7.10 Soil water storage, capacity, and fluxes

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Preamble: There are multiple measures for soil water storage, and capacity listed below, which are used for estimating water availability and storage for pastures and crops, irrigation scheduling, soil water management, and modelling in hydrological and plant production studies etc.

Much of the information below is written for a predominantly agricultural context because many of these indicators have been developed for and are used in agricultural contexts.

Field capacity (FC) is generally considered to be the water content after rapid gravity-driven drainage has effectively ceased, normally after 1–2 days, but this can vary between soils particularly in imperfectly and poorly-drained soils, and therefore, Available water capacity (AWC) can also vary [1, 2]. Field capacity is commonly measured at –10 kPa in the laboratory, but in some studies it can vary from –5 to –20 kPa, and in USA typically is at –33 kPa.

Permanent wilting point (PWP) generally considered to be the water content at which water is tightly held and unavailable to be extracted by plants, causing them to become permanently wilted [1]. This is nominally –1500 kPa although some plants (and with assistance of mycorrhizae) can access water >1500 kPa.

Available water capacity (AWC) and Profile available water (PAW). Describes the amount of water a soil can store. The profile available water is defined by New Zealand's digital soil mapping system, S-map, as the amount of water that can be stored in the soil profile and is potentially available to the plant for growth [1, 3]. It is generally considered to be between field capacity and permanent wilting point. According to [1], "PAW is an alternative to the more common term AWC. AWC is expressed as an equivalent depth (mm) or a percentage of soil volume or weight. Management such as cultivation and compaction can affect AWC. In New Zealand, PAW is commonly expressed as mm of water storage per 100 cm soil depth, or to 60 cm depth in irrigation scheduling or nutrient budget models, such as Overseer.". In the S-map factsheets, for example, PAW is expressed as 'mm' and is listed for 3 profile depth classes of 0–30, 0–60 and 0–100 cm.

Readily available water capacity (RAWC) and Profile readily available water (PRAW) generally considered to be the difference in water content between field capacity and the 'stress point', where a plant becomes stressed with a risk of growth limitation from drought stress [1]. RAWC is typically defined as the proportion of the soil water storage drained between the pressure levels of –10 and –100 kPa, but the stress point may vary depending on the crop [1, 2].

Gravimetric water content is the mass of water per mass of dry soil.

Volumetric water content is the ratio of the volume of water to the unit volume of soil reported on a volume basis.

Soil moisture deficit (SMD). NIWA provides modelled soil moisture deficit data: Soil Moisture Deficit (SMD) | NIWA. SMD is calculated based on rainfall, potential evapotranspiration, and a fixed available water capacity (this is assumed for all soil orders). SMD is useful for evaluating how dry the soil is, drought severity and for modelling.

Matric potential. This is equal to the potential energy due to the attraction of the solid matrix, and is equated to the absorption and capillary forces which hold water to soil particles [4]. It's a measure of pressure/suction (kPa) and gives an indication of how tightly soil holds onto water.

There are multiple measures for 'fluxes' including measures of:

Saturated hydraulic conductivity, Ksat. Typically measured using approx. 10 cm diameter undisturbed soil cores, and adequate replication is needed as Ksat can be quite variable. Small cores can have artefacts so modelling approaches can also be used [5]. Further details for the various flux measurements are available in [6]. Field measures are also used with results influenced by size of ring, whether single or double rings are used, and the ponding depth of water. For measures for stormwater, engineers use different methods which are generally falling head using single rings (R Simcock pers comm).

Unsaturated hydraulic conductivity, Kunsat. Typically measured using approx. 10 cm diameter undisturbed soil cores, at a range of matric potentials. For example, Manaaki Whenua – Landcare Research has cores equilibrated to −0.1, −0.4, and −1 kPa tensions [7] to measure unsaturated flow in several pore sizes. Typically, unsaturated hydraulic conductivity is much less than saturated hydraulic conductivity, and variation is also less as the influence of macropores is reduced.

