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Improving spatial resolution in soil and drainage data to combine natural and anthropogenic water functions at catchment scale in agricultural landscapes

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ABSTRACT

Discrepancies in time-space representation of indata and calibration/validation data obstructs analysis of hydrological processes thatlink natural and anthropogenic water infrastructure in catchments and landscapes. To improve indata for hydrological- and modelling of the soil-plant-atmosphere-continuum, this paper presents a high-resolution dataset of hydrological functions in the agricultural landscape of Tidan, Sw Sweden. We firstly address spatial representation of soil physical parameters, describing soil water flows and storage. Secondly, we derive tile drainage datasets from historical maps. Lastly, we explore delineation and spatial location of streams, ditches and waterbodies to improve description of water connectivity. The new soil datasets with top- and subsoil descriptions varied in depicting the sensitivity of saturated hydraulic conductivity and water holding capacity. The most representative soil map showed moderate (34%) - to very rapid (21%) saturated hydraulic conductivity, water holding capacity below 40 mm 10 cm^{-1} (94%) and a dry bulk density ranging between 1.2 and 1.8 g cm^{-3} (71%). The digitalization of drained fields suggests that 69% of the arable fields are under tile drainage, dominated by sandy loam, loam and clay loam. The combined stream network resulted in 5350 km of streams and ditches, + 14% km and + 129%, respectively, compared to available best resolution datasets. Landscape surface water storage increased with a small addition (+ 6439 m^3 storage potential) compared to previously available datasets. The improved descriptors of natural and anthropogenic flow and storage can potentially serve to improve water quantity and quality modelling under current and future climate- and hydrological changes.

1. Introduction

Balancing simplicity and complexity in the time-space domain of hydrological modelling is a classical dilemma when dealing with the soil-plant-atmosphere continuum (SPAC) (e.g., Blöschl and Sivapalan, 1995; Blöschl et al., 2019). Data and tools continuously increase in detail in space –time dimensions, especially satellite data (e.g., Sergieieva, 2022), models (Fatichi et al., 2016; Sidle, 2021) and processing capacity (Horton et al., 2022). The availability (or unavailability) of indata might enable (or inhibit) the use of more detailed and complex models in physical and conceptual functions that describe landscape hydrology and linked parameters (Wilby, 2019).

Remote sensed (RS) products and data synthesised from artificial intelligence (AI) have proven particularly useful as input for SPAC- and hydrological models. RS-products are widely used within the scientific community as model indata (e.g., Xu et al., 2014; Thakur et al., 2017; Tan et al., 2021) and in calibration-validation processes (e.g., Zhang et al., 2021). Increased detail in data, knowledge of soil-physical relationships, and more sophisticated models with higher computational capacity have been suggested as reasons to advance the use of physically based- rather than empirical models (Jarvis et al., 2022). Yet, the accuracy of hydrological parameters vary due to spatial and temporal

Abbreviations: AI, Artificial Intelligence; CMD, Coup Model soil data; DI, National ditch-network: ditches (Lidberg et al., 2021); DSM, Digital Soil Map; FAO-map, Soil textural map based on FAO soil textural classification; KTD, Soil profiles for forest (Karltun, 1995); M1, Economic Map - Original; M2, Economic Map – With tile drainage; RS, Remote sensed products; SC, Soil classes 1:25 000 – 1:100 000 (Geological Survey of Sweden 2014); SLD, SLU Soil Database (Wesström & Joel 2012); SPAC, Soil-Plant-Atmosphere-Continuum; STR, National stream network: topographically derived streams (Ågren & Lidberg, 2020); SV-map, Soil textural map based on Swedish soil textural classification; SCI, Soil and Crop Inventory; NSI, National Soil Inventory.

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resolution (e.g., Chao et al., 2021). The accuracy can furthermore be affected by the algorithm used to derive parameters from raw satellite data (e.g., Senkondo et al., 2019; Chao et al., 2021). Additionally, a mismatch in the time-space resolution of indata and calibration-validation data have potential implications for misalignment between scales, misinterpretation of results, or possibly the inability to achieve study objectives (e.g., Baffaut et al., 2015). The resolution of information for SPAC- and hydrological models also affect parameter settings and process sensitivity (e.g., Abbaspour et al., 2018). In some cases effect on parameter setting by resolution is also catchment dependent (e.g., Veith et al., 2010; Guse et al., 2017).

Sweden is an example of good national collections of open access, high-resolution spatial data linked to landscape description, such as topography and soil textural composition, as well as climate on a temporal scale. Nevertheless, parameters that typically directly influence hydrological flows are lacking in spatio-temporal representation. For example, most soil profile information only includes texture and occasionally soil organic carbon (Raulund-Rasmussen and Callesen, 1999; Jansson and Karlberg, 2004; Paulsson et al., 2015; Geological Survey of Sweden, 2018; Swedish Land Survey, 2019; Swedish University of Agricultural Sciences, 2021a). Few samples exist on parameters as, infiltration capacity, saturated and unsaturated hydraulic conductivity, water holding capacity and bulk density. These are fundamental to understanding soil physical properties governing hydrological partitioning, flow rates and water storage in soils. In hydrological catchment studies from Swedish arable landscapes, soil parameters have often been generalized to so-called type soils, with soil physical properties derived as generic parameters or from pedotransfer functions (Salazar et al., 2010; Johnsson et al., 2019). In other cases, the origin and/or estimates of soil parameters have not been fully presented in publications (e.g., Andréasson et al., 2004; Teutschbein et al., 2011; Davies and Beven, 2015; Arheimer and Lindström, 2019). Some studies (e.g., Jansson and Andersson, 1988; Grusson et al., 2021) that present their soil data have used soil physical data either directly from the SLU soil database (Wesström and Joel, 2012) or from in-situ soil sampling (e.g., Motovilov et al., 1999; Engeland et al., 2001, 2005; Verrot and Destouni, 2015, Smith et al., 2019, see compilation of studies in Malmquist, 2021a). The lack of detail concerning soil physical properties in these studies is either due to model configuration, where defined soil physical parameters are not required, or to the fact that the level of detail seems insignificant for the purpose of the specific study.

Another data gap is the lack of accurate delineation of manmade and natural streams. Information on stream pathways is somewhat accessible but limited to local applicability. Streams and ditches visible above ground are available as high-resolution datasets. Both potential locations of natural streams (Ågren and Lidberg, 2020), and manmade ditches (Lidberg et al., 2021), identify a much denser stream from topographic maps and "natural" pathways for stream formation, AI and image recognition, than those depicted in previously available maps. However, these maps do not capture subsurface tile drains and subsurface connections (e.g., culverts), which are important flow pathways. Especially in agricultural and urban catchments. The best available large-scale data on tile drainage plans is a modified version of the cadastral map (sv. Ekonomiska kartan) produced from orthophotographs between years 1935–1978. Although the maps are available as scanned- and georectified, they are not readily available for use in GIS-software and do not show the true outline of tile drainage pipes. Rather they show fields with available tile drainage plans. Neither do they include recent landscape changes, such as merged fields and shifts in spatial range over time or more recent installations of tile drains and related plans.

Anthropogenic landscape changes to land use, hydromorphology, and water storage, - withdrawal and -recharge, show alteration to evapotranspiration, runoff and soil water storage, compared to unaffected landscapes. Nevertheless, the direction of change is governed by area-specific properties, both internationally and nationally (e.g., Malmquist, 2021a; Kåresdotter et al., 2022). Hydromorphological changes (manmadeor natural) also has the potential to delay or reinforce flow patterns and alter their characteristics from perennial streams to more resemble ephermal streams, with possible further implications for, e.g., flora and fauna along streams or in waterbodies (Datry et al., 2023). Thus, a mismatch in the available spatial representation of key hydrological features - especially in landscapes with complex interactions of anthropogenic and natural waterways and storage – obstructs a thorough exploration of especially subsurface processes in catchment modelling. This is an issue, as evidence of synergies between engineered- and nature-based solutions to sustain effects of climate change on hydrological pathways is lacking (Miralles-Wilhelm et al., 2023). Thus, this paper explores the availability of high-resolution spatial data for developing the descriptions of hydrological functions in agricultural landscapes. The paper seeks to answer: *Can high-resolution data improve knowledge on anthropogenic modified hydrological functions?*

We illustrate this with three examples of spatial data adaptation to fit a catchment-scale hydrological model (here Soil and Water Assessment Tool (Arnold et al., 1998) for a Swedish agricultural catchment, SW Sweden. Our case study firstly addresses how to link point-data of soil physical properties to spatially distributed information on soil texture, in order to improve the representation of hydrological functions of soil water storage and water flows such as infiltration. Secondly, we develop spatial data for soils and their functions for water flows and storage under different degrees of anthropogenic modifications. That is i.e., "natural", and highly modified (subsurface /tile) drained soils. Finally, the delineation of streams, ditches and water bodies and effects of spatial location are explored. We discuss the implications on landscape hydrological functions for hydrological modelling.

2. Material and methods

2.1. Description of study area

Tidan catchment (696 km^2) is located in Västra Götaland County, Sw Sweden (58.6 N, 14.0 E/58.2 N, 13.9 E) in the temperate-boreal climate zone (Köppen zone Dfb, i.e., cold climate without dry season but with warm summers (Peel et al., 2007)) and zone 407 and 418 EU pedoclimate zones (Jones et al., 2010)). The landscape is heterogenous consisting of 24% (169 km^2) agricultural land, 21% (147 km^2) forest and 4% (29 km^2) urban land (Malmquist, 2021b) (Fig. 1). Tidan catchment represents a typical Swedish arable landscape with modified hydrological features and substantial surface- and subsurface drainage occurring over more than 150 years (Lindelöf, 2021). The area has historically been subjected to recurrent flooding due to high precipitation around the catchment, mainly occurring along stream Tidan, adjacent to river Ösan (Holmbom and Söderström, 2012; Wessberg, 2019), Dry spells/droughts have historically been a less recurrent issue (Holmbom and Söderström, 2012; Wessberg, 2019).

