Investing in catchments for drinking water quality: A counterfactual analysis of the 'do nothing' option

Chris J. Thompson[1]

1 Seqwater, Brisbane, Qld, 4000. Email: Chris.Thompson@seqwater.com.au

Key points

- The combined effect of climate warming on physical and biological processes, agriculture businesses and growth in southeast Queensland will influence ecosystem services and source water quality.
- Catchment Investment Decision Support System (CIDSS) is used to determine the change in loads of fine sediment and microbial pathogens based on climate warming and land-use pressures under a do-nothing scenario over the next 30 years.
- Baseline investment is required to maintain current catchment performance, preventing further decline
- Baseline investment includes riparian weed management, farm plans, livestock fencing and watering infrastructure, riparian zone and pasture monitoring, unsteady-state erosion control and strategic maintenance

Abstract

Seqwater has a long running investment program across source water catchments in Southeast Queensland. The key objective of the program was to mitigate the highest risks to drinking water quality. Herein, a spatial optimisation model was applied to identify portfolios of actions that would achieve highest risk reductions for a given budget. The program was successful in intervening in many high-risk sites but was structurally limited to targeting symptoms of processes and high threat land-use management practice, i.e. reactive to current state.

A new water quality investment strategy for source water catchments is being implemented which considers the investment for maintaining current catchment performance as the first tier and targeting highest risks to improve catchment performance as the second tier of investment. Third tier of investment considers emerging contaminants of concern. Investment to maintain catchment performance targets current and future processes that may directly or indirectly degrade system function, hence water quality. An approach to quantify future state with respect to catchment performance under 'do nothing' is presented. The approach applied to Lockyer Creek catchment suggests fine sediment loads could increase by 30% and pathogens by up to 2 LRV over a 30-year horizon. Modelling of Tier 1 investment is shown to offset these future increases.

Keywords

Source water protection, catchment investment, climate change, fine sediment, pathogen, planning.

Introduction

A drinking water supply system is made up of source water catchments (the catchment), storage reservoirs (dams), water treatment facilities, service reservoirs and distribution systems. Because each of the components are directly interrelated, the quality of drinking water supplied to consumers can be affected by hazards (eg. microbial pathogens) at any of these points. As such, the catchments are the first and most fundamental barrier in a multibarrier treatment process (eg. ecosystem services, attenuation in dams, treatment plant filtration, chlorination, UV) to ensure drinking water safety. Further, as the most "upstream" component of the drinking water supply system, the catchment can impact the reliability of drinking water supply.

Seqwater invest in Source Water Protection (SWP) activities within catchments to mitigate hazardous processes and have used a Catchment Investment Decision Support System (CIDSS) to identify portfolios of intervention actions to mitigate the highest risks to drinking water safety for least cost (Thompson et al.,2021). This methodology involved modelling the point and non-point sources of drinking water hazards (fine sediment and microbial pathogens). The point and non-point sources include onsite sewerage facilities, sewerage treatment plants, stormwater, water-based recreation, livestock grazing, intensive livestock industries, diffuse hillslope erosion, landslips, gully and channel erosion. The CIDSS models the loads delivered to water treatment plant (WTP) raw water off-take(s) (run-of-river or in water storage lakes) to determine (1) the catchment challenge (which defines the level of Catchment Performance for drinking water quality) and (2) the difference between the catchment challenge and WTP treatment capability. If catchment challenge exceeds WTP capability, then there is a treatment shortfall or alternatively a treatment buffer means that there is some redundancy in the WTP to accommodate flood events and/or breakdowns. The CIDSS used Simulated Annealing optimization to determine the highest risk point or non-point sources to each WTP and select interventions based on the cost and efficacy to mitigate the selected highest risk sites.

However, it is acknowledged that by only targeting the highest risks, lower risk processes continue to occur, expand, evolve and likely become high risks in the future and consequently much more costly to manage. For example, significant extent of river corridors and riparian vegetation has been degraded by land-use practice since European settlement in southeast Queensland (Apan et al., 2002; Healy, 2022; Olley et al., 2015 & 2024). A dominant land-use in southeast Queensland is cattle grazing which is known to significantly impact waterway banks and native riparian vegetation (Bell and Priestley 1998; Jones et al., 2022) increasing rates of above background channel erosion and decrease the functional capacity of riparian vegetation to provide roughness to flood flows, promote sediment deposition, and increasing alluvium resistance to boundary stress via root networks (Hubble et al., 2010). At a land parcel or property-scale cattle grazing typically increases channel erosion and pathogen loads above background rates but often has a lower relative risk than intensive livestock business (e.g., dairy, beef feedlots) or large erosion point source (e.g., landslip). Therefore, optimized interventions based on cost and efficacy generally target highest risk point sources rather than diffuse sources.

