

Potential impact of a tephra eruption on a dairy farm in eastern Bay of Plenty, New Zealand; implications for hazard mitigation

T.M. WILSON and J.W. COLE*

Natural Hazards Research Centre, University of Canterbury, Private Bag 4800, Christchurch, New Zealand

Abstract. This study investigates the impact tephra fall would have on ‘Tulachard’, a dairy farming operation at Rerewhakaaitu, North Island, New Zealand. This includes analysis of the potential effects on the dairy shed and milking machine, electrical supply and distribution, water supply and distribution, tractors and other farm vehicles, farm buildings (haysheds, pump sheds, implement sheds, etc), milk tanker access to the farm and critical needs of dairy cows and farm to keep milking. One of the most vulnerable areas identified in the study was the cooling of milk at the milking shed, pending dairy tanker pick-up. The cooling system’s condenser is exposed to the atmosphere and falling tephra would make it highly vulnerable. Laboratory testing with wet and dry tephra was conducted to determine its resilience to tephra ingestion. It was found to perform satisfactorily during dry testing, but during wet testing significant clogging/blocking of the condenser’s radiator occurred, dramatically reducing airflow through the condenser. Specific mitigation recommendations have been developed which include cleaning with compressed air and adapting farm management techniques to lessen usage of the condenser during a tephra fall event. Specific recommendations for management of the entire farm operation are given for dairy farmers to mitigate the effects of a tephra fall event.

Key words: tephra, dairy farming, condensers, testing, mitigation

1. Introduction

1.1 ASH SAMPLE USED FOR TESTING

The New Zealand dairy industry is one of the most productive and efficient in the world. Lush pastures, temperate climate and well-established industry infrastructure create a world-class dairy industry (www.fonterra.com). In 2004 dairy products made up 17% of New Zealand total exports (~\$5.0 billion; www.mfat.govt.nz). A significant percentage of New Zealand’s dairy farming operation is located in the Taupo Volcanic Zone (TVZ) suggesting there is a significant exposure to volcanic risk.

* Corresponding author: Tel: +64.3.364.2766; Fax: +64.3.364.2769; email: jim.cole@canterbury.ac.nz

The Taupo Volcanic Zone (TVZ) extends from White Island to Ruapehu across the central North Island of New Zealand, and is one of the most active rhyolitic centres in the world (Figure 1; Wilson *et al.*, 1995). The broad range of volcanism in the region means that the magnitude of possible eruptions range from minor andesitic events (such as the 1995-1996 Ruapehu eruptions, which had a notable effect on agriculture in the region), to a plinian Rhyolitic event that could potentially eliminate human settlement in the central North Island for a time. Tephra[†] can be deposited hundreds to thousands of kilometres from its source, making it the product that may affect the largest area and the most people during an eruption.

Intensive farming has only taken place in TVZ for the last 100 years (Keam, 1988), so there is limited historic data on the effects of tephra fall on intensively farmed land for agricultural production. Where volcanic eruptions have affected agricultural land in recent history, the depth of tephra has usually been <50mm and produced only a moderate impact (e.g. Chaplin and Braatne, 1986; Cook *et al.*, 1981). Suggested impacts of larger eruptions are conjecture and extrapolations of impacts from eruptions such as those at Mt. St. Helens, Mt Ruapehu and Hekla (e.g. Johnston *et al.*, 2000).

This study investigates the impact tephra fall would have on ‘Tulachard’, a dairy farming operation at Rerewhakaaitu in the central North Island (Figure 1), assessing the susceptibility of the dairy farm’s infrastructure, machinery, and operational processes to tephra fall.

1.2 ‘TULACHARD’

The study farm, ‘Tulachard’, is owned and operated by Mac and Lynda Pacey. It is located on Brett Road, Rerewhakaaitu, bordering the western shore of Lake Rerewhakaaitu. The farm covers 116.7 Hectares (Ha) and carries 350 cows in two herds, supplemented by a 24 Ha ‘run-off’ block rented for the purpose of supplementary feed production and extra grazing area. This is located several kilometres east of Lake Rerewhakaaitu. For the purposes of this paper the main 116.7 Hectare block is to be referred as the ‘the farm’ and the 24 Ha block as ‘the run off’

The chief economic activity of the farm is to sell milk to Fonterra. This only occurs if dairy cows can be milked, the milk able to be stored for up to 24 hours, and the milk tanker able to access the farm to pick up the milk. Scenarios that would stop milk being delivered to

[†] All unconsolidated pyroclastic debris.

Fonterra from tephra fall hazards would be inability to milk (e.g. power failure, roof collapse, inability to clean the milking shed, too much pressure on the dairy cows), if the milk cooling system were to shut down (i.e. condenser damaged) or if the roads and/or farm tracks were blocked inhibiting the milk tanker to get access onto the farm.

Following significant tephra fall it may be argued pasture recovery is perhaps the single most important long term rehabilitation step for a farm to take. However if the farm can continue economic activity throughout any eruption, the eruption's impact to the farm as an economic entity can be reduced.

It is important to note that the use of only one farm in this study may result in some bias and limitations in the hazard analysis as each farm will present its own site-specific challenges and complications if affected by a volcanic tephra fall.

2. Potential Volcanic Hazards to The Farm

'Tulachard' is near the centre of the TVZ making tephra fall a significant risk to farming operations from any eruption in the TVZ. How badly the farm will be affected will depend largely on which volcano is erupting; in terms of geographic proximity, wind direction, eruption type, magnitude of eruption, the local topography in the vent area and duration of the eruption (Blong, 1984; Nairn, 1991; 2002).

It is globally recognised that it is extremely hard to predict exactly where and when a volcano is next going to erupt with sufficient warning to completely prepare for the event (Blong, 1984; www.maf.govt.nz). The only really safe way to protect people and their livelihoods from the hazards of volcanoes is to remove the people themselves. But the reality is that people have chosen to farm in the shadow of active volcanoes and thus accept the risk this presents (Paton, 2000). This is largely because volcanic soils are good for pasture growth.

2.1 OKATAINA

The main risk to the farm is from an eruption centres on the Okataina Caldera Complex (OCC; Cole *et al.*, 2005; Spinks *et al.*, 2005), located approximately 5km to the north. OCC is the most recently active of the young rhyolitic eruptive centres in the TVZ and one of the most active, having erupted ~80 km³ of rhyolite magma and ~1 km³ of basaltic magma in 11 distinctive eruptive episodes from over 40 vents in the last 22 ka (Nairn, 2002). Eruptions

have been sourced from two volcanic centres; Haroharo Volcanic Centre in the north of OCC and Tarawera Volcanic Centre in the south, with both centres characterised by multiple vents during eruptive episodes and by linear vent zones (Nairn, 2002). 'Tulachard' has been heavily affected by these Holocene eruptive episodes suggesting the OCC represents the greatest volcanic hazard to farming operations, due to its proximity and highly active nature (Table 1). The average return interval between major eruptive episodes during the past 22,000 years at OCC has been 2090 ± 770 years (Nairn, 2002). The probability of a further eruption from Okataina, using an equation proposed by Dibble (1965) is 4.7% in 100 years (Nairn, 2002). This however assumes the post-22,000 sequence is a random sequence which seems unlikely (Table 1).

Most eruptions from the OCC in the past 22,000 years have been rhyolitic, although there is some uncertainty whether this trend is expected to continue with increasing basaltic interaction (Nairn *et al.*, 2004; Acocella *et al.*, 2003). Future eruptive episodes are likely to follow past activity with multiple vent localities, potentially across the 10 km of either vent zone, and confined to one vent zone (Haroharo or Tarawera; Nairn, 2002).

2.2 TAUPO

The rhyolitic Taupo Volcano (TV) is the most frequently active and productive rhyolite volcano in the world (Walker, 1980; Wilson *et al.*, 1995), with a major event 1.8 ka (Wilson, 2004). As such it is reasonable to predict that TV will erupt again in the future and will be a significant threat to the farm in terms of distal tephra fall hazards. This would cover the area with fine to coarse tephra and fine lapilli likely to be the grainsize variation in any airfall deposits. The farm received ~40 cm of tephra from the 1.8 ka 'Taupo Eruption' (Cole, 1970), an eruption estimated to have lasted from days to weeks (Wilson *et al.*, 2004). An initial lapilli layer of ~15 cm denotes the large amount of energy associated with the beginning of the eruption with grainsize reducing up the deposits to mainly coarse tephra.

2.3 TONGARIRO

Volcanoes within the Tongariro Volcanic Centre have erupted frequently within historic times implying that this will also continue in the near future and the farm is within the likely tephra fall hazard zone with south-south-westerly wind conditions. Many dairy farms in the Bay of Plenty experienced tephra fall with the 1995/1996 Ruapehu eruptions. Whilst the farm did not experience any tephra fall during the event, only a slight variation in wind direction would

have covered the farm (Cronin *et al.*, 1997). As an andesitic centre, eruptive activity would be on a much smaller scale, however the higher frequency with which it erupts suggests tephra fall from this centre is perhaps more likely to affect 'Tulachard' than a more infrequent rhyolitic eruption.

3. HAZARD ASSESSMENT OF THE FARM

3.1 FARM SEASONALITY

The farm is a typical New Zealand dairy farm with different farm operations carried out at different times of the year, mainly as a result of the seasonality of New Zealand's climate. A general guide to the annual farm operation is illustrated with Figure 2. This shows that an eruption in early spring (i.e. September) would have the greatest impact on 'Tulachard'. Milk yields would be severely depressed, especially with cows under considerable stress during calving and beginning lactation. This would carry over for the whole lactation, and lack of (or reduced) spring growth from tephra cover of pasture will cause major feed shortages (Neild *et al.*, 1998). October to November would also be a period of vulnerability with supplementary feed reserves at their lowest and peak milk production. The peak production period creates high energy demands on the cows, requiring consumption of large volumes of feed. It is the time the farm normally makes a significant percentage of its economic income. Some of this vulnerability would be lessened as some pasture is 'shut up' (not used for herd consumption) for grass silage production (4 – 8 Ha at the farm and 15 Ha at the 'run off' for two cuts). The pasture in these paddocks will be denser and taller than other paddocks on the farm and better able to survive light to moderate tephra falls (<50 mm). Much of this would all be located at the 'runoff' however and the cows would need to be walked the ~10 kilometres, creating animal health issues in the event of an eruption (i.e. hoof abrasion, eye and respiratory irritation; Neild *et al.*, 1998). The cows could be self fed from the maize bunkers (Figure 3), although maize silage must be supplemented with other feed due to nutritional requirements. Whilst this would result in a lot of waste it may be acceptable under survival conditions.

It would be unlikely that farmers would be able to buy any supplementary feed at this time as any regional reserves would have been mostly used it up, although 'meal' may be available depending on how much is stockpiled by farm supply stores.

3.2 MILKING SHED

The milking shed is the hub of the farm (Figure 3). Cows are milked twice daily here, with the milk picked up daily by tanker for sale to Fonterra. If the milking shed was to cease operation the farm's economic viability would be severely threatened, making it one of the most important and vulnerable areas of the dairy farm. Four main areas of vulnerability were identified that would affect the milking shed's ability to operate:

- 1) Loss of electrical power
- 2) Roof collapse
- 3) Inability to remove/clean tephra and animal excrement from milking shed (loss of water supply)
- 4) Tephra damage of the milk cooling system

The effect of tephra fall on buildings depends on thickness, mass and its chemical reactivity, the building's roof shape, construction and orientation and the spacing of other buildings near by (Johnston *et al.*, 2000). Light to moderate tephra falls will cause less damage to buildings than those greater than 100 mm thick (Blong, 1984).

3.2.1 Operation

The milking shed is a 24 station herringbone system, the operation of which depends entirely on electrical power, with water used at the end of milking to wash down the equipment and holding pad. Two herds of cows are milked twice daily for most of the year. A typical milking usually takes 3.5 hours.