2.2. Data sources

The three datasets were developed from spatial raster- and polygon data collected from open-access databases provided by the Swedish Land Survey (*Lantmäteriet*), Geological Survey of Sweden (SGU), Swedish Board of Agriculture (SJV), Swedish Water Authorities (*Vattenmyndigheterna*), County administrative board of Västra Götaland, and additional peer-reviewed publications. Quantified parameter values as point- and tabulated data sets for soil texture and soil physical parameters were accessed from the SLU soil database (agricultural soils) and CoupModel soil database (forest soils) while data from additional peer-reviewed publications were analysed and used to develop all three datasets (Table 1 and Table 2).

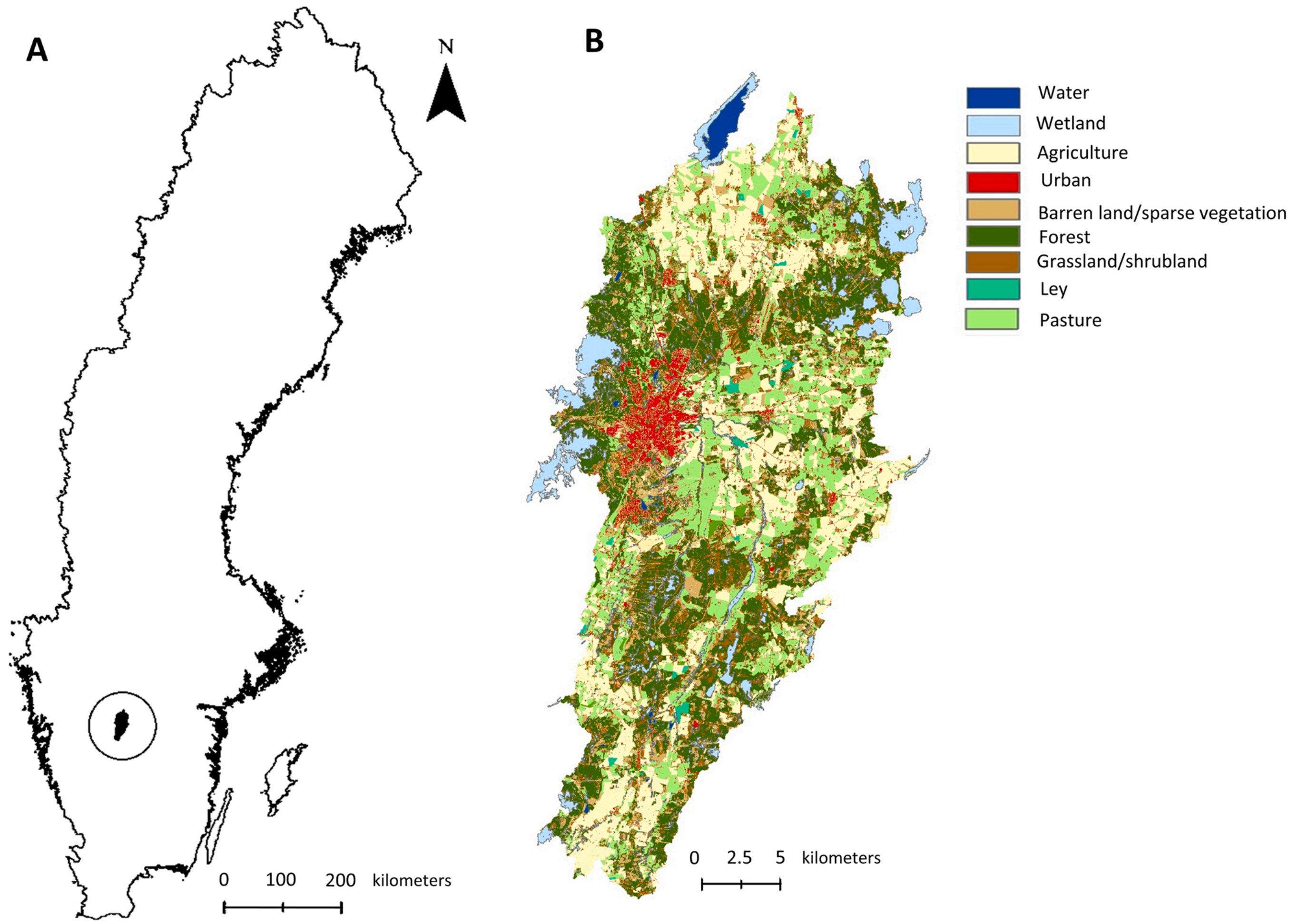

Fig. 1. Location of the study catchment, Tidan catchment (in the circle) (58.6 N, 14.0 E/58.2 N, 13.9 E) (A) and land use map of Tidan catchment for year 2020 with major land use classes (B).

2.3. Methodology

2.3.1. Linking soil physical properties of infiltration in soil profiles, water holding capacity, natural drainage and groundwater recharge to soil textural datasets

2.3.1.1. Arable soils. Soil profiles with information on soil physical properties (saturated hydraulic conductivity, soil organic carbon, dry bulk density and plant available water) from SLU's soil (Wesström and Joel, 2012) database (hereinafter *SLD*) were firstly classified to soil textural classes after the Swedish soil groups in the soil map *soil classes 1:25 000 – 1:100 000* (Geological Survey of Sweden, 2014) (hereinafter *SC*), as geological and agricultural soil particle classification systems use different grain size divisions (Supplemental material, Fig. S2). The soil profiles were additionally classified based on FAO textural classes to fit soil classification layers of topsoil from the digital soil map (Piikki and Söderström, 2019) (*DSM*). The soil physical profile point-data and soil textural layers from *DSM*, respectively, were associated with glacial/postglacial origin in *SC* and subdivided by their geological origin and soil textural class.

Two soil maps with soil physical properties were created. One was based on FAO-textural classification *(FAO-map)* by associating the soil profiles of unique geological- and textural classes from *SLD* to the closest individual soil pixel in *DSM* of same geological origin and FAO-textural class. The second map was based on Swedish soil classes (*SV-map*) and the nearest pixel from the subsoil layers of *SC*. Some soil classes in *SLD* at topsoil (0–10 cm) and subsoil (40–60 cm) were not available from all the various soil texture classes present in *DSM* and *SC* of Tidan catchment. To fill this gap in *SLD*, they were fitted to the closest soil class with the closest similar textural composition available in *DSM* and *SC*.

2.3.1.2. Organic soils. Physical parameters for organic soils are limited in the source material (Table 1). Thus, physical parameters were assigned based on their organic type (e.g., gyttja soil, bog peat or fen peat) and proximity to the study area based on soil profiles from Berglund et al. (1989) and Berglund (2011).

2.3.1.3. Forest soils. Soil texture for forest soils is available as spatially located polygons and point data while soil physical data are lacking (Department of Forest Resource Management and Department of Soil and Environment, 2022). For our dataset, we used a compilation of 24 forest soil profiles on glacial till (Karltun, 1995) (henceforth KTD) containing the bulk density and volume weight of particle size fractions for three east-to-west directed transects in southern, central and northern Sweden. For the new soil dataset, we combined soil profiles from forest land use from the Coup Model (Jansson and Karlberg, 2004) (henceforth CMD), with profiles from KTD, based on the closest value of soil carbon in topsoil (5–15 cm) and subsoil (40–60 cm). The matching profiles' saturated hydraulic conductivity was assigned based on topsoil organic carbon content. Bulk density values were then matched individually per each soil layer from the assigned profiles to achieve a realistic variation of saturated hydraulic conductivity with depth. Soil organic carbon has been shown to vary with topography and hydrologic class (e.g., Callesen et al., 2003; Olsson et al., 2009). Thus, the profiles

Table 1
Source data of soil physical parameters and spatial soil textural information used to construct an improved high-resolution soil physical properties map at catchment scale in Tidan catchment, SW Sweden. The original name of the datasets are presented in column "Map/indata".

Dataset	Year of production/ observation	Map/indata	Acronym	Resolution (period, time step, area)	Data type	Source
Soil textural and physical parameters	2016	Digital soil map: soil classes & texture	DSM	50 × 50 m, national coverage to Gävleborg county	Raster	Piikki and Söderström (2019)
	2014	Soil classes 1:25 000 – 1:100 000: classes based on Swedish soil classification	SC	National coverage. Layer JG2 – representing subsoil at approximately 50 cm	Polygon	Geological Survey of Sweden (2014)
	2018	Soil depth model 2020: gridded soil depth from point sources		10×10m	Polygon	Geological Survey of Sweden (2020)b
	2015	Sequence of soil layers: soil texture		National coverage	Point	Geological Survey of Sweden (2015)
	1952–1973**(a)**; 1956–2007**(b)**; 1982 – 1987**(c)**; 2002–2003**(d)**; 1988–1990**(e)**;1991**(f)**; *no date-generic* ***(g, h, l)****; no date – laboratory* ***(i,j,k)****; no date given – various samplers* ***(m)***	Soil profiles: texture; moist bulk density; dry bulk density; water holding capacity; impermeable soil layer; loss on ignition[a]	(a) SLD, (b) CMD (e) KTD	0–100 cm	Point	**(a)**Wesström and Joel (2012)[b] **(b)** Jansson and Karlberg (2004); **(c)** Berglund et al., (1989); **(d)** Berglund. (2011); **(e)** Karltun (ed) (1995); **(f)** Wikner et al. (1991); **(g)**Vägverket and Räddningsverket (1998); **(h)**Ferdos et al. (2015); **(i)**Mulqueen (2005), **(j)** Zhang et al. (2011); **(k)**Li et al. (2021), **(l)**Wallman et al. (2018) ; **(m)**Carlsson and Carlstedt (1977)
	1988–2017	Soil and crop inventory: soil texture		0–20 cm; 40–60 cm	Point	Swedish University of Agricultural Sciences. (2021a)
	2011–2012	National soil inventory: soil texture		0–20 cm	Point	Paulsson et al. (2015)
	2003–2012	Swedish National Forest Inventory: soil texture & soil organic carbon		0–20 cm; 40–60 cm	Point	Swedish University of Agricultural Sciences (2022a)

Note: (a) Not all parameters are present for all soil profiles
(b) Based on publications by Andersson and Wiklert (1977a, b,); Andersson et al. (1983a, b, c); Wiklert et al. (1983a, b, c, d)

Table 2
Sources and indata used for delineating tile drained fields from historical maps, adjust stream- and ditch network to a combined network of watercourses, and data to extract water bodies in Tidan catchment, SW Sweden.

