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Subsiding soils, rising costs

Possible measures against peatland subsidence in rural and urban areas

Summary and Findings

Approximately 9% of Dutch territory is composed of peat soils. A large part of these soils is subsiding. In rural areas, subsidence is closely related to the lowering of the water table (dewatering) for the benefit of agriculture, and dairy farming in particular. As a reaction to dewatering, the peatland above the water table subsides as the weak soil settles and organic matter oxidises, resulting in the need to lower the water table again (level indexation), upon which the land will continue to subside. In built-up areas on peatland, subsidence occurs due to the consolidation caused by the load from buildings and infrastructures.

The negative effects of subsidence go beyond those burdening agriculture and the owners of buildings and infrastructures. Costs are incurred by water management bodies, which continuously need to adjust the water table to suit the most important functions. There are negative effects on nature and biodiversity because ground water flows from nature areas to lower lying agricultural land, which may lead to areas drying out. It has consequences for the climate, since peat decomposition releases greenhouse gases, particularly CO_2.

Subsidence can be slowed down, and even stopped. This requires measures which come with a price tag and which may either damage or enhance various functions and interests in peatland areas. Focusing on developments between 2010 and 2050, in this study we make an inventory of the costs and the (positive and negative) benefits of alternative measures and policies and compare them to the costs and benefits of the currently followed policy. Costs and benefits are quantified in as far as possible. Where not, they are described qualitatively.

In rural areas, subsidence cannot be regarded in isolation from intensive dairy farming. This sector has an interest in maintaining a water table that is low enough to ensure the land is passable by agricultural vehicles, damage from livestock trampling is limited and grass yields are high. The downside is subsidence, averaging 8 millimetres per year. Besides the negative effects on other functions and interests, dairy farming itself is also caught in a dilemma ; at a certain point, measures will be required to slow down or halt subsidence and the sector will be facing choices.

It is estimated that in the urban area under study, the extra costs and damage to infrastructure caused by consolidation in the period up to 2050 will amount to between 1.7 and 5.2 billion euros, and that the extra costs related to the restoration of inadequate foundations in weak soils will add up to at least 16 billion euros (at the current price level). The cost of damage to infrastructure and buildings in rural areas is estimated to reach a

maximum of 1 million euros (at the current price level). In new building projects, costs deriving from subsidence can be limited or avoided by thoroughly examining which locations are most suitable for development, that is, development requiring the lowest investment and the lowest long-term maintenance costs.

The expected extra expenditure on water management as a result of subsidence is smaller, with costs estimated to be 200 million euros (at the current price level) over a 40-year period. These costs will carry little weight in future decision making on the use and management of peatland meadows.

In rural areas, the application of subsurface irrigation by submerged drains can halve subsidence while agriculture maintains its crop yields. This measure is suitable for at least 40% of the peatland. Subsidence is also halved by passive rewetting, a method applied in measures focusing on level fixation, in which the water table is no longer lowered to counteract subsiding soils. However, this method also means that agricultural yield decreases. All the same, there are opportunities for wetland agriculture (special crops) but these cannot be quantified at present. Reduced subsidence also means CO_2 emissions from peatland meadows are lower; by applying a combination of measures – passive rewetting, subsurface irrigation by submerged drains and changes in land use – a 25% reduction with regard to the current situation is feasible.

Slowing down or stopping subsidence requires devoting attention to the long term and to several other fields besides agriculture, developing an integrated vision for rural areas with input from all stakeholders, including the state, and working out innovative financing solutions for the repair of damage to foundations and infrastructures in built-up areas. The approach to the issue of foundations of built structures can benefit from thoughtful planning, aiming to limit costs as far as possible. For instance, work on foundations can be included in projects for areas that undergo redevelopment for other reasons. The issue can also be included in a city's spatial adaptation plans with regard to climate change.

