Peatland/peat soils subsidence control

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Preamble: This attribute is in the soil domain and focuses on peat subsidence control in drained peatlands. These peats, which are mapped as Organic Soils in the New Zealand Soils Classification, were formed in wetland ecosystems where waterlogged conditions prevented the complete decomposition of organic plant material. Consequently, the deposition of organic matter exceeded decomposition and over time the partially decayed organic matter accumulated to form peat that can be many metres deep, making intact peatlands significant carbon stores[1]. The drainage of peatlands for agricultural use lowers the water table and results in land subsidence and decomposition of previously protected organic material. The decomposing organic matter produces CO_2 emissions and, over time, a more consolidated and mineralised peat soil forms.

In Aotearoa-NZ, drained peatlands account for up to 8% of net GHG emissions[2]. This section focuses on peat soil subsidence control for drained peat soils and does not focus on GHG emissions from drained peat soils. The reader should also see wetland condition and extent components in the terrestrial and indigenous biodiversity domain for information that encompasses natural intact peat wetlands.

State of knowledge of the "Peatland/peat soils subsidence control" attribute: Good / established but incomplete – general agreement, but limited data/studies

Part A—Attribute and method

A1. How does the attribute relate to ecological integrity or human health?

Intact peat wetlands represent unique hydrological and ecological environments that support threatened endemic flora and fauna, are a carbon sink, and can represent a taonga for Māori[3]. Drainage of peatlands for agriculture diminishes these ecological values and results in ongoing land subsidence through shrinkage and consolidation (and CO_2 emissions through biochemical oxidation). Long term ongoing consolidation and oxidation ultimately leads to the complete loss of the peat soil, representing a loss of soil natural capital and its associated specific ecosystem services (e.g., denitrification potential can be high in peat soils). Globally, intact and undrained peat wetlands have been identified as having an important role to play in maintaining biodiversity and climate change mitigation[4].

Subsidence of drained peatlands (and CO_2 emissions[5]) is strongly correlated to water table depth, shallower water tables and wetter conditions reduce subsidence[6, 7]. The consequences of ongoing subsidence and eventual loss of peatland soils include increasingly severe impacts on adjoining/adjacent wetland ecosystems as the surrounding land subsides, and increased risk and frequency of flooding and inundation of drained land that reduces productivity (an example of this is the lower portion of the Muggeridge's catchment in the Hauraki[8], Waikato region). This can result in a requirement to upgrade, repair or install drainage and other infrastructure (e.g., flood protection, pumping, roads and utilities) or ultimately the need to abandon current land-use. The impact of subsidence is likely to be exacerbated by sea level rise where drained peatlands are close to the Coast (e.g., low-lying areas in the Hauraki Plains).

A2. What is the evidence of impact on (a) ecological integrity ~~or (b) human health~~? What is the spatial extent and magnitude of degradation?

Drainage of peatlands for agriculture and the resulting subsidence is well documented globally[6, 9] and locally[10-12]. Subsidence impacts adjacent intact wetlands and peat lakes, for example the small 114 ha Moanatuatua Scientific Reserve, in the Waikato, which is an intact peat wetland remnant is severely impacted by surrounding drainage[13], resulting in drier conditions on the edges, which encourages colonisation by weed species. Moanatuatua Scientific Reserve is one of the few remaining sites where a natural population of the relict endemic plant species *Sporodanthus ferrugineus* exists. If the long-term viability of such ecosystems is under threat from the surrounding land-use, then this conflicts with the National Policy Statement for Freshwater Management[14], which requires the significant values of wetlands be protected. In the Waikato Region, there is strong evidence that drained peatlands are subsiding at a mean rate of 20 mm/yr but with high spatial variability[10]. In other regions, local and regional authorities have some information on subsidence rates (e.g., Whangarei District Council at Hikurangi).

In Manaaki Whenua's most recent analysis of peat soil area provided to MPI and MfE[15], peatlands were calculated to cover about 220,500 ha of NZ, and only about 73,200 ha was in non-drained land use (for example vegetated wetland or forest), indicating that about 147,300 ha (67% of NZs Organic Soils) are drained and therefore subsiding. These total areas are lower than those used in NZs current GHG inventory which uses area calculated from the now outdated Fundamental Soils Layer (FSL). S-map was used where available for our most recent estimates[15] and area estimates from FSL (where S-map was not available) were improved by extracting information on proportional contributions for mixed mineral/peat soil areas that was not used in previous estimates. The difference in the area estimates between FSL and S-map occur because of uncertainty in both historic and contemporary soil maps and loss of peat soils from ongoing decomposition[2].