The cows are brought in from the paddocks in which they have been grazing and contained on the holding pad where 280 can be accommodated. Cows are milked 24 at a time. Cups are put on the cow's teats and pulsators driven by filtered compressed air stimulate the teat to milk it. The milk is pumped from the cups to a receiving can along individual lines, and is filtered to catch impurities in the milk. The milk then passes through a heat exchanger (cooling provided by a condenser) which chills the milk and deposited into the storage vat.

3.2.2 Tephra hazards to the Milking Shed

The milking shed is completely open to the north and tephra would easily enter the building from an eruption in the OCC. This would cause problems to humans, cows and equipment, if milking continued during that eruption. Tephra in the milking shed would decrease the quality of the working environment and cause health hazards to humans and animals alike. It

would be a major irritation for the cows potentially causing the on-set of mycosis, making them harder to deal with due to their distressed and irritated state, it would get onto the teats of the cows, and dirty the milking cups between milking. Mitigation of this would be to simply wash the tephra off teats before milking. If tephra was not cleaned from the cups or cow's teats it may enter the pump and milk storage equipment of the milking shed. The tephra could damage the pumps due to its highly abrasive nature, block the milk filter or get into the milk storage vat. Any tephra in the milk to be sold will lower the quality, reducing the price paid for it. Depending on the severity of the tephra contamination in the milk it may be refused by Fonterra. If the air filters on the pulsators were blocked by tephra in the milking shed, the cups would be ineffective until the filters were cleaned. The abrasiveness of tephra may damage the pulsators stopping milking. It may also allow tephra to mix with harvested milk.

Once tephra is in the milking shed it is hard to remove. The conventional method used to clean the shed is high pressure water sprayed to remove animal waste and dirt. This would be less effective against the tephra, simply turning it into a sticky paste and water may need to be preserved if electrical power supplies were down. It would be better practice to lightly wet the tephra and then shovel the tephra out. This would increase the milking time and increase the physical and time demands on the farmer, both important considerations during the stressful period of managing a tephra fall. Wet, sticky tephra would also probably block milking shed drains, as discussed later in 3.2.6.

The milk pump and pump computer are all well cased and housed under the cover of the roof in the centre of the shed and should not be affected. The compressor, filter and milk storage vat are all housed in a walled wing of the milking shed and the milking system, with associated computer and electrical system, is well contained in the middle of the milking shed. The latter is well sealed, so it is unlikely tephra would affect them. However if tephra were to get into these critical electrical systems it could lead to short circuiting and fires. Gordon *et al.*, (2005) demonstrated computers are vulnerable to damage when the tephra is wet.

3.2.3 *Roof Collapse*

Roof collapse in a thick tephra fall event is of concern to all the farm buildings. Roof collapse usually needs between 100-300 mm of tephra (depending on moisture content) to fail

(Johnston, 1997), a thickness exceeded by most of the Holocene eruptive deposits mapped on the farm. The parameters that determine whether collapse will occur are: thickness of tephra, density of tephra (including whether it is wet or dry), building's orientation, wind direction/speed and building's construction. This includes the pitch of the roof, cladding materials, structural support of roof and walls, and the span of the roof. Long span buildings (>5m) will suffer more damage than short span domestic scale construction (Spence *et al.*, 2005); which will have implications for the milking shed and other farm sheds. Collapse may not be constrained to the roof buckling or rupturing; it may be the supporting walls that fail too.

Wind will also influence accumulation of tephra on the roof, causing drifts to form and uneven loading, causing loads up to two times greater than that of the ground load (Blong, 1981). Pre-existing drifts that are subsequently wet by rainfall may cause collapse in buildings that have otherwise survived dry tephra loading. It is thus desirable to regularly clear tephra from all roofs across the farm of tephra, especially if there is risk of rain. This would be impractical on the farm as 7 roofs would need to be cleaned, so only key buildings could be done. These in order of priority would be the homestead, milking shed, water-pump sheds, and haysheds and implement shed (Figure 3). Injuries are commonly reported when cleaning tephra off roofs, such as falls from ladders and roofs (Spence *et al.*, 2005), so extreme care would need to be taken by whoever cleans the roof. This risk of injury is increased when cleaning is undertaken during a tephra fall given the reduced visibility.

The milking shed will be particularly susceptible to collapse in a moderate to heavy tephra fall due to the shallow nature of its roof pitch at $\sim 10^\circ$. However the galvanised iron used in the construction of the roof at 'Tulachard' has a low friction coefficient and should be relatively effective at shedding dry tephra (Blong, 1981). The pump, filter and vat wing of the shed may result in some drifting of tephra, causing addition loading and difficulty in cleaning.

To check how roofs might be affected from typical tephra deposits five samples of Kaharoa ash were taken from various sections around the farm. The average bulk density for Kaharoa ash on 'Tulachard' was approximately 1500 kg m^{-3} and an approximate wet density of 2000 kg m^{-3} , expected maximum values for roof loading (in kPa) from future tephra falls are given in Table 2.

3.2.4 *Spouting and Guttering Collapse*

Spouting and guttering are a common point of failure during even light tephra falls. Tephra is washed into roof guttering, blocking it and causing collapse. Several houses experienced guttering failure during the 1995-96 Ruapehu eruptions (Johnston *et al.*, 2000). Removal of guttering on the homestead would be advisable once tephra began falling. This not only minimises damage to guttering itself, but allows tephra to more easily slide off pitched roofs as it stops build up on the edge of the roof (Spence *et al.*, 2005).

3.2.5 *Condenser*

Maintaining high milk quality is paramount for modern milk producers, with Fonterra requiring high quality standards to be met for milk to be accepted. It is therefore essential that dairy farms are able to continue to chill milk on-farm. The practice of cooling milk 'on-farm' has been standard practice for most New Zealand dairy farms for the last 30 years (www.fonterra.com) and allows the time between on-farm milking, transport to the dairy processing plant and eventual consumption to be significantly greater than in the past. Temperature is the greatest single factor affecting bacteria growth, reproduction and food deterioration (www.delaval.com). By lowering the temperature of stored milk, chemical processes and microbiological growth slows, maintaining the quality and extends the time it can be stored until milk tanker pickup.

Keeping milk refrigerated is the operation of the milking shed's refrigeration system. A key aspect of this is the condenser, which acts as a heat exchanger taking heat away from the milk and into the atmosphere outside the milking shed by sucking air through radiators, allowing the air to take away heat (note a detailed description of the cooling systems has not been attempted here; rather it has been limited to the function of the condenser). Condenser units on dairy farms are mounted outside to get the best temperature contrast in the air sucked through it and so are particularly vulnerable to sucking in falling tephra. As one of the most vulnerable pieces of equipment at the farm milking shed the condenser was tested to find out effects of tephra (results given in Section 4).

Current recommended mitigation techniques are derived from guidelines for air conditioning condensers the same techniques can be assumed to apply. Damage can be prevented by turning off air-conditioning systems before a tephra fall begins or immediately at first signs of

tephra fall. However this is not economically acceptable for dairy farming situations (FEMA, 1984).

A typical dairy farm condenser has exactly the same function as an air-conditioning condenser, a piece of equipment often identified as vulnerable to tephra fall. (Gordon *et al.*, 2005). The abrasive and mildly corrosive nature of tephra can damage air conditioning units and has occurred in a number of instances with modern eruptions (e.g. Mt. St. Helens, 1981; Mt. Pinatubo, 1991). Units are vulnerable to fine tephra clogging and abrading the condenser's radiator, and (if left long enough) dissolving unprotected surfaces within the unit. Each impact causes a reduction in the efficiency of heat exchange and could cause potential failure.

The farm's condenser is located on the western side of the milking shed facing south, away from the direct danger of the OCC, but susceptible to eruptions from the south (e.g. Taupo and Tongariro). As part of the general milk cooling system, the condenser is supplied and serviced on a 12 monthly basis. It is approximately 10 years old and has a large amount of redundant capacity. The previous condenser is still installed and while no longer used would act as a back up.

The condenser is necessary for refrigeration of the milk to keep it hygienic in order to be saleable for more than a day. If the condenser fails, milking would continue but the milk would need to be discarded. This would keep the cows lactating, avoiding health issues and allowing the potential for full scale milking operations to continue once the condenser was repaired. The time milking takes place can be adapted so milk does not have to sit warm in the tank for more than several hours before the milk tanker arrived for milk pick up (assuming the milk tanker can still operate).

Tephra fall hazards for air conditioning units are usually avoided by completely shutting the systems down, however this mitigation measure is impractical on an ordinary dairy farm (without causing major disruption) as the farm must continue to sell milk to remain economically viable.

3.2.6 *Effluent Sump*

The effluent sump is located beside the milking shed to allow animal effluent washed from the milking shed to settle out of the washing water. The remaining water is then sprayed onto paddocks. In normal operation the sump occasionally blocks with silt. Tephra suspended in water from washing down the milk shed and concrete holding pad would almost certainly have a similar effect, blocking drains, and damaging the sump pump. The grills covering the drains at the milking shed would stop big clasts and some consolidated wet tephra from entering the pipes, but may block as a result causing flooding, so would need to be regularly cleaned during wash down. If the pipes were to block with tephra, removing tephra from them would be a difficult, time consuming and costly effort. Tephra fall on the surface of the sump pond would increase the concentration of suspended tephra, increasing the possibility of blocking the outlet of the sump. Any suspended tephra within the sump pond would probably cause the pump to fail. Tephra entering the sump is likely to increase the acidity and turbidity of the water, but would probably not restrict the usual practice of spraying the water on to paddocks, assuming there were no blockages in the pipes, and pump was still operational; conditions considered unlikely by Neild *et al.* (1998). This would be similar to problems that waste water systems and sewage treatment plants face during tephra falls, but on a smaller scale.

Failure of the effluent sump drains would result in cleaning water and animal effluent generated at the milking shed following the surface drainage routes into the gully to the west. Localised flooding may occur around the milking shed, including the holding pen, track, lower elevation paddocks and possibly the feed pad, creating a major inconvenience with wet tephra forming a sticky mud-paste. If this were to occur in winter with the water-table near the surface effects would be intensified making conditions difficult for human and animal movement.

To avoid blockages the best practice would be to remove as much of the suspended tephra and effluent sludge with the tractor's frontal attachments (bucket and blade) and/or shovels, and then wash away the remaining deposits which are hopefully small enough in size and volume not to cause blockages.

3.3 ELECTRICAL SUPPLY

Power is critical to the normal operation of the dairy farm. It supplies the milking shed, the homestead, water pumps and fences. The loss of power to the milking shed would mean that

the electrically powered milking pumps, water pumps, pump computer and cooling system would not operate, resulting in the complete inability to milk. Once electrical power was lost any stored milk from a previous milking would no longer be chilled, potentially needing to be dumped depending on when the milk tanker next arrived. There would also be a loss of artesian water pumps, and hence the ability to refill the water storage tanks located around the farm. If the fences are not electrified the cows are likely to push through if hungry, as is likely to be the case with pastures coated in tephra.

3.3.1 *Electrical Power Supply to the Farm*

‘Tulachard’s’ electrical power is supplied on domestic supply lines, with smaller insulators more likely to experience insulator flashover. Two sets of lines supply the farm supplying separate areas of the farm with no connection between the two. The homestead and eastern pump is powered by Brett Road lines. The western pump, milking shed and worker’s house are supplied by Bainbridge Road lines. The double connection creates some resilience if in an eruption if one line was to go down.

The power lines are very old, to both the homestead and to the milking shed. It has been recommended by the power supply company to replace them, but the cost is prohibitive. Because of their degraded condition there is an increased risk they may come down due to the extra weight of tephra on the lines and poles. This would be even more applicable to the mud erupted in phreatomagmatic eruptions, with its stickier, moister nature making it more likely to adhere to transmission lines.