Furthermore, climate change is impacting on the hydrological cycle (CSIRO & Bureau of Meteorology [BoM] 2020, Ren et al., 2024). Westra et al., (2014) and Wasko et al., (2024) describe atmospheric system and changes influencing extreme rainfall and effects of antecedent soil condition on runoff which is likely to lead to significant increases in erosion (Nearing et al., 2005) and channel change (Goudie, 2006). There is evidence to suggest riparian weeds will exploit the climate induced acute and chronic disturbance (e.g., direct flood damage to woody vegetation, grazing pressure, soil moisture stress, increasing temperature, radiation) (Clements & DiTommaso, 2022; Flanagan et al., 2015; Osunkoya et al., 2025; Ren et al., 2023) by gaining a competitive advantage to displace native woody vegetation. Key to managing the impacts from climate change on hydrology, erosion and weeds on water safety and security is having functional riparian vegetation to provide ecosystem services of reducing flood flow velocity, providing channel boundary resistance and buffer the channel from adjacent hillslope inputs (Hubble et al., 2010; Olley et al., 2015).

To prevent further decline in southeast Queensland's riparian vegetation and support processes that can lead to riparian vegetation recovery requires a different catchment investment approach. Seqwater have developed a new 30-year water quality investment strategy for source water catchments, which is currently being implemented. The strategy considers three tiers of investment:

- Tier 1. Baseline investment to maintain current catchment performance,
- Tier 2. Investment to improve catchment water quality performance required to meet WTP capability to produce safe drinking water, and
- Tier 3. Investment to manage emerging contaminants of concern.

Tier 1 investment focusses on the management of:

- Riparian vine weed management
- Unsteady-state channel erosion
- Agricultural practice improvement and riparian zone management
- Strategic maintenance to ensure existing interventions continue to meet performance objectives.

This study presents a counterfactual analysis to determine the extent of change in catchment performance over the next 30-years under a no investment strategy by considering the impacts of climate change on physical, chemical and biological processes, how these may manifest in changes to agricultural practices, combined with impacts of increasing development and land-use change in source catchments. The objective is to quantify the change to current state catchment performance under no investment over 30 years so that outcomes of catchment investment are bench marked against a ‘do nothing ’ option instead of quantifying improvements against the current state of catchment performance. To complete the analysis, the outcomes of Tier 1 investment are modelled for comparison.

Further, as per the Queensland Government’s *Business Case Development Framework* (Queensland Govt. 2024), exploration of a ’do nothing’ (or base case) option is required as a mandatory benchmark against which all other potential investment options are measured. That is, an evaluation of the future impact of making no changes to the current status, thereby allowing stakeholders to compare proposed investments against the baseline scenario of unchanged operations, highlighting the exact risks and rising costs they are trying to avoid. The model outputs and counterfactual analysis as described in this paper fulfils Seqwater’s business need to meet the requirements of BCDF, forming part of the justification for investment in SWP activities.

Study area

Lockyer Creek sub-catchment of the Brisbane River is used for this study (Figure 1). The catchment is approximately 3,000 km^2, an ephemeral waterway with deep fertile floodplains that support irrigated horticulture industry (10% of catchment). Cattle grazing is the dominate land use primarily on hillslopes (66%), Conservation and forestry comprising 17% of catchment land use and rural residential 8%. There are intensive livestock industries including dairy, feedlot and poultry. Riparian vegetation is highly degraded and contains cats claw creeper, madeira vine, giant grasses and other non-woody weeds.

