BUILDING CATCHMENT RESILIENCE PROJECT

Enabling Planning and Community Collaboration to Reduce the Impacts of Extreme Weather Events

PROJECT REPORT

2023

GRIFFITH UNIVERSITY

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Preface

This document outlines the results of a four-year project undertaken by the Australian Rivers Institute at Griffith University to develop a 'proof of concept' model that identifies where in the landscape interventions to reduce sediment and nitrogen pollution need to occur and links this outcome to a visualisation interface that provides the basis for community consultation and consensus building. This report is submitted to The Ian Potter Foundation and the Building Catchment Resilience Steering Committee as a key deliverable of the project.

Acknowledgements

Griffith University acknowledges the Indigenous custodians of the lands on which we work and live and pays respect to Elders past and present, and emerging, extending that respect to all Aboriginal and Torres Strait Islander peoples.

This project is a collaborative initiative of the Australian Rivers Institute, Griffith University, The Ian Potter Foundation, Queensland University of Technology, the Department of Environment and Science, Queensland Government, the Port of Brisbane, Urban Utilities, Seqwater, the Lockyer Valley Regional Council, Healthy Land and Water and Water Technology.

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EXECUTIVE SUMMARY

The ability of landscapes to buffer human populations from extreme weather events, supply affordable drinking water and food, and provide assimilation services at an ecosystem level is decreasing at the same time as the number of people dependent on these services increases.

There is a growing recognition of the need to invest in 'nature positive' remediation projects as a cost-effective long-term management approach to build more resilient catchments. While we understand the causal processes of river and catchment degradation and know what kinds of on-ground management actions are effective, a key challenge remains to move beyond the current incremental 'project by project' approach and develop coordinated, catchment-scale plans that optimise investment and achieve multiple benefits for the least cost.

The Building Catchment Resilience (BCR) Project set out to address this challenge by developing a world-leading, deliberative decision support tool that explores options for optimal investment in river and catchment rehabilitation to reduce erosion and associated pollutants, minimise flood risk and capture other benefits, such as carbon sequestration and biodiversity. An innovative digital interface was also proposed to enable realistic visual representations of management actions that facilitate discussion and build confidence with investors and the local community.

The BCR project team has successfully developed and trialed a prioritisation model, based on a multi-objective simulated annealing (MOSA) model approach, in the Laidley Creek catchment in southeast Queensland. The effectiveness of different management actions in reducing sediment and nutrients at each location in the catchment was analysed, together with estimates of the opportunity and implementation costs. Two investment scenarios were chosen to demonstrate the utility of the model: one aimed at optimising sediment and nitrogen loss for a fixed implementation cost of $20 million, and the other aimed at halving particulate nitrogen loads. From these, several solutions were selected from the multi-objective simulated annealing, representing different potential management outcomes. The benefits and costs of these management actions were then quantified and spatially represented as a series of optimal 'solution' investment maps of the catchment.

An innovative user interface was also developed to provide realistic visual representations of selected solutions from the MOSA model output and facilitate discussions with investors, catchment managers and the broader community. The user interface allows stakeholders, who may have different and sometimes competing priorities (e.g., in terms of minimising costs, reducing sediment or nutrients), to explore and understand trade-offs and synergies. Selected optimal solutions can be further analysed to quantify additional catchment-scale benefits, such as reduced flood risk. Flood risk was assessed with a 'rain-on-grid' catchment model to show how the selected investment solutions affect flood magnitude, extent and duration, and can be visually represented.

This report provides an overview of the catchment models and visualisation framework developed in the project, and representative solutions for investment in the pilot study catchment. The report also highlights engagement activities to date, including application of the tools in a second catchment in southeast Queensland. Further details of the model and their data requirements are available by request. Please contact us and visit the Building Catchment Resilience website for more information **(www.catchmentresilience.org).**

There is a growing recognition of the need to invest in 'nature positive' remediation projects as a cost-effective long-term management approach to build more resilient catchments.

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Lockyer Creek near Smithfield Bridge following a large storm event in May 2022

Lockyer Creek, Helidon showing homes and infrastructure, close to streambank slips following February and May 2022 storm

1. BACKGROUND TO THE PROJECT

Our catchments are no longer resilient to extreme weather events. We see the effects of heavy rainfall on degraded landscapes when summer storms intercept the east coast of Australia.

Streams and rivers break their banks and rip through properties, damaging homes and public infrastructure, and carrying away thousands of tonnes of high-quality agricultural topsoil. The eroded soil is transported downstream in muddy rivers, clogging treatment plants, and threatening valuable drinking water supplies. Sediment settles in reservoirs, reducing their storage capacity, and in downstream harbours and bays, filling in shipping channels and smothering marine habitat. Failure to address this issue at scale will lead to continued and significant increases in the cost of essential services such as water supply, food and waste disposal, as well as post-event recovery investments. In our changing climate, these outcomes will increase in magnitude and frequency.

Clearing of vegetation, modifications to stream channels, frequent burning and overgrasing in headwater catchments has led to a flashier response of streamflow to rain events, with more water concentrated in the channel network, and increased stream power. To compound this problem, stream banks and gullies have become more vulnerable to erosion – the source of most of the sediment entering our waterways.

After more than 15 years of focused research, we are no longer constrained by a lack of technical information. We know the cause of the problem, what actions are effective, and where they will have the greatest benefit. There is ample evidence to show it is not only more cost-effective to invest in solving problems at their source rather than dealing with the consequences downstream, but also that such investment comes with significant additional public-good benefits. The result is a growing interest from downstream beneficiaries, such as water utilities and port authorities, in investing in nature-based solutions in the upper catchments. Economic incentives for these investments are now a topic of conversation among government, regulators and stakeholders.

The challenge has been to move beyond the incremental, project-by-project, approach towards coordinated, catchment-scale approaches that capture costs and benefits of investment, across the full range of services provided in the catchment. These benefits include reduction of sediment and nutrients, sequestration of carbon, decreased flood risk and associated damage to homes and infrastructure, and improvements to waterway health. It is neither practical nor necessary to remediate all the degraded areas in a region, given most of the sediment and nutrients comes from a relatively small portion of the river network.

A coordinated approach, informed by good science, will support the most appropriate actions are taken in places that achieve the best outcomes. This requires an evidence-based, spatial investment tool that supports cooperative, deliberative engagement among the community, other stakeholders, and investors. Building stakeholder confidence and trust throughout the development process is key to mobilising investment and to overcome remaining institutional barriers to address this problem at the scale required.

The Building Catchment Resilience (BCR) Project was designed to address this challenge by developing a world-first deliberative decision support tool for catchment-scale investment. The Ian Potter Foundation approved project funding in December 2017, with the official project launch in October 2018. The core research team was formed in early 2018, with much of the first year of activity focused on assembling data sets and development of catchment models, building on an existing catchment planning model that had been developed for sediment alone[1]. A formal agreement between the project partners and co-funders (Seqwater, Urban Utilities, Port of Brisbane, Queensland Department of Environment and Science, Queensland University of Technology, Water Technology, Healthy Land and Water, and Lockyer Valley Regional Council) was signed in January 2019.

1. Hermoso et al. (2015) Prioritising catchment rehabilitation for multi objective management: An application from SE-Queensland, Australia. Ecological Modelling 316, 168–175.

The BCR tools were developed and tested in the Laidley Creek catchment in southeast Queensland (Figure 1). Laidley Creek is an important horticultural region and is a 'poster-child' of the problems arising from catchment and stream channel degradation. However, the tools have been designed to be generic and flexible so they can be applied to different catchment settings and challenges (for example, see Section 3.2).

Figure 1. *Laidley Creek catchment highlighted within the major catchments of southeast Queensland*

2. DEVELOPING THE DECISION SUPPORT FRAMEWORK

2.1. DATA PROCESSING AND CATCHMENT MODELS

The decision support tools developed by the BCR Project combine catchment model predictions within a multi-objective optimisation framework that includes consideration of implementation and opportunity costs, and sediment and nitrogen losses (Figure 2). It is designed to identify green infrastructure solutions for catchment rehabilitation outcomes that could include revegetation of hillslopes and riparian areas, implementation of wetlands, and gully remediation, but it could also be adapted for implementation of both green and grey infrastructure (e.g., new or upgraded wastewater treatment plants). The framework enables users to outline and run scenarios that answer specific questions such as:

- what management actions to implement, and
- where are the best locations to maximise catchment resilience?

The pre-processing component supports the assembly and processing of available spatial information on the catchment or region of interest. A digital elevation model is used to derive topographical information and to divide up the catchment into smaller planning units (Figure 3). Planning units are based on the stream and gully network; small enough to represent the scale of likely management actions (e.g., individual property scale), but large enough to keep the total number of units at a manageable level for the catchment model computations. Other sources of relevant spatial information are also collected, including lot and plan cadastres, vegetation cover, land-use, soil type, etc., as demonstrated in Figure 4.

Detailed information is collated for the key pollutants of interest. In this pilot study, sediment models were used to identify major sources of sediment and erosion, particulate nitrogen was estimated from modelled fine sediment erosion and dissolved nitrogen was estimated from soil sample leaching tests for different land uses within the catchment.

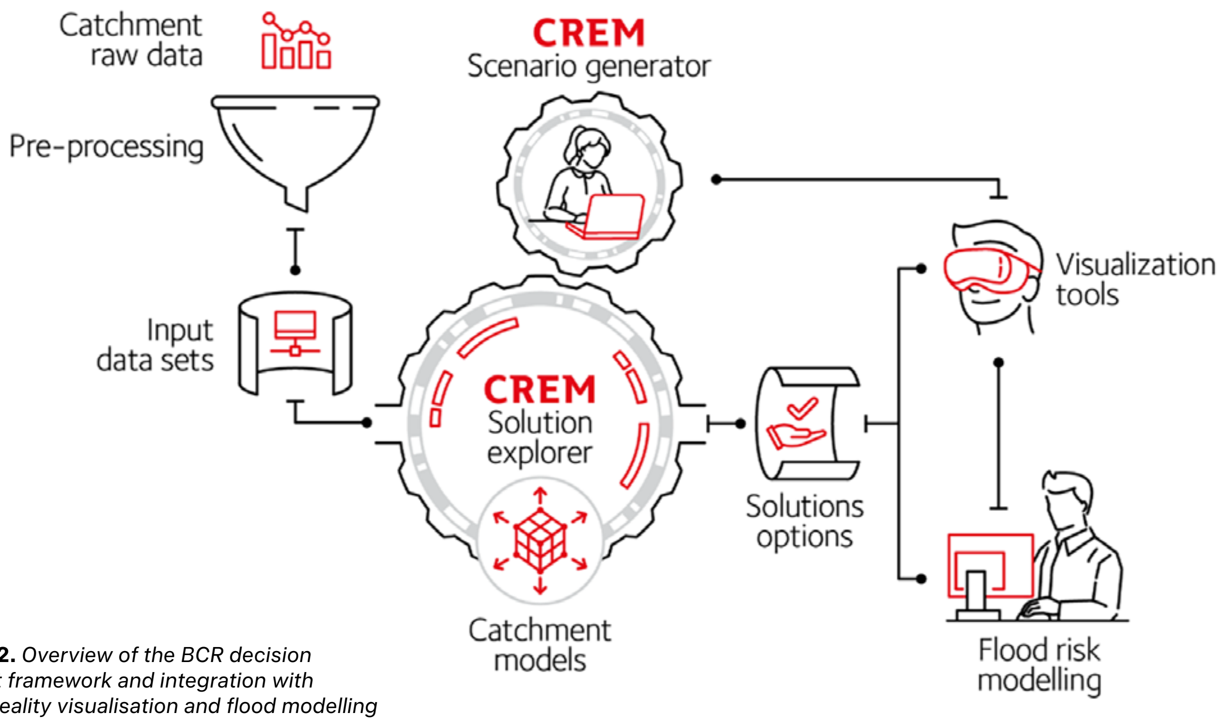


Figure 2. *Overview of the BCR decision support framework and integration with virtual reality visualisation and flood modelling*

A small set of potential management actions was also identified, including actions to slow the movement of water in stream channels and across floodplains, gully remediation, and the creation of riparian and wetland buffers. For each action, the full costs of restoration were determined: the opportunity cost – income foregone by not using land for its current purpose (reflecting how much compensation would need to be provided) – and the implementation and maintenance costs for different management actions.

The heart of the decision support framework is the Catchment Resilience Exploration Modeller (CREM) Solution Explorer (Figure 2). The Explorer considers how selected management actions alter management objectives, then produces solutions that capture the magnitude of those changes (see Section 3). These solutions provide options of slightly different outcomes with alternative spatial configuration for decision makers to choose from, with a view to optimise a management objective, or to identify useful trade-offs between several, possibly competing, objectives. Preferred solutions can be then selected and explored further.

The CREM Scenario Generator component (Figure 2) is a RESTful web-service that allows the generation and loading of catchment planning scenarios, according to stakeholders' needs. The Scenario Generator allows the catchment models of the CREM Solution Explorer component to be manipulated. Stakeholders might be interested in a scenario that aims to get the best management outcome for a fixed budget: e.g., "What management actions will minimise sediment load for an implementation cost budget of $20M?" Alternatively, they may be interested in finding out the minimum cost to achieve a particular management goal: e.g., "What management actions minimise implementation cost to halve the sediment load per year?" These types of scenarios can be explored with Single Objective Simulated Annealing. Stakeholders may also be interested in scenarios that involve multiple, and sometimes competing, objectives: e.g., What trade-offs between sediment, nutrient production and opportunity cost can be obtained with an implementation cost budget of $20M? These types of scenarios can be explored with Multi-Objective Simulated Annealing (see Section 2.2).

