

Land Drainage Interventions for Climate Change Adaptation: An Overlooked Phenomenon—A Conceptual Case Study from Northern Bohemia, Czech Republic

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Abstract: This study investigates the often-overlooked phenomenon of land drainage interventions as a means of climate change adaptation, focusing on a conceptual case study from Northern Bohemia, Czech Republic. The intensification of agriculture has led to extensive tile drainage systems, which have had significant environmental impacts, including disruption of water balance, nutrient leaching, and ecological degradation. With climate change expected to alter precipitation patterns and increase temperatures, these impacts are likely to intensify, leading to more frequent droughts and pollutant delivery from soil to water bodies. This study explores the options for the allocation and implementation of drainage-related measures such as controlled drainage, constructed wetlands, and partial drainage elimination to mitigate these effects, with the use of readily available archival data as well as aerial images, current as well as historical soil, land use, geomorphological and landowner-land user relationships. At two cadastral units with local potable water resources at the hilly Lovečkovicko case study, the paper proposes conceptual, practical approaches for integrating drainage-related measures into land consolidation processes. Here, eleven sites based on the cross-intersection of the above interventions' criteria were selected, and twenty various drainage-related measures were tentatively designed. This study categorizes the implementation potential of the proposed measures into three levels: high, medium, and low, highlighting the feasibility and transferability of these interventions within the land consolidation or similar process.

Keywords: tile drainage; adaptation to climate change; nature-based solutions; land consolidations



Academic Editors: Kristina Potočki and Carla Sofia Santos Ferreira

Received: 22 February 2025

Revised: 25 March 2025

Accepted: 3 April 2025

Published: 5 April 2025

Citation: Černý, J.; Fučík, P.; Zajíček, A. Land Drainage Interventions for Climate Change Adaptation: An Overlooked Phenomenon—A Conceptual Case Study from Northern Bohemia, Czech Republic. *Land* **2025**, *14*, 782. <https://doi.org/10.3390/land14040782>

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1. Introduction

Land drainage removes excess water from the soil to improve and speed up land accessibility for crop planting. Intensification of agriculture has led to the construction of tile drainage on 17–87% of farmland in the Atlantic, boreal, and continental Europe and the USA, being built between the period 1860–1990 [1,2]. However, the process of land drainage has also had significant environmental consequences, including the disruption of the water balance, overheating of the land, nutrient and pollutant leaching, and the deterioration of the ecological and morphological status of adjacent areas, as well as the transformation of heavily modified water streams and landscape heterogeneity [3–9].

This is particularly evident in central and eastern European countries, where large-scale drainage projects were implemented during the period 1960–1990 as part of a state

policy to achieve food self-sufficiency. Consequently, a substantial proportion of constructed single-purpose land drainage systems, i.e., without the option to control drainage runoff, is regarded as excessive, encompassing peat bogs, seasonally waterlogged soils, and submontane regions across central and eastern Europe [1,10–14].

