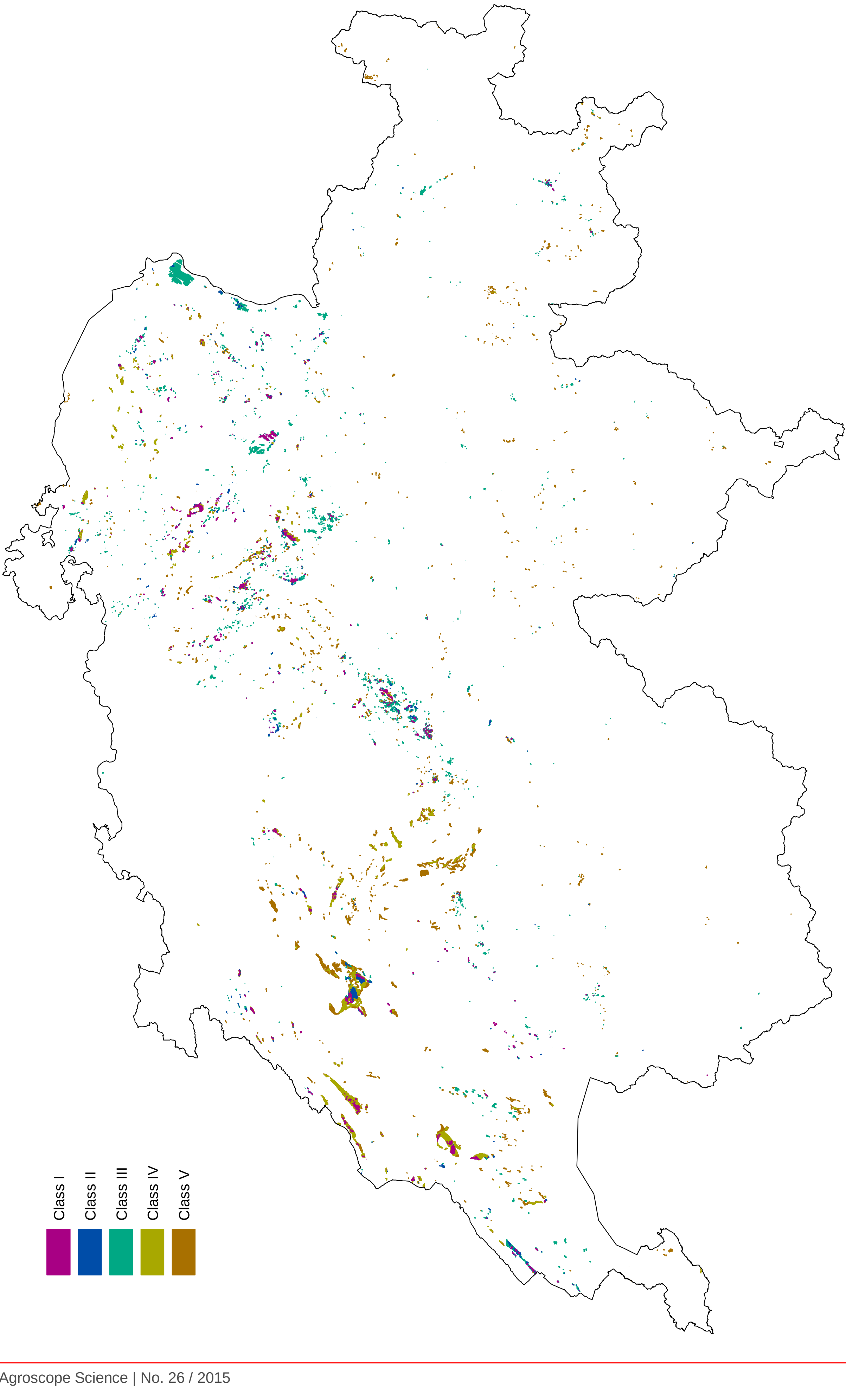
Run “model tool 5”. P1: Name of input file (e.g. Union1OrgMin_No_MinOnly); P2 = Name of file defining the boundary of Switzerland (or the boundary of whichever region is of interest); P3 = name and path of final output file (e.g. Union1OrgMin_No_MinOnly_CH).