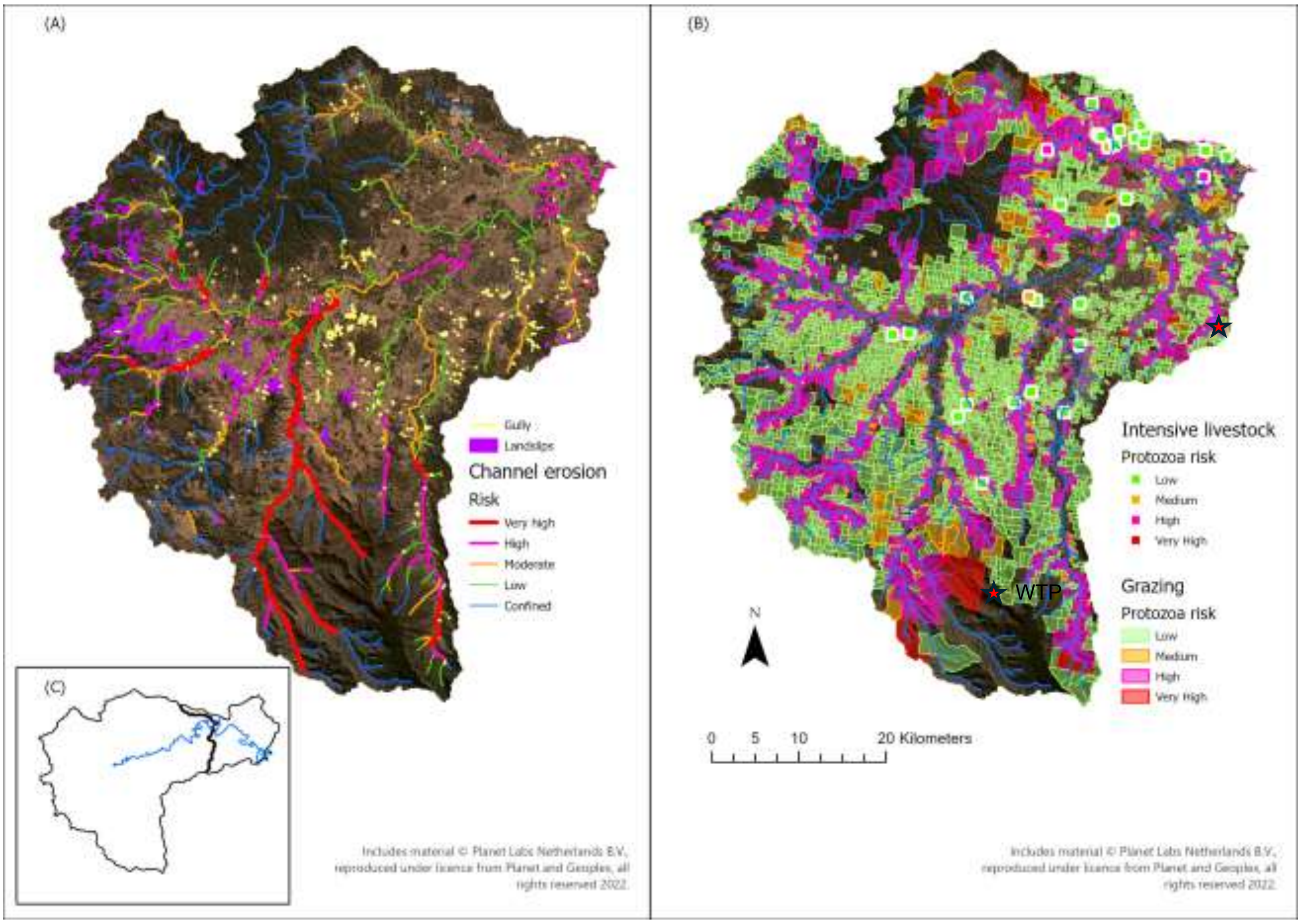

Figure 1 Lockyer Creek catchment with (A) fine sediment sources, (B) livestock derived protozoa sources and (C) Lockyer and Mid Brisbane River catchment down to the Mount Crosby WTP off-takes

Methods

Current catchment performance was determined using the first generation CIDSS (Thompson et al., 2021). Threats (hazardous processes) to catchment performance are sources of fine sediment from diffuse hillslope erosion, landslips, gully and channel erosion and point sources such as intensive livestock pens, manure stockpiles and quarries and their modelled loads delivered to WTP offtakes. Threats also include microbial pathogen sources and loads, with *Giardia* sp. used as a surrogate for modelling protozoa pathogen load delivered to WTP offtakes from domestic onsite sewerage facilities, municipal sewage treatment plants, stormwater, water-based recreation, as well as broadscale and intensive livestock production.

