SALT WATER INUNDATION

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INTRODUCTION

New Zealand has abundant annual rainfall, which means soil salinity of agricultural lands has rarely been a major problem. However, a number of critical problems affect low-lying coastal areas, making them vulnerable to salinity issues i.e. land subsidence, periodic flooding during severe storms, inundation by salt water during extreme tidal events and saltwater intrusion into groundwater.

In this report, information on what is currently known on the potential impact of salt inundation from a case study and from a literature search is presented.

FINDINGS FROM TARGETED INVESTIGATION OF TIDAL INUNDATION PIAKO RIVER, 27 JULY 2016

This report documents the technical advice provided by Waikato Regional Council in response to the tidal inundation of pastoral farmland on 27 July 2016 following a flood gate failure on the Piako River, very near to its discharge into the Firth of Thames. Paddocks were inundated for approximately 28 hours. This event was immediately followed by heavy rain.

To assist with this technical advice, soil samples from the affected area and from an adjacent area not inundated were collected the following day, 28 July 2016, and analysed for cation exchange capacity, exchangeable calcium, magnesium, potassium and sodium, and soluble salts. These results (Table 1) showed sodium was similar in both the inundated and not inundated areas, which was not surprising as it was expected salt in sea spray to be blown over the whole farm. In addition, the inundated area was not wetter than the area not inundated.

Table 1. Chemistry results for soil samples from inundated and not inundated by tidal salt water.

SITE	EXCHANGEABLE Potassium me/100g	Calcium me/100g	Magnesium me/100g	Sodium me/100g	CATION EXCHANGE CAPACITY ME/100G	SOLUBLE SALTS %	MOISTURE %
INUNDATED							
Sample1	2.5	8.3	11.8	3.2	34	0.10	54
Sample 2	3.8	8.9	10.7	1.5	34	<0.05	48
Sample 3	3.0	7.8	12.8	0.9	34	0.06	40
NOT INUNDATED							
Sample1	3.5	21.1	15.7	8.7	49	0.54	51
Sample 2	3.9	19.2	13.6	5.4	42	0.29	60
Sample 3	4.5	12.1	12.0	0.5	35	<0.05	33

The tidal salt water inundation will have little effect on the farmer's ability to graze the affected paddocks in the long term. Pasture is unlikely to be affected and there were no identifiable effects on soil chemistry. There was no apparent difference in soil moisture for sites inundated and not inundated consistent with paddocks receiving heavy rain after the inundation ceased. So saturation of the soil cannot be attributed to the inundation alone. Nevertheless, it would be wise to keep stock off in the short term to prevent pugging.

LITERATURE REVIEW ON IMPACTS OF SALT WATER FLOODING

Much of the understanding of the impacts of salt water flooding on soils comes from studies after tsunami or hurricane events. It should be noted that both tsunami and hurricanes cause physical damage to soils and plants due to the energy released as currents and winds. The salinity status of the inundated farmlands appears dependent on soil texture and therefore on the infiltration rate of the soil, soil moisture in the period immediately preceding the inundation and the duration of the inundation, as well as the relative physical position (elevation) of the farmland (Roy et al 2014, Provin et al 2009).

Soil texture plays an important role in soil water infiltration rates. Sands or sandy loams have higher infiltration rates due to the particle size distribution. On the other hand, heavy textured soils, which contain a lot of clay and/or silt, often have poor water infiltration and hydraulic conductivity because the space the soil occupies is relatively dense. Organic matter helps infiltration because it aids soil aggregation and the formation of pores. Thus the impact of saltwater inundation was seen in sandy beach sediment soils down to ~ 15 cm depth after the 2011 tsunami in Japan (Chague-Goff et al 2011), but Nakaya et al (2010) found salinity was high only in the top 1-2cm of clayey argillaceous soils with low hydraulic conductivity after the 2004 tsunami in Thailand.

