Department of Primary Industries
and Regional Development

NSW GOVERNMENT

Managing subtropical horticulture in extreme wet weather

NSW PRIMARY INDUSTRIES MANAGEMENT GUIDE

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Submerged macadamias. Photo: Graham Wessling, CL Macs.

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Managing subtropical horticulture in extreme wet weather

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Introduction

This publication offers specialised guidance for subtropical horticulture farming operations during extreme wet weather. This guide includes a range of subjects such as a plant's response to being waterlogged or submerged, how growers can prepare short and long-term for extreme wet weather or flooding, what to do immediately after substantial rainfall and through the recovery phase.

Understanding how wet weather will affect your farm

Landscape position

One key aspect that will affect the type and extent of damage from extreme wet weather is the farm's position within the landscape. Generally, subtropical horticulture will be on 3 main landscape types: plateaus, hillsides or floodplains (Figure 1).

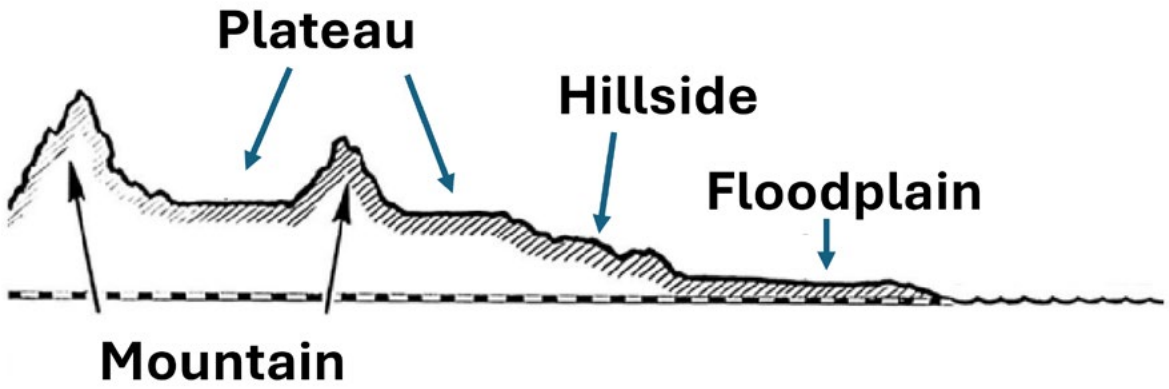

Figure 1. The 3 main landscape types for subtropical horticulture (plateaus, hillsides and floodplains).

Plateaus

Plateaus are usually flat or gently sloping, with inundation temporary (Figure 2), unless the area is a localised depression. During heavy rainfall, soil loss occurs where there is little to no ground cover and water accumulates. Periods of prolonged wet weather will temporarily saturate the soil, causing plant stress and increased pest and disease risks from those favoured by prolonged wet conditions. Plant death can occur from extended wet weather; however, it is generally slow due to a gradual decline in tree health.

Figure 2. Temporary water inundation to trees and surface wash during extreme wet weather.

Hillsides

Plants on hillsides are less likely to become inundated but are more likely to be exposed to soil loss, washouts (Figure 3), and landslides (Figure 4). During prolonged wet weather, damage from diseases and insects favouring wet conditions is likely. Issues with accessing blocks can also occur due to tracks being too slippery or eroded to drive on.

Figure 3. A washout caused by intense rainfall on a blueberry farm.

Figure 4. A landslide on a banana farm after intense rainfall.

Floodplains

Floodplains are generally flat or gently sloping, allowing water to spread during floods. The lack of significant elevation prevents rapid flow, reducing the potential for erosion and damage but increasing the risk of intense flooding (Figure 5 and Figure 6). The unpredictability and intensity of floods can cause significant damage to plants and infrastructure. Careful planning and strategies are required to minimise losses. Plants might be submerged in water for significant periods in these areas, and substantial plant loss can occur.

Figure 5. Waterlogged macadamias.

Figure 6. Submerged macadamias. Photo: Graham Wessling, CL Macs.

Plant damage caused by extreme wet weather

During periods of extreme wet weather, plants can suffer from waterlogging and submergence. Waterlogging is where the soil is saturated and there is a lack of air within the soil, creating an anaerobic environment. Submergence is where the soil is saturated (waterlogged) and water is also covering the land; part or all of the plant can be covered by water.

The following factors will influence the extent of damage suffered by plants:

1. **Waterlogging or submergence**: the type of damage will depend on whether the plant suffers from waterlogging or submergence. Generally, waterlogging will affect the roots, while submergence can affect the whole plant.
2. **Water depth**: generally plants with a greater volume of canopy under water will suffer more damage.
3. **Length of inundation**: the longer the plant parts are inundated with water, the worse the damage can be.
4. **Water quality**:
    - Warm water is more damaging than cold water as it has less capacity to hold dissolved oxygen.
    - Stagnant water is more damaging than flowing water as it holds less oxygen.
    - Sediment-laden water decreases light penetration, affecting both plant and soil organisms. Sediment can cover plant leaves, affecting the plant's ability to photosynthesise and create more carbohydrates during and after flooding.
5. **Tree health**: the poorer a tree's health, the longer it will take to recover. This reduced health can be due to insufficient carbohydrate reserves caused by a lack of leaves and/or roots, and pest and disease incidence.
6. **Phenological stage**: trees are more vulnerable just after a flush of growth or after fruit set when carbohydrate levels are low.
7. **Cultivar and/or rootstock differences**: some cultivars and/or rootstocks might be more resilient to waterlogging than others.
8. **Frequency of floods or droughts** and time since the last flood or drought.

What happens to soil and plants when the roots get waterlogged?

When soil and plant roots are waterlogged, oxygen deprivation occurs. This results in several key biochemical and physiological processes being affected (Figure 7).

Figure 7. The biochemical and physiological processes affected by oxygen deprivation when soil and plant roots are waterlogged. Adapted from: Manghwar et al. (2024).

Preparation phase

Building a resilient farm

Site selection

Topography

Elevated and sloped land: a site that is higher in elevation with gentle slopes will facilitate natural drainage. Low lying areas or depressions where water tends to accumulate will be more prone to flooding.

Slope direction and waterlogging: north facing slopes tend to dry out faster and are warmer due to longer sunlight exposure.

Soil characteristics

Soil drainage: select soil that is free draining such as sandy loam or loam. Avoid heavy clays that retain water and are prone to compaction.

Soil depth: ensure there is adequate topsoil to allow roots to grow without hitting a high water table. Shallow soil overlying rock or where a hardpan is close to the surface can be prone to waterlogging.

Access and infrastructure

Road access: setting up a site that ensures access roads to the site remain passable during extreme wet weather will help with continuing management and production while these adverse conditions persist.

Infrastructure: consider the availability of infrastructure to manage excess water such as drainage systems or retention ponds. Infrastructure such as sheds should be sited out of flood-prone areas where possible. On floodplains, identify the 1 in 100-year flood height and mound earth to be at least this height, preferably higher, and construct any infrastructure on the mound created.

Identifying poorly drained soil

Poorly drained soil can be identified by:

- **Detailed elevation mapping**, such as those from light detection and ranging (i.e. lidar; Figure 8), can provide enormous potential in modelling drainage designs for setting up new blocks and reworking established blocks. Using lidar before planting an orchard can show the areas of main water flow to avoid or divert water away from.
- **Vegetation**, such as rushes or sedges, that grow in areas frequently inundated by water.
- **Soil surveys**: digging soil pits to identify soil conditions and potential limitations, especially in areas suspected of being problematic.

Implementing effective drainage

Whether establishing a block for the first time or re-establishing areas of a farm, implementing effective drainage is essential. Poor drainage causes soil erosion and waterlogging, which limit plant productivity. Soil erosion removes resources from the orchard, and waterlogging causes several physiological disorders and plant stress responses. Poorly drained soil increases the risk of diseases such as phytophthora root rot. At critical times, such as harvest or carrying out crop protection activities, poorly drained soil can limit access. It is best to avoid planting on poorly drained soil.

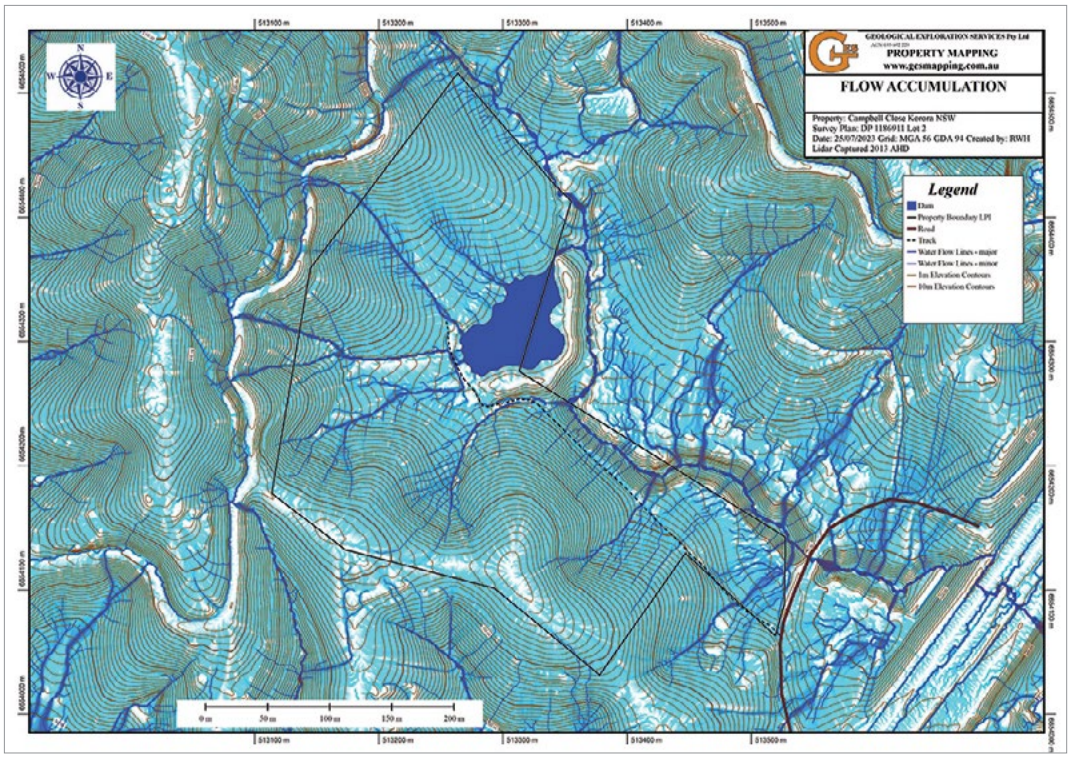

Figure 8. Lidar mapping showing drainage lines in a blueberry block. Photo: Bob Howard, GES Mapping.