Figure 3. *Map of the Laidley catchment to demonstrate planning units (red line) and stream network (blue) embedded in a grey-scale representation of relative surface aspect*

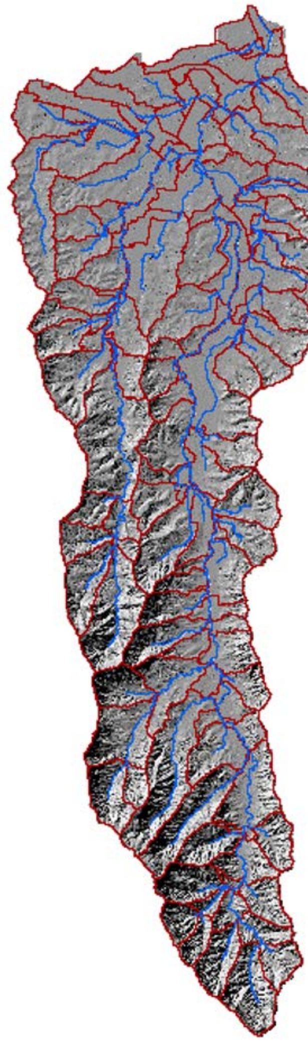
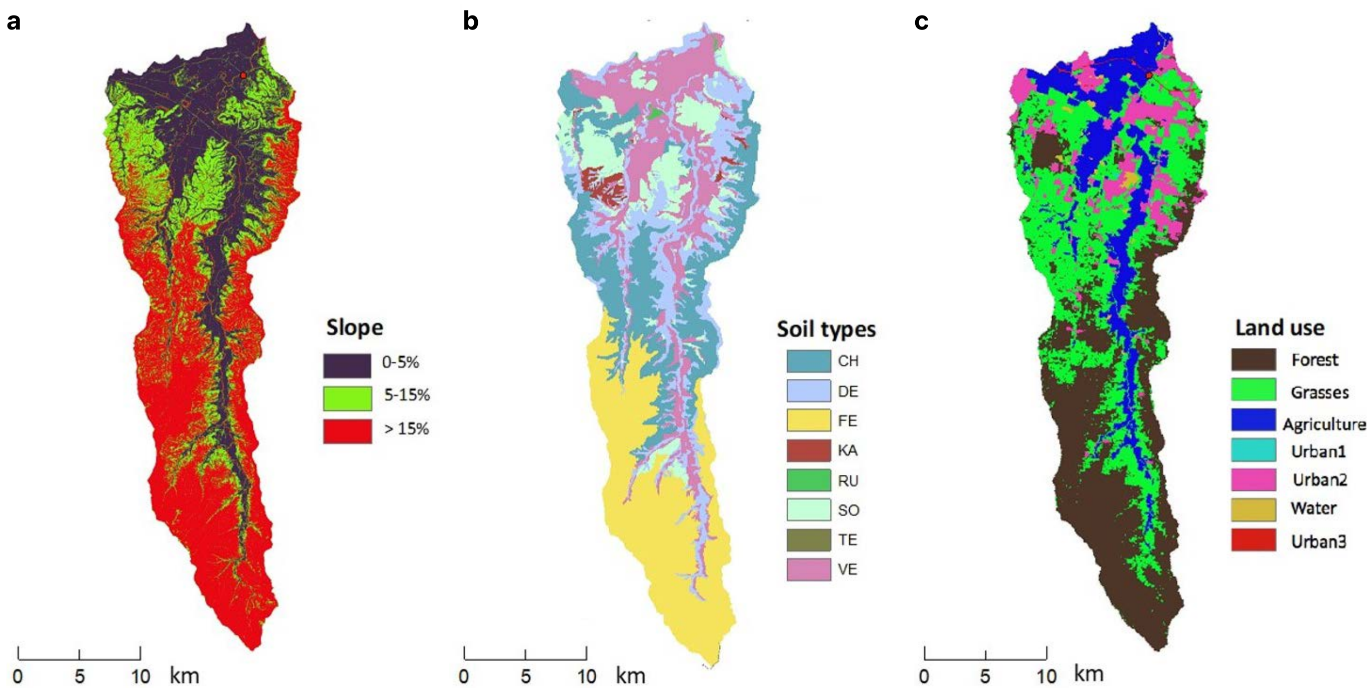


Figure 4. *Maps of the Laidley catchment to demonstrate inputs to the catchment model, including (a) slope, (b) soil type (CH = Chromosols, DE = Dermosols , FE = Ferrosols, KA = Kandosols, RU = Rudosols, SO = sodosols, TE = Tenosols and VE = Vertosols), and (c) land use categories*



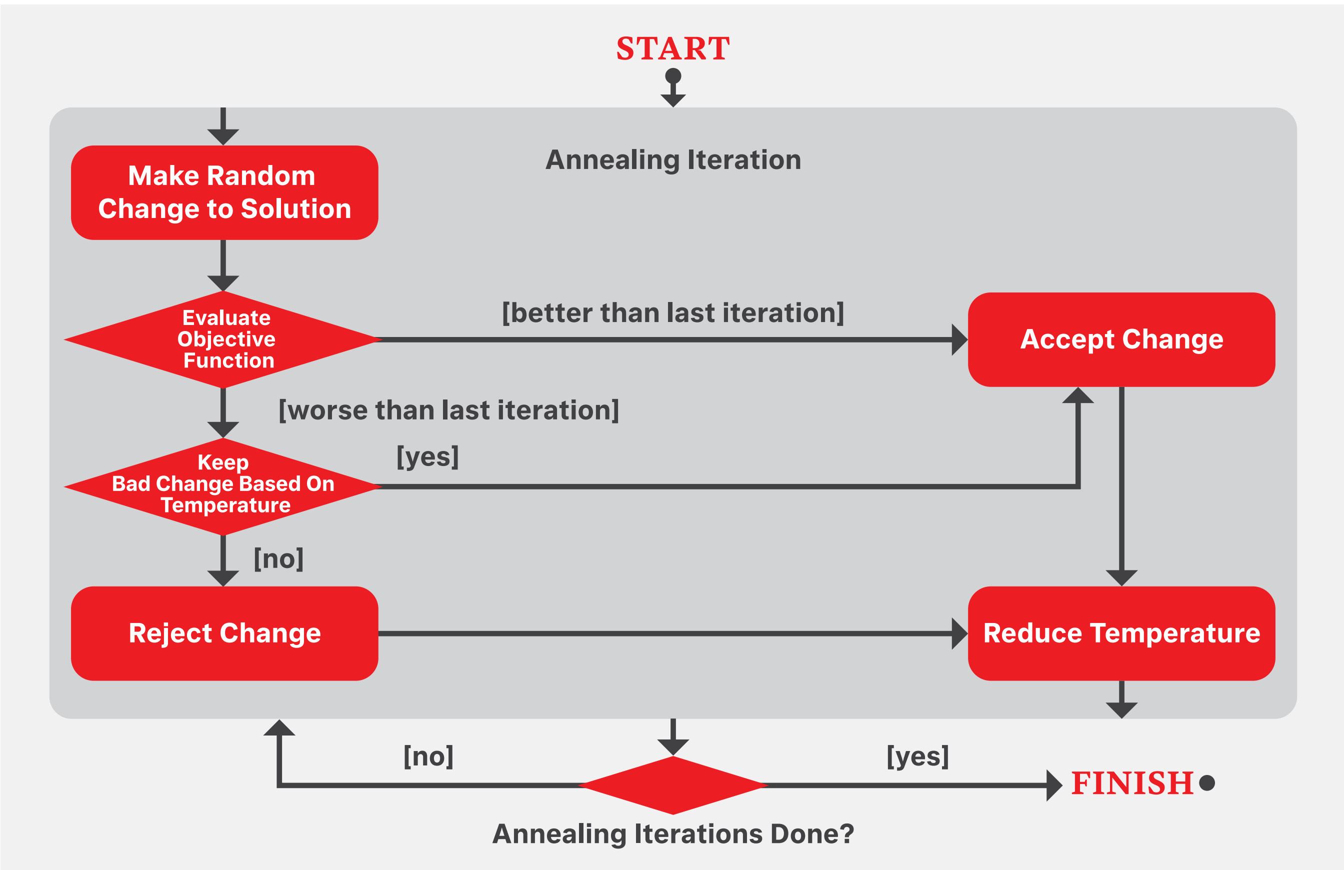
2.2. SIMULATED ANNEALING ALGORITHMS IN THE CREM SOLUTION EXPLORER

Simulated annealing represents a family of computer software algorithms that are roughly analogous to the physical process of metallurgical annealing.

They share with their physical counterpart, the idea of a controlled cooling of temperature to guide a process to a desired outcome. Simulated annealing algorithms are designed to quickly find good answers to the computational optimisation problems where it is computationally unfeasible to attempt a brute-force exploration of all possible combinations of options that are valid for the resource constraints present. Simulated annealing has been successfully used in several resource-constrained conservation planning activities to shift from the question of "what could we do" to "what should we do?"

Generally, the annealing algorithm first makes a change to the state of a model and evaluates how "good" that change is against some objective. If the change is deemed good, it is automatically accepted. If the change results in a negative outcome, the algorithm will decide to either accept or reject this change, with the chance of acceptance decreasing over time, based primarily upon the temperature at the time of decision. Rejection of the change involves reverting the model to its previous state. Accepting the change involves keeping it and using it as the basis for future changes. This concept is illustrated in Figure 5.

Figure 5. *State transition diagram of simulated annealing used in the CREM Solution Explorer to iteratively improve the outcome based on some objective*



The two major variants of simulated annealing are single-objective and multi-objective, respectively. Single-Objective Simulated Annealing (SOSA) uses the concept of an "objective function" to evaluate whether a change is closer or further away from a desired objective. This function evaluates the last random change made and calculates a numerical value that represents whether the change is a) better or worse, and b) how much better or worse. This objective function acts to guide the annealer to solutions that are closer to the desired objective. Depending on the nature of the problem, the annealer is expected to either seek a minimum or maximum possible value from its objective function. If a model offers several variables that could contribute to an objective function, this objective function must be constructed in a way that considers which variables are important for an objective and how they are important with respect to each other.

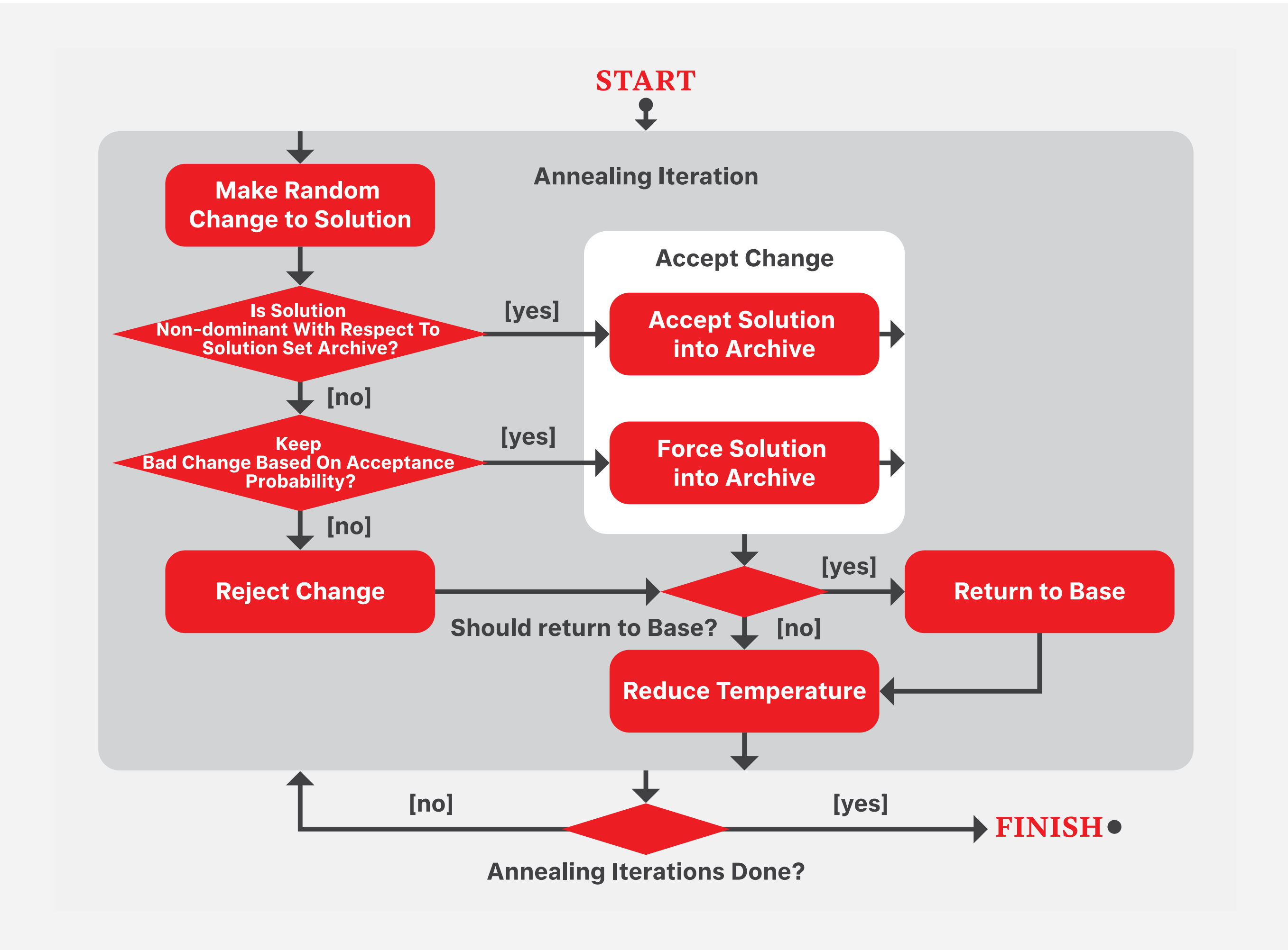
There are limitations to the SOSA approach once there are several, possibly competing objectives, for example, from discussions among a diverse group of stakeholders. Despite these limitations, however, single-objective annealing remains a popular, efficient way to find near-optimal solutions to problems involving resource scarcity where there might be a prohibitively large number of possible solutions. SOSA is therefore provided as an option for simpler resource-constrained explorations.

Multi-objective simulated annealing algorithms work around the limitations faced with SOSA algorithms when modelling systems with multiple objectives. This is done via adapting the core simulated annealing approach to the field of multi-objective optimisation (Figure 6). Instead of implementing an objective function that subjectively weighs the importance of various objectives, MOSA algorithms build a set of solutions, named a pareto-optimal or non-dominated set that captures trade-offs between the various objectives. All solutions in such a set are considered equally good. The set simply captures trade-offs between solutions, where at least one of the objectives is minimal with respect to the others for any given solution. Stakeholders can then decide what trade-offs from the overall result set they deem to be "good".

MOSA algorithms differ from SOSA algorithms in the following important aspects:

- In MOSA, the objective changes to one of building a pareto-optimal set of solutions, where the values of the decision variables are used to decide on whether any given solution is mathematically non-dominant with respect to the current set:
    - If a changed solution is non-dominant with respect to the current solution set, it can be automatically added into the solution set.
    - If a dominance relationship exists between a changed solution and members of the solution set, it is considered "bad". If we accept it, we must force this changed solution into the set by also removing all entries that would invalidate the non-dominant requirement of the set.
- There is an extra step often called "return to base", that occasionally chooses a different solution within the set to act as the base for further exploration. This mechanism ensures a wider spread of results than would be achieved otherwise.
- Variants of MOSA tend to differ primarily in a) how they handle acceptance probabilities of bad solutions and b) how the handle "return to base" behaviour.