Infiltration. Manaaki Whenua – Landcare Research has recently developed a field infiltrometer, but some aspects are still being developed and tested. More info and photos are available here: https://www.landcareresearch.co.nz/publications/soil-horizons/soil-horizons-articles/a-farmer-friendly-infiltrometer/

The relationships describing hydraulic conductivity and water retention (soil water storage), as functions of matric potential are two key attributes to describe a soil's hydraulic character [8]. Internationally, other terms can be used such as in Australia for drained upper limit (DUL) in place of field capacity, and crop lower limit (CLL) in place of PWP [9]. Similarly plant available soil water capacity (PAWC) can be used in place of RAWC [10].

State of knowledge of the "Soil water storage, capacity and fluxes" attribute: Good / established but incomplete – general agreement, but limited data/studies.

The multiple measures for soil water storage, capacity are generally well studied, but usually for research purposes rather than for monitoring per se. Soil water storage and capacity are generally used for irrigation scheduling, soil water management, and modelling soil water balances such as in modelling of plant production or farm management effects. However, fluxes such as Ksat, Kunsat, and infiltration are used less often in NZ.

Part A—Attribute and method

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

This attribute relates to ecological integrity but not to human health. Soil water is critical for ecosystem functioning as it provides water for plants, transports nutrients, enables nutrient cycling processes and (microbial) life cycles based in soils. Soil water is important as it influences soil properties including aeration (air movement), temperature and consistence [2]. How much water a soil can store (how big is the bucket) within soil pores depends on several soil properties particularly texture (hence the arrangement and size of soil pores) and organic matter, but also soil management [1, 2]. For a soil profile, taking into account the depth of the soil is also important. How much water a soil actually holds at any one time (how much is in the bucket) depends on these factors but also plants, their transpiration, climate (drought vs rain, evaporation), whether irrigated or not etc [2]. Ecosystems develop depending on the ecoclimatic zone, which is in part due to soil water availability. The status of soil moisture affects ecohydrological processes such as runoff, infiltration and evaporation and plant function such as through transpiration and photosynthetic rate [11]. Plants also affect soil moisture and dynamics through the plant's involvement in the water cycle such as root uptake, transpiration etc [11].

This group of attributes has a wide range of indicators, so some caution is required when considering them. It is important to realise that some, such as AWC and RAWC, etc can be slow to change, and are typically considered to be quite stable because they are related to physical properties and arrangement of the soil (but they can change with soil management). PWP is unlikely to change much at all as it is very depending on soil texture. In contrast, soil water content is a measure of water in the soil at any one time, and it can rapidly change with evaporation, irrigation, rainfall, soil management etc.

How water flows (water fluxes) depends on soil properties particularly pore arrangement and connectivity, and where sufficient water is available, water flow may influence movement of nutrients and contaminants through soil and into groundwater. For agriculture, soil water content can be increased by irrigation where needed.

Measurements of soil water storage (e.g., AWC, RAWC) have been used for understanding soil water balances for agricultural and agronomic purposes and pasture/crop/nutrient uses and dynamics (including modelling) [11-13], runoff or leaching losses [14, 15], and for farm irrigation scheduling. Measurements of soil water storage allow an informed approach to farm irrigation water use and the optimisation of plant yield [11, 16, 17]. Direct use of RAWC and AWC can be made for evaluating water storage for irrigation scheduling – but usually in conjunction with software or decision support tools e.g., [19]. Available water capacity (AWC) is important for accurately simulating (modelling) crop yield in dry conditions and under irrigation [16, 19]. Knowledge or representation of these measures of soil water storage is also important for modelling water and diffuse nutrient losses from agriculture.

Unsaturated hydraulic conductivity measurements data are scarce [21]. Hydraulic conductivity measurements of soils have been used to improve modelling of soil drainage and pasture yield [21].