In the event of power loss it is possible the milking machine could be run on 12 Volt batteries. The batteries could be sourced from and recharged in a vehicle (such as the tractor or ute), as long as the engine can still operate. This would at least keep the cows lactating, and thus be an asset to the farm when power is restored, even if the milk has to be dumped with no way to filter, cool or store it without mains power. It would also be beneficial to the health of the cow, avoiding mycosis. The loss of power to the homestead would be of concern with dependence on electric heating and cooking. However contingency measures have been undertaken in previous power outages with no significant disruption and the house is “well insulated” (M Pacey *pers comm.*, 2004).

3.3.2 *Effect of Tephra on Electrical Distribution Systems*

The most common problems caused by tephra are supply outages from insulator flashover, line breakage (weight of tephra and tephra laden flora falling onto the lines) and controlled outages during tephra cleaning (Heiken *et al.*, 1995; Johnston, 1997). Heavy rainfall eliminates the tephra build-up problems by washing the tephra away, but creates other problems; the risk of flashover is greatest if light rain occurs during a tephra fall (Heiken *et al.*, 1995).

Substation insulators are more vulnerable to flashovers than line insulators, because of their shape and orientation, so it is likely the regional electrical distribution network will fail at critical nodes creating widespread outages during moderate to severe tephra falls. This will cause large disruption to the dairy industry's ability to operate, even if farms aren't affected by tephra. Electrical distribution companies must communicate when power will be restored, or when controlled outages will be for cleaning, will be critical for dairy farmers to plan when they can begin milking again or whether it is better to dry off the cows (i.e. stop milking and the cows stop lactating).

Electrical storms are commonly associated with tephra falls due to the static build up from the tephra rubbing together. This creates lightning strike hazards for electrical supply networks. This was observed in the Tarawera area during the 1886 eruption, with telegraph poles and lines struck, cutting communications (Smith, 1886). Such strikes also occurred during the 1980 Mt. St. Helens eruption and during the May 1924 Kilauea eruption, when 21 consecutive poles were hit (Blong, 1984).

3.4 WATER SUPPLY

Water is critical to any dairy farm. It is required for consumption by stock (drinking water) and is used in large amounts for washing down the milking shed and associated structures to keep them in a hygienic and acceptable working environment. Where there is a significant tephra fall, uncontaminated surface water would be in short supply, with natural surface water supplies and dams contaminated, and pump functions severely reduced by the abrasive nature of the tephra (Neild *et al.*, 1998). The farm however has two artesian pumps servicing the farm's water supply needs, including the homestead. They consist of a submersible pump in a bore supplying four 22,500 litre tanks and simply keep the tanks full. Currently the eastern pump supplies all troughs on the farm and the homestead, whilst the western pump supplies water to the milking shed, but the two can be merged into one system if need be. The key

vulnerability of this system is the reliance on electrical power to access fresh water. If electrical power was cut to the farm, there is the potential to set up gravity fed troughs from the tanks, which stock could access water from. This could give several days worth of water to the herds, depending on climatic conditions. The amount of water that would be consumed by the cow herds is largely controlled by weather conditions. Dry and hot conditions would mean the cows are each drinking 40-50 litres of water daily equating to 17,500 litres for the herd. Cold and wet conditions would mean a minimal amount of water is consumed with the cows deriving hydration through pasture consumption. The lack of water for washing down the milking shed has been noted above as a key issue for the successful operation of the milking shed.

Tephra fall would contaminate the uncovered 350 litre stock-water troughs in each paddock, causing problems as cows drank suspended tephra and any aerosols dissolved within the trough water, potentially leading to poisoning. The remedy for this would be to clean the tephra out of the trough and replace the water regularly (adjusting the buoy-cock so the troughs are refilled to a lower level would mean less water needs to be replaced, but may alternatively concentrate harmful aerosols if left too long); again this would be time consuming, especially in remote paddocks. A management option would be to cover and disconnect troughs from the farm water supply in paddocks not containing stock. This would be an important but difficult task as it involves getting out to the paddocks and then working with wet tephra. Lake Rerewhakaaitu could be used as an emergency water option; however it would be filled with suspended tephra from direct fall and drainage systems.

3.5 TEPHRA ON CONCRETE SURFACES

Fine grained, moist tephra will be a problem if it coats key areas such as the feed pad and milking shed holding pen (Figure 3). Every effort should be made to remove dry tephra from critical areas before there is any chance that it is moistened.

The 'de-crap-it' and bucket attachments for the tractor would be extremely effective at removing tephra from the flat concrete pads. It would also be able to clear farm tracks of tephra and create new temporary tracks through paddocks if need be. Creating temporary tracks through paddocks is common practice during winter when mud becomes an impediment to moving stock. If the tephra is dry it can be given a light covering of water to dampen it before mechanical movement with the tractor, making it slightly more cohesive

(Blong, 1984) which would settle the dust (creating less of a hazard for the tractor) and make the tephra easier to pick up or grade. If the tephra was wet this would make it more difficult to move but these implements should still remove enough of the tephra to achieve a relatively clean concrete surface.

3.5.1 Dairy Shed

Hygienic and clean conditions in the milking shed are required by milking processing companies to ensure milk is of a high standard (www.fonterra.com). It is therefore a requirement to always keep the shed clean. Any tephra would therefore need to be removed before milking. In a crisis situation where cows are being milked simply to keep them lactating and in a healthy state, with milk not necessarily stored for collection, it would still be preferable to have the shed clean. Cows react better to a clean environment and the milking shed operators find it less stressful to do their job in a clean milking shed.

3.5.2 Feed Pad

The feed pad (Figure 3) was built in 2001 with the intention of creating a mud-free feeding surface for the winter. The close proximity to the milking shed allows all key operations can be constrained to a small area of the farm, reducing the time the tractor would have to travel in the tephra fall conditions, and travel time for humans and animals to the milking shed. With pasture covered by tephra, stock survival in the short term would be dependent on the ability to feed up to 100% of their diet in supplementary feed; until they could be evacuated out of the area, slaughtered, or pasture re-established. Following tephra falls from Ruapehu in 1995, farmers on the Rangitikei Plains noted grazing animals were readily put off their feed by light (<3 mm) tephra deposits. Hence, even with very light deposits of tephra, supplementary feed would be required (Neild *et al.*, 1998). The ability to provide supplementary feed to stock is thus critical to keep cows alive and lactating if milking continued. Animal excrement is able to be pushed off the pad by frontal attachments to the tractor. During tephra fall the pad's flat surface could be graded clear of tephra by the tractor (assuming it could operate) with 'de-crap-it' blade or bucket frontal attachment and the feed troughs cleared by shovel, so supplementary feed could be distributed on a relatively clean surface, reducing the impact on animals (tephra/aerosol ingestion with their feed, abrasion to their feet/hooves). This feature makes the feed pad an excellent medium upon which to distribute supplementary feed out onto and likely to be significant part of the farm's response to a tephra fall.

It is important to note that the physical removal of the ash from buildings, yards, tracks etc will be difficult due to the large quantity of tephra. The gullies have been identified as an option to dump the tephra in. However this may cause drainage problems with damming of water ways a potential resulting hazard. An alternative option is to dump tephra in a paddock, creating a stock pile. Any dumping sites would need to be stabilised (top soil added and seeded with grass) to prevent reworking (Tilling *et al.*, 1990).

3.6 MOBILITY

3.6.1 Vehicles

Fine tephra clogs air filters, blocks radiators, causes mechanical wear or abrasion on moving parts, and may cause breaks to fail (Blong, 1984; Johnston *et al.*, 2000). These problems can lead to engines overheating, a reduction in engine life, and potentially cause engine failure. These impacts would be disastrous as the tractor is a key asset for any response to tephra fall. Its use in terms of saved time and ease for feeding out supplementary feed and in clearing tephra from critical areas using bucket and grading attachments (noted above). In thick tephra deposits it would probably be the only vehicle on the farm that could operate due to its four wheel drive capability. Supplementary feed (grass and maize silage) is also fed out by the tractor and towed silage wagon.

The tractor is serviced regularly to the manufacturer's recommendations by a trained mechanic, and can be expected to be in good condition at any time of the year. However an increased maintenance schedule should be carried out on the tractor, and all other machinery expected to operate in the tephra fall and tephra deposits. During tephra fall the tractor should not be used unless it was critical. If operation did take place, its radiator and air filters should be cleaned with compressed air every 30-60 minutes depending on the severity of the tephra fall, however the radiator and air filter should be monitored regularly during use (<http://www.ak-prepared.com/plans/mitigation/volcano.htm>). Even when tephra fall has stopped care for the engine should be paramount when operating on unconsolidated tephra deposits, as these can be stirred up by vehicles wheels and mechanical removal (Tilling *et al.*, 1990). It is critical the tractor is well maintained during such a crisis period as access to spare parts and mechanics would be minimal due to high demand and probable lifelines damage. Tractor failure would immediately require decisions whether to reduce milking numbers, continue milking at all, and/or destroy stock.

3.6.2 *Tanker Access to the Farm*

Transportation networks are inherently vulnerable to tephra fall. Wet and dry tephra deposits make traction difficult and haphazard. Visibility is reduced by fall tephra and passing vehicles raise the tephra making visibility an on going issue after tephra stops falling. Such hazards are likely to affect the ability of milk tankers to access the farm. The farm's rural location will mean road cleaners are unlikely to open roads for many days (concentrating instead on urban areas), especially during prolonged or multiple tephra fall (P. Journeaux, *pers comm.*, 2005). Farmers may need to take on this responsibility themselves, accepting the risk of damaging machinery against the economic benefit of still selling milk. It is important to note the removal of tephra from roads is a deceptively time consuming and costly exercise (e.g. Mt. St. Helens, 1980), which may negate farmer's efforts to maintain tanker access (Blong, 1984).

3.6.3 *Stock Movement*

The passage of cows along dry tracks would stir up clouds of fine tephra, even after the tephra had stopped falling. This would make herd movement around the farm, such as to and from milking, difficult and stressful for the animal in terms of respiring, hoof abrasion, and eye irritation.

The leaders amongst the cow herd would be important in managing the rest if they were to be walked off the farm, so their health should be closely monitored.

3.7 STOCK

A moderate to severe tephra fall (>50 mm) will place considerable pressure on the farm requiring limited or total de-stocking depending on the severity of the impact (evacuation or destruction of stock). If rehabilitation strategies were successful, subsequent restocking may not be physically possible where the eruption devastated a large part of the country (Neild *et al.*, 1998).

3.7.1 *Evacuation of Stock*

Calves would be the first stock evacuated; their small size mean large numbers are easily transported. This would take pressure off farm resources, allowing concentration on keeping the milking herd alive and hopefully milking. Typically 70-120 calves are carried annually.

The shelter provided by the sheds used for calf rearing may be better utilised by the milking herd; along with the calf's water and meal demands.

If the situation arose where the two main milking herds could be evacuated in the face of a looming eruption, the PACEYS estimate it would take 20 minutes for the first herd to be brought into the cattle yards. Another person would then bring in the other whilst the first is being loaded on the trucks. The truck and trailer stock transport units do not have to un-hook in the yards, allowing them to back straight onto the loading ramp.

It is perhaps more likely that only a percentage of the dairy herd was evacuated due to the huge logistical demands a stock evacuation would create in an area. In addition to this, there needs to be somewhere for the stock to be taken to. If a situation like this arose then the best genetic stock would be selected for evacuation. A mass evacuation of entire districts would involve the movement of potentially tens of thousands of dairy cows, logistically impossible unless several months warning was given of a pending eruption. Even if such warning time was given (such certainty is unlikely with current warning techniques) it is unlikely farmers would believe it and only act when it was too late.