Dataset	Year of production/ Observation	Map/indata	Acronym	Resolution (period, time step, area)	Data type	Source
Stream network	2021	National ditch-network: ditches	DI	National coverage	Raster	Lidberg et al. (2021)
	2020	National stream network: topographically derived streams	STR	National coverage	Raster	Ågren and Lidberg (2020)
	2020	Property map, stream layer		National coverage	Polyline	Swedish Land Survey. (2021)
	2021	Digitized streams, year 2018		Tidan catchment	Polyline	Lindelöf (2021)
	2014	Ditch network: ditches, pipes and embankments		Västra Götaland County	Polyline	County Administrative Board of Västra Götaland (2021)[a]
Water bodies	2021	Database of constructed wetlands		National coverage	Polygon	SMHI (2021)
	2020	Swedish Water Archive; waterbodies		National coverage	Polygon	SMHI (2020)
	1981–2005	National wetland inventory		Scale 1:250 000, wetlands > 20 ha, National coverage	Polygon	Swedish Environmental Protection Agency (2021)
	2021	Wetlands and immersed grass surfaces for water retention and –infiltration (sv. *torrdammar)*			Point	*VISS,* Vattenmyndigheterna, Länsstyrelserna, Havs- och Vattenmyndigheten
	2013	National dam database			Point	SMHI, dam and lake register (http://vattenwebb.smhi.se/svarwebb/)
	2002–2021	Meadow and Pasture Inventory (TUVA)			Polygon	Telenius and Nordberg (2021)
	2018	National Land Cover Database (NMD: open wetlands		National coverage	Raster	Swedish Environmental Protection Agency. (2020)
	2015–2020	Agricultural block database: wetlands		National coverage	Polygons + table	Swedish Board of Agriculture (2020)
Drainage	1935–1978	Economic map (year 1935–1978)	(M1 base map, M2 map depicting tile drainage)		Scanned paper maps	Swedish Land Survey. (n.d)
	2014	Soil drainage network: historical ditch systems from mid-19th century				County Administrative Board of Västra Götaland (2021)

Note: (a) also used to evaluate tile drainage system were associated to spatially distributed hydrological classes, stating three qualitative classes of presence/absence of moving soil water. The position was based on the slope position (Department of Forest Resource Management and Department of Soil and Environment, 2022) of spatially verified soil profiles from the Swedish National Forest Inventory (Swedish University of Agricultural Sciences, 2022a). The linked soil profiles were spatially joined to subsoil layers from *SC* for land not classified as arable land, based on soil texture class (40–50 cm) from KTD and the Swedish University of Agricultural Sciences (2022a) to determine the association with the geological formation and sorting of material, i.e., till or no-till.

2.3.1.4. Gravel, boulder ridges and bedrock. Soil physical parameters for profiles dominated by coarser particle size are scarce as most soil physical property analyses are done on (cylinder) cores with a finer soil particle fraction, i.e., particles < 2 mm (e.g., Stendahl et al., 2009). However, the density of minerals in the Swedish bedrock is relatively homogenous (e.g., Knutsson and Morfeldt, 1973; Carlsson and Carlstedt, 1977; Wikner et al., 1991; Vägverket and Räddningsverket, 1998; Larsson, 2008; Wallman et al., 2018). Hence, values on bulk density and saturated hydraulic conductivity for gravel and bedrock were estimated as median values from data by Carlsson and Carlstedt (1977); Wikner et al. (1991); Vägverket and Räddningsverket (1998); Mulqueen (2005); Zhang et al. (2011); Ferdos et al. (2015); Wallman et al. (2018) and Li et al. (2021). Values on plant available water in the root zone for gravel and boulder soils were based on generic profiles from *CMD* and compared with profiles of gravel and bedrock from the American soil database SSURGO ((Soil Survey Staff, 2021).

2.3.1.5. Soil depth. The two soil maps were merged with available soil depths from the Soil Depth Model 2020 (Geological Survey of Sweden, 2020). As a majority of the soil profiles in *KTD* and *SLD* were sampled to a depth of 1 m, the physical properties below 1 m are unknown. To join the soil depth map to the soil physical layers, the depths of the soil profile layer sampled at 0.9–0.1 m from *SLD* were adjusted to the depth from the Soil Depth Model 2020 (Geological Survey of Sweden, 2020) if > 1 m. In case of soil depths < 1 m, the respective soil layers below were erased from the final spatial dataset. The schematics of how we linked soil physical parameters to soil textural data is presented in Fig. 2.

2.3.2. Delineating tile drained field

A specific purpose of this study was to develop indata combining natural and manmade waterbodies at catchment scale. Approximately 64% (300087 ha) of agricultural land is tile drained in Västra Götaland region (SCB and Swedish Board of Agriculture, 2018), yet with a high likelihood of additional forested areas being drained. To develop a map of tile drainage in Tidan catchment, we used information on tile drained fields from the historic Swedish Economic Map for the years 1935–1978 (Swedish Land Survey). Copies of the Swedish Economic Map (years 1935–1978) include fields marked with available individual tile drainage plans, compared to the original economic map that only showed field borders. Henceforth the original map is stated as M1 and the map with marked tile drainage plans M2. The colour setting of land uses and objects in the maps enables the classification of borders between land-use classes and individual fields which further enables extraction of fields that are/have been under tile drainage.

The scanned tile drained fields in M2 were laid over and geo-rectified to M1. The two map versions were classified after colour settings by ISO

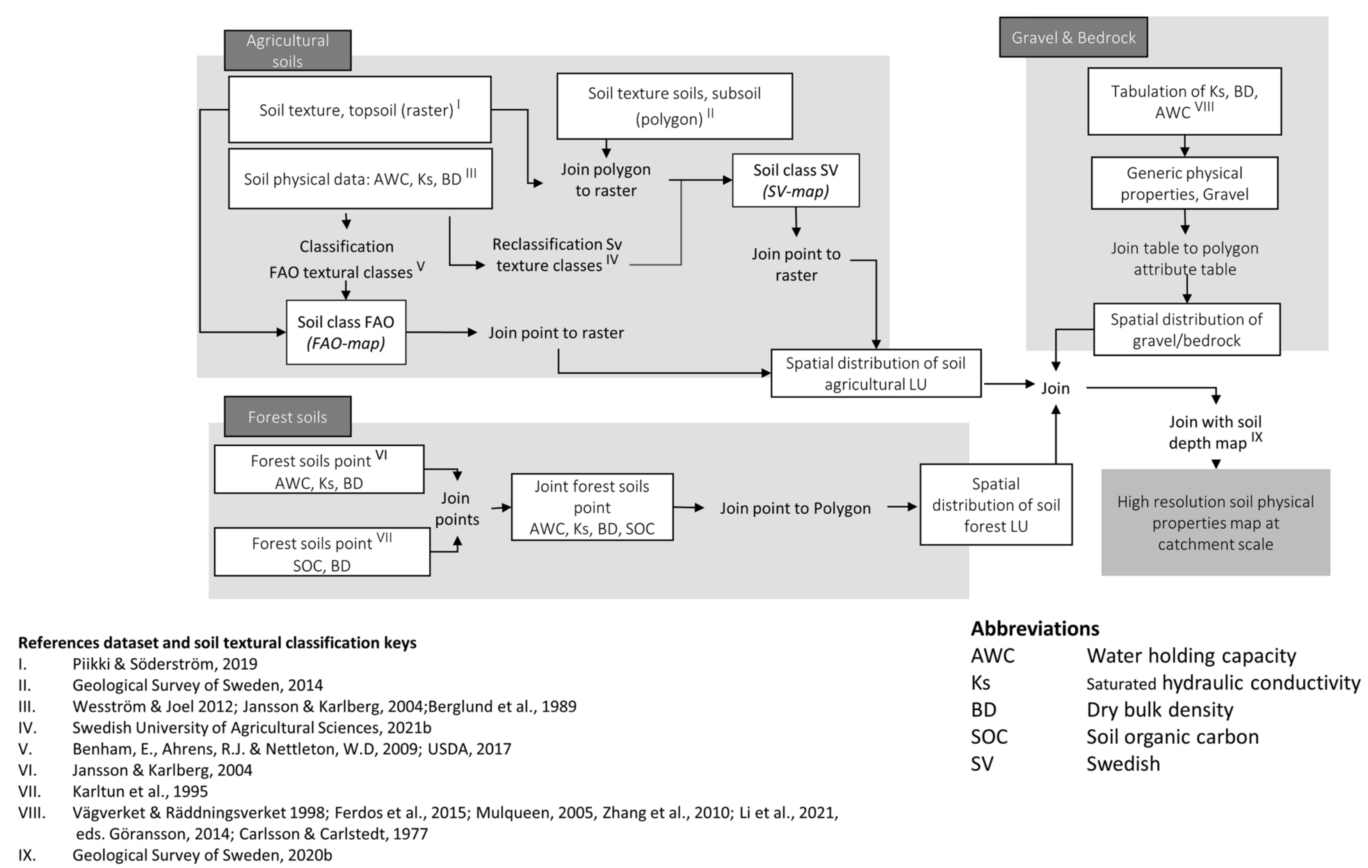

Fig. 2. Methodological approach as flowchart for the developing of a catchment scale high resolution soil physical properties map. The three light grey boxes show the separate processing of agricultural soils, forest soils and gravel and bedrock soils respectively. Other landuses than the just mentioned, were assigned soils from the agricultural soil dataset. Footnotes show the respective dataset that were used per processing step. White boxes indicate a new dataset, while free-standing texts indicate a processing step.

cluster unsupervised classification (ESRI, n.d.a). The number of classes were set to n = 10 (ESRI, n.d.b), and classes representing field boundaries and line-objects were extracted to separate layers, based on their land use class attribution from the unsupervised ISO classification. Thereafter they were transformed from raster to polyline files. The boundaries around agricultural fields from M1 were erased from M2. This resulted in maps with only diagonal lines representing fields with available tile drainage plans. Due to some misalignment during the rectification of the dataset, a buffer distance of 15 m from the border lines was included when erasing the borders. This to ensure that their full extent was erased.