A second generation of the CIDSS (CIDSSgen2), based on the Natural Capital Region product developed by Truii (2026a), is used to apply actions to the current state catchment performance to determine trajectories and change in loads of fine sediment and protozoa over 30-years.

CIDSSgen2 uses a modified cost abatement curve approach, quantifies the likely response times for on-ground actions, which can be positive and negative. An 'action' is what gets prioritised and applied to the current state baseline. The state of the baseline then changes as actions are applied, with the final state representing the load reductions or increases achieved by applying the action portfolio. Positive actions represent interventions applied to mitigate degrading processes and threats to maintain or improve catchment performance. Negative actions represent additional degrading processes and threats such as the effects of climate change and the various combinations of land use change that can increase the catchment challenge resulting in declining catchment performance for drinking water quality.

Each positive action includes an initial implementation cost and an annual strategic (planned) maintenance cost and the efficacy or load change produced by a particular type of action. For pathogen sources, actions either increase or decrease load by a Log Reduction Value (LRV) per site or grazing herd. The LRV is the logarithmic10 load of the pathogen generated per source per day (Baker et al., 2016). For fine sediment, actions either increase or decrease loads from a site or area by a percentage (efficacy), a once-off fixed amount or a yield (e.g. t/ha). Response times of actions are categorized as either immediate, linear, slow or fast. For immediate, the load change is all applied in the first year whereas the latter three are applied over a 15-year period to achieve the load change using a linear equation or exponential equation.

The extent various actions can be applied is firstly determined by the amount of land type (QLUMP), extent of vegetated and unvegetated riparian zone, and threats to drinking water quality within each sub-catchment. Each action is therefore based on a starting land type and allocated an end land type based on the characteristic of an action. For example, a riparian revegetation action has a starting land type of unvegetated riparian zone and an end land type of vegetated riparian zone whereas vine weed control has a starting and ending land type of vegetated riparian zone. Because Seqwater owns less than 5% of the total land area within its source water catchments, actions are likely to only be applied to small percentages of each land type containing threats to catchment performance. Here, not only is the percentage of a land type for which an action can be applied taken into account, but also the likely rates of adoption by landholders and the time taken to reach peak adoption rates (Truii 2026b).

Two scenarios (1) No investment and (2) maintain catchment performance (Tier 1), are developed for Lockyer Creek catchment. Table 1 lists actions to represent land-use practice and climate change pressures on the land and waterways over the next 30-years based upon interpretations of the effects of predicted climate warming on:

- livestock behaviour (Godde et al., 2021; Paixao et al., 2026),
- riparian weed growth (Osunkoya et al., 2025),
- increasing forest mortality rates (Lu et al., 2026),
- declining water yield with increasing hot and dry spells (Queensland Govt. 2026), interspersed by increasing intensity of short duration rainfall events (Wasko et al., 2024), all combined with regional growth forecasts (Queensland Govt. 2023),
- economic pressures on agricultural businesses (Bowen and Chudleigh 2018; Roy Morgan 2023),
- rural business diversification and income supplementation (Queensland Govt. 2025).

Table 2 lists actions to maintain current catchment performance and counter degrading processes (actions) listed in Table 1 but also acknowledges land-use change with new intensive livestock industries and grazing land subdivision for housing.

Table 1 No investment scenario actions

Action*	Mean sub-catchment area applied in available land-type	Start – End land type	Protozoa change & response time	Fine sediment source, change & response time
Increasing RZ grazing pressure with climate perturbations	10%	Vegetated to Unvegetated riparian zone	-2 LRV & linear	Channel erosion -50% slow
Pasture loss with grazing pressure with drought	40%	Open grazing	-0.25 LRV & linear	Gully -40% slow; Hillslope -20% linear
Pasture loss with grazing pressure with drought	30%	Forested grazing	-0.25 LRV & linear	Gully -20% slow; Hillslope -20% linear
Tree clearing of clearable veg	10%	Forested to open grazing	-0.5 LRV linear	Gully -10% fast; Hillslope -10% fast; Landslip -10% slow
Increasing riparian weeds and no control in vegetate	20%	Vegetated to Unvegetated riparian zone	N/a	Channel erosion -70% slow
Grazing conversion to rural residential	1%	Open grazing to Rural residential	-3 LRV linear	N/a
Uncontrolled river camping with swimming on private land	2%	Unvegetated riparian zone	-4 LRV linear	Channel erosion -10% slow
Increase in unsteady-state channel erosion	1%	Vegetated to unvegetated riparian zone	N/a	Channel erosion -100% linear
New intensive livestock industry	0.05%	Open grazing to Intensive Ag	-7 LRV linear	Hillslope -30% fast

