Australia's National Science Agency

Scenario testing and recommendations for future flood mitigation activities in the Richmond River catchment in the Northern Rivers region, NSW, Australia

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Northern Rivers Resilience Initiative Project

The National Emergency Management Agency (NEMA) engaged Commonwealth Scientific and Industrial Research Organisation (CSIRO) to undertake the Northern Rivers Resilience Initiative (NRRI).

The NRRI aims to understand the drivers behind the unprecedented flood events in February – March 2022 in the Northern Rivers region of NSW and develop community-supported solutions for flood mitigation and resilience investment. This initiative enables CSIRO to assess existing project proposals and identify additional long-term options to reduce flood risk in the Northern Rivers region.

The NRRI consists of two phases:

1. Rapid review and assessment (Phase 1 – July to November 2022) – This phase identified and prioritised existing flood resilience/mitigation project proposals. It characterised the catchment and climate conditions that led to the 2022 floods and analysed the most effective intervention options for the allocation of the Australian Government's $150 million of funding. Residents and councils in each of the seven flood-affected Local Government Areas in the region (Ballina, Byron, Clarence Valley, Kyogle, Lismore, Richmond Valley and Tweed) were consulted to help identify and prioritise the most effective intervention options.

Outcome – This work, delivered in November 2022, informed investment of $150 million of Australian Government funding for flood mitigation and resilience projects in the Northern Rivers region in 2022–23, to support recovery and resilience efforts (https://www.nema.gov.au/our-work/resilience/the-northern-rivers-recovery-and-resilience-program). This work also provided insights into the variability and severity of flooding across the Northern Rivers region during the February-March 2022 floods.

2. Detailed modelling (Phase 2 – January 2023 to June 2026) – This longer-term program of work has collected and generated high-resolution and high-accuracy Light Detection and Ranging (LiDAR) data (a digital representation of the bare-earth's topographic surface). The data enables spatial analysis and supports hydrological/hydrodynamic modelling of water movement for the entire Northern Rivers region. The project also collected river bathymetry (continuous river cross sections) using boats for the Richmond and Tweed rivers and their main tributaries.

These high-quality data are used to underpin a detailed hydrodynamic model for the entire Richmond River catchment. The model is used for examining and evaluating possible flood mitigation scenarios developed in consultations with the community, councils and government agencies. Six mitigation scenarios are implemented for historical flood events to investigate the possible reduction in water heights and overland flooding for the 2008, 2017 and 2022 flood events.

Outcome – CSIRO has generated high-quality digital elevation datasets for the Northern Rivers region based on the collected LiDAR and bathymetry datasets. The datasets were made publicly available through the Geoscience Australia Elvis website on 28 June 2024 and are used by

Australian, state and territory, local governments, researchers and community members across the region. These data, along with other data, were used to develop and implement a detailed hydrodynamic model for the entire Richmond River catchment. The report for this work and the fully implemented model were delivered in June 2025 and are available from the CSIRO and NEMA websites. CSIRO has used this model to undertake scenario analysis to evaluate possible flood mitigation actions as recommended by the councils and community. The report for this work on scenario testing with the findings is made available in a final report on 30 June 2026 (this report).

Acknowledgements

This work is carried out by CSIRO as part of the Northern Rivers Resilience Initiative (NRRI) project and is funded by the National Emergency Management Agency (NEMA). The authors thank officials from the following organisations: Clarence Valley Council, Kyogle Council, Richmond Valley Council, Lismore City Council, Tweed Shire Council, Byron Shire Council, Ballina Shire Council, Rous County Council, NSW Reconstruction Authority (NSWRA), NSW Department of Primary Industries, NSW Department of Transport and NSW Public Works for useful discussions and data. The authors are thankful to the federal and state members of parliament from the region especially the Hon Kevin Hogan (Federal Member for Page) and the Hon Janelle Saffin (State Member for Lismore, Minister for Recovery; Small Business and for the North Coast), the Mayors from the seven councils and the Northern Rivers Joint Organisation (NRJO), all the council staff, the project's Governance and Advisory panels, as well as CSIRO and NEMA management for continued support throughout this work. We are grateful and thankful to the enthusiastic and knowledgeable Northern Rivers local communities and organisations for having faith in the team and attending the community consultations as well as providing on-ground datasets and expert knowledge. Without your input, we could not have done this work. The authors are grateful to and thank the two external reviewers (Prof Dai Yamazaki, University of Tokyo, Japan and Prof Barry Croke, Australian National University, Australia) for their critical and detailed review. Finally, we thank the NEMA team directly involved in the work for their contributions and support.

Executive summary

The National Emergency Management Agency (NEMA) engaged CSIRO to undertake the Northern Rivers Resilience Initiative (NRRI). This is the second report in Phase 2 of NRRI, which is to implement flood mitigation scenarios proposed by the community and councils in the hydrodynamic model for historical flood events to assess potential reduction in water heights and overland flooding across the Richmond River catchment. The Richmond River catchment has a large floodplain that floods frequently. This is the first time a detailed hydrodynamic model (MIKE21 FM) has been developed and implemented for historical flood events for the entire Richmond River catchment, underpinned by high-resolution topographic data and a physically consistent modelling framework that enables robust representation of catchment-scale floodplain processes (first report in Phase 2 delivered 30 June 2025). The model was developed to investigate the impacts of any flood mitigation interventions in the catchment on the overall catchment response (any intervention in the upper parts will have downstream impacts). The modelling domain was set up to represent the entire Richmond River catchment and is suitable for understanding the water level variations and floodplain dynamics at the scale of the modelling domain. This report briefly describes the two rounds of stakeholder consultations, developed flood mitigation scenarios, the implementation of the scenarios in the MIKE21 FM model, and the results. A total of three historical flood events (2008, 2017, and 2022) and two bundles of flood mitigation options were implemented to provide six flood mitigation scenarios. The three flood events were chosen as they caused large-scale floodplain inundation and damage in different parts of the Richmond River catchment. The two bundles of flood mitigation scenarios were designed to represent a smaller set of interventions in the first bundle (called Bundle 1 hereafter) and a larger number of interventions covered in the second bundle (called Bundle 2 hereafter).

All the comparisons between model simulated historical and flood mitigation scenario Bundle 1 and Bundle 2 time series of hourly water level plots across the Richmond River catchment, the statistics for water level reductions at the peak of all the flood events and the spatial comparisons for overland maximum flood extents, maximum flood depth and maximum water level at key locations clearly demonstrates that the flood mitigation scenarios formulated with the stakeholders and implemented in this analysis can reduce historical flood peaks as well as spatial inundation extents and depth substantially. The multiple lines of evidence used to demonstrate the effectiveness of the flood mitigation scenarios provide confidence in the modelling results.

The modelling undertaken in this study clearly shows that the impact of large floods can be reduced across the Richmond River catchment with strategically located water detentions and other flood mitigation measures tested in this study. Further investigation of the results also indicates that putting one or two additional detentions on Gradys Creek on the Casino/Kyogle side and Tuntable Creek upstream of Lismore may potentially further reduce the flood levels across the Richmond River catchment. These additional measures were not suggested or discussed during stakeholder consultations but were identified after completing the simulations. If these additional measures are to be assessed, they need to be implemented in the model together with Bundle 2.

These results clearly indicate that, when new infrastructure is appropriately represented in the model setup, the model can reliably estimate flow changes associated with infrastructure development across the catchment. This is supported by the use of a high-resolution, physically based river–floodplain hydrodynamic modelling framework, which allows the effects of infrastructure to be directly represented within the flow and inundation dynamics, rather than being approximated externally. This demonstrates the suitability of the model for assessing a range of structural interventions and alternative flood mitigation scenarios. Simulations of future climate, flow scenarios, or design flood events require modification of the input climate only, whereas assessment of major infrastructure interventions beyond those considered in this study would require additional changes to the model mesh and setups.

This scientific investigation of flood mitigation scenarios undertaken using a well-implemented, detailed hydrodynamic model and credible science has demonstrated the feasibility of different flood mitigation options in the Richmond River catchment. The effectiveness of the flood mitigation options is ultimately dependent on the detailed design of the structures and the implementation on the ground. Further analysis is required before any on-ground implementation, including but not limited to a detailed business case, cost-benefit analysis, environmental approvals, geotechnical analysis, detailed structural design, Australian and state government policy clearance, as well as budget availability. All these aspects are outside the scope of the NRRI project.

1 Introduction

An exceptional flood event affected the Northern Rivers region in NSW between the end of February and the beginning of March 2022. The region was severely impacted, with unprecedented flooding especially in some parts. In response, the Australian Government, through NEMA, engaged CSIRO to analyse the drivers of the flood and investigate possible options for mitigating similar events in the future. Several local-scale flood models have been developed over recent decades for major towns within the Richmond River catchment, each designed to address localised objectives. However, to investigate flood mitigation options at the catchment scale, a new model covering the entire Richmond River catchment was required. Given the scale and complexity of the region, such a catchment model has not been attempted before. To address this gap, CSIRO implemented a 2D hydrodynamic model (MIKE21 FM) for the entire Richmond River catchment. Rather than the conventional way of using observed streamflow at multiple point locations as forcing inputs and limiting the model domain to floodplains, the model is driven by hourly spatial rainfall (i.e. rain on grid) that was generated for the region (Nguyen et al., 2026). The model generates spatial runoff on each grid at every time step and routes it through the catchment. The model was implemented across the Richmond River catchment and can accurately reproduce water levels and overland floodplain inundation across the catchment for the complete range of historical floods (Vaze et al., 2025). The validated model is used to investigate the effectiveness of flood mitigation scenarios for selected historical flood events. The flood mitigation options are developed by CSIRO in consultation with the local community, councils and the state and Australian government.

1.1 Background and Objectives

The Northern Rivers region of NSW has a history of flooding, with minor to major floods occurring every few years. An exceptional flood event affected the Northern Rivers region in NSW between the end of February and the beginning of March 2022 (Lerat et al., 2022; Lerat and Vaze, 2025). During this event, the rainfall totals and water levels exceeded historical records by a significant amount in many parts of the region. There was considerable damage in towns such as Lismore, Coraki, Woodburn, and Ballina, which prompted a range of actions by local communities, local government authorities, NSW state agencies, and the Australian Government to address emergency circumstances and formulate strategies to mitigate the impact of future floods in the region. In this context, NEMA commissioned CSIRO to initiate the 'Northern Rivers Resilience Initiative' (NRRI).

The project area covers the entire Northern Rivers region including the Clarence, Richmond, Tweed, and Brunswick River basins (and some of the coastal creeks which drain to the ocean) and seven Local Government Areas included in these catchments: Clarence Valley Council, Kyogle Council, Richmond Valley Council, Lismore City Council, Tweed Shire Council, Byron Shire Council, and Ballina Shire Council.

The project has two parts with Phase 1 being six months analysing the drivers of the 2022 flood (Lerat et al., 2022), reviewing previous existing flood mitigation studies, and identifying and prioritising options for mitigating flood risks in the region (Weber et al., 2022). Phase 2 of the project of work collected high – quality Light Detection and Ranging (LiDAR) data for the entire Northern Rivers area (~30,000 km^2) to provide spatial analysis and to underpin hydrological/hydrodynamic modelling of water movement for the Northern Rivers region. Detailed bathymetry for the Richmond and Tweed rivers, and their main tributaries, was collected (~500 km). All the data were quality assessed by CSIRO and made publicly available through the Geoscience Australia Elvis website on 28 June 2024 (elevation.fsdf.org.au).

The first report for Phase 2 of the project was made publicly available in June 2025, where a detailed 2D hydrodynamic model was developed using MIKE21 FM to characterise flooding across the entire Richmond River catchment under historical flood events. The hydrodynamic model is used to evaluate how flood characteristics may change under a range of future flood mitigation interventions for selected historical floods.

The hydrodynamic model developed for the Richmond River catchment covers a large area, with very complex terrain, steep to low gradients and complex water regulation structures. The model was set up to represent the entire Richmond River catchment and is suitable for understanding the floodplain dynamics at the scale of the modelling domain. It was developed to simulate the overall river water levels at all gauges within the catchment as closely as possible to the observed water levels without focusing on any particular gauge or area.

This report represents the second output of Phase 2 of the project. It describes stakeholder engagement activities, the development of flood mitigation scenarios arising from community consultations, the implementation of these scenarios in the model, and the resulting simulated changes in water levels and overland flood inundation for three large historical flood events.

1.2 Purpose of the Report and Outline

This report has been prepared to describe key aspects of the scenario modelling used to test different flood mitigation options, including community/stakeholder engagements, formulation of the mitigation scenarios, implementation in the MIKE21 FM model, presentation of results and recommendations. The report incorporates the following:

- the background, objectives, and outline of the report (this section)
- the study area and stakeholder engagements (Section 2)
- the final scenarios and implementation in the hydrodynamic model (Section 3)
- results and discussion (Section 4)
- summary and recommendations (Section 5).

2 Study area and stakeholder engagements

2.1 Scenario testing area in the Northern Rivers region

The hydrodynamic model was implemented for the entire Richmond River catchment, and consequently, the flood mitigation scenarios are also tested only for this area. The Richmond River catchment, located in NSW, Australia, is a significant geographic and ecological area that covers a substantial part of the Northern Rivers region. The catchment covers approximately 7,000 km^2 and is situated in the northeastern part of NSW. It encompasses parts of the Northern Rivers region, extending from the Great Dividing Range in the west to the coastal plains in the east. The Richmond River is the primary watercourse within the catchment. It originates from the Great Dividing Range and flows generally eastward, emptying into the Pacific Ocean at Ballina. There are other major tributaries, including Eden Creek, Iron Pot Creek, Leycester Creek, Wilson River, Bungawalbin Creek, Emigrant Creek, North Creek, etc., which drain different parts of the catchment into the Richmond River. The catchment experiences a subtropical climate with warm to hot summers and mild winters. Rainfall is generally plentiful, with the eastern parts receiving more rainfall than the western parts. The catchment is predominantly utilised for agricultural purposes, including grazing and crop production. The fertile floodplains and rich soils make it suitable for various types of farming. There are several towns and cities within the catchment, including Lismore, Casino, Kyogle and Ballina. Overall, the Richmond River catchment is a diverse and ecologically significant area with a complex interplay of natural systems and human activities.

The boundary of the modelling area, which is about 7,000 km^2, covers the entire Richmond River drainage basin. Figure 1 shows the Richmond River catchment along with its main streams. The entire catchment is used as the hydrodynamic modelling and scenario analysis domain.

From a numerical flood modelling perspective, accurately representing flow behaviour on a floodplain of this spatial extent and complexity presents a significant technical challenge. The model has been set up using a flexible mesh approach in MIKE21 FM, where a higher resolution mesh is used for the key areas representing the streams, major infrastructure and floodplain, and the less flood-prone areas are represented by a coarser mesh. The model mesh is designed to provide an accurate representation of the entire catchment while maintaining sufficient flexibility to implement structural changes associated with the tested scenarios. It is configured as such to balance model accuracy with computational efficiency, ensuring a manageable model size and realistic simulation times. Using this approach, a fit-for-purpose model was developed with spatial resolutions that are suitable to represent most of the important streams, floodplain channels, terrain characteristics, and other water infrastructure in sufficient detail. This level of representation is critical to ensuring that structural flood mitigation scenarios can be implemented accurately in the model for scenario testing.

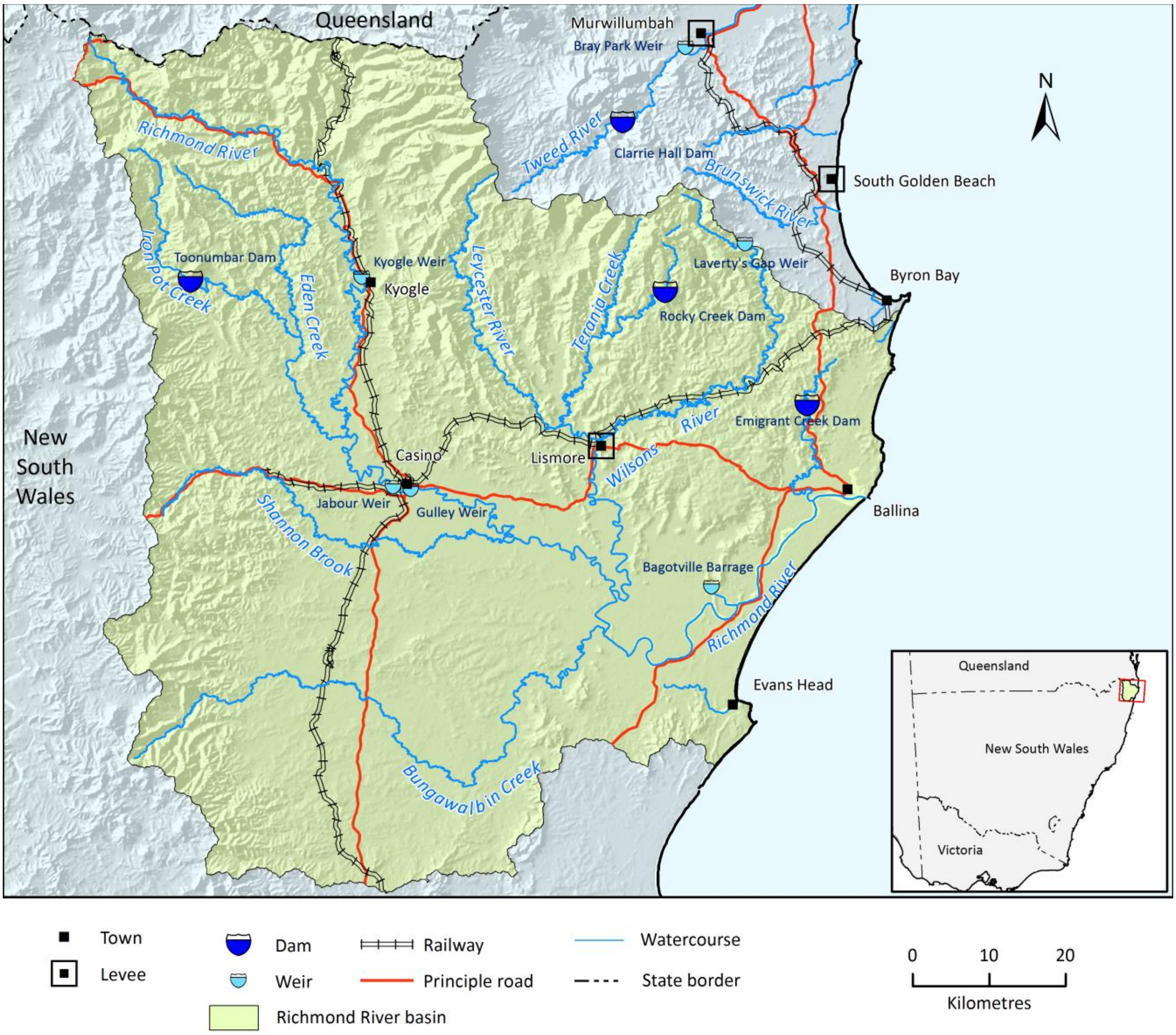

Figure 1 The spatial extent of the Richmond River catchment and hydrodynamic modelling and scenario analysis domain.

2.2 Stakeholder engagements

2.2.1 Council and community engagements

The CSIRO, NEMA and NSWRA teams conducted a series of council and community consultation workshops between 28 July and 19 August 2025 in the Northern Rivers region for the first round of stakeholder engagements. The consultations aimed to provide details of the newly implemented hydrodynamic model across the Richmond River catchment and to identify broad flood mitigation measures supported by the Richmond catchment councils and community to guide CSIRO team in designing flood mitigation scenarios to be tested with the hydrodynamic model.

The first round of community consultations was organised at five locations: Casino on 1 August, Lismore on 4 August, Ballina on 5 August, Woodburn on 6 August and Kyogle on 8 August 2025. Each consultation started at 10 am and finished at 6 pm, a period during which four NEMA staff members, two NSWRA staff and five scientists from CSIRO were available to answer questions from the community about the hydrodynamic model results and take inputs for formulating the flood mitigation scenarios to be tested by CSIRO team as part of Phase 2 of the NRRI project. Participants were also provided a printed copy of a feedback form containing three parts:

1. Flood mitigation measures: In the first part, the participants were asked to prioritise their three preferred flood mitigation measures among a set of 15 listed in Table 1. These 15 measures were selected by CSIRO team based on previously proposed measures by the community and councils in existing proposals and the scientific understanding of the flows in the Richmond River catchment.
2. Flood event: The second part asked which flood events should be used to run the NRRI scenarios, with a choice between selecting the 2017, the 2022 or both events.
3. Suggestions: The final part was an open comment box asking for general suggestions and other flood mitigation measures, or bundles of flood mitigation measures among the 15 presented in the first part.

In parallel with these consultation workshops with the local community, NEMA allowed for feedback forms to be submitted online until 15 August 2025. Finally, additional completed paper feedback forms were collected during council meetings with the Ballina Shire Council on 29 July, the Richmond Valley Council on 29 July, the Kyogle Council on 30 July, the Lismore City Council on 30 July and the Rous County Council on 30 July 2025. The Tweed Council on 28 July, Clarence Council on 19 August (online) and Byron Council on 28 July 2025 were also provided with an update on the hydrodynamic modelling and available results.

Table 1 Flood mitigation measures listed in the first part of the feedback form.

MEASURE NUMBER	MEASURE DESCRIPTION
1	Water retention or diversion on land upstream of Kyogle (location to be finalised)
2	*Kyogle partial ring levee (removed as already completed)*
3	Casino CDB levee
4	Lowering of the Bruxner Highway
5	Water diversion on land between Casino and Coraki (location to be finalised)
6	Water retention in the Wilsons catchment upstream of Lismore (location to be finalised)
7	Water retention in the Terania Creek catchments upstream of Lismore (location to be finalised)
8	Water retention in the Leycester Creek catchment upstream of Lismore (location to be finalised)
9	Leycester Creek bypass
10	Lismore CBD levee upgrade
11	South Lismore levee upgrade
12	Tuckean Swamp bypass and drainage, and Bagotville barrage upgrade
13	Opening of Boundary Creek to the Pacific Ocean
14	Ballina levee (location to be finalised)
15	West Ballina culverts and levee (location to be finalised)

Given the history of regular flooding in the region and the severity of the recent 2022 floods, the first round of engagements was attended by many community members. The numbers varied substantially across the five locations with Lismore being the largest with 224 community members, followed by Ballina 111, Woodburn 107, Kyogle 36, and Casino 24. A total of 340 completed paper feedback forms were received during these consultations. At the same time, a total of 348 completed online forms were also received. As such, a total of 688 completed feedback forms were received (Table 2).

Table 2 Statistics of first round of community and council consultations and online response forms.

TYPE OF CONSULTATION	LOCATION	NUMBER OF PARTICIPANTS	NUMBER OF FORMS
Consultation with councils			
	Tweed Shire Council	5	-
	Byron Shire Council	7	-
	Ballina Shire Council	6	1
	Richmond Valley Council	13	2
	Kyogle Council	11	1
	Lismore City Council	14	13
	Rous County Council	12	3
	Clarence Council	10	-
Public Consultations	Casino	24	8
	Lismore	224	154
	Ballina	111	50
	Woodburn	107	81
	Kyogle	36	27
Online forms			348
TOTAL		**580**	**688**

The suggestions provided in all 688 forms were analysed by the CSIRO team. The plots below show both the overall distribution of responses and the options most strongly preferred by the majority of community members who provided feedback during the consultations.

Figure 2 shows the overall ranking that the community has provided to the 15 flood mitigation measures that were provided to them in all 688 forms. Figure 3 and Figure 4 show the ranking for the 340 paper forms and 348 online forms, respectively.

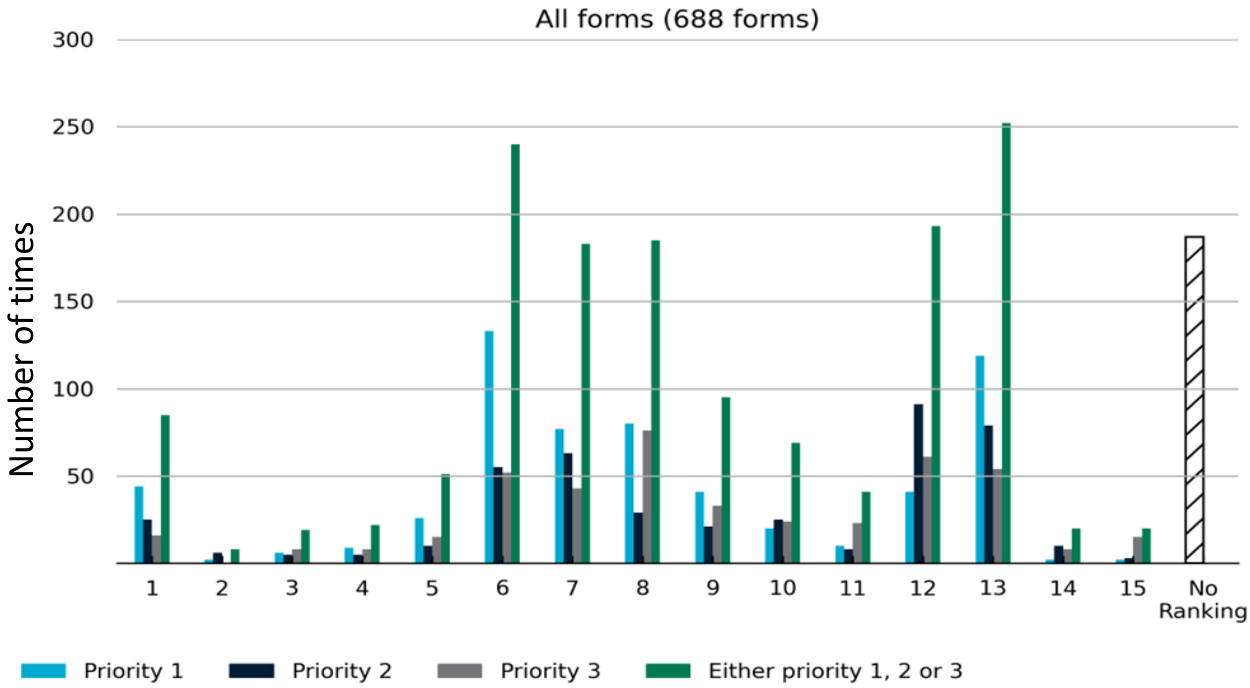

Figure 2 The statistics for all 688 feedback forms for the 15 flood mitigation measures to be tested in the Richmond River catchment.