2.3.3. Delineation and extent of stream- and ditch network

A comparison of the two recent datasets over stream networks (Ågren and Lidberg, 2020) (STR) and ditches (Lidberg et al., 2021) (DI) indicated misalignment for Tidan catchment. The topographic stream network particularly depicted water courses in arable land not present in orthopohotographs (Swedish Land Survey, 2018, resolution 0.25 m). Thus, the two datasets were processed to link and erase false streams for the best possible depiction of the catchment stream network. In addition, ditches from manually digitized maps depicting drainage ditches from the national county administrative boards verified from the mid-19th century were included (available at https://ext-geodatakatalog.lansstyrelsen.se/GeodataKatalogen). For Tidan catchment, the drainage network is dated from 1885 to 1971. Some of this dataset was not included in the more recent ditch network in *DI*.

The three datasets were combined to achieve a connected stream network consisting of both natural streams and man-made ditches. The streams in *STR* were overlaid and snapped to DI with a buffer distance of 30 m based on visual judgement. Stream network segments that shared a line with the ditch network were selected as true connectivity, and overlapping line segments of the topographic stream network were erased. The stream segments in *STR* overlapping agricultural fields were erased since natural streams are eliminated by the presence of sub- or surface drainage systems (Section 2.3.2). Lastly, the segmented topographic stream network and the ditch map were merged into a joint layer, depicting the final stream network.

Some of the main streams were not included in the above-detailed stream network maps. Hence, polylines for the main river in the catchment (*Ösan*) and streams delineated for the specific catchment by Lindelöf (2021) were snapped to the combined stream-ditch network (60 m buffer based on visual judgement, reduced by overlapping line segments, and merged to the detailed stream network dataset. The final layer was then manually adjusted by connecting line segments to gaps along river Ösan.

2.3.4. Water storage in natural and manmade lakes, reservoirs and wetlands

The locations of constructed wetlands are not always depicted correctly, or are fully missing within national databases (e.g., ter Borg and Barron, 2021). Thus, locations of constructed and natural wetlands within Tidan catchment were verified with Sentinel 2 images. Three maps with different colour band combinations were created to capture presence of waterbodies, i.e., the Modified Normalized Difference Water Index (Xu, 2006) with SWIR2 data, the Color Infrared Vegetation Map (band NIR, Red and Green) and Land/Water images (bands NIR, SWIR1 and Red). Moreover, the classified waterbodies were manually controlled and labelled as "true" or "false". Waterbodies classified as "true" were compared with national registers from the wetland database, constructed wetlands, wetland inventory and agricultural areas from the agricultural block database (Table 2). The classification of waterbodies are arbitrary as definitions for the three classes of waterbodies intersect (e.g., Langbein and Iseri, 1960; World Meteorological Organization, 2012; Tiner, 2017). However, the three classes here were limited by waterbodies classified as reservoirs if they intersected with the newly delineated stream network. Ponds were classified as open waterbodies if not intersecting with a stream network and wetlands if they contained visible vegetation.

2.3.5. Mathematical processing of datasets

The new soil texture maps (*SV-map* and *FAO-map*), the combined stream- and ditch network (DI) and delineated waterbodies were compared spatially with respective original datasets (Table 1, Table 2). All spatial analysis of data were done in ArcMap 10.8.1 (ESRI, n.d.c), while comparison of stretch-, areal- and volume between new- and original datasets were analysed in Excel2016 (© 2016 Microsoft Cooperation).

The fit of soil physical profiles to soil textural maps were compared with point textural data from Soil and Crop Inventory (*SCI*) (Swedish Land Survey, 2019; Swedish University of Agricultural Sciences, 2021a) and National Soil Inventory (*NSI*) (Paulsson et al., 2015) by fitting a simple linear regression between the datasets, with soil texture as single explaining variable (data not shown). Soil physical data (saturated hydraulic conductivity, water holding capacity and bulk density) were extracted per soil texture class, soil layer (top- or subsoil) and per undrained and drained areal respectively. Field area per class was calculated in the attribute table of the layer or respective soil physical property by *calculate geometry*. The absolute area was summarized per class and estimated as share (%) per soil texture- and drainage class (drained vs undrained fields) by dividing the share per soil texture class with total catchment area, The soil texture and soil physical properties per drainage class were divided per total area agricultural land.

The length of *DI* and *STR* and the new combined dataset was estimated by *calculating geometry* in the attribute tables. The variation in length between the datasets was calculated as the difference between the new dataset and DI respective STR.

The estimated area and volume of the waterbodies were summarized per class of waterbody (i.e. pond, reservoir or wetland). The area and volume of unique lakes not present in available datasets were extracted from the new combined datasets, and summarized separately.

3. Results

3.1. Assigning soil physical parameters for best fit to soil texture classes

The final soil dataset included n = 45 individual soil profiles in the *FAO-map* and n = 35 in the *SV-map*. This is somewhat counter-intuitive, as the Swedish soil classification system includes more soil texture classes than the FAO system (Table S1). As Swedish soil classes are lumped if classified by the FAO classification system, a higher number of soil profiles is assigned per FAO soil class compared to the Swedish system. Thus increasing the overall number fitted per soil pixel to the nearest fit. Hence, there is an increased number of final included profiles in the *FAO-map* (Fig. 3). The two datasets further differed in their lumping of the FAO soil classes, with a more diverse distribution of fine-medium particle classes for the map based on FAO-classes (Table 3).

The two soil datasets were further used to calculate the spatial distribution of saturated hydraulic conductivity (Table 4, Fig. 4a), water holding capacity (Table 4, Fig. 4b) and bulk density (Table 4). The spatial distribution of soil physical characteristics differs depending on the input soil texture data using Swedish or FAO texture classification. The soil physical datasets based on the *SV-map* have the largest area of moderately slow (44%) and very rapid (29%) saturated hydraulic conductivity, whereas the water holding capacity is mainly in the interval of 20–40 mm 10 cm^{-1} (82%). The bulk density is mainly in the interval of 1.2 – 1.4 g cm^{-3} (44%) and 1.6 – 1.8 g cm^{-3} (17%). In the subsoil, the saturated hydraulic conductivity is lower than in the topsoil, with the largest in the slow (17%) and moderate (48%) categories. The water holding capacity in the subsoil is distributed between 0 and 20 mm 10 cm^{-3} (44%) and 20–40 mm 10 cm^{-3} (41%), while the distribution of bulk density is mainly in the interval 1.2–1.8 g cm^{-3} (48% in the