Many of these water storage and flux attributes are also of critical importance for developing modelling, pedo-transfer functions (to predict soil water storage e.g., RAWC, AWC, PAW and transport e.g., Ksat and estimates and the uncertainty) associated with S-map [22-24] (NZ's digital soil map). Significant efforts have gone into improving modelling with these attributes within S-map in the last 10 years with significant sampling campaigns to improve data from a range of soil orders. For example, in recent years S-map has relied on a pedotransfer function developed in 2014. A major effort had been made to substantially increase the amount of measured data from which the model is derived; further information is available from:
https://www.landcareresearch.co.nz/publications/soil-horizons/soil-horizons-articles/new-water-retention-model-in-s-map/

Similarly, a significant effort has been made in recent years to significantly improve the hydraulic conductivity model computed from water retention curves for a range of New Zealand soils [5, 25, 26], thereby improving estimates of AWC, PAW, Ksat etc for a wide range of New Zealand soils – and therefore also improving environmental and farm systems modelling, e.g., Overseer nutrient budgeting, and in the Agricultural Production Systems Simulator (APSIM).

More recently, a new pedotransfer function for S-map was developed in 2024 [27], and a webinar gives latest information for NZ soils as at April 2024 on “Improving information in S-map - Important updates on soil water storage characteristics”
https://www.landcareresearch.co.nz/events/linkonline/

Water storage indicators (RAWC, AWC) and saturated hydraulic conductivity are also used in stormwater / flood modelling to model performance of catchments and different water retention and detention devices [28] and living roof substrates [29]. Soil water storage in specific urban stormwater treatment devices is fundamental to their performance – most critically in greenroofs/living roofs. Auckland Council developed a greenroof media that has an available water storage to meet stormwater quality targets when placed at a depth of 100 mm [30].

Finally, regarding human health, soil stores water, so there may be an indirect pathway for nutrients and contaminants that affect human health to travel when water moves through soil.

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

The ability of soils to store water for ecological functioning differs with their properties, different soil types and spatially in the landscape. Dominant factors influencing the various indicators of soil water storage capacity for ecological functioning are soil texture, presence of stones, pore sizes and pore arrangement. Soil type influences texture and stones, but both soil type and management of soil influence pore sizes and their arrangement. Managing soil water availability in soils with low AWC is challenging (e.g., in shallow, stony soils).

In agriculture, more specifically under irrigation, the spatial extent and magnitude of degradation of water storage properties is not well known for modern sprinkler irrigation and farm grazing systems, with some studies conducted only recently [1, 17]. However, there have also been a number of studies under older border-dyke irrigation systems, reviewed in [1]. An example is a study across Canterbury, where the effects of irrigation on soil physical properties under pastoral grazing were evaluated. Under irrigation there was a shift towards a greater abundance of smaller soil pores, thus reducing readily available water capacity to pastures under irrigation than under no irrigation [17].

When there is limited water storage it is important that as much capacity as possible is preserved through good soil management on farms [31]. Knowing more about the attribute would help to better manage irrigation and water use, as would knowledge of their spatial variability across the landscape. Improved knowledge on a paddock scale could be combined with soil mapping and use of variable rate irrigation, measurements of soil physical properties in the lab, sensor-based technology for soil or plants, and soil-water balance irrigation scheduling etc, which can all improve crop yields and water use efficiency [12, 20, 31, 32].

Flood risk is increased where soil water storage is reduced. In urban and rural context, reduced storage is associated with loss of organic matter, compaction and/or reduction of soil profile depths through earthworks [33].

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)?

Significant changes in New Zealand in the last two decades include a 10% expansion in urban areas between 1996 and 2012 with a loss of high-quality soils for food production [34]. Areas of irrigation have expanded, often resulting in dairying and arable cropping expansion [1, 35]. The area of irrigated agricultural land increased by 91% between 2002 and 2019 [35].

The pace and trajectory of change and impacts associated with these land use changes over time for this soil attribute however is largely unknown. In agriculture, research of soil water storage in soil types in border-dyke irrigation systems was undertaken in the 1960s and 1970s where agricultural development, climate and irrigation on soils were evaluated [1], or more recently under modern irrigation systems but typically this has been only a single point in time or for short time periods [16, 31].