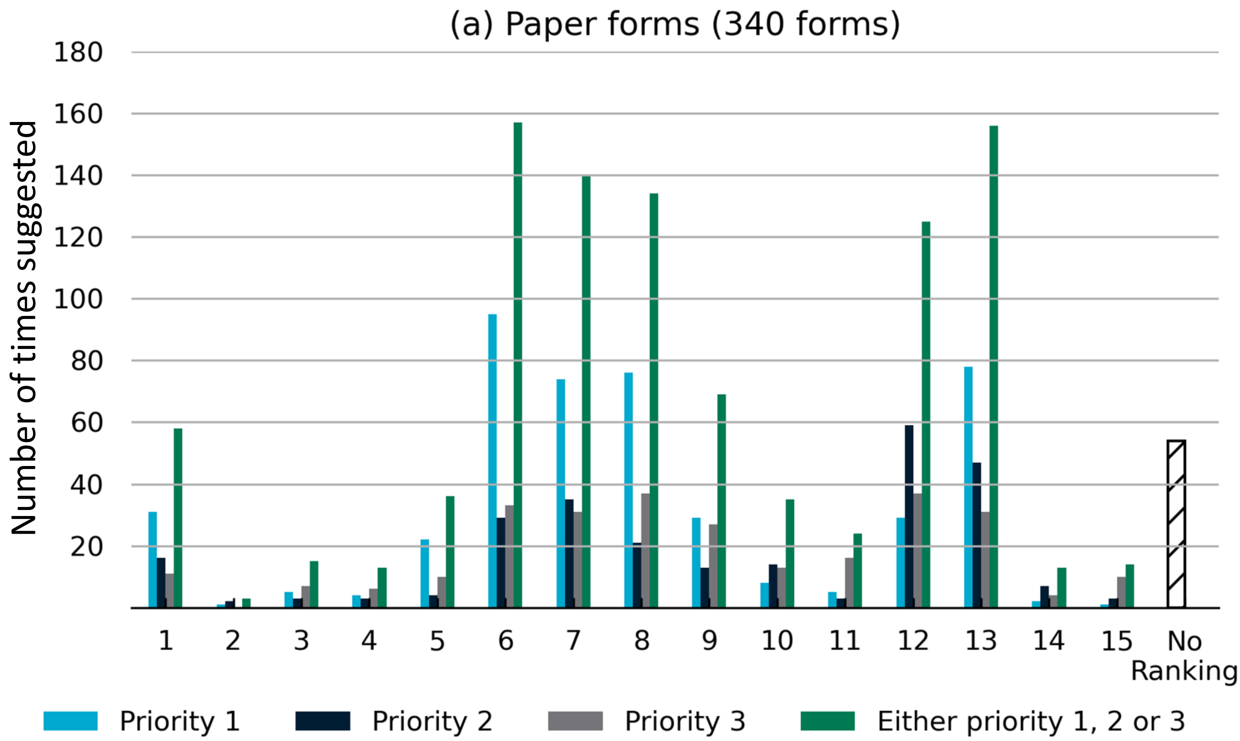

Figure 3 The statistics for the 340 paper feedback forms for the 15 flood mitigation measures to be tested in the Richmond River catchment.

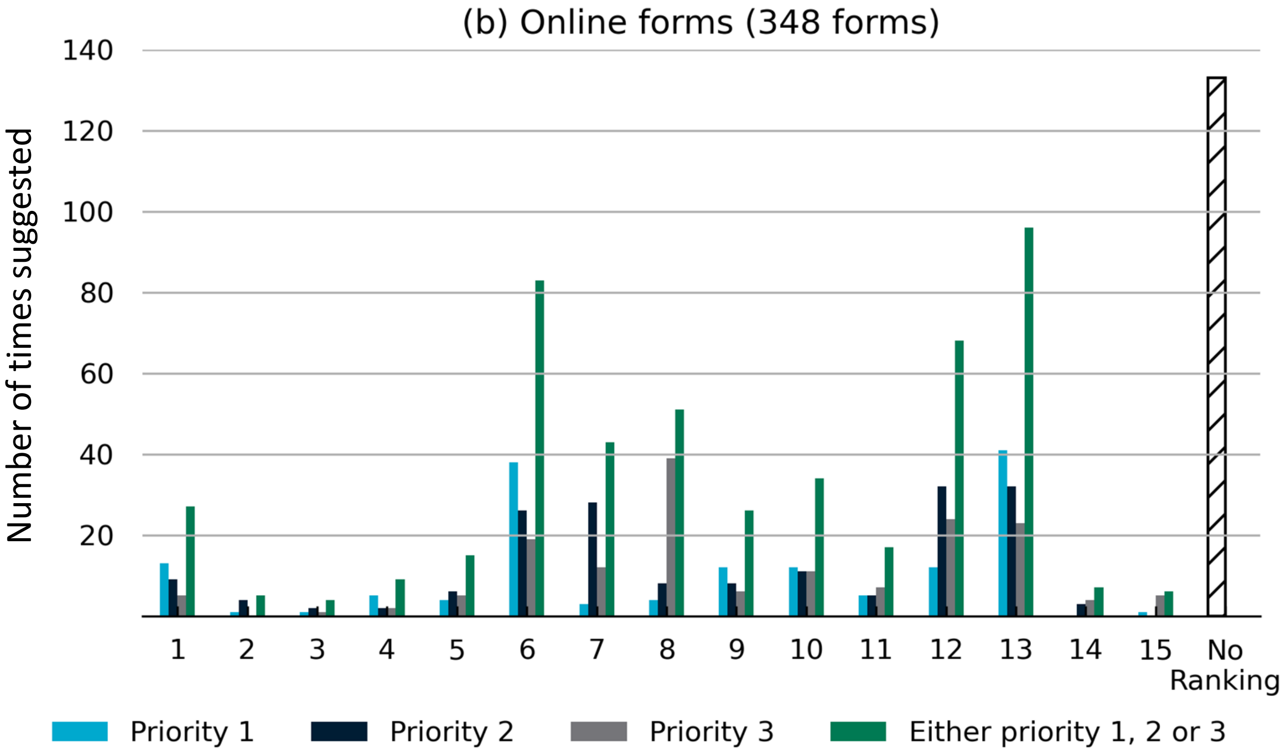

Figure 4 The statistics for the 348 online feedback forms for the 15 flood mitigation measures to be tested in the Richmond River catchment.

As shown in Figures 2, 3, and 4, the majority of respondents, from both paper and online survey forms, preferred options 6, 7, 8, 12 and 13. These options correspond to water retention in the Wilsons, Terania Creek, and Leycester Creek catchments upstream of Lismore (locations to be finalised), the Tuckean Swamp bypass and drainage works, the Bagotville Barrage upgrade, and the opening of Boundary Creek to the Pacific Ocean, respectively. Given that the largest number of community members attended the Lismore consultations, the majority of responses focused on detaining water upstream of the Lismore township to assess whether the impacts of large flood events can be reduced. There was also a strong interest in restoring full functionality of the Bagotville barrage and opening the Boundary Creek to the Pacific Ocean, which was the case historically. This opening of Boundary Creek has the potential to reduce flood impacts in the downstream reaches of the Richmond River.

Community members also proposed additional flood mitigation measures beyond the 15 options included in the feedback forms. Figure 5 shows the statistics for the other suggested measures, and Figure 6 shows the statistics for nature-based solutions suggestions.

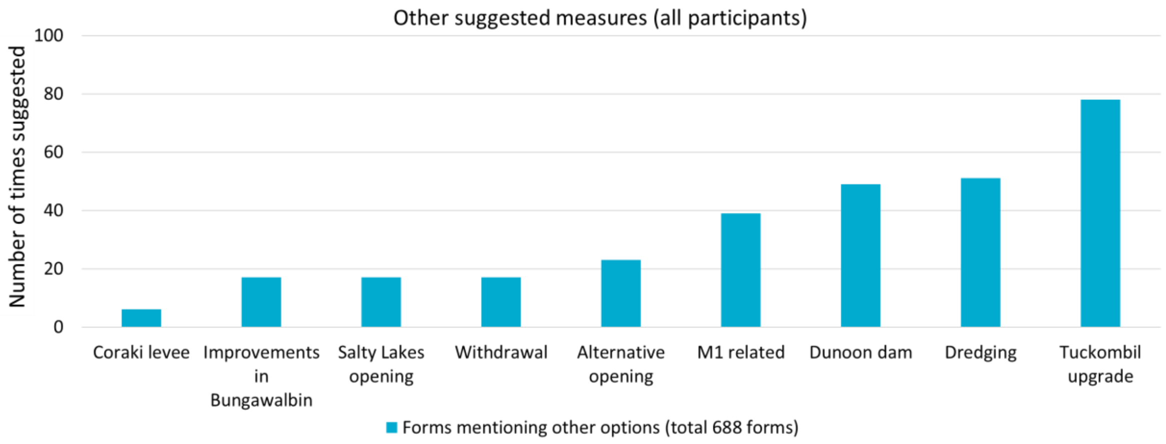

Figure 5 The statistics for other suggested measures in all the 688 feedback forms.

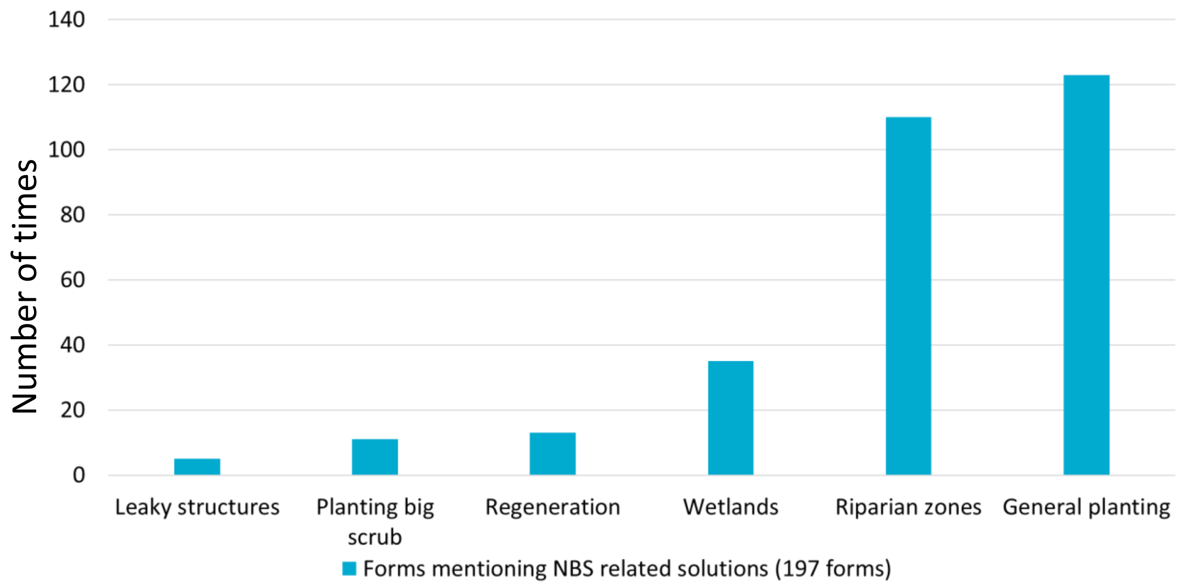

Figure 6 The statistics for the nature-based solution measures in all 688 feedback forms.

As can be seen from the statistics in Figure 5, nine additional flood mitigation measures were suggested by more than five community members. The Tuckombil upgrade was the most preferred measure with nearly 80 community members suggesting it, and the other more preferred options were Dredging, the Dunoon Dam, M1 (Pacific Highway) related and alternative openings to the ocean. There were no details or locations provided for the dredging measure, nor were there any specific suggestions for the M1 related and alternative openings to the ocean. As a result, only the Tuckombil upgrade and Dunoon detention options were considered for further analysis.

The statistics in Figure 6 for nature-based solutions show that 197 feedback forms mentioned some form of nature-based solutions. However, these suggestions are largely generic and lack sufficient detail to define specific interventions, including information on location and scale. There are also two large-scale nature-based solutions projects funded as part of the Northern Rivers Recovery and Resilience Program (NRRRP) work funded through NEMA, based on suggestions from Phase 1 of NRRI and the results are awaited to see whether these options can be utilised for large-scale flood mitigation. Discussions were held with the current nature-based solutions project leaders, and they confirmed that they did not have any proposed options in time for testing in the NRRI project. Based on this, it was decided to defer consideration of nature-based solutions until results become available and, subject to their effectiveness, to assess their implementation in parallel with the structural flood mitigation scenarios tested under the NRRI. Nature-based solutions have other environmental benefits, and so they can always complement any structural solutions for major flood mitigation.

Figure 7 show the statistics for the preferred climate from these consultations.

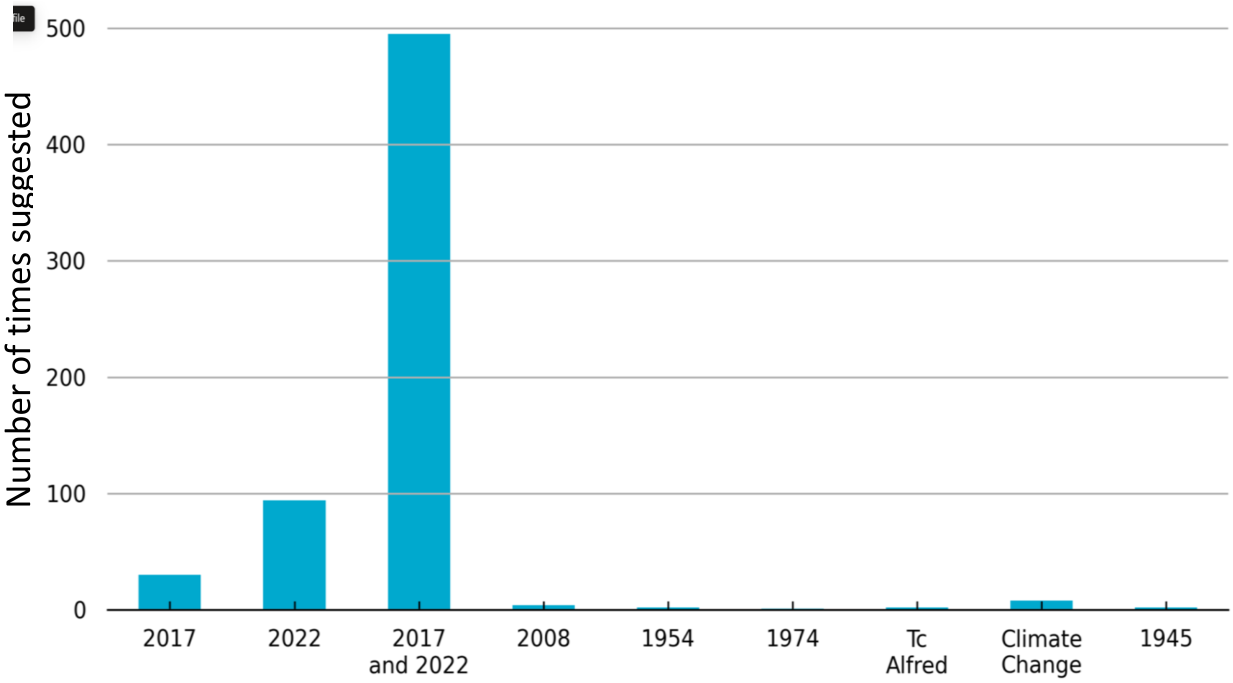

Figure 7 The statistics for the preferred climate in all 688 feedback forms.

As shown in Figure 7, the majority of the community members preferred the 2017 and 2022 flood events, as both caused severe impacts across the region. However, during consultations with the Kyogle and Casino councils, it was recommended that the 2008 flood event also be included given the substantial impacts experienced in those areas at that time. Accordingly, the 2008 flood event was incorporated into the subsequent analysis and finalisation of scenarios, as it also differed markedly from the 2017 and 2022 events in terms of rainfall spatiotemporal patterns, and antecedent conditions, thereby providing an opportunity to test the robustness of mitigation options under contrasting flood-generating conditions.

The CSIRO team analysed all the suggestions provided by the councils and community during this first round of engagements and further refined the flood mitigation measures to be assessed in the scenario analysis. Based on this further analysis and refinement, the CSIRO team formulated six scenarios, comprising combinations of three climates and two bundles of multiple flood mitigation measures. These refined scenarios were subsequently presented to the community and councils in the second round of consultations to seek endorsement and to incorporate any additional feedback for further improvements.

The two bundles of flood mitigation measures formulated based on the input from the majority of the community and councils are:

Bundle 1: Fawcetts Detention, Eden Detention, Rock Valley Detention, Dunoon Detention, Corndale Detention and Corndale Detention side dyke, Tuckean Swamp Upgrade, Opening of Boundary Creek, Tuckombil Upgrade.

Bundle 2: Fawcetts Detention, Eden Detention, Rock Valley Detention, Dunoon Detention, Corndale Detention and Corndale Detention side dyke, Tuckean Swamp Upgrade, Opening of Boundary Creek, Tuckombil Upgrade, Collins Valley Detention, Barlings Detention, Bentley Detention, Goolmangar Detention, and Booyong Detention.

The only difference between the two bundles is that extra detentions are added to Bundle 1 to get Bundle 2.

The three climates selected by the majority of the community and councils are:

1. 2008 (requested by the Kyogle and Richmond councils)
2. 2017
3. 2022

The six revised scenarios for consideration are:

1. 2008 climate and Bundle 1
2. 2008 climate and Bundle 2
3. 2017 climate and Bundle 1
4. 2017 climate and Bundle 2
5. 2022 climate and Bundle 1
6. 2022 climate and Bundle 2

The CSIRO, NEMA and NSWRA teams conducted a second round of councils and community consultation workshops in September 2025 in the Richmond River catchment. The consultations aimed to share details of the final identified climate and flood mitigation measures, and to provide an opportunity for council and community feedback on the final revision of the scenarios for testing with the hydrodynamic model.

The second round of community consultations was conducted at the same five locations: Lismore and Ballina on 22 September, Casino and Kyogle on 23 September, and Woodburn on 24 September 2025. Each consultation was for 2 hours, during which CSIRO, NEMA and NSWRA staff explained how community and council feedback had informed the final scenarios and provided additional details and maps for the revised scenarios. Any further suggestions were noted, but overall, the feedback indicated that community members were satisfied with the proposed scenarios. The team also met with the Lismore, Ballina, Kyogle, Casino and Rous County councils to present the revised scenarios and noted their feedback, which was minor. The statistics for the second round of council and community engagements is provided in Table 3.

Table 3 Statistics of second round of community and council consultations.

TYPE OF CONSULTATION	LOCATION	NUMBER OF PARTICIPANTS
Meeting with Councils		
	Ballina Shire Council	12
	Richmond Valley Council	14
	Kyogle Council	15
	Lismore City Council	19
	Rous County Council	12
	Jali Local Aboriginal Land Council	9
Public meetings	Casino	8
	Lismore	43
	Ballina	22
	Woodburn	36
	Kyogle	5
TOTAL		**195**

The stakeholder engagements in both the first and second rounds were extremely valuable in understanding all the local expertise, views and thinking of the community and councils in the catchment towards flood mitigation. Participants represented a broad cross-section of the community, including businesses, professionals, farmers, etc. Given the frequency of floods in the region and the on-ground experience of the recent devastating floods of 2022, most council and community members possess a practical and realistic approach towards flood mitigation. Stakeholders expressed strong support for the CSIRO to test scenarios with the potential to reduce the impacts of large floods across the region.

The CSIRO team reviewed all the minor suggestions provided by the councils and community during the second round of engagements and noted broad agreement with formulated scenarios. Overall, stakeholders strongly supported CSIRO team proceeding with only minor refinements and testing the two mitigation bundles across the three climates using the newly developed hydrodynamic model.

3 Final scenarios and implementation in the hydrodynamic model

3.1 Final scenarios

Following completion of the two rounds of stakeholder engagements, the CSIRO team applied a flow accumulation model developed in-house, together with the LiDAR Digital Elevation Model (DEM) collected as part of NRRI, to estimate the volume of water that could be detained at the stakeholder-suggested locations. This in-house model was also used to estimate design details required for the hydrodynamic model such as location, capacity, detention wall heights and widths, and indicative gate dimensions. The structures were implemented as temporary detention storages, where the water is held only during the flood and released completely, keeping flow in-bank once the flood peak has passed, so that the river flow is not impeded during non-flood times providing fish passage.

Following these analyses, minor refinements were made to the final scenarios, and further details were estimated for the detention storages. Details of the final selected scenarios were made available on the NEMA and CSIRO NRRI webpages. The final scenarios were also shared with the relevant Australian and NSW State ministers, who expressed support for proceeding with the scenario testing.

The locations and details of the detentions and other flood mitigation measures included in scenario Bundle 1 and Bundle 2 are shown in Figure 8 and Figure 9, respectively and each of the measures is listed below each map.

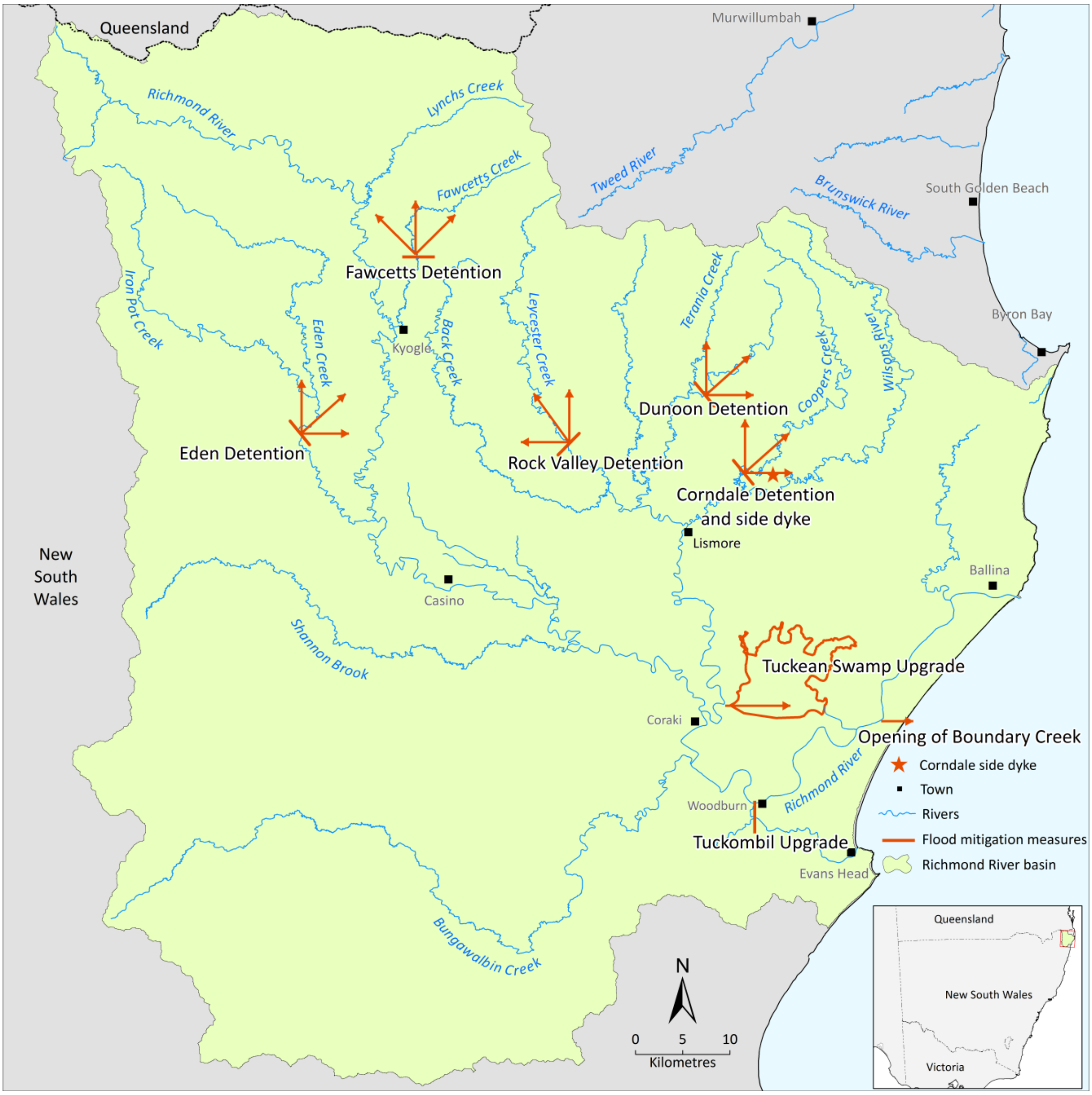

Figure 8 The location and details of all detentions and other measures included in Bundle 1.