Clarifying the issue of subsidence

Subsidence caused by land use

Approximately 9% of Dutch territory is composed of peatland. These low-lying areas are formed by the accumulation of the remains of plants and trees below the water table which in a later stage may or may not have been covered with a thin layer of clay or sand. A critical negative property is the limited load-bearing capacity of the soil and its sensitivity to oxidation – the decomposition of organic matter when exposed to oxygen. Peatlands have a long history of use for agriculture and human settlements. Many innovations in the fields of agriculture, water management and building technology have contributed to the intensive use of peatland in the Netherlands for food production – mainly dairy farming in peatland meadows – and as areas for settlements and dwellings. Since they are low-lying areas, over the past centuries a complex network of retaining structures and pumping stations have been built to protect peatland areas from flooding and enhance dewatering.

The water board drains the peatlands for the benefit of agriculture, bringing the water table down to several decimetres – sometimes even more than one meter – below the land surface. This process is called *dewatering*. As a reaction to dewatering, the peatland above the water table subsides due to settling of the weak soil and the oxidation of organic matter, resulting in the need to lower the water table again, upon which the soil will subside even more.

If present-day management continues the practice of lowering the water table in the peatland meadows, the drained soils will keep on subsiding. If no action is taken, management costs for water boards and road administrations will rise and the agricultural sector will run into limitations to operational management, leading to poorer performance and a more pessimistic outlook for the future. Dewatering also leads to the drying up of nature areas and the consequent pressure on biodiversity; as surrounding agricultural areas subside, ground water gradually flows away from the higher lying nature areas.

Peat oxidation leads to CO_2 emissions. In some areas, such as those with many pockets of seepage water or with soils that are overly sensitive to subsidence, water management has already been adapted by introducing rewetting or function changes in nature environments. More areas are being contemplated for transition to different uses and management. In the long term, a hundred years or more, the consequences of the irreversible process of peatland subsidence will become more and more serious and more investments will be required to ensure the risk of flooding due to breaches in dikes does not get bigger.

In built-up areas – cities, villages and infrastructures – subsidence is a consequence of consolidation. Consolidation is caused by loads which compress the soil. This can damage homes with inadequate foundations and means infrastructures require extra maintenance. In cases where during the building phase insufficient attention is paid to the limited load-bearing capacity of peat soils, dwellings and infrastructures subside and cracks appear. This leads to many extra repair expenses for building owners and infrastructure administrators.

Envisaging alternative policies

This study provides insight into the problems of subsidence in the Dutch peatlands and explores possibilities for action to slow the process down in rural and urban areas or to reduce or avoid its consequences. Thereby, the study presents material for administrative assessments so that well-founded policy choices can be made to face the issue of peatland subsidence. Offering a methodology which helps to unravel the complexities of peatland subsidence, this work contributes to a transparent administrative assessment. The research uses the conceptual framework of a social cost-benefit analysis, and in part also the related line of thought. In addition to an outline of the problem and the main topics, the study examines possible measures and provides insight into future peatland subsidence and the order of magnitude of the related costs and benefits.

It is found that the effects of the measures are not always quantifiable, particularly those applying to built-up areas. An exploration from the points of view of the administrator, the user and the property owner and from the wider perspective of society serves to form a picture of the policy options for action and, accordingly, of practical implementation. The time horizon for the study is 2050.

These *Findings* deal with the main points of the Dutch study. The full Dutch report goes into further detail, setting out the objective of the study, providing insight into the problem of subsidence and describing the main topics that are at issue in both peatland meadows and built-up areas, including infrastructures. Then we explore the costs and the effects of measures to slow down subsidence on use and management of peat meadows. In the cost-benefit analysis of peat meadows, we give more insight into the effects on social prosperity of costs which can be expressed in monetary terms and of costs expressed as societal values. In built-up environments, the main points are damage prevention measures involving the application of innovative techniques, location selection and facilitating measures for repair of foundations.