Mounding

Mounding shapes the topsoil to form continuous ridges (Figure 9), increasing height and giving somewhere for water to drain away. This process increases the available topsoil that a plant can use and moves water away from the plant's root zone. Mounding is only practical when there is enough suitable soil. Do not include heavy clay or hardpan material in tree mounds.

Establish ground cover as soon as possible after creating mounds, especially on steeper slopes and next to the mound. Immediately after earthworks are completed, a quick-to-establish grass such as millet or ryegrass (depending on the time of year) should be sown. As this germinates, it will help prevent erosion.

Figure 9. Mounded macadamias to assist with diverting water to designated water courses and drainage channels.

Sub-surface drains

Sub-surface drains are trenches with gravel and ag pipe at the base. They run sub-surface water away to create a more aerated soil environment. They are best installed before planting permanent crops (Figure 10). Sub-surface drains are used as part of a system to improve growing conditions. They will not completely resolve the site's limitations.

Figure 10. Installing a sub-surface drain.

Sub-surface drains need to:

- be deep enough (usually >0.5 m deep) to create an adequate oxygenated root zone above them and not be disturbed by orchard operations.
- have risers at least every 100 m or less of drain run to help with clean out.
- run water to a stable discharge point.

Before embarking on any drainage work, always check if any approvals are required for this work on your farm. For more information, refer to:

Saving soil: a landholders guide to preventing and repairing soil erosion (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/270881/saving-soil-complete.pdf).

If you are in an area considered an acid sulfate risk, you need to follow the actions set out in the *Acid sulfate soil: assessment and management guide* (https://www.epa.nsw.gov.au/licensing-and-regulation/authorised-officers-and-enforcement-officers/resources-and-training/acid-sulfate-soil-assess-and-manage).

Considerations for developing and managing macadamia on floodplain soil (https://www.dpi.nsw.gov.au/agriculture/horticulture/nuts/soil-nutrition-floor-mgt/considerations-for-developing-and-managing-macadamia-on-floodplain-soils).

Reducing erosion and other soil degradation in macadamia orchards (https://www.dpi.nsw.gov.au/agriculture/horticulture/nuts/soil-nutrition-floor-mgt/soil-macadamia)

Make an emergency flood plan for your farm

Creating a farm that is resilient to floods and extreme weather helps growers return to a more productive, healthy orchard quickly. Preparing your farm should help to reduce some of the damage. Have a plan that has set points to trigger decisions. Discussing what to do during a flood and extreme weather will help you make clear decisions in an emergency.

Some essential things to have in a flood plan include:

- Have an adequate amount of non-perishable foods and ensure access to clean drinking water.
- If possible, make sure your insurance covers flood damage.
- Store important documents and photos in an emergency kit that is waterproof. Include a torch, batteries and first aid kit.
- Anchor fuel tanks and relocate waste, chemicals and poisons to high areas.
- Move equipment where possible e.g. tractors, farming equipment, and other vehicles.
- Remove pumps from waterways and relocate them to high ground.
- Store electrical tools in the highest possible places.
- Know the safest escape routes for when you need to leave.
- Plan for flash floods and/or slow-moving floods (depending on your location), as these are likely to require different responses.
- Make sure you have essential documents at hand such as an emergency contact list, legal documents and accounting records.
- If possible, clean and/or mow drains so that water can flow more easily.

Knowing how flooding might affect your property and how high the floodwater could reach is important. One of the best ways to prepare for a flood is to make a plan everyone in your home agrees on. Discussing what to do before a flood happens means you will be better prepared to make clear decisions in an emergency.

Some information to include in an emergency plan is:

1. An agreed meeting place for all people from the household.
2. An alternative place to stay including contact name, phone number and address.
3. Any current medications and where they are in case someone else needs to get them.
4. Phone numbers of support networks.
5. An important items list and a plan for where these items will go, i.e. if machinery needs to be moved somewhere else, has the location been identified and is permission granted.
6. If people have to be evacuated or equipment needs to be transported off the farm, make sure the evacuation plan includes the flood levels that cut access to roads and low-level bridges, and alternative access routes.
7. Emergency information such as Medicare number, tax file number, and driver's licence.
8. Account numbers and contact details of services such as electricity, water and phone.
9. Insurance details including the insurer, contact details and policy number.

Local Land Services has developed a *Farm flood readiness kit* that will help you get your property flood-ready (https://www.lls.nsw.gov.au/__data/assets/pdf_file/0007/798901/LLS-flood-readiness-091122-web-final.pdf).

Cleaning up phase

During the clean-up phase, it is crucial to prioritise safety and emotional well-being. Ensure that flooded areas are only accessed when safe to do so and take time to be with family and friends. This information provides tips on looking after yourself and your friends.

Tips for looking after yourself and others

Doing things every day to take care of yourself is important. It will help you to deal with stress, make clear decisions and support loved ones. It is important to:

- maintain social networks and speak openly with friends and family about what you are going through
- maintain routines with good diet, exercise, quality sleep and sufficient rest
- have some down time to remove yourself from the stresses of the farm
- focus on the things you can control
- seek information from reliable sources to ensure you are well informed
- remember that challenging times will pass
- get help early; it can make a difference to how you feel in the long run.

If you are not feeling yourself, there are plenty of support services for help. Taking care of yourself is the first step in taking care of your family and your farm.

Telephone support

- NSW Mental Health Line, 1800 011 511
- Lifeline, 13 11 14
- MensLine Australia, 1300 78 99 78
- Rural Aid Counselling Line, 1300 175 594

Online counselling and information

- Rural Adversity Mental Health Program (https://www.ramhp.com.au/) informs, educates and connects people living and working across regional, rural and remote NSW to mental health support.
- Rural Aid (https://www.ruralaid.org.au/) offers free, confidential counselling to Rural Aid registered farmers and their families.
- Beyond Blue (https://www.beyondblue.org.au/) can help you chat to a counsellor, connect you with peers, and find mental health professionals in your area.

Assess and plan

- Assess the damage and record the evidence, i.e. take photographs as you assess the damage.
- There is an online form to report damage on the NSW Primary Industries natural disaster damage assessment (PiNDDA) website. If you are unable to submit this form yourself, call your local NSW DPIRD office (https://www.dpi.nsw.gov.au/contact-us/local-office), and someone will submit it on your behalf.
- Create a plan for how you are going to approach the clean-up.

Clean-up

- It is highly likely that flooded growing sites will have been contaminated by floodwaters that could contain sewerage, animal waste, dead animals and decaying vegetative waste; safety is paramount.
- People conducting clean-up activities in these areas should be equipped with personal protective equipment (PPE), i.e. long sleeves and long pants, sturdy boots, gloves, eye protection and dust masks.
- Where debris, waste, vegetative matter or rubbish are being collected when cleaning up, it is recommended to segregate this where possible to contain its decay/disease spread potential. It could be some time before all rubbish can be removed.
- After handling any contaminated soil, rubbish or water, wash your hands thoroughly with disinfectant soap and use a hand sanitiser.
  - Ensure thorough hand washing practices include full coverage of hands to wrists, underneath nails, and between fingers for 20–30 seconds, followed by effective drying until hands are completely dry.
  - Repeat this often, even if hands are visibly clean.
- Mosquito activity can also increase in extreme wet weather, so a strong repellent product is recommended to help avoid contracting mosquito-borne viruses.
- Be aware of risks associated with rodents, snakes and spiders that might have taken refuge in unusual places.

Facilities, equipment and tools

- Businesses should also ensure thorough cleaning and disinfection/sanitation of all surfaces, equipment and tools that have been in contact with floodwater.
- Cleaning should start from the top down, rinsing all surfaces first to remove gross debris and soil, then cleaning with a food-grade detergent and hot water (where available), followed by applying a suitable sanitiser and leaving to air dry.
- All food contact surfaces should be cleaned with a food grade detergent.
- For water tanks, chlorine is considered an effective disinfectant. The NSW Health website (https://www.health.nsw.gov.au/environment/water/Documents/chlorine-ready-reckoner-tables.pdf) has a fact sheet to help you calculate how much chlorine to use and how to apply.
- All drains within facilities should be flushed to prevent re-contamination of cleaned areas.

Check agricultural chemicals

- In a flood, chemical containers, fertiliser and soil additives might be immersed, bags soaked, or products contaminated.
- Where labels and product identity are lost, or the chemicals are damaged beyond use, the chemicals should be separated and disposed of through ChemClear (https://www.chemclear.org.au/) or registered collection agencies.
- Empty drums should be carefully and appropriately emptied of any floodwater, segregated and disposed of through drumMUSTER (https://www.drummuster.org.au/).