In Bundle 1, the five detentions and other flood mitigation measures are:

- Fawcetts Detention
- Eden Detention
- Rock Valley Detention
- Dunoon Detention
- Corndale Detention and Corndale Detention side dyke
- Tuckean Swamp Upgrade
- Opening of Boundary Creek
- Tuckombil Upgrade

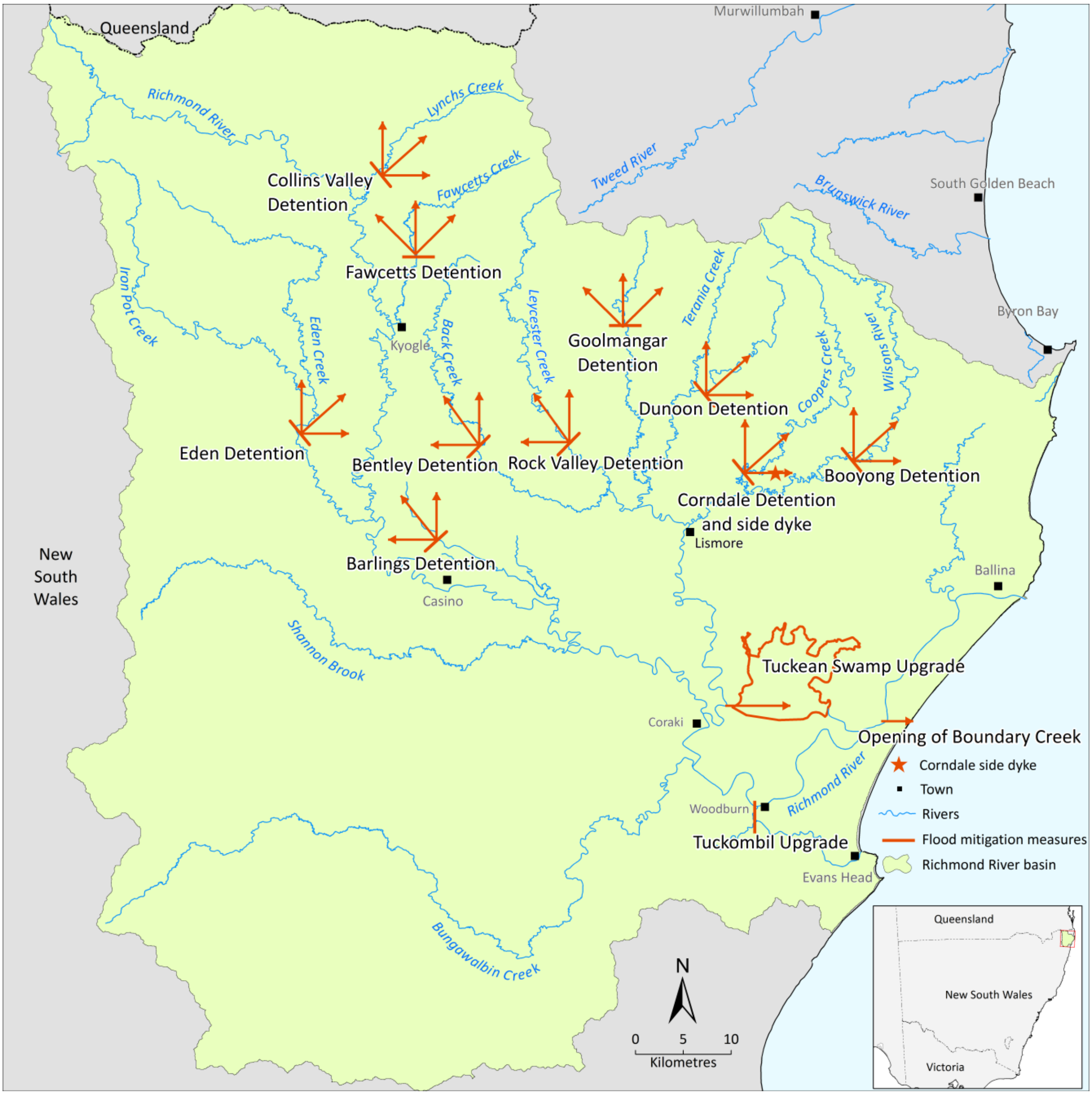

Figure 9 The location and details of all detentions and other measures included in Bundle 2.

In Bundle 2, the ten detentions and other flood mitigation measures are:

- Fawcetts Detention
- Eden Detention
- Rock Valley Detention
- Dunoon Detention
- Corndale Detention and Corndale Detention side dyke
- Tuckean Swamp Upgrade
- Opening of Boundary Creek
- Tuckombil Upgrade
- Collins Valley Detention

- Barlings Detention
- Bentley Detention
- Goolmangar Detention
- Booyong Detention

The opening to the Pacific Ocean at Boundary Creek was historically a natural opening that used to get activated, especially during high flows/floods. These details are available in the literature, and they were also confirmed in the meeting with the Jali group, who provided more details. In the model, the Boundary Creek opening is represented as a modified flow path that allows floodwaters to discharge to the Pacific Ocean during flood conditions, thereby reducing downstream flood impacts along the Richmond River. During non-flood conditions, pressure-controlled gates prevent the ingress of saline water from the ocean into the Richmond River.

The Tuckombil upgrade is represented by replacing the fixed-height barrage with pressure gates, consistent with the function previously provided by the inflatable fabri-dam at this location. Based on feedback from the second round of council engagements, especially with Rous County Council, the Tuckean Swamp upgrade assumes that the pressure gates at the Bagotville Barrage are operating as intended and are fully functional. The issue of bypass flow from the side of the Corndale detention area was identified during the initial simulations and the side dyke was needed to stop that flow. The Corndale Detention side dyke is represented as a structure designed to prevent the bypass flow from the side of the Corndale detention area. The Bruxner highway option which was in the initial list was removed based on the information that work on it is already underway.

The exact locations of detentions are carefully selected by running the DamSite model (Petheram et al. 2017), analysing the DEM data, and ground observations where possible from multiple site visits conducted by the CSIRO team. Firstly, we ran the DamSite model developed in-house to find natural choke points in all river tributaries upstream of Casino and Lismore. The detention walls were put at natural choke points on the river/stream to minimise the widths and depths of the walls while allowing detainment of a sufficient amount of water for the purpose of flood mitigation. The terrain analysis using the DEM data and ground observations was conducted to double check the topographic conditions at the potential sites. After the exact locations were selected, we used the results from the historical model to calculate the volume of floodwater flowing down the tributaries. From there, storage capacities, widths and depths of the detentions are finalised. The details of the final flood mitigation measures, including the detention storages and other measures, are provided in Table 4.

Table 4 Name, location and details of all the detention storages and other flood mitigation measures in both the bundles.

Name	Location (Lat, Long)	Storage capacity (GL)	Total Wall height from bottom of stream (m)	Stream bank height (m)	Wall width (m)	Bundle 1	Bundle 2
Corndale Detention Basin	153.33, -28.76	91.3	23	8.9	548	Yes	Yes
Booyong Detention Basin	153.43, -28.75	82.8	19.5	8.1	498		Yes
Goolmangar Detention Basin	153.21, -28.61	53.9	28	13.9	219		Yes
Rock Valley Detention Basin	153.16, -28.73	94.3	39	16.7	389	Yes	Yes
Bentley Detention Basin	153.08, -28.73	40.7	29	10.3	389		Yes
Collins Valley Detention Basin	152.98, -28.48	39.5	29	6.8	469		Yes
Dunoon Detention Basin	153.29, -28.68	43.0	42	65.6	150	Yes	Yes
Fawcetts Detention Basin	153.02, -28.55	39.2	22	6.8	658	Yes	Yes
Barlings Detention Basin	153.04, -28.82	11.3	5	1.7	489		Yes
Eden Detention Basin	152.91, -28.71	69.4	27	12.9	459	Yes	Yes
Name	**Location (Lat, Long)**		**Mitigation measure**			**Bundle 1**	**Bundle 2**
Tuckean Swamp upgrade	153.41, -28.98		Operation of existing pressure gates at Bagotville Barrage to ensure full functionality.			Yes	Yes
Tuckombil upgrade	153.34, -29.08		Conversion of the fixed height barrage to pressure gate operation.			Yes	Yes

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Opening of Boundary Creek	Start: 153.46, -28.99 End: 153.48, -28.99	Opening of Boundary Creek to enable floodwater to discharge to the Pacific Ocean during floods via pressure gates at the ocean outlet.	Yes	Yes
Corndale Detention Side Dyke	Start: 153.356, -28.760 End: 153.356, -28.757	Construction of a small dyke to prevent bypass flow around the Corndale detention, with a maximum height of 10 m above the lowest point at the railway line.	Yes	Yes

A schematic representation of the detention storages and associated gates is shown in Figure 10. While all detention structures are represented using a common conceptual design, the detention structures are dimensioned to reflect site-specific topographic and hydraulic characteristics. An aerial view of the maximum storage extent across all detention sites within the Richmond catchment, along with zoomed-in views of two representative detention storages at full capacity, are shown in Figure 11, Figure 12, and Figure 13.

As illustrated in the schematic, the collapsible (sluice) gates span the full river cross-section at each detention location and are designed to close only during flood conditions to temporarily detain water. Under normal (non-flood) conditions, the gates remain open, allowing rivers and streams to flow under near-natural conditions. Figure 11 indicates that, even at full capacity, the detention areas inundate relatively small extents, which are mostly confined to areas immediately upstream of the stream channels.

Figure 10 Schematic of one of the representative detention storage structure with gates.

Figure 11 Aerial view of all completely full detention storages in Bundle 2 across the Richmond River catchment.

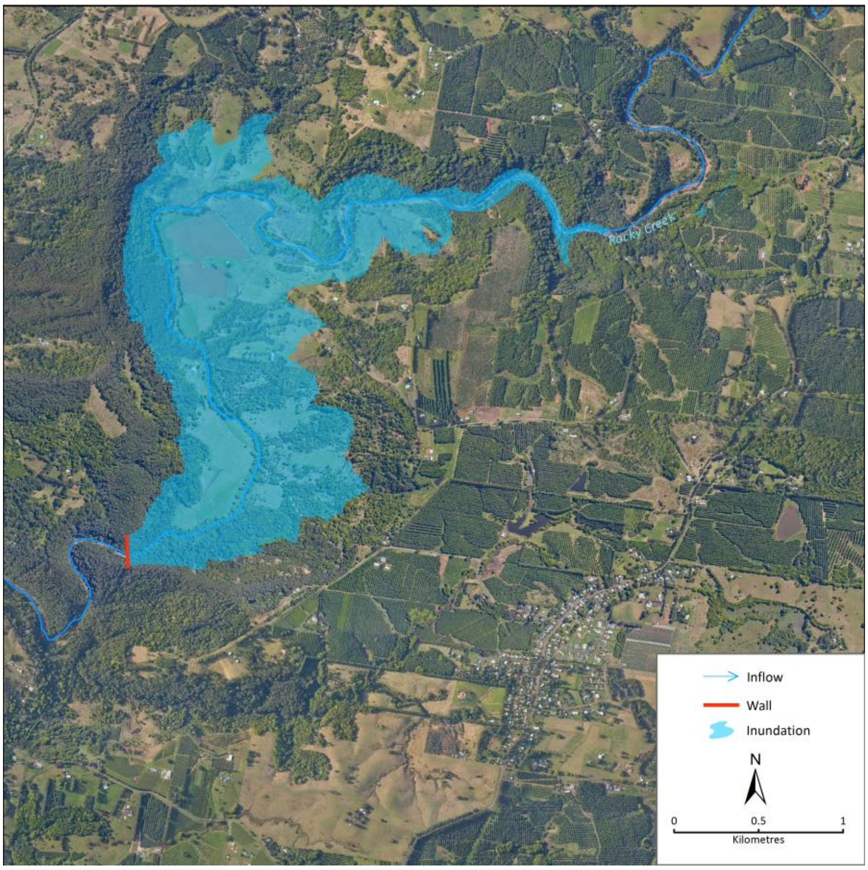

Figure 12 Aerial view of completely full Dunoon detention storage.

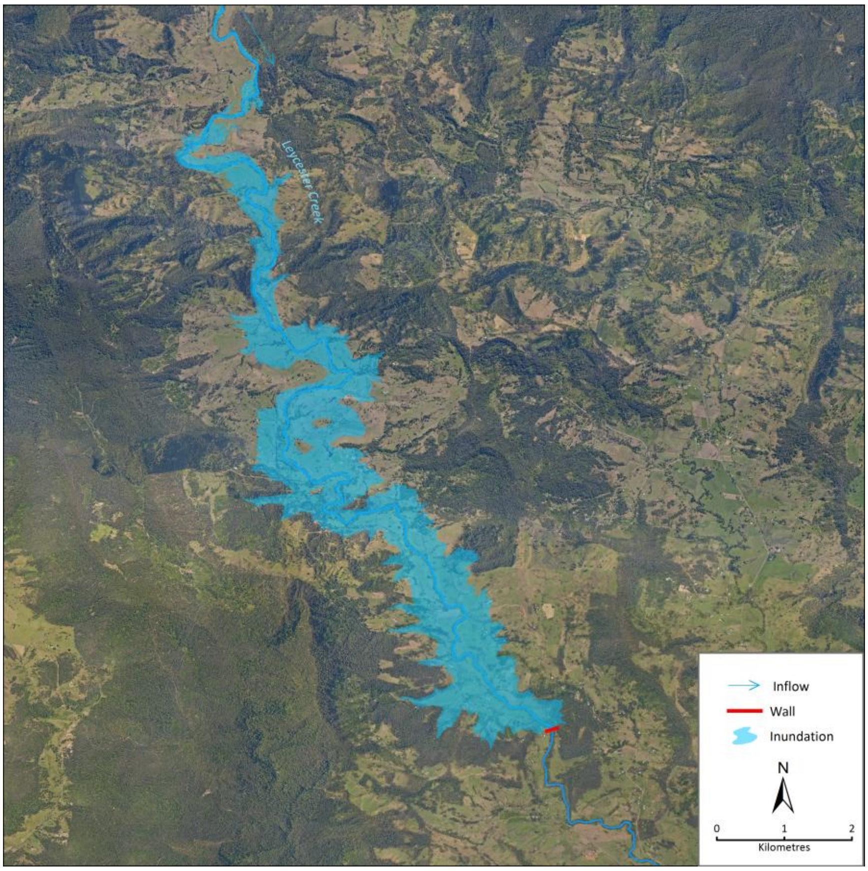

Figure 13 Aerial view of completely full Rock Valley detention storage.

3.2 Setting up scenarios in the MIKE21 FM hydrodynamic model

The hydrodynamic module of the MIKE21 Flow Model FM of MIKE ZERO 2024 for Linux (referred to as MIKE21 FM) was implemented for the entire Richmond River catchment as part of earlier work (Vaze et al., 2025) in the NRRI project. This was necessary to reproduce flooding behaviour across the entire Richmond River catchment for a range of historical flood events and to assess the catchment-wide impacts of flood mitigation interventions, explicitly accounting for the downstream responses to upstream measures. For the scenario analysis, all model configurations, parameter settings, and input datasets remain identical to those used for historical simulations and validation, with the exception of the inclusion of structural representations of the flood mitigation measures being tested. MIKE21 FM was selected at the outset of the project due to its capability to robustly represent both overland floodplain inundation and channelised streamflow, consistent with the project objective of accurately simulating overall flood behaviour across the catchment.

Several alternative hydrodynamic modelling approaches exist for this type of catchment-scale flood analysis such as one-dimensional modelling (1D) and coupled 1D-2D modelling frameworks. MIKE11, a 1D modelling framework, is commonly applied for the assessment of detention structures; however, it is primarily suited to simulating streamflow within channels and does not represent overland floodplain processes. Consequently, MIKE11 alone is not suitable for applications such as the Richmond River catchment, where the objective is to reproduce both river water levels and spatial patterns of overland inundation, including flood extent, depth, and duration. While MIKE11 provides a range of options for representing detention storages that are not directly available in MIKE21 FM, these advantages were outweighed by the need for comprehensive floodplain representation at the catchment scale.

At the commencement of the project, a coupled MIKE 1D–2D modelling framework was also available, whereby MIKE11 was used to represent river channels and MIKE21 FM to represent floodplain processes, with dynamic linking between the two. However, at that time, the coupled framework was not sufficiently stable for application at the scale and complexity of the Richmond River catchment, which comprises approximately 10.2 million mesh elements. For this reason, a fully two-dimensional (2D) MIKE21 FM approach was adopted for the current analysis. Ongoing development and improvements to the MIKE 1D–2D framework suggest that its applicability for similar large-scale catchment studies should be investigated in future implementations.

The following subsections describe the methods used to implement the mitigation measures in the model and the scenario comparison framework used to evaluate the results from the mitigation bundles. Implementation of the structural flood mitigation measures within the model mesh was technically complex, reflecting both the scale and resolution of the hydrodynamic model. The Richmond River catchment model comprises approximately 10.2 million mesh elements, and careful modification of the mesh and hydraulic structures was required to ensure accurate representation of each mitigation measure. Every effort was made to implement all measures in both scenario bundles as realistically and consistently as feasible within the modelling framework.

3.2.1 Implementation of detention storages and gate operations

In parallel with the MIKE21 FM implementation, the CSIRO team also developed a MIKE HYDRO River model (the successor to the phased-out MIKE11 model) for the relevant river systems in the Richmond River catchment. This 1D model was tuned to reproduce streamflows and water levels at key locations, using outputs from the 2D MIKE21 FM model, which had been validated against observed gauge data for historical flood events.

Once agreement was achieved between the 1D and 2D models in terms of simulated channel water levels and flows, the selected detention storages were implemented within the MIKE HYDRO River framework using the sluice-gate functionality. This functionality, which is not directly available in MIKE21 FM, provides greater flexibility for representing detention operations and was therefore used to assess the impacts of the timing and sequence of gate closure and release at each detention location for the three selected flood events. As 1D models employ simplified flow equations and run significantly faster than 2D models, the use of MIKE HYDRO River in parallel with the MIKE21 FM enabled efficient exploration of multiple gate-operation and controlled-release strategies. Detention gate operations and controlled releases were developed to balance competing objectives, including downstream flood mitigation, storage availability for subsequent events, and minimisation of adverse upstream inundation.

The gate-operation rules derived from the MIKE HYDRO River simulations were then used to inform the operation of detention storages within MIKE21 FM, where gate behaviour must be represented using a simplified gate function. In MIKE21 FM, each detention structure is represented by two dikes (on both sides of the gate), with total wall dimensions as listed in Table 4, extending from both riverbanks perpendicularly towards the surrounding hills. The detention gate spans the river cross-section between the two dikes, as illustrated in Figure 10. The initial opening and closing levels and timings from MIKE HYDRO River were subsequently refined within MIKE21 FM to achieve optimal performance under the constraints of the available gate representation. While the MIKE21 FM gate function does not offer the same operational flexibility as the sluice-gate implementation in MIKE HYDRO River, it provides a suitable surrogate for the purposes of this scenario-based investigation.

For each detention storage, gate-closure timing for the initiation of floodwater detention was automated based on water levels at a specified gauge location and was held constant across all flood events (2008, 2017, and the February and March 2022 events). This approach is necessary and reflects operational reality, given the inherent uncertainty in flood magnitude despite the availability of forecasts; detention operation must therefore commence at levels expected to reduce downstream impacts.

In contrast, post-flood gate opening and controlled-release strategies were allowed to vary between events. In any flood event, once flood peaks have passed, the volume of water detained at each site will be known, enabling event-specific adjustment of release rates to ensure that downstream water levels do not exceed defined thresholds and cause secondary flooding during the release phase. This approach also allows detention storages to be emptied as efficiently as possible, ensuring they are fully available should subsequent flood events occur, as was the case in March 2022.

3.2.2 Implementation of other flood mitigation measures

The remaining flood mitigation measures were comparatively straightforward to represent within the MIKE21 FM modelling framework. The reopening of Boundary Creek was represented by widening the existing channel to accommodate increased flood conveyance and modifying the channel grade, based on the existing DEM, to enable flood flows to discharge to the Pacific Ocean. A pressure-controlled gate was incorporated at the ocean outlet to regulate exchanges between saline and freshwater conditions.

The Bagotville and Tuckombil barrages were represented as pressure-controlled structures at their existing locations for the Tuckean Swamp and Tuckombil upgrade options, respectively, consistent with the approach used for the Boundary Creek gates. Within the MIKE21 FM model, pressure-controlled structures are represented using culverts fitted with check valves at the outlet. These check valves permit flow only from the river side to the ocean side when water levels upstream exceed those on the downstream, a condition that typically occurs during flood events. Under non-flood conditions or during tidal surges, the check valves automatically close to prevent reverse flow when ocean water levels are higher than upstream river levels. This configuration is necessary to protect towns from tidal surges and to prevent saline water intrusion into the freshwater river system, which is critical for maintaining water availability for agricultural uses.

The Corndale detention side dyke was implemented as a simple linear embankment to block a potential bypass flow path upstream of the Corndale detention wall. Without this structure, floodwaters would divert and inundate areas outside the intended storage footprint.

3.2.3 Scenario comparison framework

Scenario results were evaluated by comparing simulated hourly water levels against baseline historical simulations at the same eight gauge locations used for model validation. Table 5 lists the gauges included in the comparison, and Figure 14 shows their spatial distribution across the catchment. This consistent comparison framework enables robust assessment of changes in flood behaviour arising from the tested mitigation scenarios.

It is important to note that this analysis represents a scientific and technical assessment of the potential effectiveness of proposed flood mitigation measures in reducing flood levels and overland inundation across the catchment, including the influence of upstream interventions on downstream responses extending to the ocean outlet at Ballina. The structural representations used in the model are indicative only, and the final design and specification of detention structures would differ from those implemented here. Detailed structural design, including materials selection and engineering certification, is outside the scope of the NRRI project and CSIRO and would be undertaken by specialist agencies during subsequent project phases.

Table 5 Gauges used for comparing the scenario analysis results for the Richmond River catchment.

Position	Gauge name	Gauge ID
Upstream of Lismore	Leycester Creek at Tuncester	203443
Upstream of Lismore	Wilson River at Woodlawn College	203402
At Lismore	Wilson River at Lismore	H058176
Downstream of Lismore	Wilson River at East Gundurimba	203427
At Casino	Richmond River at Casino	203004
At Coraki junction	Richmond River at Coraki	203403
At Wardell	Richmond River at Wardell	203468
At Byrnes Point Ballina	Richmond River at Byrnes Point	203461

Figure 14 Location of the eight internal gauges where the model simulated historical and scenario hourly water levels are compared.

4 Results and Discussion

The modelling results from the hydrodynamic model for the six flood mitigation scenarios are presented and discussed. The same eight flow gauges used in the hydrodynamic model implementation report, at key locations representing all parts of the Richmond River catchment (Table 5 and Figure 14), are used for presenting the scenario modelling results. This is done to investigate the ability of the implemented flood mitigation scenarios in influencing the water levels (water level plots) and overland floodplain inundation (maximum spatial floodplain inundation plots: maximum flood extent and maximum flooding depth) based on the selected historical flood events.

4.1 Results

The Scenario modelling results are compared against baseline hydrodynamic simulations for the historical flood events of 2008, 2017 and 2022 to assess the extent to which the tested mitigation scenarios influence flood behaviour. Baseline results for these events are documented in Vaze et al. (2025), which demonstrated that the hydrodynamic model reproduces observed river water levels and spatial floodplain inundation characteristics, including inundation extent, timing and flood depth, across the Richmond River catchment with a high degree of accuracy. These validated baseline simulations are therefore used as the reference condition for comparison in the scenario analysis presented here.

Table 6 summarises key water-level responses and detention performance metrics resulting from the application of the gate-operation rules described in Section 3.2. These include maximum detention volumes reached prior to controlled release, drawdown duration (that is, the time required to drain a detention after a flood peak has passed), and the time taken for the receding limb to fall below the minor flood level at reference gauges for the two scenario bundles across the three selected flood events. For the detentions upstream of Casino, the control gate is the water level gauge at Casino town (Gauge ID: 203004). For the detentions upstream of Lismore, the control gate is the water level gauge at Lismore junction (Gauge ID: H058176).

Table 6 Details of detention gate shutting water levels (WL), the release/opening water levels, maximum water detained, time for completely emptying the detention storages after an event and time for the event peak to reach below minor flood level for the two scenario bundles and the three selected events.