Subsidence leads to complications and high costs

Rural areas: a dilemma for agriculture; the effects on nature and climate

In many rural locations the water table has been lowered for the benefit of agriculture. On dairy farms, the land is more easily passable for agricultural vehicles, there is less damage from livestock trampling and grass yields are high. However, the practice of dewatering also means the peat settles and oxidises, resulting in gradual subsidence of the soil. It is estimated that peatland subsidence averages around 8 mm per year, but in heavily drained areas and in land used for crops such as maize, subsidence can amount to several centimetres. If no changes are made to water table management, peatland subsidence will continue to occur as long as there is peat in the soil which can be oxidised. At the local level, users and administrators face the negative effects of the practice, such as damage to buildings and increased maintenance requirements for infrastructure. Dewatering leads to complications where nature is concerned, but also affects the preservation of features with cultural-historical value. Further complications arise when various functions within one management area all have different requirements for water table management. Where agriculture requires lowering the level, nature often demands maintaining the water table, or even raising it. Where further lowering of the water table is not possible – due, for example, to the presence of seepage water, the risk of salinisation or high management costs – reduced dewatering leads to rewetting. As a result, crop yields per hectare decrease, which has negative effects for the operational management of dairy farms. Finally, peatland subsidence leads to CO_2 emissions, an issue which is also dealt with in this study.

Built-up areas: damage to buildings and infrastructures

In built-up areas, peatland subsidence is mainly the consequence of consolidation. Consolidation is usually caused by heavy loads on the weak soil. The degree of consolidation depends greatly on local circumstances and the actual physical load. On average, consolidation reaches several millimetres per year. The consequences include damage to infrastructures, such as roads, sewer systems and underground utilities, and subsidence of houses and gardens and cracks appearing in walls. Damage can especially be caused by uneven consolidation. Altogether this leads to rising costs for infrastructure administrators and homeowners. These effects occur in places where in the past consolidation was not taken into account adequately. As a result, historic city centres in particular have few options for action to stop subsidence. Repairing the damage caused by subsidence of houses and infrastructure is both technically complex and very costly. Damage can become more serious if complementary measures are not implemented.

The choices facing water boards and provincial councils in rural areas

In peatland meadows, water boards and provincial councils face a series of questions. How should they continue to deal with peatland subsidence? How urgent are the issues? Where can different functions be combined and where is it preferable to keep them separate? Another matter to be addressed is determining what needs to be done now and what can wait until later. Several areas are known as *turning point locations*. Their present use has few future options and costs for their administrators are rising, which means choices as to their future need to be made in the short term. Besides these complications of a more regional nature, soil subsidence also poses wider issues for society, such as biodiversity and climate change. The call to act urgently partially stems from the need to protect nature, such as field birds and wetland birds, and the need to reduce greenhouse gas emissions or enhance carbon fixation. Both issues rank high on national and international agendas.

The choices for municipalities in urban areas

In urban areas, municipalities and other stakeholders are searching for answers to questions concerning the most effective approach in the long run in the existing environment, ways to limit the financial burden on citizens and businesses, and means to finance the heavy expenditure on repair and maintenance. Another matter at stake is how future damage and costs can be avoided in new buildings and after the rehabilitation of subsided houses and roads. Here too, timing is important; what should be done now to avoid further damage, and what can wait until later? Finally, there is the question of whether and how synergies can be realised in the built environment by linking the approach to peatland subsidence to efforts to make the housing stock more energy efficient.

Policy alternatives for peatland meadows

Three measures and four policy alternatives

To gain insight into appropriate ways to slow down peatland subsidence, three measures are drawn up and calculations are made of the effects they have on slowing down or stopping peatland subsidence. Then, the implementation of these measures, by themselves or in combination, is specified for four policy alternatives. The study determines the effects of these alternatives by making a comparison with the current situation in which level indexation is applied (lowering the water table, as a reaction to subsidence), meaning subsidence continues unabated.

Two technical measures are subjected to calculations: subsurface irrigation by submerged drains and level fixation. Subsurface irrigation by submerged drains maintains the water table at the same depth all year round, so that subsidence, which occurs primarily in the summer, is reduced, drastically. Level fixation involves refraining from adjusting the current depth of the water table. Both measures contribute to slowing down peatland subsidence but they have different effects on current functions, CO_2 emissions and biodiversity. The third measure involves a transition in land use; changing the function to that of a nature area or to wetland agriculture. While the first two measures slow down subsidence, the third stops the process.