Check fresh horticultural produce

Fresh horticultural produce that has come in contact with flood water is considered adulterated and cannot be sold for human or animal consumption. If the crop comes in proximity to, or is exposed to a lesser degree, a thorough risk-assessment should be conducted involving factors such as the floodwater hazards, type and stage of crop growth, degree and duration of crop exposure to floodwater and related conditions and likelihood for crops to absorb or internalise potential contaminants. The major hazards associated with floodwater are shown in Figure 11. Microbiological testing of fresh produce for faecal indicators and foodborne microbial pathogens (e.g. *Salmonella*, *Listeria monocytogenes*) should be the objective and integral part of food safety risk assessments. A NATA-accredited laboratory must be used for any testing conducted (https://nata.com.au/find-organisation/). For more details, refer to *Flooding adversely affects fresh produce safety* (https://www.publish.csiro.au/ma/MA23054).

Growing site

- When safe to do so, inspect the orchard/production field as soon as possible and mark (e.g. with coloured pegs) areas affected by poor drainage. If possible, immediately take steps to improve the drainage of these areas so the water can disperse, e.g. dig drains to let the water get away quickly or pump the water away. Flowing water will reduce the effect of anoxia (absence of oxygen) and draining flood levels quickly will reduce root damage.
- For perennial orchard production systems, a risk assessment for soil contamination due to flooding is recommended. Foodborne pathogens such as *Salmonella* can survive in the soil for months depending on soil type, moisture and climatic conditions. Testing of soil samples for various foodborne pathogens is recommended for crops grown in proximity to soil or likely to be in contact with soil (e.g. macadamia nuts).
- For annual crops (e.g. vegetables), flood-affected fields should not be replanted for at least 30–60 days after the water recedes. The waiting period for replanting is based on the known die-off rates of pathogens and other factors such as temperature, weather, and soil type. Replanting with fresh produce crops such as leafy vegetables, herbs, melons and strawberries is not recommended. Crops with edible parts away from the soil and that are likely to be consumed after cooking or processing are more suitable for replanting.
- The United States Food and Drug Administration (US FDA) recommends segregating flood-affected crops from non-affected crops with a 10 m buffer zone to prevent cross contamination. Conducting thorough risk assessments of flood-prone areas and implementing appropriate mitigation strategies are important for managing flooding risks.
- Enhancing hygiene practices during harvesting, processing, and transporting fresh produce, along with regular testing and monitoring of water sources used in preharvest and postharvest operations, are among the practical management options.
- Poor drainage is further exacerbated by wheel ruts created by tractors and implements operating on wet soil; this should be avoided.

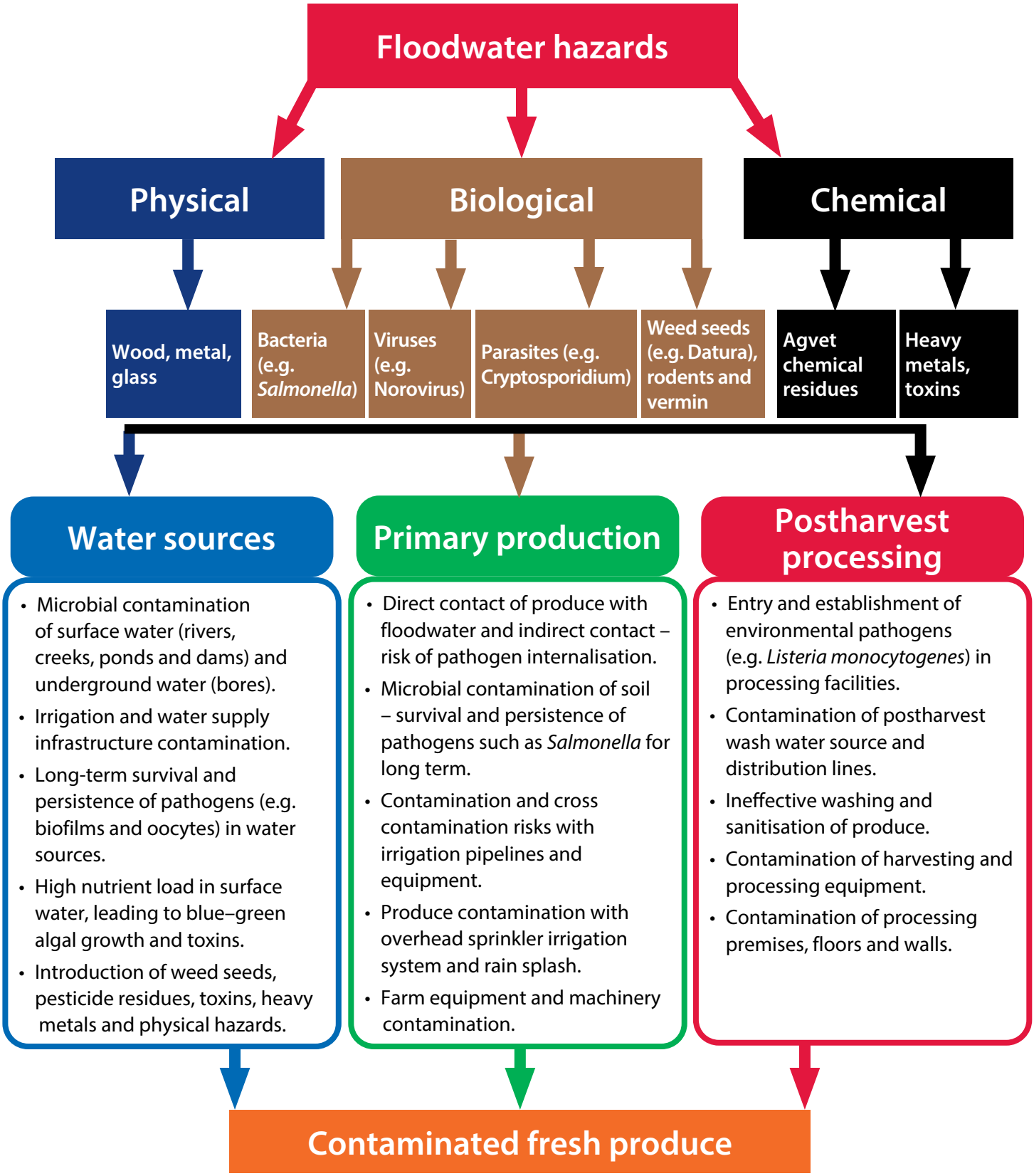

Figure 11. Floodwater as a source and route of microbial contamination in fresh horticultural produce adjacent to livestock, industrial and residential areas. Source: Singh (2023).

Check water sources

The nature and location of the water source determine the influence of extreme wet weather on water quality and suitability for various purposes. Surface waters (e.g. rivers, creeks, ponds and dams), which are more exposed to the environment and run-off, are more susceptible to contamination after extremely wet weather. The following key factors should be considered while conducting risk assessments of water sources:

- Livestock activity on-farm and its surroundings, including the run-off direction and management.
- Upstream microbial contamination of water sources (e.g. rivers, creeks) due to the proximity of animal operations (e.g. piggery, poultry, cattle) and wildlife in the region.
- Other on-farm factors such as compost yards, manure storage areas, and septic tanks should be considered for their potential role in water contamination.
- All water source equipment and infrastructure that has been affected must be completely cleaned and disinfected before being used. This includes all irrigation lines, storage tanks, pumps, taps and other equipment.

Water sources should be sampled and tested to ensure their suitability for irrigation (*Escherichia coli* <100 cfu/100 mL) and cleaning and handwashing (*E. coli* <1 cfu/100 mL). Should irrigation water come in direct contact with fresh horticultural produce to be consumed raw, the quality of irrigation water, if used within 48 hours of harvest, should be the same as for postharvest cleaning and handwashing (*E. coli* <1 cfu/100mL). Any results outside these parameters indicate water is unsuitable for use, and treatment or alternate sources must be used. Some examples of places that carry out this type of water testing include NSW DPIRD (https://www.dpi.nsw.gov.au/about-us/services/laboratory-services/water-quality) and Envirolab (https://www.envirolab.com.au/). For more details, refer to *Flooding adversely affects fresh produce safety* (https://www.publish.csiro.au/ma/MA23054).

Recovery phase

General advice

Prioritise blocks: it might be tempting to try and get to the worst blocks first, but it would be worth considering prioritising the blocks that require less effort and will give you a better return on investment.

Plants that have been fully submerged in flood water might have dying or dead leaves and potentially branches. Check branches by scraping back the bark; if it is green, it is still alive, but if it is brown, it has died. Remove dying or dead branches as they can become an entry point for disease organisms or a breeding ground for insect pests.

Diseases and pests

Many diseases are more active in wet, humid conditions. Where water is ponded or soil is waterlogged, the humidity will increase, adding to disease pressure. This should be factored in when considering disease control programs.

As part of the plan for disease control, a monitoring program should be implemented and be based on identifying areas infected by pests and diseases, with thresholds for control used.

More information on crop monitoring tools can be found in *Monitoring tools for crop protection* (https://ausveg.com.au/biosecurity-agrichemical/crop-protection/monitoring-tools-crop-protection/).

Diseases likely to occur after prolonged wet weather and flooding

Table 1. Common diseases found on subtropical horticulture crops due to prolonged wet weather and flooding.

Disease (common name)	Avocados	Bananas	Blueberries	Macadamias
Anthracnose	leaf and fruit lesions (*Colletotrichum* spp.)	fruit lesions (*Colletotrichum musae*)	fruit lesions (*Colletotrichum simmondsii*)	husk rot (*Colletotrichum* spp.)
Banana leaf spot		leaf lesions (*Pseudocercospora musae*)		
Blueberry rust			leaf and fruit lesions (*Pucciniastrum minimum*)	
Botrytis			flowers and fruit (*Botrytis cinerea*)	flowers (*Botrytis cinerea*)
Branch dieback				branches and trunk (*Dothiorella ribis*, formerly *Botryosphaeria ribis*)
Husk spot				nuts (*Pseudocercospora macadamiae*)
Phytophthora	roots (*Phytophthora cinnamomi*)		roots (*Phytophthora* spp.)	roots (*Phytophthora cinnamomi*)

Pests likely to occur after prolonged wet weather and flooding

Table 2. Common pests found on subtropical horticulture crops due to prolonged wet weather and flooding.