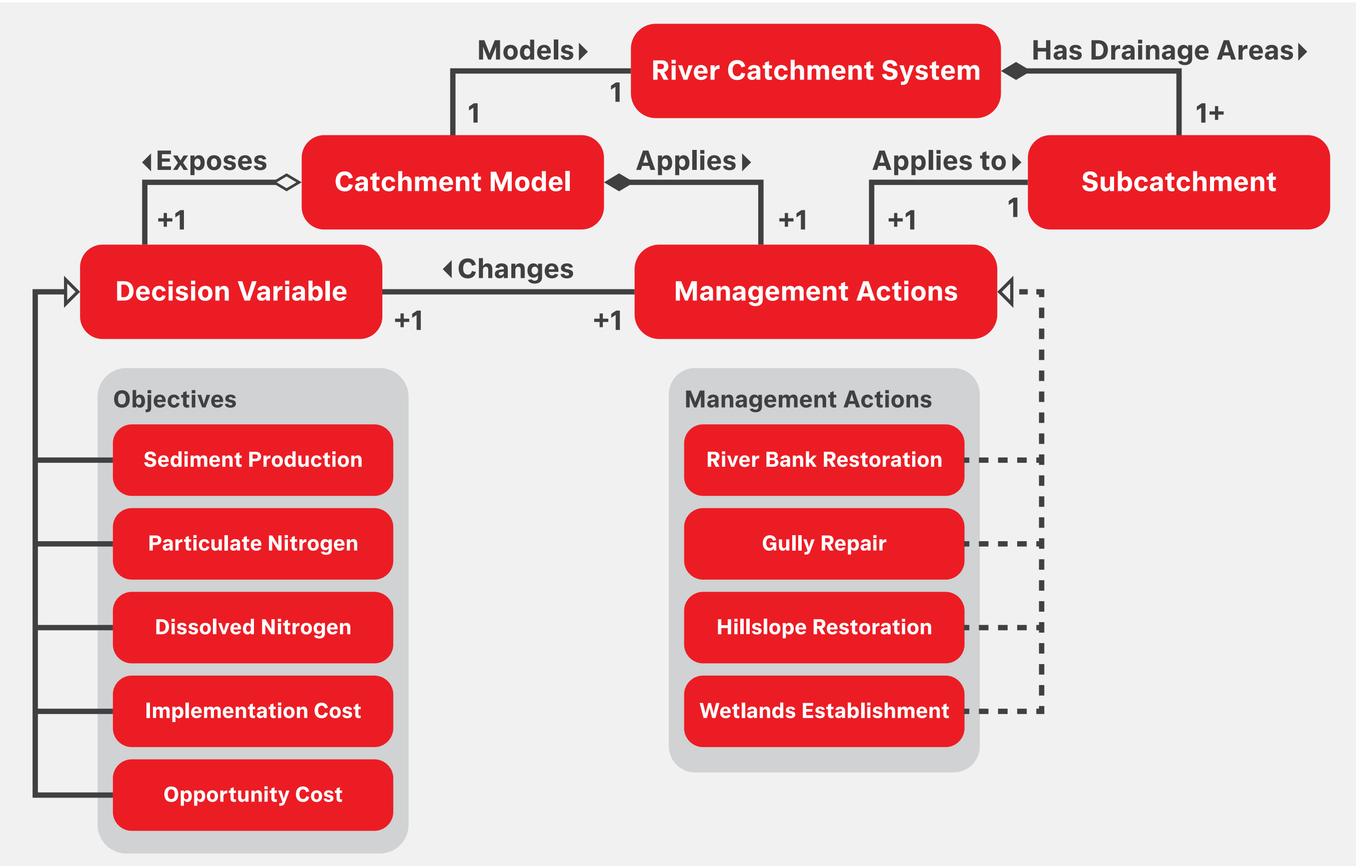
Figure 6. *State transition diagram for a general MOSA algorithm*



2.3. THE CATCHMENT MODEL AND SIMULATED ANNEALING

The catchment model in the CREM Solution Explorer includes decision variables that represent an estimate of key pollutants of concern, a set of management actions that can reduce pollutant delivery to the river, and decision variables representing various aspects of the costs expected in applying these management actions (Figure 7).

Figure 7. *Key catchment model components*

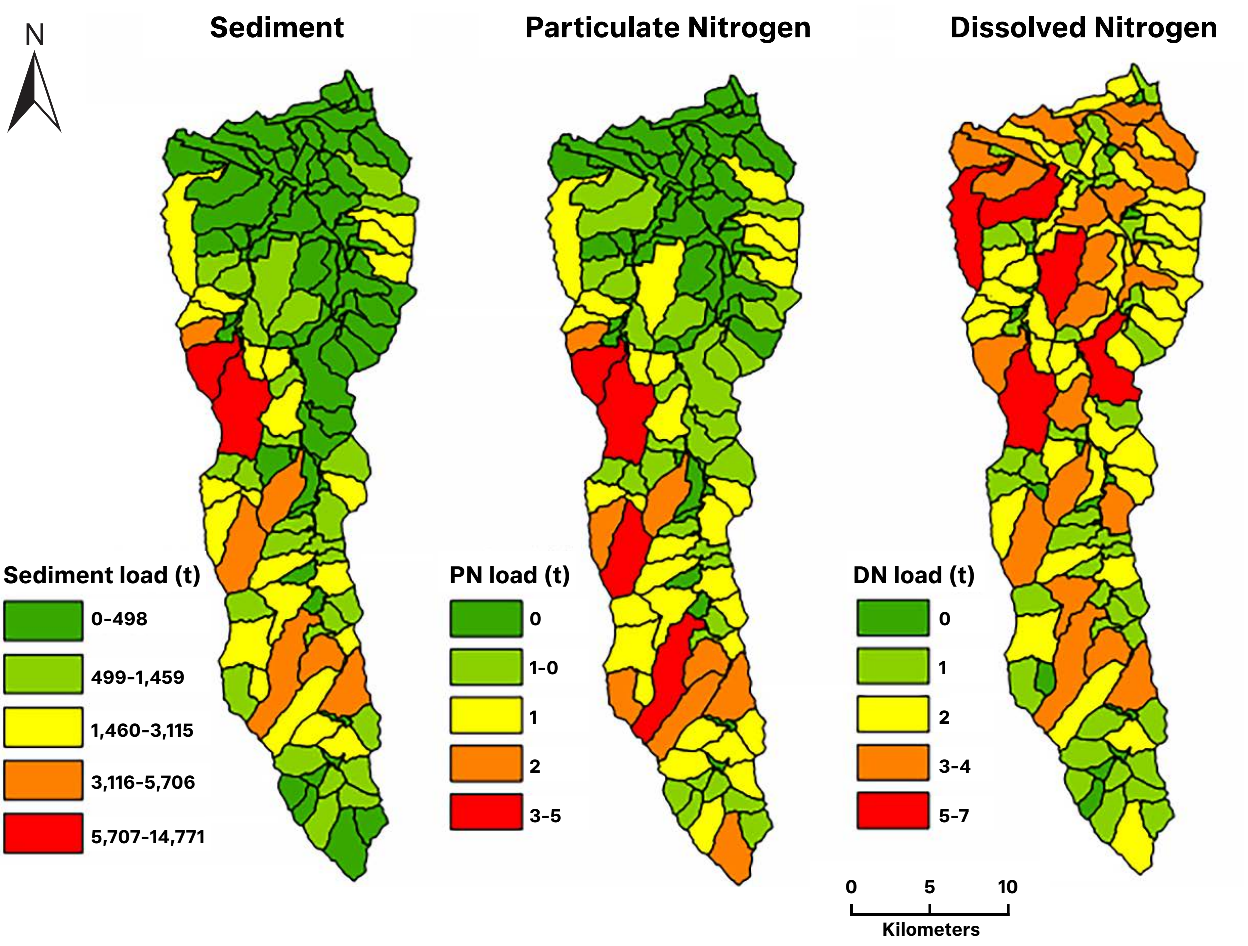


As the catchment model is expected to work within a simulated annealing algorithm, it must be computationally extremely efficient. To that end, several design principles have been adopted in the construction of the catchment models that have influenced the system's overall behaviour:

- The tracking of pollutant production is calculated only at-source and is referenced to each planning unit, as shown in Figure 8. Attenuation of pollutants through the channel network have not been addressed in this version of the system. Management actions are also assumed to affect only the sub-catchment in which they are spatially embedded. This avoids the computational overhead of accounting for attenuation across sub-catchments.
- Management Actions toggle between an "on" and "off" state only. An "off" management action represents the current state of some spatially explicit part of the landscape that has not had any management applied. An "on" management action represents a fully realised change to that landscape aimed at reducing/removing the production of pollutant(s) that could enter the system at the sub-catchment to which the action is attached.
- The number of decision variables and management actions within the catchment model has been restricted to just those that are key to improving catchment resilience. Every time a new action is added, its impact on all existing decision variables must be catered to. Similarly, every new decision variable added must explore how existing management actions affect them.

- The number of model solutions possible and the range of solutions that can be explored via annealing grows at an exponential rate with respect to the number of possible management actions. Although this is the reason for choosing simulated annealing, as it grows, we need to dedicate more computational resource to the running of annealing explorations to achieve useful results. As a consequence, computational inefficiencies within the model are avoided where possible.
- Other stakeholder objectives are possible to consider (e.g. flood risk reduction, carbon sequestration), but if they can be derived from key driver objectives post-annealing then the added computational overhead they introduce is not carried within the catchment model.

Figure 8. *Model output for the base case (current land use and management actions). The heat map colours refer to yields in tonnes from each planning unit.*



3. TESTING THE BCR TOOLS

3.1. THE LAIDLEY CREEK CATCHMENT PILOT

In consultation with the BCR Steering Committee, two example investment scenarios for the Laidley Creek catchment were chosen: one aimed at optimising benefits for a fixed implementation cost of $20 million, the other aimed at halving particulate nitrogen load.

The range of optimal solutions derived from the CREM Solution Explorer can be plotted to illustrate the trade-offs between key objectives. In the scenario exploring the range of outcomes that can be achieved with an implementation cost budget of $20 million, we can explore the trade-offs between sediment, nitrogen and opportunity cost (Figure 9).

The optimal solutions cover a range of potential outcomes for sediment and nitrogen reduction and the associated opportunity costs.

From these, several solutions from the multi-objective simulated annealing, representing different potential management outcomes, were selected, and benefits and costs of these management actions quantified and spatially represented as a series of optimal 'solution' maps (Figure 9). These chosen solutions were then be explored using the visualisation tool (Section 4) and analysed further to assess flood risk (Section 5) and other benefits.

Figure 9. *Pareto front and three selected solutions from the range of optimal solutions for a $20M implementation budget scenario for the Laidley Creek catchment*

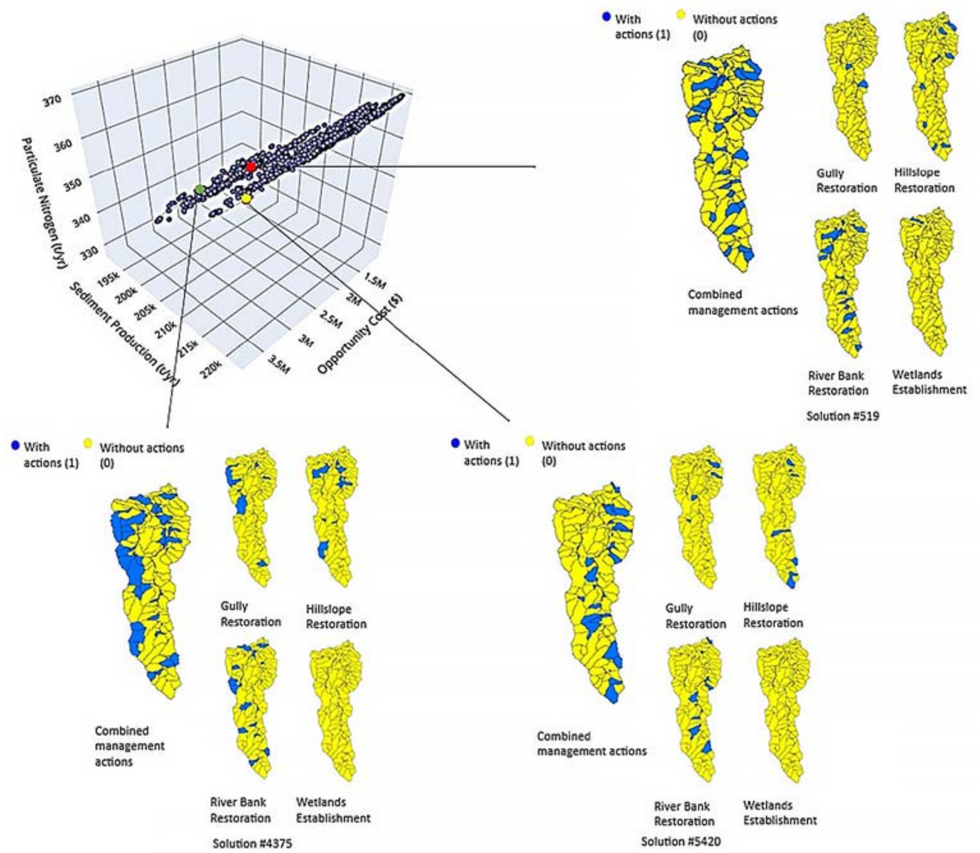


Table 1. *Example solutions from Run 10 of a $20M investment scenario for the Laidley Creek catchment and their associated costs and benefits (see Figure 9). DN is dissolved nitrogen and PN is particulate nitrogen.*

	SEDIMENT PRODUCTION (T/YR)	NITROGEN LOAD (T/YR)		COSTS ($)		DESCRIPTION
		Dissolved	Particulate	Implementation	Opportunity	
Current state	222,991	176	371	0	0	No actions
Solution #519[1]	207,169 **(7%)**	165 **(6%)**	352 **(5%)**	19,984,399	2,340,376	Low DN option
Solution #4375[1]	191,060 **(14%)**	168 **(4%)**	333 **(10%)**	19,883,584	2,090,764	Low sediment option
Solution #5420[1]	196,028 **(12%)**	171 **(3%)**	327 **(12%)**	19,395,545	1,451,665	Low PN option

1. The run numbers and model output are specific to each model run due to the randomised methodology of the annealing procedure. The output from each model will therefore not be identical, but very similar. Percentages are % reduction.

Solution #519 (Run 10) provides a good outcome for dissolved nitrogen but a relatively poor outcome for sediment and particulate nitrogen and would result in a relatively high opportunity cost ($2.34M). Solution #4375 provides the best outcome for sediment (14% reduction) but also comes with a relatively high opportunity cost ($2.09M). Solution #5420 however, would provide almost the same sediment benefit as #4375 (12% reduction) at a much lower opportunity cost ($1.45M). It would also provide the best outcome for total nitrogen load (DN + PN), reducing it by 48 t/yr.

Although the predicted reduction in nitrogen seems rather modest in terms of the current total load generated, this still has a significant economic value as a potential offset. For example, if a water utility was prepared to pay $120/kg to offset their nitrogen loads downstream, Solution #5420 would provide a nitrogen offset worth $5.74M/yr, easily covering the opportunity cost and recovering the implementation cost in less than 5 years. Given the small scale of this investment scenario, the solutions are unlikely to generate significant additional economic benefits in terms of flood risk reduction (see Section 5).

In the scenario exploring the costs and benefits associated with the ambitious goal of halving the particulate nitrogen load, we can explore trade-offs between sediment reduction, and the implementation and opportunity costs (Figure 10). From the very large number of potential solutions (23,360), several solutions from the multi-objective simulated annealing, representing different potential management outcomes, were selected (Table 2). The benefits and costs of these management actions were then quantified and spatially represented as a series of optimal 'solution' maps (Figure 10).

This scenario explores a very ambitious target with high implementation and opportunity costs but provides a good illustration of the scale of rehabilitation required to significantly reduce nitrogen pollution. Clearly, all three solutions not only achieve the target of halving the particulate nitrogen load but also result in a significant reduction (>50%) of sediment (Table 2).