A3. What has been the pace and trajectory of change in this attribute, and what do we expect in the future 10 - 30 years under the status quo? Are impacts reversible or irreversible (within a generation)?

Based on Waikato knowledge, peatland drainage for agriculture (and therefore subsidence) began in the early 1900s and accelerated in the mid-1900s as mechanized approaches to drainage were more available[3], and this is likely similar across NZ. In the future 10-30 years we do not expect further expansion of the drained area because of policy designed to prevent this (National Policy Statement for Freshwater Management). However, on already drained peatlands, subsidence will continue until the peat no longer remains. The rate of subsidence and time to loss of peat will be dictated by land and drainage management, and peat depth. Potentially, there could be some rewetting of drained peatlands to mitigate subsidence and GHG emissions, but the likely trajectory of potential rewetting activity is unclear.

There is strong evidence that rewetting will slow or stop subsidence (based on international literature) within a generation[3]. Subsidence rates are relatively high (~20 mm/yr[10]) but peat growth and accumulation is much slower (~1 mm/yr[16]) so recovery of already lost peat will take 100s to 1000s of years. In contrast to the shorter time required to slow or stop subsidence through rewetting, timeframes to slow or stop GHG emissions from rewetting of peatlands is highly uncertain. This is largely because reductions in CO_2 emissions following rewetting may be offset by increases in CH_4 and N_2O emissions from nutrient rich rewetted peat soils, especially if surface flooding occurs [17].

A4-(i) What monitoring is currently done and how is it reported? (e.g., is there a standard, and how consistently is it used, who is monitoring for what purpose)? Is there a consensus on the most appropriate measurement method?

There is currently no standard or monitoring program related to subsidence of drained peat soils at the national scale. However, the Waikato Regional Council (WRC) manage a continuous monitoring network that measures subsidence and water table levels at 11 point locations across their region. This approach could be expanded nationally but requires ongoing site maintenance so is potentially best led through regional authorities. WRC also fly LiDAR transects with a helicopter every 5 years to gain greater spatial understanding of subsidence (the first baseline flight was done in April 2021). A design summary of both these monitoring networks can be found in [18], and [19] reviewed a range of potential monitoring techniques for WRC.

Historically, WRC has measured subsidence using depth probing, and as such, current regional scale estimates of peat subsidence are based on that monitoring. Outputs from this monitoring have previously been reported as technical reports (e.g., [20]), a paper[10], and as a state of the environment indicator on the WRC website (Peat subsidence | Waikato Regional Council). Depth probing for subsidence monitoring in the Waikato region has now been replaced with the continuous monitoring network and LiDAR transects referred to in the previous paragraph.

A4-(ii) Are there any implementation issues such as accessing privately owned land to collect repeat samples for regulatory informing purposes?

Yes, access to private land is important for setting up continuous monitoring sites and ground truthing airborne LiDAR based approaches.

A4-(iii) What are the costs associated with monitoring the attribute? This includes up-front costs to set up for monitoring (e.g., purchase of equipment) and on-going operational costs (e.g., analysis of samples).

Continuous peat surface level/subsidence and water level logging at single point location:

Based on WRCs experience, materials to set up each single continuous monitoring site cost about $5000 in June 2022. This included two levelloggers, a barologger, dipwells, mesh, rods, and associated mounting hardware and site fencing. Labour, including site selection and set up, was about $6500 per new site and required access to high precision GPS based survey gear. WRC estimate about another $5500 per year to maintain the sites including downloading, checking/plotting and storing the data. However, there will be some synergistic gains when this is done over multiple sites meaning, ongoing per site cost could be lower.

Helicopter based LiDAR:

In 2021, [18] calculated that for a regionally representative peat subsidence monitoring network, WRC should budget $100,000 for 5-yearly helicopter based LiDAR measurements with a coverage of about 10,000 ha of drained peatland. About 20% of the budget was for project management (job safety assessment, flight planning, liaising with landowners), 25% for helicopter time, 10% for ground truthing, 30% for data processing and DEM differencing, and 20% for reporting and communication of results.