3.7.2 *Destruction of Stock*

The destruction (slaughtering) of cows with lesser value may allow continued operation of the farm. This is not an option to be taken immediately; rather it should be a 'last resort' as the loss of valuable stock means immediate financial loss, loss of potential earnings and loss of genetic value that would take many years to rebuild (Neild *et al.*, 1998). However, the benefits would quickly reduce any pressure on reserve water supplies and supplementary feed stocks. The cows likely to be destroyed first are:

- 'non-cyclers' (not pregnant and thus not lactating)
- bulls (but not during mating period)
- empties (not lactating)
- low milk producers
- old cows
- cows with bad temperament (many cows may react badly to the tephra fall)

3.7.3 *Behaviour of cows under stress*

Stressed cows will react badly during movement and milking, hampering efforts. Rough handling from stressed humans will accentuate this. The hunger of the cows would be a key factor in many of the key decisions as to how to adapt the farm to the tephra fall event. This would be especially important in terms of the cow's energy levels and whether milking should continue. The stress level of the cows should be closely monitored by the farmer to determine whether milking would continue and at what level (i.e. twice a day milking). Once-a-day milking would be introduced at the first sign of stress to the cows and or feed concerns.

3.8 SUPPLEMENTARY FEED

Supplementary feed would be critical to continue feeding cows when grass is covered by tephra. The quantity of supplementary feed usually stored and consumed at 'Tulachard' consists of:

- Round wrapped bales - 160 at runoff; 110 on the farm
- Chopped Silage - 30-40t at runoff
- Dry matter maize - 100t on the farm

The majority of supplementary feed is stored at the runoff, a 24 Ha leased block used for growing most of the supplementary feed and winter pasture for grazing. It would be an excellent 'reserve option' that would take the stress off the farm's pastures. Whilst both dairy herds are familiar with the road walk to the 'runoff', they may react differently under the stressful conditions of tephra fall.

Once supplementary feed ran out, trips would need to be made back and forth from the runoff with the tractor and silage wagon to bring back feed. If sufficient warning was given about a pending eruption, supplementary feed could be transported to the farm in preparation and the milking herd remaining on the farm with the majority of the supplementary feed stocks, and all other non-milking cows moved to the run-off to 'fend for themselves'.

There is no extra or reserve feed in case of an emergency of any kind, it is all intended to be used during the following year. The ability to 'buy in' more supplementary feed is very dependant on the season, but at most times of the year hay or wrapped silage can be purchased, but this may only be practical during a small eruption as demand and transport availability would be at a premium during a moderate to large event. Palm kernel may also be an option. Government aid for such an event could include the mass transport of hay and

straw from non-affected areas, such as the South Island (e.g. Marlborough, Canterbury), to affected areas (P. Journeaux, *pers comm.*, 2005).

3.9 PEOPLE, THE GREATEST ASSEST

One of the most important variables as to whether the farm will recover from a tephra fall event is how well the farmer(s) manages the farm. Key decisions will have to be made at the beginning of a tephra fall to cope successfully, the hardest ultimately being what to do when advised to evacuate if an eruption began to endanger the farmer's lives.

Dairy farming involves working outside and in exposed conditions which will bring dairy farmers and their workers into prolonged contact with tephra which may result in health problems. The ability of people to operate in the tephra will again depend on tephra fall rate, deposit's thickness and moisture content. Health problems likely to arise during a tephra fall event will be similar to the animals, with breathing difficulty and irritation of the eyes. Minor skin irritations (tephra rash) may affect people exposed to the tephra for an extended period of time, (<http://volcanoes.usgs.gov>). The possibility of contracting chronic bronchitis, known as silicosis (derived from tephra with high contents of free-silica), may occur from prolonged breathing in a tephra laden atmosphere. Medical reports following the Mt. St. Helens eruption showed that only those with long exposures to high concentrations of tephra were at any risk of developing chronic medical complaints (<http://volcanoes.usgs.gov>). Dairy farmers are in exactly this situation.

Precautions that should be taken include wearing a dust mask, full cover overalls, hat (balaclava would be preferable), gloves and sturdy gumboots to avoid contact with the tephra on the skin. Some of these items are clothing commonly worn by most dairy farmers and represent little change to normal operation; however the dust mask may cause some impairment and discomfort. An enclosed-cab tractor would be of great value, but tractor use should be restricted, as mentioned above.

4. Condenser Testing

Laboratory testing was undertaken to establish how badly tephra would affect a condenser and to investigate mitigation measures that might be applied to allow the condenser to operate during a tephra fall.

4.1 TEST CONDENSER

Although the condenser utilised for testing is 11 years old it has similar mechanical and electrical characteristics to most modern machines used on dairy farms. Its physical dimensions are 0.72 x 0.86 x 0.35 m (Figure 4), similar to that of the farm's. The fan within the condenser still operated well, although the heat exchange system was no longer operational due to risk of exposure to Freon (coolant). This was not considered a significant problem as the physical effects on a condenser from tephra fall will be primarily controlled by how much tephra is sucked in by the condenser's fan.

4.2 TEST SET-UP

A sealed Perspex testing box was designed to house the test condenser so that tephra could be added in a controlled environment. The testing box had a measured volume of 0.96 m³ (1.2 x 1.0 x 0.8 m). This allowed the condenser to fit inside with plenty of space for circulation of tephra. Small 'tephra catchers' were placed at locations in and around the condenser to monitor the occurrence of the tephra and establish what tephra grain size was mostly likely to affect the condenser.

The condenser was set up inside the Perspex box with two computer cooling fans connected to a 12 volt battery to provide mixing of the tephra and attempt to keep the tephra airborne for longer. The fans were elevated on wooden stilts to allow air and tephra to circulate under them and be re-injected into the air. The fans were run for the entire length of the test run. They prevented large tephra build up in the corners of the box and kept a 'plume' of tephra in the box aloft for well over 60 seconds following tephra introduction.

Two tests were carried out on the condenser; a dry test and a wet test. A control test proceeded tephra testing during which an insignificant temperature increase of 1.7°C was recorded within the test box, ensuring the condenser's fan motor was in a proper working condition. Temperature and wind flow was monitored during all tests with a Kestrel 3000 Environmental Meter. This is a combined electronic anemometer, thermometer and hygrometer in one hand-held instrument. It allowed airflow velocity readings (maximum and average flow) and the ambient temperature within the test box to be recorded every 30 minutes (www.nkhome.com). The temperature outside the box was measured with the same instrument at the same time interval.

The tests were designed to best simulate volcanic tephra with lateral and vertical velocities coming into the volumetric space from which the condenser sucks cooling air. Tephra was added to replicate continued deposition of airfall tephra from an eruption plume, continual movement of fine tephra particles stirred up from machinery or stock movement, and wind entraining tephra and blowing it towards the condenser. Tephra was introduced at the rate of 1000 g of dry tephra per 30 minutes through a hole in the top of the test box. This rate is greater than concentrations measured from historic eruptions (e.g. Mt. St. Helens 1980; av. 174 488 $\mu\text{g}/\text{m}^3$, and max 219 536 $\mu\text{g}/\text{m}^3$; Heiken *et al.*, 1995), but the initial testing showed high tephra addition rates had the same, but accelerated, effects on the condenser as lower addition rates. The rate used was chosen to simulate high tephra addition rates over a test period of 7 hours. The large interval between tephra introductions being used so temperature changes over time could be monitored.

4.3 TEPHRA USED IN TESTING

Three types of tephra were collected: Kaharoa ash, Taupo ash, and Tarawera ash; deposits from the three most recent tephra falls observable in the stratigraphic record. A simple limited tephra test preceded the main tests where the three tephra were individually introduced into the test box in 500g fractions and subsequently observed. It became apparent tephra chemistry was not a significant factor, given that no aerosols were likely to remain on the tephra. So a blend of tephra types was used in dry and wet tests. The tephra blend was mixed randomly and baked at 105°C in an oven for 48 hours to remove moisture. The dry tephra was then divided into 500 gram bags and blended to provide a testing medium diverse in grainsize and composition. Grainsize distribution is shown in Figure 5.

4.4 AIRFLOW MEASUREMENTS

Airflow velocity readings (maximum and average flow) and ambient temperature were taken for one minute using the Kestrel 3000 Environmental Meter. It provided fast, accurate measurements of the environmental conditions inside the box. Readings were taken from approximately 200 mm and 700 mm off the base of the box and approximately 150 mm away from the outdoor facing side of the condenser. The airflow was tested throughout the initial 'temperature test' and found to remain stable during the entire time at all test locations. Measurements also matched initial control measurements at the beginning of the dry and wet

tests. Readings were taken directly before the addition of new tephra to ensure the situation within the box was relatively stable.

4.5 TESTING PROCEDURE

Temperature inside and outside the box were monitored in order to monitor the motor's temperature too. The airflow was also measured from several points on either side of the condenser. The dry tephra was introduced in 500g increments by slowly trickling it in front of the continually running condenser, which then sucked in a portion of the tephra whilst the rest fell to the base of the box. The airflow through the condenser was monitored (effectiveness).

At the end of the test the condenser was removed and visually examined to determine any damage. The condenser was then air cleaned with an air-compressor and examined for signs of wear. Tephra was collected in "tephra-catchers" positioned throughout the test box and condenser, and analysed by 'laser range sizer' to determine what size tephra particles were being deposited where.

For the wet test the condenser was put back into the test box, but this time moisture was introduced with the tephra to simulate a humid environment. This was done by drilling a hole in the side of the box and spraying a mist of water into the test box at the rate of 250 ml per 30 minutes.

4.6 RESULTS

4.6.1 *Dry Tephra Test – 16 May 2005*

This test was carried out to see how a condenser performs under dry tephra fall conditions. Once the dry tephra was introduced, it took approximately 6 minutes for most of the tephra to come out of suspension. This occurred mainly by tephra hitting the test box's walls and depositing at the base of the wall. A coarser, heavier component immediately fell to the base of the box on introduction. After the first tephra introduction there was a thin coating blanketing the entire condenser. The air mobilised fines were either deposited inside the condenser's vanes, onto the condenser's base inside the fan cavity or was blown through the condenser. Tephra blown through the condenser generally rebounded off the wall of the box and re-circulated around to the front where it was kept suspended by the supplementary computer fans, with a portion depositing onto the base of the box.

Twenty minutes after the test began, coarse tephra and lapilli were observed to be trapped between the protective grill and the radiator. After approximately 1 hour, tephra deposition occurred on damaged vanes. Two hours into the test side facing vanes began to show some tephra deposition, tephra also built up where cooling pipes joined the vanes inside the radiator and fine lapilli caught between radiator vanes. 3.5 hours into the test tephra deposition on radiator vanes was very noticeable across the entire radiator, with an estimated 10-15% blocked. After 5 hrs 45 min the motor noise increased. This noise eventually faded out over 10 minutes, suggesting tephra had got into the bearings of the motor and then slowly cleared. 6 hours into the test vanes were significantly clogged at the top and at the base of the curved radiator. Tephra preferentially deposited in vanes behind the protective grill situated in front of the radiator, suggesting turbulent flow as a result of the grill caused increase tephra deposition.

One to three millimetres of ~ 0.5mm sized tephra was deposited on top of the motor; in addition to which a thin veneer of ultra-fine tephra fully coated the entire surface of the motor. However it still appeared to be in working order. The fan spun freely, with no sign of wear or abrasion. There was no indication that tephra had got into bearings with no rubbing or grinding occurring as the fan is manually spun. Slight wear occurred to the tips of the condenser fan blades, but there was no abrasion on the blade's surfaces.

The electronics and power section of the condenser was covered with a thin dusting of tephra (<1 mm); even the tephra catcher placed there only had a thin coating, suggesting only fine ash entered this area through gaps in the internal seals of the condenser. Over all this would not be enough to cause any issues with the electronics. Tephra clung readily to several small spider webs in the electronics section, thus farmers should ensure their condenser is clean before tephra begins to fall or the condenser is used.