Figure 10. *Pareto front and three example solutions from the range of optimal solutions for an investment scenario for the Laidley Creek catchment that aims to halve the particulate nitrogen*

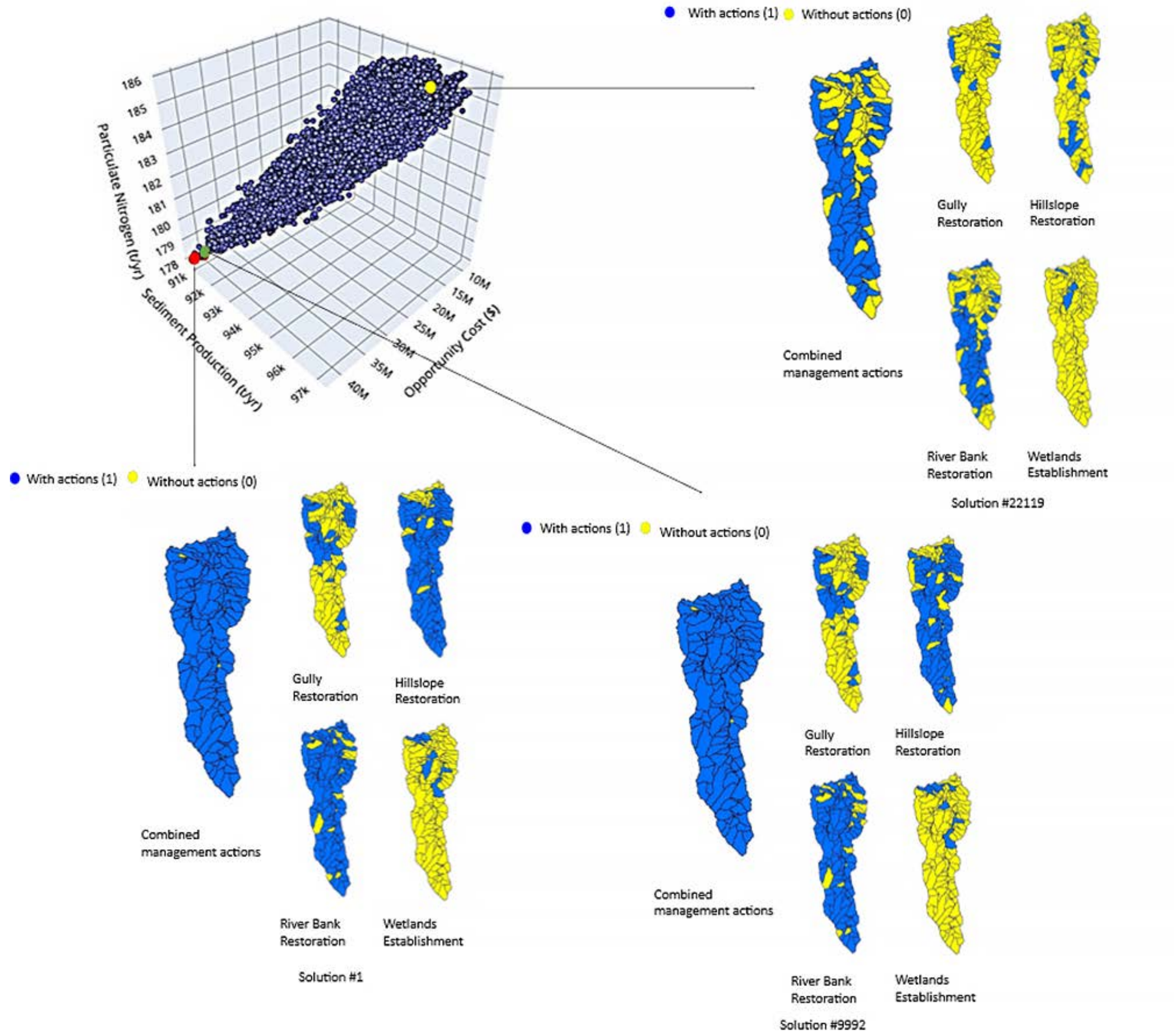


Table 2. *Example solutions from an investment scenario for the Laidley Creek catchment that aims to halve the particulate nitrogen load, and their associated costs and benefits (see Figure 10)*

	SEDIMENT PRODUCTION (T/YR)	NITROGEN LOAD (T/YR)		COSTS ($)		DESCRIPTION
		Dissolved	Particulate	Implementation	Opportunity	
Current state	222,991	176	371	0	0	No actions
Solution #1	90,746 **(59%)**	88 **(50%)**	178 **(52%)**	417,178,083	41,934,098	Min DN
Solution #9992	90,829 **(59%)**	90 **(49%)**	178 **(52%)**	399,732,159	40,123,490	Min SED
Solution #22119	95,512 **(57%)**	133 **(25%)**	185 **(50%)**	116,333,026	12,800,043	Min Imp

The main trade-offs appear to be between dissolved nitrogen and costs. Solutions that also halve the dissolved nitrogen load would require much higher implementation and opportunity costs (#1, #9992) associated with the broadscale revegetation of hillslopes and riparian areas (see Figure 10). However, a similar outcome in terms of particulate N and sediment reduction (Solution #22119) could be achieved at ~30% of the costs of the other two solutions. The additional costs associated with the other solutions appear to be related to actions to reduce dissolved nitrogen.

Halving the nitrogen load could provide significant direct economic benefits in terms of potential N offsets. Solutions #1 and #9992 would reduce total nitrogen by ~280 t/yr, which would equate to an annual offset value of $33.6M (assuming nitrogen offsets can be sold for $120/kg). Solution #22119 would achieve a slightly lower reduction in total nitrogen (~230 t/yr) with an annual offset value of $27.6M. This would cover the opportunity cost ($12.8M) and recover the implementation cost within 8 years.

Given the spatial scale of the revegetation required to achieve this scenario, additional catchment scale benefits are also likely to be considerable. Carbon sequestration from woodland plantings on hillslopes and in the riparian corridor would generate marketable Australian Carbon Credit Units (ACCUs) under the Federal Government's 'Reforestation by Environmental Plantings Methodology'[2]. Estimates of CO_2 sequestration rates for mixed species environmental plantings at indicative rehabilitation locations on hillslopes and in the riparian corridor were produced using the Federal Government's Full Carbon Accounting Model (FullCAM)[3]. Knowing a site's location and the initial planting density, FullCAM predicts the quantity of carbon that will be accumulated into the wood of the trees, and stored in woody debris, as the trees grow. The corresponding quantity of ACCUs produced annually per hectare can then be calculated using formulae set out in the 'Reforestation by Environmental Plantings Methodology'. Assuming an ACCU price of $40/ACCU (i.e., $40/tonne of CO_2 sequestered) as current in late January 2023, the stream of carbon revenues per hectare can be calculated from indicative locations over a 25-year duration.

FullCAM was used to estimate the per-hectare total present value of carbon revenues over the first 25 years from environmental plantings, averaged across six indicative riparian sites and five indicative hillslope sites identified in the $20M investment scenario (Table 1). The total present value of carbon revenues was then calculated for the $20M investment scenario and two of the scenarios that aimed to reduce particulate nitrogen load by 50% by applying those average per hectare revenues across the total riparian and hillslope areas that would be covered by dense woody vegetation (Table 3). All three solutions are also likely to have a significant effect on catchment hydrology and result in reductions in flood height and velocities in the downstream reaches of the catchment and the township of Laidley. This is explored further in Section 5.

2. https://www.cleanenergyregulator.gov.au/ERF/Choosing-a-project-type/Opportunities-for-the-land-sector/Vegetation-methods/Reforestation-by-Environmental-or-Mallee-Plantings-FullCAM

3. Australian Government (2020) Full Carbon Accounting Model (FullCAM), Public Release, v6.20.

Table 3. *Estimated total present value of carbon credit revenues from environmental plantings on hillslopes and in riparian buffer zones over a 25-year period from initial planting under different catchment rehabilitation solutions*

	TOTAL AREA OF TREES & DENSE VEGETATION (Ha)	HILLSLOPES ($M)	RIPARIAN CORRIDOR ($M)	TOTAL ($M)
Scenario 1b ($20M)	2,116	8.3	0.7	9.0
Scenario 2b (high cost 1/2 PN)	14,874	58.2	5.2	63.4
Solution 3b (lower cost 1/2 PN)	7,216	28.2	2.5	30.7

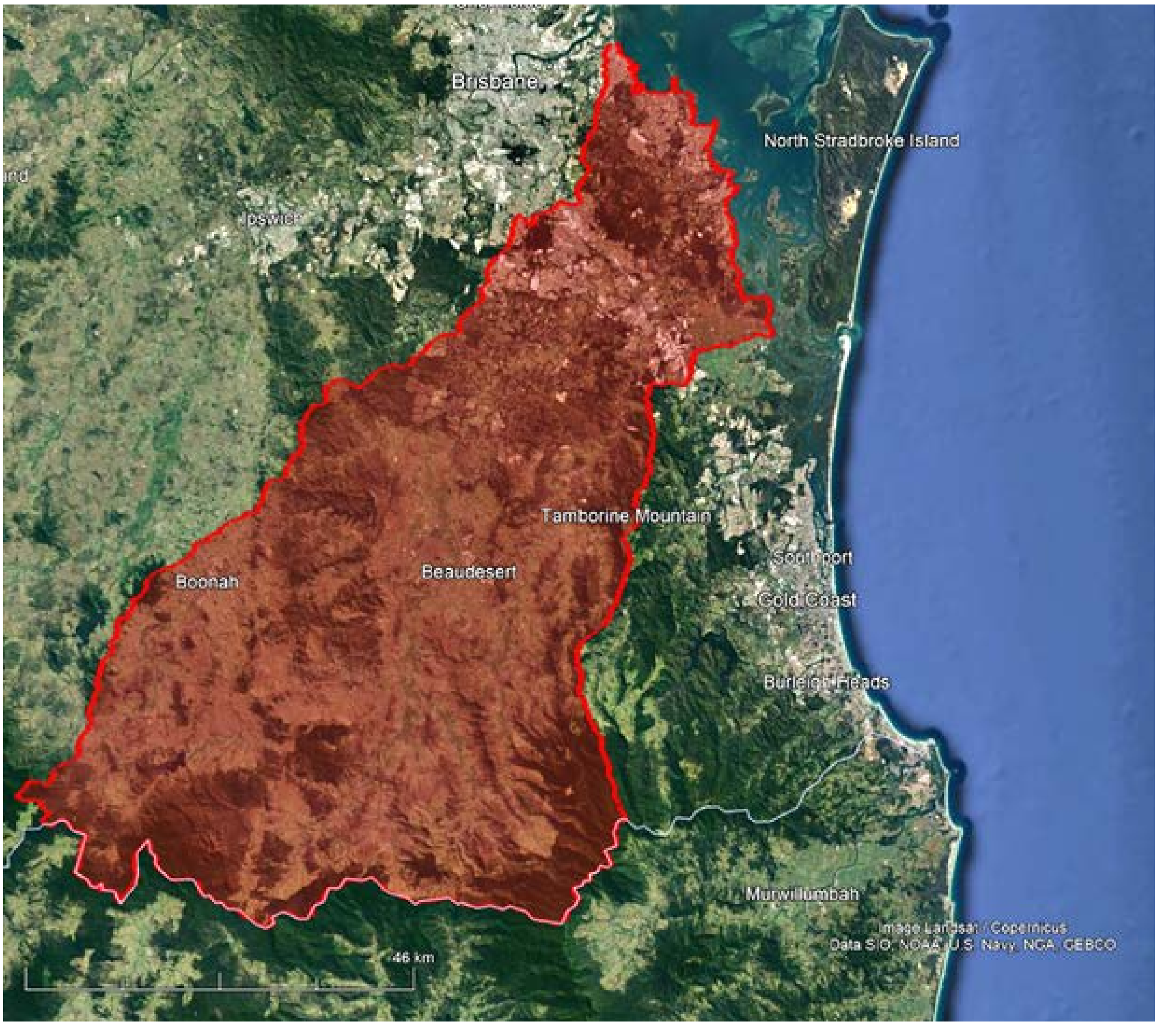
Assumptions: Total present value of ACCU sales calculated over a 25-year period at a real discount rate of 7% per annum.
Assumed ACCU price = $40/ACCU, held constant in real terms over the 25-year evaluation period.
For hillslopes, new environmental plantings are assumed to cover 50% of the rehabilitated area (as some trees are still present at most locations). Hillslope plantings are assumed to be belt plantings at a density of less than 1500 stems per hectare.
For riparian revegetation, new environmental plantings are assumed to cover 75% of a 25m wide riparian corridor on each side of the river.
Carbon sequestration estimates via FullCAM v6.20.03.0827.

3.2. THE LOGAN-ALBERT RIVER CATCHMENT PILOT

We sought to test the generality of the BCR Catchment Resilience Model by establishing a baseline catchment model for the Logan-Albert catchment, carried out mostly by the project team from Water Technologies Ltd.

Like the Laidley catchment, the Logan-Albert River, in southeast Queensland south of Brisbane, is subject to many of the same environmental issues arising from historical land clearing and inability to adequately address catchment health and build resilience to flooding at a scale and in locations that are effective. Sediment loads from the Logan-Albert are estimated to have increased by a factor of 35, and nitrogen and phosphorus loads by a factor of 3.2 and 4.7, respectively.[4] The downstream effects of major floods have also been disastrous, with ex-tropical Cyclone Debbie (March-April 2017) rendering many homes uninhabitable and causing widespread infrastructure (e.g., roads and power) damage. Food damage was even more disastrous and extensive in February-March 2022, following 420 to 888 mm of rainfall recorded in one week in at different rainfall gauges in the catchment. The Logan-Albert catchment has been identified as an area for continued major urban expansion, requiring additional wastewater treatment to complement the current treatment from two major wastewater treatment plants that discharge in downstream estuarine locations.

Figure 11. *Map of the Logan Albert catchment boundary, including terrain. The catchment area is approximately 3862 km^2*



4. Australian Government National Pollutant Inventory, 2019. Bioregional Assessment – Surface Water Quality. https://www.bioregionalassessments.gov.au/assessments/11-context-statement-clarence-moreton-bioregion/1152-surface-water-quality.

The BCR Catchment Resilience Model of the Logan-Albert catchment resolved 174 planning units, which included 166 stream reaches and 1396 gullies (Figure 12). The spatial data layers for land use, soil type, vegetation, etc., were input to the model using the same categorisation as the Laidley (Figure 4) and the default parameters were initially used to examine fine-sediment, particulate nitrogen, and dissolved nitrogen yields at the planning unit scale. Adjustments to some of these parameters were made to be consistent with sediment tracing[5] and other studies that had examined sediment sources and transport in the Logan-Albert catchment. Examples of the spatial distribution over the catchment of sediment erosion parameters are given in Figure 14. Guidance for such parameter adjustments is provided in the CREM Technical Report and User Manual, with literature reviews and/or field studies also recommended to develop parameter values, including costs of management actions, that are specific to the catchment.