Detention Location (Control Location, Casino – C, Lismore – L)	Bundle 1				Bundle 2			
	Shut WL (m)	Release WL (m)	Max water detained (GL)	Time to empty (days)	Shut WL (m)	Release WL (m)	Max water detained (GL)	Time to empty (days)
2008 Event								
Fawcetts (C)	12.3	18.1	20.4	4.3	12.3	16	20.4	5.6
Eden (C)	12	13.6	60.7	5.6	13	11.7	58.1	7
Collins (C)					9.6	14.3	29.7	6.3
Barlings (C)					14.4	11.7	10.2	4.3
Dunoon (L)	4.5	6.8	5.9	4.7	4.5	6.4	5.9	6
Rock Valley (L)	4.5	6.7	25.2	3.4	4.5	5.9	25.2	4
Corndale (L)	6.9	7.1	26.3	6.3	6.2	5.7	29.3	8
Goolmangar (L)					4.5	6.4	12.3	4.3
Bentley (L)					6.2	5.7	12.7	3.2
Booyong (L)					6.8	6.5	18.9	6.5
	Time from event peak to reach below minor flood level (days)							
Casino	6.6				8.7			
Lismore	5.5				7.7			
2017 Event								
Fawcetts (C)	12.3	16.1	12.3	3.5	12.3	16.7	12.3	3.8
Eden (C)	12	12.1	24.1	4	13	14.6	23.1	4.4
Collins (C)					9.6	16.5	12.8	4.2
Barlings (C)					14.4	14.6	8.2	3.4
Dunoon (L)	4.5	6.4	12.1	6.7	4.5	6.6	12.1	7.8
Rock Valley (L)	4.5	6.2	32.3	4	4.5	6	32.3	4.3
Corndale (L)	6.9	7	44.7	8	6.2	7.1	45.4	9.7
Goolmangar (L)					4.5	6.7	22.3	5.4
Bentley (L)					6.2	6.4	10.2	2.7
Booyong (L)					6.8	6.6	35	9
	Time from event peak to reach below minor flood level (days)							
Casino	5.5				5.7			
Lismore	6.9				8.6			
28 Feb 2022 Event								
Fawcetts (C)	12.3	18.9	39.2	6.1	12.3	15	39.2	7.4
Eden (C)	12	14.7	69.4	6.7	13	11.2	69.4	8
Collins (C)					9.6	13.7	39.5	7
Barlings (C)					14.4	11.2	11.3	4.4
Dunoon (L)	4.5	6.9	42.9	12.2	4.5	7.2	42.9	13.6
Rock Valley (L)	4.5	6.8	92.8	12.3	4.5	6.2	92.8	13.6
Corndale (L)	6.9	7.6	91.3	12.4	6.2	6.4	91.3	14.3
Goolmangar (L)					4.5	7.2	53.9	13.8
Bentley (L)					6.2	6	39.6	8.8
Booyong (L)					6.8	6.8	82.8	15

	Time from event peak to reach below minor flood level (days)							
Casino	8.7				10.4			
Lismore	12.6				17.0			
31 Mar 2022 Event								
Fawcetts (C)	12.3	15.2	11.3	3.3	12.3	14.2	11.2	3.8
Eden (C)	12	12.6	19.2	3.9	13	11.7	18.2	4.1
Collins (C)					9.6	13.5	9.7	3.7
Barlings (C)					14.4	11.7	8	2.7
Dunoon (L)	4.5	6.4	9.6	7	4.5	5.4	9.6	9.3
Rock Valley (L)	4.5	6.7	9.3	4.9	4.5	5.8	9.1	5.3
Corndale (L)	6.9	7.6	54.6	9.3	6.2	7	56.7	11
Goolmangar (L)					4.5	5.4	6.4	6.2
Bentley (L)					6.2	6.4	3.4	2.8
Booyong (L)					6.8	5.7	60.5	11.5
	Time from event peak to reach below minor flood level (days)							
Casino	5.7				5.9			
Lismore	6.4				9.8			

The water detention and release strategy is designed and assessed on a system-wide basis, accounting for the combined behaviour of all detentions and their cumulative impact on downstream water levels. This ensures that detention gate operations and controlled releases are coordinated to meet overall downstream flood constraints, rather than being optimised in isolation for individual storages. Detention operation involves balancing competing objectives during both gate closure and controlled release. Earlier gate closure can increase floodwater storage and reduce downstream water levels, but may lead to premature filling, spill during flood peaks, and prolonged upstream inundation. Likewise, while rapid release is desirable to restore storage capacity and ease upstream flooding, simultaneous high-volume releases from multiple detentions can elevate downstream flood risk. The operational strategies simulated in this study were developed with these trade-offs in mind, seeking a balanced approach that manages downstream flood risk while maintaining detention availability and minimising adverse upstream impacts. The use of 2D hydrodynamic modelling framework allowed these competing objectives and their dynamic interactions to be evaluated consistently across the catchment, capturing both local and cumulative catchment-wide impacts.

As can be clearly seen from the statistics for all flood events, the gate-shut water levels for a particular detention gate remain the same across all flood events in a scenario bundle but differ between Bundle 1 and Bundle 2 to achieve optimum overall reduction in downstream water levels. As mentioned earlier, this approach is necessary because the maximum magnitude of a flood peak is not known at the start of an event. Therefore, detention must start at a water level that reliably reduces downstream impacts.

The statistics also show that the detention gates opening water levels can be different at the same detention for different flood events and for the two scenario bundles. This is because once the flood peak has passed, the exact volume of water detained in each detention will be known. This information can then be used to determine the most appropriate combination of controlled releases from each detention, ensuring that the downstream water levels does not exceed a defined water level thresholds and cause any flooding during the release. The release times and volumes also need to be managed to ensure that the detentions are emptied as soon as practicable, so that they are fully available to store water in the event of a subsequent flood event. Although the release combinations tested are not exhaustive, the results show that effective and safe release of detained water can be achieved within reasonable timeframes across the assessed flood events.

As shown by the maximum water detained values for the two scenario bundles and the three flood events, different detentions stored different volumes of water for each flood event. Bundle 2 can detain larger total volumes for an event due to inclusion of additional detentions. The statistics for the time required to completely empty each detention once releases commence show that all storages can be fully emptied in periods ranging from approximately 2.7 days for Bentley and Barlings detentions to 15.0 days for Booyong detention.

The longest release duration occurs for 28 Feb 2022 flood event, during which almost all storages were completely full. For this event, the total volumes requiring release were very large: 227 GL and 403 GL from the Lismore side for Bundle 1 and Bundle 2 respectively and 109 GL and 159 GL from the Casino side for Bundle 1 and Bundle 2 respectively. As a result, it takes the longest time of about 15.0 days to completely empty the Booyong detention in Bundle 2 as it has held back 82.8 GL of water. In contrast, the Barlings detention in Bundle 2 which detained only 11.3 GL, can be emptied in approximately 4.4 days for the same event.

While detained volume is a primary driver of release duration, other factors, including local channel capacity, surrounding topography, and a detention’s location relative to other storages, also influence the rate at which water can be safely released. For example, although the Booyong detention did not hold the maximum detained volume, it required the longest release duration because it is located upstream of the Wilsons River reach that also receives releases from Corndale, one of the largest detention storages. Downstream of this confluence, channel banks are lower than those through the Lismore CBD, making the reach more susceptible to flooding during controlled releases and therefore constraining release rates. In contrast, Rock Valley detained the largest volume of water but drains into Leycester Creek, which has deeper channels and is influenced by releases from Bentley, where detained volumes are comparatively smaller. This allows higher release rates and shorter emptying times despite the larger stored volume.

During practical implementation, controlled release rates could potentially be increased for Bundle 1 and Bundle 2, allowing the detentions to be emptied earlier. As discussed previously, the controlled releases will always be decided once the flood peak has passed and the detained volumes are known.

The time required (in days) for water levels at the control gauges to fall from the event peak to below the minor flood level during controlled release is also provided in Table 6. These results indicate that water levels can be reduced to below minor flood levels at the control gauges within approximately 5.5 to 17 days following a flood peak, depending on the total water detained for a flood event.

As shown in Figure 17 and Table 6, all detentions can be completely emptied, even after the 28 Feb 2022 flood peak, which was the largest observed event and during which most storages were completely full in both bundles, within a maximum of 15.0 days from the start of controlled releases. This ensures that all detentions are fully available to detain water for the subsequent event on 31 Mar 2022 flood event, which is why all detentions are able to operate for this event to keep the flood peak below the Lismore CBD levee.

4.1.1 Water level at key river gauges

The MIKE21 FM simulated water level at key gauges for scenario Bundle 1 and Bundle 2 across the model domain are compared to historical simulated water levels for the three selected flood events. Figure 15, Figure 16 and Figure 17 show the hourly water level comparisons between the simulated scenarios of Bundle 1 and Bundle 2, and historical water levels for the flood events in 2008, 2017, and the two flood events in 2022 at all the same eight internal gauges that were used for model validation (Vaze et al., 2025). The results show that the structural measures implemented as part of the scenarios can reduce the water levels for all events at most of the gauges spread across the Richmond River catchment.

The 2008 flood is a small event for Lismore and other areas, but it is reasonably large for Casino and Kyogle. Figure 15 shows the comparison between the hourly water level for the scenarios and the historical simulations at all eight internal flow gauges for the 2008 flood event. As can be seen from the plots, the scenario results for Bundle 1 and Bundle 2, when compared to historical, clearly show that the peak water levels at gauges 203443 and 203402 on the Leycester Creek and the Wilson River upstream of Lismore junction can be reduced substantially due to water detention upstream of Lismore junction. The reduction in flood peak is larger for Bundle 2, where we have six detentions, compared to Bundle 1, where we only have three detentions upstream of Lismore. The reduction in peak water level at the Lismore gauge (H058176) as well as at gauge 203427 at East Gundurimba downstream of Lismore, is similar to the gauges upstream of Lismore. There is a reasonable reduction in water levels for scenario Bundle 1 (~2 m) and Bundle 2 (~2.7 m) at gauge 203004 at Richmond River at Casino. The results at 203403 Richmond River at Coraki are also reasonable with consistent, but a bit smaller water level reduction. The scenarios simulated water levels at gauge 203468 at Wardell and gauge 203461 at Byrnes Point do not show much difference from the historical levels, as the water levels at these gauges were dominated by the tidal influence for this flood event. The overall scenario simulation results for the 2008 flood event show that the model can reduce historical water levels across the Richmond River catchment for a flood event of this size quite well. As expected, the reduction in flood peak is larger for Bundle 2, where we have more detentions compared to Bundle 1 at all gauges in the Richmond River catchment. For this flood event, all the detentions detain maximum water below their designed capacities.

The 2008 flood event’s falling limbs after the peak for all gauges, except for gauge 203468 at Wardell and gauge 203461 at Byrnes Point, show the impact of the controlled releases from the detentions after the flood peaks. This delays the falling limb of the water level plots by a few days to weeks to reach the minimum level until all the detentions are completely empty. These are controlled releases after the flood peak and start at a water level where it is safe to release detained water, making sure that the released water stays within the riverbanks/instream and does not flood downstream areas during release. The gauges at Wardell (gauge 203468) and Byrnes Point (gauge 203461) show little difference for the scenarios compared to historical levels, as it was a minor flood for those gauges and at these lower water levels, the tidal influence masks any changes.

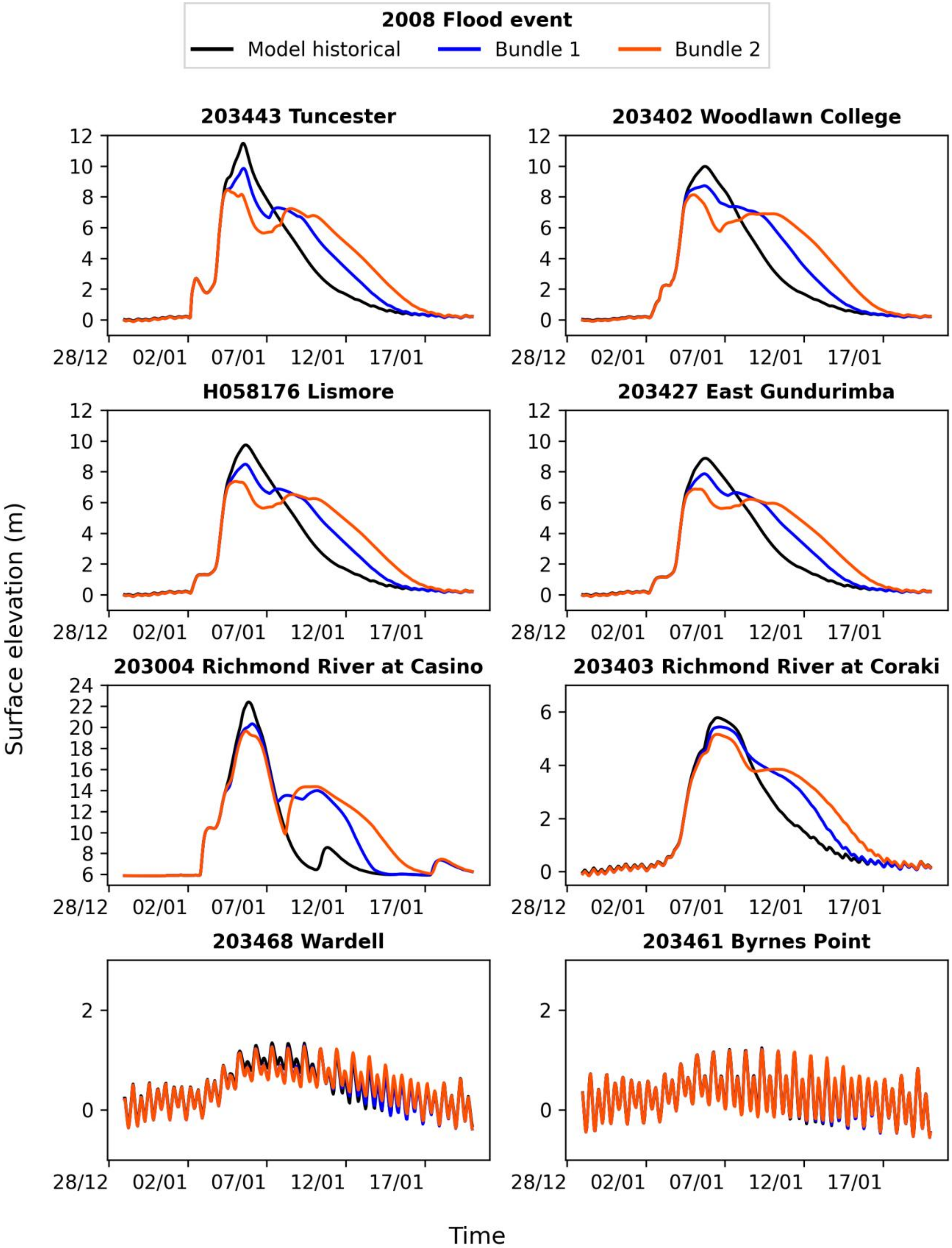

Figure 15 Comparison between the historical water level and scenario Bundle 1 and Bundle 2 water level at all the selected gauges for the flood event of 2008.

The 2017 flood is a reasonably large event for Lismore and medium-to-small for other areas across the Richmond River catchment. Figure 16 shows the comparison between the hourly water level for the scenarios and the historical simulations at all eight internal flow gauges for the 2017 flood event. As can be seen from the water level plots, the scenario results for Bundle 1 and Bundle 2, when compared to historical, clearly show that the peak water levels at gauges 203443 and 203402 on the Leycester Creek and the Wilson River upstream of the Lismore junction, respectively, can be reduced due to water detention upstream of the Lismore junction. The reduction in water level for gauge 203402 on the Wilson River is much higher than that for gauge 203443 on Leycester Creek. The reduction in peak water level at the Lismore gauge (H058176) as well as gauge 203427 at East Gundurimba is similar and substantial, especially for Bundle 2. The 2017 historical water level for the Lismore gauge (11.72 m) overtopped the Lismore CBD levee (10.65 m). With Bundle 1, the water level is reduced to 10.75 m (still overtopping the levee), but with Bundle 2, it can be reduced to 10.32 m, keeping it well below the levee. There is a reasonable reduction in water levels for scenarios Bundle 1 and Bundle 2 at gauge 203004 on the Richmond River at Casino. The reduction in water levels for the scenarios at gauge 203403 on the Richmond River at Coraki is much smaller than the other upstream gauges. The scenarios simulated water levels at gauge 203468 at Wardell and gauge 203461 at Byrnes Point do not show much difference from the historical water levels, as these gauges are dominated by the tidal influence. The overall scenario simulation results for the 2017 flood event show that the model can reduce historical water levels across the Richmond River catchment for a reasonably large flood event quite well. As expected, the reduction in flood peak is larger for Bundle 2, where we have more detentions, compared to Bundle 1 for all gauges in the Richmond River catchment. For the 2017 flood event, none of the detentions are completely full and overflowing.

Similar to the 2008 flood event, the 2017 flood event falling limbs after the peak at all gauges, except for gauge 203468 at Wardell and gauge 203461 at Byrnes Point, show the impact of the controlled releases from the detentions after the flood starts receding. This delays the falling limb of the water level by a few weeks since the minimum level isn’t reached until all the detentions are completely empty. These are controlled releases after the flood peak and start at a water level where it is safe to release, making sure that the released water stays within the riverbanks/instream and does not flood areas during release. The gauges at Wardell (203468) and Byrnes Point (203461) show little difference for the scenarios compared to historical, as it was a minor flood for those gauges, and at these lower water levels, the tidal influence masks any changes.

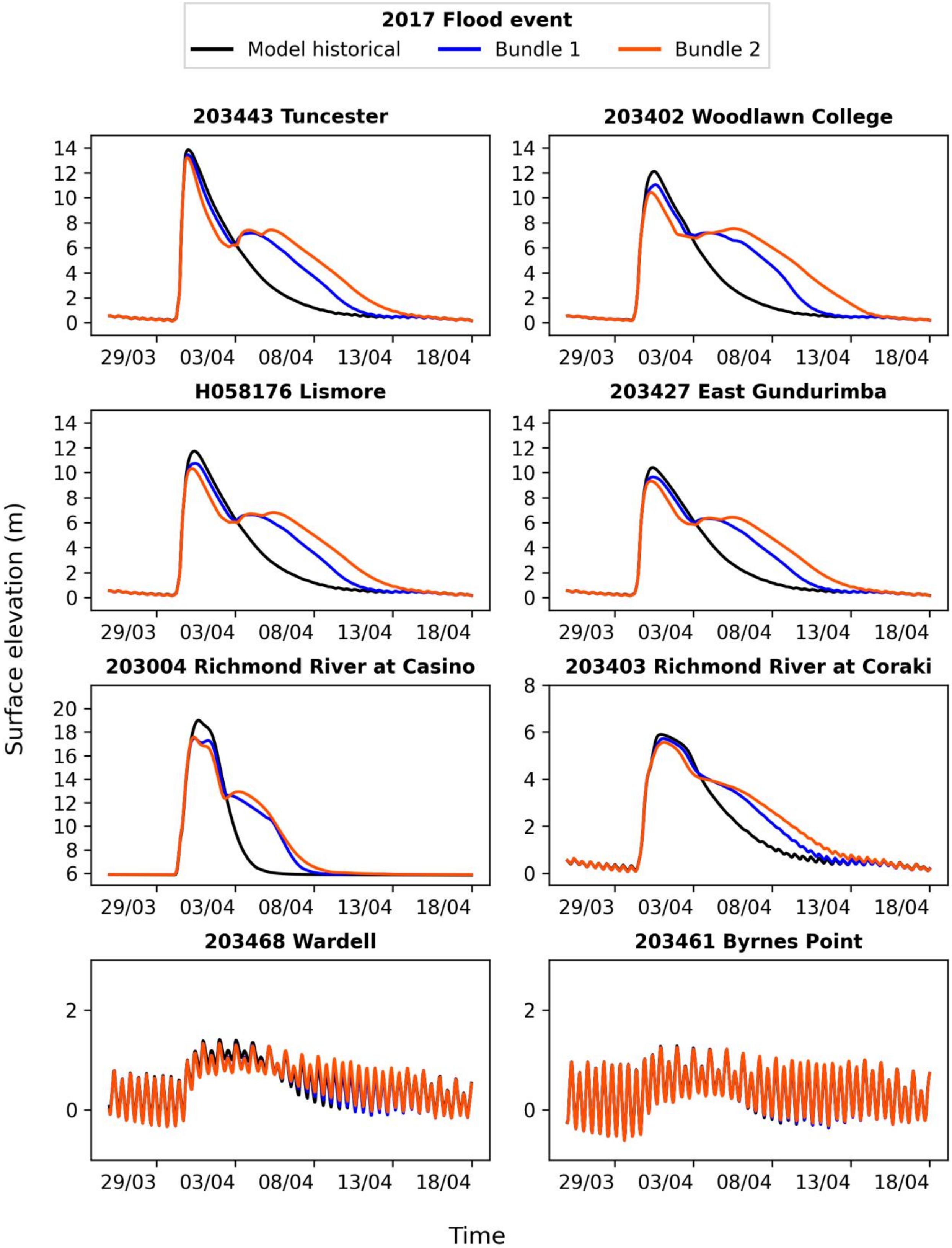

Figure 16 Comparison between the historical water level and scenario Bundle 1 and Bundle 2 water level at all the selected gauges for the flood event of 2017.

The first large flood peak in 2022 on 28 Feb is the largest recorded flood event for Lismore (the maximum observed event) and all other gauges across the Richmond River catchment. Figure 17 shows a comparison between the hourly water level for the scenarios and the historical simulations at all eight internal flow gauges for the 2022 complete flood event. As can be seen from the plots, the scenario results for Bundle 1 and Bundle 2, when compared to historical, clearly show that the peak water levels at gauges 203443 and 203402 on the Leycester Creek and the Wilson River upstream of the Lismore junction can be reduced for the 28 Feb flood event due to water detention upstream of the Lismore junction. The reduction in peak water level at the Lismore gauge (H058176) as well as gauge 203427 at East Gundurimba is similar and substantial, especially for Bundle 2. The 28 Feb 2022 historical water level for the Lismore gauge (14.87 m) overtopped the Lismore CBD levee (10.65 m) but with Bundle 1 that level can be reduced to 13.75 m (still over topping the levee) and with Bundle 2 it can be further reduced to 12.80 m (still over topping the levee but by ~2 m less). This reduction is still reasonable given the magnitude of the 28 Feb 2022 flood. There is a reasonable reduction in water levels for scenarios Bundle 1 and Bundle 2 at gauge 203004 on the Richmond River at Casino. The reduction in water levels for the scenarios at gauge 203403 on the Richmond River at Coraki is smaller than that of the other upstream gauges. For the 28 Feb 2022 event, the scenarios simulated water levels at gauge 203468 at Wardell and gauge 203461 at Byrnes Point do show a significant reduction compared to the historical levels, as for large floods, the tidal influence is diminished at the peak flows. The opening of Boundary Creek and upgrade to the Tuckombil canal also contribute to a reduction in water levels and flooding downstream by diverting water to the ocean especially during very high flows.

For the second large peak on 31 Mar 2022, the scenario results for Bundle 1 and Bundle 2, when compared to the historical results, clearly show that the peak water levels at gauges 203443 and 203402 on Leycester Creek and Wilson River upstream of Lismore junction are reduced due to water detention upstream of Lismore junction. The reduction in peak water level at the Lismore gauge (H058176) as well as at gauge 203427 at East Gundurimba is similar and substantial, especially for Bundle 2. The 31 Mar 2022 historical water level for the Lismore gauge (11.02 m) over topped the Lismore CBD levee (10.65 m), but with Bundle 1 that level can be reduced to 10.10 m (under the levee) and with Bundle 2 it can be further reduced to 9.30 m (under the levee by more than 1 m). This is only possible because all the water detained during the 28 Feb event has already been released, and all the detentions are completely empty to detain water for the 31 Mar flood event. There is a reasonable reduction in water levels for scenarios Bundle 1 and Bundle 2 at gauge 203004 on the Richmond River at Casino. The reduction in water levels for the scenarios at gauge 203403 on the Richmond River at Coraki is smaller than that of the other upstream gauges. For the 31 Mar 2022 event, the scenarios simulated water levels at gauge 203468 at Wardell and gauge 203461 at Byrnes Point do not show much difference from the historical, as the water levels at these gauges are dominated by the tidal influence.

The overall scenario simulation results for the 2022 flood events show that the model can reduce historical water levels across the Richmond River catchment for an extremely large flood event quite well. As expected, the reduction in flood peak is larger for Bundle 2, where we have more detentions, compared to Bundle 1 for all gauges in the Richmond River catchment. Most of the detentions are full and overflowing for the 28 Feb 2022 flood event (except Rock Valley and Dunoon, which are almost full).

Similar to the other flood events, the 31 Mar 2022 flood event's falling limb after the peak for all the gauges, except for gauge 203468 at Wardell and gauge 203461 at Byrnes Point, show the impact of the controlled release from the detentions after the flood starts receding. This delays the falling limb of the water level by a few weeks since the minimum level isn't reached until all the detentions are completely empty. These are controlled releases after the flood peak and start at a water level where it is safe to release, making sure that the released water stays within the riverbanks/instream and does not flood downstream areas during release. The gauges at Wardell (203468) and Byrnes Point (203461) show a large difference for the 28 Feb event but little difference for the 31 Mar event in the scenarios compared to historical. As can be seen from the complete 2022 water level plot, the 31 Mar 2022 event peak can be kept under the Lismore levee because all the water detained during the 28 Feb event has already been released, and all the detentions are completely empty allowing them to detain water for the 31 Mar peak.

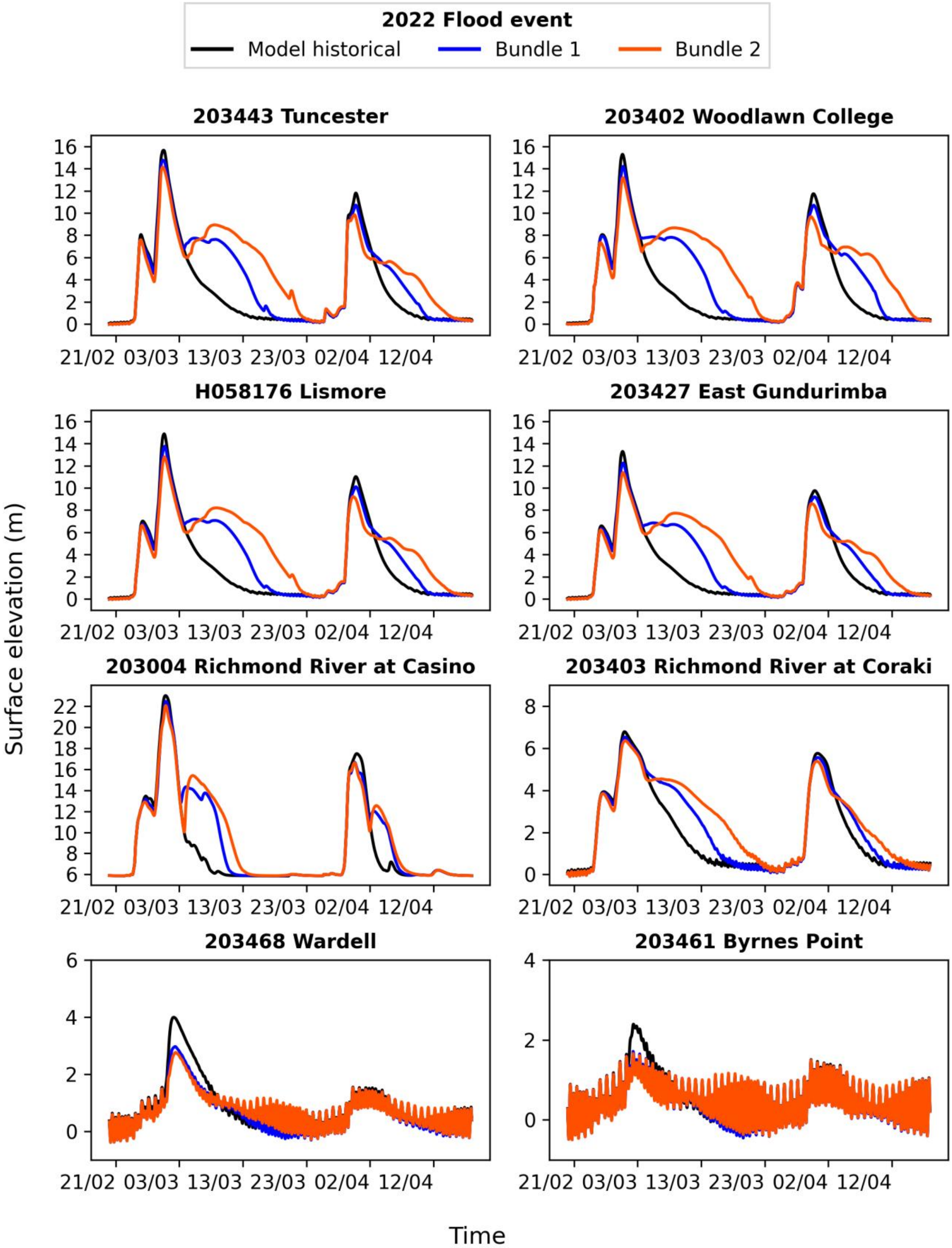

Figure 17 Comparison between the historical water level and scenario Bundle 1 and Bundle 2 water level at all the selected gauges for the two flood events of 2022.