The projected effects of climate change on temperate catchments will likely lead to a shift in water balance parameters. Specifically, during the vegetation season, the climate studies expect, due to the presumed changes in precipitation patterns, shorter wet periods, more often flood events, and an increase in episodic tile drainage flow. This may lead, together with the projected growth of air temperature, to the overheating of drained farmland, increasing droughts, and a more significant pollutant delivery from soil to drains and water bodies [15–17]. For heavily drained landscapes, there is consequently an untapped potential to design and implement currently under-utilized suitable interventions on existing land drainage systems, including both tiles and ditches, since these measures may slow down the runoff, support water infiltration, and enhance water self-cleaning processes. Many of these measures, known as Nature Based Solutions (NBS) or Natural Small Water Retention Measures (NSWRM), include controlled drainage, constructed wetlands/biofilters/pools, drainage blinding, two-stage ditches or canal revitalisation and management. Indeed, these measures have been found to be potentially effective in adapting to climate change, with their efficiency and limitations being partially documented [10,12,18–26]. Controlled drainage on tiles (CD) is reported to increase the shallow groundwater table by 20–70 cm by regulating drainage runoff, delaying the peak drainage flow by 50–90%, and reducing the total drainage runoff by about 25–60%. In terms of improving drainage water quality, CD mechanisms enhance nutrient use by crops, reduce flow (and therefore nutrient transport), and, to a lesser extent, promote self-cleaning processes in the soil (e.g., denitrification in a water-saturated, anaerobic environment). On average, reductions in nutrient removal by CD in drainage water for nitrogen have been documented by 20–50%, and for phosphorus by 15–40%, while maintaining or slightly increasing crop yields [1,10,19,27]. Analogously, weir management at drainage ditches may reduce the discharge by 20–67%; nevertheless, the evidence of the effects at drainage ditches is less documented compared to CD [18,22,26]. Constructed wetlands or biofilters treating drainage waters, implemented under the optimal design (e.g., wetland-to-catchment and length-to-width ratios, substrate, plants) and operational factors, can deliver the load removal rates of nitrogen between 15 and 70%, phosphorus between 10 and 50% and some pesticides between 10 and 90% [24,28]. Controlled spontaneous ageing of drainage (i.e., interrupting or blinding the drainage pipes, letting the rooting of drainage), untubing (opening) the tubed streams as well as the two-stage channels and drainage ditch management have been documented to deliver some improvements in deceleration of flow, re-wetting, and, especially biodiversity- and ecosystem restoration-related parameters, such as soil organic carbon content, bacterial and plant communities [5–7,11].

The most promising potential for implementing drainage-related structural measures lies in the land consolidation process. However, to our knowledge, analyses of land drainage (the presence, condition, functioning), proposals and subsequent accomplishment of the measures are rarely incorporated in the common measures plan in Central Europe [29,30], although these steps are accommodated as mandatory in the valid methodology for Land Consolidations in Czechia and recommended in the FAO Legal Guide on Land Consolidation [31]. The complicated ownership of drainage (many landowners of a single tile-ditch system), the true location, extent and condition as well as the investment and management costs, sometimes together with the low climate change literacy of the local actors are mentioned as the main barriers to the adoption of the aforementioned measures [12,30–33]. In the present study, we address this issue in the Lovečkovicko region,

located in Northern Bohemia, the Czech Republic. This area, characterized by a heterogeneous natural condition and a manifold history, was heavily tile-drained during the 1960s and 1980s. Lovečkovicko is a headwater of three small streams and an area of small villages with their own local potable water resources; see the details in Materials and Methods. Thus, the design and implementation of water retention measures on drained farmland, considering the options for water quality improvements, are the steps to adapt to climate change and mitigate its above-mentioned negative effects. In this paper, at two cadastral units, we combine various new and readily available data on natural, agricultural, and drainage characteristics, together with the information of land ownership, to introduce practically applicable approaches for analysis and feasible yet conceptual proposals of water retention measures related to land drainage. We hypothesize that the potential for implementing drainage-related measures is considerable and transferable within the land consolidation process due to the precise identification of drainage locations and less complicated land user–landowner relationships under similar conditions.

2. Materials and Methods

2.1. Case Study Background

The Litoměřice district (North-West Bohemia), including the Lovečkovicko region, is characterized by a rich and diverse history. Inhabited since the Middle Paleolithic period, from the 13th century on, the Germans started to come and to cultivate especially the hillier areas. Gradually, this region became famous for fruit planting at small orchards, divided by dense stone fences and hedgerows, i.e., features together called *Plužiny* (Flur in German, Hedgerow in English). These linear structures, being the natural field borders, along with the small fields pattern, also stabilized the slopes, supported water infiltration, and diminished surface runoff and soil erosion [34]. The region was called the Garden of Bohemia. From the 1920s on, cereals and other field crops were planted more often, and some fields were locally tile-drained. After WWII, with the displacement of the local German population and the advent of the socialist era, the landscape underwent profound changes, similar to other regions in Central and Eastern Europe, for various reasons [35–37]. In the region, the orchards, meadows, and small fields were mostly replaced by larger blocks of arable land, very often gradually drained with extensive, systematic subsurface tile drainage. After 1990, much of the arable land was converted to grassland and pasture, while after 2000, many parcels were bought up by agricultural companies.