This model tool has two main roles. The first role is to deal with polygons identified in step 4 as ‘potentially conflicting’. For each of these polygons, the model tool finds the date of the most recent data set indicative of organic soil and the oldest data set indicative of mineral soil, and compares these two dates. For the same set of polygons, the model tool also finds the spatial quality score of the most spatially accurate organic soil data set, and of the most spatially accurate mineral soil data set; these two scores are compared. Using a set of rules given in Table 13, polygons are then assigned to one of three categories (mineral, organic or represented by conflicting data).

As a final step, the spatial extent of the map is clipped to the boundary of Switzerland.

10. Appendix IV – Distribution of Organic Soil Surfaces by Class

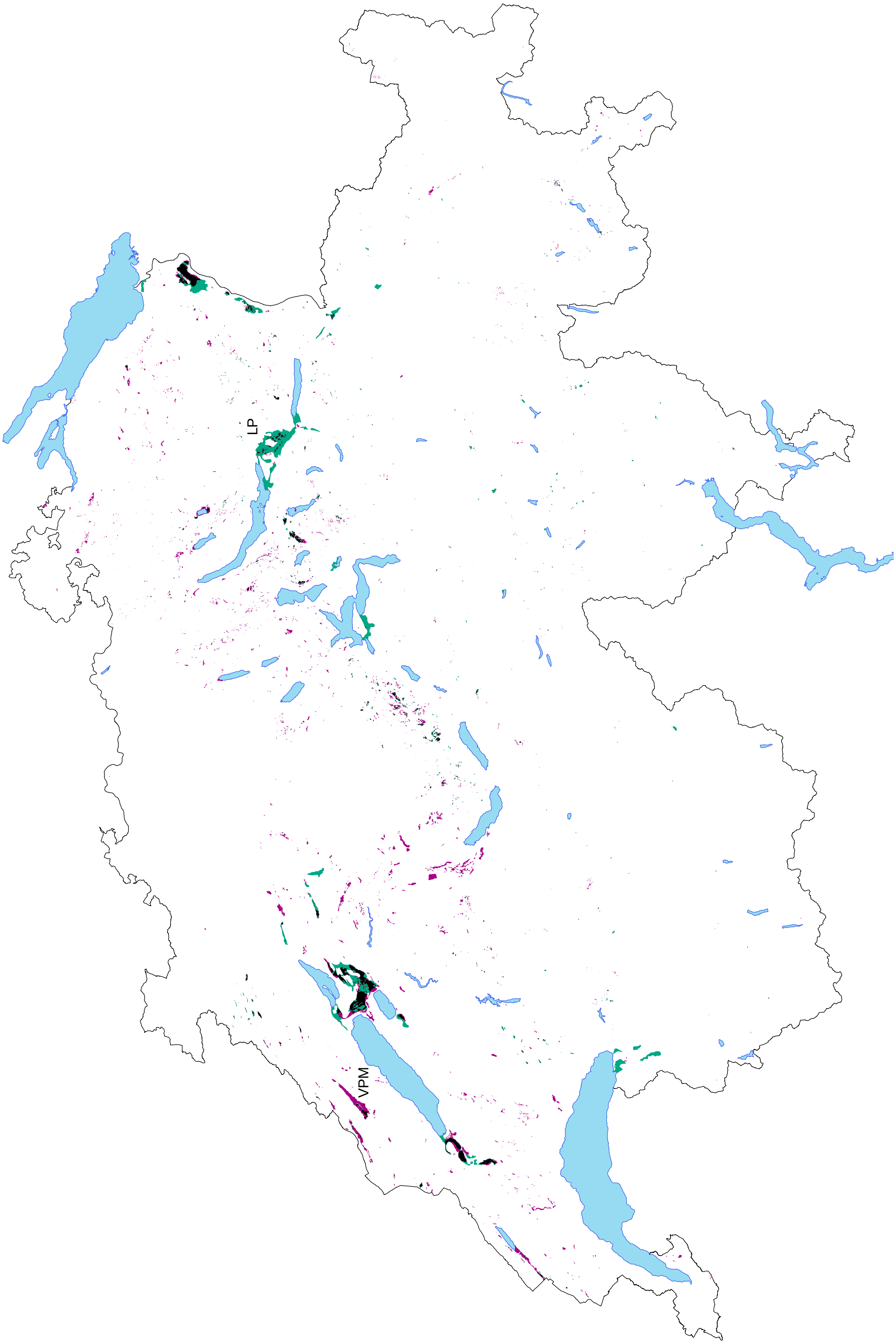
The map overleaf shows the distribution of the organic soil surfaces (classes I to V) by class. Pink surfaces represent class I surfaces; blue surfaces, class II; green surfaces, class III; dark yellow surfaces, class IV and brown surfaces, class V. Surfaces are exaggerated in size for better visibility. The original data sets used to create this map (and their proprietors) are listed in appendix I; national outline © Swisstopo.