* RZ = riparian zone

Table 2 Maintain catchment performance (Tier 1) scenario actions

Action*	Mean sub-catchment area applied in available land-type	Start – End land type	Protozoa change & response time	Fine sediment source, change & response time
Riverbank engineering – complex for unsteady-state channel erosion	1%	Channel erosion	N/a	Channel erosion +90% fast
Riparian weed treatment	50%	Vegetated riparian zone	N/a	Channel erosion +50% linear
Farm plans, riparian fencing, off-stream watering	10%	Vegetated riparian zones	3 LRV immediate	Channel erosion +90% linear
Farm plans, riparian fencing, off-stream watering	10%	Unvegetated to vegetated riparian zones	3 LRV immediate	Channel erosion +70% linear
Pasture monitoring (LCAT)	30%	Open grazing	0.5 LRV linear	Hillslope +10% linear
New intensive livestock industry	0.05%	Open grazing to Intensive Ag	-7 LRV linear	Hillslope -30% fast
Grazing conversion to rural residential.	1%	Open grazing to Rural residential	-3 LRV linear	N/a

Results

No investment

Under a no investment scenario for Lockyer Creek catchment, mean annual fine sediment loads delivered to Mount Crosby WTP increase by up to 30% over 30 years as the ecosystem service capacity of riparian vegetation is diminished through increasing riparian weed and grazing pressure from livestock seeking shade and water from increasing heat and declining pasture condition (Figure 2). The increase in usage of the riparian zone reduces woody vegetation recruitment, increases bare ground, increases sub-aerial erosion on the lower banks, promotes concentrated flow along cattle tracks and increases bank erosion during flood events due to reduced roughness and declining bank strength (Alexander et al., 2026; Jones et al., 2022; Zaimes et al., 2019). Increased streambank erosion increases lateral connectivity and the delivery of fine sediment from diffuse hillslope erosion from events following dry spells. More sediment is delivered downstream due to diminished roughness of riparian vegetation as it becomes more open and replaced by non-woody weeds. In the Lockyer catchment giant grass and other riparian weeds are spreading rapidly and displacing native vegetation. These weeds provide negligible roughness and bank resistance during flood events (Ede and Hunt, 2008) resulting in fluvial scour, bank mass failure and increased sediment delivery downstream.

Protozoa load increase by 2 LRV due to the increase in livestock accessing the riparian zone and watercourse and the increase in lateral connectivity during events (Figure 2). While river camping and swimming could have a large impact on protozoa loads, the Lockyer Creek is assumed to have limited capacity for these opportunities particularly in the lower reaches. There are opportunities for camping and swimming in the upper reaches where bedrock can support more permanent water holes however, the large distance from source to WTP attenuates the load. There will be an increase in human wastewater from onsite sewerage systems installed as part of the increasing footprint of rural residential development (Wang et al., 2021). The protozoa increase depends on percentage of onsite systems not maintained (Goonetilleke et al., 1999; 2002).

Tier 1 – Maintain catchment performance

The Tier 1 investment is aimed at improving management of degrading processes (riparian weeds and cattle grazing) along approximately 200 km of riparian zones over a 30-year period to facilitate recovery and conserve remnant riparian vegetation. An intervention to an unsteady-state channel erosion site near the outlet is also being implemented.

The Tier 1 scenario for fine sediment shows a 31% improvement from a future state if no investment was made to manage degrading processes (Figure 2). Notably, this only represents a 1% improvement in the current state fine sediment loads delivered to Mount Crosby WTP which is partly due to mitigating a single unsteady-state channel erosion site. The majority of actions focus on preserving existing riparian vegetation through weed control and facilitating riparian vegetation recovery by engaging with land holders to support farming practice change and infrastructure to improve productivity.