The accumulation of sodium chloride (NaCl) is the main reason for salinisation in agricultural soil exposed to salt water. Sodium Na^+ ions can attach to clay particles but chlorides (Cl^-) do not associate strongly with soil and are washed out easily by rainfall (Roy et al 2014), e.g. salinity was almost completely removed by rainfall over one rainy season in Thailand (Nakaya et al 2010). The data from table 1 shows two-thirds of the sites in both inundated and not inundated areas had sodium values that are rated very high (Blakemore et al (1987) suggesting sea salt spray is the source of sodium rather than the inundation.

Provin et al (2009) provide data on pasture survival after inundation for different lengths of time (note that the grass species differ from the rye grass and clover pasture used in New Zealand):

- Forages under salt water for 24-48 hours: Bermudagrass recovery is apparent with most leaf tissue showing a healthy green colour. The bahiagrass we observed had some discolouration and curling of leaves. Some other species appeared to be brown and desiccated due to exposure to salt water, although a number of weed species, including nutsedge, remained yellow green to green.
- Forages under salt water for 48-96 hours: All bermudagrass leaf tissue appeared to be brown. This could be due simply to the plants being submerged for an extended period of time or to excessive desiccation of the leaf material due to prolonged exposure to the salt water. We did observe, however, some green stem material and normal rhizomes indicating the potential for recovery of the bermudagrass. Other species were brown and desiccated.
- Forages and all other species under salt water for >96 hours: All bermudagrass leaf tissue appeared brown and many stems were also desiccated and broke under pressure. Rhizome health differed depending on sampling. All other desired forage species appeared dead.

The pasture at the sites sampled showed no visible difference in rye grass and clover health as the inundated sites were only flooded for about 28 hours.

OTHER IMPACTS OF FLOODING ON SOILS

Extended periods of soil saturation, whether by salt or fresh water, can result in significant negative impacts to soil and the services it provides, including loss of soil permeability, loss of aeration, the saturation of the soils ability to hold and filter nutrients and contaminants, overland flow mediated erosion and formation of tomos. However, interactions between physical, chemical and biological factors result in complex outcomes. Examples based on experience with applications of effluent to land are presented below.

1. The existence of flooding indicates the infiltration rate of water into soil has been exceeded, the soil has become saturated, bypassing the filtering service of the soil and by-pass flow of nutrients, pathogens and contaminants to groundwater may be occurring (McLeod et al 2008, Monaghan & Smith 2004).

2. Tidal and wave-driven currents can be strong and may re-suspend sediment or erode soil (Green & Coco 2014, Bloesch 1995, van Straaten et al 1958). The fine pores in the soil filter out these suspended particles very effectively, but become stopped up by them, reducing the rate of percolation. A layer of sediment may form on the surface of the soil if there is enough suspended matter and the flood water is deep enough. This sediment can decrease infiltration of salt water into the soil.

3. When large amounts of water are allowed to pass through soils composed of particles of different sizes, the rate of percolation has been found to gradually decrease. The reason for this is that the flow of water causes smaller particles to become dislodged and to be swept into some of the larger soil pores where they become lodged in constricted areas, effectively blocking the pore (Harkin et al 1975). For salt water, this effectively limits the amount of salt entering the soil. However, this blocking of soil pores will subsequently increase the time taken for rain to wash out the salt that entered the soil and recovery may be delayed.

4. Resuspension processes can also move nutrients, pathogens and other contaminants from one location to another (Zonta et al 2005). This could be an issue for regional councils if, for example, matter from an old landfill was scoured out and deposited on farmland.

5. Smearing can occur if heavy machinery or animals are run or used on wet soils. This compression effect can cause reduction in flow through the soil as it effectively seals off soil pores (Batey 2009, Kozlowski 1999, Harkin et al 1975). Machinery and animals should be kept off inundated land until the water has drained and the soil is no longer saturated.