Class I
Class II
Class III
Class IV
Class V

11. Appendix V – Comparison of Previous and Current Estimates

The map overleaf shows the distribution and intersect of the old and current (result of this work) estimates of organic soil for the Swiss GHGI. The old estimate is based on a combination of the Swiss soil suitability map (units Q3, "Grundnasse Alluvionen, Moore", water impermeable alluvial soils, mires; and unit F1, "Moore, Torf", mires, peat) and the federal inventory of raised and transitional bogs. The new estimate corresponds to classes I to V.

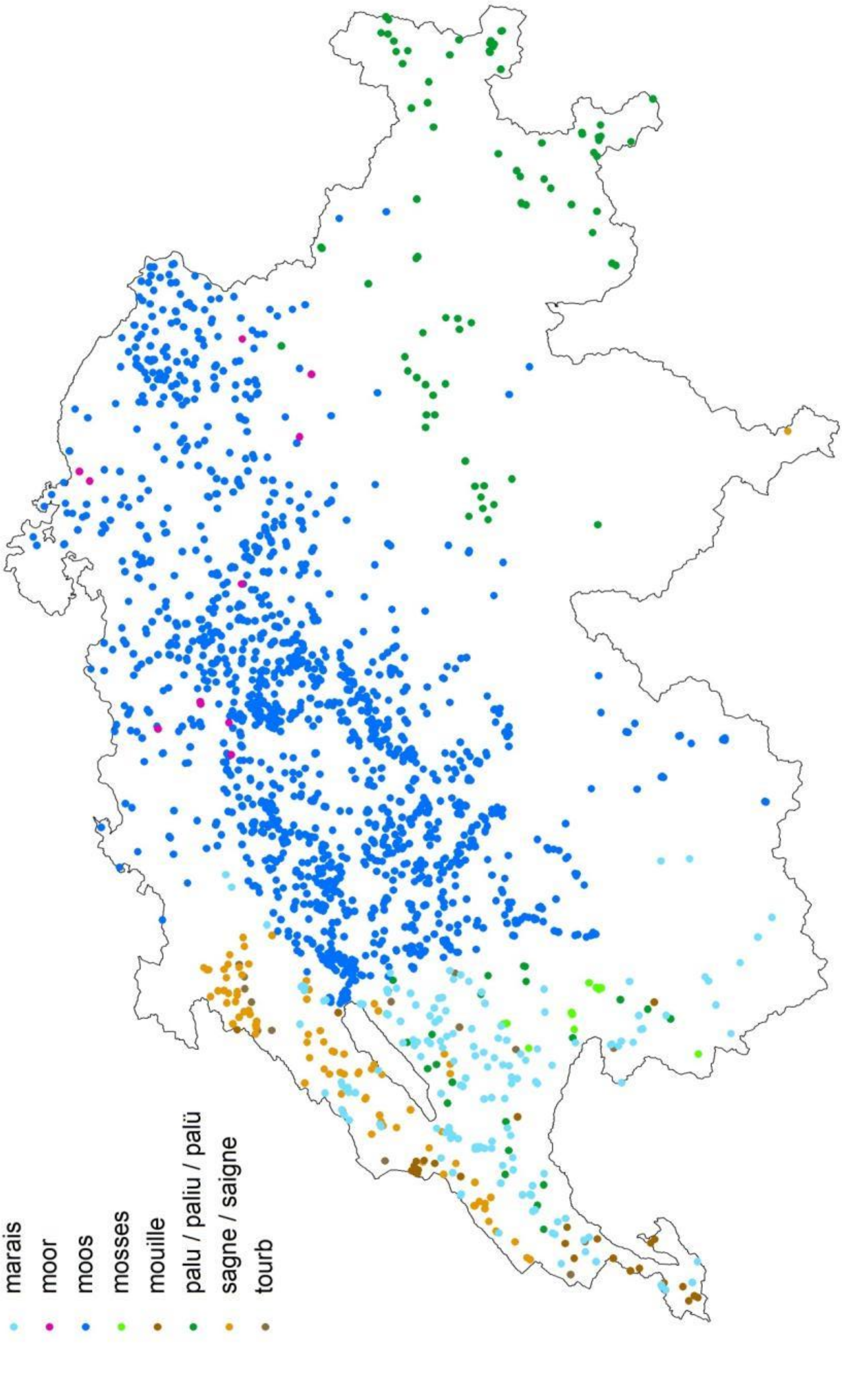
The numerous small surfaces of organic soil identified in the new estimates (pink surfaces) are apparent and – coincidentally – cover the same surfaces area as those surfaces only represented in the old estimate (green surfaces). The Linth plain is an example of fragmentation of a large previously-declared organic soil surface (section 3). This fragmentation is a result of increased spatial precision of the more modern maps used, as well as increased specificity of the attributes associated with these maps. In contrast, the Vallée des Ponts-de-Martel (the name reflects the wooden bridge ['pont'] which crossed the peatland ['Martel is the old French word for 'marais', referring to the peatland] build in the Roman age) is an example of a region whose extent has increased in the new estimate of organic soil, from circa 170 ha to circa 1,200 ha. Much of the surface identified by the new estimate of organic soil (only) is currently under intensive land use but still contains a peat layer often more than 2 m thick.