The statistics for all the Bundle 1 and Bundle 2 scenario simulations flood peak comparisons with the historical simulations for the 2008, 2017 and 2022 flood events are summarised in Table 7. Figures 15, 16 and 17 showed the complete water level comparisons visually for the entire flood events as water level plots for eight selected gauges across the Richmond River catchment, and the statistics here are for the flood peaks for gauges at key towns.

Table 7 Statistics of comparison between the historical and scenario (Bundle 1 and Bundle 2) flood peaks at key gauges.

Reference Location	Historical peak (m)	Bundle 1		Bundle 2	
		Peak WL (m)	Reduction (m)	Peak WL (m)	Reduction (m)
2008 Event					
Lismore	9.73	8.48	1.25	7.37	2.37
Kyogle	58.94	58.62	0.32	58.09	0.84
Casino	22.38	20.31	2.07	19.62	2.76
Coraki	5.77	5.43	0.34	5.15	0.63
Ballina	1.24	1.22	0.02	1.21	0.03
2017 Event					
Lismore	11.72	10.75	0.97	10.32	1.40
Kyogle	57.66	57.23	0.43	56.31	1.35
Casino	19.00	17.49	1.51	17.57	1.43
Coraki	5.89	5.72	0.17	5.56	0.33
Ballina	1.28	1.25	0.03	1.25	0.03
28 Feb 2022 Event					
Lismore	14.87	13.75	1.12	12.80	2.07
Kyogle	58.47	58.13	0.33	57.67	0.80
Casino	22.99	22.44	0.56	22.05	0.95
Coraki	6.78	6.52	0.26	6.36	0.42
Ballina	2.39	1.71	0.68	1.66	0.73
31 Mar 2022 Event					
Lismore	11.02	10.10	0.91	9.30	1.71
Kyogle	55.73	54.97	0.77	54.70	1.03
Casino	17.48	16.67	0.81	16.65	0.84
Coraki	5.76	5.53	0.22	5.39	0.36
Ballina	1.51	1.49	0.02	1.49	0.02

As can be seen from Table 7, for the 2008 flood event, the flood peak at the Lismore gauge for scenario Bundle 1 can be reduced from 9.73 m to 8.48 m with a reduction in water level of 1.25 m, and for scenario Bundle 2, it can be reduced to 7.37 m with a reduction in water level of 2.37 m. The Kyogle flood peak can be reduced by 0.32 m for Bundle 1 and 0.84 m for Bundle 2. The reduction in the flood peak for Casino is 2.07 m for Bundle 1 and 2.76 m for Bundle 2. The Coraki flood peak reduced by 0.34 m for Bundle 1 and 0.63 m for Bundle 2. There is minimal change in the Ballina flood peak, as the water level at these lower levels is dominated by the tidal influence.

For the 2017 flood event, which is a major flood for Lismore (1 in 21 years flood frequency), the flood peak at Lismore gauge for scenario Bundle 1 can be reduced from 11.72 m (overtopping the Lismore CBD levee) to 10.75 m for Bundle 1 (still overtopping the Lismore CBD levee) and to 10.32 m for Bundle 2 (under the Lismore CBD levee by about 0.4 m). The Kyogle flood peak can be reduced by 0.43 m for Bundle 1 and 1.35 m for Bundle 2. The reduction in the flood peak for Casino is 1.51 m for Bundle 1 and 1.43 m for Bundle 2. The Coraki flood peak reduced by 0.17 m for Bundle 1 and 0.33 m for Bundle 2. There is minimal change in the Ballina flood peak, as the water level at these smaller levels is dominated by the tidal influence.

For the first flood peak of 28 Feb 2022, which is the largest observed flood peak for Lismore, the flood peak at Lismore gauge for scenario Bundle 1 can be reduced from 14.87 m (overtopping the Lismore CBD levee) to 13.75 m for Bundle 1 (still overtopping the Lismore CBD levee) with a reduction in water level of 1.12 m, and to 12.80 m for Bundle 2 (still overtopping the Lismore CBD levee) with a reduction in water level of 2.07 m. The Kyogle flood peak can be reduced by 0.33 m for Bundle 1 and 0.80 m for Bundle 2. The reduction in the flood peak for Casino is 0.56 m for Bundle 1 and 0.95 m for Bundle 2. The Coraki flood peak reduced by 0.26 m for Bundle 1 and 0.42 m for Bundle 2. The Ballina flood peak reduced by 0.68 m for Bundle 1 and 0.73 m for Bundle 2.

For the second flood peak of 31 Mar 2022, which is a major flood for Lismore, the flood peak at Lismore gauge for scenario Bundle 1 can be reduced from 11.02 m (overtopping the Lismore CBD levee) to 10.10 m for Bundle 1 (below the Lismore CBD levee) and to 9.30 m for Bundle 2 (under the Lismore CBD levee by more than 1 m). The Kyogle flood peak can be reduced by 0.77 m for Bundle 1 and 1.03 m for Bundle 2. The reduction in the flood peak for Casino is 0.81 m for Bundle 1 and 0.84 m for Bundle 2. The Coraki flood peak reduced by 0.22 m for Bundle 1 and 0.36 m for Bundle 2. There is minimal change in the Ballina flood peak, as the water level at these smaller levels is dominated by the tidal influence there.

The reduction in the flood peak for the 2017 event for the Casino gauge is slightly larger for Bundle 1 compared to the reduction for Bundle 2. This is because the shutting times for a detention gate stay the same for all the flood events, and our focus for Kyogle and Casino was to get 2008 and 2022 events right (both large flood events for this region). The closing times for the detentions are not optimum for Bundle 2 for 2017 event, causing this discrepancy.

4.1.2 Spatial floodplain inundation comparisons

The spatial comparisons for historical and scenario Bundle 1 and Bundle 2 overland maximum flood extents and maximum flood depth for the 2008, 2017 and 2022 flood events are presented and discussed. The comparisons between the historical and the two bundles are shown for the entire Richmond River catchment as well as four key locations: Kyogle, Casino, Lismore and Ballina. The green dots in the figures for maximum inundation extent and depth represent the main towns, and the grey lines represent roads.

4.1.2.1 Maximum flood extents

The MIKE21 FM simulated historical inundation extents for the three selected flood events are compared against the scenario Bundle 1 and Bundle 2 simulated inundation extents at maximum overland flooding. This comparison is undertaken to investigate and demonstrate whether the flood mitigation scenarios can reduce the maximum extent of overland flooding across the Richmond River catchment. The modelling domain for the Richmond River catchment model is relatively large (~7000 km^2), and it is difficult to visualise the differences at the whole of catchment scale. To overcome this issue, these comparisons are also shown at four key locations across the catchment.

Figure 18 and Figure 19 show the catchment scale and focused comparisons at key locations between historical and scenario Bundle 1 simulated maximum inundation extent for the 2008 flood event. The historical (Blue) and scenario (Orange) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results clearly show that scenario Bundle 1 can reduce the maximum extent of flooding across the Richmond River catchment for the 2008 flood event. As expected, the extent of flooding for small areas upstream of the detentions where water has been detained has increased, whereas the maximum inundation extent downstream has decreased. The reductions in maximum extent for the key locations for the 2008 flood event for scenario Bundle 1 show that there is hardly any reduction in Kyogle, the largest reductions in extent are for areas upstream of Casino and the Lismore CBD, whereas there is hardly any reduction for the Ballina area, where there is little to no flooding.

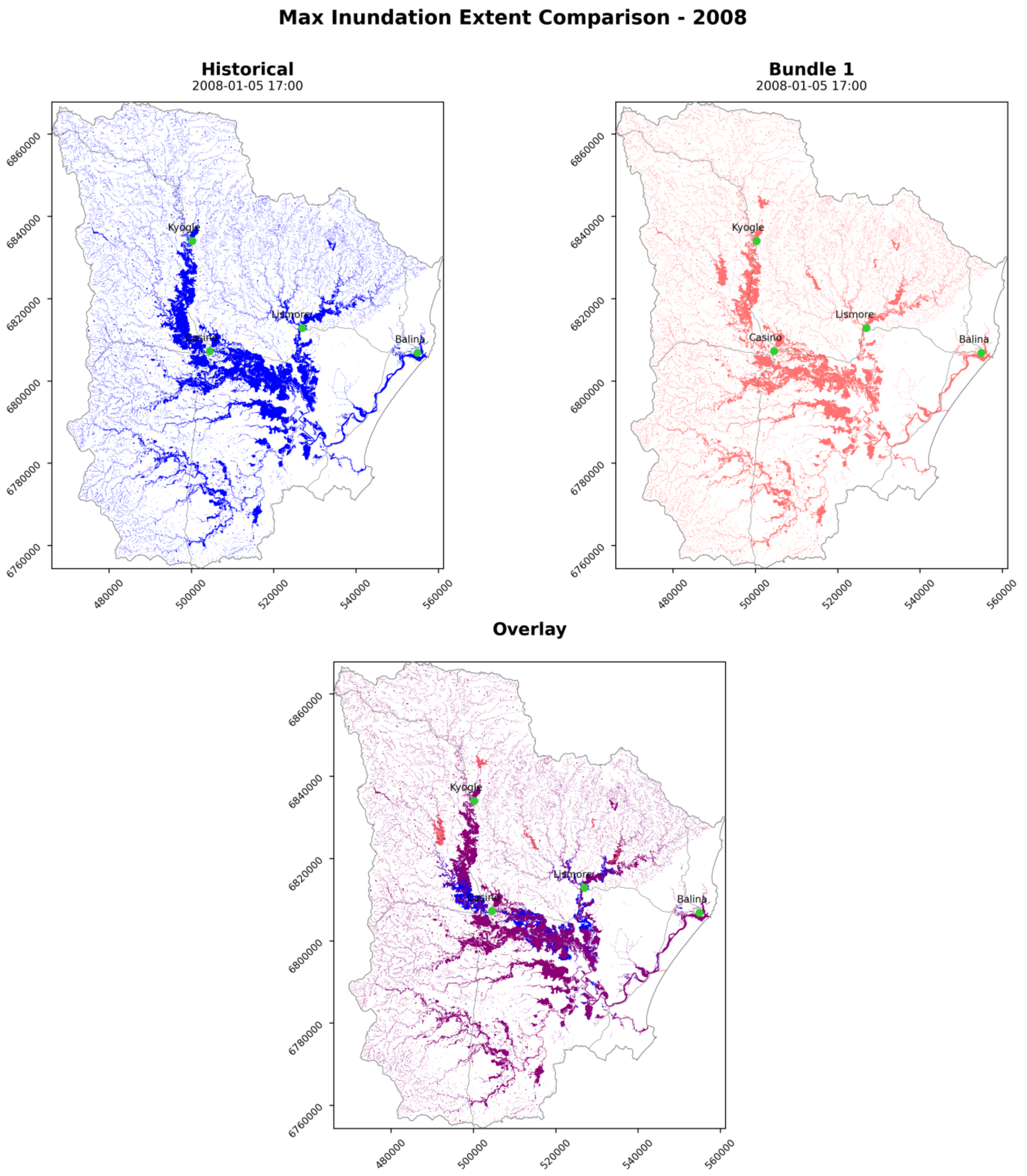

Figure 18 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for the Richmond River catchment for the 2008 flood event. The green dot represents the main towns, and the grey lines represent roads.

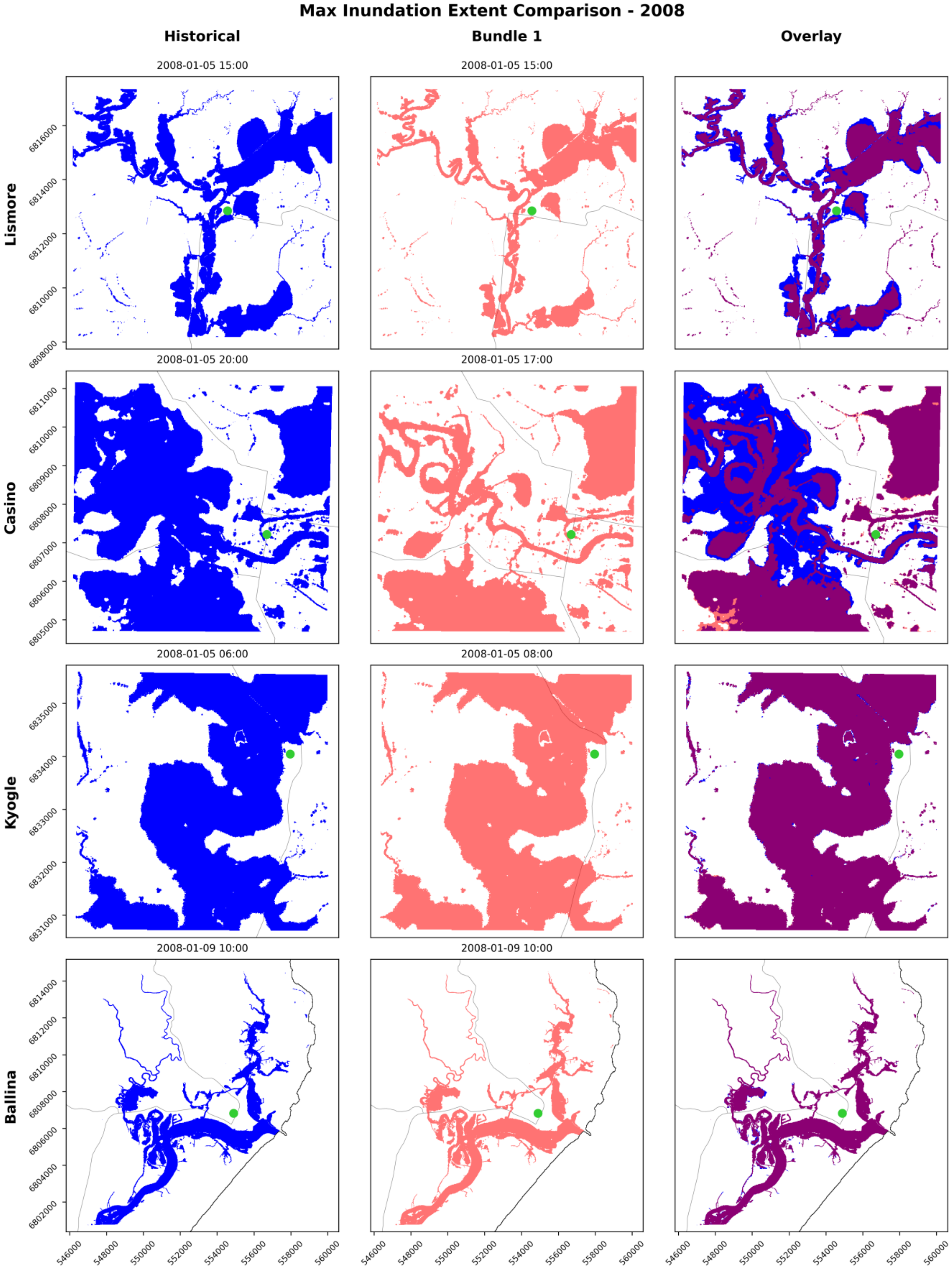

Figure 19 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for four key locations in the Richmond River catchment for the 2008 flood event.

Figure 20 and Figure 21 show the catchment scale and focused comparisons at key locations between the historical and scenario Bundle 2 simulated maximum floodplain inundations for the

2008 flood event. The historical (Blue) and scenario (Pink) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results clearly show that scenario Bundle 2 can reduce the maximum extent of flooding across the Richmond River catchment for the 2008 flood event. As expected, the extent of flooding for small areas upstream of the detentions, where the water has been detained, has increased, whereas the maximum inundation extent downstream has decreased. The reduction in maximum extent for Bundle 2 is larger than that for Bundle 1 as we are detaining a larger quantity of water. The reductions in maximum extent for the key locations show that the largest reductions in extent for the 2008 flood event for scenario Bundle 2 are for areas upstream of Casino and the Lismore CBD. There is a small reduction for the Kyogle area, whereas there is minimal difference for the Ballina area, where there is little to no flooding.

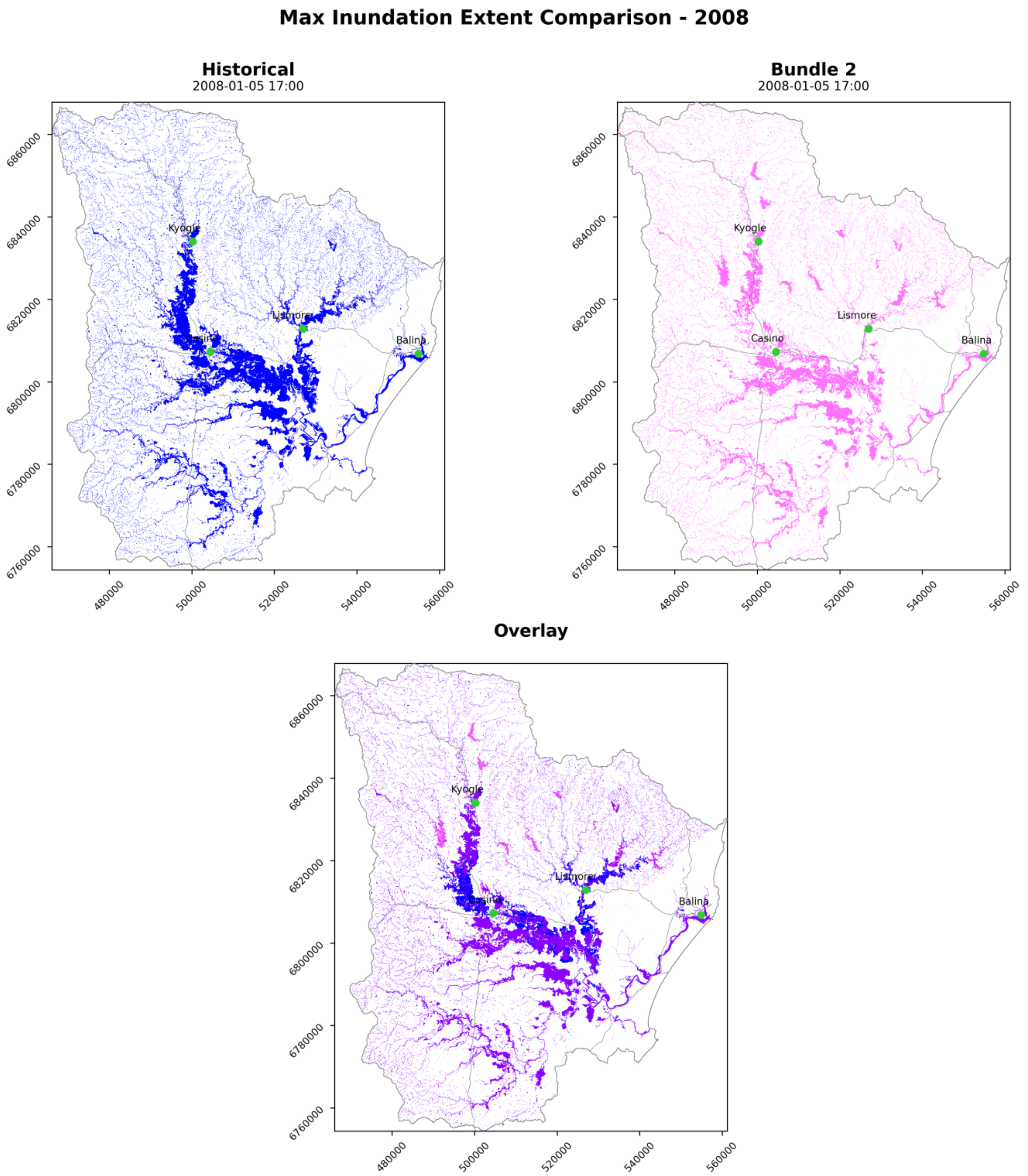

Figure 20 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for the Richmond River catchment for the 2008 flood event.

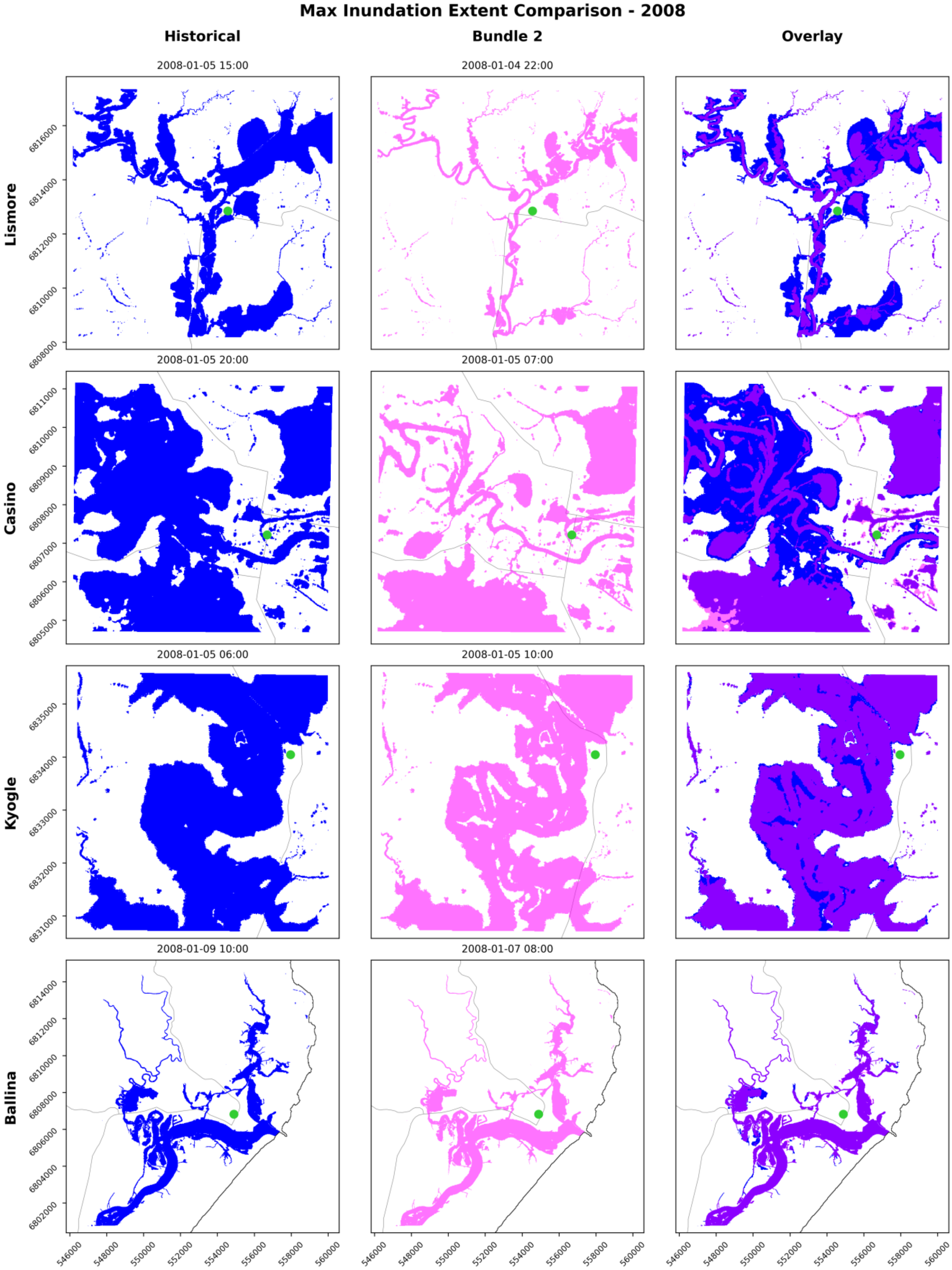

Figure 21 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for four key locations in the Richmond River catchment for the 2008 flood event.

Figure 22 and Figure 23 show the catchment scale and focused comparisons at key locations between historical and scenario Bundle 1 simulated maximum inundation extent for the 2017 flood event. The historical (Blue) and scenario (Orange) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results show that scenario Bundle 1 can slightly reduce the maximum extent of flooding across the Richmond River catchment for the 2017 flood event. The reductions in maximum extent for the key locations show only a minimal reduction for Kyogle, some reduction for Lismore, and there is hardly any difference for Casino and Ballina.

