Geoderma 204–205 (2013) 1–9

Contents lists available at SciVerse ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

# Soil maps of The Netherlands

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ARTICLE INFO

*Article history:*
Received 25 January 2013
Received in revised form 14 March 2013
Accepted 20 March 2013
Available online xxxx

*Keywords:*
Digital soil mapping
Soil survey
Pedology
Physiographic mapping
Soil classification
Soil geography

ABSTRACT

The Netherlands has a long history of soil research. Over the past 150 years, seven national soil maps have been produced at scales ranging from 1:50,000 to 1:1,000,000. The maps were based on different conceptual models which reflected advances in soil science as well as societal demands. There are four phases in the development of soil mapping in The Netherlands. The first three are: (i) the geological phase (1837–1937), (ii) the physiographic phase (1937–1962) and (iii) the morphometric phase (1962–1995). The earliest soil maps, made in the mid-1800s, were largely based on surface geology. In 1950 the first national soil map was published based on physiographic soil mapping. From the 1960s onwards, mapping followed a pedogenetic–morphometric approach and these maps have been widely used in land use planning, hydrologic studies, re-allotments, and agricultural land evaluations. An increase in environmental awareness with the need to assess environmental impacts and developments in information technology induced the digital soil information phase (1995–present). New technologies have improved the collection, storage, analysis and presentation of soil geographic information. It is concluded that initial soil mapping in The Netherlands had a strong agricultural focus but that the current maps are used in a wide range of applications.

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## 1. Introduction

The Netherlands has a number of distinct soil geographic regions (Edelman, 1950; Jongmans et al., 2013). About half of the country is below sea level and would be inundated in the absence of dikes, dunes and pumping plants. It is also a wet country and more than 90% of the soils have groundwater within 140 cm of the soil surface during the winter. As a result, most Dutch soils have hydromorphic properties and require artificial drainage when taken in use. There is hardly soil derived from consolidated rock. Non-urban areas are dominant by sandy soils (43%), marine clays (24%), fluvial clays and loams (8%) or organic soils (14%). Soils developed in loess deposits (1.4%) occur mainly in the southern part of the country. This unique trait of soil geographic regions in combination with high population densities has led to characteristic soil research and mapping approaches.

The Netherlands has a long history in soil research. Initially, most of the soil research was focused on improving soil conditions for agriculture and horticulture. There was a great need to improve soil productivity, and to include new insights from chemistry, physics and mechanics into Dutch agriculture. The first publications on the spatial distribution of Dutch soils and their properties are from the beginning of the 19th century (Felix, 1995). Until the 1930s, there was little activity in soil surveying in The Netherlands although much work was done in the Dutch East Indies by E.C.J. Mohr (1873–1970) and there was mapping in reclaimed polders by D.J. Hissink (1874–1956) and A.J. Zuur (Bouma and Hartemink, 2002). Systematic soil mapping became institutionalized in August 1945 with the establishment of the Dutch Soil Survey institute (StiBoKa). StiBoKa produced several national soil maps (Table 1). Large scale soil mapping ended in 1995 when the final sheets of the 1:50,000 soil survey were published. It was felt, as in other countries, that soil survey and mapping were finished in the 1990s. The question of what next steps to be taken was formulated by Bouma (1988) as: “when the mapping is over, then what?” Soil survey institutes merged, closed and were seeking new grounds for existence (Young, 1991). As a result some considered soil surveyors an endangered species (Nachtergaele, 1990) and pedology dead and buried (Basher, 1997). This changed in the 1990s when new technologies were developed to satisfy the increasing demand for soil information. These technologies combining GIS, spatial statistics, existing soil maps and a whole range of covariates were dubbed digital soil mapping (McBratney et al., 2003). As a result, a continued use and production of spatial soil information can be seen in many parts of the world—including The Netherlands.

Here, we review the history of soil mapping in The Netherlands from the mid-19th century to the present. We focus on the rationale behind soil maps and the conceptual models that have been used in the past with respect to soil forming processes, soil survey and soil classification, and synthesized the information in four periods or phases that are linked to international soil mapping developments. The objectives of this paper are to (i) present an inventory of soil

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0016-7061/$ – see front matter. Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.geoderma.2013.03.022

**Table 1**
Overview of national soil maps and their use in The Netherlands.

| Phase | Year | Map | Number of sheets | Scale | Mapping concept | Use, reference |
|---|---|---|---|---|---|---|
| I | 1858–1867 | Geological soil map | 28 | 1:200,000 | Lithology | Agriculture, education (simplified versions) Staring (1860) |
| I | 1915 | Geological soil map | 1 | 1:800,000 | Lithology | van Baren (1915) |
| II | 1950 | Provisional soil map | 1 | 1:400,000 | Physiography | Edelman (1950) |
| II | 1961 | NeBo soil map | 9 | 1:200,000 | Physiography | Stiboka (1965) |
| II/III | 1966 | Generalized soil map | 1 | 1:1,000,000 | Physiography/pedogenesis/ morphometry | Appendix in De Bakker and Schelling (1966) |
| III | 1964–1995 | 1:50,000 soil maps | 89 | 1:50,000 | Pedogenesis/morphometry | Regional land use planning, land evaluation, selecting sites for mining soil materials, pipeline constructions, informati on on water table depths from the maps 1:50,000 used in manure applications policy |
| III | 1985 | Generalized map | 4 | 1:250,000 | Pedogenesis/morphometry | Regional planning, national planning |
| III | 1986 | Generalized map | 1 | 1:1,000,000 | Pedogenesis/morphometry | EU soil map |
| III/IV | 1990–present | Thematic maps, soil property maps | (digital) | Various scales and resolution | Quantitative | Environmental assessments, model inputs (phosphate leaching, nitrate leaching, organic matter) |
| IV | Present | Digital soil maps | (digital) | Updating of soil geographical data | Quantitative | Update maps in regions with organic soils |

Phase I = Geologic phase; II = Physiographic phase; III = Pedogenetic/morphometric phase; IV: Digital information phase.

maps of The Netherlands which in the 19th and 20th century to present, (ii) unravel the mapping concepts from those maps, (iii) discuss how the maps have been used in research and planning and (iv) highlight some challenges for soil survey in the digital soil mapping era. We limit ourselves to The Netherlands sensu strictu and not to the kingdom of The Netherlands which in the 20th century also included several colonies.