Green surfaces = surfaces identified only in the old estimate of organic soil; pink surfaces = identified only in the new estimate of organic soil; black surfaces = surfaces identified in both estimates of organic soil;. VPM = Vallée des Ponts-de-Martel; LP= Linth plain (see below). The original data sets used to create the modern estimate (and their proprietors) are listed in appendix I; national outline © Swisstopo; outline of the Federal Inventory of Raised and Transitional Bogs © FOEN, CH 3003 Bern; outline of units Q3 and F1 from the soil suitability map © Swiss Federal Statistical Office (SFSO), GEOSTAT.

12. Appendix VI – Locations of Placenames Potentially Associated with Peatlands

The map overleaf shows the locations of placenames including the terms “marais”, “moos”, “mosses”, “mouilles”, “moor”, “palu”, “paliu”, “sagne”, “saigne” or “tourb”, from the 2012 Swissnames data base; national boundary and Swissnames © Swisstopo


marais
moor
moos
mosses
mouille
palu / paliu / palü
sagne / saigne
tourb

13. Acknowledgements

The authors would like to thank the following people for help with preparation of data sets, help during fieldwork or for laboratory analysis of soil samples: Pasha Naeem, his for patience and work digitising the first edition of the Siegfried maps; Andreas Rohner for digitising numerous vegetation maps; Manuel Schuler for help with fieldwork for the ground-truthing of fen vegetation types; and Robin Giger for the laboratory analysis of soil samples. The ground-truthing of the forest vegetation map units was carried out as part of the master's thesis of Eva Mössinger (University of Basel); Eva is thanked for her work in the field and the laboratory.