Disease (common name)	Avocados	Bananas	Blueberries	Macadamias
Banana weevil borer		stem (*Cosmopolites sordidus*)		
Bark beetles				trunk and branches (*Cryphalus subcompactus*)*
Red-shouldered leaf beetle	leaves, shoots and flowers (*Monolepta australis*)		leaves, fruit and flowers (*Monolepta australis*)	flower racemes, young nuts and lush foliage (*Monolepta australis*)
Trunk boring moths			trunk (*Idiophantis habrias*)	

*Bark beetles are an issue due to stress from water logging and/or submergence but not prolonged wet weather.

Avocado

Diseases

Anthracnose

Anthracnose is caused by *Colletotrichum* spp. Infection occurs in the field, but the fungus remains latent until the fruit ripens, then the fungus resumes growth, and the fruit starts to rot (Figure 12). This means fruit infected with anthracnose can rarely be identified at packing and are usually only discovered when being prepared by the consumer.

Tactics for managing anthracnose in avocados include selecting a suitable planting location (high humidity favours disease), cultural practices to remove dead limbs and mummified fruit that can contribute fungal spores, applying fungicides (before and/or postharvest), careful fruit handling, managing crop nutrition and controlling fruit storage conditions.

Pruning (Figure 13) and appropriate plant densities allow good aeration of mature tree canopies, so wet fruit and foliage dry quickly after rainfall, which helps to inhibit anthracnose infections. Minimising wounds to fruit skins during and after harvest, and managing stinging insect pests, will also help to reduce postharvest disease development.

Figure 12. Anthracnose lesions on avocado fruit. Photo: Dann et al. (2020).

Figure 13. Third year pruning in avocados. Photo: Avocados Australia Limited (https://avocado.org.au/bpr-articles/page/22/).

Phytophthora root rot

Avocado trees are highly susceptible to *Phytophthora cinnamomi*, the water mould that causes phytophthora root rot. When soil is thoroughly waterlogged, the long-term survival spores of phytophthora will not be very active. However, as the soil begins draining and becomes more aerated but still moist, phytophthora spores will thrive.

Managing phytophthora requires an integrated program. A treatment with phosphorous acid will be most effective when the trees are in a well-drained location and have a good layer of mulch around them. When deciding to treat with phosphorous acid, inspect the roots for signs of root rot by digging up feeder roots (Figure 14) and looking for sloughing-off of the root cortex (i.e. layers of tissue peeling off the root surface), leaving behind the thread-like stele (the central cylinder of vascular tissue) of the root (Figure 15).

Phosphorous acid should be applied when the roots are growing because it will go to the growing parts of the tree when it is applied. Only apply when the leaf flush has hardened and the roots are actively growing. Phosphorous acid can be applied by injection or foliar spray. Only use the foliar method if the trees have a full and healthy canopy of leaves as this enables sufficient chemical uptake. In other cases, use the trunk injection method unless the trees are too young to inject, then use enough foliar spray volume to thoroughly wet the bark and leaf canopy.

Figure 14. Sampling roots to assess root health. Photo: Jay Anderson, Southern Cross University.

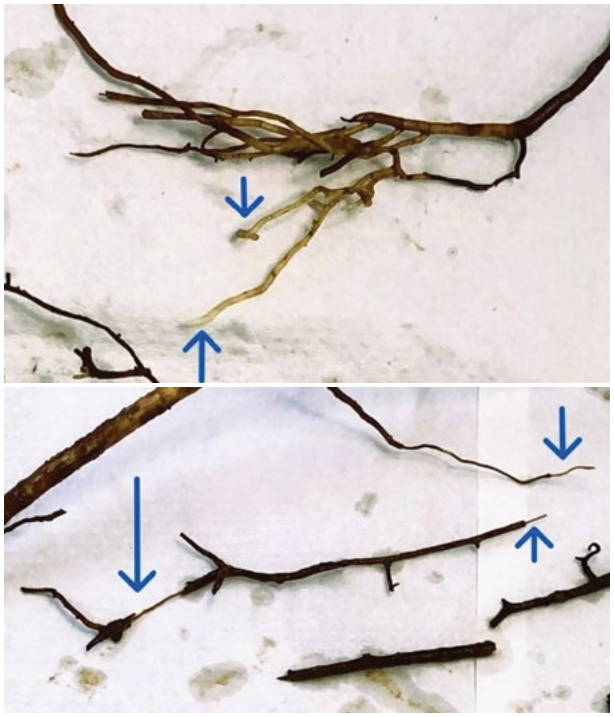

Figure 15. Healthy white avocado roots (top) and rotted roots with a sloughed-off cortex (bottom). Photos: Jay Anderson, Southern Cross University.

Insects

Red-shouldered leaf beetle

Red-shouldered leaf beetles (*Monolepta australis*) are 6 mm long and yellow, with a dark red band across the shoulders and 2 purple spots on the ends of their wing covers (Figure 16). The beetles use grassroots for breeding when the soil moisture levels allow large numbers to survive. This is why it is common to see outbreaks of large populations after floods. If larval populations in the soil are high, the emerging beetles will form an aggregation, and swarms can migrate into avocados at any time of the year, causing serious damage within 2–3 hours (Figure 17).

Check flowers and new growth for beetles, particularly following the first substantial rain after a dry spell. Disregard individual beetles or groups of fewer than 10. Only swarming beetles in a feeding frenzy cause damage. Control is necessary when beetles are active and damage is evident. Consider the effect on bees if spraying is required at flowering.

Planting *Eucalyptus torelliana* (Cadaghi) as a windbreak is highly attractive to these beetles and is useful for early detection and control. Yellow sticky traps in boundary trees can provide an early indication of beetle presence.

Figure 16. Red-shouldered leaf beetle (*Monolepta australis*).

Figure 17. Damage to avocado plants from red-shouldered leaf beetle (*Monolepta australis*).

Case study: Laurel Park Avocados, Tom Silver, Northern NSW

What crop do you grow?

We are a family business that has been running for 37 years. We grow avocados and have trees with a range of ages.

How were you affected by the wet weather in early 2022?

During the weather of early 2022, we saw an overall decline in tree health. Much of the initial tree deaths occurred simply through waterlogging of the soil. Overall, we lost or removed over 1,000 avocado trees.

Phytophthora root rot is favoured by wet weather, and it definitely affected tree health. It was also difficult to get access for management activities on the farm.

Figure 18. Tom Silver, avocado grower on the Northern Rivers.

What did you do to manage the effects of the weather in early 2022?

As we know phytophthora can be a problem, we made sure that we mounded up the rows well and incorporated organic matter into those rows when we set up our most recent blocks a few years ago. Those trees still showed signs of phytophthora but were the first to grow new roots. We also pruned to reduce the canopy size to match the root size. The trees get lots of mulch to give the roots a good place to grow.

What did you learn or will do differently next time?

Some trees just did not come back as well as we would like and will always struggle, so we knocked them out. They were not the greatest nursery stock to start with, so it just reinforced that it is essential to start with plants with healthy, vigorous roots.

Before re-establishing blocks, we installed sub-surface drains, which have been excellent and are already making a big difference. In future, all avocado plantings we do will have sub-surface drains. We have also decided to diversify and plant citrus in areas of the farm that would be too difficult to return to avocado production.

Banana

Diseases

Anthracnose

Anthracnose in bananas is caused by *Colletotrichum musae*. This fungus causes dark, sunken spots or lesions, often with a raised rim and masses of pink spores (Figure 19). Immature fruit do not show infection until they ripen. Disease development after harvest results from fruit infection on bunches before harvest. The fungus can remain dormant in green fruit for many months. *C. musae* can infect bracts, flowers, petioles and leaves of banana plants but the fungus can remain dormant in green fruit for many months (Jones and Slabaugh 1998).

Figure 19. Anthracnose symptoms on banana fruit include dark sunken lesions and pink spores.

Practices to help prevent the disease include using bunch covers to cover bunches as soon as possible after emerging to protect young fruit, careful fruit handling, using fungicides, and controlling fruit storage conditions (ethylene).

Banana leaf spot (yellow sigatoka)

Banana leaf spot (also referred to as yellow sigatoka) is caused by *Pseudocercospora musae*, a fungus that causes leaf lesions. Symptom development of yellow sigatoka is broken up into 5 stages (Figure 20).

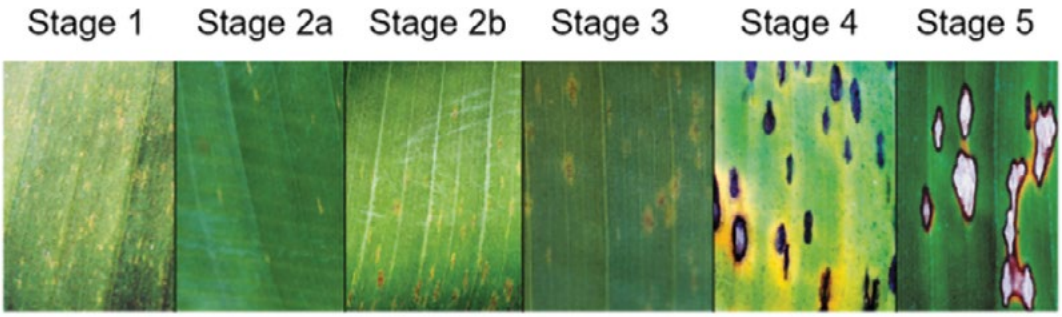

Figure 20. The 5 stages of yellow sigatoka symptom development. Source: Better Bananas (https://betterbananas.com.au/2024/02/07/yellow-sigatoka-leaf-spot-general-information/).