Rapid changes have occurred in urban areas – most soils having reduced AWC through compaction and profile truncation. However, specific anthropic soils are specified for stormwater devices and tree pits that have increased AWC through provision of deeper profiles, organic amendments to topsoils, and use of high AWC components (e.g., pumice) [33].

Some impacts are reversible. Common techniques increase water held by adding amendments (organic materials, biochar, pumice, clays), increasing topsoil depths, or, where rooting depths are limited, using imported soils or physical amelioration such as ripping or subsoiling. This is often done in combination with increasing infiltration rates and slowing water runoff to maximise the rate at which water enters the soil profile (i.e., reducing runoff). Such techniques are core to regenerative agriculture and urban stormwater management. Adding municipal compost has been shown to increase water storage pores [37].

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?

Several councils (Auckland, Waikato) have invested in soil moisture content monitoring [38, 39] for the benefit of farmers and council. Auckland Council indicate for their monitoring, “The purpose of this network was to assist with agricultural farm management and for drought information purposes” [39]. A National Environmental Monitoring Standard (Soil quality and trace elements. Sampling, measuring, and managing soil quality and trace element data. Version 1.0.0) [40] has been developed. However, regional council methods for routine monitoring of soil water content vary considerably [38-39].

For example, Auckland Council established their soil moisture monitoring network in 2014 with ten soil moisture sensors (aquaflex) installed across the Auckland region between 2014 and 2016 and in accordance with the National Environmental Monitoring Standard [39]. Several other councils (e.g., Hawke's Bay, Otago) have information available on their websites. Southland Regional Council also monitors soil water. These councils monitor soil water content on a routine basis. My understanding is that GWRC has monitored soil moisture using small in-situ probes, but this information may be out of date.

There is no routine monitoring of soil water capacity or fluxes e.g., Ksat, that I'm aware of.

NIWA provides modelled soil moisture deficit data: Soil Moisture Deficit (SMD) | NIWA. Soil moisture deficit is reported on their web page with historical soil moisture deficit, the soil moisture deficit at the same time last year, and the current soil moisture deficit.

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

For direct soil measurements for many of these attributes, or for ongoing soil water content monitoring, there would be a need to access privately owned land. Landowners may be more, or less, willing to provide access to land for sampling and to have data from their land used to inform monitoring.

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).

A key cost will be staff time to undertake sampling, with additional staff required for interpretation and reporting etc.

AWC, RWAC, FC, PWP etc are sampled using undisturbed cores using lab-supplied stainless-steel rings, i.e., not 'bulked' soil samples. The Manaaki Whenua – Landcare Research physics laboratory routinely does these as part of a range of measurements, generally for research purposes. Further information is available from: https://www.landcareresearch.co.nz/partner-with-us/laboratories-and-diagnostics/soil-physics-laboratory/

Current costs for RAWC and AWC from the soil physics lab at Manaaki Whenua – Landcare Research are approx. $110 per sample.

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

Yes. Ngāi Tahu Farming is involved in a soil health project with AgResearch, where field capacity (−10 kPa), available water capacity and wilting point (−1500 kPa) were measured [41]. There may be other monitoring being carried out by representatives of iwi/hapū/rūnanga that we are unaware of. As land owners and farmers, aspects of this attribute are likely to be of high interest to Māori.

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

Soil properties that influence soil water storage, capacity and flux were described in sections A1 and A2. Attributes that relate to some of those properties are: soil carbon, soil compaction, erosion attributes, peat soil subsidence, wetland extent, and soil nutrients. Other factors that may influence soil water content are climate and weather events and catchment properties, attributes relating to those factors are catchment permeability, surface water flow alteration, groundwater depletion.

There is an established relationship between size ranges of soil water storage pores, matric potential, and therefore how tightly soil water is held [1, 8]. There is a relationship with the attribute macroporosity, in terms of the soil matric potential (tension) commonly used to define the pore size boundary (–10 kPa) that is also typically the upper boundary for AWC and RAWC. The relationships describing hydraulic conductivity and water retention (soil water storage), as functions of matric potential are two key attributes to describe a soil's hydraulic character [8].