Implementation of the measures in four policy alternatives

The policy alternative of *mitigation measures* is a further elaboration of the first measure, based on extensive application of subsurface irrigation by submerged drains while land use remains the same. The *passive rewetting* alternative is based on the second measure, level fixation. A critical condition is that a maximum degree of rewetting needs to be established after a certain period of time, to ensure land use can remain unaffected. In the policy alternative *interweaving functions*, drained plots are combined with plots being rewetted within a single dairy farm. The policy alternative *separating functions* is more open to the third measure and displays a wider range of existing and new forms of land use.

To calculate the effects of these policy alternatives on subsidence and other effects felt in rural areas, the study uses a peatland subsidence model and spatial planning data on land use, soil and water systems and water management. Also included in the computations are the relationship between peatland subsidence and water management costs, and the relationship between dewatering and loss of revenue. While these relationships are important inputs for policy assessments, as yet relatively little is known about them and therefore the results presented here should be interpreted as an indication of order of magnitude rather than exact data.

Alternative policies often involve spatial considerations

The four policy alternatives make it clear that administrators involved in territorial processes where slowing down peatland subsidence is a key issue must not only consider the technical options for management but also assess whether the current function is suitable as to the physical characteristics of the area. Future oriented solutions are intimately linked to choices on use and functions, and therefore to spatial planning decisions. In concrete terms, separation of functions could, in some areas, form a suitable alternative policy which enables the water administrator to facilitate individual functions in a better way. For example, by adopting a policy geared towards agriculture with subsurface irrigation by submerged drains in one particular area, and aiming for rewetting or a change in function in another. For yet other areas, a more obvious choice might be that of interweaving functions, to ensure that other users, including nature area and landscape administrators, are given more opportunities. In both cases, subsidence is slowed down and the measures contribute to reducing CO_2 emissions. The spatial planning considerations related to separating or interweaving functions might prove to be the crucial step towards attaining several goals in a single area. In view of this, it is important to realise that the interrelation between agriculture, nature, dwellings and infrastructure is a fact to be dealt with throughout peatland areas and therefore tasks lie ahead everywhere, requiring integrated spatial consideration. It is also important to include promising future functions or land use in the deliberations. Time is a crucial factor in this integrated assessment, not only when it comes to choosing the appropriate measures, but also when deciding which issues need to be dealt with now and which can wait until later.

Policy alternatives for the built-up environment

In the examination of built-up areas, this study looks primarily at damage that will be caused up to 2050, if the current reactive approach is continued with its short-term focus on damage repair. Unlike in the exploration of peatland meadow areas, no calculations are made of peatland subsidence in built-up areas. The measures and policy alternatives for existing and new buildings are described mainly qualitatively and in a more narrative way. The results give an impression of the initial order of magnitude; the uncertainties are substantial, due to the use of generic indicators. For existing buildings and the construction of new buildings, the study outlines an approach with closely connected measures; technical innovations to prevent roads from subsiding and/or drains from breaking, or a more integral approach in which a row of buildings with widely divergent foundations could be made subsidence-proof. Such concrete measures cannot be regarded in isolation and must be supported by meticulous planning and knowledge of the subsoil. As in rural areas, here too the factor time plays an important part; which investments are required now and which can be put off till later.

Conclusions

Urban areas

A financing plan is required to manage the billions of euros towards the rehabilitation of existing buildings

It is estimated that in the urban area under study, the extra costs and damage to infrastructures caused by consolidation in the period up to 2050 will amount to between 1.7 and 5.2 billion euros and that the extra costs related to the restoration of inadequate foundations in weak soils will add up to at least 16 billion euros. This figure is an estimate of the minimum one-off costs to be borne by owners to build better, subsidence-proof foundations under their properties. The amount forms a serious obstacle for municipalities, businesses and individual home owners. This means it is important to involve the relevant parties in planning, foundation repair and securing the required financing. In this context, consideration can be given to funds or innovations in financing methods. With regard to infrastructures, longer life cycles (e.g. a hundred years) and amortisation periods add perspective to the calculations, giving property owners and administrators sufficient extra margin to write off investments over longer periods.