This project drew upon many information sources and data sets produced by others. We would like to thank the following departments for providing us with data sets and metadata:

Departement Bau, Verkehr und Umwelt, AGIS Service Center, both of canton Aargau; Land- und Forstwirtschaftsdepartement, Appenzell Innerrhoden; Departement Volks- und Landwirtschaft (Oberforstamt), canton Appenzell Ausserrhoden; Amt für Wald, canton Bern; Service des forêts et de la faune, canton Fribourg; Service de géomatique et de l'organisation de l'information, canton Geneva; Departement Volkswirtschaft und Inneres, and Departement Bau und Umwelt (Abteilungen Raumentwicklung und Geoinformation and Umwelt, Wald und Energie), all of canton Glarus; Amt für Natur und Umwelt, canton Graubünden; Dienststelle Landwirtschaft und Wald, Dienststelle Umwelt und Energie (Amt für Umweltschutz), and Dienststelle Raum und Wirtschaft, all of canton Luzern; Service de la faune, des forêts et de la nature, Neuchâtel; Amt für Wald und Energie, canton Nidwalden; Amt für Wald und Landschaft, canton Obwalden; GIS-Daten AG, cantons Nidwalden and Obwalden; Dr. Walter Keller, Birmensdorf; Amt für Wald und Naturgefahren, canton Schwyz; Amt für Umwelt, Amt für Wald, Jagd und Fischerei and Amt für Geoinformation, all of canton Solothurn; Kantonsforstamt, Amt für Umwelt und Energie and Amt für Raumentwicklung und Geoinformation, all of canton St. Gallen; Amt für Umwelt and Amt für Geoinformation and the Forstamt, all of canton Thurgau; Amt für Forst und Jagd, canton Uri; Service des forêts et du paysage, canton Valais; Service des eaux, sols et assainissement, canton Vaud; GIS-Fachstelle, Amt für Umweltschutz and Amt für Wald und Wild, all of canton Zug; and the Amt für Raumentwicklung and Amt für Landschaft und Natur, both of canton Zürich.

The FOEN are thanked for making their inventory data sets publically available online; alongside the Swiss Geotechnical Commission (Schweizerische Geotechnische Kommission / commission géotechnique suisse) and the WSL (Eidg. Forschungsanstalt für Wald, Schnee und Landschaft WSL / Institut fédéral de recherches sur la forêt, la neige et le paysage WSL), they are also thanked for allowing the use of the digitised hydrogeological maps, and detailed data relating to the fen inventories, respectively. The Swiss Federal Statistics Office is thanked for making the digital version of the Soil Suitability Map available. Swisstopo is thanked for provision of the GeoCover, Swissnames and the Vector25 data sets, as well many 'accessory' data, including the orthophotos and lake, canton and national boundaries. The ETH (Zürich) map library is thanked for their generous support and for the provision of scans of historical topographical and vegetation maps.

The Landscape Dynamics research group of the WSL, in particular Matthias Bürgi and Urs Gimmi, are thanked for their cooperation, helpful discussion and allowing us to use the digitised Dufour maps, as well as two of the three editions of the Siegfried maps. Cécile Pellet, formerly of that research group, is thanked for carrying out the digitisation of the latter. Andreas Schellenberger of the FOEN is thanked for continuous constructive feedback throughout the project. Daniel Bretscher is thanked for comments related to quality assurance and quality control and Philippe Grosvernier is thanked for help translating the French abstract. The FOEN, Jeanne Woodtli, Gabriela Brändle and Margrit von Euw are thanked for allowing the use of photographs for this publication.

14. Figures and Tables

14.1. List of Figures

14.2. List of Tables

14.3. List of Figures and Tables in the Appendices

Schweizerische Eidgenossenschaft
Confédération suisse
Confederazione Svizzera
Confederaziun svizra

Swiss Confederation

Federal Department of Economic Affairs,
Education and Research EAER
Agroscope