Catchment-based assessment of drainage to assist water management on small farms

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Key points

- Catchment character, hydrological connectivity and land use influence drainage and water quality issues in agricultural catchments.
- Flow accumulation modelling from digital elevation data enables identification of drainage lines and flow entry/exit points associated with production nursery farm plots and their water storage areas.
- Farms in upper catchment positions typically generate runoff during storm events, whereas those further downstream are more exposed to inputs of stormwater from uphill and/or upstream.
- Catchment-based drainage assessment provides a practical basis for identifying hazards and supporting water management on farms, including mitigation of waterborne contaminants.

Abstract

Recent severe rainfall and runoff events have highlighted the importance of understanding the position and susceptibility of small farms to floods at a catchment scale. These conditions have significant implications for water management, as water may be captured and reused on-site, or else distributed through the surrounding landscape. Quantification of surface flow paths and water retention areas on farms is required to assist the management of water quantity and quality. We assessed factors including catchment setting, predicted wetness and flow accumulation, stream power, and major flow paths entering and leaving production nursery farms using a combined spatial analysis and field validation approach. High-resolution digital elevation data formed the basis of a flow accumulation model, from which flow entry and exit points and water storage areas could be identified at the farm scale. Production nurseries located in upper catchment positions generally had fewer tributary flow paths, and where flow exit points occurred, they may be prone to runoff and/or overflows during large rainfall/runoff events. Other production nurseries had more tributary flow paths and exit points and may be susceptible to water impacts from upstream catchment areas. Catchment-based assessment of drainage can assist water management on farms, including early identification of key hazards and risk areas for water storages and runoff into receiving waterways. This is highly relevant for management of waterborne contaminants in high intensity agriculture broadly and underlies a framework to identify and mitigate water storage contamination concerns at production nurseries in NSW and the ACT.

Keywords

Catchment position, hydrological connectivity, flow paths, contamination, stream power, water quality

Introduction

Water is a critical resource for agriculture and is central to the operation of plant production nurseries, which require consistent volumes of water to maintain plant health and productivity (NGIA, 2010). Increasing pressure on water resources, combined with variable hydroclimatic conditions, has led to widespread adoption of water capture and reuse practices in these agro-ecosystems. However, these practices also introduce challenges associated with runoff, flooding and water quality, particularly during high rainfall events.

Storms and floods such as those experienced eastern Australia in 2021 and 2022 can generate large volumes of runoff that mobilise sediment, nutrients, pesticides and biological contaminants across catchments. These materials may be transported into on-farm water storages or discharged to downstream environments, with implications for both agricultural production and aquatic ecosystem health. In production nurseries, runoff is commonly captured and recycled for irrigation, which can improve water use efficiency but may also increase the risk of contaminant accumulation and recirculation within the system (Gomes et al., 2025). The same is the case for many other intensive agricultural activities that require irrigation water (DPIE, 2020), so water and farm management should be informed by accurate and up-to-date information.

Catchment characteristics such as topography, land use and vegetation cover influence hydrological and sediment connectivity, which in turn controls the transfer of water and associated contaminants across landscapes. Connectivity reflects the interaction between land surface processes, climate and human activities, and plays a key role in determining whether water, sediment and material such as contaminants are retained, redistributed or exported from a system (Fryirs, 2013). Increased connectivity during rainfall and flood events can enhance the movement of water and contaminants through catchments and into farm properties, particularly where vegetation cover is reduced or drainage pathways are well developed.

An important aspect related to catchment connectivity is the position of a nursery farm within the catchment. Farms located near a catchment divide are typically dominated by rainfall inputs and generate runoff to downstream areas, whereas farms located further downstream may receive water from hillslopes, tributaries and floodplain flows. These differences influence both the quantity and quality of water available to farms and the degree to which they are exposed to external inputs (Gomes et al., 2025). Understanding these spatial relationships is therefore critical for assessing water-related hazards and developing appropriate management strategies. Considerations for management should include factors related to water availability, transfer, storage and release at both catchment- and farm-scales (Figure 1).