A5. Are there examples of this being monitored by Iwi/Māori? If so, by who and how?

I am not aware of specific peatland subsidence monitoring being carried out by representatives of iwi/hapū/rūnanga. However, there is iwi-led monitoring being done of quality/condition for intact peat wetlands (see wetland condition and extent components in the terrestrial and indigenous biodiversity domain for information that encompasses natural intact peat wetlands).

A6. Are there known correlations or relationships between this attribute and other attribute(s), and what are the nature of these relationships?

There are relationships between peat subsidence and wetland extent and wetland condition in the terrestrial indigenous biodiversity domain. Drained peatlands were previously vegetated peat wetlands, so their drainage is linked to the large loss of wetlands in NZ. Continued subsidence of drained peat soils will negatively impact the sustainability of adjoining wetland ecosystems. For example, drainage of peatland adjacent to Kopuatai Peat Dome (a globally unique Ramsar site and the largest unaltered restiad peat bog in New Zealand – a bog type most extensively found in NZ, formed from jointed rush-like herbs from the Restionaceae family[21]) and Moanatuatua Scientific Reserve results in drier conditions on the edges, which encourages colonisation by weed species[13].

There are also potential relationships to surface and shallow groundwater quality. Highly organic (usually more recently drained and developed) peat soils can have low anion storage capacity (ASC<60%), so added P is highly mobile relative to most mineral soils[22]. In the absence of careful nutrient budgeting and application, P added to low ASC peat soils can infiltrate to shallow groundwater or surface water. Typically, as the peat soil becomes more mineralised and consolidated, anion storage capacity increases (ASC>60%) and risk of P loss decreases[23]. Rewetting of drained peatlands that have a legacy of heavy fertilisation application and animal excreta returns could also mobilise these nutrients and result in eutrophication of receiving waterways[17, 24].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

The extent of peatland drainage is well understood at national scale and can be quantified by intersecting Organic Soils area with either the LUCAS LUM (land-use map) or land cover database

(LCDB). Although, some regions have more up-to-date and accurate area mapping (e.g., S-map) than others (e.g., FSL). As outlined in section A2, about 147,300 ha of NZs total Organic Soils area (220,500 ha) are under a LUCAS LUM land-use that indicates drainage, representing about 67% of the area[15]. A more complete national drains spatial layer would help to better quantify drainage intensity and options for rewetting.

In contrast, the subsidence rates of drained peat soils are not well quantified at a national scale, but we do know that with drainage these soils will be subsiding, and this will continue until the peat no longer remains if drainage is maintained. The only region with information that could feed into a national monitoring programme is likely the Waikato Region (monitoring summarised in A4). The Waikato region has about 40% of NZs drained peatland area, and historic and contemporary subsidence information is available (e.g.[10], WRC monitoring (Peat subsidence | Waikato Regional Council)). This monitoring shows that contemporary subsidence rates average about 20 mm/yr with high spatial variation in subsidence rates. Other regions have some ad hoc data on subsidence rates from intermittent consultancy work (e.g., Whangarei District Council for Hikurangi swamp).

B2. Are there known natural reference states described for New Zealand that could inform management or allocation options?

Yes there are remaining intact peatland areas, and work done to characterise these includes detailed research[13, 25-27] and condition monitoring (e.g., NZ National Wetland Database[28]). Manaaki Whenua manages the NZ National Wetland Database (about 249 wetlands around NZ), which holds data on soil bulk density, carbon and nutrient content in the top 7.5 cm for remaining intact peatlands together with wetland condition scores. This data could be used to inform the relative condition of drained peatlands at selected monitoring sites compared to the natural state and potentially inform progress toward recovery where peatlands were rewet/restored.

B3. Are there any existing numeric or narrative bands described for this attribute? Are there any levels used in other jurisdictions that could inform bands? (e.g., US EPA, Biodiversity Convention, ANZECC, Regional Council set limit)

We are not aware of numeric bands set for monitoring peatland subsidence in NZ or elsewhere in the world. Waikato based research[10] and regional council monitoring shows drained Waikato peatland are subsiding at an average rate of 20 mm/yr with high spatial variation. While any subsidence is an indicator of a poor state, potentially a band could be calculated based on average rates and values above the determined average range could be indicative of a poorer state. Any potential band developed would need to account for the relationship between subsidence rates and time since drainage from international literature[10]. In general, subsidence rates are expected to reduce over time in the absence of drain deepening or infrastructure upgrades (e.g., drainage pump installation/upgrade). General guidance for minimising peat soil subsidence under agricultural management has been provided by WRC[29], but this guidance needs updating.