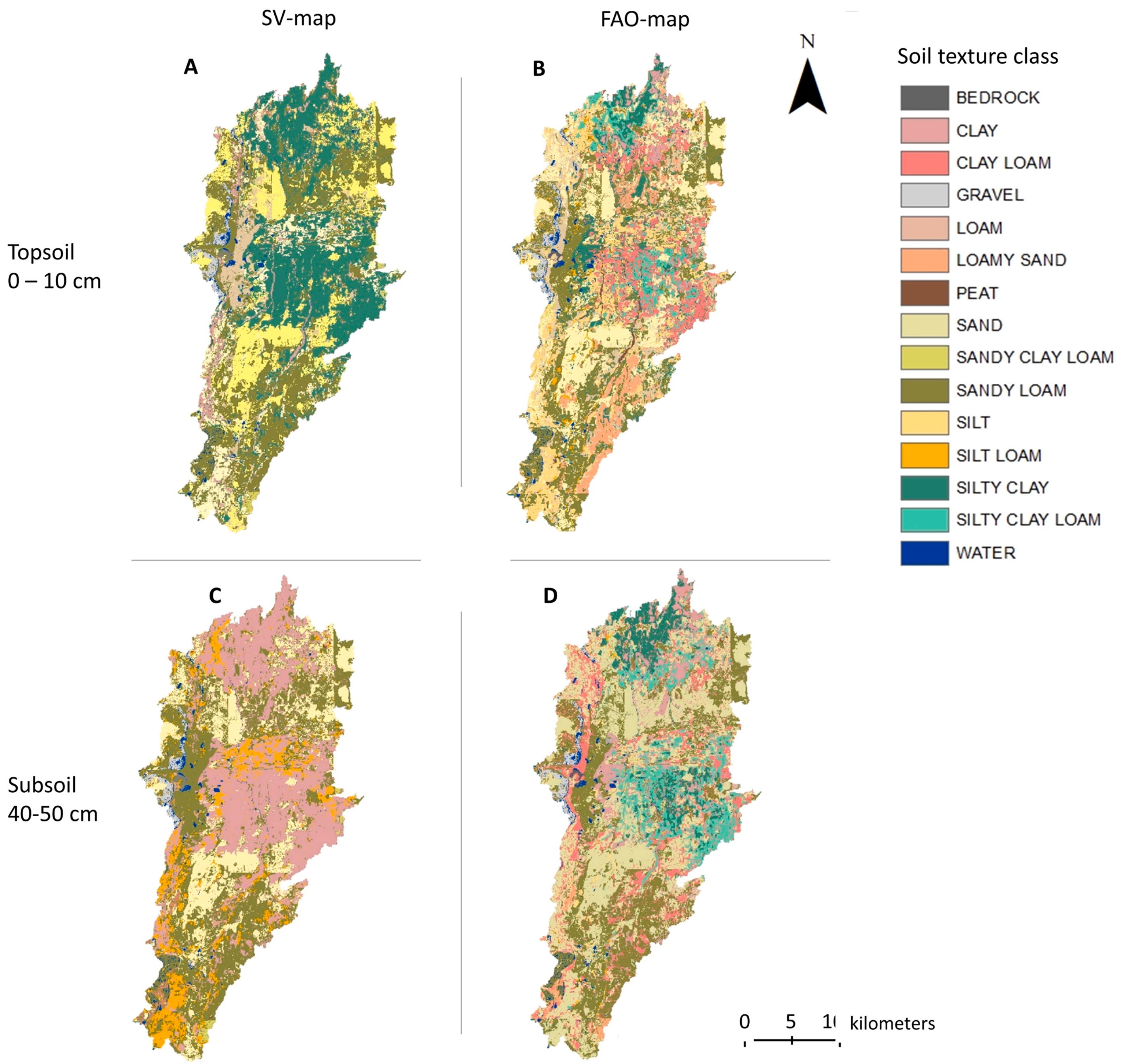

Fig. 3. New soil textural maps in Tidan catchment with fitted soil profiles based on Swedish soil classes (SV-map) (A & C) and FAO/USDA soil classes (FAO-map) (B & D). The right and left column show the SV-map and FAO-maps respectively, while upper two maps show topsoil (0–10 cm) and the lower to soil maps show subsoil layers (40–50 cm). The soil texture is based on soil profiles from the SLU soil database (Wesström and Joel, 2012) and fitted to soil map of Piikki and Söderström (2019).

interval of 1.4 – 1.6 g cm^{-3}). For the input from the *FAO-map*, the largest area in the catchment has a moderate (34%) - to very rapid (21%) saturated hydraulic conductivity, and the water holding capacity is below 40 mm 10 cm^{-1} soil (94%) in the topsoil. These values are reflected in the soil classes of sand, sandy loam, silt loam and loam, which constitute the larger areas in the catchment. Bulk density is between 0.8 and 1.6 g cm^{-3} in the topsoil and increases in the subsoil to the interval 1.4–1.8 g cm-3 (Table 4).

Comparing the two soil datasets, two things stand out. The FAO-map dataset results in larger area of rapidly saturated hydraulic conductivity, which might impact infiltration at precipitation events. However, the water holding capacity is lower over a larger area compared to the *SV-map*. This increase the risk of drought impact. The highest saturated hydraulic conductivity areas are distributed spatially in the centre of the catchment/along stream -and ditch network and water bodies to a greater extent than the Swedish derived data (Fig. 4a). Due to a lack of stand-alone datasets of soil texture and soil physical properties, the datasets have not been independently validated.

3.2. Identification and delineation of tile drained fields on landscape scale

The extraction of fields with tile drainage plans from the economic map (Swedish Land Survey, n.d.) in Tidan suggests that 69% (205 km^2) of the arable fields within Tidan catchment have tile drainage plans available. This is in line with the official statistics of drainage in Västra Götaland from 2016 where 64% of the agricultural land was under tile drainage (SCB and Swedish Board of Agriculture, 2018). Combining the delineated tile drainage field with the soil texture map classification

Table 3
Area of soil classes for Tidan catchment SW Sweden and the share of soil classes in fields with tile drainage plans extracted from the economic map (years 1935–1978) (Swedish Land Survey n.d).

Soil texture class	Area [km^2]				Soil texture area drained of total area [%] (Topsoil)[c]	
	SV[a]		FAO[b]		SV	FAO
	0–10 cm	**40–50 cm**	**0–10 cm**	**40–50 cm**		
Clay	23	232	10	58	1.0	1.1
Clay loam	0	0	47	84	0.0	5.7
Peat	1	1	5	1	0.0	0.0
Gravel	7	7	7	7	0.0	0.0
Loam	43	2	50	3	0.8	3.4
Loamy sand	2	6	75	8	0.1	0.3
Sand	117	126	140	235	0.2	1.1
Sandy clay loam	3	3	2	0	0.0	0.0
Sandy loam	216	240	173	168	5.1	4.8
Silt	0	0	0	9		
Silt loam	64	69	82	3	4.3	6.1
Silty clay	209	0	62	45	16.5	2.6
Silty clay loam	0	0	32	65	0.0	3.0
Water	9	9	9	9	0.0	0.0
Bedrock	2	2	2	2	0.0	0.0
SUM	**696**	**696**	**696**	**696**	**28**	**28**

Note: (a) Show area [km^2] per soil textural class for soil maps (topsoil and subsoil) derived based on Swedish soil classification system (SV-map).
(b) Show area [km^2] per soil textural class for soil maps (topsoil and subsoil) derived based on FAO/USDA soil classification system (FAO-map).
(c) Present the area per soil class [%] with available tile drainage plans based per soil textural map based on either Swedish classification system (SV) or FAO/USDA soil classification system (FAO)

(Section 2.3.1) shows that mainly sandy loam, loam and clay loam were drained (Table 4). The final map of fields with tile drainage plans showed higher clay content (median 17% ± 13 SD) compared to undrained fields (median 14% ± 10 SD) and lower sand- and silt content (Fig. 5).

3.3. Alignment of natural and manmade stream network

The combined stream and ditch network resulted in 5350 km of streams and ditches within Tidan catchment, showing a landscape of more water flow infrastructure than previously identified for the catchment. This is an increase of 649 km compared to *STR* and an increase of 2927 km compared to *DI* (Table 5). Of the topographic stream network, 2690 km lie on agriculturally managed fields, with 2470 km not intersecting with the ditch network. Thus, the topographic stream network identified on agricultural land was assumed to be falsely delineated, as field management, ditch networks and tile drainage systems that reallocated streams that would otherwise have occurred naturally due to topography. Approximately 269 km of the total length of the ditch network (774 km) from the County Administrative Board of Västra Götaland (2021) intersects with tile drained fields identified under Section 2.3.2, and these are not depicted in *DI*. A buffer of 5 m was used around the ditches from Lidberg et al. (2021) to extract non-intersecting ditches from the County Administrative Board of Västra Götaland (2021), thus some segments are missing in the total length estimate.

There is a difference, with a median of 35 m ± 0.72 m, between the AI delineated ditches and closest vertices of the topographically delineated stream network, despite using the same topographic maps as base maps. Ditches in topographic maps should be visible if the resolution with an average width in the ditch map is higher than 2 m ± 1.3 m (Lidberg et al., 2021). Thus, it can also be expected to initiate stream delineation from topographic maps at the same location as the ditches when using topographically governed stream delineation tools in GIS-software, where flow direction- and accumulation is identified by the lowest topographic cell neighbours (Schäuble et al., 2008; López-Vicente et al., 2014) (Fig. 6).

3.4. Land cover corrected for natural and constructed water storage

In total, n = 6 additional water bodies were identified from satellite images (Copernicus Sentinel Data, 2020a, b) and orthophotos (Swedish Land Survey, 2018), comprising a total surface area of 4.3 * 10^{-3} km^2 and an estimated volume of 6.4 * 10^3 m^3 (Table 6), compared to readily available databases (SMHI, 2020, 2021; SMHI, n.d; Swedish Board of Agriculture, 2020; Swedish Environmental Protection Agency, 2021; Vattenmyndigheterna, Länsstyrelserna, Havs- och Vattenmyndigheterna, n.d.). This is a small addition compared to the total area and volume of delineated water bodies from previously known datasets (surface area 1.82 km^2, volume 2.68 *10^{-3} km^3) combined (Table 6). Although the added area/volume the waterbodies is small, they can still possibly impact water balance if they are located in hydrologically important spaces.

4. Discussion

4.1. Opportunities and limitations in the three new datasets

The new datasets increased spatial resolution via a weighting approach for point to pixel derived from measured soil physical properties governing soil hydrological properties rather than pedotransfer functions, using point measured soil texture as input. The dataset also accounts for multiple soil layers not (fully) depicted in existing national datasets (see references Table 1), an issue also noted in commonly used global soil datasets (e.g., Batjes, 2009; IASA et al., 2012; Origiazzi et al., 2018). The resolution in the new soil dataset remained 50 × 50 m, after the base map (*DSM*) (Piikki and Söderström, 2019). This is, however, the best available resolution dataset for Sweden, compared to the map (*SC*) by the Geological Survey of Sweden (2014) and, e.g., European (Panagos, 2006; Kristeensen et al., 2019) or global datasets (IASA et al., 2012; Global Soil Data Task, 2014), which are based on interpolated values or derived from correlated parameters.

The increased number of soil profiles per soil textural group for the dataset based on FAO soil classification (*FAO-map*) compared to the Swedish classification *(SV-map)* expanded the spatial variation of soil physical properties within the catchment and their respective soil physical properties. The dataset based on FAO classification resulted in an addition of n = 35 (n = 25 with Swedish classification) soil profiles compared to, e.g., the set of generic soil profiles (n = 10) used in calculations of nutrient leakages and environmental impact from soils to waterbodies on both a multi-catchment and national scale (Johnsson et al., 2019). Thus, the method presented herein is one alternative for increasing the spatial representation of soil physical properties, not only in Tidan catchment, but also as extended to other catchments to enhance the representation of soil heterogeneity.

As no stand-alone dataset was available for the validation of either soil texture or soil physical properties, the new soil physical dataset should be used with caution. A common issue is the backtracking of Swedish spatial soil physical datasets to the sampling in Soil and Crop Inventory and National Soil Inventory (Paulsson et al., 2015; Swedish Land Survey, 2019; Swedish University of Agricultural Sciences, 2021b), resulting in the absence of independent datasets. To our knowledge, only three additional compiled datasets (Geological Survey of Sweden, 2018; Jansson and Karlberg, 2004; Raulund-Rasmussen and Callesen, 1999) of quantified soil texture composition for land uses other than agricultural ones are available for Swedish soils. Two of these datasets were used for the delineation of our new soil datasets. The dataset from Raulund-Rasmussen and Callesen (1999) was not accessible at the time of our

Table 4
Area distribution of saturated hydraulic conductivity, water holding capacity and dry bulk density of the intervals 20 mm 10 cm^{-1} and 0.2 g cm^{-1}, respectively in Tidan catchment, SW Sweden. The columns named “SV” represents values from soil physical maps originating from soil maps based on Swedish soil classification system (SV-map) and columns named “FAO” represent values from soil textural maps based on FAO/USDA soil classification system (FAO-map).