Recent work has emphasised the importance of integrating catchment-scale assessments with site-specific observations to support decision-making in production nursery systems (Ralph et al., 2025a; Ralph et al., 2025b). Mapping flow pathways, water storages and other features can provide a basis for identifying areas of potential risk and informing management actions before, during and after storm and flood events

This paper summaries an assessment of drainage characteristics at small nursery farms using a catchment-based approach, with a focus on identifying major flow pathways, water storage areas, and potential flow exit and entry points across scales. This information is used to evaluate and discuss how drainage patterns influence water management and potential contamination risks.

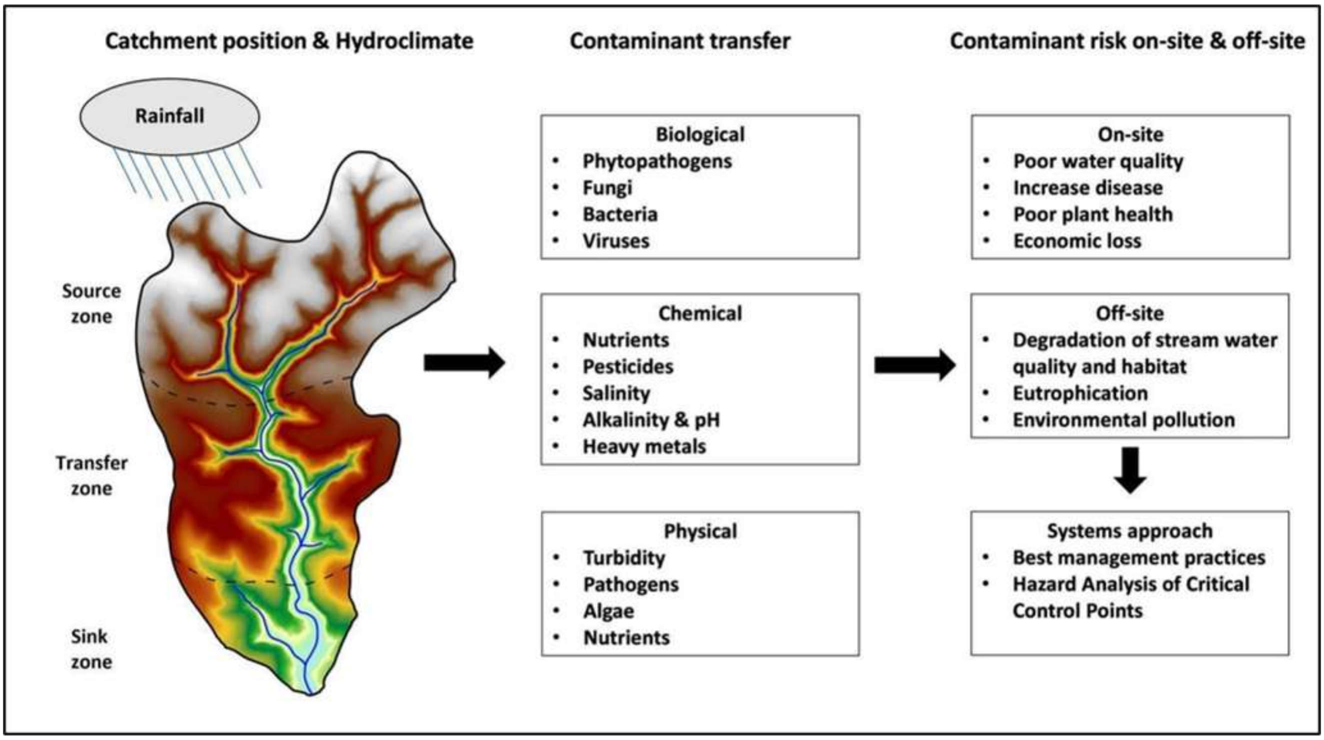

Figure 1 Factors that influence the transfer of biological, chemical and physical contaminants within catchments, leading to water contamination issues on farms and downstream systems (Source: Gomes et al., 2025)

Methods

Catchment and flow path mapping

The study area covered all of NSW and ACT, based on the member database held by Greenlife Industry NSW and ACT (GINA; formerly Nursery and Garden Industry NSW and ACT). Compilation of data from publicly available sources and analysis within GIS software allowed characterisation of the production nurseries by their location, lot size, and catchment context. Lot boundaries were derived from publicly available cadastre data (DCS, 2021) and relevant catchment boundaries extracted from the Australian Hydrological Geospatial Fabric (AHGF) database (BOM, 2022). On-farm water storages (e.g. lined and unlined dams) were digitised manually in GIS from ESRI high-resolution satellite imagery (ESRI, 2020), representing locations of water capture during rainfall events (Ralph et al., 2025a).