## 2. The geologic phase 1800–1937

In 1822, a first national geological map of The Netherlands was published (d'Omalius d'Halloy, 1823) which had two legend units for the entire country: one for Southern Limburg (Cretaceous), and one for the rest of the country (post-Cretaceous). The need to produce a more detailed map describing the earth conditions in The Netherlands was expressed at a Dutch agricultural congress in 1846 (van der Poel and Wessels, 1953; Veldink, 1970). This congress was organized to address the question why agriculture in The Netherlands lagged behind that of surrounding countries and in comparison to other Dutch industries (Floor, 2012). It was concluded that a thorough overview of agriculture was required, and the need was expressed to create a geological map and a geological description of The Netherlands, including a description of crops that were typical for the various geological conditions.

A committee was formed consisting of six members that were assigned the task of producing the map. The committee member W.C.H. Staring (1808–1877) was familiar with the subject since he had published a 1:800,000 scale geological map in 1844 (Staring, 1844). Due to personal conflicts, the committee broke up and Staring solely published the book *De Bodem van Nederland* in two volumes in 1856 and 1860 (Staring, 1856 en 1860). The maps appeared between 1858 and 1867 and were printed onto 28 different sheets at a scale of 1:200,000. The maps contained 8 soil units. Reprints of the map were made in 1888 and 1889 in which the topography was improved (de Bakker et al., 1981).

The main distinction on Staring's map was between (i) alluvial (Holocene) soils, (ii) diluvial (Pleistocene) soils and (iii) tertiary soils. The distinction between Alluvium and Diluvium was based on biblical perceptions and not uncommon in the mid-19th century (Hartemink, 2009). The concept of Diluvium was introduced in 1815 by the English theologian and geologist W. Buckland (1784–1856). He used the term to distinguish between Alluvium layers, deposited by rivers and wind, and Diluvium layers resulting from a large flood. The younger Alluvium period was the period when all post-flood sediments were deposited. An early user of these terms in the Northern Netherlands was G. Acker Stratingh (1804–1877) who published a first geological soil map of the Dutch province of Groningen in 1837, which legend influenced Staring (Acker Stratingh, 1837; Floor, 2012).

The first volume of Staring's work, on alluvial soils, mainly covered organic soils, marine soils, dunes, river deposits and drift sands. The second volume described soils developed in older deposits such as loess and Pleistocene fluvial deposits. The map contained 60 legend units, mainly distinguished on the basis of (unconsolidated) lithology. Although Staring's map was essentially a geological map, he also considered human activities in the landscape that had produced soils as anthropogenic or plaggen soils (Pape, 1970). Staring's map distinctions within the young Holocene soils yielded him an award at the World Exposition in London in 1862.

At the request of a teacher's society a simplified version of Staring's map was published in 1860 and this map contained 19 legend units (Fig. 1) (Staring, 1860). Another simplified version of the geological map was published in 1877 and contained seven legend units (Felix, 1995). It was used in education on basic schools for over a century. Colors used for sand (yellow), clay (blue), brook sediments (green) and peat (purple) have been used for legends of all Dutch soil maps ever since.

Although the maps appeared to be not directly useful for agricultural use, Staring believed that "… geological knowledge should precede agronomic knowledge, agronomic knowledge being in essence the practical application of it" Staring (1860). A new version of Staring's map was published in 1915 at a scale of 1:800,000 (van Baren, 1915). The agrogeologist Prof. J. van Baren (1875–1933) published revised versions of Staring's book between 1908 and 1927 (van Baren, 1920–1927). The first revised version was published commemorating the 100$^{th}$ birthday of W.C.H. Staring. van Baren incorporated new insights on processes during the Pleistocene, and the role of glaciers in the transportation and deposition of northern rocks and boulders.

A governmental decision to produce a 1:50,000 scale geological map of The Netherlands was taken in 1918 and these maps were used by a co-worker of van Baren, W.A.J. Oosting (1898–1942), to create a 1:800,000 scale geological map of The Netherlands on the occasion of the International Agricultural Congress in 1937 (Oosting, 1937). The publication of the 1:800,000 scale geological map marks the end of the first geologic phase.

## 3. The physiographic phase 1937–1962

Prof. J. van Baren was succeeded by C.H. Edelman (1903–1964) in 1933. Edelman intended to make a new soil map of The Netherlands and he was inspired by W.A.J. Oosting whose PhD-thesis combined principles from geology, geomorphology, topography, hydrology and archeology (Oosting, 1936). His principles and focus on agricultural use of soil maps influenced the production of soil maps in the decades to come (de Bakker, 1995; Sonneveld, 2010).