The disease causes leaf lesions and leaf death, leading to reduced photosynthetic capacity, which can cause smaller bunch sizes and delayed fruit development. In severe cases, there can be mixed ripening, which could affect market access.

Banana leaf spot is a very difficult disease to control in warm, wet conditions. An integrated disease management program involving cultural and chemical measures is required. Cultural practices aim to reduce spore levels in the crop and humidity levels around the leaves. De-leafing removes infected leaves from the canopy and helps keep disease inoculum levels low.

Both protective and systemic fungicides are available to manage yellow sigatoka. Each chemical group has a different mode of action and an important role in a spray program, influencing when these products should be used. Protective fungicides help to prevent the development of yellow sigatoka and should form the bulk of applications throughout the year. Systemic fungicide activity is limited to the early stages of the disease (stages 1 to 2b). These products do not affect lesions beyond stage 2b (Figure 19), and applying these products to lesion stages 3, 4 and 5 encourages fungicide resistance. Therefore, systemic fungicides should be applied when conditions are conducive to disease development (warm and wet weather) and not when the symptoms are obvious.

Insects

Banana weevil borer

Banana weevil borer (*Cosmopolites sordidus*) adults are about 12 mm long, hard-shelled and have a pronounced snout (Figure 21). The larvae tunnel within the corm that is below the soil surface. When there are large populations, tunnels are found through most of the corm tissue and a short distance up the pseudostem.

This tunnelling (Figure 22) weakens the plant and renders it susceptible to 'blowdown' in windy weather. Heavy infestations interfere with the movement of nutrients to the plant, and plants appear unthrifty. In severe cases, the young suckers wither and fail to develop.

Always use weevil-free planting material from weevil-free blocks, plant nurseries, or tissue-cultured plantlets. When replanting into old banana land, all banana residue must be destroyed, and the land left fallow for at least 6 months after all residue has rotted down to prevent carry-over of adult borers.

If the average banana weevil borer counts from bait trapping are more than 2 to 4 per trap, registered chemical treatments should be applied according to label directions.

A commercial pheromone (Figure 23) is available in Australia and can be used to monitor populations of this pest. It lures female and male adult banana weevil borers and can help inform chemical management.

Figure 21. Banana weevil borer adult (left) and larva (right). Photo: Donna Chambers, Queensland Department of Agriculture and Fisheries.

Figure 22. Dark tunnelling pattern from the borer in the corm. Photo: Better Bananas (https://betterbananas.com.au/2023/10/16/banana-weevil-borer-general-information/).

Figure 23. A commercial pheromone is available for banana weevil borer.

Case study: banana grower, Coffs Harbour, NSW

What crop do you grow?

I have been growing bananas my entire life, following on from my grandfather and father and now my son is involved in the business too. Our family have been growing bananas since the 1980s. We have 10 hectares of Cavendish bananas on some very steep slopes (e.g. >10 degrees or approximately 15% slope gradient). In Coffs we face a wide range of climatic conditions, including strong winds and unpredictable rainfall varying from valley to valley. Planning for the worst is crucial in such an unpredictable climate.

How were you affected by the wet weather in early 2022?

We had some damage from the severe weather in 2022, but the investment we made in slope and water management beforehand significantly reduced the amount of damage.

What did you do to manage the effects of the weather in early 2022?

We focused on preserving the soil by making modifications such as grassing gullies, fixing drainage farrows, and maintaining roads.

Some of the things we have found to work best include putting a concrete layer over rocks in the furrow to minimise degradation (Figure 24), putting in concrete tracks with steel reinforcement and pinned to the ground (Figure 25), using high-quality road gravel and having it compacted and sealed (Figure 26), having a water slowing point at the bottom of the hill that connects to the spillway (Figure 27) and using a carpet layer to further help minimise erosion of drainage furrows (Figure 28).

Figure 24. A concrete layer over rocks minimises furrow degradation.

Figure 25. Steep slope concrete tracks with steel reinforcement and pinned to the ground.

Figure 26. High-quality road gravel compacted and sealed.

Figure 27. The bottom of a hill with a rock-based water slowing point that connects to the spillway.

It is hard to invest considerable amounts of money to manage water on your property, as it is hard to grasp the financial benefits or reductions in productiveness if you do not do anything. Only after the work was complete did I see the investment's benefits. All this work was not without its challenges though; it was hard to spend money on grassing drainage areas that might fail. Finding contractors with a sufficient understanding of water flow and sourcing the stone and gravel for improvements were also challenging. It is important not to overcomplicate drainage designs; my advice is to take responsibility for understanding the natural features of your land.

Figure 28. A carpet layer to minimise erosion of a drainage furrow.

We also used modern technology and practices typically seen on public roads or civil construction work. For example, we used a wet seed spray gun to apply and sow seed along the steep bank next to the roads or gullies.

What did you learn or will do differently next time?

Some of the key lessons that we have learnt that other growers should consider if taking a similar journey are:

1. **Contractor selection**: finding the right contractor is crucial. Understanding the job, its purpose, and the intended outcomes, is essential. Managing earthworks for water flow requires experienced, knowledgeable planning and skilled earthmoving contractors. It is more than just placing rocks in a gully; it involves understanding the water dynamics and the potential effects the new design will have on your property.
    - We recommend seeking advice from a suitably qualified professional to design earthworks, especially where land is steep and landslides are possible.
2. **Consider your actions**: every action on the farm has a reaction, and this should be carefully considered when making changes to topographical features. For example, using grass furrows might seem like a simple solution, but it can have unintended consequences. In some cases, it might disrupt water flows, redirecting water into vulnerable areas and exacerbating existing issues.
3. **Incremental approach**: trying to fix all drainage issues at once is not practical or effective. Managing and changing drainage areas are ongoing processes that require a thoughtful and patient approach. Implementing changes gradually allows for careful observation of their effects and adjustments as needed, leading to more sustainable and effective solutions in the long run.

By doing this work over time, we managed to prevent substantial soil and nutrient loss from the property, which meant we could allocate resources towards investment in other areas such as fertilisers and soil conditioners. We are committed to furthering our sustainability efforts, such as by reusing old carpets from housing to seal drain furrows. Hopefully, these ongoing practices will help the farm's long-term viability and will assist the family in continuing to grow through the next generations.

Blueberry

Diseases

Anthracnose

Anthracnose affects blueberries and is caused by *Colletotrichum* species fungi, mainly *Colletotrichum simmondsii*. Anthracnose develops in moist conditions with temperatures between 20 and 27 °C. Spores are released during warm, wet weather and are spread by rain splashing onto blossoms and green berries.

Figure 29. Orange spore masses characteristic of anthracnose. Photo: Carolyn Teasdale, ES Cropconsult (https://fieldguide.bcblueberry.com/anthracnose/).

Infection on fruit begins during flowering, but the fruit appear symptom-free until berries ripen. The first symptom will usually be berry shrivelling, and then the characteristic sunken lesions will develop, particularly during warm, moist conditions. On ripe fruit, orange–pink spore masses form during humid conditions (Figure 29). Symptom development is often delayed until after harvest.

Regular pruning allows air circulation in the canopy and reduces drying time after the bushes have become wet. Removing all dead twigs, fruit and pruned material from blocks also helps reduce the disease level in the field. Botector® is a biological fungicide containing a naturally occurring fungus, *Aureobasidium pullulans*. It is registered in blueberries for the suppression of anthracnose.

Blueberry rust

The fungus *Pucciniastrum minimum* (syn. *Thekospora minima*) causes blueberry rust. Spores spread from old infections to infect new tissues. Infected leaves remaining on the plant after pruning can become an inoculum source for new infections. Young leaves are most susceptible to infection. Periods of leaf wetness (e.g. 7 hours at 21 °C) are required for infection.

Early blueberry rust signs will appear as small chlorotic (yellow) spots on upper leaf surfaces. As the disease develops, the spots become larger and turn dark red–brown (Figure 30), then merge and become necrotic. Yellow-orange pustules develop on the corresponding lower leaf surface (Figure 31).

Figure 30. Progressive blueberry rust symptoms.

Cultural practices should be used to minimise conditions favourable for infection and the spread of blueberry rust, as well as to improve spray deposits on foliage. These practices include:

- Orientating rows in the direction of prevailing winds or northern facing slopes (where possible) to encourage airflow and using appropriate planting densities to help minimise crowded canopies.
- Pruning to open the canopy will promote ventilation and reduce the time that leaves remain wet and conditions are favourable for rust infection. Opening the canopy can also improve fungicide contact and penetration.
- Preventing water from pooling in the orchard as this leads to high humidity, which can encourage blueberry rust infection. Ensure that wet and boggy areas are eliminated via better drainage.

Figure 31. Orange pustules on the underside of the leaf surface.

Botrytis (grey mould)

Botrytis cinerea is a fungus that causes blossom blight during flowering and fruit rot during postharvest handling and storage. Infections occur in the field during flowering, so this is the most effective time to implement control. *Botrytis cinerea* is always present but causes serious losses when the weather is wet and cool for several consecutive days. Infection is favoured by high relative humidity, fog and long wet periods.

Blossoms are the most susceptible tissue, turning brown when infected (Figure 32) after only a few days of high relative humidity. In continued humid conditions, masses of grey mycelia and spores are produced on blighted blossoms.

Figure 32. Blueberry flowers infected by *Botrytis cinerea*.