Within all catchments, potential surface water flow paths were derived using a flow accumulation model based on slope from a 5 m digital elevation model (DEM) (DCS, N.D.). The D8 single-flow direction model was used to simulate surface water flow paths where each cell is assigned a flow direction toward the steepest downslope neighbour among its eight surrounding cells. A contributing area threshold of 10,000 m^2 (equivalent to 1 ha or 0.01 km^2) was applied using the CON tool in ESRI ArcPro v3.2. This approach is consistent with established methods used to map drainage networks and flow pathways in agricultural catchments, where DEM-derived flow paths are a useful representation of potential water movement across the landscape (Ralph et al., 2021).

Catchment, waterway and lot data were collated in GIS. Flow paths were intersected with nursery farm lot boundaries to identify flow entry points (i.e. where water enters a property from upstream) and flow exit points (i.e. where water leaves a property). Field validation was undertaken at 10 nurseries to confirm drainage lines, evidence of runoff and erosion, and configurations of water storages and drainage infrastructure (Figure 2). Field observations are important for verifying DEM-based interpretations, especially where vegetation, infrastructure or land management influence flow pathways.

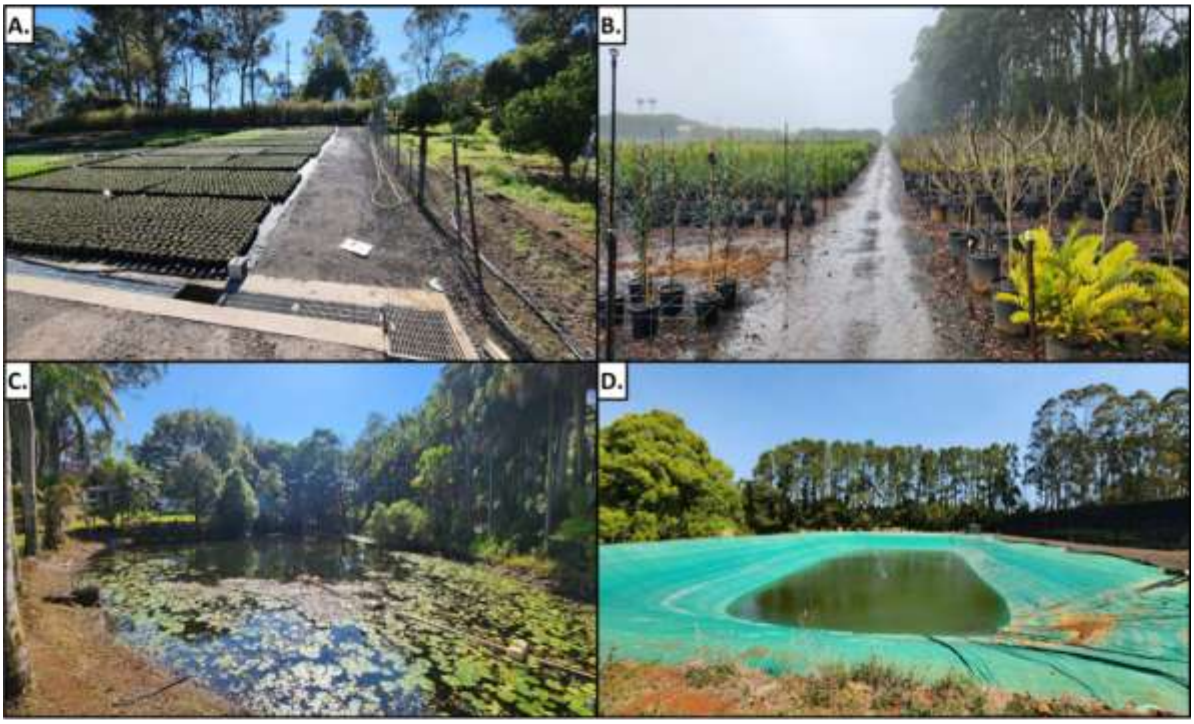

Figure 2 Examples of field validation photographs used to ground-truth maps and to understand flow paths and water storages. A) Plants on gravel beds with drains. B) Plants on gravel beds with storm water on a nearby track. C) Unlined water storage dam. D) Lined water storage dam