2.2. Assessed Cadastral Units and Accomplished Analyses

2.2.1. Natural and Land Use Conditions

The Lovečkovice case study (LCS) is located north of the Elbe River, in a triangle of Litoměřice, Ústí nad Labem, and Česká Lípa towns (Figure 1), at a watershed divide of three small streams. The altitude ranges between 335 and 618 m a.s.l. (415 m being the mean). The long-term average precipitation is 550 mm, and the long-term average daily temperature is 8.1 °C. The geological substrate comes mainly from the Tertiary: Ash rock, Traprock, and Pyroclastic rocks, and related alluvial deposits occur the most [38]. Soil assessment was performed with the help of Valuated Soil Ecological Units available as an SHP layer (VSEU, 1:5 000; BPEJ in Czech) and the historical Soil Complex Survey [39]; the morphology was analyzed via the 4G Digital Elevation Model (5 × 5 m). There are five main soil types in the LCS: Cambisols, Stagnosols, haplic Luvisols, Gleysols, and Albeluvisols. Among them, Stagnosols are prominent, with varying soil textures from loamy sand to clay.

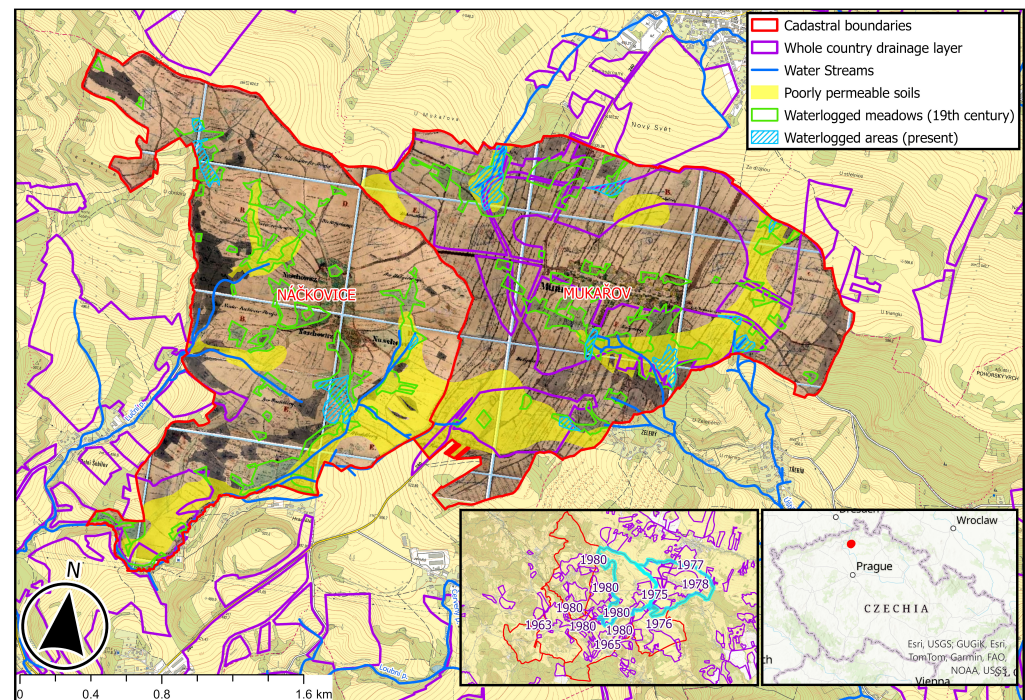


Figure 1. The CU-2 site location, historical/present wet areas, registered drainage extent, and soil conditions.

The LCS consist of eight cadastral units (CU-8; Lovečkovice, Levínské Petrovice, Knínice, Dolní Šebířov, Hlupice, Mukařov u Úštěku, Náchkovice, Touchořiny). Within the two CU—Mukařov u Úštěku and Náchkovice (CU-2), a detailed analysis and a proposal of measures were performed (see the next subchapter for the details). There is a local drinking water resource (shallow wells) for these two CU. The total area of CU-8 is 22.72 km², of CU-2 6.35 km².