Choice of location geared towards avoiding subsidence in new constructions

In new construction projects, choice of location is an important consideration. Savings can be made at the outset, if locations are chosen for which only minor subsidence issues are expected to arise. The construction method is another important aspect. Several options are available; from light-weight construction to the opposite solution of heavier structures. Restricting usage of roads can be another alternative. This is of importance in city centres and also for agricultural roads in rural areas. To make a real step forward in avoiding future costs, there is a need to gain fundamental knowledge on subsoil processes and practically applicable knowledge. Innovations and field experiments in which new technologies are used are also necessary. Costs can be reduced by aiming for innovation, calculating cost-effectiveness and taking advantage of economies of scale. Linking the approach to subsidence to issues such as energy saving can also contribute to enhancing the cost effectiveness of the measures.

Peatland meadows

The effect of subsidence on water management costs is limited

With regard to peatland meadows, we conclude that if the current policy is maintained, the water boards will continue to face rising costs due to peatland subsidence. However, the expenses will not have significant weight in future decisions on function, use and management. The extra costs are estimated to amount to 200 million euros, at the current price level, over a 40-year period. Nonetheless, at the local level, there are still situations, in the *turning point areas* for example, in which these costs will have a strong influence. In view of the current costs of water management in peatland meadows, the increase is rather modest.

The effect of consolidation on the cost of built structures in rural areas represents around 2 billion euros.

Substantial extra costs in rural areas stem from infrastructure and rehabilitation of homes with inadequate foundations. Estimates based on the 2010 price level put the extra costs for infrastructure over the period 2010 - 2050 between 0.3 and 1.0 billion euros and the one-off costs for foundation repair between 0.5 and 1.0 billion euros. Water table management measures have little effect here, since the main issue is consolidation of the soil caused by the roads' own weight. In countryside villages, which are subject to the water table management of the polder where they are located, investments are (or more correctly, *were*) habitually made in high water protection facilities – expensive measures which also require maintenance. As an alternative, increasing homes' and roads' resistance to subsidence can be contemplated. These considerations deserve more attention. As is the case for cities, this means more attention for the impediments to funding and for financial innovation.

Subsurface irrigation halves subsidence and has no consequences for crop yields

The study shows that subsurface irrigation by submerged drains in agricultural areas leads to a halving of subsidence without exerting negative effects on crop yields. The measure preserves agricultural features and improves the outlook for dairy farming on peatland. This measure is suitable for at least 40% of the peatlands. Concerning mostly peatland with limited dewatering, the measure is also appropriate for areas where dewatering is practiced at deeper levels, such as Friesland, but this is only effective in combination with actively raising the water table. It should be noted that this measure does little to enhance biodiversity, though it does lead to a reduction of greenhouse gas emissions.

Passive rewetting (level fixation) halves subsidence but has consequences for crop yields

The study also shows that passive rewetting (brought about by policies focusing on level fixation) slows down peatland subsidence but also leads to loss of crop yield. In that case, farming will need to adapt more and more to the changes occurring over time in its physical environment and make a transition towards extensive management. The benefits of level fixation and the ensuing rewetting are primarily found in nature and in the reduction in greenhouse gas emissions. Passive rewetting is better suited to peatlands where dewatering is limited or highly limited and functions are interwoven, such as land under pasture bird control programmes and agriculture. Rewetting leads to loss of crop yield, reduced milk production and higher costs per product unit. In all, this means decreased benefits for the dairy farm sector. If extensive dairy farming is to preserve its *raison d'être*, a necessary condition is sale of products against higher market prices, such as products with a bio label or regional specialities.

Opportunities for wetland agriculture

Transitions in land use are a different class of measures for which control from the provincial councils is essential, for example with regard to changes in functions. This study does not look into the economic aspects of wetland agriculture. This is partly because of a lack of data on business performance and because no realistic estimates exist of the potential of wetland crops. We do identify opportunities for wetland agriculture, particularly in locations which are near nature areas and already have a shallow water table. These spaces can also function as a buffer around nature areas.