Tephra built up mainly on the inside and outside faces of the radiators. Tephra coated the front of the condenser with a varying thickness, but never appeared to be thicker than 1.5 mm, suggesting it fell off after this point. The pile of tephra that developed at the base intake side of the condenser completely blocked airflow and infiltrated into the radiator vanes. Dry tephra adhered to radiator vanes that were non-parallel to the suspended tephra's direction of flow. Preferential tephra deposition occurred on damaged vanes, side facing vanes, and

where turbulent flow (as a result of the protective grill in front of the radiator) caused tephra to meet vanes at an oblique angle. However tephra deposition occurred on all vanes to some extent, especially in the centre of the radiator directly in front of the fan. Some fine tephra built up on the inner radiator, but was only a fraction (~5 %) of what was deposited on the outer radiator, suggesting it provided a shielding/filtering effect. There was no apparent abrasion of the radiator vanes.

Tephra was comparable to the fine dust encountered in summer harvest equipment, and was easily removed out of the radiator vanes; an air compressor easily blew out the radiator and other difficult to access areas.

4.6.2 Wet Tephra Test – 21 June 2005

This test was carried out to see how a condenser performed under wet tephra fall conditions. There was very limited circulation of tephra initially, but within 30 seconds of tephra introduction, the test box's atmosphere was clear of suspended circulating tephra. This period of tephra circulation within the box following each tephra introduction decreased as the test progressed. This was in contrast to the dry test where tephra circulated for up to 15 minutes and this was due to fine, air-mobile tephra immediately depositing on the wet vanes of the condenser's radiator rather than predominantly passing through the condenser. Preferential build up occurred on the area of the radiator directly in front of the circulation fan. Once again the inside walls of the test box became covered with a fine build up of tephra preventing useful photographs to be taken during the test (Figure 6).

Tephra immediately deposited onto the wet vanes and then began to 'accrete', depositing on top of previously deposited tephra in blister like clumps. Again damaged vanes were the location of initial tephra deposition, but this occurred in the first 20 minutes of the test and such sites became rapidly indistinguishable as tephra deposition occurred over the entire face. Tephra deposited on any moist surface. After 70 minutes the front face of the condenser was becoming significantly clogged up and after 100 minutes an estimated 70% of the front face of the condenser was covered in tephra (in contrast to the estimated 10-15% blocked 3.5 hours into the dry test).

After 2 hours suspended tephra began to preferentially move towards the left side of the condenser with the curved radiator vanes, suggesting airflow was now predominantly flowing

through this section of the condenser. These were much less affected by tephra deposition than vanes parallel to the airflow at the front. The tephra coating on the centre front face of the condenser had become significantly thick and reached out from the radiator to the metal screen (~15 mm). 30 minutes later the sides began to become more clogged as airflow was blocked in the centre and had to flow through the extremities. The fan motor also began to make a rubbing, grinding noise for ~30 seconds, similar to that made in the dry test after 5 hrs 45 min. The suction noise from the front of the test box had distinctly changed from a light hum to more of a whistle, suggesting a changed airflow regime. After 4 hours the front screen had lost definition in the centre of the condenser's front face, and after 5 hours the entire front face was significantly blocked. The least affected areas were worse than the most heavily clogged areas in the dry test. Even the curved section of the radiator at the left side was blocked in many places. The blister like clumps on the front face continued to grow, probably through electro-static attraction as airflow at the front had stopped, and some would fall off. This continued through to the end of the test, with a larger proportion of the introduced tephra simply falling to the base of the test box due to the reduced wind-flow regime and thus energy to pull the tephra into the condenser. At the end of the test an estimated 75-80% of the front intake face was blocked with deposited tephra (Figure 7)

The motor received a ~1 mm coating of fine grained tephra on top of it and was again fully covered in a thin veneer of ultra fine tephra, but still appeared to be in perfect working order. The fan still spun freely, with no sign of wear or abrasion. There was no indication of tephra having penetrated the bearings with no rubbing or grinding occurring as the fan is manually spun. No wear occurred to the tips of the condenser's fan blades, as did in the dry test.

The electronics and power section of the condenser was covered with a thin dusting of tephra (<1 mm), which coated the front of the condenser with a varying thickness, from ~1.5 mm to over 20 mm. This is significantly different to the dry test, suggesting the wet tephra has greater cohesion. Again a pile of tephra developed at the base of the front intake side of the condenser completely blocking airflow and infiltrated into the radiator vanes. Some fine tephra built up on the inner radiator, but was similarly only a fraction (~5 %) of what was deposited on the outer radiator suggesting a shielding/filtering effect. There was no apparent abrasion of the radiator vanes. Tephra was not as easily removed out of the radiator vanes as after the dry test; but an air compressor still easily blew out the radiator and other difficult to access areas.

4.7 GRAINSIZE VARIATION WITHIN THE CONDENSER

Tephra samples were taken from various points on and around the condenser following the dry and wet tests to determine the grainsize of tephra at different locations. Samples were analysed using a Saturn DigiSizer 5200 laser particle sizer made by Micrometrics.

4.7.1 *Front facing vanes in middle of radiator*

This shows that a similar range of tephra grain sizes between 0-300 μm were deposited on the front, even when there were several magnitudes more material deposited on the front face of the condenser during the wet test.

4.7.2 *Behind condenser (gone through)*

In Figure 8 a finer but more varied range of tephra was sucked through the condenser and deposited behind it during the dry test, compared to the more concentrated distribution of 100 – 200 μm sized particles sucked through in the wet test. This is likely to be the result of a filtering effect the clogged front had on fine particles in the 0-75 μm size range, initially at least. The greater concentration of coarser material that has passed through the condenser again suggests coarse material in the dry test was pulverised, especially when coarse material would be expected to be filtered out by the veneer of tephra that accumulated on the front face of the condenser during the wet test.

4.7.3 *Side facing radiator vanes*

Both tests show a slight increase in concentrations of grain sizes at 150 μm suggesting some preferential deposition of particles 150 μm on side facing vanes (Figure 8). The spiky nature of the distributions may be attributed to damaged vanes attracting greater deposition of tephra than non-damaged vanes, especially in the dry test. Note that for both tests, deposited tephra is finer than that deposited in front facing vanes (Figure 8).

4.7.4 *Inside condenser*

Figure 8 shows the dry test distribution has the greatest range of particle sizes and a higher mean than the wet test particles. This suggests coarser tephra was able to enter the condenser in dry conditions. The wet test distribution of grainsize inside the condenser approximately follows a normal distribution, centred on ~280 μm , suggesting 300 μm was the optimal grainsize to deposit within the condenser. However, nearly all possible grain sizes used in the

test were able to penetrate the condenser and deposit within it. Whilst there is likely to be a greater degree of abrasion and mechanical wear on the condenser from coarse particles entering the condenser, there was little evidence of any wear or abrasion occurring. It is thus likely the greatest hazard for a condenser would be deposition of fine particles within the condenser with their higher surface area carrying a greater volume of corrosive aerosols.

4.8 DISCUSSION

4.8.1 *Wind flow and Temperature Results*

The most important result of the wet test was the complete blocking of air flow from the front of the condenser. The 75-80% clogging of the front intake face would have extremely significant implications on the efficiency of heat exchange from the condenser. This could potentially cause overheating leading to damage and possible fire hazards.

The increased temperature noted in both tests of the air is considered negligible. However the significantly increased surface temperature of the motor in the dry test is cause for concern. It could be inferred that if the test continued for a greater time period the risk of the motor burning out would have greatly increased. This was less of a hazard for the wet test as the moisture appeared to act as a coolant.

There is a danger of electrical arcing and fire due to moisture getting into the motor in any tephra fall. However farm condensers (indeed all outdoor air conditioning condensers) are weather sealed so if wet tephra built up on the motor in significant quantities that would present the greatest risk. This test did not suggest that this was a significant risk with only minor tephra deposition on the motor.

4.8.2 *Effects of Tephra Deposition on the Condenser*

The tephra that was deposited in the vanes of the radiator would have an effect on the efficiency of the condenser's ability to exchange heat with the outside air. The reduced airflow and the smaller exposed surface area available for the radiator to radiate heat will cause a noticeable loss in efficiency within the cooling system. It is important to note however that the condenser's fan did not fail in the testing, with air continuing to flow through (albeit in a much reduced state from extremities of the front and side intake face in the wet test), theoretically allowing some heat exchange to occur.

Abrasion of moving parts, especially rotating elements is extremely common in areas affected by tephra fall (www.ak-prepared.com). The strange noises observed during both wet and dry tests suggest this may have occurred at some point and subsequently cleared. It is possible that the electric fan motor would eventually jam due to fine tephra getting into bearings or the motor itself, although no evidence of this was observed in the test.

There was no evidence of shorting or grounding of circuits. This may have been due to the electrical insulation the Perspex testing box provided, although there was no evidence of arcing or damaged wires inside the electrical compartment of the condenser following either test.

There was some evidence of etching of painted and metal surfaces. The metal vanes of the radiator appeared cleaner and shinier after each test, suggesting an oxidized coating had been etched away. Fresh tephra coated with acidic aerosols (e.g. H_2SO_4 and HF) could corrode the 'fresh' metal surfaces causing irreversible damage to the condenser, possibly resulting in the need for replacement far earlier than may have been the case. Any future testing should use fresh tephra – with volatiles still on it.

Generation of excessive heat under a blanket of dust or because of obstructed vents was observed in both tests, although more so in the dry test. It can be assumed the water acted as a coolant in the wet test and that less tephra covered the motor due to the higher deposition of tephra on the radiator. With time it could be expected the motor may overheat causing failure and or an electrical fire that could destroy the condenser.

Tephra concentrations were tested at elevated concentrations of those measured at Mt. St. Helens. They are unlikely to occur unless roof collapse caused catastrophic entry of tephra, however initial testing suggested they had negligible influence on results and allowed a greater amount of tephra to be introduced during the testing period.

4.9 SUGGESTED MITIGATION MEASURES - CONDENSER

The most practical mitigation measure would be to regularly blow out the condenser with compressed air. Most farms have an air compressor, commonly stored at the dairy shed. Taking into account the accelerated nature of these results, a regime where cleaning occurred every 2-3 hours in dry tephra fall conditions and every hour in wet tephra fall conditions

during condenser operation would be extremely beneficial to maintaining the condenser in a working condition. Note such a regime would be very difficult to maintain in the highly stressful and busy time of a tephra fall. In general, the severity and frequency of such problems would be reduced through sound and regular maintenance programmes. These measures apply to mechanical as well as to electrical systems.

An important consideration is that the uncontrolled use of compressed air can also cause problems when blowing-out tephra affected machinery. Thirty psi or less has been found to be acceptable for blowing items clean; any more pressure and sandblasting may occur (www.ak-prepared.com). Care must also be used to avoid blowing tephra onto other surfaces or machinery that should be kept clean. Ideally it is better to use a vacuum when possible, although this would not be practical on a dairy farm.

Key Recommendations are:

1. Go to 'once a day' milking and milk just before the tanker arrives so that minimal time is spent using the condenser.
2. Ensure the condenser is not damaged, especially the radiator vanes. This may require bending vanes back into line with a thin screwdriver for example, as this will delay dry tephra build up on the radiator.
3. House the condenser under a roof, perhaps with a hessian cloth enclosing it to provide a filtering effect so minimal tephra and moisture are sucked in. This may need to be replaced during heavy tephra falls.
4. Blow out the condenser regularly with compressed air.
5. If arcing is considered a danger (i.e. in moist tephra fall conditions), use stabilants for the improvement of electrical connector contacts.