Landowner-land user analyses, as well as the land use, were retrieved from the Cadastre (Land Registry) and the LPIS (Land Parcel Identification System; farmer's registry). The general land use at the CU-8 is as follows: Arable land (71.8 ha, 4%), Grassland and Pastures (1134.4 ha, 62.9%), Forests (404 ha, 22.4%), Built-Up (22 ha, 1.2%), other (171 ha, 9.5%). There are large differences in the LCS agricultural land use as based on the Cadastre or on the LPIS data, see Table 1. This is due to the fact that (i) grassland and pastures are predominant and neither the farmers nor the landowners reconcile the reality with the cadastre, and (ii) not all agricultural land is registered in the LPIS. There are only two blocks of arable land in CU-2; the rest of the farmland is used as pasture or, to a lesser extent, hay meadows.

Table 1. Agricultural land use in CU-8 according to the Cadastre and LPIS.

Agricultural Land Use	Cadastre	LPIS
Arable land	1104.4 ha	71.8 ha
Permanent grassland	764.6 ha	1134.4 ha
Orchards	1.2	2.46

For the analysis of the historical land use at CU-2, especially the wet/waterlogged areas, the publicly available Stable Cadastre maps (s.c. Indication Sketches) from the years ca. 1824–1843 were used, which contain information, e.g., on the location of the former waterlogged meadow [40]. In addition, the more recent aerial images (2015–2023) from various sources (Czech Office of Surveying, Mapping and Cadastre; CUZK—archive

of aerial images, a Czech online map portal *Mapy.cz*—aerial images) were used for the detection of current wet sites [41,42]. These data were georeferenced, and the waterlogged meadows and current wetlands were then vectorized. Further, the less permeable soils (soil hydrology groups C and D) were delineated according to VSEU. In addition to calculating the areas of the above categories, the correspondence between these categories was analyzed, namely the correspondence between former waterlogged meadows and less permeable soils, the correspondence between registered drained areas and less permeable soils, and the correspondence between registered drained areas and former waterlogged meadows. The LCS position within Czechia, the landscape pattern, registered drainage, as well as the historical/current wet areas and low-permeable soils are depicted in Figure 1.

2.2.2. Land Drainage—Analyses and Proposals of Interventions

A general overview of the registered land drainage was performed with the help of the whole country tile drainage layer [43]. This layer was compiled in the years 2000–2006 from the digitized paper maps at the scale of 1:10,000–1:5000 with drainage polygons and is to be considered as informative only, with many inaccuracies, as no systematic verification was carried out. For a more detailed and accurate drainage identification, three other information sources and approaches were used. Firstly, the registers of the State Regional Archives in Litoměřice (SOA) and the Archives of the Ohře River Board in Česká Lípa (ORBA) were searched for detailed old paper drainage projects and plans. Secondly, the available online archival aerial photographs (Czech Office of Surveying, Mapping and Cadastre—ČÚZK; google maps; *Mapy.cz*; TomTom maps) taken in the period 1956–2024 were analyzed, as they are a good source for the topology and extent of the actually implemented and hydrologically active drainage, especially the tiles, above-ground manholes or drainage failures [14,44]. Thirdly, the drainage ditches (open or tubular) were taken as an SHP layer from the Geoportal of the State Land Office [45]. The unmanned aerial vehicle (UAV) campaigns for targeted drainage monitoring and the detailed field surveys and measurements were not used at this stage of the study, although these approaches could profoundly refine the drainage topology and its condition [25,46] and are planned for the next phase of the study. The available data and sources were processed in ESRI ArcGIS version 10.6 (vectorization, orthorectification). At CU-2 (Mukařov u Úštěku, Náchkovice), a thorough analysis of land drainage and, in particular, a proposal of measures was carried out. The following methods and approaches were used to propose the measures:

Wetlands/biofilters on drainage—the placement proposal was based on a combination of former/current wetlands, together with the delineation of waterlogged soils. Specifically, these interventions were proposed where water quality aspects were an issue, i.e., in the vicinity of drinking water resources [24,28]. Controlled drainage was designed on slopes up to 5%, on hydromorphic, semi-hydromorphic, medium to deep, sandy loam to clayey loam soils [27,47]. Drainage ageing and ditch interventions (stream blocking, small dams, ditch rerouting, untubing, shallowing, and defortification) were proposed for sites where drainage dysfunction or altered ditch parameters do not significantly interfere with agricultural management and/or on historically wet sites [25]. In addition, we proposed a simple categorisation of the implementation potential of measures within land consolidations (1-best; 2-average; 3-low), based on the estimated measure-related number of land parcels, landowners, and land users. For the proposed measures, the precise delineation, design, and efficiency assessment will be carried out in the next phase of the study.

3. Results and Discussion

At CU-2, there were 76.19 ha of former waterlogged areas according to the Indication Sketches. Less permeable soils were found on a total area of 125.49 ha. The correlation between former waterlogged meadows and less permeable soils was 31.06 ha (41.8% of former waterlogged meadows were on less permeable soils). According to the whole country drainage layer, 211.64 ha of drained areas are registered in CU-2. The correspondence between the registered drained areas and the less permeable soils was 87.44 ha (69.7% of the less permeable soils are now registered as drained). The correspondence between the registered drained areas and the former waterlogged meadows was 44.11 ha (57.9% of the former waterlogged meadows are now registered as drained).

The total area of currently waterlogged land was 13.4 ha, as determined from the aerial photographs. There is a clear difference between the cultivated and uncultivated farmland, which can be seen in the aerial photographs, as the vegetation is not mown, and the difference between the mown and un-mown meadow can be seen in the arrangement of the grass cover [41]. The current waterlogged areas on the farmland were most likely caused by either failure of the drainage system, presence of less permeable soils, geomorphology, or a combination of these factors. Overall, at CU-2, 53% of the current farmland waterlogged areas were found on soils with low permeability. The correspondence between the former mid-19th-century waterlogged meadows and the current farmland-related waterlogged areas was analyzed to be 71%. According to the whole country drainage layer, 626.7 ha of systematic land drainage is registered in CU-8 and 211.6 ha in CU-2, which covers 33.5% and 39.8% of the current agricultural land in CU-8 and CU-2, respectively. Archival documentation of drainage projects from the years 1963 to 1980 was found for 666.4 ha at CU-8 and 179.7 ha at CU-2. Based on the available data sources, there were 8.42 and 2.48 km of drainage ditches (open/piped) at CU-8 and CU-2, respectively.

The aerial images together revealed 32 drainage manholes. However, the drainage tiles detected from the old aerial images were only revealed on 54.1 ha at CU-8 and on 29.6 ha at CU-2. We explain this low manifestation of drainage tiles compared to the large extent of drainage recorded by the lower detection of drainage under grassland, in general, and the fact that aerial photographs in the visible spectral range usually reflect only the hydrologically active drains [44,46]. In addition, there is a large uncertainty associated with the extent of land drainage actually constructed, as some of the planned and designed drainage projects may not have been completed. Nevertheless, UAV monitoring of the tiles under suitable conditions will be provided in the next phase of the study.

All these assessments, together with the landowner/land user analyses, allowed a proposal of measures, either individually or in an interlinked system, aimed at supporting water retention, improving cereal or hay yields, and enhancing biodiversity and water quality. All the proposed measures are shown in Figure 2 and listed in Table 2. In addition to characterizing the measures, the potential for implementation of each measure or system of measures was specified. Using this approach, we proposed twenty drainage-related measures at eleven sites within CU-2, taking into account historical, soil, morphological, and landowner/land user aspects. Four sites with one or two landowners had the highest implementation potential. Five sites were classified as having medium implementation potential, with three to four landowners, while the low implementation category was assigned to two sites with five to six landowners. We attribute this relatively high theoretical implementation potential of the proposed measures to the fact that in these parts of the country, there are generally fewer landowners/users per unit area than the average.