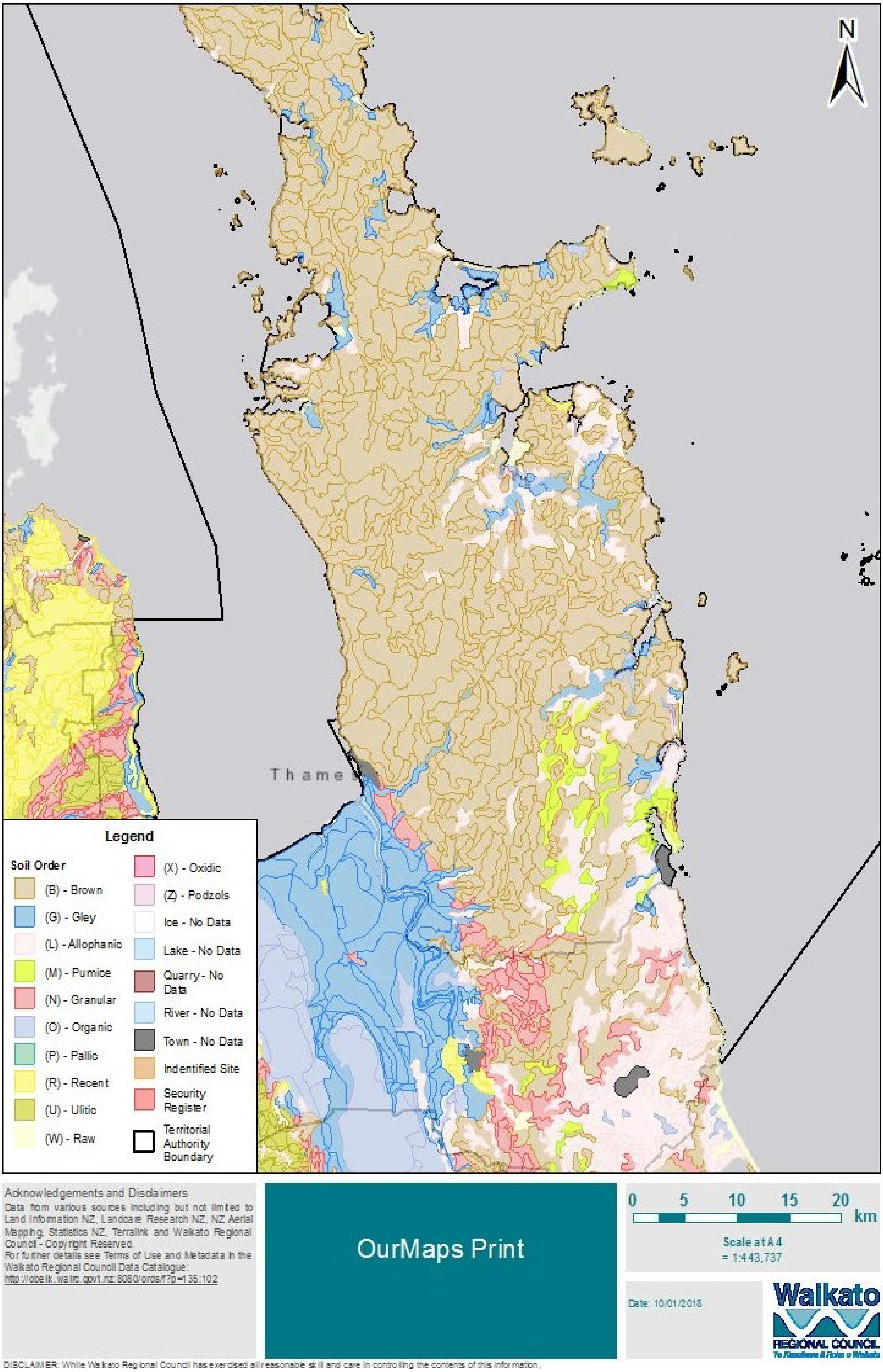
6. Interactions between microorganisms and sulphur can deposit insoluble sulphides in the soil pores and kill off many beneficial types of bacteria. During microbial fermentation, microorganisms digest organic materials, using part of them for energy maintenance and part for forming their cellular mass. In order to break down and utilise organic compounds, microorganisms must have other compounds available to be used as electron acceptors. The oxygen present in the air is the normal terminal electron acceptor used by all aerobic organisms in this process. The oxygen is reduced to water and used to produce carbon dioxide (CO2) from some organic compounds. If no air is available, microorganisms that can live in the absence of air (anaerobic bacteria) will use other inorganic (e.g. nitrate or sulphate) or organic compounds as electron acceptors. Reduction products associated with organic matter conversion under anaerobic conditions include nitrogen (from nitrate), sulphide (from sulphate) and methane (from organic matter), each again being accompanied by CO2 produced from organic matter decomposition (Harkin et al 1975).