Part B—Current state and allocation options

B1. What is the current state of the attribute?

We don't know the current state of many indicators of this attribute, namely AWC, RAWC, FC, PWP, and fluxes (Ksat, Kunsat), as they are not routinely monitored. Information and data on these attributes has typically been gained through research studies include characterising soil water storage attributes under land uses, land management practices, characterising soils etc [5, 16, 19, 22-25, 37-39], and farm or crop system studies [11, 19, 29, 40]. Other studies use these attributes or estimate them for a range of uses [41, 42]. Soil water storage attributes like AWC are linked from S-map to models such as Overseer and APSIM. Research has been conducted in NZ to evaluate more cost effective methods [48].

In contrast, soil water content (which can change rapidly with weather events) is monitored by several regional councils as described in section A4-(i). However, this monitoring of soil water content has limited coverage within regions. Monitoring soil water content is useful for specific situations, e.g., irrigation and effluent application for agriculture, growing pasture and crops etc. However, it can change rapidly so may not be relevant/suitable as national scale indicators or attributes, but that is dependent on the purpose and scale of the intended monitoring.

NIWA provides modelled soil moisture deficit (SMD) data on their web page: https://niwa.co.nz/nz-drought-indicator-products-and-information/drought-indicator-maps/soil-moisture-deficit-smd. SMD is calculated based on rainfall, potential evapotranspiration, and a fixed available water capacity (this is assumed and is not monitored). SMD is useful for evaluating how dry the soil is, drought severity and for modelling. This modelled attribute would be useful as a national attribute, but currently it is too coarse, so finer resolution and using soil type (soil sibling) data from S-map would be required. Other refinements may also be required.

Measuring AWC, RAWC, FC, and PWP are useful for specific situations, e.g., irrigation and effluent application for agriculture, growing pasture and crops etc, but are unlikely to change rapidly (depending on circumstances described in A1), so are unlikely to be relevant/suitable as national scale indicators or attributes, but that is again dependent on the purpose and scale of the intended monitoring.

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

The concept of reference states does not seem particularly relevant for the practical use of this attribute in agriculture, but has been applied in the urban environment. For example, the concept of reference states is relevant for the practical use of this attribute in a) the context of urban soils, where stormwater quality and flood volumes in areas that will be urbanised are modelled using 'pre' and 'post' development that uses soil water storage (with 'before' being the reference state) (R Simcock pers com) and b) in the context of soil rehabilitation (with the non-depleted, high-organic matter soil being the reference state) [49-51].

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)

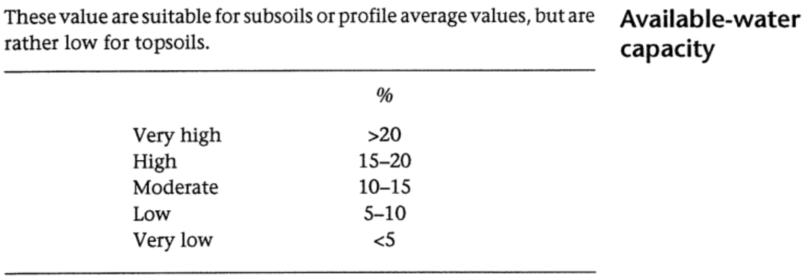
The following presents existing numeric or narrative bands described for this attribute 'state'. These are not related to regulation or any specific management, but in general are related to plant growth and the availability of water that can be used by plants during dry periods (more water storage means greater resilience to drought). In terms of regulation and guidance, good practice for dairy effluent application is typically using application depths of 10 mm or less [44], but the current attribute is not typically specified in council regulations.

The MWLR S-map factsheets present modelled information for the public for example 'profile available water' as bands: "PAW of 100 mm implies that 10% of the soil volume is water available to plants. Low PAW is <60 mm, moderate is between 60 and150 mm, and high is ≥150 mm." Source: https://smap.landcareresearch.co.nz/support/glossary#profile_available_water_paw.