Figure 12. *Map of the Logan-Albert catchment (approx. 3862 km2) showing 174 resolved planning units, 166 stream reaches and 1396 gullies*

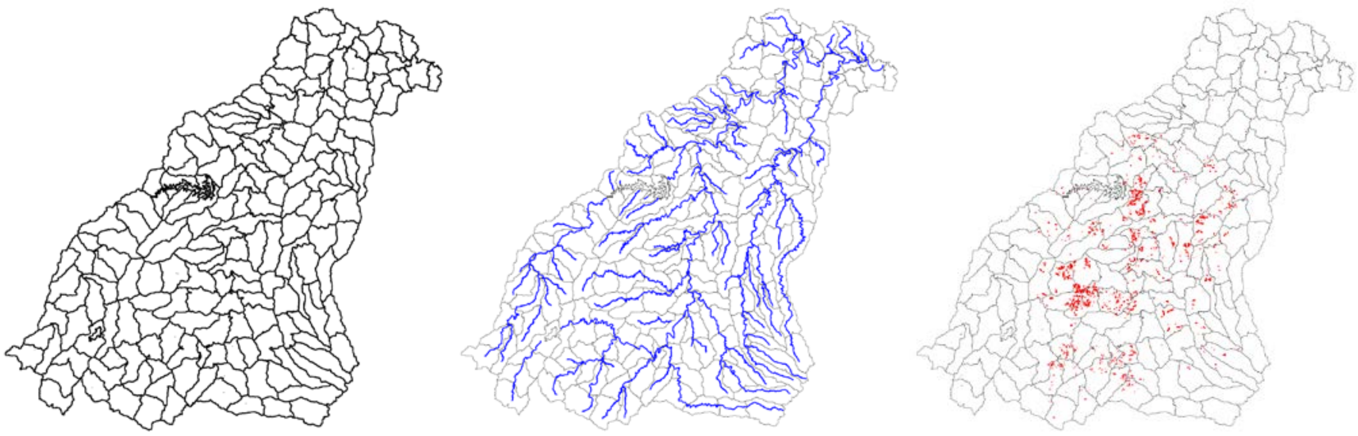
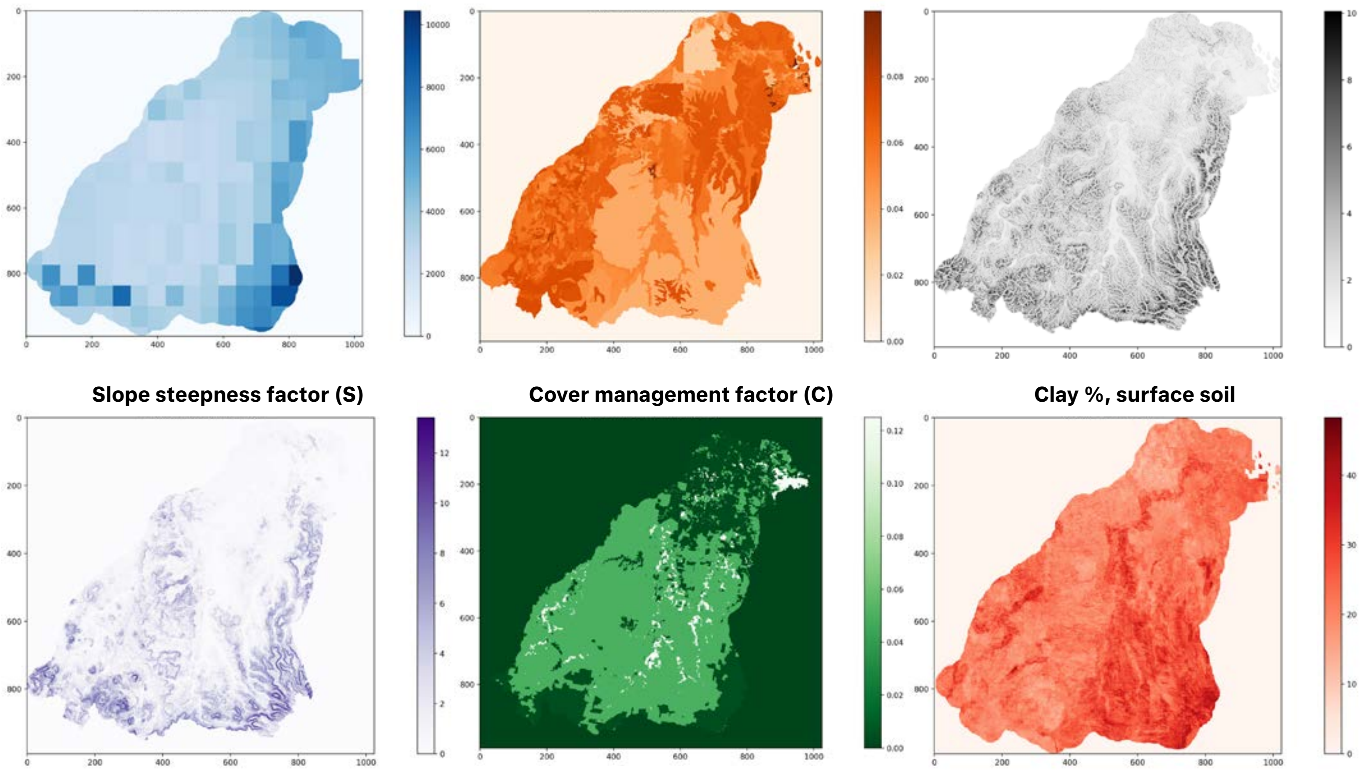


Figure 13. *Spatial representation (model output) for the Logan-Albert catchment of different parameters that affect sediment yields at the planning unit scale*

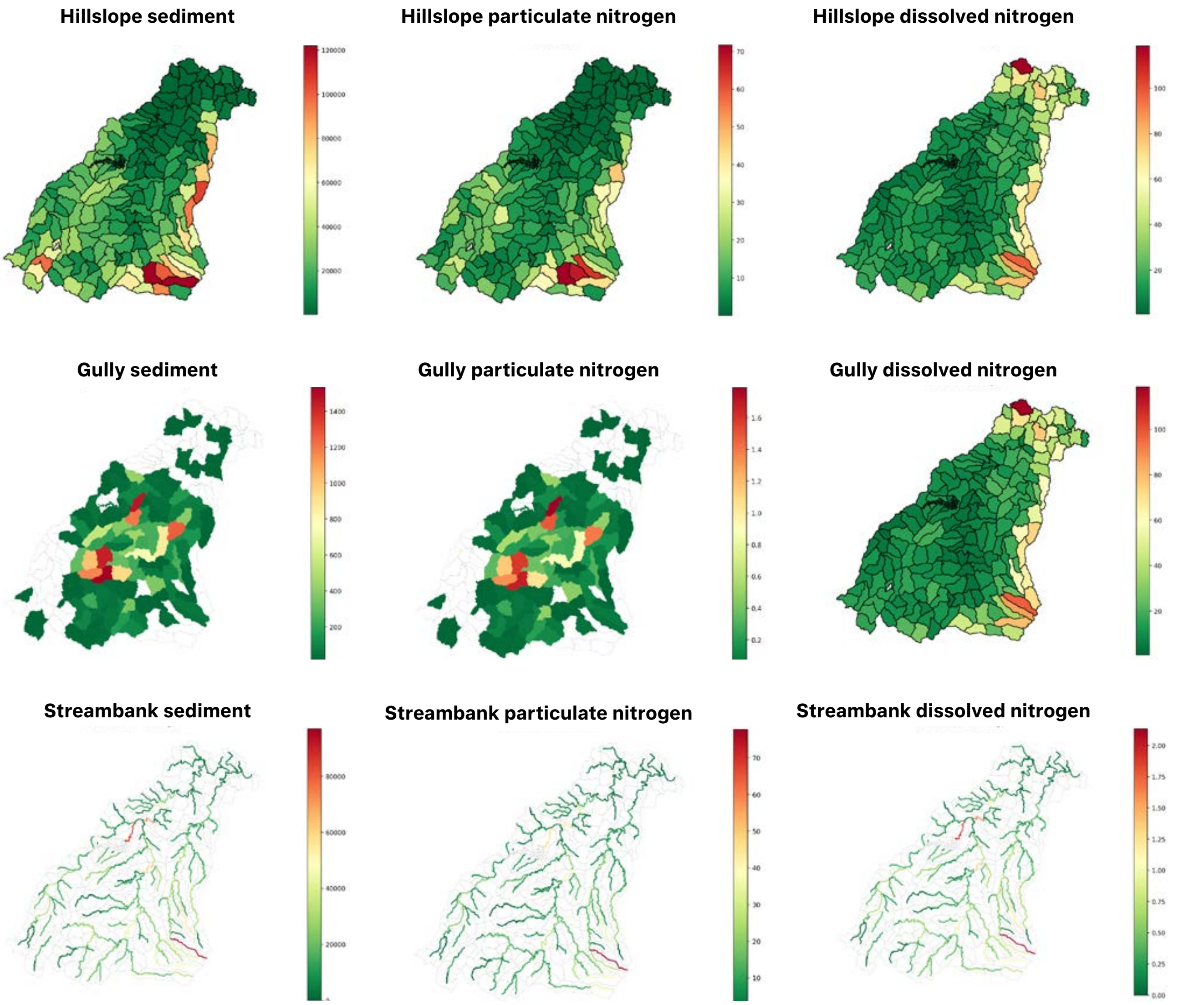


[5] Hancock, G.; Caitcheon, G. 2010. Sediment sources and transport to the Logan-Albert River estuary during the January 2008 flood event. CSIRO; 2010-07. https://doi.org/10.4225/08/5858228549f6a.

The objective of the BCR Catchment Resilience Model application to the Logan-Albert was to progress the model application to a proof-of-concept of the baseline prototype application. Additional work, beyond the scope of the present report, would be required to engage broadly with stakeholders and develop management scenarios by running CREM, carrying out flood modelling and analysing model output from the catchment resilience and flood models.

The baseline outputs in Figure 15 illustrate the generation of fine-sediment, particulate nitrogen and dissolved nitrogen at a planning unit scale, differentiated by hillslopes, gullies and floodplains. The maps provide a graphic illustration of the specificity of areas that are generating the greatest amounts of sediment and nitrogen, and the opportunity for targeted remediation to address these contaminants. The scales for hillslope and streambank erosion are comparable in Figure 14, while the scale for gullies is nearly two orders of magnitude lower. Though this difference may seem significant, gullies provide an opportunity for targeted intervention; this contrast should not be interpreted as a basis to neglect gully remediation. The BCR model includes gully remediation options along with mitigation costs and a number of other variables in single or multi-objective analysis. Further, most of the erosion from gullies occurs in just a few of the planning units, mostly in the central part of the catchment. Steep hillslopes in the upper southeast of the catchment generate high levels of sediment and particulate nitrogen. Two major stream reaches are 'hotspots' of sediment and nitrogen yield; Widgee Creek and Christmas Creek and the right branch of the Logan River.

Figure 14. *Model output of hillslope (top row), gully (middle row) and streambank (bottom row) generation of sediment (left-hand side), particulate nitrogen (middle) and dissolved nitrogen (right-hand side) for the Logan-Albert catchment. The scale is tonnes per year for each variable.*




As Is
40,061.6 | 40,061.6
Skys

4. VISUALISATION TOOL DEVELOPMENT

The Building Catchment Resilience interdisciplinary project team have developed an innovative visualisation tool that brings together GIS data and complex mathematical model outputs, in an immersive virtual reality (VR) application.

Traditional mapping and scientific communication methods are recognised as falling short of expectations about the way they influence and change environmental management funding decisions. These techniques have remained largely unchanged for the past 40 years, revealing a need to better communicate and visualise the relationships between natural systems, economics, and management actions using modern digital tools.

The Building Catchment Resilience project is an example of interdisciplinary teams successfully working together to explore new opportunities to advance current approaches for visualisation and communication of modelled data for environmental management options. The collaboration between Queensland University of Technology and Griffith University researchers was foundational to the success of the project with the visualisation team involved in across the project's evolution. The team worked closely with individual researchers and programmers to interpret, conceive, design, build and test the finished product.

New ways of understanding modelled environmental management actions are being uncovered with the successful integration of a realistic 3D simulation, based on aerial imagery and elevation data together with a dynamic multi-objective optimisation engine in a VR visualisation tool. The VR application is based on the catchment model planning units, each with the capacity to simulate losses of sediment and nitrogen. Individual planning units are of a scale suitable to have one or more management actions applied to reduce their annual loads, however these management actions come at a cost. The VR tool presents pollutant loads and economic costs together in an interactive 3D environment, where users can observe actions, reduction in sediment and nitrogen loads, and costs associated with modelled sets of management actions, at a planning units scale.

A unique feature of the VR tool is the visualisation of how management actions affect the landscape of each sub-catchment. For example, it can include dynamically generated 3D trees growing along the buffer zone for riverbank restoration, or the addition of rocks and shrubs in gully restoration and additional vegetation and trees across hillslope areas (Figure 15). Users can navigate to a creek level view and see trees grow as a reflection of the effect a management action will have at a given location.

Figure 15. *Visualisation Tool: Dynamic vegetation positioned in the 3D landscape based on GIS data (yellow areas indicate riparian areas)*

4.1. VISUALISATION METHODOLOGY

The production methodology implemented combined aspects from multiple disciplines including spatial data analysis, data visualisation, game design, user experience design, user interface design and VR usability, and a new discipline, VR-3D data visualisation.

A central pillar of this methodology is the importance of exploring and understanding how data are used in the generation of modelled results, and what the model can do that is not currently available to the two major user types: landholders and policy/funding decision makers.

Complex multi-objective modelling is not able to be calculated by humans; it takes detailed software (multi-objective annealer) to calculate scenarios that ask questions about assumed methods of targeting high producing versus socially visible areas. From this understanding of the modelling data inputs, processing, and outputs the team has built solution software that takes key geospatial features and provides users with a tool that connects the conceptual elements into a usable, understandable visualisation of a complex system.

The project team embraced the new world of agile design and technical development driven by understanding the need for innovation and the importance of user experience in successfully delivering the product. The opportunity for QUT team to work directly with the catchment model developers at Griffith University was critical to ensure the integration between the CREM engine and the visualisation. There were hundreds of iterations to connect the engine and the visualisation based on conversations around technical issues, efficiencies, flexibility, and stability. There were two other critical areas of activity: the development of the application, and the design of the user interface. Each had thousands of iterations as the work progressed, the application development covering how best to handle the base terrains, aerial imagery, vegetation, and usability solutions to provide users with capability to navigate around the catchment.

The user interface design had to consider the entire scope of the modelled data and how users could understand what they were seeing. VR technology is not necessarily new, however the design of interfaces that connect spatial environmental data, economic data, and modelled data in a 3D, interactive space is a new area of exploration and, to the best of our knowledge, a world first.

4.2. UX (USER EXPERIENCE) RESEARCH

Established visualisation design and development methodology provided the foundations for the identification of a set of key features that the VR project could offer users.

The term *User Experience* has many interpretations, but fundamentally it is focussed on identification of the key features of a product and how best to give users seamless access to them. The QUT team designed a product with core capability to visualise impact (environmentally and financially) of a modelled series of management actions. Users can see the catchment as a whole and as individual sub-catchments, planning units or management actions, to better understand the impacts from a series of proposed scenarios.

The project's goal was to deliver a visualisation tool that would enable users to immerse themselves into the landscape while exploring various scenarios proposed by the modelling. A set of user requirements was refined through meetings, presentations, ad-hoc discussions with groups of potential users. Multiple structured sessions were held with QUT and Griffith University research teams and project stakeholders. Below are the high-level requirements defined from the sessions where users must:

- Be able to orient themselves in the landscape/ environment (Figure 16)
- Move easily around the landscape with minimal unnatural movement
- Understand quickly what data they are seeing
- Select a specific area of interest based on pollutant levels
- Understand regional differences at a sub-catchment scale
- Understand a holistic picture of the emissions and economic data
- Understand sediment and nitrogen outputs in relation to implementation and opportunity costs
- Understand the level of improvement from different actions on specific area

Figure 16. *Orientation in the location was a critical consideration for the planning and implementation of the user interface within the VR tool*

The UX process was broken into six stages:

1. **Strategy:** The early stages of the project where QUT built a full understanding of the modelling data and processes to support the development of a VR based application that allows users to understand the complex relationships between the different components of the project, forming the base of the UX strategy.

2. **Personas:** Understand the users in detail and answer the question: How does each user type interact with the system and what are their desired outcomes? Through a series of workshops, presentations, and face to face meetings, QUT was able to generate a clear picture of the government, policy, and funding user groups. Several sessions were held with individuals that represented landholder interests although COVID limited the extent of engagement in the middle stages of the project.

3. **User Flow:** Map out the "user flow" for each interaction process/point in the visualisation tool:

   a. Includes strategic user flow design to ensure that users do not get lost in the various processes.

   b. Further identify and remove any potential barriers to a successful user outcome.

   c. Ensure a clear and easy to understand flow for any user interacting with the system.

4. **System Analysis:** Workshops with representatives from each key user group (scientific research, policy, environmental and general public) to understand the desired outcomes each user type.

5. **Wireframes:** The creation of schematic charts that illustrate each interaction element and process detailed in the requirements document. Each action in the Visualisation Tool could be wire-framed using an iterative process to ensure user engagement and further support were iterative, leading to technical development and ensuring all requirements were met.

6. **UI (User Interface):** Creation of an attractive, clean, clear, and functional graphical user interface. The core challenge was the integration of each aspect of the modelled data into a single interface where the user can see each important component together to quickly get a sense of the whole and the individual sub-catchments. An overall visual styling/theme was adopted to unite all elements of the VR application.