   As long as air continues to be drawn into the soil as the water drains, a mixed population of aerobic microorganisms will remain to effect soil services such as biodegradation of organic matter. However, as more and more soil pores become plugged, the rate at which the water seeps away becomes slower and slower so that less and less air is drawn into the soil. Under these conditions, aerobic fermentation is gradually replaced by anaerobic fermentation. Similarly, when air is no longer drawn into the soil, the range of electron acceptors available to microorganisms becomes very restricted because any free oxygen in the water has already been used up in fermentation.

   One significant electron acceptor available in ponded fields is sulphate (SO4). SO4 is rapidly reduced to sulphide during reduced condition when the soil is saturated. Sulphides are toxic to most microorganisms. Only some microorganisms, which can reduce sulphides further to elemental sulphur, can survive in the presence of high sulphide concentrations. The presence of free sulphide in stagnant water may therefore kill off many of the bacteria, which would otherwise be degrading organics. Some of the free sulphide may be converted to insoluble sulphur, causing further physical blockage of soil pores. However, very little of the sulphide remains in the free state as the bulk of it combines with ions of heavy or transition metals (e.g. iron, manganese, chromium, cadmium, nickel, copper, magnesium, zinc, etc.) present in the soil or water. This causes the deposit of insoluble, inorganic sulphides in the soil pores (Harkin et al 1975).

7. Some low density soils are very vulnerable to tomo formation. This may occur if there is an area of ponding left once the main flooding has receded. As the ponded water drains through the soil, sideways lateral water flow below the soil surface can create a pipe. As flow continues the pipe enlarges as soil particles are eroded unseen underground. Eventually the pipe becomes so large that it collapses. This can be a precursor to gully formation (Hagerty 1991). The soils most vulnerable to tomo formation after salt water inundation are Pumice and Allophonic soils of the east Coromandel Peninsula near the coast (Figure 1).

Figure 1. Map of soils of the Coromandel Peninsula showing tomo vulnerable Pumice (bright yellow) and Allophanic (pale pink) soils.



FORMATION OF SALT CRUSTS

Where land is ponded for periods more than three days, salt concentration due to evapotranspiration may become apparent. As water is evaporated, rather than infiltrated or drained, the remaining water becomes more salty and eventually this salt could be deposited as a crust on top of the soil once all the water is evaporated (Smith & Compton 2004). Shiftlet (1963) found water that had ponded after Hurricane Audrey continued to increase in salinity until eight months after the hurricane when levees were restored and a new pump installed. Excess salt will be washed out in rainfall, but it will take more rain and a longer period for the soil to return to its salt concentration before the inundation compared to land where the inundation drained quickly. As all productive vegetation is expected to be killed by the period underwater already, any salt crust will have no immediate effect on pasture. However, resowing should be delayed until the salt has been washed out by rain as excessive salt can reduce or prevent ryegrass pasture germination (Marcar 1987).

RESTORATION OF SOILS AFTER SALT WATER FLOODING

Based on the experiences of past tsunami, soil could be returned to its original (pre-tsunami) salinity levels within two years (Plett, 2012). Of course, the tsunami investigated are much more significant flood events than a 28 hour inundation.

Flushing of soil particles with freshwater (rainwater) is the best option for treating saline soil in lowland fields (Roy et al 2014). Salt leaches out of the soil most readily in sandier soils with good drainage (Provin et al 2009).

Lessons can also be drawn from experiences with other salty liquids that can have high sodium contents, such as whey. When whey was first applied to land, application rates were what would be considered excessive today. Damage to soils resulted from excessive salt content and ponding. Treatment was applying gypsum to supply calcium to balance the excess sodium. Although this land has continued to receive whey (at much lesser amounts) for many years, pasture now appears to grow well.

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