Remove infected fruit and plant material from the orchard, as each infected fruit with spores can infect more flowers and fruit. Blueberries should be pruned annually to keep the canopy open and improve air circulation. This will help the plant dry after it has become wet from dew or rain. Several biological and traditional fungicides are available for controlling botrytis in blueberries. Always follow anti-resistance strategies on the fungicide label and rotate with different modes of action to prevent fungicide resistance for *Botrytis cinerea*.

Phytophthora root rot

Phytophthora species cause phytophthora root rot in blueberries. Moisture is required for disease reproduction and spread. Fine feeder roots are infected, compromising water and nutrient uptake. Phytophthora root rot develops when soil temperatures are greater than 12 °C, where there is poor drainage, water ponding, heavy soil types or low levels of organic matter.

In blueberries, early symptoms are often above ground and include leaf yellowing and wilting (Figure 33), resembling drought or water stress. As the disease advances, stunting of terminal growth, leaf necrosis and plant dieback can occur. Below-ground symptoms include young rootlet and crown necrosis, with the main roots turning reddish–brown. Disease symptoms might follow drainage lines as the pathogen can be spread by water.

Figure 33. Foliar symptoms of phytophthora root rot. Photo: M Rocchetti, Costa Berries.

Management for phytophthora root rot includes:

- Sourcing new planting material from phytophthora-free nurseries.
- Prepare new sites by mounding and improving soil organic matter using cover crops and manure. Ammonia and volatile organic acids released by decomposing organic material reduce phytophthora spores and stimulate beneficial microorganisms. Incorporating gypsum into planting sites also helps to act as a weak fungicide and reduces the movement of spores in the soil.
- In heavy soil types or high rainfall areas, grow blueberries on mounds with good drainage in the inter-row. In high rainfall areas, blueberry mounds should run up and down the slope for quick drainage rather than across the contours.
- Avoid planting in poorly drained sites or improve the drainage before planting.
- Grow rooted cuttings or nursery plants on raised beds and avoid over-irrigating and ponding.
- Monitor irrigation to avoid over-watering and waterlogging.

Insects

Blueberry stem girdler

Blueberry stem girdler (*Idiophantis habrias*) was reported to be causing damage in blueberries around Corindi, NSW, in 2015. After the extreme wet weather on the Mid-North Coast in 2022, this pest started to cause damage in other areas.

The adult moths have brown forewings, each with a white area near the base, a dark triangle on the middle of the costa, and a network of yellow lines along the margin (Figure 34).

Figure 34. Adult blueberry stem girdler (*Idiophantis habrias)*.

The first symptom of blueberry stem girdler damage in blueberries is discolouration of the bush and frass on the crown. Branches might also easily detach from the plant. This is because blueberry stem girdler ringbark the crown of the bush, producing callused tissue and killing off branches (Figure 35).

There are very few control methods available for this pest. An *Ichneumonid* wasp has been found to be a potential biological control method.

Figure 35. Typical damage caused by blueberry stem girdler (*Idiophantis habrias)* includes ring barking and calluses at the crown of blueberry plants.

Red-shouldered leaf beetle

Red-shouldered leaf beetles (*Monolepta australis*) are 6 mm long and yellow, with a dark red band across the shoulders and 2 purple spots on the ends of their wing covers (Figure 36). The beetles use grassroots for breeding when the soil moisture levels allow large numbers to survive. This is why it is common to see outbreaks of large populations after floods.

Figure 36. Red-shouldered leaf beetle (*Monolepta australis)* adult.

Adult beetles attack leaves, fruit and flowers. High populations will shred leaves and strip plants of flowers (Figure 37). Hatching occurs from grassed rows in spring through to autumn after rain. Infestations are likely after heavy rainfall (20–40 mm) in spring and summer.

Effective control can be achieved if incursions are discovered early and are spot-sprayed before they disperse to the rest of the orchard. Check crops after heavy rainfall as populations greater than 20 beetles per square metre will cause significant damage. *Eucalyptus torelliana* is highly attractive to red-shouldered leaf beetle and is useful for early detection and control. Yellow sticky traps in boundary trees provide an early indication of beetle presence.

Figure 37. Damage to blueberry flowers and young flush caused by red-shouldered leaf beetle (*Monolepta australis)*.

Case study: tunnels for managing diseases, blueberry grower, Corindi NSW

How were you affected by the wet weather in 2021 and 2022?

I have been growing blueberries on the Mid-North Coast for the last 8 years. The high-intensity rainfalls and continual wet weather in 2021 and 2022 made it hard to manage our blueberries effectively. Most of our blueberries were out in the open and only under netting. Continuous wet weather makes it difficult to control diseases such as blueberry rust (Figure 38) and botrytis.

The wet weather increases disease pressure and prevents you from being able to get out and spray to reduce the damage. It also means that you cannot get out to harvest the blueberries on time (Figure 39), which can result in production losses and reduced shelf life.

Figure 38. Blueberry rust from extreme wet weather.

Figure 39. Fruit drop caused by extended periods of wet weather, which prevents picking.

What did you learn or will do differently next time?

We decided to put a protective cover over our blueberries instead of netting. Since 2021, we have gone from having 0 to 15 hectares of tunnels over our blueberries (Figure 40). As most diseases rely on leaf wetness to germinate and spread, the covers have greatly benefited disease management and allowed us to pick in wet weather.

In some blocks, we had 90% damage to bushes from blueberry rust and botrytis when they were growing out in the open and exposed to wet conditions. Since we put up the tunnels, we have seen only about 10% damage from these diseases. The savings have been significant. It has also meant that we have reduced spraying by 30%, significantly reducing chemical and operational costs.

Figure 40. Blueberries grown in tunnels.

Macadamia

Diseases

Botrytis blight

Caused by the fungus *Botrytis cinerea*, botrytis blight occurs mostly in mature flowers, especially during wet, humid weather with temperatures between 18 and 22 °C. Light rain or heavy dew can disperse the spores and outbreaks usually occur when showery weather prevails during this temperature range.

Figure 41. Botrytis blight. Photo: Femi Akinsanmi, University of Queensland.

Diseased flowers appear dark brown and cluster on the raceme with fungal strands and greyish fungal spores (Figure 41). Complete destruction of the raceme can follow with grey fuzzy mould covering dead flowers. Dense canopies can increase botrytis blight risk, so opening the canopy for better air movement and thorough spray coverage will reduce infection risk. A good guide is to ensure that tree height is only 80% of the row width. Temperature and moisture play an important role in deciding when to spray; the aim is to have fungicide in place before flower petals start to turn brown.

Branch dieback

Branch dieback is caused by the fungus *Dothiorella ribis*. Dieback symptoms will appear as gummosis (bleeding) on the infected branch or trunk. Early indicators of the disease include discolouration of the leaves, where the veins will turn reddish. On younger trees, the leaves will become dark khaki green.

Figure 42. A discoloured cross-section typical of branch dieback.

The affected plant parts die slowly while the disease progresses from the infection site to the roots. The infection will be present before the plant starts to develop symptoms. The bark at the infection site will appear darker than normal and water-soaked at the edges of the infection. Cutting the infected limb will reveal discoloured wedges at the cross-sectional area (Figure 42).

Branch dieback is becoming more prevalent, and its incidence and severity are strongly influenced by weather, especially high humidity and wet weather, which encourage the spores to spread. Any environmental stresses (e.g. too wet or too dry) and mechanical damage can weaken the trees, making them more susceptible to the fungus.

Strong sap flow is needed to reduce the incidence of the disease. When the tree suffers from prolonged waterlogging and stress, sap flow is reduced. This combined with warm, humid weather will create an environment for this disease to thrive.

Cut out dead branches until the cross-sectional cut is clean. Ensure the cut is done on an angle so that water does not pool on the fresh cut. If the discolouration continues, the whole tree might need to be removed. Dispose of infected material immediately. Do not make burn piles that are left in the orchard for long periods, as these will provide a perfect breeding environment for bark beetles.

Macadamia husk spot

Macadamia husk spot is caused by the fungal pathogen *Pseudocercospora macadamiae*. Most macadamia varieties are prone to husk spot, but it is more prevalent in those with sticktight husks (e.g. A16, A38, 816, Beaumont, and MIV1-P). Multiple and consecutive rainy days during early nut development increase infection rates.

Figure 43. Husk spot symptoms on macadamias. Photo: Femi Akinsanmi, University of Queensland.

Early symptoms of husk spot appear as pale yellow flecks with a diffuse halo on the husk. These spots become a darker yellow to tan-brown (Figure 43) and expand to 5–10 mm in diameter. Dry husk spots are woody and harder to cut through than unaffected husks. While the shell and kernel are not affected, macadamia husk spot can result in nuts dropping 4–6 weeks early. These nuts will be immature, have low oil accumulation and will be unsuitable for processing.

Studies have shown that removing sticktights from the trees will reduce husk spot infections. Macadamia varieties differ in their susceptibility to husk spot, which might be reduced or exacerbated by nut drop patterns. Earlier dropping varieties are considered less susceptible. The most susceptible varieties are Own Venture, H2, A16, A38, A268, 816, 842, and 849.

Cultural management for husk spot includes:

- Tree shaking reduces sticktights left in trees between seasons.
- Thoroughly cleaning the orchard floor of infected nuts that drop during nut development.
- Composting the husks to destroy spores before spreading them in the orchard.
- Managing the canopy to increase air movement and light in the orchard to reduce infection periods.

Macadamia husk rot

Husk rot and canker are caused by various fungi, including *Colletotrichum* spp., *Diaporthe* spp. and *Phomopsis* spp. These are more likely to appear after wet weather and warm temperatures.

Soft and spongy black lesions up to 10 mm in diameter will appear on the green fruit pericarp. These lesions can form greasy decay of the entire fruit pericarp. The husk rot fungi can spread rapidly and will discolour the whole husk.