Topographic wetness and stream power

To support interpretation of flow paths and provide estimates erosion potential at the farms, topographic wetness index (TWI) and stream power index (SPI) were derived from the DEM data. TWI is a hydrological metric that gives an estimate of the spatial distribution of water accumulation potential across landscapes. TWI was generated in the ESRI ArcPro Raster calculator tool using catchment area and slope metrics following standard methods (Gallant and Wilson, 2000). TWI categories were defined using typical values:

- Minimal water accumulation (~5.5): Typically upper slopes with steep gradient and limited area.
- Moderate water accumulation (~7.3): Typically mid-slopes where water is likely to converge.
- Water accumulation (~11.5): Typically lower convergent areas.

SPI is a topographic metric that gives an estimate of the relative energy of surface flow and its spatial variability across a landscape. It combines the effects of upstream catchment area and slope to identify areas with some potential for erosion. SPI was generated in the ESRI ArcPro Raster calculator tool following the methods of Moore et al. (1988). Generally, higher SPI values indicate areas with greater flow accumulation and steeper slopes, which may be more prone to erosion than areas with lower SPI values.

Results and discussion

Catchment, drainage and lot characteristics

The results show wide variation in catchment setting, drainage patterns, and water storages at the nursery farms (Figure 3). Most were small (<0.1 km^2) and had relatively small contributing catchments areas (<4 km^2). More than half had <20 km of mapped drainage lines, although several farms had larger catchments and more extensive drainage networks. This indicates that most farms have relatively localised runoff sources, but that some are connected to much larger drainage networks and may therefore be more exposed to upstream runoff, sediment and contaminant transfer during large rainfall events.