Similarly, MWLR S-map factsheets present modelled information for the public for example 'permeability of slowest horizon' as bands, "The permeability of the slowest permeable layer of the soil. As well as being expressed as 'slow', 'moderate' or 'rapid', this is also expressed as the movement of water in millimetres per hour.". Source: https://smap.landcareresearch.co.nz/support/glossary#permeability_of_slowest_horizon.

Some base information/rating systems for permeability classes including those used in S-map are found in [52]. This is expressed at the soil family level, and there are more permeability classes at the Functional Horizon level – these are documented in the S-Map manual (L Lilburne pers comm). The bands for permeability classes used at the soil family level in S-map are 'slow' <4mm/h, 'moderate' ≥4 to<72 mm/h, and 'rapid' ≥72 mm/h (L Lilburne pers comm).

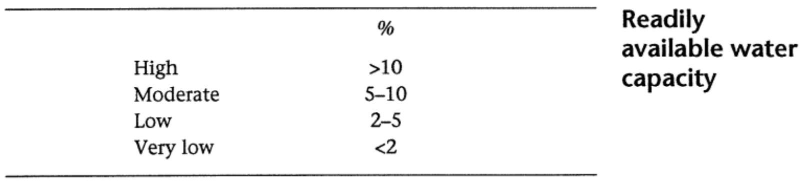
A number of classes, bands or ratings are available for available water capacity, readily available water capacity, profile available water and soil permeability for NZ soils, and these are explained with further details in [4], with some of these band values copied in the images below.



These value are suitable for subsoils or profile average values, but are rather low for topsoils.

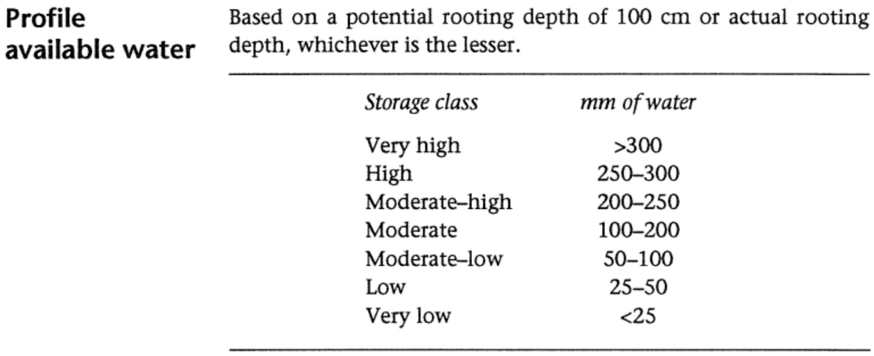
Available-water capacity

	%
Very high	>20
High	15–20
Moderate	10–15
Low	5–10
Very low	<5



Readily available water capacity

	%
High	>10
Moderate	5–10
Low	2–5
Very low	<2



Profile available water

Based on a potential rooting depth of 100 cm or actual rooting depth, whichever is the lesser.

Storage class	*mm of water*
Very high	>300
High	250–300
Moderate–high	200–250
Moderate	100–200
Moderate–low	50–100
Low	25–50
Very low	<25

Internationally, other terms can be used such as in Australia for drained upper limit (DUL) in place of field capacity, and crop lower limit (CLL) in place of PWP [9]. Similarly plant available soil water capacity (PAWC) can be used in place of RAWC [10].

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

Yes. Specific effects on ecological integrity occur when soils are changed to the extent that AWC is reduced and cause a) increased flooding or b) reduced resilience to drought. This can occur with changes to rooting depth or to changes in volume of water held per unit of soil (most commonly reduced organic matter) (R Simcock pers comm).