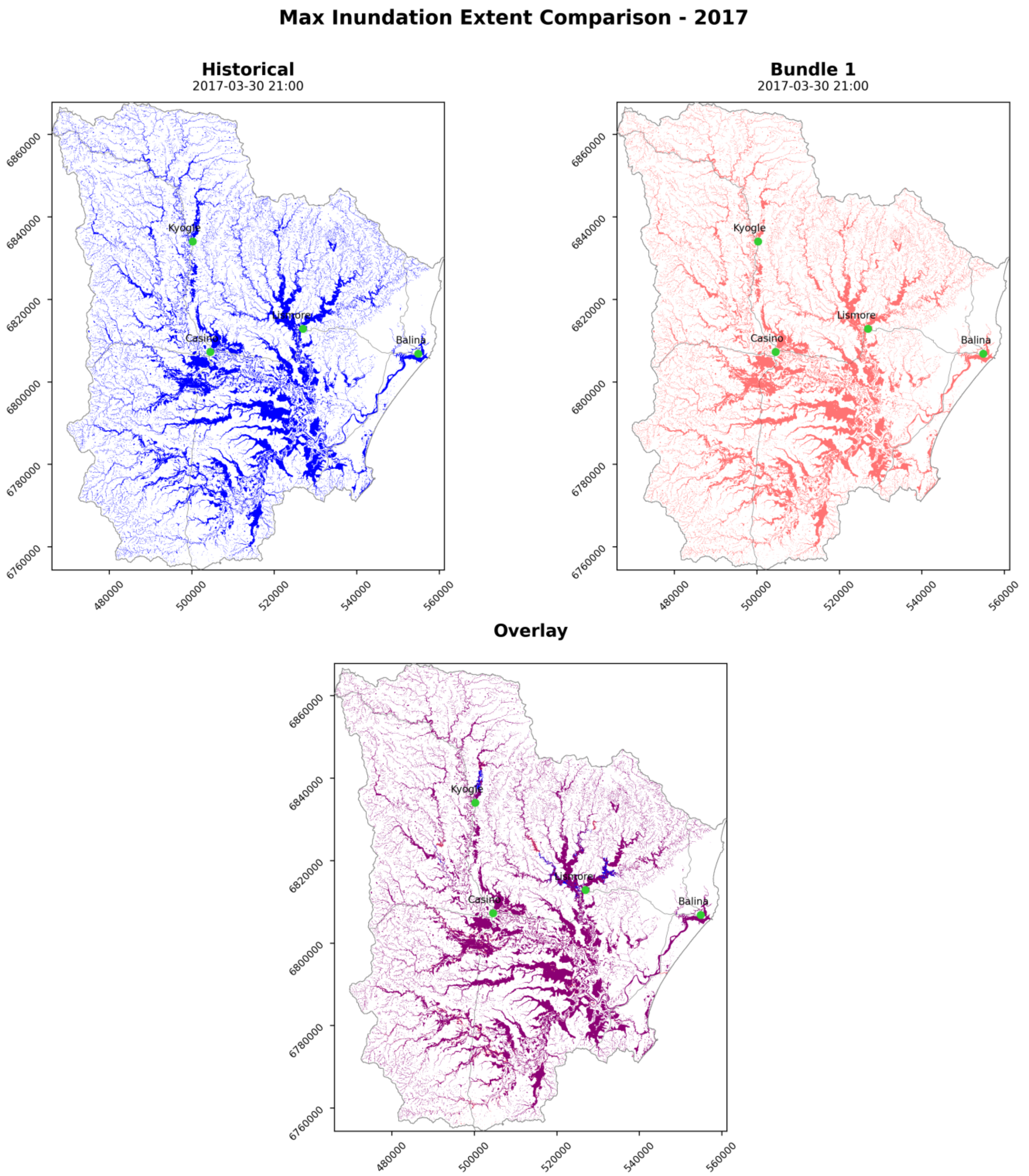

Figure 22 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for the Richmond River catchment for the 2017 flood event.

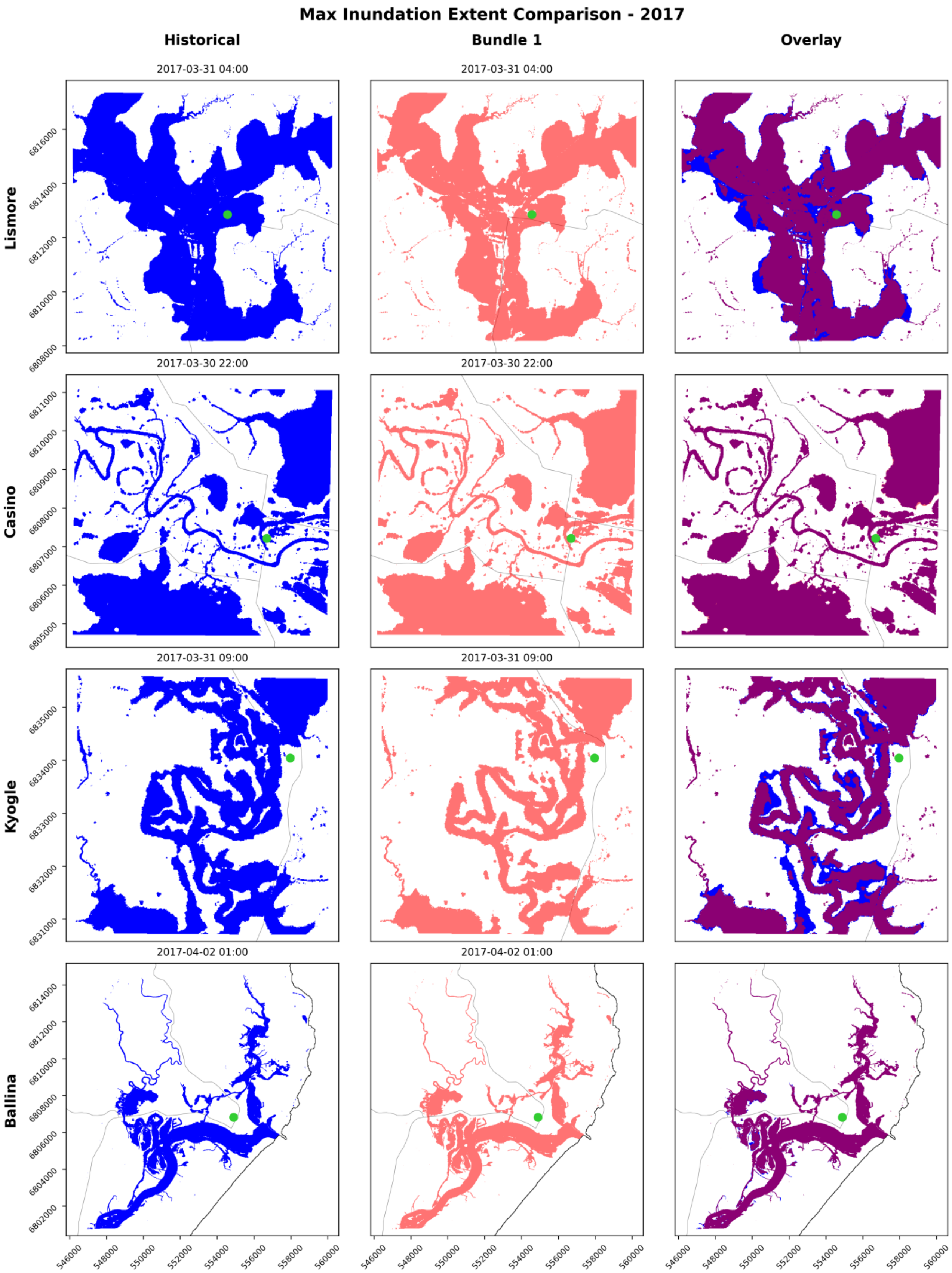

Figure 23 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for four key locations in the Richmond River catchment for the 2017 flood event.

Figure 24 and Figure 25 show the catchment scale and focused comparisons at key locations between historical and scenario Bundle 2 simulated maximum floodplain inundations for the 2017 flood event. The historical (Blue) and scenario (Pink) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results clearly show that scenario Bundle 2 can reduce the maximum extent of flooding in some areas across the Richmond River catchment for the 2017 flood event. As expected, the extent of flooding for small areas upstream of the detentions where the water has been detained has increased, whereas the maximum inundation extent downstream has decreased. The reduction in maximum extent for Bundle 2 is larger than that for Bundle 1 as we are detaining a larger quantity of water. The reductions in maximum extent for the key locations show that there is a noticeable reduction for Kyogle and Lismore, with little to no difference for Casino and Ballina, where there is little to no flooding in the historical simulation. For the 2017 scenario Bundle 2, the water level at Lismore is reduced below the Lismore CBD levee, and the flooding around the CBD is mostly caused by local area-generated runoff, which cannot be controlled by any detentions upstream.

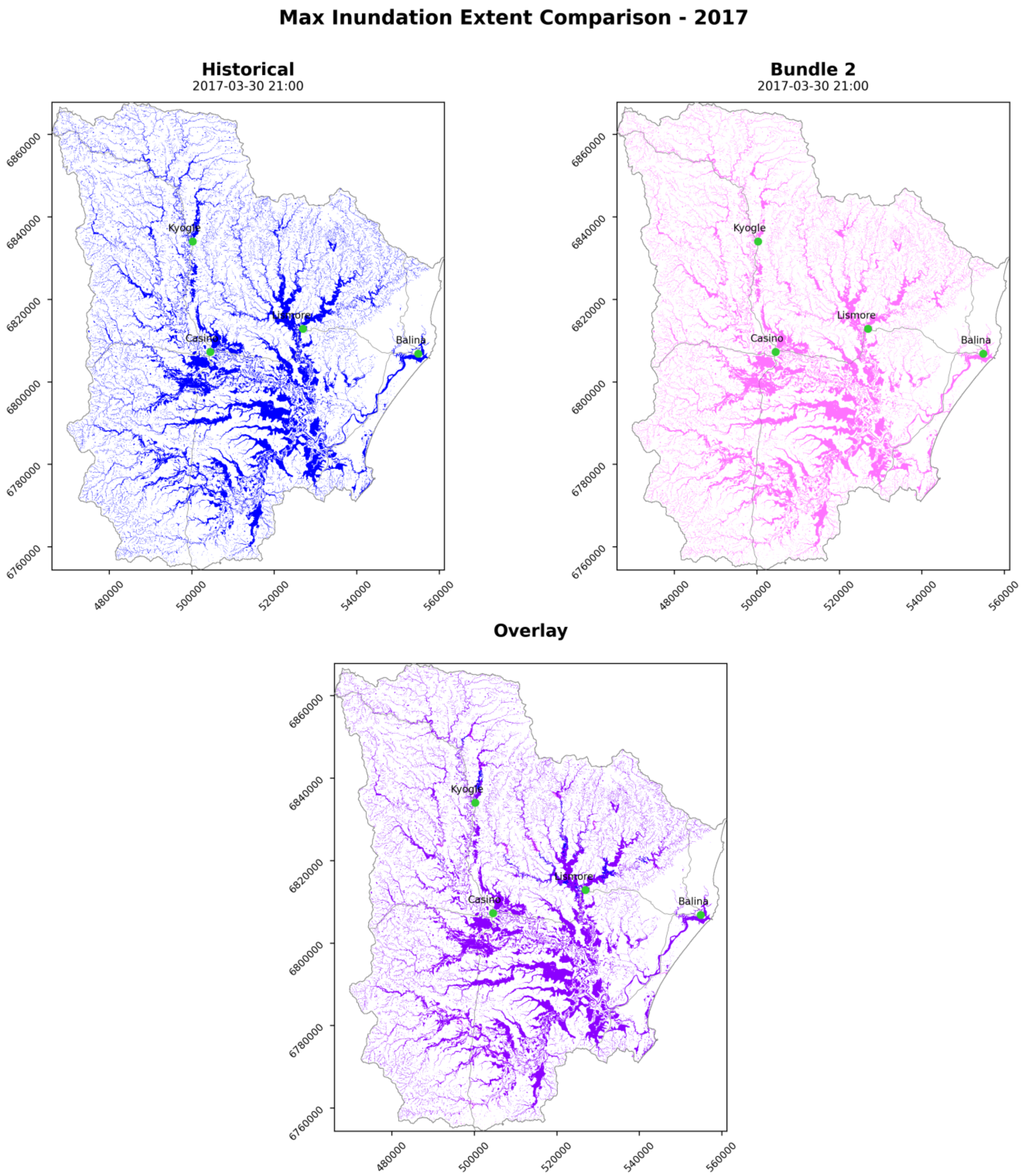

Figure 24 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for the Richmond River catchment for the 2017 flood event.

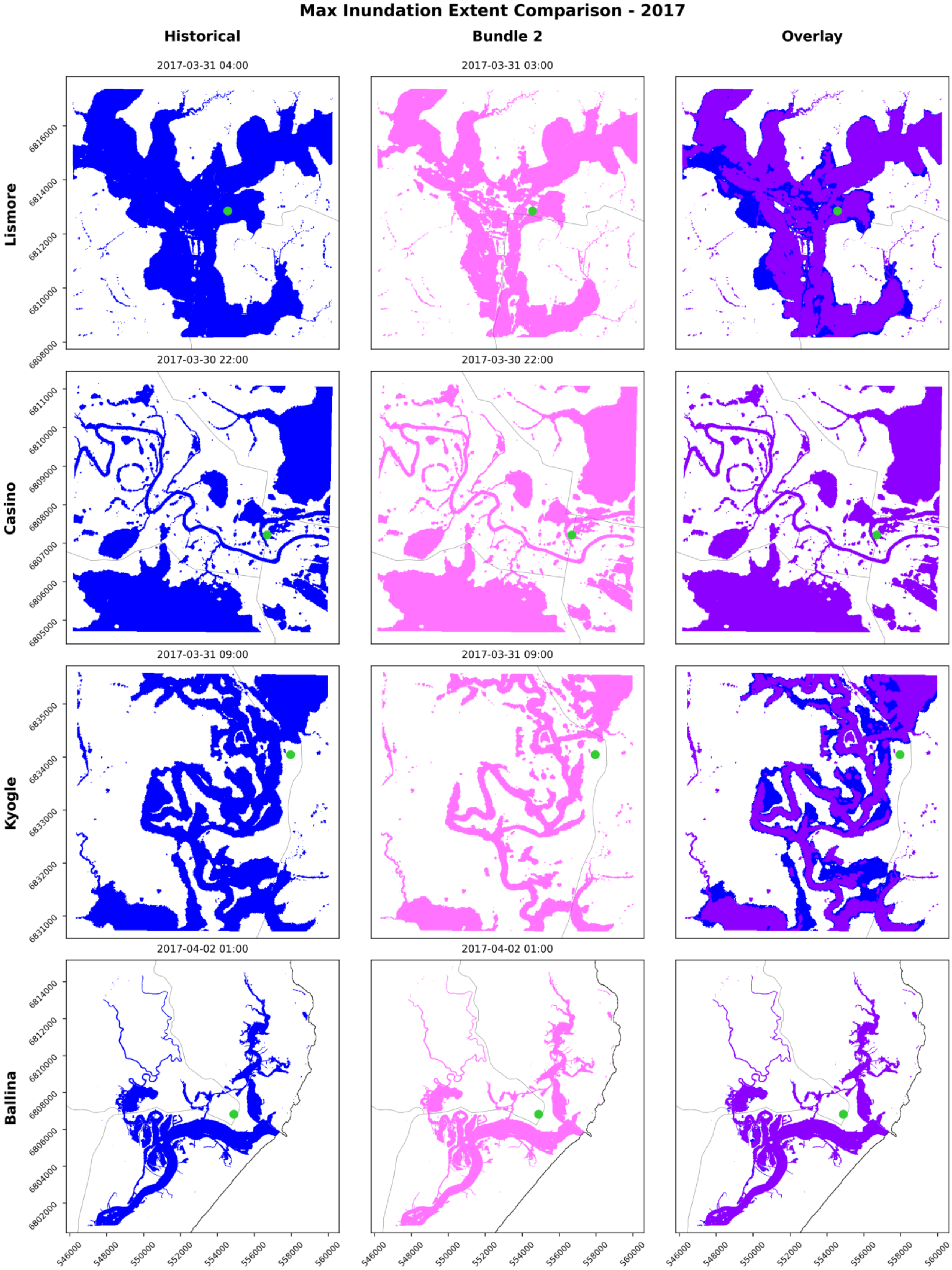

Figure 25 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for four key locations in the Richmond River catchment for the 2017 flood event.

Figure 26 and Figure 27 show the catchment scale and focused comparisons at key locations between historical and scenario Bundle 1 simulated maximum inundation extent for the 2022 flood event. The historical (Blue) and scenario (Orange) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results clearly show that scenario Bundle 1 can reduce the maximum extent of flooding across the Richmond River catchment only marginally in some areas for the 2022 flood event. The 2022 flood event is the largest observed flood event in the catchment, which flooded an extremely large area across the catchment. Most of the detentions were completely full and overflowing for the first event of 2022. The reduction in maximum extent for the key locations shows that the largest reductions in extent are for Casino and Ballina, with a marginal reduction for Lismore and Kyogle.

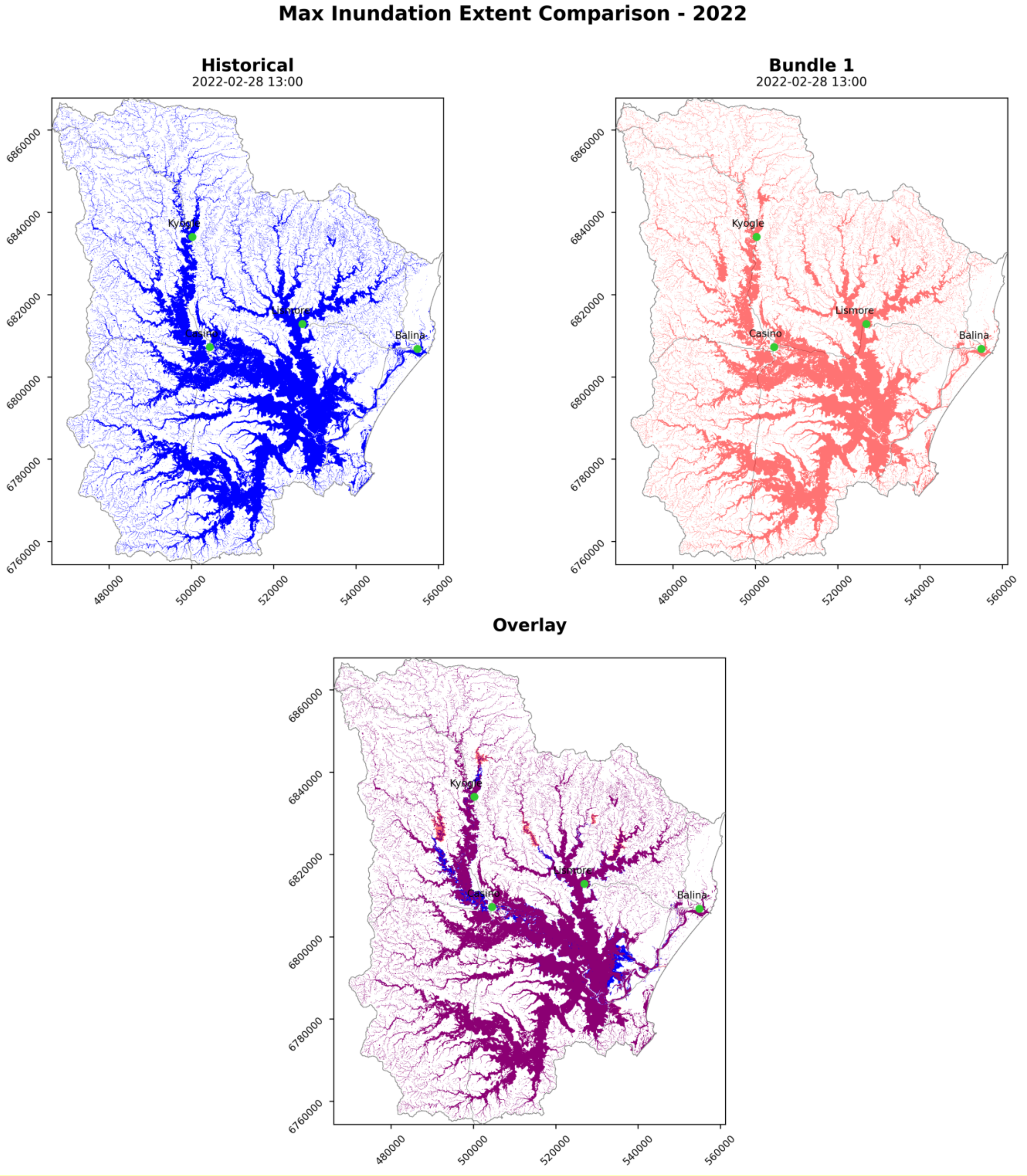

Figure 26 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for the Richmond River catchment for the 2022 flood event.

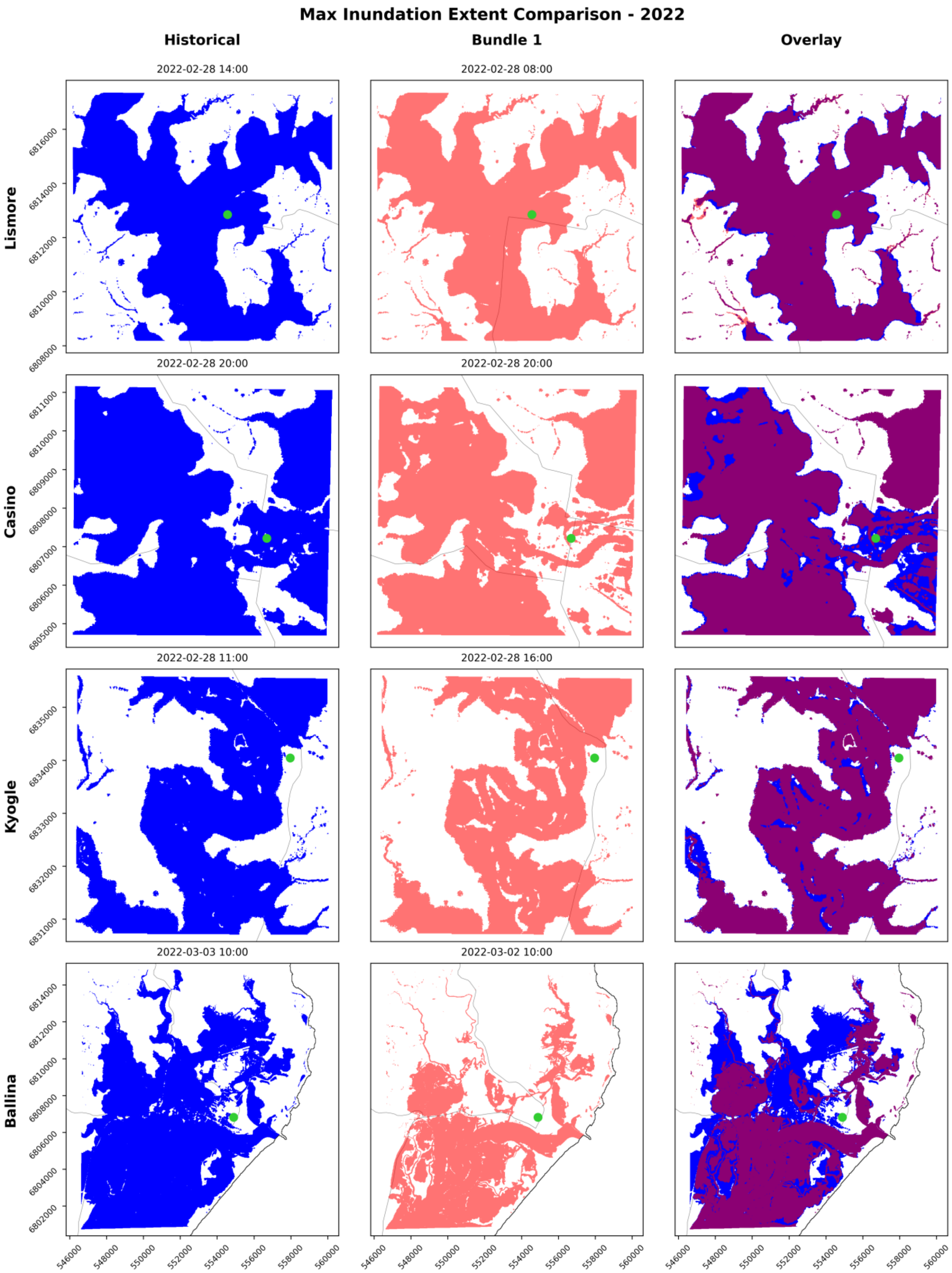

Figure 27 Comparison between the historical and scenario Bundle 1 simulated maximum water extent for four key locations in the Richmond River catchment for the 2022 flood event.

Figure 28 and Figure 29 show the catchment scale and focused comparisons at key locations between historical and scenarios Bundle 2 simulated maximum floodplain inundation for the 2022 flood event. The historical (Blue) and scenario (Pink) simulated maximum inundation extent maps are shown next to each other, and they are also overlapped with 50% transparency to highlight the differences.

As can be seen from the comparisons, the results clearly show that scenario Bundle 2 can reduce the maximum extent of flooding across the Richmond River catchment in some areas for the 2022 flood event. The 2022 flood event is the largest observed flood event in the catchment, which flooded an extremely large area across the catchment. Most of the detentions were completely full and overflowing for the 28 Feb flood event. The reductions in maximum extent for the key locations show that the largest reductions in extent are in Ballina, Casino and Kyogle, with a marginal reduction for Lismore.

Compared to the 2008 and 2017 flood events, there is a noticeable reduction in the maximum flood inundation upstream of Bagotville and in the Tuckean Swamp area (shown in Figure 26 and Figure 28) because of the upgrade of the pressure gates and Boundary Creek opening to the ocean. This reduction is observed in both Bundles 1 and 2. During an extreme flood event like 2022, Boundary Creek allows floodwater to flow to the ocean, which also significantly reduces flooding downstream in Wardell and Ballina.