Saturated hydraulic conductivity[a] **[mm h^{-1}]**	Area [km^2]				Share of total area [%]				Drained area of total agricultural land [%]			
	SV		FAO		SV		FAO		SV		FAO	
	0–10 cm	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**
Very slow < 1.3	67	67	72	72	10	10	10	10	0.4	0.4	3	3
Slow 1.3–5	0	115	16	47	0	17	2	7	0	16.4	4.6	6.8
Moderately slow 5–20	309	36	96	2	44	5	14	0	47.1	0.7	8	0.1
Moderate 20–63	90	331	233	285	13	48	34	41	7.5	43.6	30.5	20.1
Moderately rapid 63–127	24	85	18	126	3	12	3	18	2.5	6.4	0.5	19.8
Rapid 127–250	6	6	113	20	1	1	16	3	0	0	21.1	4.1
Very rapid > 250	200	57	147	144	29	8	21	21	11	0.9	0.7	14.5
Water holding capacity[b] [mm 10 cm^{-1}]	**Area [km^2]**				**Share of total area [%]**				**Drained area of total agricultural land [%]**			
	SV		**SV**	**FAO**	**SV**		**FAO**		**SV**		**FAO**	
	0–10 cm	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**
0–20	66	304	214	308	9	44	31	44	0	41	25	38
20–40	571	283	438	305	82	41	63	44	65	24	42	30
40–60	30	108	13	53	4	16	2	8	4	4	2	1
60–80	29	1	30	30	4	0	4	4	0	0	0	0
80–100	0	0	0	0	0	0	0	0	0	0	0	0
Dry bulk density[c] [g cm^3]	**Area [km^2]**				**Share of total area [%]**				**Drained area of total agricultural land [%]**			
	SV		**FAO**		**SV**		**FAO**		**SV**		**FAO**	
	0–10 cm	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**	**0–10 cm**	**40–50 cm**
0 – 0.2	0	0	0	0	0	0	0	0	0	0	0	0
0.2 – 0.4	45	24	0	5	7	3	0	1	0	0	0	0
0.4 – 0.6	23	0	4	0	3	0	1	0	0	0	0	0
0.6 – 0.8	1	0	1	0	0	0	0	0	2	2	0	0
0.8– 1.0	88	0	88	0	13	0	13	0	0	0	0	0
1.0 – 1.2	43	5	66	45	6	1	10	7	7	7	6	0
1.2 – 1.4	304	113	260	25	44	16	37	4	42	42	30	4
1.4 – 1.6	62	337	236	434	9	48	34	62	6	6	31	41
1.6 – 1.8	120	99	31	153	17	14	4	22	10	10	0	23
1.8 – 2.0	0	23	0	23	0	3	0	3	0	0	0	0
2.0 – 2.2	0	0	0	0	0	0	0	0	0	0	0	0

Note: Area distribution of saturated hydraulic conductivity is presented after permeability class (a), water holding capacity (b) and dry bulk density (c) presented as the area distribution of the intervals 20 mm 10 cm^{-1}and 0.2 g cm^{-1}, respectively.

study. Furthermore, soil physical-, subsoil texture data and quantitative compilation on soil composition and soil physical parameters in forest and urban landscapes is lacking in quantification and resolution (Department of Forest Resource Management and Department of Soil and Environment, 2022).

Swedish textural point data has previously been shown to be too scattered for traditional interpolation methods in predicting soil texture for soil textural maps in Swedish landscapes (Djodjic et al., 2009). Also shown for the European dataset in LUCAS (Cordeiro et al., 2018). Additionally, Piikki and Söderström (2019) point to the increased errors of datasets with local- compared to national scales due to the availability of fewer calibration/validation samples. However, the development of pedotransfer functions adapted for Swedish soils have shown good fit regarding water content and porosity with the inclusion of soil organic carbon at a higher water content and bulk density linked to soil textural class (e.g., Kätterer et al., 2006). Furthermore, topsoil and subsoil textures have been shown to be overall correlated in Swedish soil profiles. At least in currently available soil samples (Sohlenius and Eriksson, 2009). However, to include subsoil characteristics in finer soil sampling, a grid is still required to develop robust regional pedotransfer functions. Leastways by the compilation of soil organic carbon and bulk density for deeper soil layers (Wösten et al., 2001), or by fitting pedotransfer functions based on a priori determination and sampling of most sensitive study area parameters (van Alphen et al., 2001). Overall, a lack of sampling of soil physical parameters, including soil structure and porosity, is a major gap to include in long-term soil monitoring. Especially since temporal changes of soil properties, such as hydraulic conductivity and soil organic carbon (Moberg, 2001), occur.

The spatial description of subsurface flow was improved by delineating fields with tile drainage plans from the economic map (Swedish Land Survey, n.d.). The new map, together with the soil hydrological dataset, can be of direct use for comparing drained and undrained fields and improve the water partitioning description. The drained arable land indicated a higher share of drainage on soils with higher clay content (Fig. 5) and a larger area of slow to moderate saturated hydraulic conductivity (Figure S2 Supplemental material). This is expected as we would anticipate a prioritization of fields with lower hydraulic conductivity as these fields are more susceptible to standing water. However, Table 4 indicates that drainage mainly occur in fields with moderate to rapid saturated hydraulic conductivity classes. This reflects that a major part of arable land is already drained, covering both less self-draining soils as well as soils with higher infiltration capacity.

The adjusted datasets under Sections 2.3.2 and 2.3.4 improved the spatial delineation of the water flow pathway (Fig. 6, Table 4 and Table 5). However, the effectiveness of tile drains remains unaccounted for. For example, nationally, 12.0% of all tile drainage in cropland was in need of maintenance in 2016. Additionally, 12.1% were considered to require the implementation of new drainage systems (SCB and Swedish Board of Agriculture, 2018). The rate of required maintenance of tile drained fields (exempting the requirement for implementing new

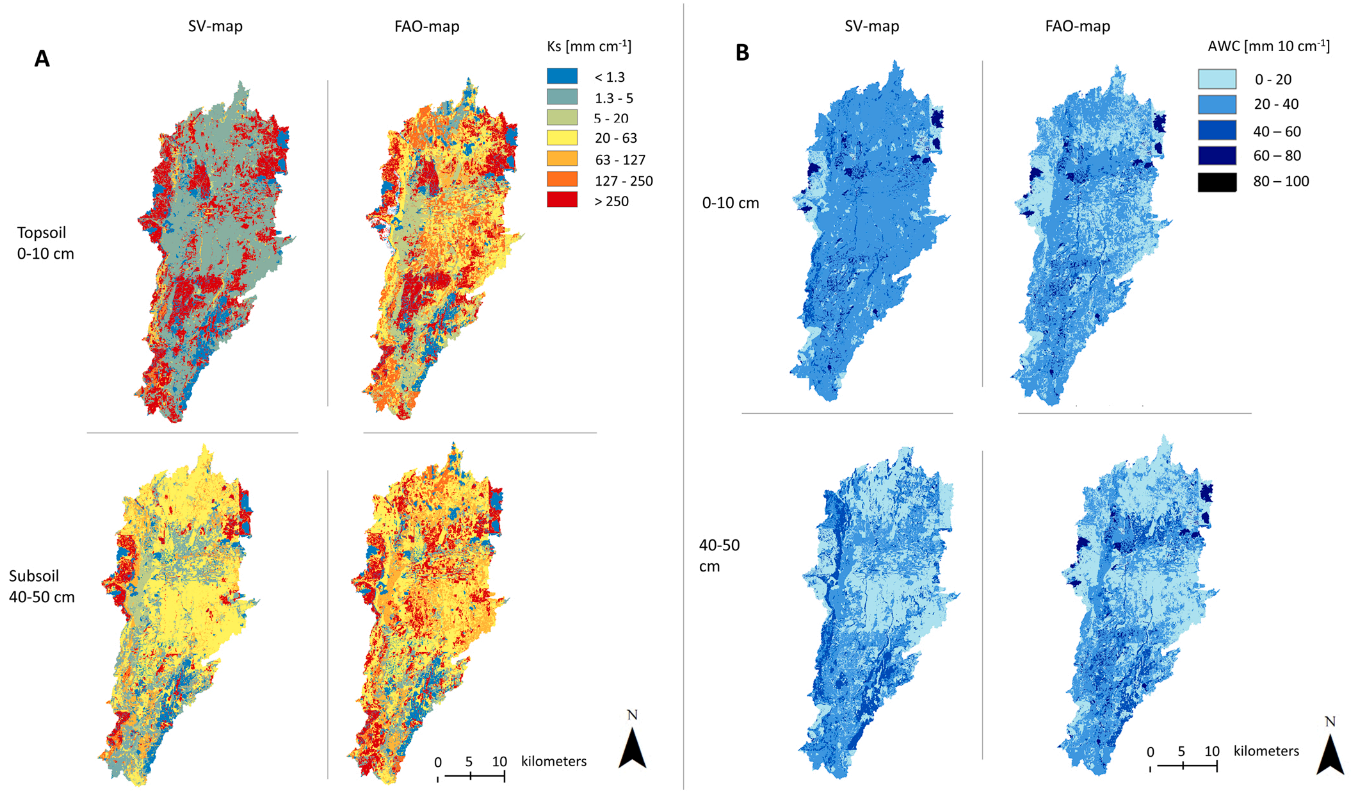

Fig. 4. Saturated hydraulic conductivity (Ks) [mm h^{-1}] (A) and water holding capacity (AWC) [mm mm^{-1}] (B) for Tidan catchment, SW Sweden. The Ks and AWC were mapped by combining point soil physical data with spatially distributed datasets of soil textural data. The left upper and lower maps in Fig. A and Fig. B respectively show Ks and AWC derived from soil textural maps classified by the Swedish soil texture system (SV-map). The right upper- nad lower maps in Fig. A and B show Ks and AWC derived from soil textural maps classified by FAO/USDA soil textural system (FAO-map). The upper maps show Ks (A) and AWC (B) for topsoil (0–10 cm soil depth). The lower maps show Ks (A) and AWC (B) for subsoil (40–50 cm).