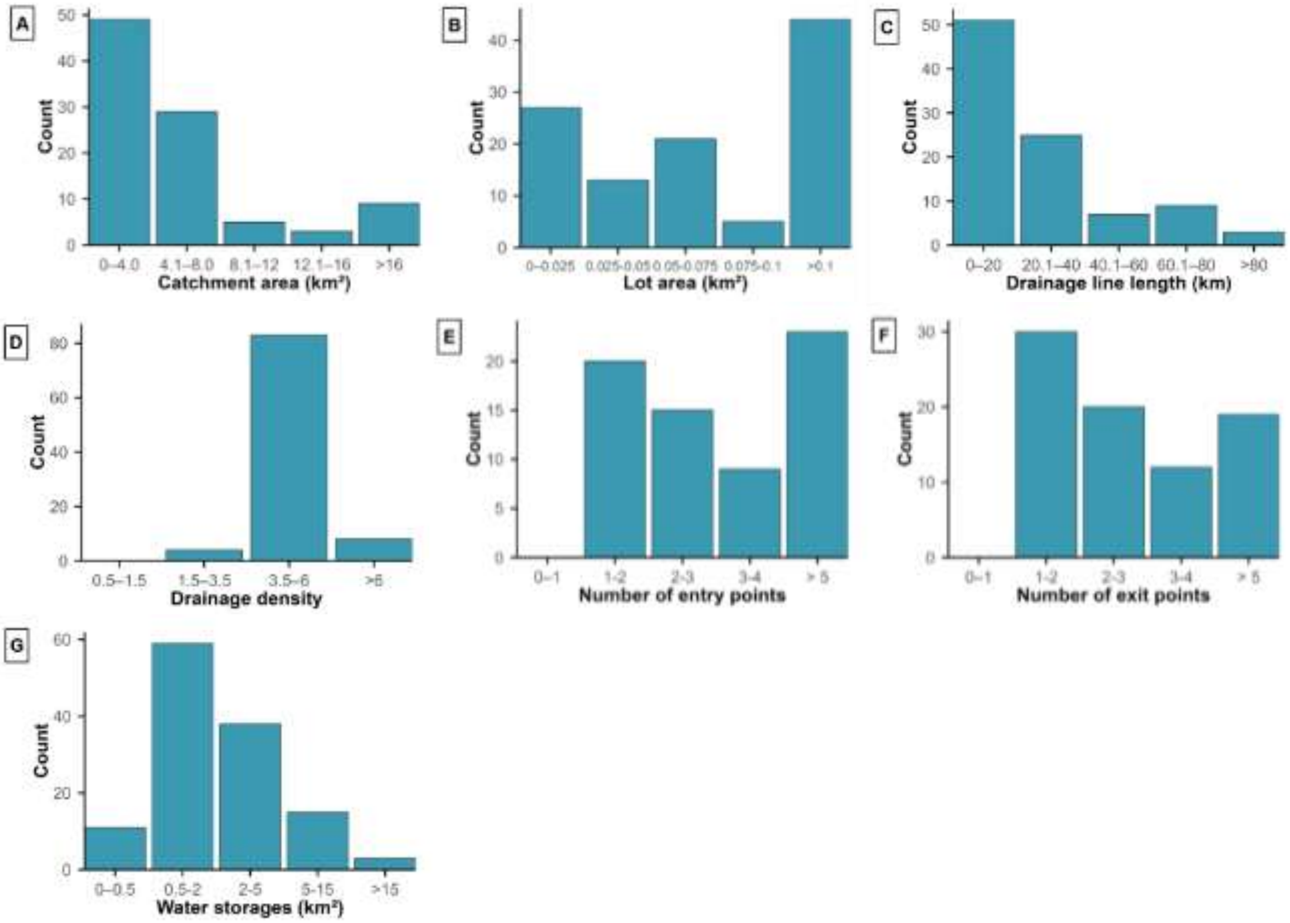

Figure 3 Catchment and lot metrics for NSW production nurseries, including A) catchment area, B) nursery lot area, C) drainage line length, D) drainage density, E) number of flow entry points to lots, F) number of flow exit points off lots, and G) size of water storage dams on lots

Drainage density was concentrated in the 3.5-6 range, suggesting that most farms sit in catchments with moderate drainage networks (Figure 3). This is important because drainage density provides a broad indication of how efficiently runoff may be routed through a catchment.

Many nurseries had more than one flow entry point, and a substantial number have more than five, indicating that runoff usually enters farm lots through multiple locations rather than a single defined drainage line (Figure 3). Exit points showed a similar pattern, with most farms having one or more locations where water can leave the property. The number and arrangement of flow entry and exit points show that most farms are not isolated hydrologically from their surrounding catchments. Water storage areas also varied substantially, suggesting that farms differ in their capacity to capture and retain runoff during rainfall events. This supports the need for lot-scale drainage assessment, because water management depends not only on effective catchment area, but also on where water enters, how it moves through a property, and where it leaves.

Catchment position and connectivity

A general trend emerged in line with the conceptual model of catchment position and connectivity (see Figure 1), in that nursery farms located in upper catchment (source zone) positions were characterised by relatively small contributing areas and limited numbers of flow entry points (Figure 4). In these locations, water inputs would be primarily derived from direct rainfall, and drainage patterns were generally simple, with runoff likely to be generated on-site and conveyed downhill and/or downstream through a small number of exit points. This translates to a low-moderate degree of lateral hydrological connectivity from farms to downstream areas.

In contrast, farms located in mid-catchment (transfer zone) positions exhibited more complex drainage networks, with multiple flow paths entering and leaving the property (Figure 4). These sites would be exposed to both rainfall and run-on from surrounding hillslopes, resulting in greater variability in water inputs due to higher lateral and longitudinal connectivity. The presence of multiple flow pathways increases the potential for both water accumulation and redistribution within the property, as well as the transfer of sediment and contaminants from upstream areas.

Nursery farms located in lower catchment (sink zone) positions generally had large contributing areas and multiple flow entry points (Figure 4). These sites were often associated with low-gradient environments where water can spread across floodplains during high flow events. The high degree of longitudinal hydrological connectivity in sink zone farms increases their exposure to floodwaters and upstream-derived contaminants, which may accumulate in water storages, be redistributed across the property, or washed further downstream.