Less subsidence means less CO_2 emissions

With regard to greenhouse gas emissions, we conclude that measures which slow down peatland subsidence have a direct impact on CO_2 emissions. Implementing subsurface irrigation by submerged drains can greatly contribute to this. Under the present policy of level indexation, emissions from agricultural land amount to around 4 million tons of CO_2, which is about 2% of yearly national greenhouse gas emissions. If level fixation were to be applied in all peatland areas, it would result in a yearly reduction in emissions of around 1 million tons of CO_2. Large-scale implementation of subsurface irrigation by submerged drains in suitable areas, or those which can be made suitable, would lead to a yearly reduction in emissions of around 0.9 million tons of CO_2.

A 25% reduction of CO_2 emissions from peatland meadows is feasible

Of the presented policy alternatives, passive rewetting contributes most to reducing CO_2, followed by the policy focusing on subsurface irrigation in those areas where its application is practicable. Interweaving functions and separating functions are policy alternatives whose net contribution to reducing CO_2 is smaller because the effect of level indexation is relatively high and subsurface irrigation is not among the applied measures. At the local level however, other conclusions may be reached depending on the choices that are made. Based on this analysis, we conclude that by applying a combination of measures, it is possible to attain a reduction in CO_2 emissions of around 1 million tons per year, a 25% decrease with regard to current emissions from peatland meadows.

Attention for the long term and for other questions besides agriculture

Tailor-made solutions are needed for peatlands, with special attention for the long term, a well thought-out planning of stages, serious local studies of costs and benefits and careful thought on what needs to be done now and what can wait until later. The study also shows that a focus on peatland subsidence offers opportunities to give meaning to other social issues, particularly biodiversity, but also, more indirectly, the climate, landscape and cultural-historical questions. The agricultural sector, and dairy farming in particular, faces choices and it is recommended that the figures on development approaches be included in the broader issue of dairy farming.

In urban areas, the most important thing to achieve is a change from short-term thinking, which is reactive and focuses on damage repair, to long-term judgment involving proactive measures and focusing on avoiding future damage and limiting disruption. In rural areas it is particularly important to explore the functions of areas in more detail and relate them to a series of relevant social issues.

Integrated view on rural areas, involving all stakeholders

The question is who is to make the next move? The relationship between water management and land use requires an integrated way of thinking and outlook for the future. The water boards and provincial councils are taking steps and exploring alternatives. An essential aspect is that the involved farmers, nature area administrators and citizens collaborate with provincial councils and water boards on the development and implementation of the most promising alternatives. It is important to look beyond the short term and include the future outlook of dairy farming and the range of development approaches that are possible in agriculture.

Innovation in financing for urban areas

Making urban development subsidence-proof is the competence of municipal authorities, but they can only do this in collaboration with all stakeholders, including individual property owners. Technical innovations, but also innovations in financing, are crucial to be able to make the step towards less damage and less costs in both the existing environment and in new constructions.

It is time for the decentral authorities to make a move but the state should also be involved

Broad social concern for slowing down peatland subsidence creates opportunities for the quality of human settlements and nature and for the reduction of greenhouse gas emissions. By linking the problems of subsidence to questions around biodiversity, cost saving, climate change and the obstacles posed by dairy farming, which is becoming more and more intensive, a basis is created for choices about interweaving and separating functions, intensification or extensification of dairy farming, and about food production and biodiversity. As for avoiding future costs and preventing damage caused by consolidation, built-up environments offer options to link the questions to issues such as the quality of the human living environment, the business establishment climate, the city-countryside relationship and energy saving. The provincial councils, the water boards and municipalities have an important role to play, in close collaboration with residents, property owners and business sectors, to ensure that areas where peatland subsidence is an issue are made future-proof. The state should be part of the process and contribute to it from its position as the agent responsible for nature and climate system management. The state could also be involved in the activation of efforts to develop funding instruments.