Tier 1 scenario results in a large reduction in protozoa loads (3 LRV) because the actions minimize the degrading processes in riparian zones and facilitate their recovery, act to disconnect or buffer the waterways from the pathogen sources (Figure 2). Riparian fencing, rotational grazing, pasture improvements, and off-stream watering reduce the probability of protozoa connecting to waterways. Actions such as fencing riparian zones and supplying off-stream watering can have immediate results for pathogen connection. However, rates of adoption by landholders, staged practice change (ie. moving from full riparian grazing to rotational grazing to full grazing exclusion) and gradual pasture improvement result in the incremental reduction in protozoa loads over a 15-year period.

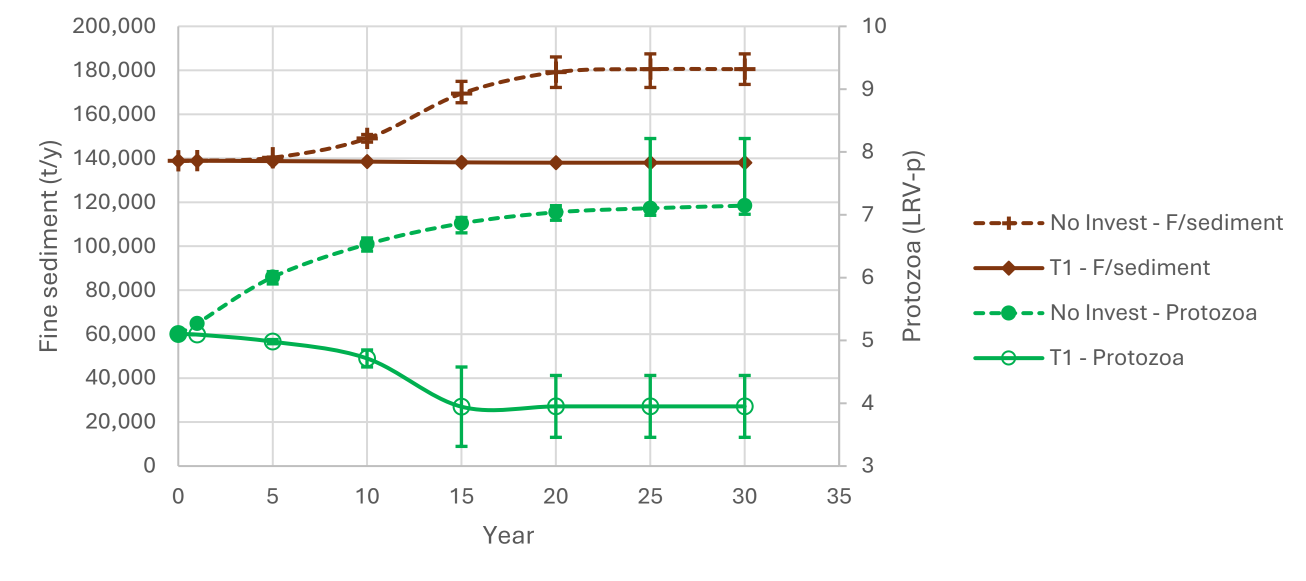

Figure 2 Modelled loads of fine sediment and protozoa delivered to Mount Crosby WTP from Lockyer Creek catchment based on scenarios of no catchment investment and investment to maintain catchment performance (T1)

There is uncertainty in the modeled approach based on the selection of efficacy or load change values. Selected values for various intervention improvements in this model align with values used in Thompson et al. (2021) for the Logan catchment and align with loads and mitigation measures presented by Baker et al. (2016). Predicted increase in fine sediment loads under climate change falls within the range (25%-55%) predicted by Nearing et al. (2005) based on their modelling of the impacts of change in rainfall intensity. Given Nearing didn't include land-use and livestock behaviour change in their modelling of changes in erosion, the modelled increase of 30% in mean annual loads is likely conservative.