Husk rot is different from husk spot; if pressure is applied to the damaged area, husk rot is quite soft, whereas husk spot lesions are hard.

Good orchard hygiene and insect control will help prevent husk rot. Removing old sticktight husks is a good practice to prevent the husk rot fungi from being dispersed by rain splash. Prune trees to allow good ventilation and remove and destroy old branches and cankers.

Phytophthora

Phytophthora disease in macadamias is caused by *Phytophthora cinnamomi*. It will often appear at the bottom of slopes where water can pond, on drainage lines and at the tops of slopes where soil has been eroded. Phytophthora becomes more apparent when trees are suffering, such as from nutritional or moisture stress.

Affected trees will look pale green and sickly (Figure 44). They will lack vegetative vigour, and leaves will turn yellow and drop. Trees can also be stunted. Soil health is important for preventing phytophthora. Compost, chicken manure, woodchip and husk will help improve soil health and inhibit phytophthora. However, be careful when adding fertilisers and animal manure that can release ammonia and salts as these can damage young roots.

Phosphorous acid should be applied when the roots are growing because it will go to the growing parts of the tree when it is applied. For foliar sprays, apply to affected macadamia trees at mature leaf flush during spring and autumn. Do not apply foliar spray of phosphorous acid to trees that are under severe water stress, during hot weather or to young leaf flush. In these circumstances, it is best to use the trunk application method and apply it to affected macadamia trees at root flush.

Figure 44. Macadamia trees affected with phytophthora look pale green and lack vegetative vigour. Photo: Femi Akinsanmi, University of Queensland.

Insects

Bark beetles

Unhealthy and dying trees are prone to infestations of many bark beetle species. When plants are waterlogged and stressed, they put out a stress signal that attracts the classic bark beetle, *Cryphalus subcompactus*, which enters through the bark due to the limited sap flow and feeds on the cambium layer. While feeding, it will lay hundreds of eggs along and around the stems. This feeding causes ringbarking (Figure 45) on the limbs, which can result in significant dieback and further entry points for other bark beetles.

Figure 45. Ringbarking caused by the bark beetle (*Cryphalus subcompactus*).

A clear sign of bark beetle infestation is dieback (Figure 46) and the associated exit holes of the branches (Figure 47). Any areas of dieback should be cut out of the tree. When cutting, check the cross-sectional cut. It should be clean and without any discoloured wedging. If wedging is apparent, it is an indicator of branch dieback (*Diothiorella ribis*). Keep cutting the branch lower until the cross-section is clear. If you find an affected tree that has beetle exit holes, regularly check nearby trees because when beetles leave an infested tree, they usually move onto other adjacent trees that are stressed or have low sap flow.

Figure 46. Bark beetle (*Cryphalus subcompactus*) was identified in these trees due to low sap flow following flooding. Photo: Jay Anderson, Southern Cross University.

All infested material should be burnt as soon as possible. Do not make a burn pile that will sit in the corner of the orchard for months, as this will provide a perfect breeding shelter for the beetles. If you cannot burn, such as during a flood, the next best option is to finely chip all dead and decaying timber. These can then be incorporated into a composting pile where temperatures range between 50 and 65 °C before turning. Another non-burn chipping option is to expose the chips to heat. This involves laying plastic over the chip pile and placing it in direct sunlight. Temperatures will reach over 70 °C, which is enough to kill the beetles.

Figure 47. Exit holes caused by newly hatched bark beetle (*Cryphalus subcompactus*).

The primary way to manage most beetle pests is to maintain healthy trees with optimum sap flow and standard orchard hygiene. If the tree has reasonable sap flow, the beetles cannot enter. When sap flow is reduced, for example, during long periods of flooding of the root system or due to disease, the beetles can tunnel into the stressed plant.

Red-shouldered leaf beetle

Red-shouldered leaf beetles (*Monolepta australis*) are 6 mm long and yellow, with a dark red band across the shoulders and 2 purple spots on the ends of their wing covers (Figure 48). The beetles use grassroots for breeding when the soil moisture levels allow large numbers to survive. This is why it is common to see outbreaks of large populations after floods. If larval populations in the soil are high, the emerging beetles will form an aggregation and swarms can migrate into macadamias at any time of the year. The beetle can destroy flower racemes. Young nuts and lush foliage are also attacked (Figure 49). High beetle populations will shred leaves. This is of particular concern for newly planted macadamia and nursery trees.

Check flowers and new growth for beetles, particularly following the first substantial rain after a dry spell. Disregard individual beetles or groups of fewer than 10; only swarming beetles in a feeding frenzy cause damage. Control is limited to spraying when beetles are active and damage is evident. Consider the effect on bees if application is required at flowering.

Planting *Eucalyptus torelliana* (Cadaghi) as a windbreak is highly attractive to these beetles and is useful for early detection and control. Yellow sticky traps in boundary trees provide an early indication of beetle presence.

Figure 48. Red-shouldered leaf beetle (*Monolepta australis)* adult.

Figure 49. Red shouldered leaf beetle (*Monolepta australis*) damage to macadamias. Photo: QLD Government Department of Agriculture and Fisheries (QDAF).

Due to macadamias being grown in multiple landscape locations (plateaus, hillsides and floodplains), the effects of extreme wet weather resulted in 3 major problems: submergence, inundation and washouts. The case studies reflect these 3 scenarios. The climate before extreme wet weather (e.g. drought) and after extreme wet weather are critical to how and whether an orchard can be managed to recover.

Submergence case study: Stibbards Creek Macadamias, Dungarubba, NSW (floodplain)

What crop do you grow?

Johan Jacobs and the Stibbard's team grow approximately 350 ha of macadamia cultivars 344, 849, A203, A38, MCT1 and G on sandy loam soil. The lowest planting is 2.1 m above sea level.

How were you affected by the wet weather in early 2022?

In February 2022, record amounts of rain fell, with 700 mm in 24 hours reported in the Northern Rivers region of NSW. Not only was the property submerged twice, but the soil was waterlogged and temperatures were cool for weeks afterwards. Macadamia plants aged from 1–3 years old were completely underwater (Figure 50) for 1 week and then submerged again a month later. The second submergence, just 4 weeks after the first, made management decisions difficult.

Figure 50. Flood levels above 3 m completely submerged 1–3-year-old macadamia trees. Photo: Johan Jacobs, Stibbards Creek Macadamias.

We were establishing Stibbards Creek Macadamias with trees aged from newly established to around 3 years old. In February 2022, we had abnormally high rainfall and then flooding. In places, the flood water was 3–4 m deep, which is way over the top of the young macadamia trees. We saw further rain after the major flood. This was followed up by a second flood, which was not as high as the first but still deep enough to put trees underwater again (Figure 51).

Figure 51. Trees went fully under flood waters twice within a month. Photo: Johan Jacobs, Stibbards Creek Macadamias.

We then saw dramatic tree decline, especially where trees had pushed bud from the first flood. Recovery now relied on our inputs from the start of building this orchard, including having the correct lime and pH in the mounds and applying organic matter over time to build the soil. It also relied on the soil we chose, which was a sandy loam. This gave us a better recovery time than if we were on heavy clay.

There was a varying rate of tree decline relative to rootstock and cultivar. Generally, Beaumont appeared to handle flooding better than H2. The 16–18-month-old MCT1 performed the best of all the cultivars. The 2–3-year-old trees of MCT1 had the best survival rate (Figure 52 and Figure 53), followed by 344, A38, A203, then 849.

Figure 52. Recovering MCT1 tree. Photo: Johan Jacobs, Stibbards Creek Macadamias.

Overall, we lost or removed 67% of the orchard. Some trees are still going down, so we will replace them. Certain blocks we will leave alone. Immediate recovery (1 week to 1 month) after the flooding was difficult due to the continual rain and difficulty accessing the blocks. The older tree losses ranged from 5–60%, depending on variety and rootstock. All the 1-year-old and newly planted trees were lost.

What did you do to manage the effects of the weather in early 2022?

Business as usual. Replace dead trees; in some sections, this meant transplanting trees from one area to fill up rows of another area. This gave us a year head start, and cost-wise, it was slightly cheaper than planting nursery trees. We are building the trunks and roots of the trees through regular pruning. Some cultivars have more extensive pruning than others. We prune low on the west side to high on the east side to combat the predominant SE wind. We aim to grow the tree into the wind rather than have a big sail (Figure 54). We also flat-top the G variety to create more of a round tree than a natural upright tree. We believe this frequent pruning intervention has created a more resilient tree for the floodplain conditions.

We also took soil samples soon after the flood to assess the soil. The floods stripped our contribution to the soil over the years and pH was low. We immediately amended these deficiencies and started our annual composting program again, with 4 kg/tree shovelled on.

What did you learn or will do differently next time?

Some trees just did not come back as well as we would have liked, and they will always struggle, so we knocked them out. They were not the greatest nursery stock to start with, so it just reinforced that it is essential to start with a healthy plant, which includes having a healthy, vigorous root system. Beaumont rootstock had a 30% higher survival rate than H2 with the same scion on top.

Figure 53. 2–3-year-old trees (in 2022) are now producing harvestable yields. Photo: Johan Jacobs, Stibbards Creek Macadamias.

Figure 54. Pruning at Stibbards Creek Macadamias to have trees grow into the predominant winds. Low on the west (right) and high on the east (left of tree).

Inundation case study: Tony Flick, Broken Head, NSW (floodplain)

What crop do you grow?

On the 45-hectare farm in Broken Head, I have mixed varieties of macadamias ranging from 1 to 3 years old.

How were you affected by the weather in early 2022?