5. Discussion

The farm is most vulnerable to electrical power loss. The best way to mitigate tephra fall hazards to electrical power supply is to bury power-lines, and install insulators and power lines resistant to tephra accumulation. This is however costly and difficult to justify to New Zealand's current energy sector. A controlled power outage to allow cleaning of the insulators is commonly used, but this is also costly, both in terms of cleaning and the loss of power to consumers (e.g. as used by Transpower during the 1995-96 Ruapehu eruptions;

www.transpower.co.nz). It is also unlikely power supply maintenance personnel would be available to rural customers immediately, with urban centres and higher voltage lines getting priority. The installation of a diesel powered electrical generator would be extremely useful and allow a degree of self-sufficiency. It would cost \$10,000 - \$12,000 for a generator and appropriate additional transformers that would supply a regular current to the milking shed that wouldn't harm the sensitive pump computer (discussed further below).

A generator would be invaluable if district and or regional electrical networks were to go down. Even if just one central farm had a generator, that farm's milking shed could milk the local area's cows, with the dairy herds all dropping to once-a-day milking. This would continue production for all the farms and provide certain economies of scale. A bottle neck would be the storage capacity of the milking shed's vat, normally required to store only one farm's own milk production it is unlikely to cope with the volume of milk from cows of 3 to 4 farms (even with a change to once a day milking). The milk tanker would have to make several pick ups of the milk daily from this node, given many farms would not be milking. Fonterra would want access to as much milk as possible so is likely to be flexible. Supplies of cleaning water may also be an issue, possibly leading to only cleaning cups with water and excrement shovelled out by hand. Keeping diesel supplied to the generator may be an issue if this arrangement had to continue for an extended period, although neighbour's diesel tanks would be a ready source of fuel. Road clearing requirement for milk-tanker access would be dramatically reduced under such a scheme. Such an arrangement could allow milking to continue for several days to even several weeks until power was restored. This could potentially be undertaken using a farm, such as the neighbouring 'Hills' modern (5 years old) rotary milking shed. This is a high capacity semi-automated modern milking shed with a back up diesel generator. The milking shed (equipment and infrastructure) and yards are in very good condition and would be able to cope with the increased load of additional herds being milked there. For the herd to reach the neighbouring farm it would simply be a case of 'dropping' (lowering) a southern boundary fence and a short trip across the road to the Hill milking shed. Such a venture would largely be reliant on the good will of the Hills. However the fostering of community spirit and working together in a crisis event is well documented in rural communities (Gough, 2000).

The milk shed is the economic hub of the farm and may need to be protected. A solution to tephra contamination would be to enclose the milk shed. This could be achieved by simply

hanging wet sacking or previously used silage pit covers (effectively large plastic sheets) from the shed's roof to block tephra from entering the shed. Both resources could be found on the farm or easily sourced. This would need to be completed during final preparations before a tephra fall, or as soon as tephra had begun to fall.

6. Conclusions and Recommendations

This study has shown a tephra eruption would impact on the entire farming operation. The electrical power supply is perhaps the most critical and most vulnerable part of farm infrastructure that could be lost during a tephra fall. The water supply, the use of the tractor and the condenser are the most vulnerable. Injury to one of the labour units on the farm would be something that should be avoided at all reasonable cost, given the probable need to have all labour units fully utilised during a tephra fall.

If there is more than 100mm of tephra fall it will be very hard for a dairy farm to recover. Below this the farm will survive, but measures need to be taken for recovery. It is important to note how a farm responds to tephra fall is dependant on social, health (physical and mental), economic and political considerations in addition to the amount of tephra it receives. The 100mm threshold has important implications for farmers when deciding when they must evacuate; building roof collapse can be considered a similar 'evacuation threshold'. Ultimately it will be farmers themselves that determine when the most appropriate time is to leave the farm; hard as that may be (Rogers, 1997). Emergency management agencies responding to a major volcanic eruption could also use the 100mm isopach line as a guide to where recovery efforts are most appropriately allocated or directed.

Even in a major volcanic eruption, there will be a number of farms on the fringe able to successfully recover from tephra fall. The quality of the actions taken (related to information available to the farmer) will determine how successfully a farm will recover; and indeed whether they recover at all (Slovic, 1986). Recommendations developed in this study will hopefully allow dairy farmers to become more resilient to tephra fall, minimising the effect it has on their farms and lives.

Any farm affected by tephra will be dependent on the financial resources of the farmer and the robustness of the farm business, as even a 50mm fall of ash will have serious financial

implications in the year of the tephra fall and following season due to lost production and the increased costs of rehabilitation. In severe tephra falls land use change may be the only option. Given New Zealand's exposure to volcanoes, and the importance of agriculture to the national economy further research on simulating effects of different types of tephra fall on dairy farms, in terms of infrastructure, operational process and rehabilitation of pastoral agricultural systems, is necessary. Such programmes should be investigated and developed in conjunction by key industry players, such as MAF, Fonterra and Federated Farmers.

6.1 TEPHRA FALL HAZARD MITIGATION

The effect of tephra fall will depend on the magnitude, style of eruption, location of active vent zone, vent positions within the active vent zone, local topographic controls and wind directions. It is extremely hard to predict any of these factors for the next eruption given the variety of styles of eruptions that have affected the farm during the last 22,000 years.

Warning time is variable. There may be 1 year to 3 months warning for a rhyolitic eruption, while only 3-4 hours for a basaltic eruption is likely. Key recommendations to minimise the hazard are as follows:

1) Long Term Planning (*periods of quiescence*)

- Maintain power supply lines so they are in good order.
- Develop a water supply with large tank storage capacity.
- Develop a 'feed pad' that is easily cleared of tephra for distributing supplementary feed.
- Ensure roof pitches are greater than 30° on any new buildings.
- Ensure the tractor is 4WD and has front bucket and blade attachments.

2) Medium Term Planning (*12 to 3 months out from eruption*)

- Conduct a vulnerability analysis of equipment and facilities to determine which would be the most affected by tephra fall, and which are adequately and inadequately protected (<http://volcanoes.usgs.gov>).
- Identify appropriate methods of protecting vulnerable equipment and facilities from ash.
- Off load non-essential stock (i.e. beef cows, sick animals in the herd, dry milkers, old cows).

- Increase reserves of supplementary feed (i.e. buy in or produce more; alternatively use less by off loading stock).
- Ensure tractor and milking machine have been serviced recently.
- Attempt to stockpile tractor engine and milking machine filters (air, oil, pulsators, and milk), lubricating oil, brake and hydraulic fluids, and seals.
- Purchase an air compressor or ensure it is in good working order.
- Ensure diesel tank is maintained at a high level.
- Have ladders and brooms (roof cleaning).
- Ensure sump, drain pipes, and drain grills are clear. Make sure sump pump is in good working condition.
- Be prepared for false alarms; predicting a volcanic eruption prediction is difficult.

3) Short Term Planning (*immediately before an eruption*)

- Cover all essential equipment (either within sheds or under a covering).
- Move essential stock (milking herd) close to the milking shed.
- Store transportable supplementary feed close to areas where it would be distributed (i.e. feed pad, paddocks close to the milking shed).
- Ensure enclosed water storage tanks are at their maximum (especially if surface water is the farm's water supply).
- Place ladders for access to key roofs in a secure way for easy safe cleaning. Plan to have a lot of time to clean roofs (prevent injury).
- *Do not put stock onto the road* in the hope of finding somewhere better as they will hinder emergency service's and evacuee's mobility. They have a greater chance of survival on their farm (Neild *et al.*, 1998).
- Conduct any maintenance on tractor, milking machine and other key machinery (e.g. change filters). If there is time purchase new filters.

4) During Eruption

- Keep tephra out of buildings, machinery, vehicles, downspouts, water supplies, and wastewater systems (e.g. dairy shed drains) as much as possible. The best way to prevent damage is to reduce machinery usage as much as possible, shutting down, closing off or sealing equipment. However critical farm functions such as milking

should be preceded by removal of as much tephra as possible before operating equipment.

- Minimize human exposure to airborne tephra by using dust or filter masks (or a wet cloth, for example a handkerchief) and minimizing travel.
- Removed tephra from roofs to prevent collapse and on going remobilisation. Take your time whilst cleaning roofs of tephra. Try to undertake the activity when you are alert and physically fresh.
- Plan each day, in terms of what activities are critical, required and optional. These may change each day so be prepared to remain flexible. Develop a priority list of facilities that must be kept operative versus those that can be shut-down during and after ash falls.
- Stay aware of the condition of your cows; they are the most important part of your farm.
- *Do not put stock onto the road* in the hope of finding somewhere better as they will hinder emergency service's and evacuee's mobility. They have a greater chance of survival left on your farm.
- Prioritize and sequence areas for cleanup (top to bottom).

References

- Acocella, V., Spinks, K.D., Cole, J.W., Nicol, A.: 2003, Oblique back arc rifting of Taupo Volcanic Zone, New Zealand, *Tectonics* **22(4)**, (Article 1045), 1-18.
- Alaskan Division of Homeland Security and Emergency Management Website. "Electric and Electronic Equipment Protection – Commercial and Major System". <http://www.ak-prepared.com/plans/mitigation/volcano.htm> (3/7/2005).
- Blong, R. J.: 1981, Some effects of tephra falls on buildings, in, Self, S., and Sparks, R.S.J., (eds.), *Tephra studies*, Dordrecht, Holland, Reidel: 405-420.
- Blong, R.J.: 1984, *Volcanic Hazards: A Sourcebook on the Effects of Eruptions*. Academic Press, Sydney, Australia, 424 pp.
- Chaplin, D.M., Braatne, J.H.: 1986, Nutrient relations of subalpine plants native to Mount St Helens. In: *Mount St Helens: Five years later*. Eastern Washington University Press, 173-181.

- Cole, J.W.: 1970, Description and correlation of Holocene Volcanic Formations in the Tarawera-Rerewhakaaitu Region, *Transactions of the Royal Society of New Zealand (Earth Sciences)*, **8(7)**, 93-108.
- Cole, J.W., Milner, D.M., Spinks, K.D.: 2005, Calderas and caldera structures: a review, *Earth-Science Reviews* **69**, 1-26.
- Cook, R.J., Barron, J.C., Papendick, R.I., Williams, G.J.: 1981, Impact of Agriculture of the Mount St. Helens Eruptions, *Science* **211**, 16-22.
- Cronin, S.J., Smith, R.G., Neall, V.E.: 1997, Impact of Ruapehu ash fall on soil and pasture nutrient status 1. October 1995 eruptions, *New Zealand Journal of Agricultural Research* **40**, 383-395.
- DeLaval Website, 'Efficient Cooling'. http://www.delaval.com/Dairy_Knowledge/EfficientCooling/default.htm (13/3/2005).
- Dibble, R.R.: 1965, Earthquake risks in the Wellington area. *New Zealand science review* **14(8)**, 109-112.
- FEMA: 1984, The mitigation of ashfall damage to public facilities: lessons learned from the 1980 eruption of Mount St. Helens, Washington. *Federal Emergency Management Agency*, 70 pp.
- Fonterra Website, 'The New Zealand Dairy Industry'. <http://www.fonterra.com/content/dairyingnz/history/default.jsp> (19/4/2005).
- Gordon, K.G., Cole, J.W., Rosenberg, M.D., Johnston, D.M.: 2005, Effects of Volcanic Ash on Computers and Electronic Equipment, *Natural Hazards* **34**, 231-262.
- Gough, J.: 2000, Perceptions of risk from natural hazards in two remote New Zealand communities, *The Australasian Journal of Disaster and Trauma Studies*. <http://www.massey.ac.nz/~trauma/issues/2000-2/gough.htm> (10/8/2005).
- Heiken, G., Murphy, M., Hackett, W. and Scott, W.: 1995, Volcanic hazards to energy infrastructure: Ash fallout hazards and their mitigation, *World Geothermal Congress*, Florence, Italy, 2795-2798.
- Johnston, D.M.: 1997, Physical and Social impacts of past and future volcanic eruptions in New Zealand, PhD Thesis, Massey University, Palmerston North.
- Johnston, D.M., Nairn, I.A., Cole, J.W., Paton, D., Martin, R.J.: 2000, Distal impacts of the ~1300 AD Kaharoa eruption on modern day New Zealand. 2000/27, Institute of Geological and Nuclear Sciences Limited, Lower Hutt.
- Keam, J.M.: 1988, *Tarawera: the volcanic eruption of 10 June 1886 A.D.*, R.F. Keam Physic Department, University of Auckland.
- Ministry of Agriculture and Forestry Website. <http://www.maf.govt.nz> (20/5/2005).