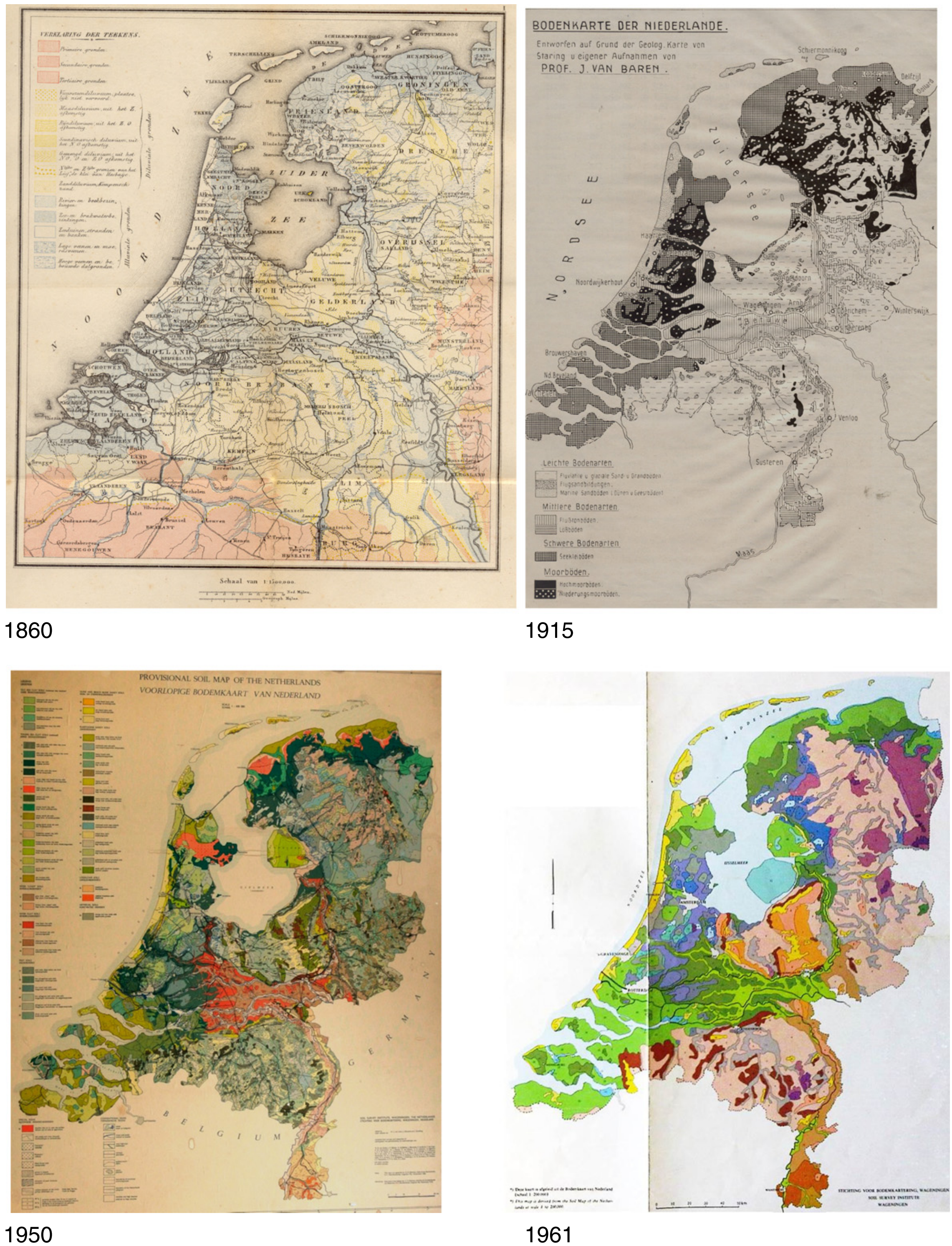


**Fig. 1.** Soil maps of The Netherlands. L to R: Staring's map (1860); van Baren (1915), Edelman (1950), and the simplified NeBo map (1961).

Edelman's approach became known as the physiographic approach in which the properties and distribution of soils were strongly related to the geomorphological characteristics of regions in addition to the integration of geology, vegetation, soil forming processes and historical geography (Pijls, 1964). Although The Netherlands is a flat country dominated by young soils, the physiographic approach to soil mapping worked well. Field workers were generally excellent observers and landscapes were more easily to interpret because drainage and land leveling, that were common during later re-allotment programs, had not yet taken place.

The field work for this phase was started in 1943 with the mapping of the soils of the Bommelerwaard in the central riverine part of The Netherlands. The area has a complex pattern of riverside soils, crevasse soils, natural levee soils, back swamp soils, Pleistocene sandy soils and ancient dwelling soils (Edelman, 1948). The Bommelerwaard project was not only the start of the physiographic mapping approach it was also initiated by the practical need to rank soils with respect to their agricultural and horticultural value, and to improve soil drainage in the area.

The rationale behind the mapping followed the approach used in the USA where soil classification was considered at four levels: Level I—soil types; level II—soil series, level III—soil provinces and level IV—great soil groups. Edelman considered the legend of the soil map of Staring as soil provinces' classification, and the mapping in the Bommelerwaard as soil series. The actual field mapping in the Bommelerwaard was at a scale of 1:10,000 which resulted in a map with soil types (*bodemtypen*), whereas the 1:25,000 scale map represents soil series. In the view of Edelman (1950), soil types unified soils that held the same properties for the growth and husbandry of agricultural and horticultural crops.

In August 1945, the Dutch Soil Survey Institute (StiBoKa) was established with C.H. Edelman as its first director. The main goal of the institute was to execute the soil surveys as commissioned by the Department of Agriculture and other agencies but also to support the use of these maps for evaluating soil suitability for agriculture, horticulture and forestry. Soil maps were in high demand in areas with severe WWII damage, like for examples polders that were inundated with sea water, minefields, and for restoring airfields to agricultural use. Between 1948 and 1969 the Dutch Soil Survey Institute published a series of reports under the title *De Bodemkartering van Nederland* (Soil Survey of The Netherlands), all of which followed the physiographic approach. The first edition was published in 1948 and covered a detailed soil survey of a municipality in the eastern part of the country (Pijls, 1948). The 1:10,000 soil map distinguishes the landscape of old mixed farming and reclamation landscape, and it shows the connection with landscape types. Subsequent editions for other regions followed quickly (e.g. Pons, 1948; Schelling, 1949; van Liere, 1948). In total 24 regional editions were published in this series in the period 1948–1969, 17 of which served as PhD-theses for the respective authors (Anonymous, 1981). These were pioneering using a novel mapping approach at that time and also yielded information that proved useful for geological Quaternary studies (Jongmans et al., 2013). Also at that time historical geographic research was started that related soils and landforms to historical land use (Edelman and Vlam, 1949). This proved to be useful in many areas in The Netherlands that had been cultivated for centuries, and the approach was a unique trait of Dutch soil survey.