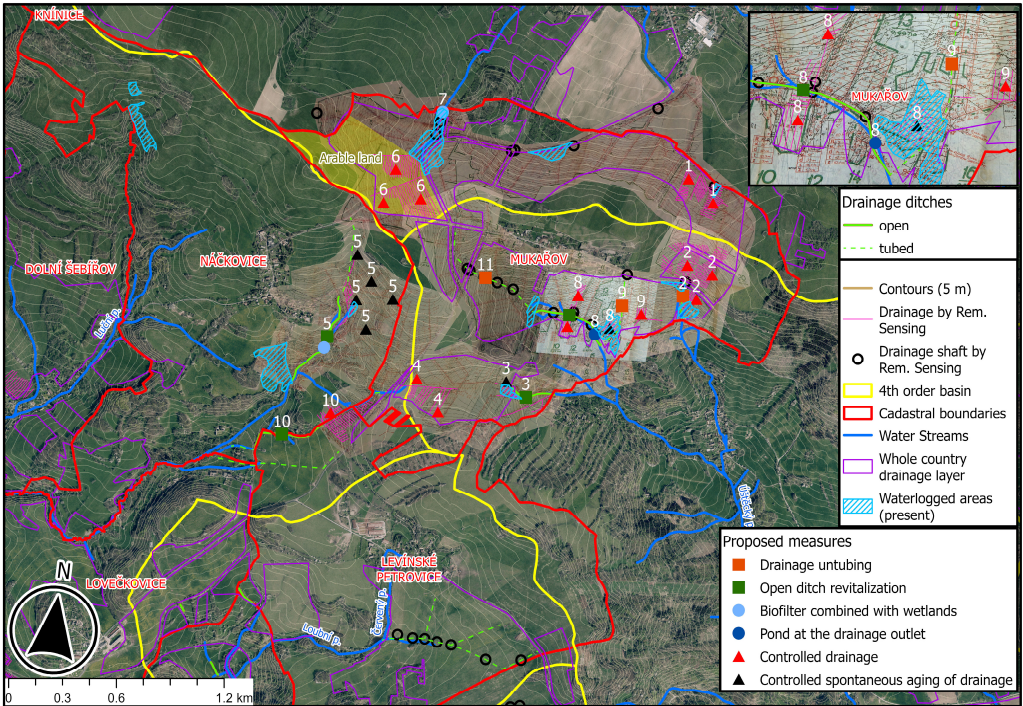


Figure 2. The CU-2 site with allocation of the proposed measures; the numbers represent the individual sites described in Table 2.

Table 2. A list of proposed drainage-related measures, specifications, and potential for implementation.

ID	Proposed Measures	Measure Specification/Effect	No. of Land Parcels/Landowners/ Land Users	Potential of Measure Implementation
1	▲ Controlled drainage	Improvement of hay quality and yields in meadows	14/3/1	2
2	▲ Controlled drainage ■ Drainage untubing	Improvement of hay quality and yields in meadows Stream revitalization, biodiversity support, and hay yields improvement	15/6/2	3
3	■ Open ditch revitalization ▲ Controlled spontaneous aging of drainage	Stream revitalization, biodiversity support, and hay yields improvement Elimination of undue drainage, biodiversity, and water retention support	8/1/1	1
4	▲ Controlled drainage	Improvement of hay quality and yields in meadows	13/4/1	2
5	● Biofilter combined with wetlands ■ Open ditch revitalization ▲ Controlled spontaneous aging of drainage	Improvement of water quality (potable water wells below) Stream revitalization, biodiversity support—small pools Elimination of undue drainage, biodiversity, and water retention support	8/3/1	2

Table 2. *Cont.*

ID	Proposed Measures	Measure Specification/Effect	No. of Land Parcels/Landowners/ Land Users	Potential of Measure Implementation
6	▲ Controlled drainage	Improvement of hay quality and yields in meadows	33/4/1	2
7	● Biofilter combined with wetlands	Improvement of water quality (potable water wells below), and biodiversity support	1/1/1	1
8	■ Open ditch revitalization	Stream revitalization, biodiversity support—small pools	8/3/2	2
	▲ Controlled drainage	Improvement of hay quality and yields in meadows		
	● Pond at the drainage outlet	Support of biodiversity and water retention		
	▲ Controlled spontaneous aging of drainage	Elimination of undue drainage		
9	▲ Controlled drainage	Improvement of hay quality and yields in meadows	16/5/2	3
	■ Drainage untubing	Stream revitalization, biodiversity support, and hay yields improvement		
10	■ Open ditch revitalization	Stream revitalization, biodiversity support—small pools	3/2/1	1
	▲ Controlled drainage	Improvement of hay quality and yields in meadows		
11	■ Drainage untubing	Stream revitalization, biodiversity support, and hay yields improvement	4/1/1	1