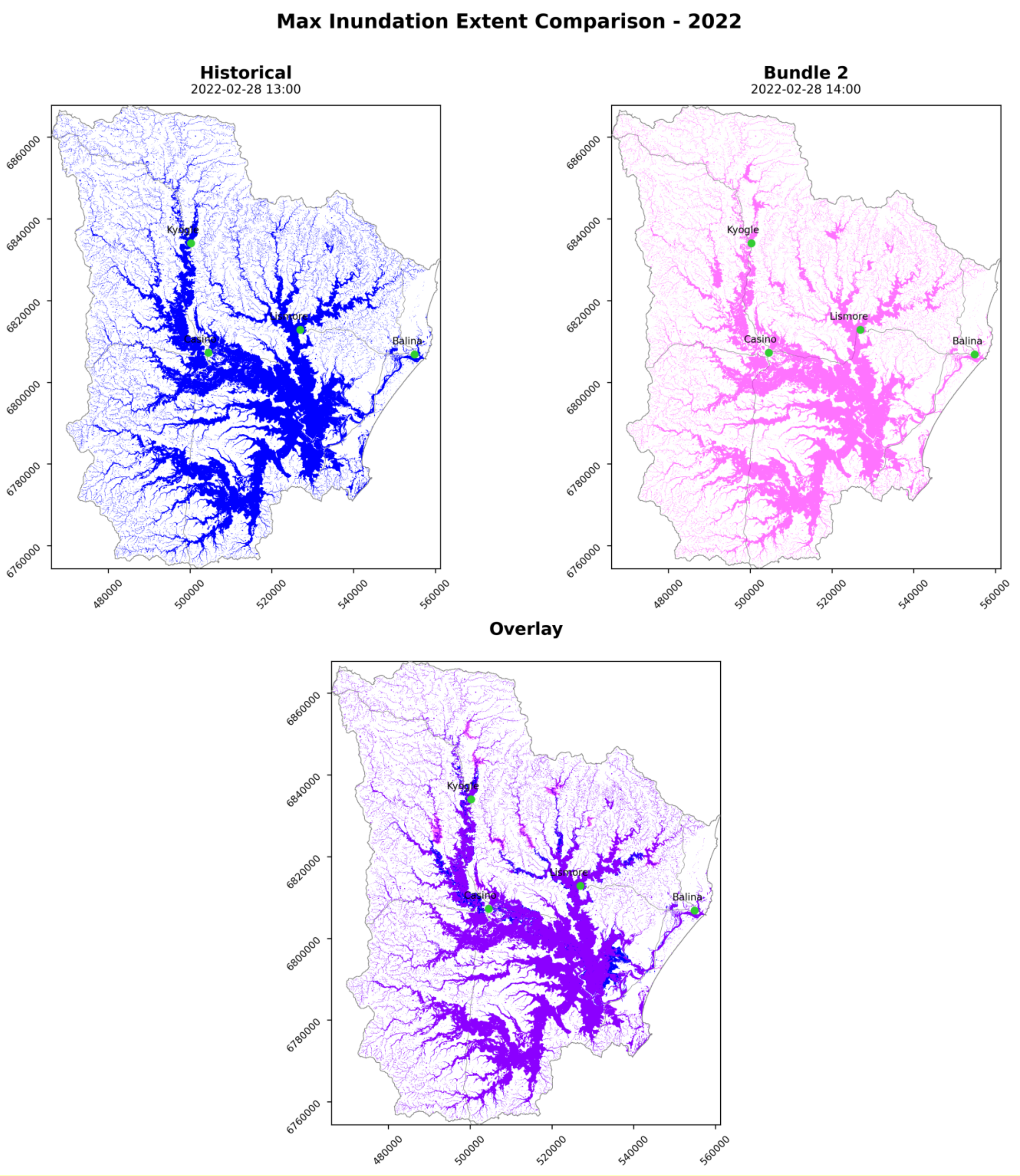

Figure 28 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for the Richmond River catchment for the 2022 flood event.

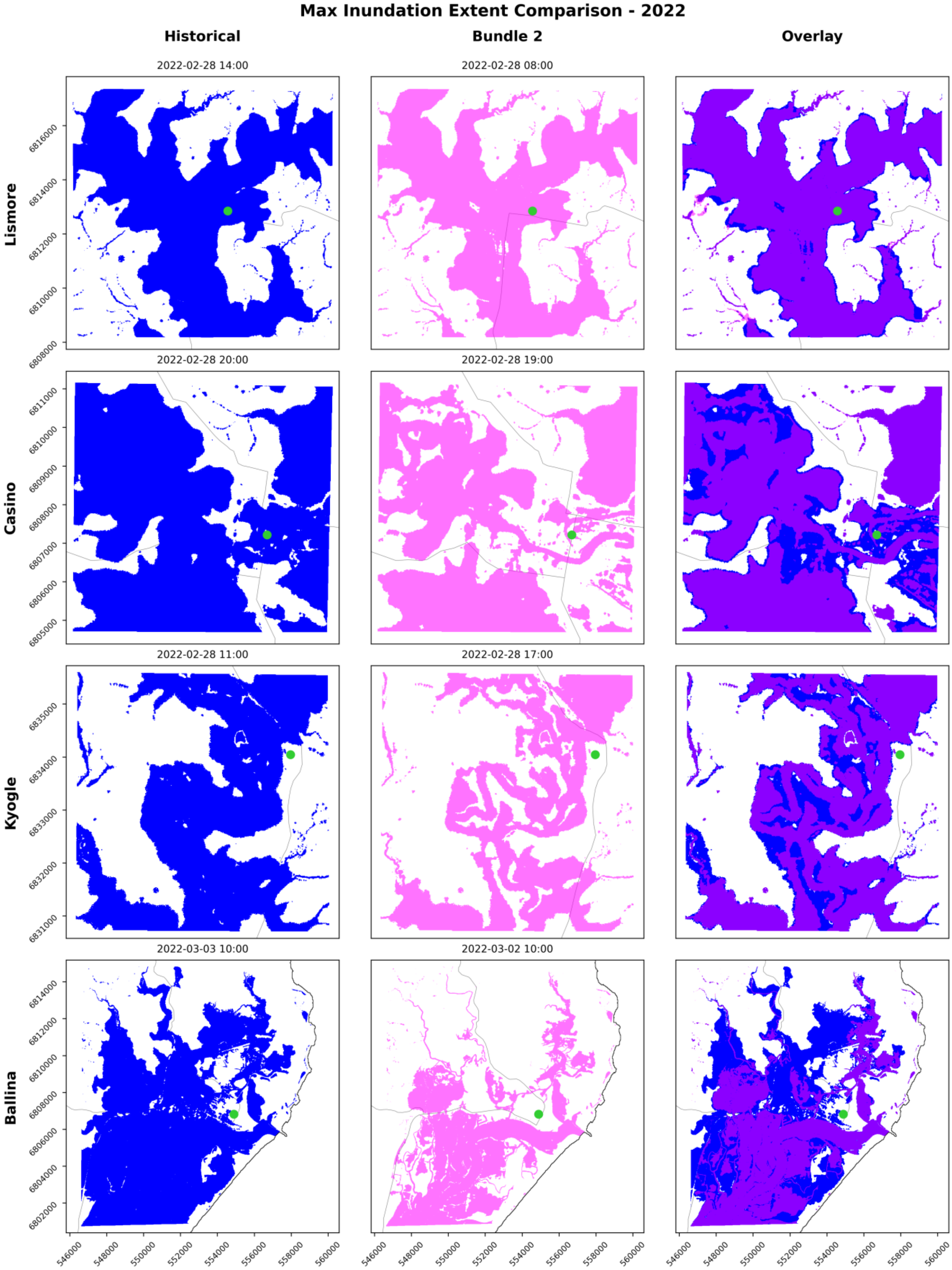

Figure 29 Comparison between the historical and scenario Bundle 2 simulated maximum water extent for four key locations in the Richmond River catchment for the 2022 flood event.

Based on all the comparisons between the historical and scenarios Bundle 1 and Bundle 2 maximum flood extents for the 2008, 2017 and 2022 flood events, it can be seen that the scenarios can reduce the maximum extent of flooding in some areas. As expected, the reduction in maximum flooding extent for Bundle 2 is larger than that for Bundle 1, as we are detaining a larger quantity of water.

4.1.2.2 Maximum flood depth

The MIKE21 FM simulated historical maximum inundation depths across the catchment for the three selected flood events were compared against the scenario Bundle 1 and Bundle 2 simulated maximum inundation depths. This comparison is undertaken to investigate and demonstrate whether the flood mitigation scenarios can reduce the maximum depth of overland flooding across the Richmond River catchment and at four key locations across the catchment. In the following figures, the difference maps (at the bottom of the figure for full catchment comparisons, and in the far-right column for the key locations figure) represent a value of maximum historical flood depth at any location minus the scenario maximum flood depth at the same location. A positive value (Blue) in the difference map represents that the maximum inundation depth is higher in the historical simulation than the scenario bundle simulation, and a negative value (Red) means that the maximum inundation depth is higher in the scenario bundle simulation than the historical simulation.

Figure 30 and Figure 31 show the catchment scale and key locations comparisons between historical and scenario Bundle 1 simulated maximum inundation depths for the 2008 flood event. As can be seen from the comparisons, the results clearly show that scenario Bundle 1 can reduce the maximum flood depth across the Richmond River catchment in large areas downstream of the detentions for the 2008 flood event. As expected, the maximum inundation depth for the detention areas increased due to the temporary detainment of water. The reductions in the maximum depth at the key locations show that the largest reductions in depth are for Casino, Lismore and Kyogle, with a minor difference for Ballina, which did not experience any flooding for the 2008 flood event.

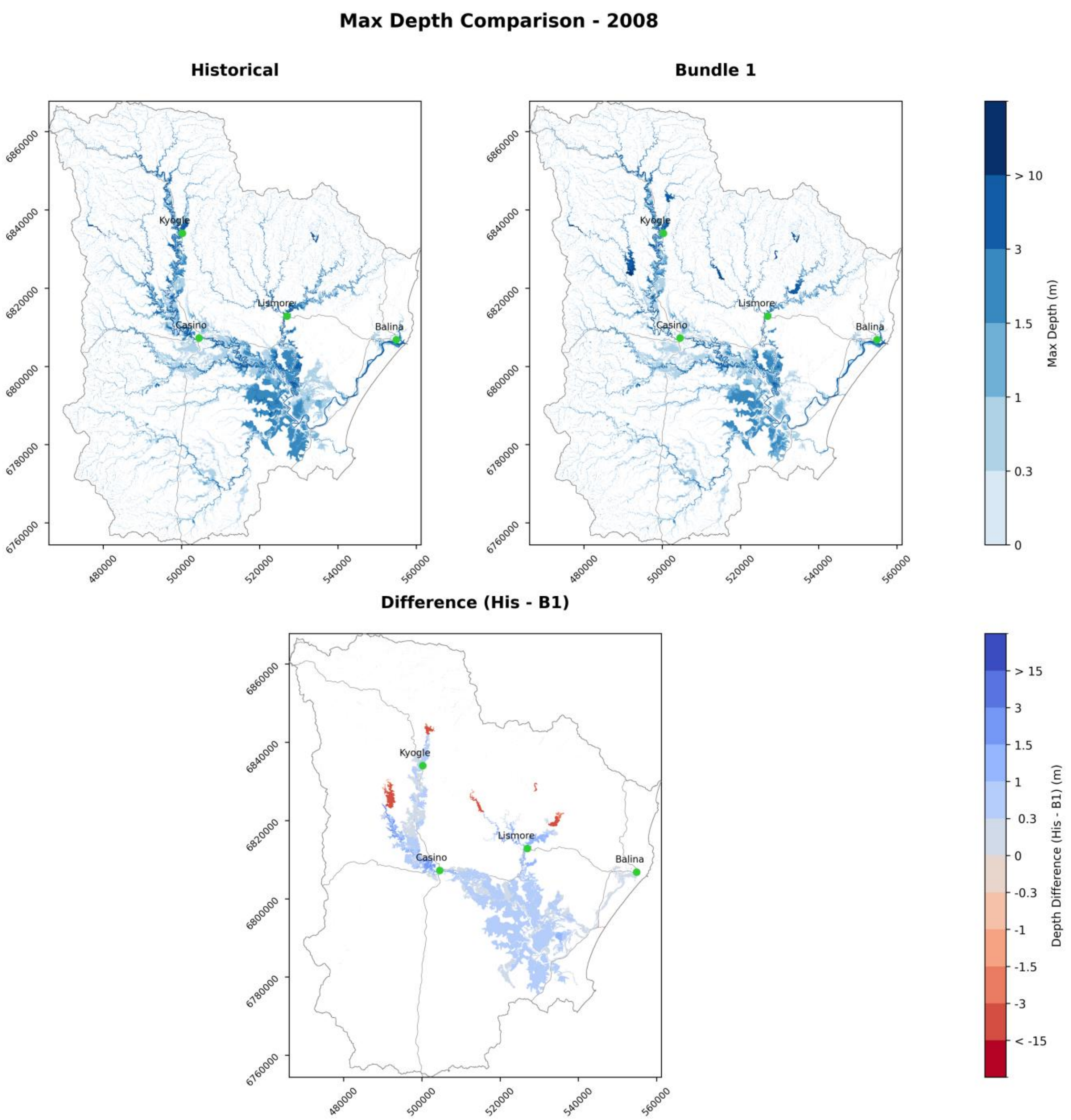

Figure 30 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for the Richmond River catchment for the 2008 flood event.

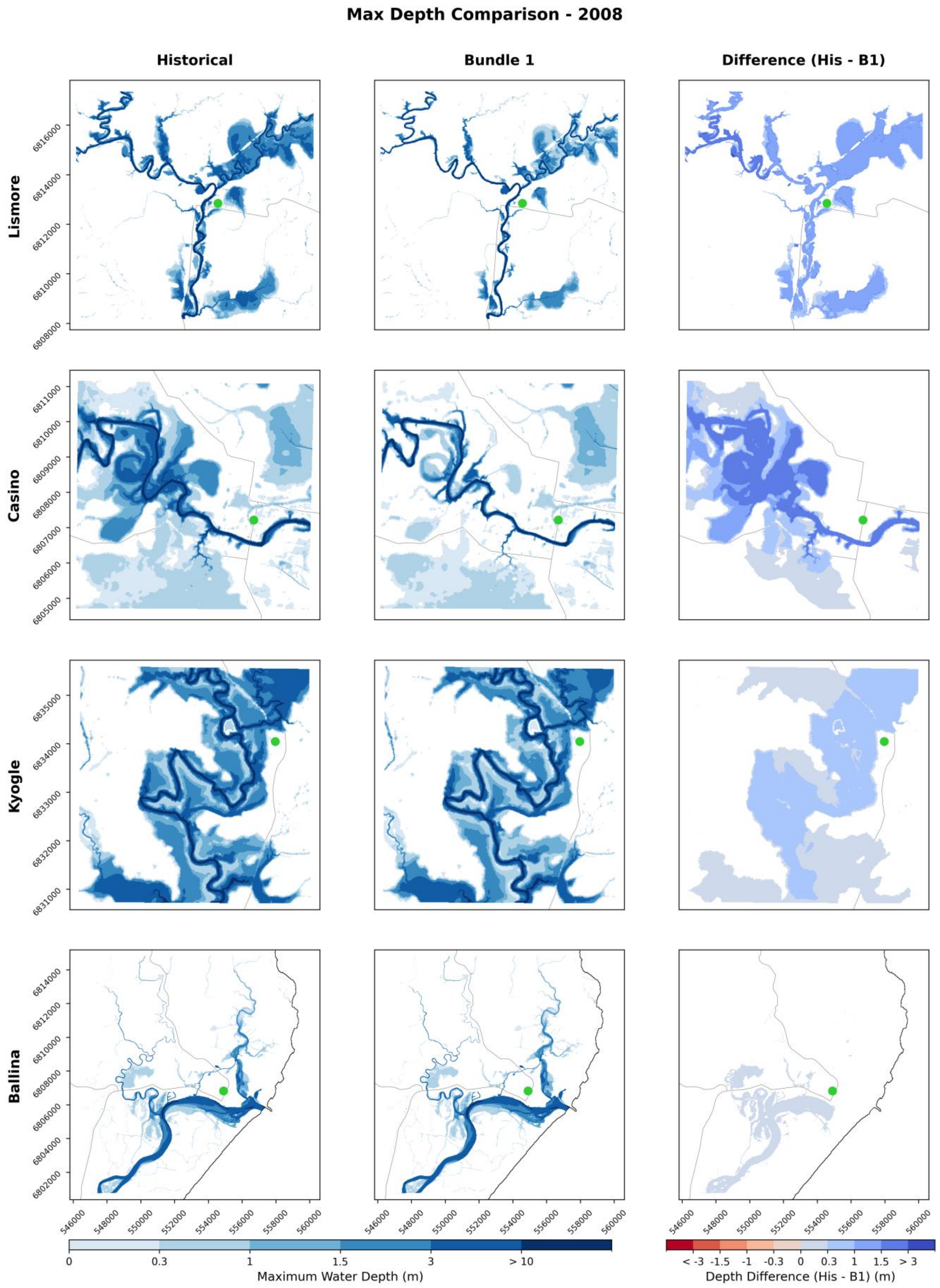

Figure 31 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for four key locations in the Richmond River catchment for the 2008 flood event.

Figure 32 and Figure 33 show the Richmond River catchment scale and key locations comparisons between the historical and scenario Bundle 2 simulated maximum inundation depths for the 2008 flood event. As can be seen from the comparisons, the results show that scenario Bundle 2 can reduce the maximum flood depth across the Richmond River catchment in large areas downstream of the detentions for the 2008 flood event. The reductions in scenario Bundle 2 (both maximum depth and area) are slightly larger than those in scenario Bundle 1. Similar to Bundle 1, the maximum inundation depth for the detention areas increased due to the temporary detainment of water. The reductions in maximum depth at the key locations for scenario Bundle 2 are very similar to Bundle 1, with the largest reductions in depth for Casino, Lismore and Kyogle, with a minor difference for Ballina, which did not experience any flooding for the 2008 flood event.

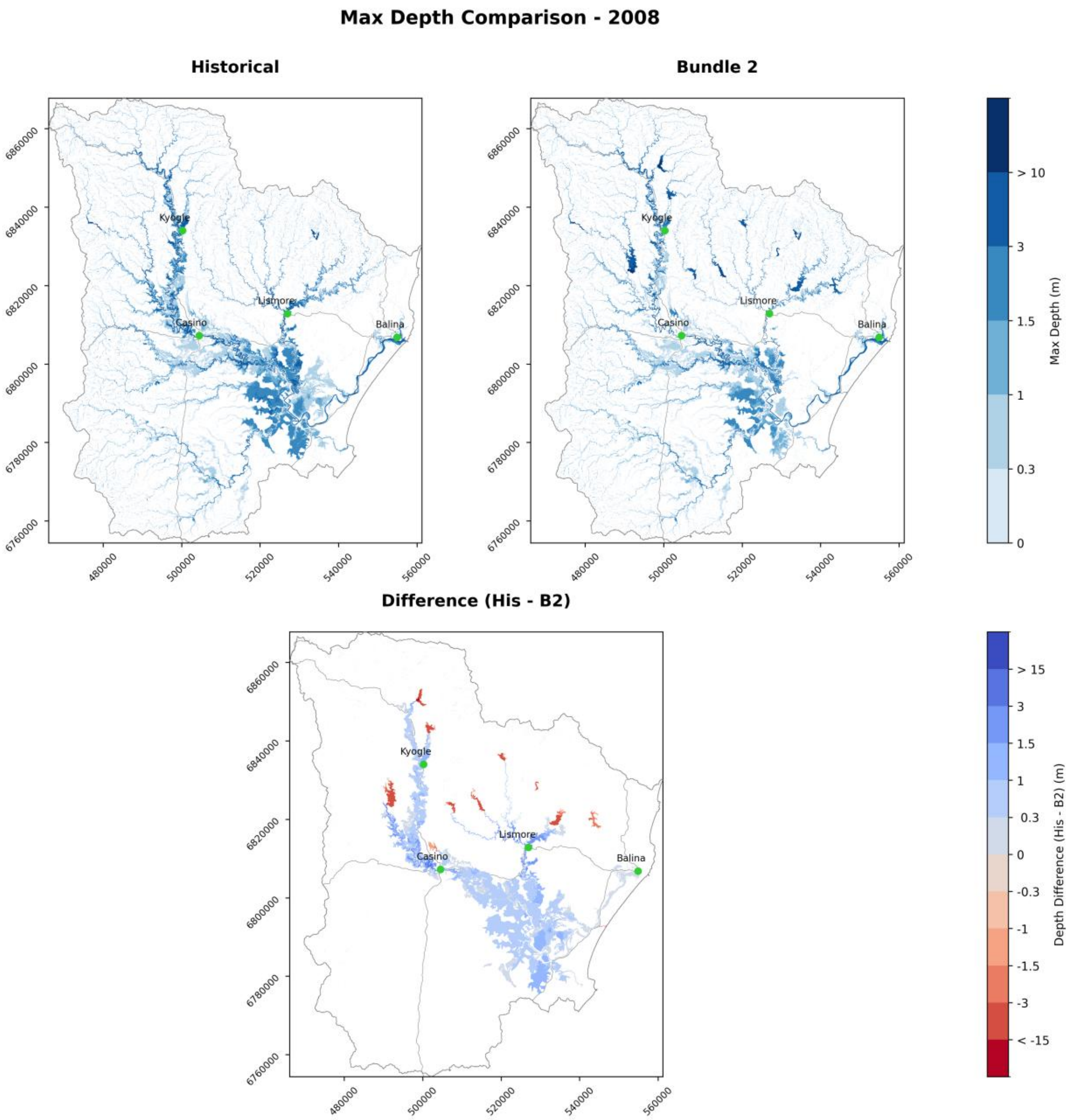

Figure 32 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for the Richmond River catchment for the 2008 flood event.

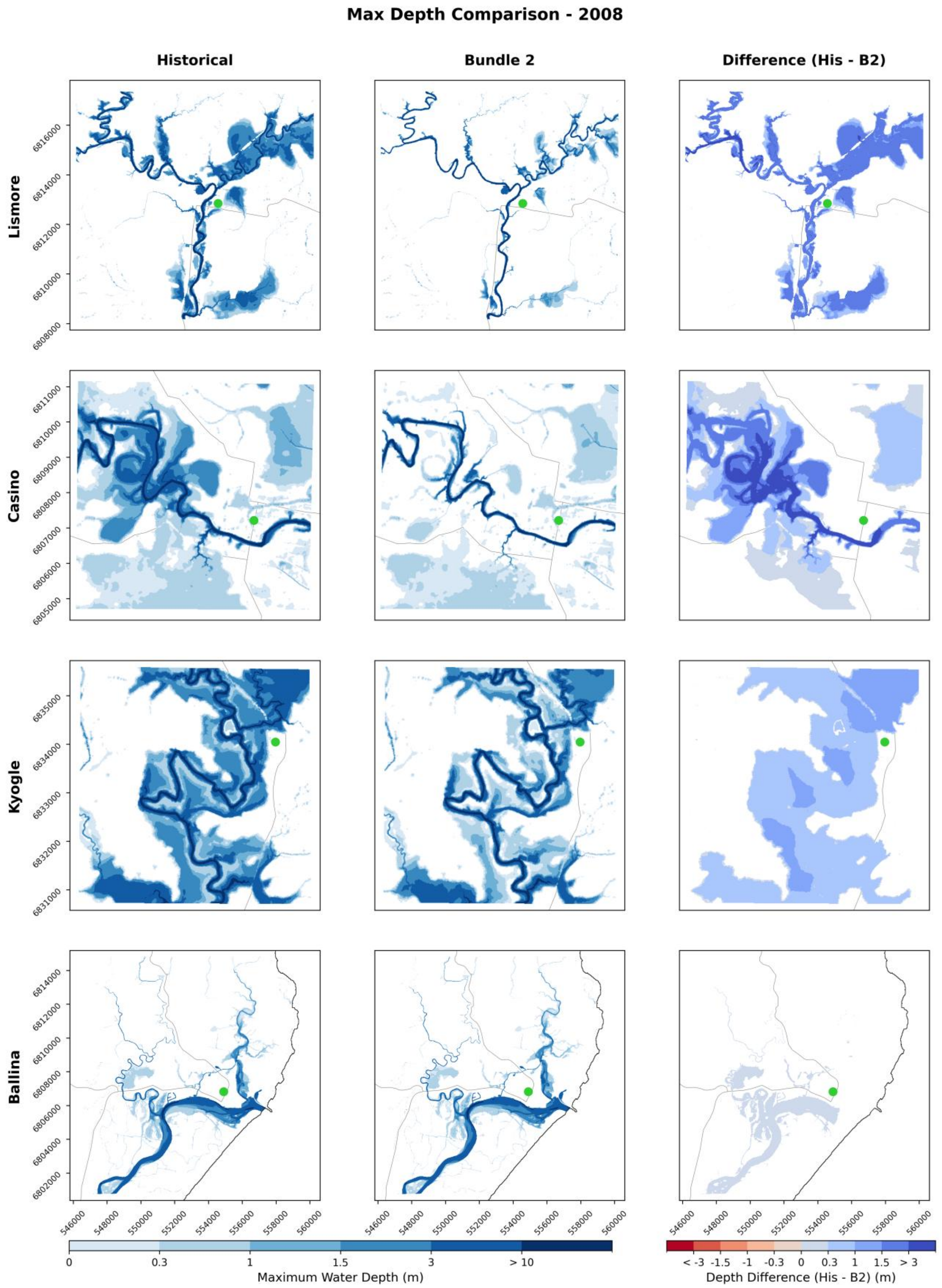

Figure 33 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for four key locations in the Richmond River catchment for the 2008 flood event.