The legend structure varies substantially between for example the Bommelerwaard map (Edelman, 1948), the map of Pijls (1948) and the map of van Liere (1948) highlighting the broad definition of landscape that was used. According to de Bakker (1995), the concept of landscape at that time involved geological, geomorphological, sedimentary and historical–geographic aspects and an overarching national legend structure for the physiographic maps was lacking. Edelman was the President of the first Congress of the International Soil Science Society (ISSS, now IUSS) in1950 in The Netherlands. On this occasion *Soils of The Netherlands* (Edelman, 1950) was published that contained a provisional soil map of The Netherlands at a scale of 1:400,000. The map has 55 legend units, that are grouped into: old sea clay soils (4 units), young, reclaimed sea clay soils (16 units), river loam soils (2 units), river clay soils (4 units), peat soils (6 units), dune and beach bank soils (3 units), Pleistocene sandy soils (16 units), loess loam soils (2 units), artificial soils consisting of dumps and man-made soils (1 unit), and boulder clay on or near the surface (1 unit). The map (Fig. 1) was prepared by W.J. van Liere, J. Bennema and J. Schelling. The detailed differentiation in the young, reclaimed clay soils and Pleistocene sands reflects the soil knowledge that was gained during the surveys that were conducted prior to 1950.

In 1951, StiBoKa was requested by a committee on agricultural water and drainage to collect soil information at a national scale to support investigations into the hydrology of Dutch agricultural soils. This led to intensive fieldwork in the years 1952–1954. The 1:200,000 scale soil map (nine sheets) that followed from this survey was known as the NeBo map (1961). The legend for this map contained marine clay soils (64 units), river clay soils (16 units), peat soils (20 units), sandy soils (38 units), loamy soils (13 units) and other soils (10 units). Based on the NeBo map, a generalized soil map of The Netherlands at a scale of 1:600,000 was published in 1964 as part of a new Dutch Atlas. In 1965, a general explanation was written for the NeBo map (StiBoKa, 1965). Separate explanations for all the provinces were published from 1965 to 1974 resulting in eleven provincial books (e.g. De Smet, 1965; van den Broek, 1966). The NeBo mapping was used for mapping land qualities and included crop yield losses, excess water problems and sensitivity for drought (Stiboka, 1967; Vink and van Zuilen, 1974).

The NeBo mapping made it necessary to develop a uniform and suitable legend that could be used at the national level. This resulted in standardize terminology to describe soil texture, soil organic matter and soil color (Pijls, 1965). The main units at the NeBo map still reflected Staring's original subdivision and can be regarded as soil provinces. At the second level, physiographic distinctions are used like old river clay soils and young river clay soils. At the third level, morphometric criteria were introduced to delineate soils based on carbonate content, texture and hydrology. The mapping of newly reclaimed polders was carried out by another institute: the *Institute for the IJsselmeer Polders* (RIJP: *Rijksdienst voor de IJsselmeerpolders*), which used a different approach than StiBoKa. They developed a system for mapping that was mainly based on sedimentary composition and clay content. The criteria to classify soils in these landscapes (Zuur, 1953) were taken up by de Bakker and Schelling (1966) when they published the Dutch system of soil classification—a key publication marking the beginning of the morphometric phase in soil mapping.

## 4. The morphometric phase 1962–1995

The physiographic soil mapping approach may be preferable when little is known about the soil geography of an area (de Bakker, 1970). This was the case for The Netherlands until the 1960s, but with the NeBo map of 1961, information existed for most part of the country. Physiographic soil mapping proved to be not suitable for soil classification because of its emphasis on landscape genesis rather than pedogenesis. For example, it appeared that soils formed in completely different landscapes, such as marine landscapes and river landscapes, were classified differently under the physiographic approach whereas soil formation and soil properties of these soils were comparable. It was also realized that soil classification and the legend of a soil map are two separate but related entities.

In the 1950s and 1960s soil classification was widely discussed and there was wide international interaction following the ISSS congress in 1950. In the USA soil classification moved from genetic to a more quantitative and soil property based system (7th Approximation) (Bockheim and Gennadiyev, 2000). Dutch soil scientists discussed the series of approximations and a committee started to frame a system of soil classification using soil properties as differentiating criteria rather than physiographic and geological criteria. In 1966, the first Dutch system of soil classification was published (de Bakker and Schelling, 1966) that formed the base for the current Dutch system of soil classification. The main purpose of this classification was to serve as a basis and framework for the legend of the soil map, at a scale of 1:50,000. The morphometric approach intended to group natural soil individuals on the basis of measurable pedogenetic criteria. Examples of elements of the pedogenetic–morphometric approach are the degree of soil ripening and the presence of hydromorphic features. The difference with the physiographic approach was that soil properties became the main diagnostic criteria and not landscape genesis.