As stated in the introduction, let this paper be perceived as a preliminary, conceptual part of a in-depth study, which will demonstrate the practical approaches applicable to tile-drained landscapes, where climate adaptation measures on drained farmland could be the solution to support biodiversity as well as water retention directly on fields and meadows or in their immediate vicinity, and at the same time establish sustainable agricultural land use with support of crop or hay yields. However, in order to obtain a more precise picture and design of the proposed interventions, as well as to assess their effectiveness, it is necessary to carry out a thorough analyses of the sites with the proposed measures, focusing in particular on the monitoring or modelling of the current/projected drainage and surface water balance, hydrology/hydrochemistry (water flow, seasonality, water quality) and the overall suitability of the site in terms of drainage related measures. Further, some form of cost–benefit analysis as well as discussion with landowners, land users, and other stakeholders is also needed, to ensure the legitimacy and sustainability of these interventions, so that they can be applied to land consolidation or similar activities.

4. Conclusions

This study highlights an often-neglected issue—the historical drainage of farmland and the approaches for incorporating related climate adaptation measures into the land consolidation process in Central European drained agricultural landscapes. We have shown that, using relatively simple methods and available data, both historical and current, it is possible to make a preliminary proposal together with a well-founded allocation of drainage-related measures. Although a more thorough analysis, particularly of the hydrological data and financial aspects, is required for a detailed design of the measures, it can be assumed that the proposed measures, once implemented, are likely to have a positive effect on biodiversity and overall water retention, as well as reducing water stress on crops and hay, as the proposed measures will help to delay the availability of soil water in drier periods. Moreover, the proposed measures can improve overall water quality, which can have a positive impact on drinking water sources for local communities. These approaches and findings can be applied to the design of drainage-related measures in various conditions and sites, especially where intensive drainage is no longer desirable, or in cases of waterlogging of farmland, either historical or because of drainage system failure. The results and methods of this preliminary study hold substantial importance when considering climate adaptation interventions on drained farmland and are applicable either in land consolidation processes or in land use planning in general.

Author Contributions: Investigation, data curation, visualization, writing—original draft preparation, J.Č.; conceptualization, writing—review and editing, supervision, P.F.; project administration, funding acquisition, A.Z. All authors have read and agreed to the published version of the manuscript.

Funding: This study was supported by IGA Faculty of Environmental Sciences CZU Prague “Study of the applicability of adaptation procedures for agricultural drainage within the framework of the land consolidation and quantification of the effects of the proposed measures on the water regime of the subject area in the hydrological units of the selected cadastral areas—No. 2024B0011”. Further, this research was supported by the project No. QK21010341 “Optimization of a set of measures for agricultural catchments in the framework of the land consolidation process” supported by the National Agricultural Research Agency (NAZV), by the Ministry of Agriculture of the Czech Republic, institutional support MZE- RO0223.

Data Availability Statement: Data Availability is on request from the authors.

Acknowledgments: The authors thank two anonymous reviewers whose comments substantially improved the quality of the paper.

Conflicts of Interest: The authors declare no conflicts of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript; or in the decision to publish the results.

Abbreviations

The following abbreviations are used in this manuscript:

CU-2	Cadastral Units-2
CU-8	Cadastral Units-8
FAO	Food and Agriculture Organization
LCS	Lovečkovice case study
LPIS	Land Parcel Identification System
ORBA	Ohře River Board Archives in Česká Lípa
UAV	Unmanned Aerial Vehicles
SOA	State Regional Archives in Litoměřice
VSEU	Valuated Soil Ecological Units
WWII	World War II.

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