- Nairn, I.A.: 1991, Volcanic Hazards at Okataina Volcanic Centre, Ministry of Civil Defence, *Volcanic Hazards Information Series No. 2*. Wellington, New Zealand.
- Nairn, I.A.: 2002, Geology of the Okataina Volcanic Centre, scale 1:50,000. Institute of Geological and Nuclear Sciences geological map 25. 1 sheet + 156 p. Lower Hutt, New Zealand: Institute of Geological and Nuclear Sciences Limited.
- Nairn, I.A., Shane, P.R., Cole, J.W., Leonard, G.J., Self, S., Pearson, N.: 2004, Rhyolite magma processes of the ~ AD 1315 Kaharoa eruption episode, Tarawera volcano, *New Zealand. Journal of Volcanology and Geothermal Research* **131**, 265-294.
- Neild, J., O'Flaherty, P., Hedley, P., Underwood, R., Johnston, D., Christenson, B., Brown, P.: 1998, Impact of a Volcanic Eruption on Agriculture and Forestry in New Zealand. *MAF Policy Technical Paper 99/2*, 101pp.
- Paton, D.: 2000, Disasters and communities: Resilience, information and preparedness. *Proceedings of the Earthquakes and Society Workshop*. Institute of Geological and Nuclear Sciences, Lower Hutt, New Zealand, 28 February – 3 March.
- Rogers, G.O.: 1997, The dynamics of risk perception: how does perceived risk respond to risk events? *Risk Analysis* **17 (6)**, 745-757.
- Shanks, D.F.: 1997, Clinical implications of volcanic eruptions on livestock – case studies following the 1995 and 1996 eruptions of Mt. Ruapehu. *In: Procedures of the 27th Seminar of the Society of Sheep Beef Cattle Veterinarians, New Zealand Veterinary Association Publication 175*, 1-13.
- Slovic, P.: 1986, Informing and Educating the Public About Risk. *Risk Analysis* **6(4)**, 403-415.
- Smith, S.P.: 1886, *The Eruption of Tarawera*, A report to the Surveyor General, Wellington Government Printer.
- Spence, R. J. S., Kelman, I., Baxter, P. J., Zuccaro, G., Petrazzuoli, S.: 2005, Residential building and occupant vulnerability to tephra fall, *Natural Hazards and Earth System Sciences* **5**, 477–494.
- Spinks, K.D., Acocella, V., Cole, J.W., Bassett, K.N.: 2005, Structural control of volcanism and caldera development in the transtensional Taupo Volcanic Zone, New Zealand, *Journal of Volcanology and Geothermal Research* **144 (1-4)**, 7-22.
- Tilling, R.I., Topinka, L., Swanson, D.A.: 1990, Eruptions of Mount St. Helens: Past, Present, and Future, *USGS Special Interest Publication*. <http://vulcan.wr.usgs.gov/Volcanoes/MSH/Publications/MSHPPF/framework.html>. (23/5/2005).
- Transpower Website. <http://www.transpower.co.nz>. (24/4/2005).
- United States Geological Survey Volcano Hazards Program. <http://volcanoes.usgs.gov>. (12/5/2005).

Walker, G.P.L.: 1980, The Taupo Pumice: Product of the Most Powerful Known (Ultraplinian) Eruption? *Journal of Volcanology and Geothermal Research* **8**, 69-94.

Wilson, C.J.N., Houghton, B.F., McWilliams, M.O., Lanphere, M.A., Weaver, S.D., Briggs, R.M.: 1995, Volcanic and Structural Evolution of Taupo Volcanic Zone, New Zealand: a review, *Journal of Volcanology and Geothermal Research* **68**, 1-28.

Wilson, C.J.N., Scott, B.J., Houghton, B.J., 2004. Volcanoes of New Zealand, *Tephra* **21**, 2-11, Ministry of Civil Defence and Emergency Management publication.

Figures

Figure 1: Location of Rerewhakaaitu, eastern Taupo Volcanic Zone.

Figure 2: The annual farm activities at 'Tulachard' shows the key vulnerable periods during the year of farming operations. The farm's most important activities are closest to the centre, with activities of decreasing importance progressively further out from the centre.

Figure 3: This aerial photograph shows the boundary and infrastructure layout of 'Tulachard'

Figure 4: Condenser located inside in the test box

Figure 5: Grain size distribution of the blended tephtras

Figure 6: One hour into the Wet Test. Note the greater accumulation of tephra on the walls of the test box and the circulation pattern of the airflow.

Figure 7: Surface of the condenser's intake face following the wet test

Figure 8: Dry and wet test grainsize distributions collected from the condenser

Tables

Table 1: Eruptive Episodes of the Okataina Caldera Complex (OCC) of the last 22,000 years**