The 1966 Dutch classification system is a nested-categorical system with four levels. At the highest level, subdivisions are based on pedogenetic processes (Siderius and de Bakker, 2003). The next level uses other pedogenetic criteria such as hydromorphic properties and ripening. The third level mainly distinguishes between parent materials and the occurrence of organic horizons, whereas the fourth level identifies the so-called modal individual, the characteristic soil (centroid, orthic type) for a certain class. These four levels were considered to be the higher levels. The lower levels consider for instance texture and carbonate contents, elements that have not been included in the classification system but can be found in the 1:50,000 map legends. The 1966 system of soil classification included a 1:1000,000 soil map that was based on the 1:200,000 NeBo map but its legend was simplified and reclassified to match the highest level of the new classification system. The last edition of the Dutch soil classification has 5 orders, 13 suborders, 23 groups, and 58 subgroups.

The 1:50,000 scale mapping started in 1962, marking the start of the third phase, with the first sheet (Map 43 West) being published in 1964 (Fig. 2). The legends of these maps show that, although the units delineated soil bodies that were defined using pedogenetic–morphometric criteria, the major legend units still used physiographic criteria. Of the thirteen major legend units on the soil maps (Table 2), five were derived from the 1966 classification system, two were newly introduced (old clay soils and stony soils) and six were more or less derived from Edelman's map from 1950 (de Bakker, 1995; Steur, 1966). Before the 1:50,000 soil map was completed there was a need for a more up-to date small-scale national map. Steur (1985) compiled a map at a scale of 1:250,000 by simplification and generalization of the 1:50,000 soil maps, for which at the time about 70% of the fieldwork had been completed (Fig. 3). Other, more detailed soil maps and some additional fieldwork were used to obtain the remaining 30%. Subsequently Steur (1986) produced a generalized soil map at a scale of 1:1,000,000. This map was the basis for the Dutch contribution to the soil map of Europe at a scale of 1:1,000,000 (CEC, 1985; van der Pouw and Finke, 2005).

The last sheets of the 1:50,000 soil map were published in 1995. In total 89 sheets and 69 survey reports had been published after a period of thirty years of systematic soil mapping (Bouma and de Vries, 2010). An overview of the number of surveys performed for the 1:50,000 soil maps is given in Fig. 4.

For the mapping at a scale of 1:50,000, a system of groundwater-table classes was developed (van Heesen, 1970). These are based on mean highest water tables and mean lowest water tables and are included within the map units (van der Sluijs and De Gruijter, 1985) and proved to be important for land evaluation purposes.

Apart from the supply-driven 1:50,000 scale mapping program, many detailed and demand-driven soil surveys (1:25,000; 1:10,000) were conducted. These detailed surveys were an important activity of Dutch soil survey, and were conducted as commissioned projects e.g. for water extractions, regional re-allotment projects and forestry assessment (van der Pouw and Finke, 2005). An overview of both analog as well as digital large scale soil maps is given in Fig. 5 showing that maps at scales of 1:10,000 and 1:25,000 are available for a large part of the country.

In 1966, StiBoKa and the Royal Dutch Geological Survey decided to systematically map the geomorphology of The Netherlands at a scale of 1:50,000 (van den Berg, 2007). The geomorphological mapping was intended to facilitate the soil mapping and geological mapping. The first 1:50,000 scale maps in this series were published in 1975 (ten Cate et al., 1975) and the legend structure was published in 1977 (ten Cate and Maarleveld, 1977). In 2003 the first digital version of the geomorphological map was made available (Koomen and Maas, 2003).

## 5. Digital soil information phase (1995–present)

The 1:50,000 soil mapping that took place between 1962 and 1995 was the largest soil mapping effort in The Netherlands. In the period 1970–1980 about thirty to forty StiBoKa staff members were full-time involved in surveying, reporting and coordinating this mapping program. We estimate that approximately 750 man-years were needed in total to produce the 1:50,000 soil map for The Netherlands. It is common that small and highly populated countries have good coverage of detailed soil maps (Hartemink, 2008).

After these maps were published, there was reorganization and the digital era evolved. The digital phase had already emerged in the early 1970s when the first attempts were made to develop a digital soil