Topographic wetness and stream power

TWI provided information about where water is likely to accumulate in the landscape. Since TWI combines upslope contributing area with local slope, higher values generally occur in low-gradient areas that receive runoff from larger contributing areas. In practical terms, these are places where soils may remain wetter for longer, where ponding is more likely, and where runoff and contaminants may concentrate during storms. As expected, nursery farms located in mid-catchment and lower catchment positions generally had higher TWI values than those located in elevated, upper catchment positions (Figure 4). TWI is not a flood model, but when combined with mapped flow paths, flow entry and exit points, water storages, aerial imagery and field checks, it provides a useful way to identify where stormwater and flood-related hazards may occur and where more detailed assessment or management actions should be focused.

SPI provided additional insight into the potential distribution of flow energy across the landscape. Areas of high SPI values were generally associated with steeper slopes and convergent flow pathways, where runoff is concentrated and erosion processes are more likely to occur. These areas often corresponded with flow entry and exit points, indicating that these locations are critical for managing water, sediment and contaminant transport. Identification of such areas can support targeted management interventions, such as stabilisation of drainage lines or interception of runoff.

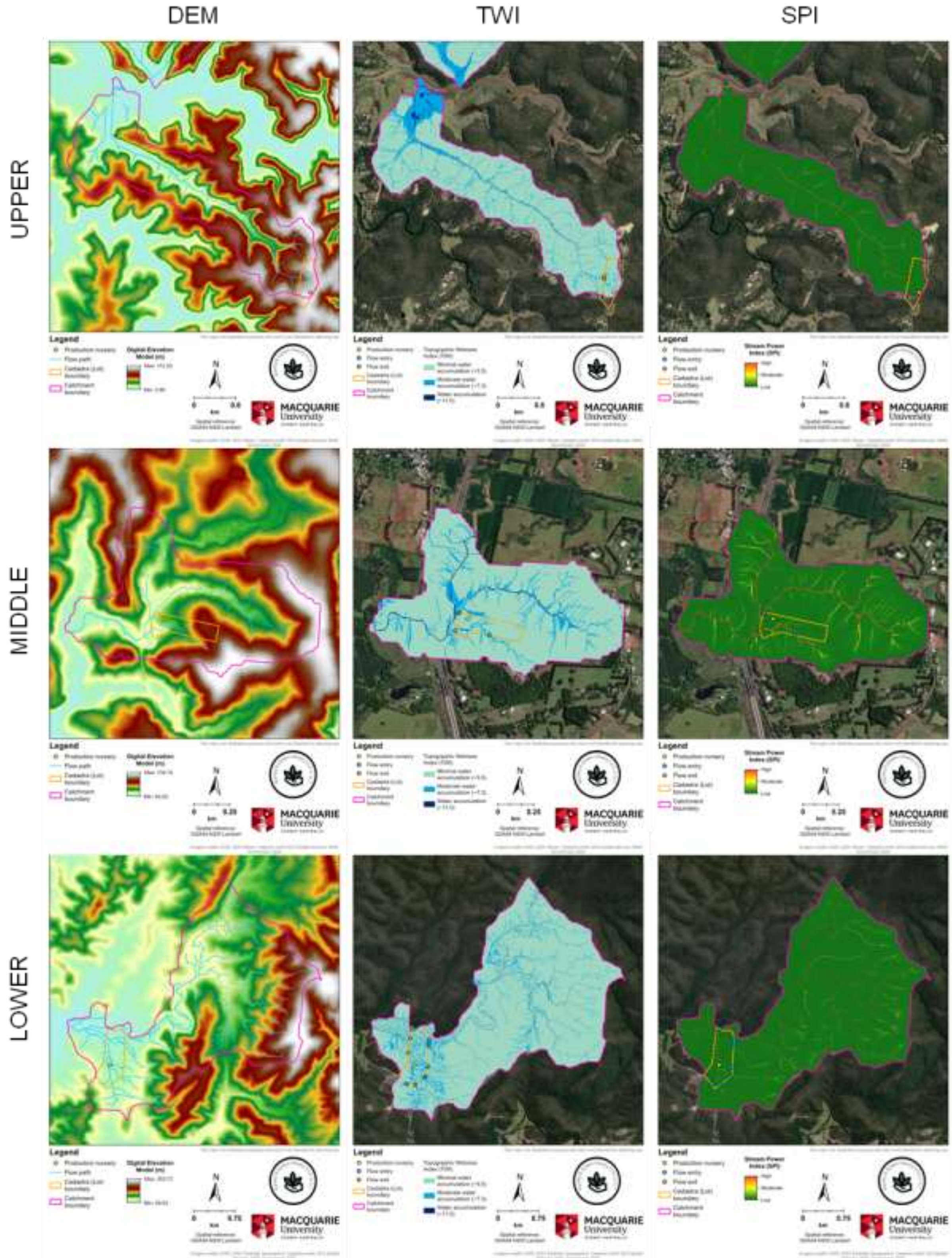

Figure 4 Example map outputs showing nursery farms in upper, middle and lower catchment positions, with their catchment and lot boundaries, flow paths and entry and exit points overlain on the DEM, as well as their catchment topographic wetness index (TWI) and stream power index (SPI). In the upper (source) zone example, there is only an exit point, with minimal water accumulation and erosion potential at the farm, whereas in the middle (transfer) and lower (sink) zone examples there are more flow entry and exit points and greater water accumulation and erosion potential

Water management considerations

The findings of this study provide a basis for improving water management in production nurseries and other types of small, intensive farms through a better understanding of drainage and connectivity. Drainage patterns and associated storm and flood risks are controlled by a combination of catchment-scale processes and local site conditions. The interactions between catchment position and topography, hydrological connectivity, potential water accumulation and dispersal of energy, the arrangement of flow entry and exit points, and location and type of water storage determines how water and associated materials move onto and through small farm systems, and therefore how they should be managed.