The UX process revealed the need for a seamless connection between the modelled base scenario data and visualisation of that extended over the landscape. The application needed to build users' trust and understanding of the complex relationship between each sub-catchment of planning unit, to enhance understanding of the environmental and economic impacts of the proposed modelled solutions.

As part of the UX process the team explored the logistics of using a VR application and headset on location with diverse target audiences and the need for the specific hardware setup to support a seamless experience for both the presenter and users. The VR application is designed to hold the most recent set of modelled results, to enable quick, easy setup to foster confidence in the technology, VR application and modelling results from the target audience.

Figure 17. *Visualisation Tool User Interface showing 'world terrain', mini-map, and data dashboard*

4.3. UI (USER INTERFACE) RESEARCH AND DESIGN

There were many unique aspects to realisation of a VR product that combines high-resolution spatial data, visualisation, user experience, usability, technical requirements for the delivery of a robust, scalable virtual reality (VR) visualisation solution for the project (Figure 17). The BCR modelling provides scenarios for how best to reduce pollutant loads while balancing economic implications. These scenarios are strings of geospatially referenced data that constitute a solution which illustrates the relationship between load reduction and the costs. The visualisation combines existing GIS spatial data and generated statistical data in a way that enables users to explore the role economics play in the identification of a realistic set of management actions.

The user interface and overarching navigation system have been designed to combine dynamic visual elements attached to the landscape with those of the modelled results to provide an effective method for users to understand the impact of management actions for both individual sub-catchments and across the entire catchment (Figure 17). The visualisation solution encapsulates sediment and nitrogen production, management actions and economics for each sub-catchment, scalable to the entire catchment in a way that users "see" the relationship between sediment and nitrogen sources and the landscape.

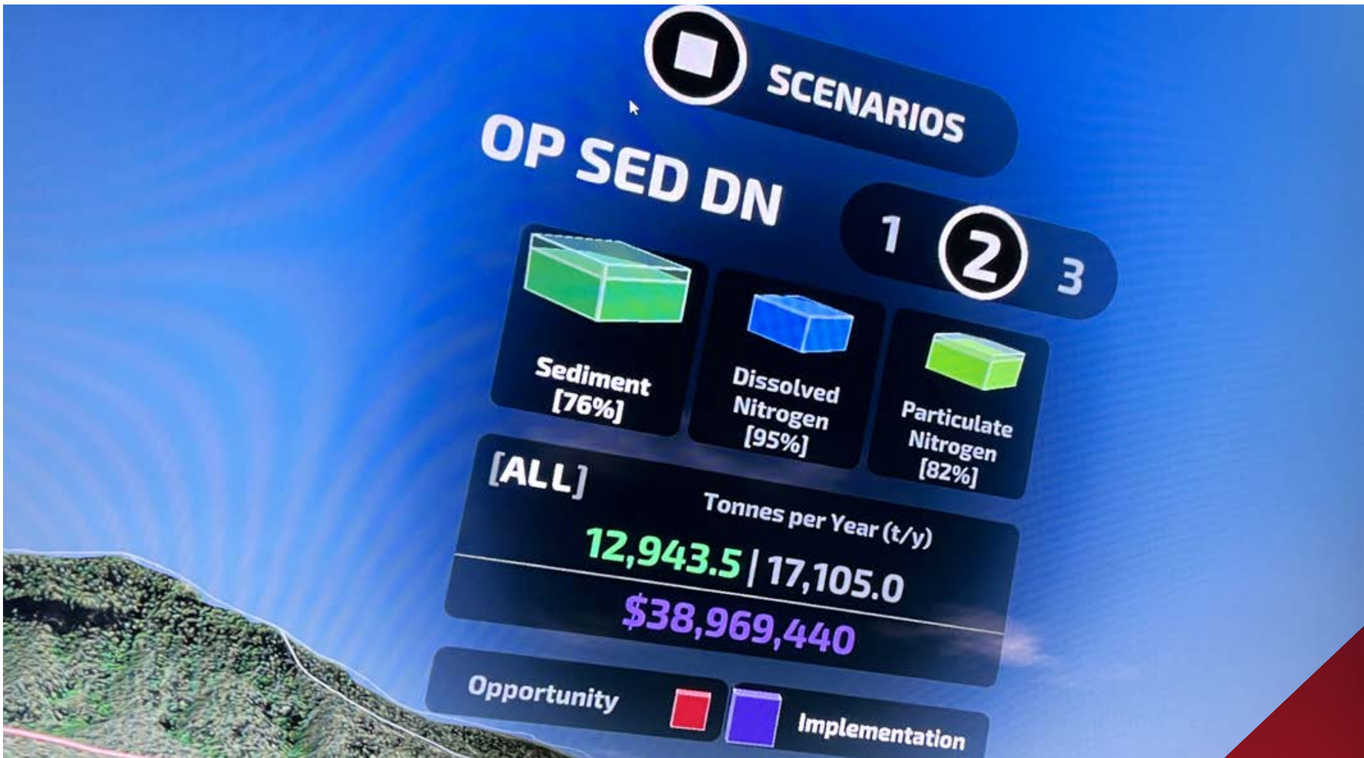
Central to the establishment of the final UI was a highly iterative design process between the design and technical teams, with frequent user testing with other external individuals. The 3D data visualisation includes elements of terrain, with users able to freely explore required hundreds of management modifications. Visualisation using 3D interfaces is an area of design research that has until recently been largely unexplored due to the high cost associated with equipment, design, and development teams. Some challenging questions were: How far from the user's face is the display? Is the display attached to the controller? Is the display always available and does the display turn on and off? Each of these questions and many more were explored trialled, tested and eventually implemented when satisfactorily addressed.

User movement in VR is a serious issue as the wrong type of movement can trigger nausea for the individual. How the interface worked to move users around in the landscape via a 'teleport' method proved to be most efficient. The user interface supported how the people could trigger the teleport function from one sub-catchment to another via the use of a mini map.

Another core challenge solved in the design of the Visualisation Tool was how best to provide users with a combined view of the modelled spatial and numerical data (Figure 18). Users who are considering the catchment as a whole need to understand the environmental and financial impacts of the management scenario (i.e., set of management actions proposed from the model output).

A typical catchment model application has >100 planning units, each one contributing differently. The VR tool enables users to understand the complex relationship between management actions, emissions reductions, and economics by visualising a hierarchy of producing areas, including their impact vs cost ratio.

Figure 18. *Example screenshot: VR data interface showing Sediment reduction by 24% from 17,105 to 12,943.5 tonnes per year with an Implementation cost of $38,969,440*



4.4. TERRAIN DATA AND VR

During VR application development, we identified issues associated with the resolution of satellite imagery and DEM, specifically in relation to the requirement to provide an "on-the-ground" view of the catchment for a VR user. A technical model that utilised streaming high-resolution map tiles based on the user's field-of-view and location was developed to find a balance between the terrain resolution and frame rates different VR headsets can display. The flow on from these processes supported the display of massive-scale terrain data in a VR headset and an immersive VR experience to communicate greater understanding of issues, impacts and possible outcomes.

4.5. CONSTRUCTING TERRAINS AND IMAGERY ASSETS FROM DATA FOR 3D RENDERING

To handle the realism required for the VR experience, a series of options were explored. Rendering massive areas of realistic terrain with detailed imagery at interactive frame rates, where a user can smoothly fly and navigate through the environment, has been a difficult challenge that required a large amount of graphical and computational power.

For the Laidley catchment prototype, two resolutions of terrain were created:

1. A lower resolution tiled terrain of the full catchment (4m/pixel terrain with 1m/pixel aerial) primarily to be viewed at higher altitudes, which enables the entire catchment to be rendered in full and providing a complete overview of the project area
2. more detailed and higher resolution terrains for each individual sub-catchment were produced (1m/pixel terrain with 0.5m/pixel aerial), cropped to the exact boundary; to be viewed at closer proximity.

Due to higher detail and increased rendering and memory requirements only one of the high-resolution sub-catchments were enabled at a time. When users selected a specific sub-catchment of interest, the low-resolution terrain was replaced with a stylised wireframe mesh to represent the rest of the catchment, while the selected high-resolution sub-catchment is loaded and displayed.

4.6. CONNECTION WITH CREM SCENARIO GENERATOR

An application manager handles import and parsing of editable app-level configuration parameters and other common functions related to file and path management. A scenario manager component provides the primary functions related to loading the TOML-based scenario configuration, communicating back and forth with the RESTful web client, which in turn handles the actual client-server communication with the CREM Scenario Generator. The scenario manager uses an event system to which components can subscribe to receive updated scenario model results from the CREM Scenario Generator service; this is the mechanism used to update the map and visualisation elements when the model is updated, either via changes to management actions or when a completely new solution is loaded.

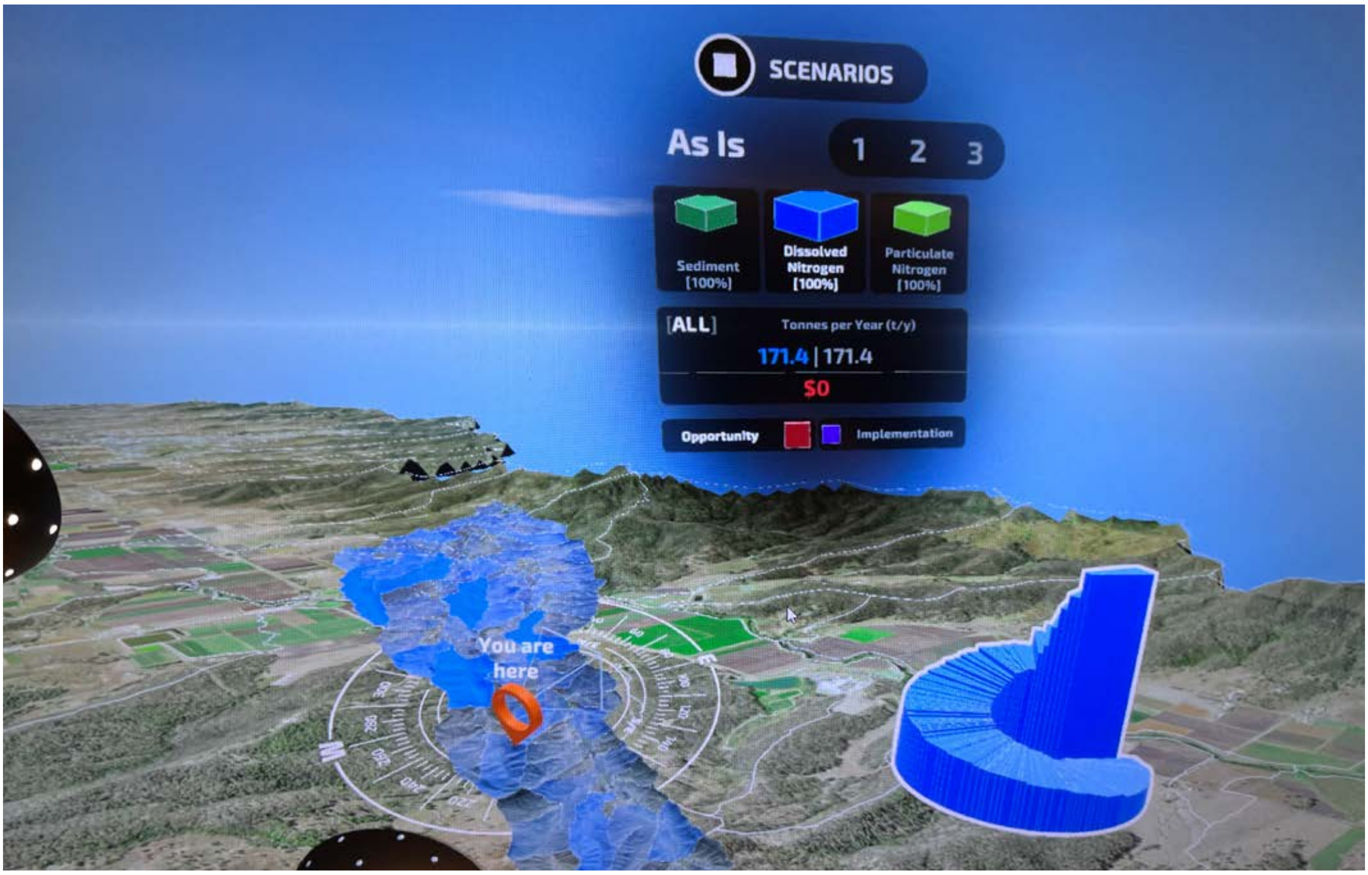
4.7. VISUAL REPRESENTATION OF SCENARIOS

Considerable progress has been made on the use of localised high-resolution environmental assets ("biomes") that can be used in conjunction with high-resolution textures to generate optimised realistic landscapes within the VR application. These have been used in the visual representation of the scenario solutions from the MOSA. Additional work has also been completed to provide visualisations of the modelled flood impacts associated with each solution. The following are extracts from the Visualisation Tool displaying the 3D terrain with the overlayed mini-map and dashboard UI.

In the "As Is" scenario (Figure 19 and Figure 20), no management actions have been applied to any sub-catchments and both the opportunity and implementation costs are zero. Each component of the interface (mini-map and statistical visualisation) are also in their default states. The mini-map is displaying the sub-catchments which have high loads (the bright green areas – sediment; bright blue areas – dissolved nitrogen). The statistical visualisation component is showing all the sub-catchments in a hierarchy based on their individual load levels.

Figure 19. *View of the "As Is" scenario for Sediment production*

Figure 20. *View of the "As Is" scenario for Dissolved Nitrogen*



In Figure 21, the Visualisation Tool is in a state where a set of management actions (orange markers on the map) have been applied to specific sub-catchments based on the model's output. The mini-map shows a modified set of load values, based on implementation costs for the set of management actions applied. The statistical visualisation component now shows the sub-catchments in a modified hierarchy, the grey/shadow areas are what the value of loads for the sub-catchment was before the action was applied. Below the line are the Implementation costs.