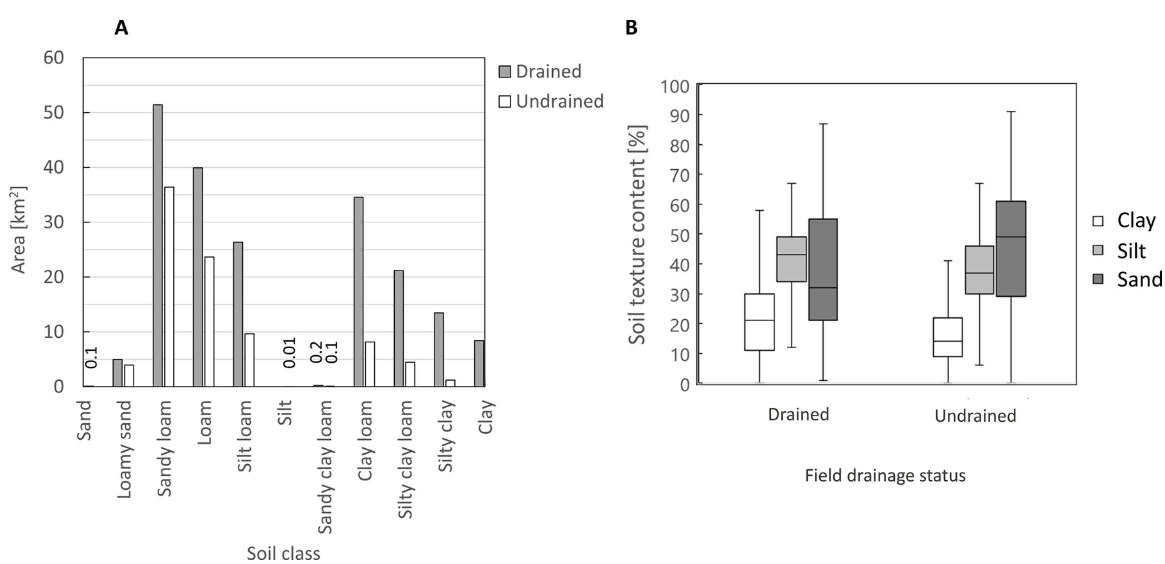

Fig. 5. Comparison of area per soil class with and without available tiled drainage plans (A) and soil texture content (percent clay, silt and sand respectively) for fields with and without available tile drainage plans (B) in Tidan catchment, Sw Sweden. The numbers above the bars for sand, silt and sandy clay loam in fig. A is the area written out for these soil classes.

drainage) has been estimated at 1–2% annually, in order to meet drainage requirements (Reiter and Bölenius, 2020). Thus, drainage capacity might be overestimated, as caused by estimations of the efficiency and effects of the national tile drainage network, or underestimated due to the expansion of newly drained fields. Comparing the ditch maps by Lidberg et al. (2021) (*DI*) with the manually delineated ditch maps produced by the County Administrative Board of Västra Götaland (2021) showed a change of ditches, likely representing a shift from surface drainage to subsurface drainage in later times (Jacks, 2019). There is a shortcoming in depicting the connectivity between ditches in the new main drainage map consisting of open ditches (Lidberg et al., 2021). This can possibly be explained by challenges in depicting subsurface

Table 5
Total length of existing detailed stream (STR)- and ditch maps (DI) compared to the new combined stream and ditch network based on the three individual datasets.

Nr	Product	Reference	Total length [km]
1	New hydrologic stream and ditch network[a]	This study, final product	**5350**
2	Natural streams	Ågren and Lidberg (2020)	4701
3	Ditches (AI)	Lidberg et al. (2021)	2423
4	Ditches (manually delineated)	County Administrative Board of Västra Götaland (2021)	774

Note: (**a**) is the new dataset derived from joining the below free-standing datasets (nr 2–4) where overlapping stream segments from nr 2 and 4, and stream segments from nr 2 overlapping agricultural fields have been erased.

pathways as culverts or poorly maintained ditches exposed to, e.g., the erosion of ditch banks.

The processing of data herein was done manually. We see a great potential for automation to shorten the processing time, for example by linking the processing steps and unify the in-data tables to a common format for use in common software handling spatial data. This is possible for all three datasets. The use of e.g. AI for constructing a model for point-to-pixel fitting of the soil data, to extend outside the dataset herein, is an appealing idea. However, such development would require larger independent dataset of soil physical properties for training and validating the model. This is a major limitation, as discussed in above sections. For the ditch- and stream network however, similar to the AI-model used by Lidberg et al. (2021), training a model for identifying "false" streams from the topographic stream network (Ågren and Lidberg, 2020) is a possibility for further exploration.

Automating the processing would additionally enhance the possibility to upscale the method to national level. This would be possible for both the soil datasets and the stream- and ditch network. Although the linking of soil physical properties data would reduce in spatial variation for northern Sweden, due to the absence of coverage from the digital soil map (Piikki and Söderström, 2019) in these areas. The methodology is simple and the possibility to extend outside Sweden is mainly linked to textural- and soil physical properties data available in other countries. Extracting the tile-drainage system based on the adjusted economic map is limited to Västra Götaland County, as we could not find similar dataset for other counties. However, the method of classification of line structures based on colour recognition is a simple and effective method for extracting linear features representing tile drains from maps of similar appearance from other regions. The extraction of waterbodies from satellite images or ortophotos is a concept used globally and the efficiency mainly dependent on image quality (e.g. reduced by cloud cover) and pixel resolution.

4.2. Implications of higher resolution spatial soil physical and hydrological functions datasets

The requirements of high spatio-temporal resolution depends on the research objective (Baffaut et al., 2015). Nevertheless, the increased availability of high resolution spatio-temporal data improves possibilities to study more complex questions when using models. For example, the inclusion of known subsurface flows in the Soil and Water Assessment Tool (SWAT) has been shown to improve water balance (Strömqvist et al., 2020; Rumph Frederiksen and Molina-Navarro, 2021;

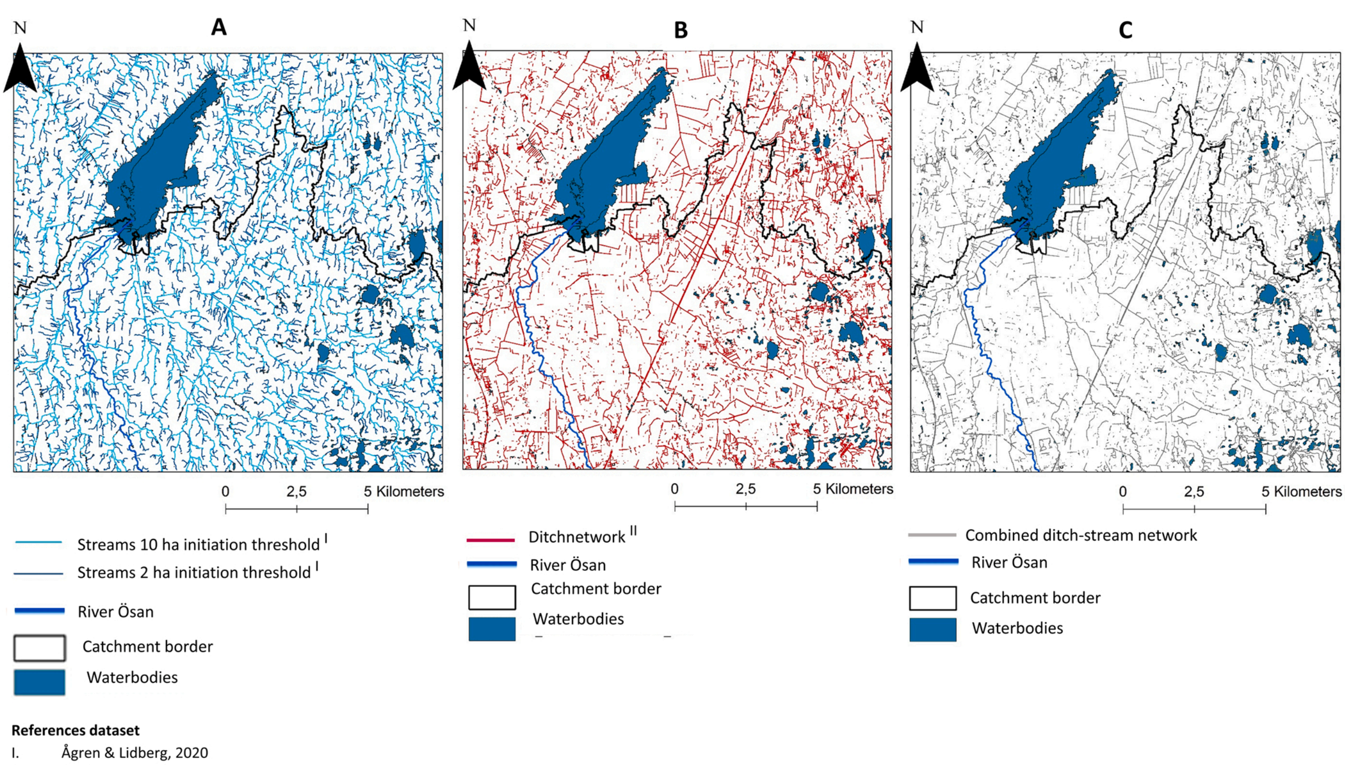

Fig. 6. Comparison of the delineation of the hydrological network in Tidan catchment where A shows streams delineated from topographic maps with stream initiation threshold of 2 ha (dark blue) and 10 ha (light blue) by Åberg & Lidberg (2020). The thicker dark blue stream depicts the river Ösan. Blue filled polygons represents lakes and wetlands. Fig. B delineates ditches (red) from Lidberg et al. (2021). Fig. C shows the new elaborated network from this paper, which is a joint network of the stream network (A), ditches (B), and additional ditches from the County Administrative Board of Västra Götaland (2021) and streams from Lindelöf (2021) where line segments overlapping each other-,and stream segment intersecting agricultural fields have been erased as "false" streams,.The black line in upper 3rd of the images shows the north border of Tidan catchment, and the lake is the south part of lake Östen. The image is an extraction (within 13.748 E; 58.595 N/14.065E; 58.401 N) from the larger Tidan sub-catchment.