*All eruptions are rhyolitic unless otherwise stated

** Taken from Nairn (2002)

Table 2: Maximum possible tephra loading from 'Kaharoa' tephra fall

Figures

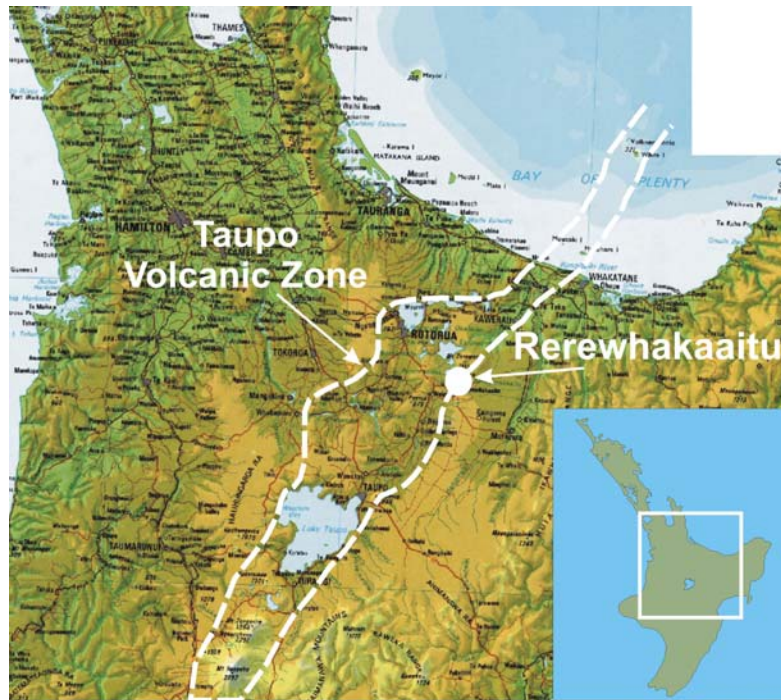


Figure 1

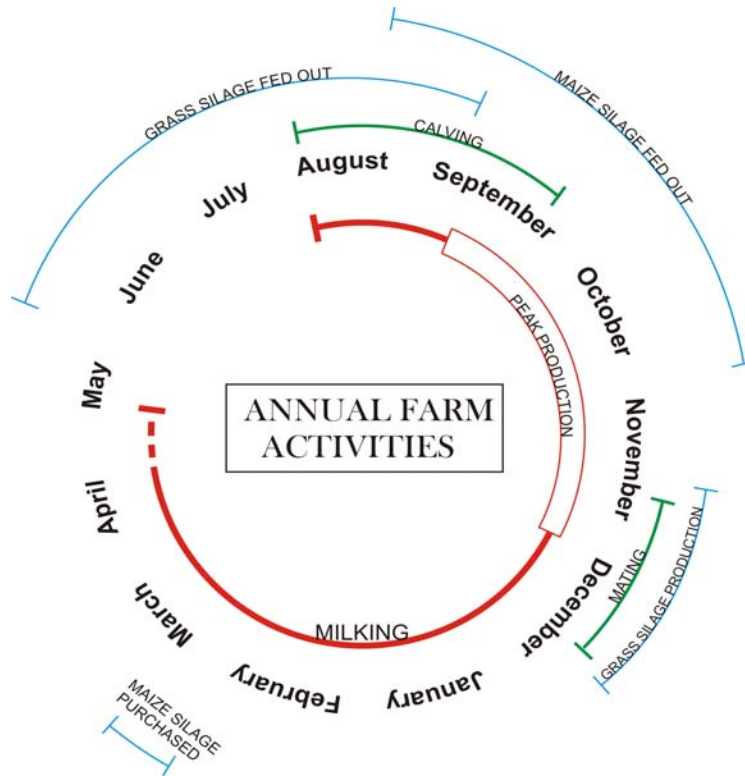


Figure 2

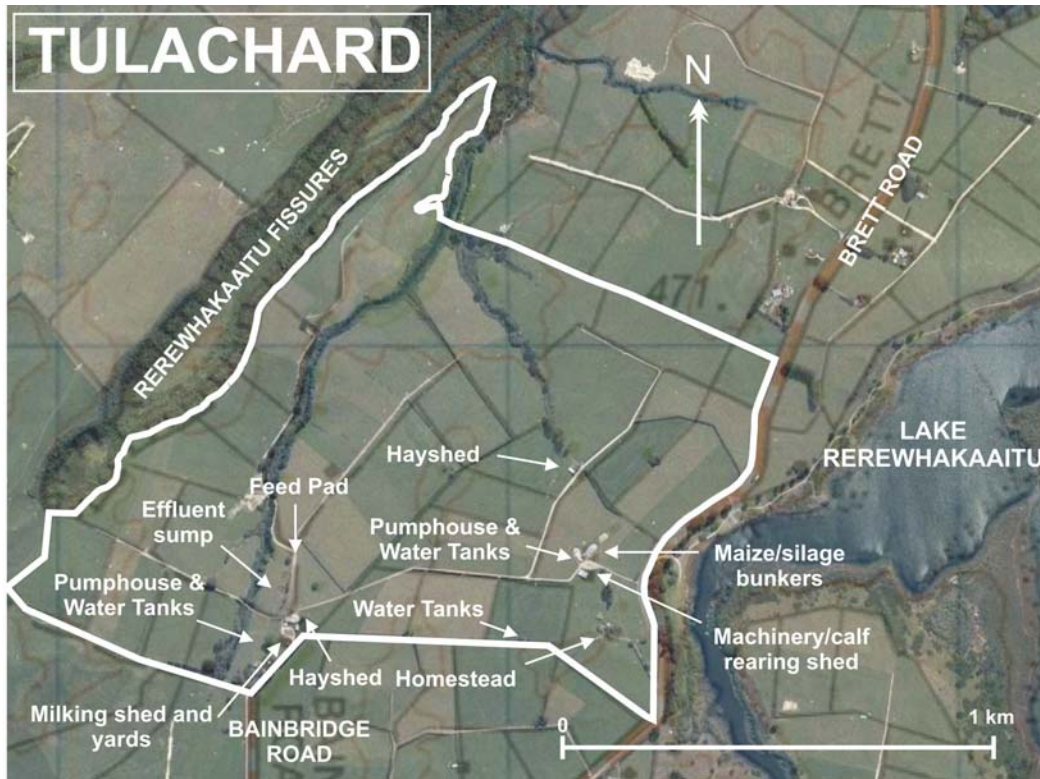


Figure 3

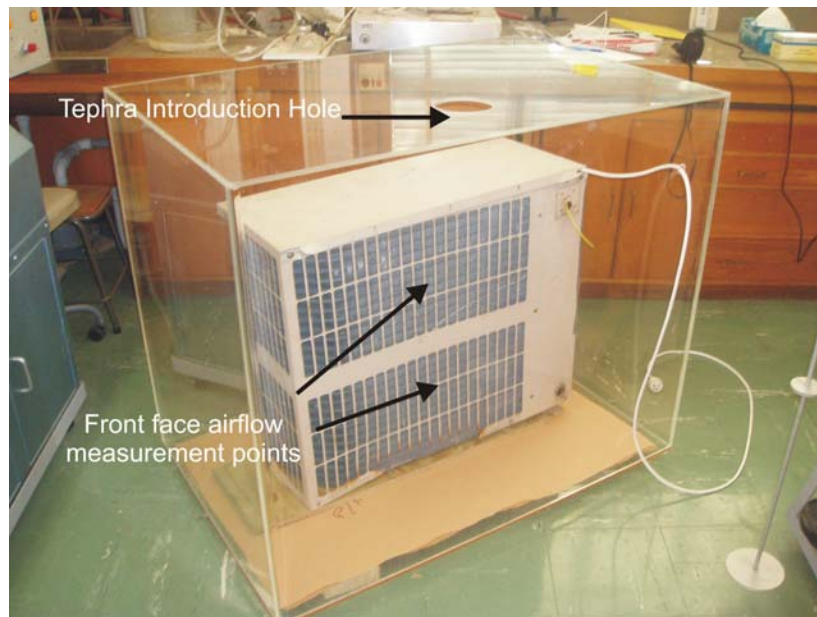


Figure 4

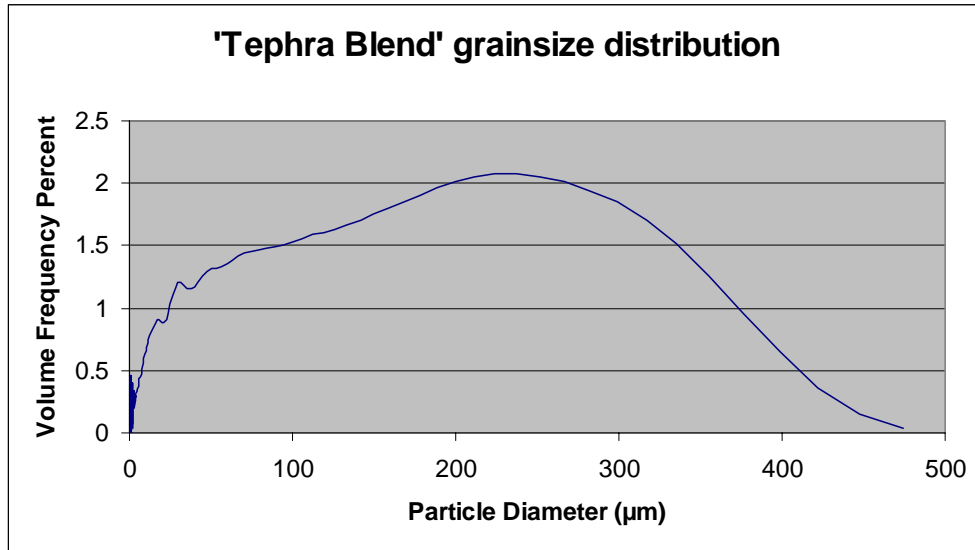


Figure 5

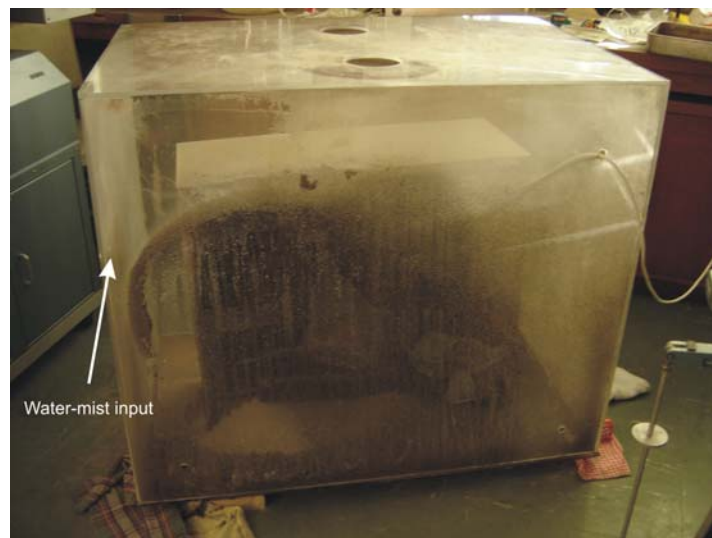


Figure 6

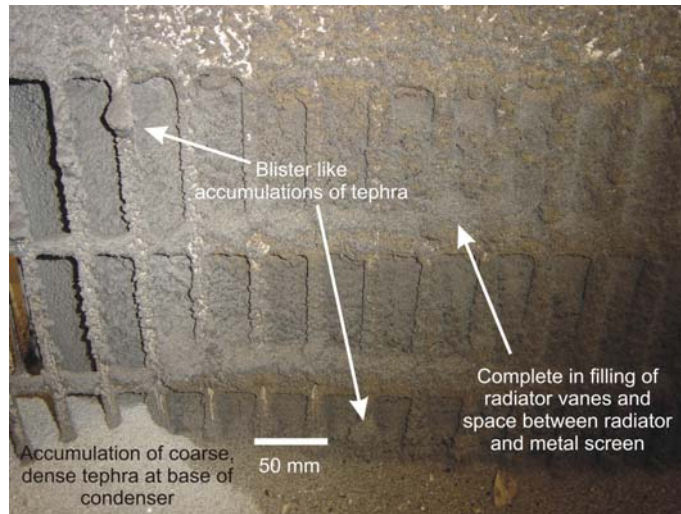
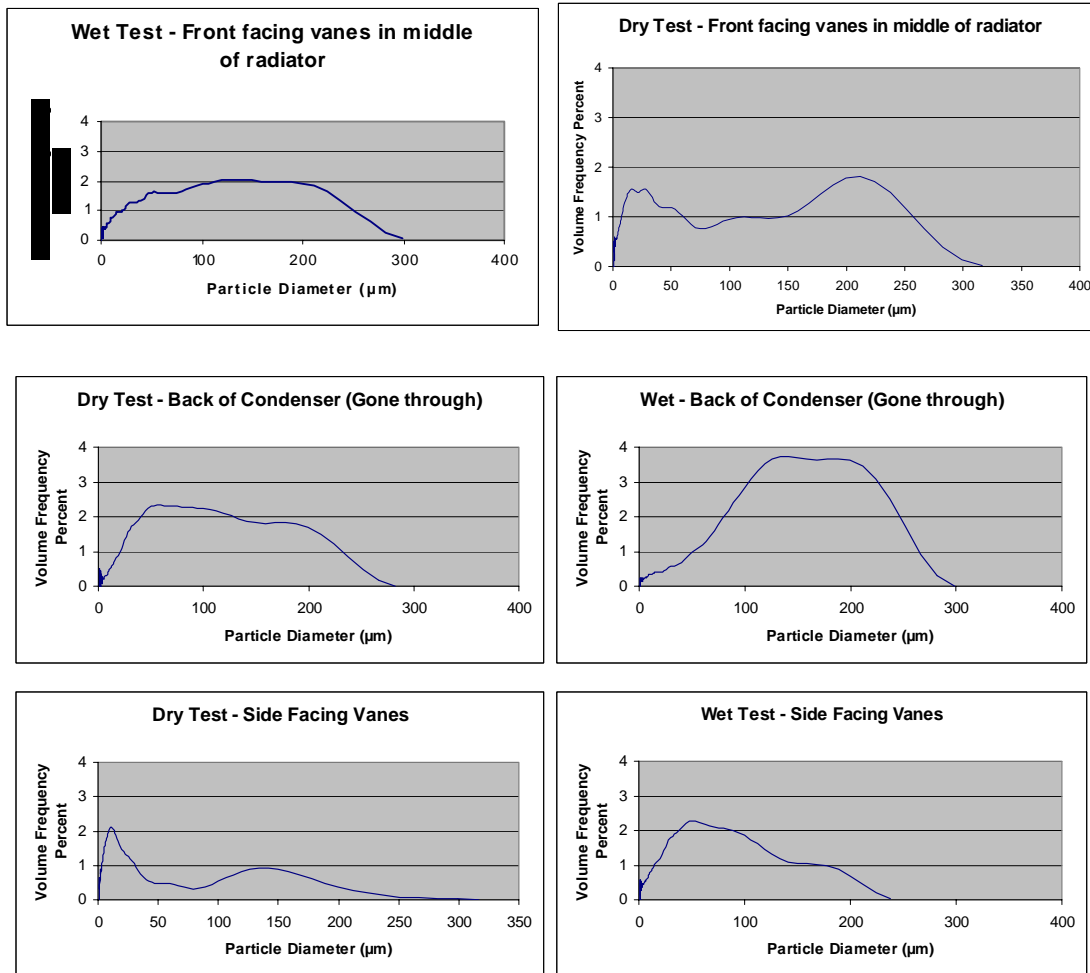


Figure 7



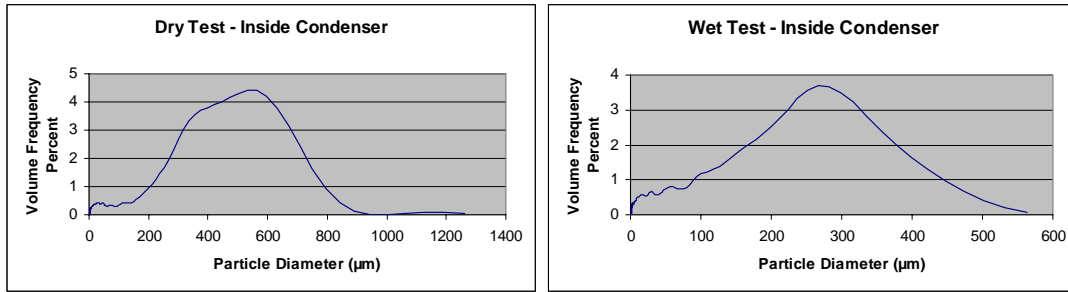


Figure 8: Dry and wet test grainsize distributions collected from the condenser

Tables

Eruptive Episode*	Age (ka)	Lava Volume (km³)	Pyroclastics Volume (km³)	Eruptive Centre
Tarawera Basalt	1886 AD	-	2	Tarawera
Kaharoa	0.7	2.5	5	Tarawera
Rotokawau Basalt	3.4	-	0.7	Haroharo
Whakatane	5	9	10	Haroharo
Mamaku	7.5	15	6	Haroharo
Rotoma	9	2	13	Haroharo
Waihau	11	4	15	Tarawera
Rotorua	13.5	1	7	Haroharo
Rerewhakaaitu	15	2	6	Tarawera
Okareka	18	5	6	Tarawera
Te Rere	21	10	5	Haroharo
	Total	40.5	75.7	

Table 1

Max. possible tephra thickness	Loading dry tephra, no wind drifts	Max. loading dry tephra with wind drifts	Loading wet tephra, no wind drifts	Max. loading wet tephra with wind drifts
300 mm	4.4 kPa	8.8 kPa	5.9 kPa	11.8 kPa
150 mm	2.2 kPa	4.4 kPa	2.9 kPa	5.9 kPa
75 mm	1.1 kPa	2.2 kPa	1.5 kPa	2.9 kPa
50 mm	0.7 kPa	1.5 kPa	1.0 kPa	1.9 kPa
25 mm	0.4 kPa	0.7 kPa	0.5 kPa	1.0 kPa

Table 2