Figure 21. *The view now shows "Low SED" (Low Sediment) Scenario*

Figure 22. *Selected sub-catchment with current management actions*

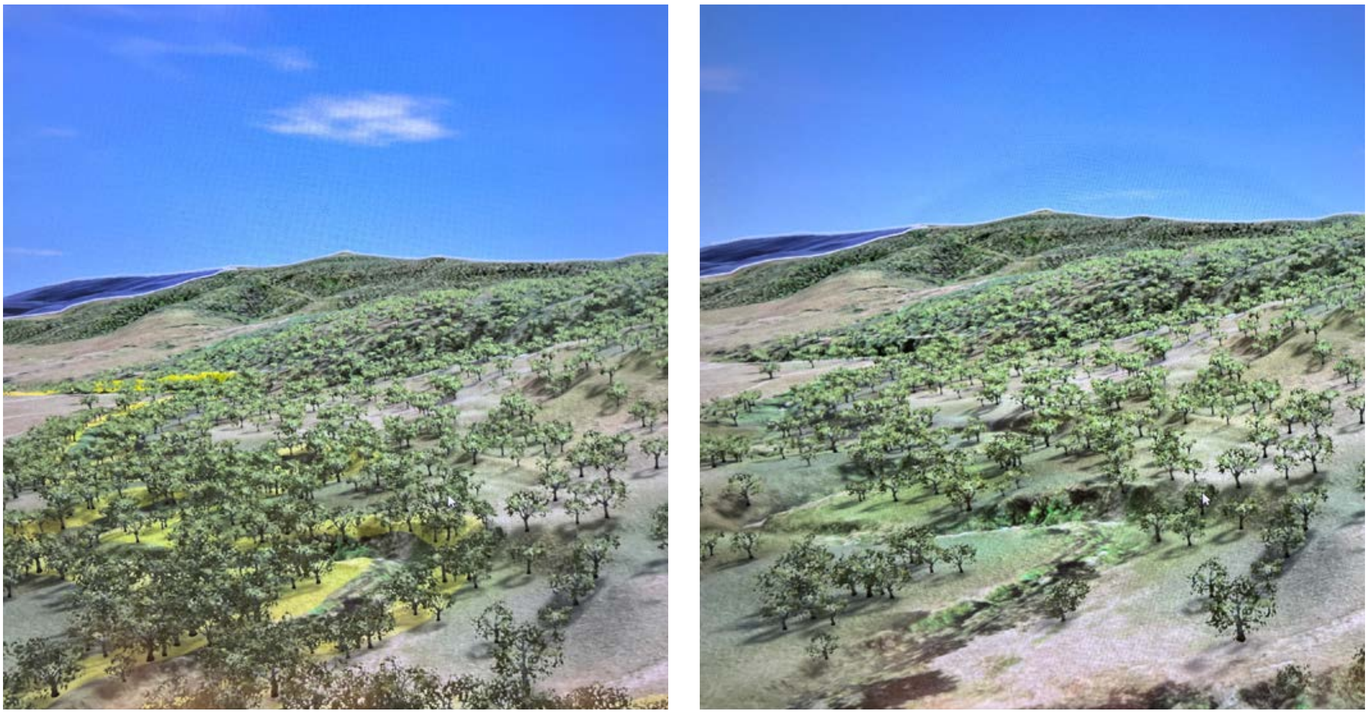
Users can choose to select individual sub-catchments from the statistical view or by selecting the sub-catchment directly on the mini-map (Figure 22). In this example, an individual sub-catchment (081) has been selected. The statistical visualisation shows that sub-catchment 81 has the largest particulate nitrogen load in the catchment. The user can now see what management actions are currently applied (in this case Gully rehabilitation is active).

Once an individual sub-catchment is active, the figures displayed are appropriate to the location. In this example (Figure 22), particulate Nitrogen in sub-catchment would be reduced from 5.1 tonnes per year to 5.0. The implementation cost to perform Gully restoration on the sub-catchment was estimated to be $141,110. Note that the benefits for sediment and dissolved nitrogen reduction can also be explored by selecting their respective icons.

Selecting a specific area on the mini-map teleports the user to the location in the background (Figure 24). The user is then able to explore the area, turning on and off the management action and viewing the difference (Figure 24).

Figure 23. *'On ground' visualisation of a select area*

Figure 24. *Aerial view of the area selected in Figure 23, with (left) and without (right) riparian vegetation*



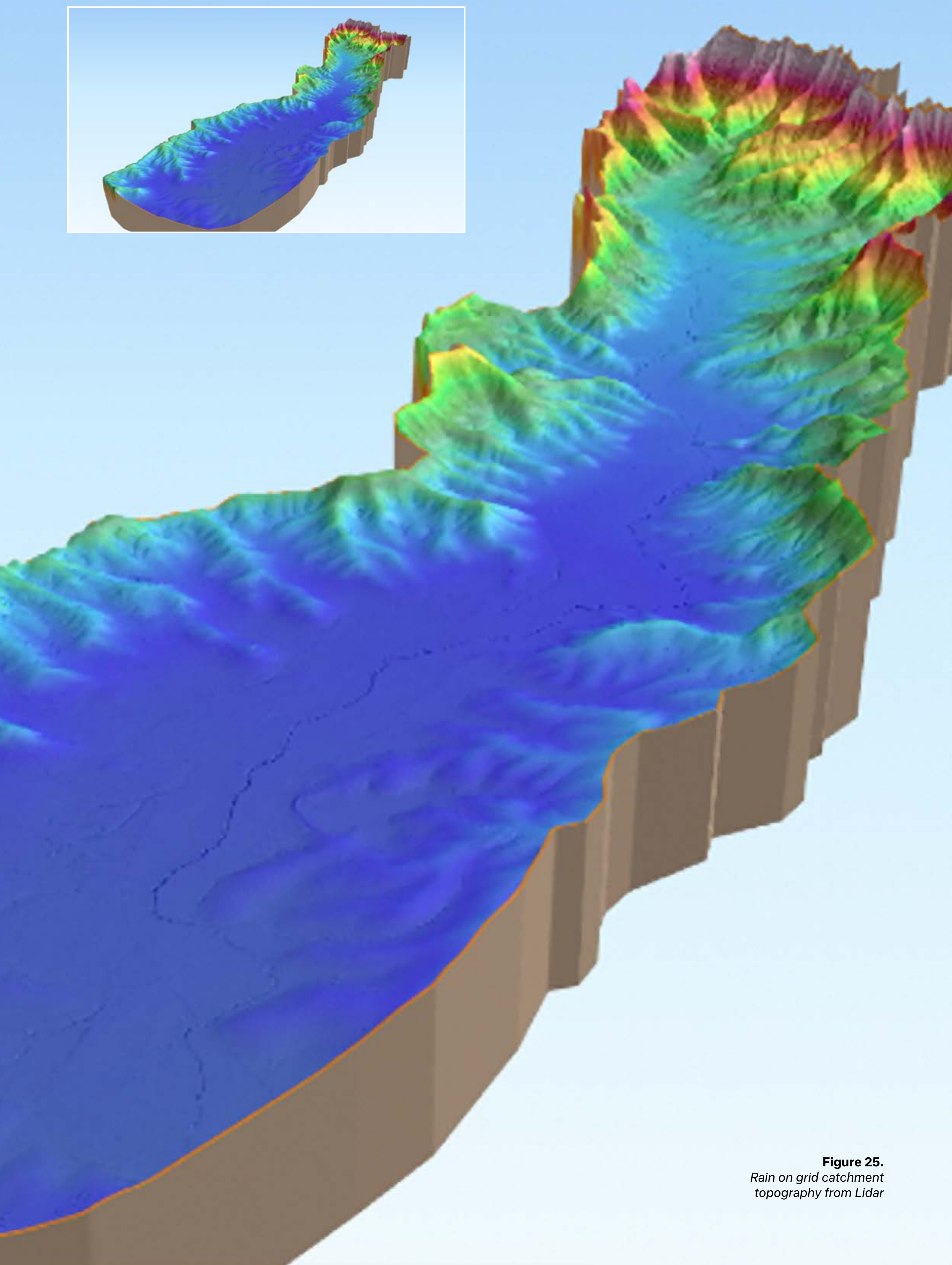


Figure 25.
Rain on grid catchment topography from Lidar

5. FLOOD MODELLING

Many of the proposed management actions undertaken to reduce sediment and nitrogen loads are designed to slow water down and protect riverbanks and gullies from erosion.

As a consequence, implementation of the rehabilitation solutions produced by the CREM Explorer can also have potential beneficial impacts on flooding that can be explored at the catchment scale. Having a robust flood model associated with the catchment rehabilitation solutions is a critical decision-making input to the Building Catchment Resilience Decision Support Framework.

Our partner, Water Technology, explored the impacts of catchment rehabilitation solutions identified by the Multi Objective Simulated Annealing (MOSA) model on flood risks in the Laidley Creek Catchment. To do this, Water Technology has undertaken all work necessary to understand and simulate existing flood behaviour in the Laidley Creek catchment and to predict the flood impacts of potential catchment rehabilitation solutions.

5.1. DATA COLLATION AND REVIEW

The development of the flood model in the pilot catchment involved the collection of data sets related to catchment topography, rainfall data, flood data and land use. Detailed LiDAR data were sourced and checked for accuracy. These data were used to create a hydrologically sound Digital Elevation Model (DEM) of the catchment to inform subsequent flood model establishment and impact assessments (Figure 25). This work required some degree of data correction and 'pit filling' using the CatchmentSim software package.

A riparian buffer layer (Figure 26), gully layer, and wetland layer (Figure 27), were sourced from the visualisation tool developed by QUT. Relevant gauged rainfall data collected within the catchment was collated and reviewed, focusing on the major flood event which occurred in 2011. Gauge calibrated radar rainfall data to provide complete time histories of rainfall surfaces across the catchment throughout the 2011 event had also been obtained from the HydroNET data portal. Relevant gauged water level and flow data were obtained from the Water Monitoring Information Portal. All relevant land use data were collated and reviewed (Figure 28).

Figure 26. *Riparian buffer*

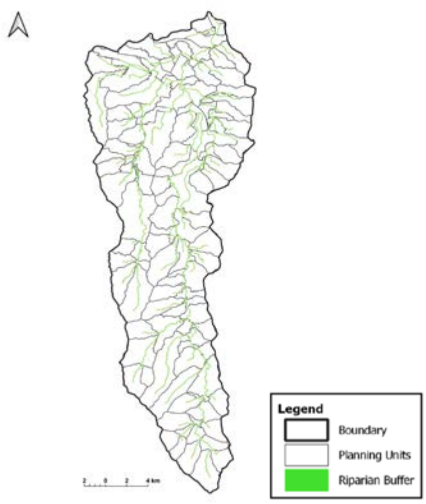


Figure 27. *Gullies and wetlands*

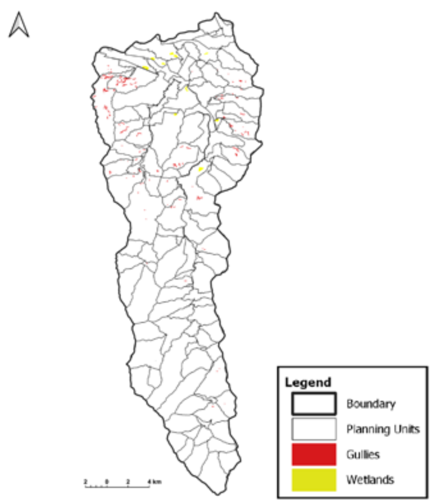
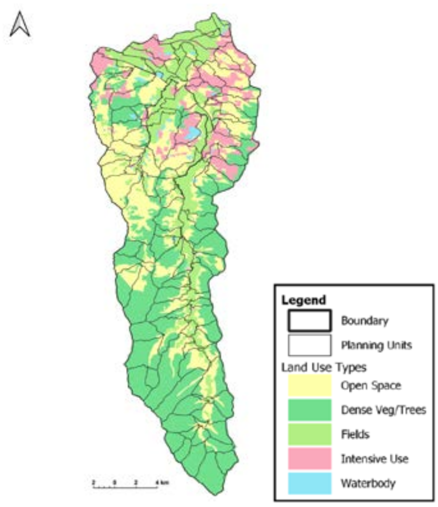


Figure 28. *Land use data*



Groundcover and riparian vegetation influence Manning's roughness coefficient values and thus the floodwater behaviour in hillslope areas and waterways. Constant Manning's roughness values for hillslope areas, streams, and riparian buffer areas (Table 4) were used across the same land use types, though noting that groundcover and riparian vegetation can vary spatially.

Table 4. *Manning's Roughness Coefficients (n) used in the Baseline Model*

Hillslope Areas	Manning's n
Residential Lots	0.1
Fields	0.06
Waterbody	0.03
Open Space	0.05
Dense Vegetation	0.13
Streams and Riparian Buffers	
Low Density Riparian Vegetation	0.04

5.2. MODEL DEVELOPMENT

Using the above datasets, a 'Rain on Grid' flood model of the Laidley Creek catchment and waterway system was built using the Tuflow HPC software package. This was calibrated and validated to data collected for the 2011 flood event.

The modelled water level and discharge rate compared well with that recorded at the Laidley Creek at Mulgowie (143209B) gauge during the 2011 flood event (Figure 29).

The modelled water depth compared with observed flood debris data for the 2011 flood event is also shown (Figure 30). A high degree of simulation accuracy was achieved to the available data set which provides confidence in the developed rain-on-grid flood model. As a fit for purpose model, this can be used to assess the relative flood impacts of the selected catchment rehabilitation solutions.

Figure 29. *Comparison of the Modelled Water Level (left) and Discharge (right) to the recorded water level and discharge in Laidley Creek at Mulgowie (143209B) during the 2011 Flood event*

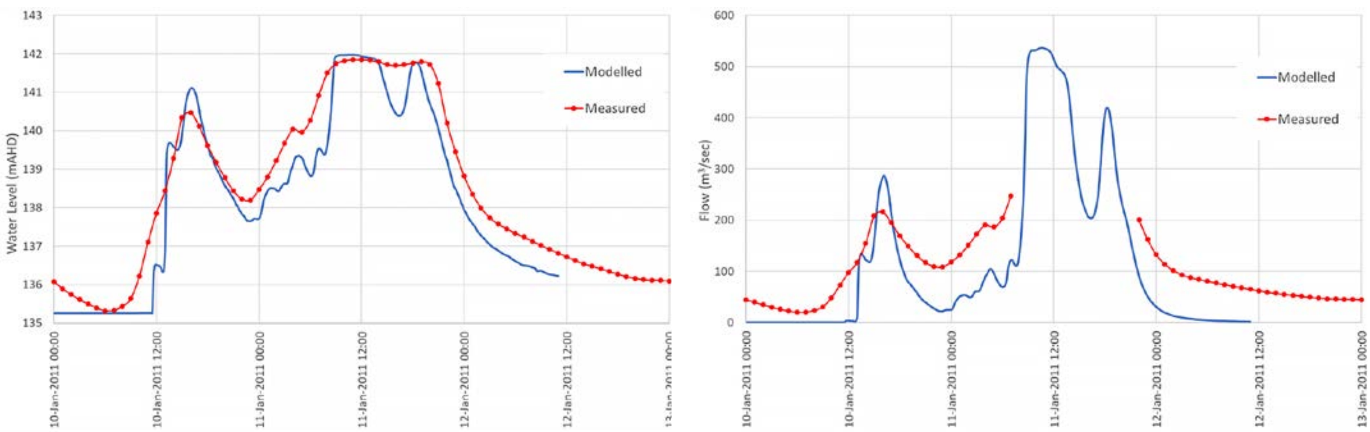
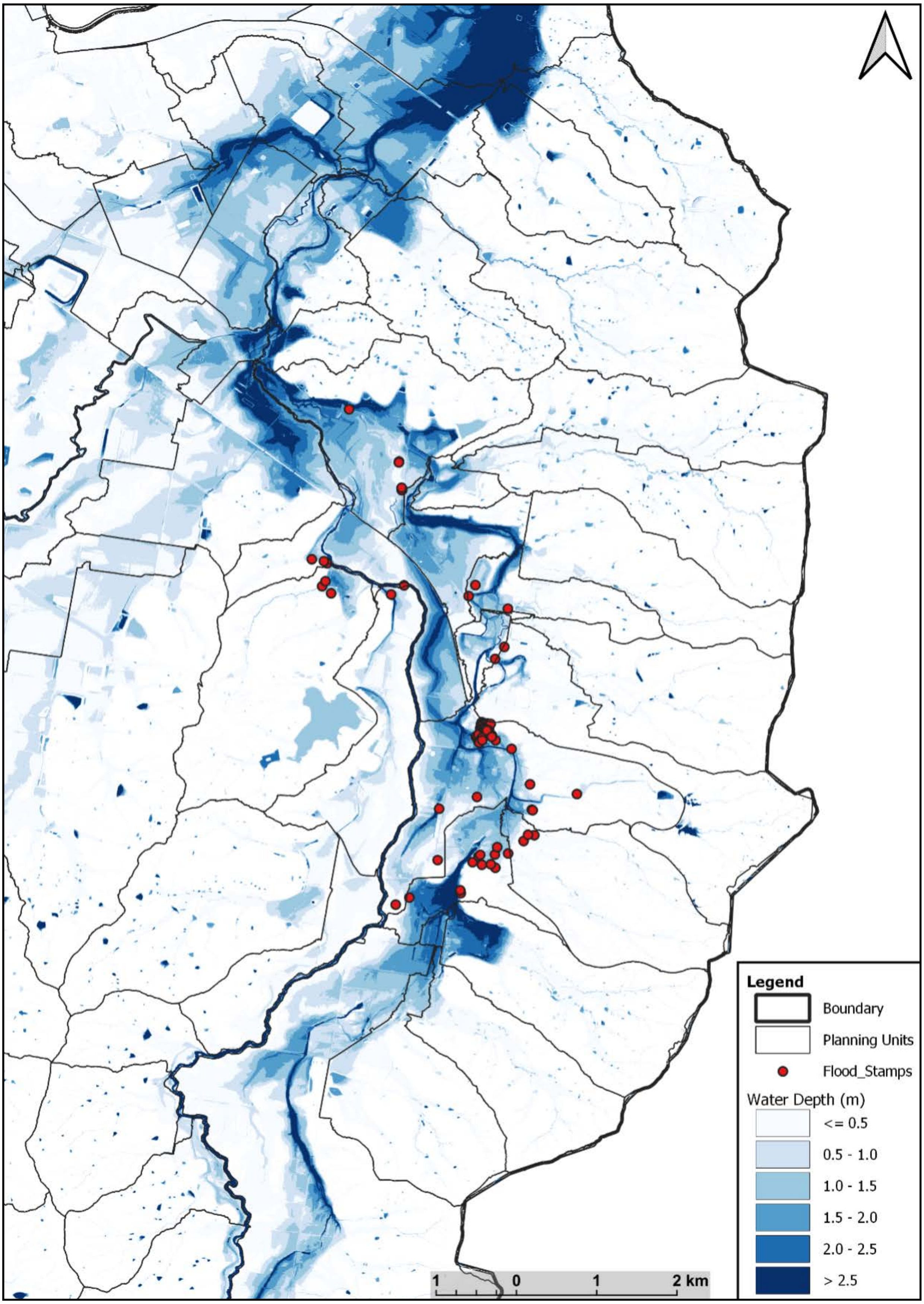