Inundation is not unusual on floodplains (Figure 55), with trees going underwater up to the canopy several times a year. The problem was the continual rainfall after the flood. This made it extremely difficult to do some much needed repairs to the orchard floor and tree health. Another issue was the washout of all the amendments and good inputs we have been building the orchard with over the past few years. The biggest problem from the flood was not so much tree death but collaring (Figure 56) from the continuous wind pushing the tree trunks around the planting hole over a long period.

Figure 55. Water inundation in macadamias on the floodplains. Photo: Tony Flick.

What did you do to manage the effects of the weather in early 2022?

I started fixing the collaring issue by applying blue metal to secure the tree in the hole. Another problem was the trees sinking in their plant hole. This is created by using an auger when establishing a planting tree hole. The hole is slightly deeper than required and the refill below the plant roots gets too wet, causing the tree to sink further into the ground. These trees require replanting. Tree deaths were observed where the soil had more clay than the other areas on the farm. These trees were also replanted. The other areas of the farm, with predominantly sandy loam soil, dried fairly quickly once the water ran off, so delays in access were not too long, as was the case for other farms. Other issues were phytophthora and bark beetle, which caused sudden death. Affected trees were removed and replaced.

Figure 56. Collaring from the continuous wind pushing the tree trunk in prolonged wet soil.

As the orchard was pretty much stripped of organic matter and returned to a natural pH state, once the ground was dry enough, Tony started reapplying his special chicken manure and compost blend. He also corrected the low pH with agricultural lime (aglime).

What did you learn or will do differently next time?

When planting out, be aware of going too deep when digging the planting hole, especially when using an auger. Good site selection is the key to quick recovery and building resilience within the orchard. Be wary of poor sites as they do not recover easily. Secure trees will result in better/quicker recovery.

Water crystals used in drier times worked well then, but they created an environment where the plantings remained 'loose' in the planting hole. The flood washed out the soil surrounding the new plants, and they sank to the depth of the augured hole, which was too deep. The trees that were planted without the water crystals were more stable in their planting hole.

Wash out case study: Chris Cook, Dymocks Farm, Yarrahapinni, NSW

What crop do you grow?

We have 200 ha of macadamias and grow the varieties A16, A4, A38 and A29. The tree ages vary, ranging from 5 to 30+ years old. In the first 3 months of 2022, 1,444 mm of rain fell on our farm. Water went up to the tree canopies on the flatter land and there were washouts on the slopes. The flooding was long-term, with continuous rain and wet conditions for most of 2022. We had a total of 2,825 mm for the year; the long-term average rainfall is 1,466 mm. We did have some drier months, however, they still had above-average rainfall, severely impeding operations.

How were you affected by the weather in early 2022?

Dymocks Farm had both inundation and washouts. Washouts are fairly common on steeper macadamia farms with little organic matter and poor ground cover; however, this farm has years and years of good organic matter that binds the tree roots and grass covering the centres of the inter-rows. Usually, there is a little bit of orchard floor repair after some heavy rain, but 2022 was different. The water fell with such intensity that the force of the flow took away many years of hard work; tree roots were fully exposed from the washouts. Constant rain, nuts on the ground and labour shortages made it difficult to repair the damage to the orchard floor. We only lost a couple of trees from the rain in 2022; the losses came when we had the driest year on record in 2023 (590.4 mm).

What did you do to manage the effects of the weather in early 2022?

Having all the organic matter, soil and nutrition removed from the orchard caused major tree decline. We have been able to rectify most of the damage done by the rain, but with the lowest prices in history, we have not been able to spend as much money as I would have liked on labour and inputs. The dry weather we had last year was helpful from an operational perspective, but it was devastating for tree health. After suffering through 2 extremely wet years, the trees had diminished root systems due to widespread waterlogging. They also had very low carbohydrate reserves. When the extreme dry came, the trees did not have the required roots or energy to find water and nutrients. This inability to feed has caused significant dieback, with over 20,000 trees suffering. The areas that could retain the organic matter, typically the higher, flatter ground, did not suffer the dieback and have recovered quickly.

Rain in late 2023 and early 2024 increased the presence of phytophthora in the area. This, in combination with many trees having reduced root systems and the inability to grow new roots, has resulted in many trees suffering from dieback. The sheer number of trees that we need to treat for phytophthora is very high, so we have opted for foliar phosphorous acid treatments as a defence against phytophthora, which are just as effective as trunk applications. Also, we are trying to bring back the soil and amendments of organic matter (Figure 57) to give the new roots a better chance of thriving when funds allow.

Figure 57. Chris's plan for recovery is to replace the lost soil with compost to cover the roots and allow light to the orchard floor for good ground cover.

We are also watching our soil analysis results closely and trying to correct the deficiencies where possible. We want the trees healthy so they have a fighting chance against bark beetles that tend to attack stressed trees with low sap flow.

What did you learn or will do differently next time?

We lost a lot of root covering and saw the trees rapidly decline. This helped us understand the benefits of creating a better orchard floor that relies on light infiltrating the canopy. We also saw the importance of drainage systems and diversion banks, which suppressed what we could have lost.

We need to improve the resilience for both wet and dry times. Fortunately, this is the same for both conditions, e.g. integrated orchard management (IOM) stage 2.

Re-establishing phase

Extreme wet weather and flooding can lead to significant changes in your farm. If you are re-establishing horticultural crops, it is the best time to undertake significant remediation work to prevent problem areas from becoming worse.

Some of the key issues associated with extreme wet weather and flooding to be aware of when re-establishing are:

- changes in soil structure and compacted soil
- soil erosion, nutrient loss and depletion
- soil pH imbalances
- reduced soil organic matter and microbial activity.

Assessing site suitability and mitigating limitations

If sections of the orchard require replanting due to plant decline or death from submergence or waterlogging, keep in mind that some areas might be more suited to having the plants removed and the area used for another crop or purpose.

Before replanting, it is best to determine the limitations to the site, whether these can be overcome, and what is needed to correct them. While there are many factors to consider, some of the most common ones are drainage, erosion, and soil health and nutrients.

Drainage

Lidar mapping uses pulse lasers to map topographic elevations. Lidar can pinpoint elevation changes and determine which areas are more prone to flooding. It can also help identify areas around blocks that require better drainage to protect them from flooding.

Drains should be constructed to carry water away on a suitable grade from the orchard. The best practice for creating surface drainage consists of laser-guided machinery or a survey with an optical level to establish an accurate grade in the surface drains.

Building mounds for future tree rows might help in marginal areas if they are oriented to allow the water to drain away without pooling. These rows should be linked to designated grassed watercourses throughout the orchard to ensure this happens. Correct soil limitations before mounding.

Managing erosion and sediment

Intense rainfall can accelerate erosion, which contributes to soil degradation and water quality issues if left unmanaged. To respond to erosion caused by intense rainfall, you can:

- Construct flumes (Figure 58) to divert water away from slopes vulnerable to erosion and onto stable ground.
- Use coir logs, silt fencing, or hay bales to capture loose sediment from exposed slopes or paddocks or divert run-off away from areas of active erosion. Place silt fencing or coir logs across exposed slopes or drainage lines, or uphill of active erosion points. Secure with stakes that are cut level with the coir log or hay bale to reduce the risk of flood debris being caught.
- Use gravel compacted and sealed on main roads to reduce erosion on the main tracks (Figure 59).
- Use mulch on bare ground or plant cover crops to provide temporary ground cover and prevent erosion. Avoid applying mulch too heavily on regenerating areas to enable natural regeneration.

- When laying jute (Figure 60) or coir mesh over exposed slopes, make sure to anchor the mesh down securely using timber pegs, metal staples or rocks. Make holes in the mesh for planting seedlings to increase vegetation cover and stabilise the slope.
- Steep slopes are particularly vulnerable to erosion. Hydro mulching and aerial seeding are approaches to revegetate exposed slopes (Figure 61) quickly with minimal disturbance.

Figure 58. Concrete flume to divert water away from vulnerable slopes.

Figure 59. A compacted gravel driveway used to reduce erosion on the main track.

Figure 60. Jute mesh used to line a cross drain. Grass will grow through the mesh and break down afterwards. Photo: C Colmer, Soil Conservation Service.

Figure 61. Grassing slopes helps to reduce erosion in extreme wet weather.

Soil structure and nutrients

A healthy soil has a good structure with a crumbly texture and a good balance of air, water, and pore spaces. This allows water, nutrients, air, plant roots, and microorganisms to move through the soil freely. Soil organic matter additions can help improve soil structure, encourage healthy root development, promote microbial activity, and assist in managing phytophthora. Soil organic matter can be incorporated into the soil before replanting, with compost, mulch and manure being common materials.

Soil chemistry can be affected by extreme wet weather, with mobile nutrients such as nitrogen, phosphorus and potassium being washed out of the profile. The soil's pH and structure can also be affected. Before replanting, conduct a soil test so that any issues can be corrected. For slow-moving amendments (i.e. gypsum or lime), adding these before replanting is advisable to allow incorporation into the soil profile before planting. If damage to the root system after prolonged waterlogging is suspected, it is better to apply small amounts of fertiliser often to avoid burn and allow the root system to regrow.

For more information, refer to *Saving soil: a landholder's guide to preventing and repairing soil erosion* (https://www.dpi.nsw.gov.au/__data/assets/pdf_file/0008/270881/saving-soil-complete.pdf)

Available flooding assistance in NSW

There is a range of assistance options available in NSW for when you are affected by significant weather. Some of the most common are:

Local Land Services Flood recovery, https://www.lls.nsw.gov.au/floods/flood-recovery-resources

NSW Government Support to apply for grants, loans or payments, https://www.nsw.gov.au/emergency/recovery/support-to-apply-for-help

Rural Assistance Authority Storm and flood programs, https://www.raa.nsw.gov.au/disaster-assistance/storm-and-flood-programs

Resources

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NSW GOVERNMENT

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