Tipping points result in changes in relative competitiveness of different species, e.g., from kiwifruit or avocado (intolerant of waterlogging/wet soil) [53] to pipfruit (more tolerant) (R Simcock pers comm). There are also differences in tolerance to drought and waterlogging between cultivars in grapes and apples, with drought stress reducing photosynthesis, and transpiration rate [54]. Soil drainage, aeration and water storage properties should be used to guide plant selection [55]. Different species have different tipping points as they have different vulnerability to water stress (exacerbated in droughts and where there is no irrigation) and to anaerobic soil conditions (linked to wet soils). Tipping point is also influenced by the stresses plants experience as they grow, especially long-lived species such as trees – plants with larger and deeper root systems are more resilient to drought (R Simcock pers comm). Areas that have wetter hollows, have lower aeration reflected as poorer crop emergence, stunted plants, more root diseases, increases in species (often weeds) that are more competitive [56, 57] (R Simcock pers comm).

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?

Legacy effects include peat drained and subsiding soils [58,59], so potentially they could be losing water storage capacity. This will have links to the peat subsidence attribute.

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.

As noted previously, soil health is an area of high interest to Māori and there are many tohu/indicators that are utilised according to mātauranga-ā-hapū and mātauranga-ā-iwi [67, 68]. In addition to discussing this attribute directly with iwi/hapū/rūnanga, there is likely to be tikanga and mātauranga Māori relevant to informing bands, allocation options, minimally disturbed conditions and/or unacceptable degradation in treaty settlements, cultural impact assessments, environment court submissions, iwi environmental management and climate change plans, etc.

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?

The effects of management were briefly described earlier (sections A2, A3). For example, the effects of irrigation on soil physical properties under pastoral grazing suggests a reduction in readily available water capacity in soils under irrigation than under no irrigation [17]. AWC and the other attributes are affected by soil texture, structure, soil depth and layering, organic matter, and stone content, and also management such as cultivation and compaction.

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

No. As indicated previously, some councils monitor soil water content, but it is unknown if the information is used for regulatory purposes. Auckland Council indicate for their monitoring, “The purpose of this network was to assist with agricultural farm management and for drought information purposes” [39]. Auckland Council has developed a guidance for flood modelling and stormwater quality device design [60].

C2-(ii). Central government driven

We are not aware of interventions/mechanisms being used by central government to directly affect this attribute.

C2-(iii). Iwi/hapū driven

We are not aware of interventions/mechanisms being used by iwi/hapū/rūnanga to directly affect this attribute.

C2-(iv). NGO, community driven

We are not aware of NGO or community driven interventions/mechanisms being used to affect this attribute.

C2-(v). Internationally driven

We are not aware of any internationally driven interventions/mechanisms being used to affect this attribute.

Part D—Impact analysis

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

Not managing soil water content, water use through irrigation etc is likely to lead to water over use, wastage of water, greater nutrient losses, and less than optimum management of pastures and crops for production [61-64].

As discussed earlier, adequate AWC, RWAC, etc, along with good management of these, are valuable for managing crops, pasture etc, and associated environmental and production modelling is important [12]. These will become increasingly important for climate change resilience.

In cities, increased flooding and increased water use for garden irrigation occurs where soil water storage is reduced [65]; increased urban vegetation drought stress leads to slower growth and a narrower range of species, with less temperature moderation (links to climate change) [33].

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)

Economic impacts are likely be felt by farmers directly, and industry where crop or pasture production is affected, or where irrigation water is rationed. I'm not aware of economic studies.

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

Arrangement of soil pore space, and thus ability to store water can be affected by climate (and therefore climate change) via drying and soil wetness, and so crop and pasture growth can therefore be affected by climate change. It is likely under wetter conditions, from increased storm intensity or frequency under climate change, there may be more soil compaction, thus affecting RAWC and the other water storage attributes indirectly. Climate change is likely to directly affect soil carbon and soil compaction [66] (and therefore RAWC, AWC etc. indirectly).

In cities, climate change is likely to increase flooding in more intense, frequent high rainfall, and in drier conditions increase temperatures resulting in vegetation drought stress, such as for canopy trees [33].

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