Figure 30. *Modelled water depths against debris data from the 2011 flood*



5.3. CATCHMENT REHABILITATION SOLUTIONS

Two MOSA optimisation scenarios with the following objectives were run to assess flood impacts of the potential catchment rehabilitation solutions:

- Twenty-million-dollar budget; and
- Halved particulate nitrogen target.

The "Twenty-million-dollar budget" scenario was run to identify the best set of catchment rehabilitation solutions for a fixed budget, while the "Halved particulate nitrogen target" scenario was run to know the cost associated with reducing the particulate nitrogen loads by 50%.

Three MOSA solutions were selected to understand the flood impacts of the catchment rehabilitation solutions selected from the above MOSA model runs (Table 5, Figure 31).

Manning's roughness coefficients were increased in the rain-on-grid model to represent the catchment rehabilitation solutions and thus assess their flood impacts (Table 6). Depth varying Manning's roughness coefficients were used to represent streambank restoration solutions. Flood impacts of the catchment rehabilitation solutions selected by MOSA were assessed by comparing water levels and discharge at Mulgowie gauge location and Laidley township.

Table 5. *MOSA solutions selected for flood impact assessment*

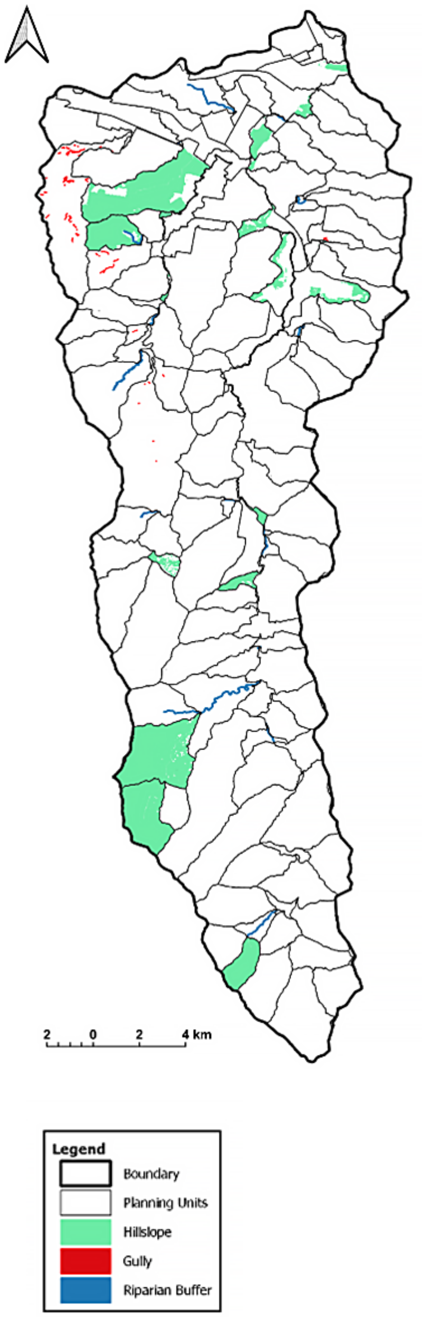
Flood Impact Scenario	MOSA Objective	Selected MOSA Solution	Reason for the Selection	Number of Restoration Projects			
				Gully	Hillslope	Riverbank	Wetlands
1b	Twenty-million-dollar budget	Pareto front member 1405 of 5554	Low Sediment Load	6	17	18	0
2b	Halved particulate nitrogen target	Pareto front member 946 of 23991	Low Dissolved Nitrogen and Particulate Nitrogen Load	28	104	125	8
3b		Pareto front member 6528 of 23991	Low Cost	17	37	86	0

Table 6. *Manning's roughness coefficients used to represent catchment rehabilitation solutions coefficient*

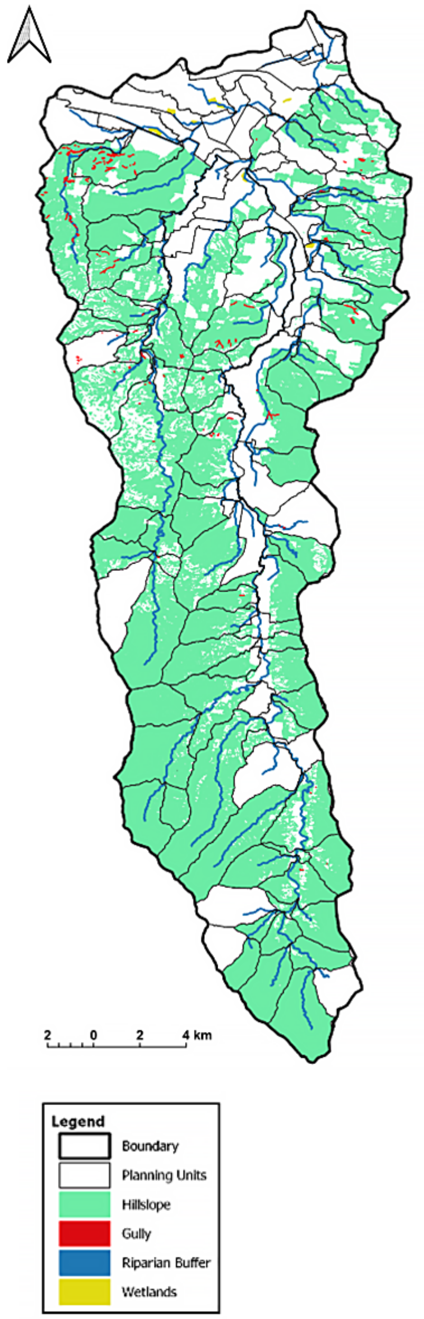
Hillslope and gully restoration	**0.13**
Wetland construction	**0.13**
Streambank restoration	**▪ 0.15 applied up to 1.5 m depth** **▪ 0.125 applied between 1.5 m and 1.8 m depth** **▪ 0.1 applied above 1.8 m depth**

Figure 31. *Catchment rehabilitation solutions selected by MOSA (left – scenario 1b, middle – scenario 2b, right – scenario 3b) flood*

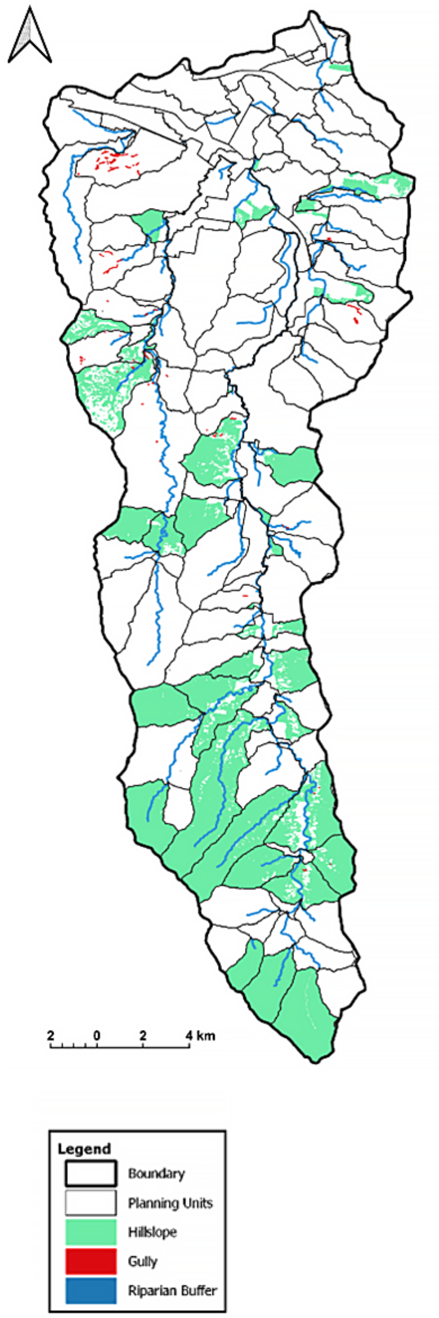
SCENARIO 1b



SCENARIO 2b



SCENARIO 3b



Modelled water levels and discharges during the 2011 flood event at Mulgowie for the baseline and scenario models are shown in Figure 32 and Figure 33. Modelled water levels during the 2011 flood event at Laidley for the baseline and scenario models are shown in Figure 34.

Figure 32.

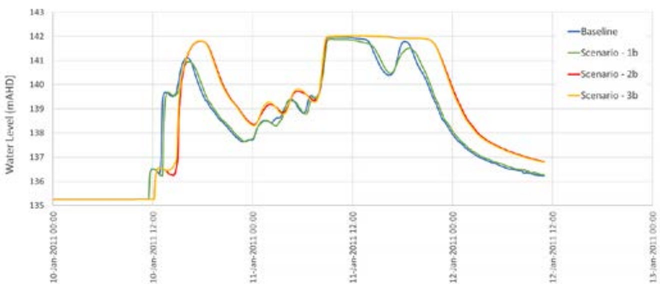


Figure 33.

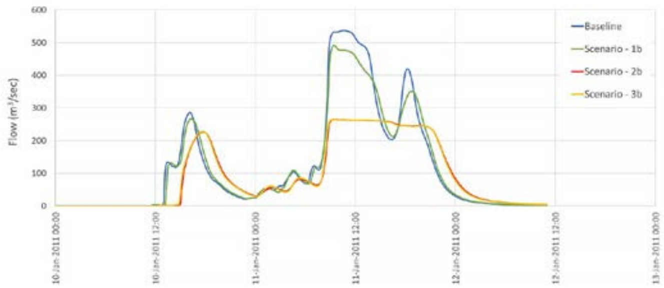


Figure 34.

Figure 32. *Modelled water levels during the 2011 flood event at Mulgowie*

Figure 33. *Modelled discharges during the 2011 flood event at Mulgowie*

Figure 34. *Modelled water levels during the 2011 flood event at Laidley*

The rain-on-grid modelling assessment showed that the catchment rehabilitation solutions identified by MOSA to reduce particulate nitrogen loads from the catchment by 50% (scenario 2b and scenario 3b), would have a positive impact on flood behaviour in the township of Laidley, reducing flood levels by at least 10cm and delaying the peak by approximately one hour (Figure 34).

Moreover, they would significantly affect the behaviour of floodwaters further upstream within the catchment, reducing in stream discharge flow rates by approximately 50% at Mulgowie and thus significantly reducing erosion and infrastructure damage. However, as a trade-off to the downstream benefits, the catchment rehabilitation solutions identified as part of scenario 2b and scenario 3b would extend the duration of flooding in sections of the catchment adjacent to and upstream of Mulgowie.

Catchment rehabilitation solutions identified by MOSA for the fixed twenty-million-dollar budget option (Scenario 1b) showed little variation compared to the baseline model outcomes. This may be due to lower number of management actions achieved with a limited budget in Scenario 1b than that for Scenarios 2b and 3b.

Rain-on-grid model outputs such as water depths, velocities, stream power, bed shear stress, etc. can provide visualisations of the likely changes in flood risk as well as erosion potential associated with different combinations of on-ground management actions.

6. SUMMARY

The Building Catchment Resilience Project commenced in July 2018. The project Steering Committee, representing key partners from government, industry and academia, was established in July of that year and key project staff were recruited shortly after. Dr Vanessa Reis led the modelling and sediment work, supervised by Professor David Hamilton. Dr Jing Lu led the nitrogen work, supervised by Prof Michele Burford. Dr Habtamu Kassahun led the economics work supervised by Prof Jim Smart. Dr Lindsay Bradford, who developed the original spatial planning tool, was appointed senior programmer. The Project was officially launched at the International River Symposium in October 2019 and the collaborative agreement signed between project partners in February 2019, confirming cash and in-kind commitments and setting out each party's obligations.

The Laidley Creek catchment was selected for the pilot study and priority issues were identified for restoration activities and included sediment and nitrogen reduction, carbon sequestration and flood mitigation. The collection of biophysical and economic data, and all field experiments and trials were completed by June 2021. The decision support tools were developed, comprising the Catchment Resilience Exploration Modeller (CREM) Explorer, CREM Scenario Generator. These tools were used to identify potential catchment investment solutions under different scenarios in the Laidley Creek catchment. Guided by the Steering Committee, we chose two example investment scenarios: one based on optimising benefits for a fixed implementation budget of $20 million and one based on an objective of halving the particulate nitrogen load. Data collection and user testing was also undertaken in the Logan River catchment.

Additional catchment scale benefits were estimated for the investment solutions in the Laidley catchment. Rain on grid modelling of the 2011 flood in the Laidley catchment was developed in the first twelve months of the project. Additional modelling was then undertaken for three example solutions from the two different investment scenarios to illustrate potential flood risk benefits. The longer term carbon benefits associated with this green infrastructure investment were also estimated for each of the catchment scale solutions.

The visualisation and data interface requirements were developed between QUT and the Griffith team. QUT undertook consultation with visualisation end-users to determine requirements and developed visualisation prototypes and interfaces prior to COVID-19 but, user experience reviews were delayed until 2022, during which limited consultation was possible with Partners and other stakeholders. Since then, presentations and demonstrations of the modelling and visualization tools have been delivered at various stakeholder meetings, workshops, networking events and international conferences.

We thank our funding partners, the project team and members of the Steering Committee involved in this project to date.

If you wish to know more about this project and how it might apply to you, please contact us via our website, **www.catchmentresilience.org.**

Shingle Hut Creek at Thornton

photograph by H. de la Mare

GRIFFITH UNIVERSITY