B4. Are there any known thresholds or tipping points that relate to specific effects on ecological integrity ~~or human health~~?

Drainage of peat soils results in ongoing consolidation and decomposition of the peat soil and ultimately the complete loss of peat and reclassification of the soil to a mineral soil (e.g., Gley Soil) when the surface organic layer is reduced to less than 30 cm cumulative depth. This is a loss of soil natural capital and will result in a change in soil flora/fauna and associated specific ecosystem services (e.g., denitrification potential which is high in peat soils). The time taken for this to occur will depend on depth of drainage, management practices, and peat depth. In some circumstances there maybe a risk that the underlying sediments contain iron sulphides (Acid Sulphate Soils) that when exposed to oxygen can form sulphuric acid resulting in very low pH (<4) that can have deleterious effects on flora and fauna[30].

There is also likely a bulk density threshold or tipping point where long-term consolidation and decomposition would make it very difficult to reestablish the dominant peat forming vegetation (*Empodisma robustum*) required for successful restoration. Further research is required to better understand how much degradation/consolidation will make restoration particularly challenging (further detail in B5 below).

In relation to nutrient loss from peat soils there is some evidence that an anion storage capacity of about 60% represents a tipping point where P loss reduces[22]. Highly organic peat soils have low anion storage capacity (ASC<60%) so P loss from peat soils to ground water (by infiltration) can be higher than from mineral soils. As the peat soil becomes more mineralised and consolidated anion storage capacity increases (ASC>60%) and risk of P loss decreases.

B5. Are there lag times and legacy effects? What are the nature of these and how do they impact state and trend assessment? Furthermore, are there any naturally occurring processes, including long-term cycles, that may influence the state and trend assessments?

Subsidence rates of drained peat soils is typically high following drainage and slows over time (see Figure 2 in [10]). Long-term subsidence is likely to continue at rates of about 20 mm/yr [10]). In contrast, peat growth and accumulation is much slower (~1 mm/yr [16]). Therefore, recovery of already lost peat will take 100s to 1000s of years.

For a drained peatland, the long-term trend is surface subsidence but superimposed on this long-term subsidence is a seasonal cycle of surface swelling and shrinking, known as peat surface oscillation (PSO) [31]. PSO occurs in both drained [32] and natural peatlands [31] and is driven largely by soil moisture and water table dynamics. During extended dry periods, the surface shrinks and during extended wet periods the surface swells resulting in a seasonal cycle of increase and decrease in surface height. Understanding this cycle is important for any peat subsidence monitoring programme.

During the preparation of drained peatlands for agriculture they were typically heavily cultivated and large quantities of soil nutrients were added to ensure productivity[11]. Ongoing cultivation is often required to work lime into the soil profile, reducing acidity and allowing adequate plant rooting depth. Through time, the soil bulk density increases along with nutrient content. Bulk density is an indicator of peat development. In their natural state, bulk density is often <0.05 t/m^3, while in drained and consolidated peat soils, it can range considerably but often sits in the range of 0.2-0.5 t/m^3[11, 29]. Highly decomposed consolidated peat soils typically have higher nutrient content as a result of long-term agricultural nutrient input. This higher nutrient content increases the risk for nitrous oxide and methane emissions, and also mobilisation and loss of these nutrients to receiving water bodies, if rewetting occurs [17].

B6. What tikanga Māori and mātauranga Māori could inform bands or allocation options? How? For example, by contributing to defining minimally disturbed conditions, or unacceptable degradation.

I am not aware of examples of tikanga Māori and mātauranga Māori informed bands or allocation options, this is an area that requires further exploration which must be done in consultation with Māori. However, there is iwi led monitoring being done of quality/condition for intact wetland/peatland (also see wetland condition and extent components in the terrestrial and indigenous biodiversity domain for information that encompasses natural intact peat wetlands).

Part C—Management levers and context

C1. What is the relationship between the state of the environment and stresses on that state? Can this relationship be quantified?

Historically the ecosystem service value of intact peat wetlands was not widely appreciated or understood and pressure for increased agricultural land resulted in the drainage of these areas. Much of this drained peatland area is now high value agricultural land, largely used for dairy production, and raising of water tables would threaten some areas of this high-return land-use.