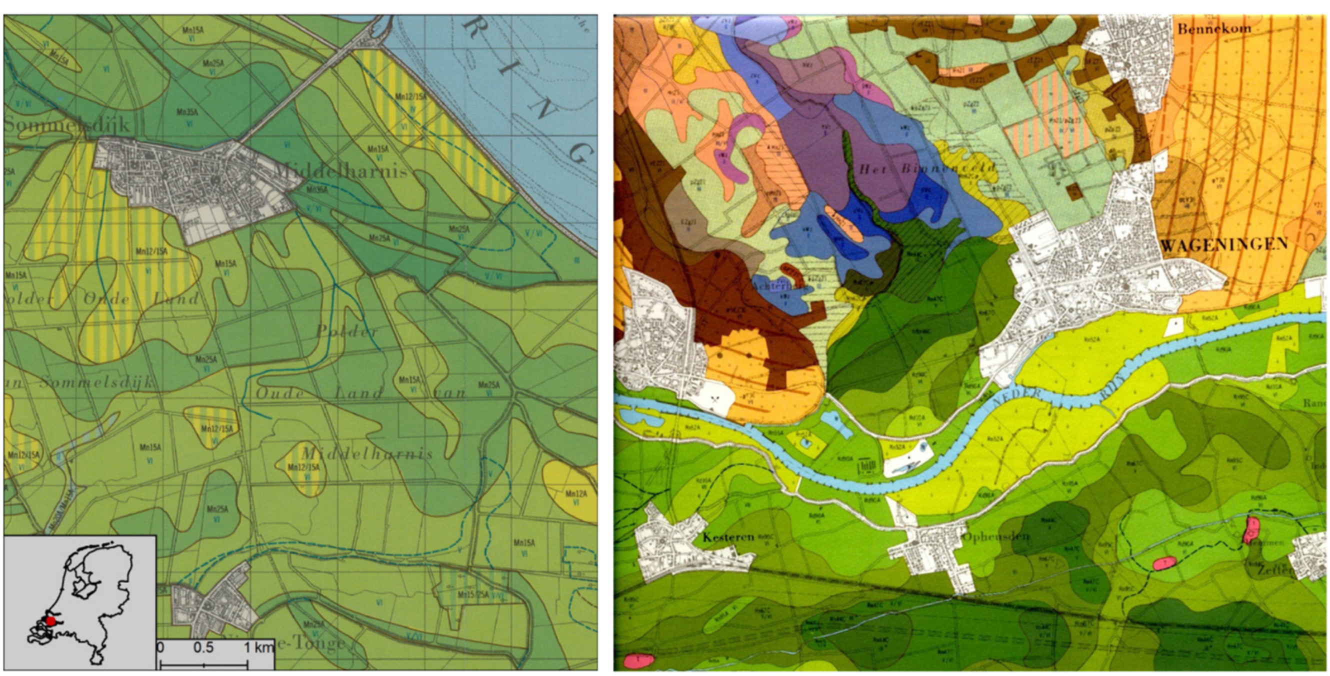


**Fig. 2.** Part of the first map sheet (43W) from the 1:50,000 mapping program; the map was published in 1964 (left). Detail of part of the 1:50,000 soil map of Wageningen, published in 1973, depicting riverine clays (green), peat (purple) and ice-pushed ridges (yellow) (right). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

**Table 2**
Overview of selected national scale soil maps and characteristics of their legend.

| Soil map | Scale | Number of main legend units | Characteristic of main legend units | Number of legend sub-units | Reference |
|---|---|---|---|---|---|
| 1858–1867 | 1:200,000 | 3 | Kenozoic formations, Mezozoic formations and Paleozoic formations | 60 | Staring, 1860 |
| 1915 | 1:800,000 | 4 | Marine clay soils, river clay soils and loess soils, sandy soils, Peat soils, | 8 | van Baren, 1915 |
| 1950 | 1:400,000 | 10 | Old marine clay soils, young marine clay soils, loamy river soils, river clay soils, peat soils, dune and coastal barrier soils, sandy soils, loess soils, artificial soils | 55 | Edelman, 1950 |
| 1961 | 1:200,000 | 6 | Marine clay soils, river clay soils, peat soils, sandy soils, loamy soils (including loess soils), other soils | 161 | Stiboka, 1965 |
| 1966 | 1:1,000,000 | 5 | Histosols, Spodosols, Alfisols, Inceptisols, Mollisols, Entisols | 23 | de Bakker and Schelling, 1966 |
| 1964–1995 | 1:50,000 | 13 | Histosols, Spodosols, Alfisols, Mollisols, non-calcareous sandy soils, calcareous silt- and sandy soils, unripened mineral soils, marine clay soils, river clay soils, old clay soils, loamy soils, stony soils. | 260 | Steur, 1966 |
| 1985 | 1:250,000 | 7 | Peat soils, sandy soils, marine clay soils, young river clay soils, old clay soils, loamy soils, stony soils | 89 | Steur, 1985 |

information system. One of the activities was to scan the published 1:50,000 soil maps and store soil profile data into databases (Bregt, 2010). In 1984, a relational database, BIS (*Bodem Informatie Systeem*) became operational to store soil point data and maps. BIS gradually expanded and contained in 1990 almost 4400 soil profile descriptions with data on many soil properties, and over 80,000 soil profile descriptions. Currently, the database contains data from approximately 15,000 soil samples as well as soil profile descriptions of approximately 300,000 locations (De Vries et al., 2007).

Quantitative approaches for soil mapping and soil inventories dawned in the 1970s. Attempts were made for numerical soil classification (de Gruijter, 1977) followed by quality investigation of