Conclusions

This study presented a modelling approach to demonstrate the influence of land-use combined with climate warming over a 30-year projection of catchment performance based on two drinking water quality parameters, protozoa microbial pathogens and fine sediment. The approach is used to support the case that significant investment is required just to maintain current catchment performance into the future, and the baseline to measure Tier 1 investment benefit against is represented by the 'no investment' trajectory. For this study example, in 30-years' time, the Tier 1 investment will be reducing fine sediment loads by 31% (~40,000 t/y) and protozoa by 3 LRV. If the progressive decline in catchment performance forced by climate impacts on physical and biological processes and land-use are ignored, then then result would suggest only a 1% & 1 LRV improvement respectively and the investment may be seen as a failure to reach its targets leading doubts in credibility of the investment program, loss of social license and a high risk to future investment in catchment management.

This modelling approach is being developed to show how much investment is required in each source water catchment to maintain current its current performance state and therefore set baseline investment budgets upon which budgets to improve catchment performance can be applied.

Acknowledgements

Truii (truii.com) for development and customizing of their web app Natural Capital Region to meet Seqwater needs for CIDSS gen2. Thanks to Andrew Smolders and Amar Doshi for their inciteful reviews that improved the paper.

References

Alexander, J.S., Eddy-Miller, C.A., Stout, J.B. & Brown, H. (2026). The influence of riparian zone grazing on channel stability in an arroyo. Geomorphology 506, 110331

Apan, A. A., Raine, S. & Paterson, M.S. (2002). Mapping and analysis of changes in the riparian landscape structure of the Lockyer Valley catchment, Queensland, Australia. Landscape and Urban Planning 59(1), 43-57.

Baker, D., Ferguson, C., Chier, P., Warnecke, M. & Watkinson, A. (2016). Standardised survey method for identifying catchment risks to water quality. Journal of Water and Health 14(3), 349-368.

Bell, I. & Priestley, T. (1998). Management of Stock Access to riparian zone. Department of Primary Industries Water and Environment Tasmania.

Bowen, M.K. & Chudleigh, F. (2018). Grazing pressure, land condition, productivity and profitability of beef cattle grazing buffel grass pastures in the subtropics of Australia: a modelling approach. Animal Production Science 58, 1451–1458.

Clements, D. R. & DiTommaso, A. (2022). Climate change and the persistence of weeds. Mahesh K. Upadhyaya, M. K., Clements, D. R. & Shrestha, A. Persistent Strategies of Weeds. John Wiley & Sons.

CSIRO, & Bureau of Meteorology (BoM). (2020). State of the climate. CSIRO and Bureau of Meteorology.

Ede, F.J. & Hunt T.D. (2008). Habitat management guide—Riparian: Weed management in riparian areas: south-eastern Australia. CRC for Australian Weed Management, Adelaide.

Flanagan, N. Richardson, C. & Ho, M. (2015). Connecting differential responses of native and invasive riparian plants to climate change and environmental alteration. Ecological Applications 25(3), 753–767

Godde, C.M., Mason-D'Croz, D., Mayberry, D.E., Thornton P.K. & Herrero M. (2021). Impacts of climate change on the livestock food supply chain; a review of the evidence. Global Food Security 28, 100488.

Goonetilleke, A., Rigen, B. & Dawes, L. A. (1999). Performance evaluation of onsite sewage treatment: Evaluation of current research. Queensland University of Technology, October 1999.

Goonetilleke, A., Dawes, L. A. & Biddle, D. (2002). Performance evaluation of septic tanks in the Gold Coast. Queensland University of Technology, January 2002

Goudie A. S. (2006). Global warming and fluvial geomorphology. Geomorphology 79, 384-394.

Healy, A. (2022). Riparian Forest and Ground Cover Levels in Southeast Queensland Catchments. Department of Environment and Science, Queensland Government.

Hubble, T. C. T., Docker, B. B., & Rutherfurd, I. D. (2010). The role of riparian trees in maintaining riverbank stability: A review of Australian experience and practice. Ecological Engineering 36(3), 292-304.

Jones, C. J., Duncan, D. H., Rumpff, L., Robinson, D. & Vesk, P.A. (2022). Permanent removal of livestock grazing in riparian systems benefits native vegetation. Global Ecology and Conservation 33, e01959.