Table 6
Comparison of area and volume of "missing"water bodies in Tidan catchment Sw Sweden, identified from ortophotos and satellite images, compared to available national datasets of open waters and wetlandss.

	Type[a]	Number	Area (km^2)	Estimated volume [m^3]	Numbers not included in readily available maps/ geospatial layers		Area (km^2)	Estimated volume [m^3]
Unique waterbodies	Reservoirs combined data	111	1.2	$21.37 * 10^4$	Reservoir	3	0.0011	$0.111 * 10^4$
	Ponds combined data	234	0.52	$47.83 * 10^4$	Ponds	2	0.00073	$0.022 * 10^4$
	Wetlands combined data	22	0.1	$5.824 * 10^4$	Wetland	1	0.0025	$0.510 * 10^4$
	Dams	6						
Original references	**Dataset[b]**	**Number of waterbodies**	**Total area [km^2]**	**Total volume [m^3]**	**Number of water bodies without statistics**			
	Meadow and Pasture Inventory	32	2.3	$2735 * 10^4$	5			
	Agricultural block database 2021	13	0.2	$23.18 * 10^4$	1			
	National Land Cover Database open wetlands	6088	12.5	$2827 * 10^4$	3930			
	Database of constructed wetlands	7	0.1	$35.10 * 10^4$	2			
	Swedish Water Archive waterbodies	10	0.4	$286.7 * 10^4$	5			

Note: Type (**a**) of water body were classified as reservoirs if they intersected with streams or ditches. Ponds were classified as open waterbodies if not intersecting with streams or ditches. Wetlands if they contained visible vegetation. Dams are constructed wetlands from the national database of constructed wetlands (SMHI, 2021. *Anlagda Våtmarker*. https://vattenwebb.smhi.se/wetlands/ accessed [2021–09-15]). *Nota bene: in the Swedish Water Archive, there are additional wetlands that could not be confirmed in their existence due to limitations of heavy vegetation cover such as forest and not identified* via *analysis of satellite data. These wetlands have not been included in the above calculated dataset on area and volume but should be considered if the total dataset is used for additional landscape analysis.*
Waterbodies in column Datasets (**b**) are the area and volume estimated from the original datasets. Note that the waterbodies overlap between the databases in some cases.

Valayamkunnath et al., 2022). Higher resolution in indata and parameters can furthermore reduce uncertainty for parameters known to be sensitive to model algorithms (see, e.g., Romanowicz et al., 2005; Veith et al., 2010; Arnold et al., 2012; Koo et al., 2020; Escamilla-Rivera et al., 2022). Additional details in temporal variation enables an improved description of short-term events, e.g., seasonal- or sub-daily effects. Although the impact of input data that is dependent on resolution, i.e., the aggregation of land units in e.g. hydrological response units (s.c. HRUs) and hydrological processes in models with a larger scale, might masks differences in the high spatial resolution of indata (e.g., Li et al., 2012). The same might not be valid for temporal effects, e.g., where hydrological response variation in a catchment is dependent on the spatial intra-catchment heterogeneity of both climate and land-soil properties (e.g., Jothityangkoon and Sivapalan, 2001). The changed distribution of weather extremes caused by climate change speed up hydrological process in field to landscape scales (Fischer and Knutti, 2014). Trends in the current climate indicate more extreme rainfall events (e.g., Grusson et al., 2021), and the synergetic effects of multiple weather events (so-called compound events) call for improved knowledge of landscape responses to various events and their interactions at local scale (Zscheischler et al., 2018). The change of pulse events will require new approaches in data collection and hydrological modelling; moreover, complementary studies at various scales are needed to understand the impacts and, e.g., design of mitigation measures (e.g., Garg et al., 2022). Furthermore, although data might be available at high spatial resolution, the temporal scale of input parameters for modelling short-term events might be too coarse to match the means, an issue to discuss, e.g., when linking landscape hydrology with short-term weather events.

The datasets presented herein mainly relate to surface waters. Nevertheless, considering retention to groundwater storages is equally important, with respect to both storage- and flow pathways in natural- and manmade (anthropogenic) water infrastructure. A limit from surface to subsurface flows from the dataset herein concerns the age of the economic map and the tile drainage plans it refers to, as well as the limited access to tile drainage plans for other areas. Further work is needed to highlight delineated subsurface flows and water outtake/return flows for anthropogenic use in agriculture, industry, households and other sectors. For example, the inclusion of irrigation outtake and re-routing in the catchment water balance can be important in achieving a better hydrological representation of anthropogenic landscapes (Strömqvist et al., 2020). Some of these data are accessible through the national statistical unit (SCB), yet limited due to secrecy (Strömqvist et al., 2020). Additionally, a model representation of connectivity between groundwater/surface waters in hydrological models is needed to accurately quantify hydrological pathways (Berghuijs et al., 2022). It has already been established that the dynamic representation of especially sub-soil hydrological flows for Swedish conditions is missing (Barthel et al., 2021).

4.3. Policy implications

Our new and improved datasets indicate the spatial complexity of both natural and manmade water infrastructure at catchment scale. This is critical information for accurate water balance under current and future water balance studies. As climate change accelerates, events and periods of both excess and scarcity of water increase in incidence and duration. Knowing the combined strengths of water infrastructure for partitioning, flows and storage will be critical at both local (e.g., field and farm) and catchment scale. The improved datasets can be used in the evaluation of landscape sensitivity to drought and flood events accounting for spatial heterogeneity. An accurate depiction of waterbodies and soil properties improves estimations of landscape water storage. Together with the improved ditch-stream network dataset, it might also improve knowledge on the connectivity of water storages and upstream-downstream effects of the surplus/deficiency of water throughout catchments. The datasets are a basis to inform and evaluate the synergetic effects of local adaptation measures at catchment scale. The analysis and data collection in this paper clarify that additional effort would be of value to tile drainage data linked to field levels, in order to incorporate accurate field bound drainage capacity at a catchment scale, as well as coupling with effects on the subsurface level.

Despite increased possibilities for data collection by, e.g., reduced costs and improved automation for the in-situ collection of spatio-temporal data, there are paradoxical signs that data availability as open source becomes more limited and less monitored (Harris et al., 2020; Thorslund and van Vliet, 2020; SMHI, 2022a; b). Hence, paradoxically, the number of suggestions/method developments of incorporating effects of soil structure dynamics in soil-crop systems caused by biological activity, e.g., at the plot- and centennial-decennial scale (e.g., Meurer et al., 2020) and in intra-annual fluctuations in soil porosity (e.g., Chandrasekhar et al., 2018) and vegetation (e.g., Thompson et al., 2011), increase the demand for soil data sampling intervals both spatially and temporarily. According to some, the increase of openly available RS data, the development of various innovative ways of processing and data mining of various landscape parameters reduces direct dependency on in-situ sampling (e.g., Cui et al., 2021; Duethmann et al., 2022; Fuentes et al., 2022; Xue et al., 2022; Yan et al., 2022). However, in this work we show the more remote data products that are available – the more it paradoxically enhances the importance of having accurate in-situ datasets for thorough, independent validation (e.g., Cosh et al., 2004; Weerasinghe et al., 2020; Gelebo et al., 2022). Thus, a thorough campaign of support from national and regional funders, as well as land owners and local populations that enables in-situ sampling for verification is still on the agenda. This should possibly be synced or incorporated in any research programme for improving remote access data on landscape parameters to match the means.

5. Conclusions

In this study, we have developed the information of soil physical characteristics, natural and manmade water flow as well as storage at catchment scale to improve water balance partitioning and the description of landscape (catchment) hydrology. We show that with available soil texture data, improved with point measured soil physical properties, key landscape hydrological functions such as soil water holding capacity and saturated soil hydraulic conductivity, change significantly. Further, the explicit addition of tile drainage and merged natural and manmade ditch networks increases flow pathways significantly. Finally, the catchment water storage was comparatively well understood in available/existing data.

To secure water under climate change, water allocation will increase in importance for many water users at catchment scale, including safeguarding environmental flows alongside human supplies and agricultural needs. The use of more complex models and the improved model performance of hydrological processes need to better capture both natural parts and the impact of anthropogenic structures and processes concerning the hydrological cycle at landscape scale linked to both surface and subsurface (unsaturated soil) water flows. Improved soil physical properties and merged water flow paths and storage, distributed accurately, will be as equally important as climate input for these water balances estimates. This calls for the long-term increased/maintained data collection of essential landscape-, hydrological, climate parameters with the evaluation of sampling size and interval (spatial and temporal) for, at a minimum, calibration/validation purposes. In addition, transparency of access for available data linked to water outtake/recharge/storage is needed to be able to evaluate and follow up any landscape measures affecting landscape hydrological storage capacity.

CRediT authorship contribution statement

Louise Malmquist: Methodology, Investigation, Formal analysis, Validation, Visualization, Data curation, Writing – original draft. **Jennie Barron:** Conceptualization, Writing – review & editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data Availability

Data will be made available on request.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agwat.2023.108304.

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