Subsidence of drained peatlands (and CO_2 emissions) is strongly correlated to water table depth, based on strong consensus in international data[5-7]. However, there is little data on the relationship between water table depths and subsidence rates for NZs drained peatlands, although, in the Waikato region a dataset of subsidence rates relative to water table depth is growing from monitoring on drained peatlands by WRC.

Water table depth is controlled through drainage infrastructure (drains/pumps/weirs) when water is in excess (i.e., winter months), which is managed by private landowners and by regional and district councils. However, many smaller farm surface drains often run dry during summer or autumn periods, indicating drains are no longer controlling the water table depth. During these dryer periods, available energy and surface evaporation rates have increasing control over water table depths in drained agricultural peatlands. This is in contrast to intact natural restiad peatlands where the vegetation strongly limits evaporative water loss during dry periods[33].

C2. Are there interventions/mechanisms being used to affect this attribute? What evidence is there to show that they are/are not being implemented and being effective?

C2-(i). Local government driven

Waikato Regional Council are likely the most proactive council with respect to monitoring of peat soil subsidence and exploring options to reduce subsidence (the Waikato region has about 40% of NZs peat soils). The Waikato Regional Policy Statement (Policy LF-P10) requires WRC to manage adverse effects of activities from use of peat soils. Under this, Method LF-M38 directs WRC regional plans to slow the rate of subsidence and carbon loss, mitigate adverse effects from the use and development of peat soils, and ensure drainage infrastructure minimises any adverse effects on peat soils and peat lakes. Methods LF-M39 and LF-M40 promotes research and advocacy into better peatland management.

However, there is currently limited robust local information to implement Policy LF-P10. Recognising the need for robust information, the soil and land science team at WRC have applied for and received funding through sequential Long Term Plan processes. This work began in 2018 and resulted in development of a regional subsidence monitoring programme with 5-yearly monitoring[18]. They have also funded reviews to examine management practices to slow subsidence[3] and reviews are in progress to identify risks and alternative land-use opportunities. Going forward, they plan to design field-based mitigation testing, develop decision support tools for peatland managers, and extend and update good practice guidelines[29].

In 1999 and again in 2006, WRC published good practice guidance for peatland management[29]. However, uptake of this information by land and drainage managers on peat is unknown, and the published guidance is overdue for an update.

Note that WRC has responsibility to meet particular levels of service to maintain and manage drainage and this is, to some extent, conflicting with policy to mitigate adverse effects of activities from use of peat soils.

C2-(ii). Central government driven

I am not aware of central government driven work directly focused on interventions to better understanding and mitigate subsidence of drained peat soils. However, central government has funded work to better understand and quantify GHG emissions from drained peat soils through the GHG Inventory Fund managed by MPI and approaches to reduce emissions through a joint collaboration fund set up between MPI and their equivalent in Ireland (DFAM). These projects will indirectly help understand and mitigate peat soil subsidence by exploring options and effectiveness of raising water tables and alternative potential wet land-use options.

Historically there was an attempt to develop strategic direction and policy for the management of peatlands in NZ in 1982[34]. North and South Island working groups were established to identify conflicts and requirements for different land-uses on peat soils. Water table control and drainage aspects were deemed to be priorities. The report included recommendations for management, conservation, and further research. Some of the recommendations have been implemented over time but many are still relevant and unresolved, for example, 'We recommend the true cost of agricultural development be determined. We further recommend that peat shrinkage rates be investigated in some detail, by comparing the effects of various agricultural, horticultural and pastoral regimes'[34].

C2-(iii). Iwi/hapū driven

Iwi are involved in projects to restore peatland environments. For example Iwi driven mitigation work is occurring in the lower Waikato and this group in collaboration with others have reviewed options for alternative wet land uses [35]. In the Hauraki, iwi is involved in restoration projects adjacent to Kopuatai and may also be initiating work around Torehape. We are not able to provide detail on these projects but representatives of Ngāti Hako may be able to provide more information.

C2-(iv). NGO, community driven

I am aware of a large farming operation in the Waikato region that manages land adjacent to Moanatuatua peat reserve who is exploring opportunities to retire and restore a buffer strip beside the reserve to reduce the impact of farming activities and drainage on the reserve. There are also community driven projects involving local farmers focused on protecting Waikato peat lakes and wetlands that have involved planting buffer zones around the lakes. I am not aware of any monitoring activity to assess the effectiveness of these activities.