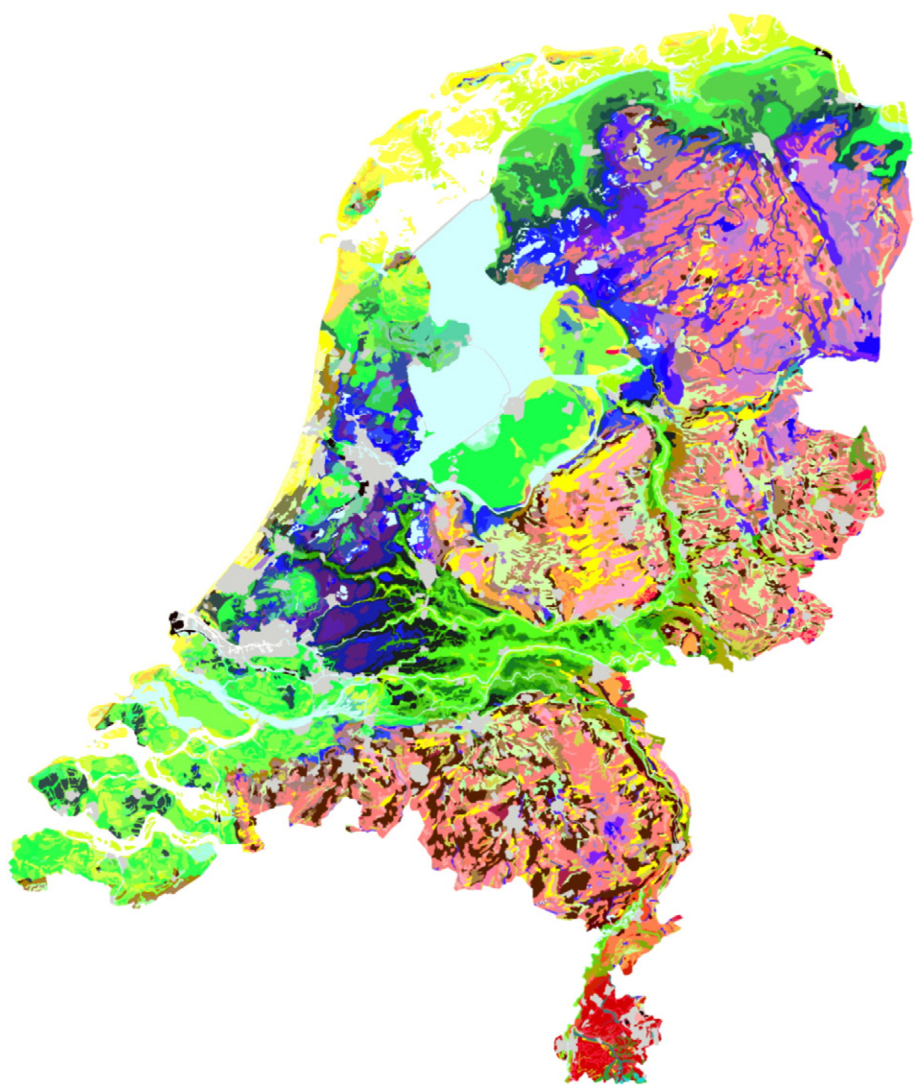

**Fig. 3.** Generalized and simplified soil map published at a scale of 1:250,000 from Steur (1985).

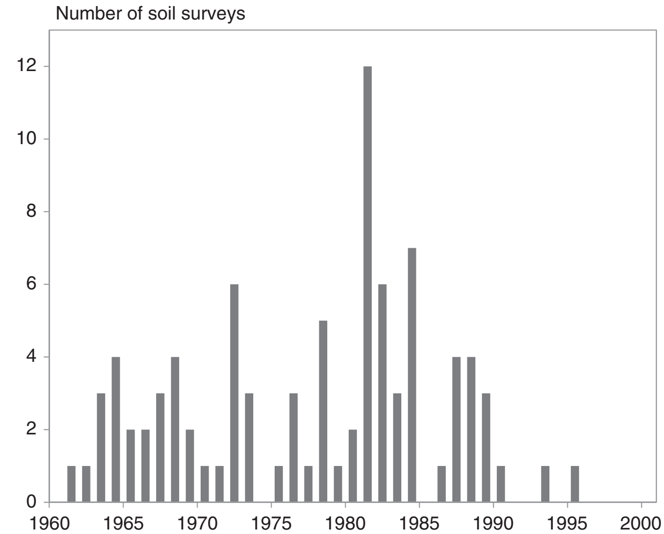


**Fig. 4.** Overview of number of 1:50,000 surveys published per year.

the soil maps (Marsman and de Gruijter, 1986). Developments in computer technology allowed the development of new methods for soil mapping (Bregt et al., 1987), and updating existing soil survey information (Brus et al., 1992), and numerical methods for soil classification (McBratney and De Gruijter, 1992).

During the 1990s it became clear that land reclamation, drainage, re-allotment, leveling and groundwater extraction had influenced groundwater levels and dynamics. It appeared that mapped groundwater table (GWT) classes no longer satisfied user demands—a situation that also existed in Belgium (Boucneau et al., 1996). For The Netherlands, a mapping method, using time series analysis and phreatic head measurements, was developed to obtain a large set of parameters describing groundwater table dynamics (Finke et al., 2004). Results of these methods showed that reasonable maps of various aspects of groundwater dynamics could be obtained by this method, at much lower cost than traditional survey-based mapping methods. van de Wauw and Finke (2012) evaluated the predictive quality of the current drainage class map of Flanders (Belgium) using data from monitoring networks. They suggested that about 50% of the area of Flanders would benefit from remapping groundwater level classes.

## 6. Use of the soil maps

The aims of StiBoKa were soil mapping and supporting land use decision making. A key outcome of the soil surveys was that for the first time the distribution and relative importance of different soil types were assessed. However, the initial maps were not always useful for agriculture and several approaches were developed in the