Catchment-based assessment allows identification of key flow paths, storage areas and points of interaction between farm properties and the surrounding landscape. This information can be used to identify hazards, such as areas prone to runoff concentration, inundation or contaminant accumulation (Gomes et al., 2025). Understanding catchment position is particularly important for assessing and mitigating risks to water quality. Farms located in upper catchment areas are generally less exposed to external inputs of waterborne contaminants but may contribute runoff to downstream environments. As such, water management in source zone farms will probably largely focus on capturing and managing locally generated runoff. Farms located in lower catchment areas are more exposed to upstream influences and may require additional management to address flood risk and water quality. These differences highlight the need for site-specific management strategies that account for both local conditions and broader catchment context.

The integration of spatial analysis, field observations and conceptual models aligns with broader efforts to develop adaptive management frameworks that consider pre-event planning, monitoring during events, and post-event recovery in response to storms and floods (Ralph et al., 2025a). By identifying key risks and understanding how they vary across the landscape, farm managers can implement targeted strategies to improve water use efficiency, reduce contamination risk and enhance resilience to future events. Analysis of catchment characteristics, drainage patterns, flow entry and exit points, and likely areas of water accumulation or erosion should be undertaken early in the adaptive management cycle for water quality at small farms such as production nurseries. Understanding the farm setting and production activities, as well as potential water contamination issues, will allow identification of hazards and measures to reduce risks to water quality associated with storm and flood events (Ralph et al., 2025a). Risk reduction actions may include preparing catchment and drainage maps, avoiding flood-prone areas, monitoring water quality conditions, maintaining drainage systems, establishing infiltration or buffer systems, and managing water storage levels to mitigate overflow impacts. Other actions can then be taken during and after storm or floods events to monitor and assess on-farm and downstream impacts, as well as to learn and adapt when planning for future water use and management scenarios.

Future work should focus on sampling and monitoring water at production nurseries and other small farms to help identify whether runoff, stored water or receiving waterways are likely to pose risks to agricultural production, aquatic ecosystems or downstream users. This should be done in keeping with established methods for comparison with water quality guidelines for freshwater (e.g. ANZG, 2018) and irrigation water (e.g. DPIE, 2020), which provide reference values against which measured or expected concentrations of key contaminants can be assessed. Formal water management strategies (e.g. ANZECC, 2000) also provide a practical basis for prioritising monitoring, interpreting water quality data, and deciding when management actions such as treatment, diversion, dilution or further investigation may be required.

Conclusions

Catchment-based assessment of drainage provides a practical framework for understanding likely water movement, storage, and associated contaminant risks in agricultural systems. When combined with field validation, and ideally water sampling and monitoring, this approach can support improved water management and contribute to broader efforts to manage waterborne contaminants and enhance resilience in high intensity agricultural systems.

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