Lu, R., Williams, L. J., Trouvé, R., Murphy, B. P., Baker, P. J., Carle, H., Forrester, D. I., Green, P. T., Liddell, M. J., Marunda, C., Mannes, D., Mazanec, R., Ngugi, M. R., Neldner, V. J., Prior, L., Ruthrof, K. X., Suitor, S. Xia, J. & Medlyn, B. E. (2026). Pervasive increase in tree mortality across the Australian continent. Nature Plants 12, 62-73. doi.org/10.1038/s41477-025-02188-2

Nearing, M.A., Jettenb, V., Baffautc, C., Cerdand, O., Couturierd, A., Hernandeza, M., Le Bissonnaise, Y., Nicholsa, M.H., Nunesf, J.P., Renschlerg, C.S., Souche`reh, V. & van Oost, K. (2005). Modeling response of soil erosion and runoff to changes in precipitation and cover. Catena 61, 131–154

Olley, J., Burton, J., Hermoso, V., Smolders, K., McMahon, J., Thomson, B., & Watkinson, A. (2015). Remnant riparian vegetation, sediment and nutrient loads, and river rehabilitation in subtropical Australia. Hydrological Processes 29, 2290- 2300.

Olley, J. M., Coat-Marnane, J. Orr, D., Heeley, B., & Tsoi, I. (2024). Temporal changes in sediment and nutrient loads and the influence of riparian forests. Healthy Land and Water. Brisbane, Australia.

Paixao, G., Mata, F., Cerqueira, J. & Araújo, J.P. (2026). Weather and seasonal effects in behavioural patterns for grazing cattle. Applied Animal Behaviour Science 298, 106935.

Queensland Government (2023). ShapingSEQ South East Queensland Regional Plan 2023. State of

Queensland, the Department of State Development, Infrastructure, Local Government and Planning.
Queensland Government (2024). Business Case Development Framework. Release 3.1. State of Queensland, the Department of State Development and Infrastructure.
Queensland Government (2025). Supporting agritourism through Local Government planning schemes, Guidance for local government. 27 October 2025.
Queensland Government (2026). Queensland Future Climate Dashboard – CMIP6. https://www.longpaddock.qld.gov.au/qld-future-climate/adapting/water/ Accessed 30/1/2026.
Ren, P., Stewardson, M., Peel, M., Turner, M. & John, A. (2024). Assessing climate change impacts on yield of “dual-priority” water rights in carryover systems at catchment scale. Water Resources Research 60, e2023WR035376.
Ren, H., Wen, Z., Liu, Y., Lin, Z., Han, P., Shi, H., Wang, Z. & Su T. (2023). Vegetation response to changes in climate across different climate zones in China. Ecological Indicators 155, 110932.
Roy Morgan (2023). Economic conditions pose greatest challenge to Australian farmers; except WA where government policies are the top challenge. Article 9316 Tuesday 22 August 2023.
Thompson, C., Stewart, M., Marsh, N., Phung, V. & Lynn, T. (2021). A Planning Tool for Optimizing Investment to Reduce Drinking Water Risk to Multiple Water Treatment Plants in Open Catchments. Water 13, 531. https://doi.org/ 10.3390/w13040531.
Truii (2026a). https://naturalcapitalsuite.au/region/
Truii (2026b). https://truii.com/stories/natural-capital/what-is-the-likelihood-of-adoption-of-your-management-action/
Westra, S., Fowler, H. J., Evans, J. P., Alexander, L. V., Berg, P., Johnson, F., Kendon, E. J., Lenderink, G. & Roberts, N. M. (2014). Future changes to the intensity and frequency of short duration extreme rainfall. Reviews of Geophysics 52, 522–555, doi:10.1002/2014RG000464.
Wang, M., Zhu, J. & Mao, X. (2021). Removal of Pathogens in Onsite Wastewater Treatment Systems: A Review of Design Considerations and Influencing Factors. Water, 13, 1190.
Wasko, C., Westra, S., Nathan, R., Pepler A., Raupach, T. H., Dowdy, A., Johnson, F., Ho, M., McInnes, K. L., Jakob, D., Evans, J., Villarini1, G. & Fowler, H. J. (2024). A systematic review of climate change science relevant to Australian design flood estimation. Hydrological and Earth System Science 28, 1251–1285.
Zaimes, G.N., Tufekcioglu, M. & Schultz, R.C. (2019). Riparian Land-Use Impacts on Stream Bank and Gully Erosion in Agricultural Watersheds: What We Have Learned. Water 11, 1343; doi:10.3390/w11071343 .