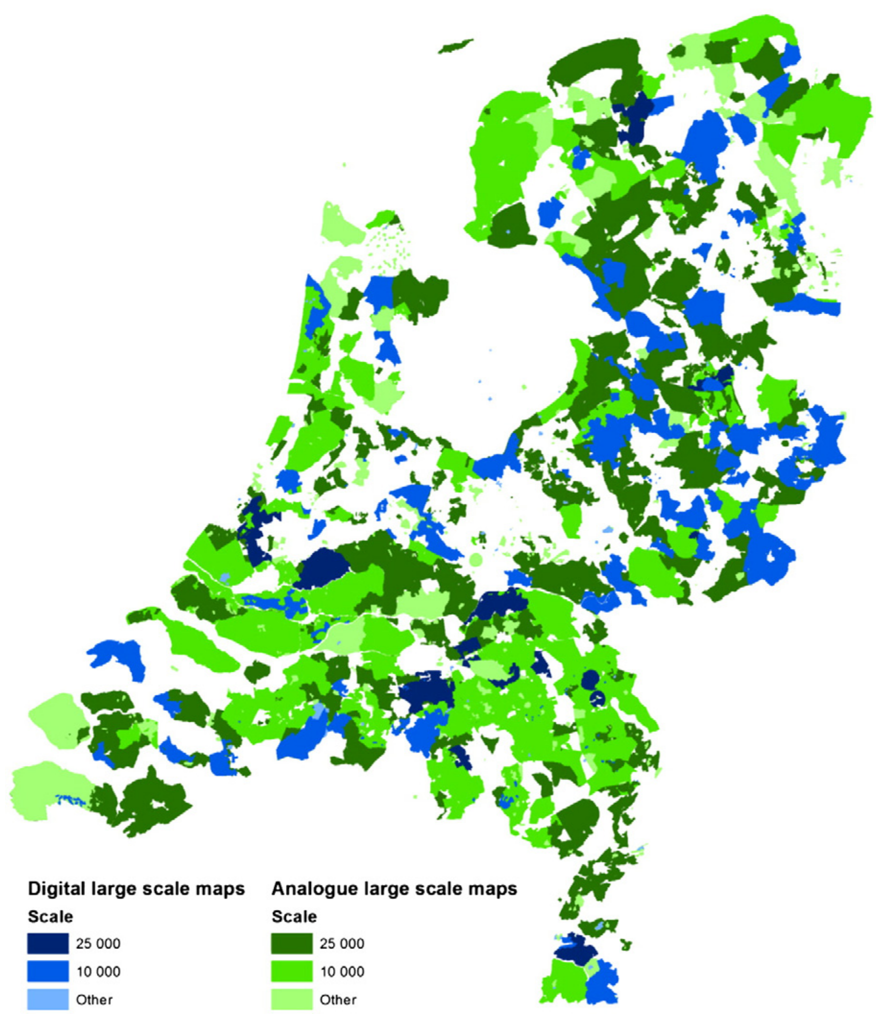


**Fig. 5.** Overview of Dutch regions for which large scale soil maps have been made.

1940s and the early 1950s to integrate soil mapping with land evaluation. A first general soil suitability map for arable land and grassland based on the NeBo map and the hydrological map (Visser, 1958) was published in 1963 and 1974 (Vink, 1963; Vink and van Zuilen, 1974). The translation of soil maps into practical applications for land evaluation reached a climax in 1979 when a systematic land evaluation procedure was published (Sonneveld et al., 2010) which was directly coupled to the 1:50,000 soil maps (Haans, 1979; Haans and Westerveld, 1970). The evaluation procedure to assess land suitability involves a series of steps in which soil properties were translated into soil qualities. Other applications of the 1:50,000 scale maps were land consolidation projects and road constructions (van Heesen, 1970).

Deteriorating quality of the environment due to agricultural practices and the pressure on the land with competition in rural areas stimulated a demand for soil information. Simulation models needed quantitative soil information, and pedotransfer functions were developed in the 1980s to translate basic soil survey information (Finke, 1995) into data needed for simulation models (Sonneveld et al., 2010). Examples are maps that indicate vulnerability for soil acidification, suitability to use low-emission techniques (van Lanen and Wopereis, 1992) and the degree of phosphate saturation (Reijerink and Breeuwsma, 1992).

Because of the increase in use of soil information, procedures were needed for accessibility of data, using internet portals and provision of meta-data. Current users include government departments, provinces, municipalities, water boards, research institutes, nature organizations, expert bureaus, educational institutes and companies (de Vries et al., 2007). Most of the users are in need of soil property information and the soil class information from the digitized 1:50,000 has been disaggregated to derive such information. Soil maps have also been used in archeological and historical studies. Spek (2004) used the 1:50,000 scale soil map to understand settlement and land use patterns through time. Kooistra and Maas (2008) used these maps to compare the properties of Celtic Fields systems in various parts of The Netherlands.

Soil data user inventories, held between 2004 and 2008 revealed additional needs to the soil spatial information in BIS (Visschers et al., 2007). These were: i) a growing demand for information with higher spatial resolution, ii) a need for more quantitative, accurate and detailed description of the variation of soil properties within the mapping units of existing national soil maps and iii) a need for information on soil physical and chemical properties not presented on the existing soil maps. Additionally, it was realized that part of the information depicted on maps was outdated due to human impact on the landscape (Visschers et al., 2007), especially in regions dominated by organic soils because of peat decomposition (Kempen, 2011). In a region dominated by peat soils a traditional field survey campaign started in 2009, but this method proved to be insufficient capable to provide a new series of maps with limited period of years (2009–2014). Kempen et al. (2009) explored the possibility to update the national 1:50,000 soil maps using legacy data and digital soil mapping principles. In 2011 a national inventory started to update soil information for selected regions with organic soils, covering in total 400,000 ha.

This development supports the idea that decision makers require information about how soils change (Tugel et al., 2005) and that new tasks for soil survey organizations may include monitoring (Young, 1991). Although soil classification and data collection systems have mostly focused on static soil properties, dynamic properties such as SOM and structure that respond to management are related to soil functioning and ecosystem services. Data collection may therefore need to focus on soil change and dynamic soil properties in combination with simulation modeling (Sonneveld et al., 2002). This is a challenge for soil survey to provide users with information on soil changes following management activities and to link these changes to agronomic, environmental and hydrological consequences.

In addition to the need to monitor soil properties and processes for a wide range of uses the need remains to increase our understanding of the soil landscape continuum. With the emphasis on digital analysis and products and a much reduced field staff and field knowledge base, there is the risk that our understanding of the soil will eventually lag behind our abilities to spatially predict its properties. Field studies remain essential to produce the next generation of soil maps for The Netherlands.

## 7. Conclusions

Soil maps in The Netherlands have evolved from geological and physiographic approaches towards pedogenetic and quantitative approaches. Soil survey was initially somewhat supply-driven and has witnessed a gradual broadening of the use of its products from agricultural users towards hydrologists, planners, environmentalists, ecologists and archeologists. Soil mapping concepts in The Netherlands have often been in the frontier position of international developments, exemplified by the classification of unconsolidated sediments (phase i), physiographic principles in mapping (phase ii), morphometric approaches (phase iii) and digital soil mapping approaches (phase iv).

Current technologies stimulate the improvement of the collection, storage, analysis and presentation of soil geographic information. The digital era opens up new opportunities to translate soil survey products into other products that are useful for a wide variety of end users. Future mapping activities should include monitoring of soil changes and the mapping of soil properties at fine resolutions.

## Acknowledgments

The authors want to thank Martin Knotters and Folkert de Vries (Soil Geography Team, Alterra), Bas Kempen (ISRIC) and two anonymous reviewers for their valuable suggestions in improving this manuscript.

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