C2-(v). Internationally driven

I am not aware of any international obligations directly related to peat soil subsidence mitigation. However, commitments under the Paris Agreement (2016) require NZ to meet 2030 and 2050 GHG targets. Drained peat soils likely contribute about 8% on NZs net GHG emissions from less than 1% of its land area[2], so rewetting to help meet these targets could occur and would also mitigate peat soil subsidence.

Part D—Impact analysis

D1. What would be the environmental/human health impacts of not managing this attribute?

Continued subsidence of drained agricultural peatland threatens adjacent remaining peat wetlands through lowering of the regional water table during dry periods and increased risk of flooding and inundation during wet periods due to a lowering of the land surface, especially toward the edge of intact wetlands. Both increased drying and inundation threaten unique and endemic flora and fauna found in peat wetlands. Additionally, remaining peat in both drained and intact peatlands represents a large irrecoverable[36] (in our lifetimes) carbon store, which drainage destabilises, contributing to NZs total GHG emissions and climate change. Intact peat wetlands also represent a taonga for Māori, however, Māori researchers are better placed to elaborate on this aspect. Ongoing subsidence of drained peatlands also increases risk and frequency of flooding and inundation of managed agricultural land, reducing productivity. Ultimately the peat soil can be completely lost and reclassified as mineral soil (e.g., Gley Soil). The time taken for this to occur will depend on depth of drainage, management practices, and peat depth. The impact of this loss will vary spatially and in some circumstances there may be a risk that the underlying sediments contain iron sulphides (Acid Sulphate Soils) that, when exposed to oxygen, can form sulphuric acid, resulting in very low pH (<4) that can have deleterious effects on flora and fauna[30].

D2. Where and on who would the economic impacts likely be felt? (e.g., Horticulture in Hawke's Bay, Electricity generation, Housing availability and supply in Auckland)

Continued subsidence will result in increased risk and frequency of flooding and inundation leading prolonged high soil moisture and ponding. Excessively wet drained peatlands result in loss of agricultural production for farmers and lead to an ongoing cyclic requirement to upgrade, repair or install drainage and other infrastructure (e.g., flood protection, pumping, roads and utilities), which is costly for both responsible councils and their rate payers. Urban development has also occurred on peatlands in the Waikato and the building and engineering challenges associated with building on drained peat soils cannot be understated [37]. There are many personal accounts of rural buildings in the Waikato region where continued subsidence resulted in the need to build up the land surface around houses or jack up buildings and cut piles down to lower buildings including the need to modify attached infrastructure. In some cases, farm milking sheds have been abandoned because the concrete pads they were built on were poured over piles and the shed floor is now so far above the land surface they are no longer useable (examples can be viewed off Valentine Road, Gordonton). We are aware of areas (e.g., parts of Hikurangi and parts of Hauraki) where prolonged high soil moisture is making pastoral farming uneconomic, and farmers need an equitable exit strategy. Therefore, ongoing subsidence poses environmental, economic, and social challenges for future land management. However, there is currently no national level strategy for the management of peatlands along with little robust New Zealand-based information or examples of how to slow or stop subsidence. Under contract to Waikato Regional Council, [3] reviewed international literature to identify potential approaches to slow or stop subsidence. Lifting water tables and reducing cultivation (associated with cropping and pasture renewal) were likely the most certain ways to reduce subsidence, but this work also identified the need for better decision support tools for land managers and policy incentives to drive change [3].

D3. How will this attribute be affected by climate change? What will that require in terms of management response to mitigate this?

Increased frequency of extreme weather events (both floods and drought) will exacerbate existing challenges for the management of drained peatlands. For example, subsidence rates are higher during prolonged dry periods (drought years) and more frequent and extreme rainfall events will exacerbate the frequency of inundation and flooding risk. Increased subsidence and flooding risk will require increased frequency of infrastructure upgrades (e.g., flood protection, pumping, roads and utilities), and greater levels of intervention, which is costly for responsible councils and rate payers. The impact of subsidence is likely to be exacerbated by sea level rise in low coastal catchments, for example the lower Waihou Piako catchment on the Hauraki Plains in the Waikato Region.

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