Figure 34 and Figure 35 show the catchment scale and key locations comparisons between the historical and scenario Bundle 1 simulated maximum inundation depth for the 2017 flood event. As can be seen from the comparisons, the results show that scenario Bundle 1 can reduce the maximum flood depth across the Richmond River catchment in some areas downstream of the detentions for the 2017 flood event. The reductions are smaller for 2017 compared to those for 2008, as 2017 is a larger event for Lismore compared to 2008. As expected, the maximum inundation depth for the detention areas increased due to the temporary detainment of water. The reductions in maximum depth at the key locations show that the reductions in depth are noticeable for Lismore and Kyogle, with little difference for Casino and Ballina.

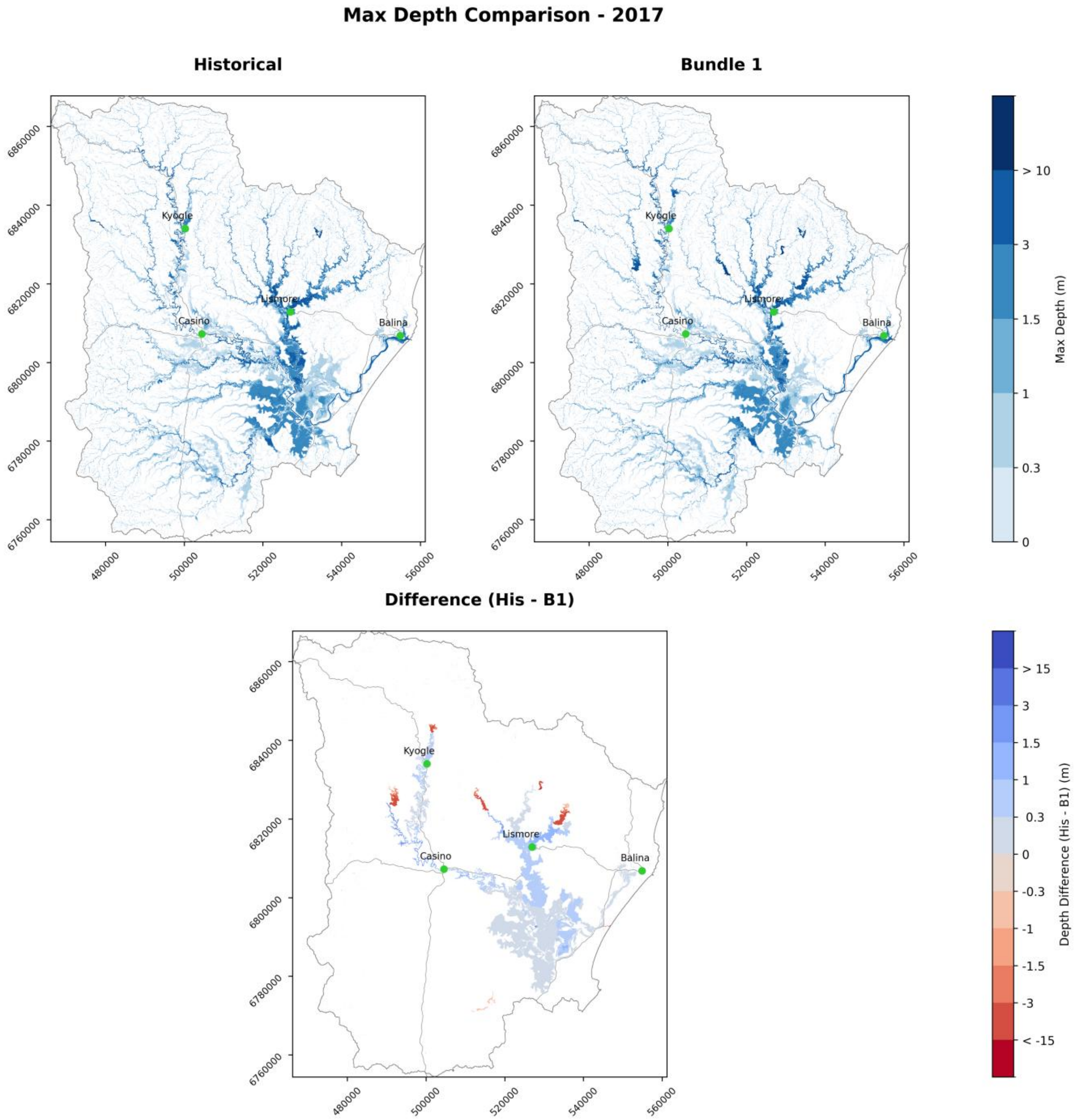

Figure 34 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for the Richmond River catchment for the 2017 flood event.

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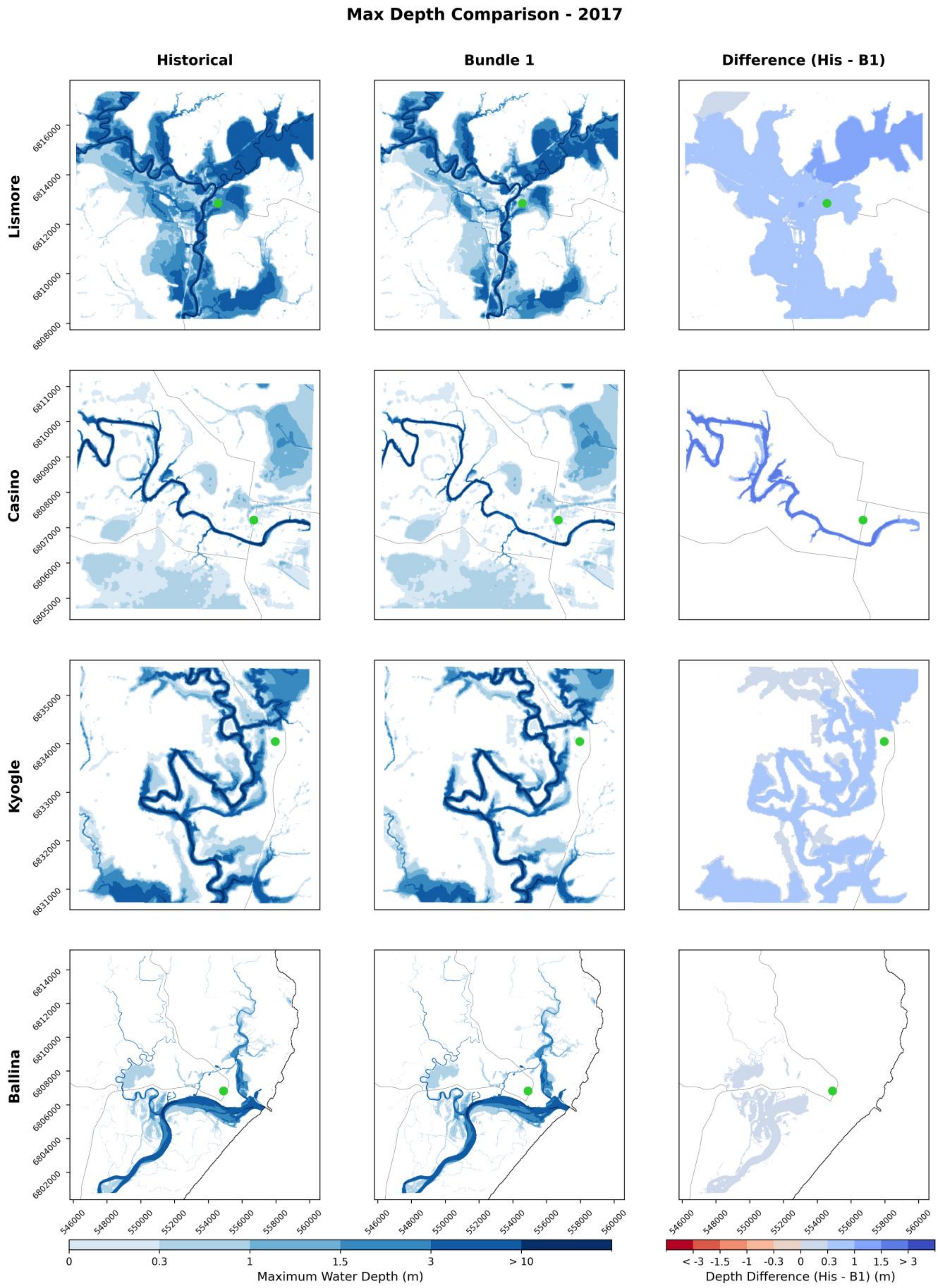

Figure 35 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for four key locations in the Richmond River catchment for the 2017 flood event.

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Figure 36 and Figure 37 show the catchment scale and key locations comparisons between the historical and scenario Bundle 2 simulated maximum inundation depths for the 2017 flood event. As can be seen from the comparisons, the results show that scenario Bundle 2 can reduce the maximum flood depth across the Richmond River catchment in some areas downstream of the detentions for the 2017 flood event. The reductions in scenario Bundle 2 (both maximum depth and area) are slightly larger than those in scenario Bundle 1. Similar to Bundle 1, the maximum inundation depth for the detention areas increased due to the temporary detainment of water. The reductions in maximum depth at the key locations for scenario Bundle 2 are very similar to Bundle 1, with the largest reductions in depth for Lismore and Kyogle, some reduction in the Ballina area, with little difference for Casino.

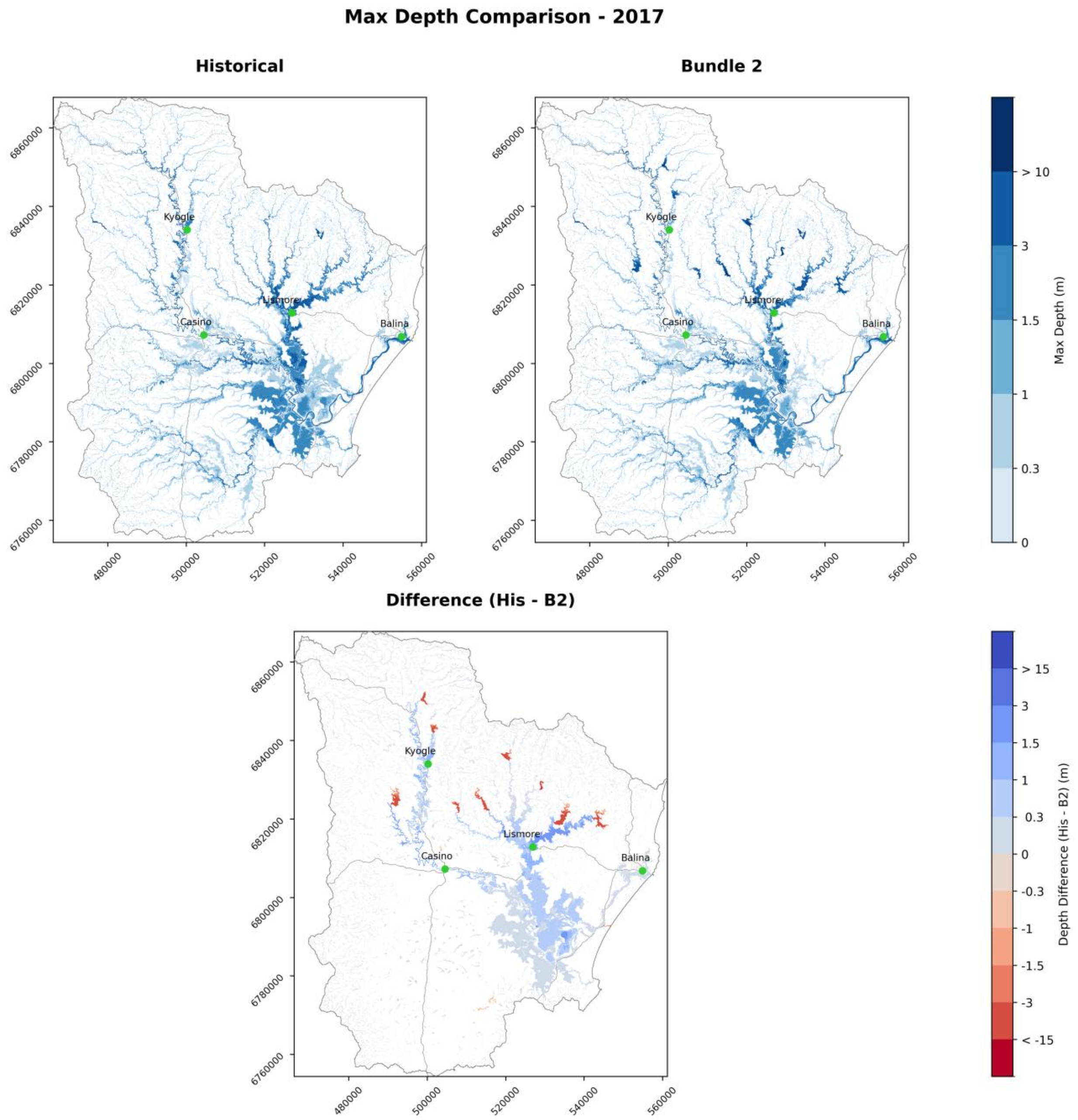

Figure 36 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for the Richmond River catchment for the 2017 flood event.

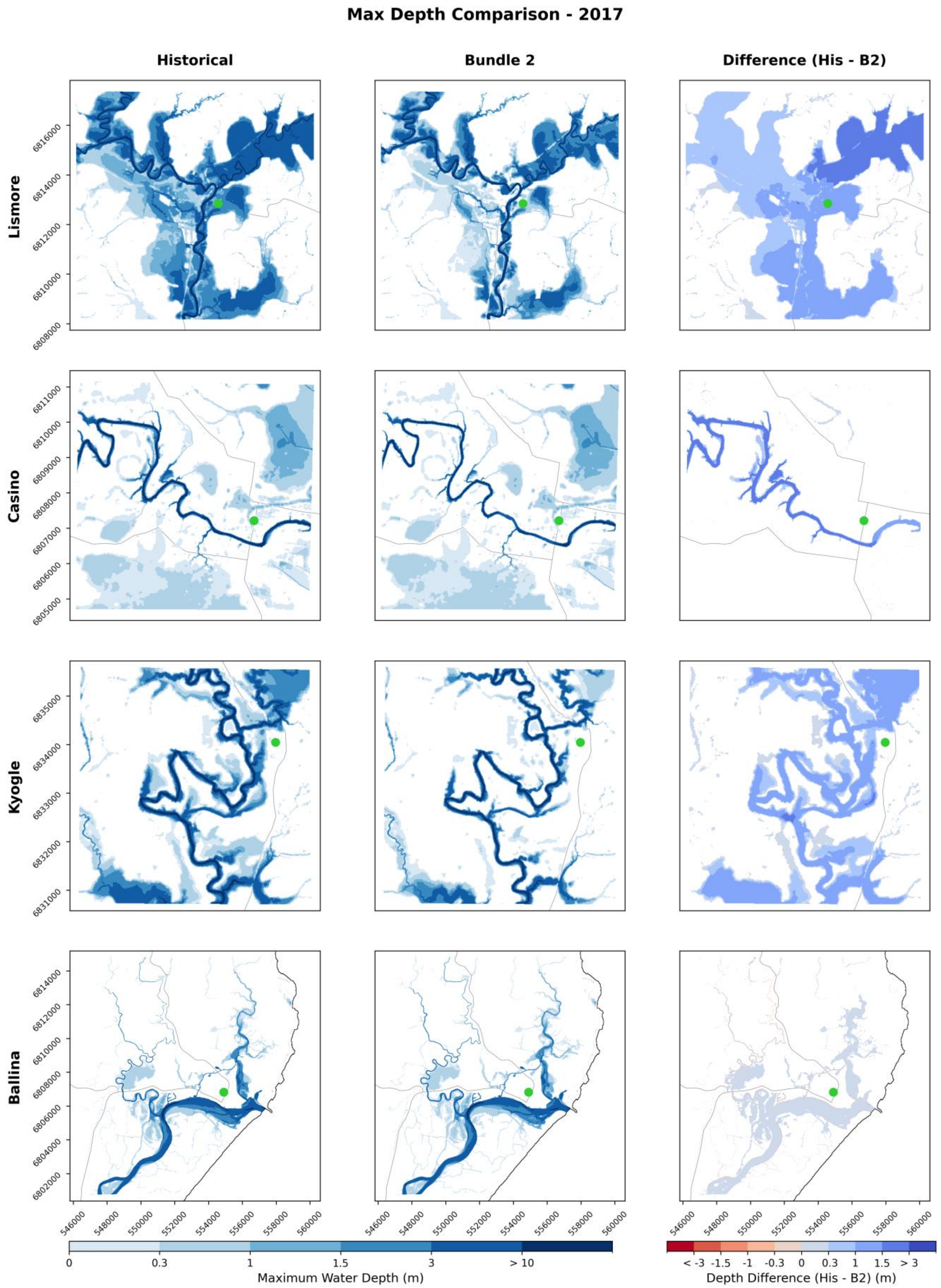

Figure 37 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for four key locations in the Richmond River catchment for the 2017 flood event.

Figure 38 and Figure 39 show the catchment scale and key locations comparisons between the historical and scenario Bundle 1 simulated maximum inundation depths for the 2022 flood event. As can be seen from the comparisons, the results show that scenario Bundle 1 can reduce the maximum flood depth across the Richmond River catchment in most areas downstream of the detentions for the 2022 flood event, which is an extremely large flood. As expected, the maximum inundation depth for the detention areas increased as they were completely full and overflowing due to water being temporarily detained there. The reductions in maximum depth for the key locations show that there are reductions in depth at all four key areas of Kyogle, Casino, Lismore and Ballina.

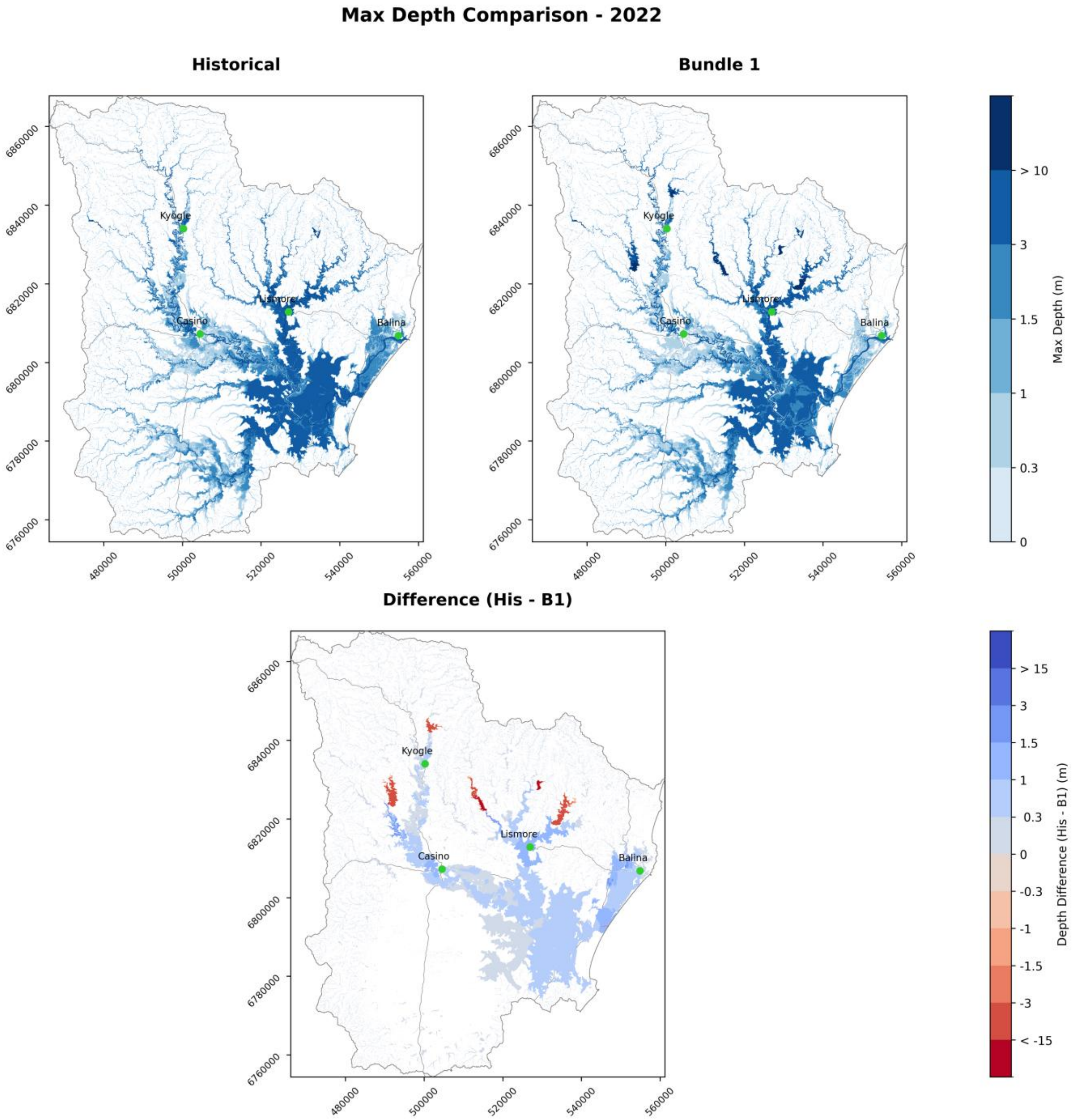

Figure 38 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for the Richmond River catchment for the 2022 flood event.

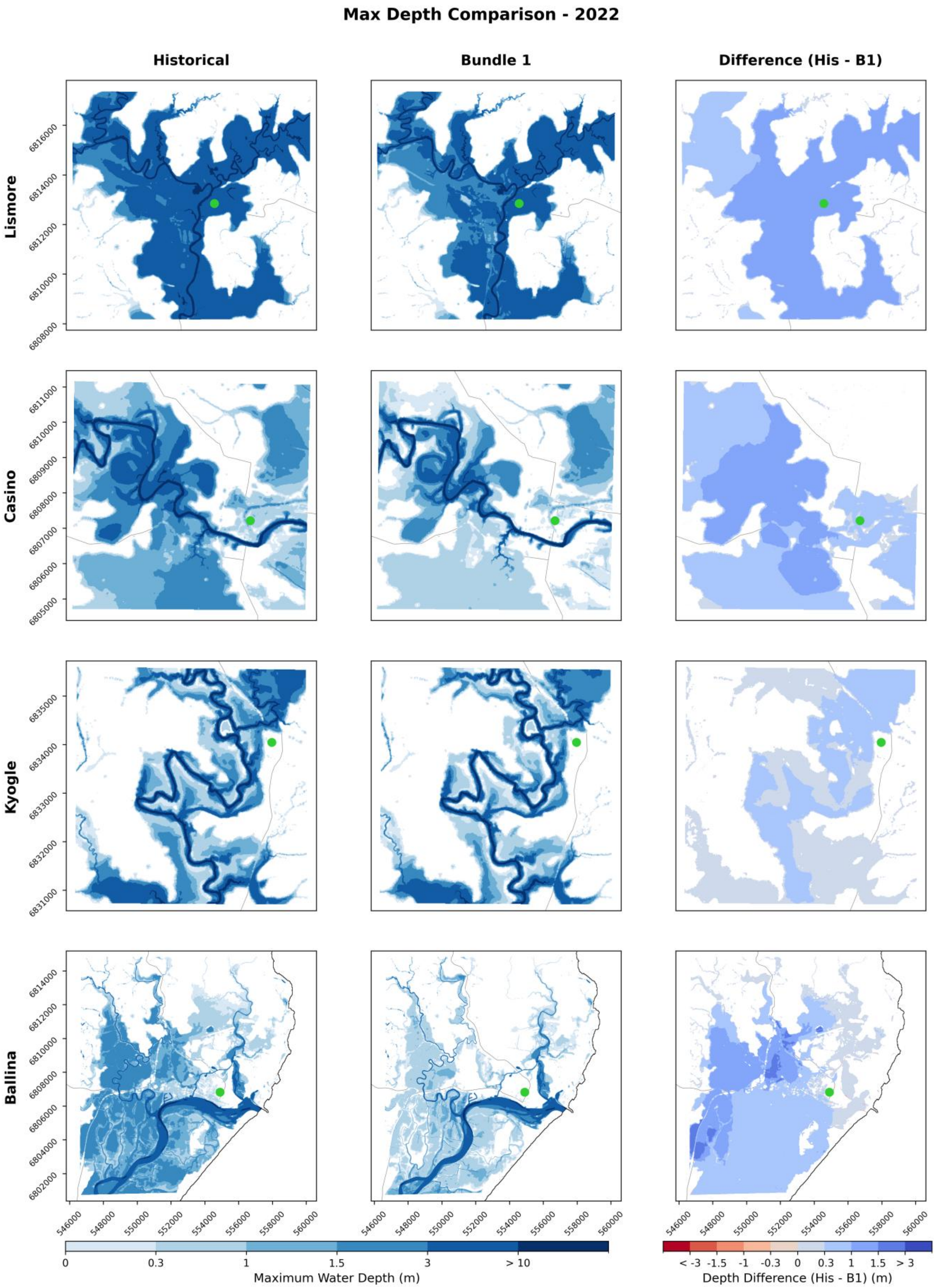

Figure 39 Comparison between the historical and scenario Bundle 1 simulated maximum water depth for four key locations in the Richmond River catchment for the 2022 flood event.

Figure 40 and Figure 41 show the catchment scale and key locations comparisons between the historical and scenario Bundle 2 simulated maximum inundation depths for the 2022 flood event. As can be seen from the comparisons, the results show that scenario Bundle 2 can reduce the maximum flood depth across the Richmond River catchment in large areas downstream of the detentions for the 2022 flood event. The reductions in scenario Bundle 2 (both maximum depth and area) are significantly larger than those in scenario Bundle 1, given that we are detaining a much larger quantity of water in the detentions in Bundle 2. Similar to Bundle 1, most of the detentions were completely full and overflowing. The reductions in maximum inundation depth for the key locations for scenario Bundle 2 are larger than those for Bundle 1, with substantial reductions in depth for Casino, Kyogle, Lismore and Ballina.

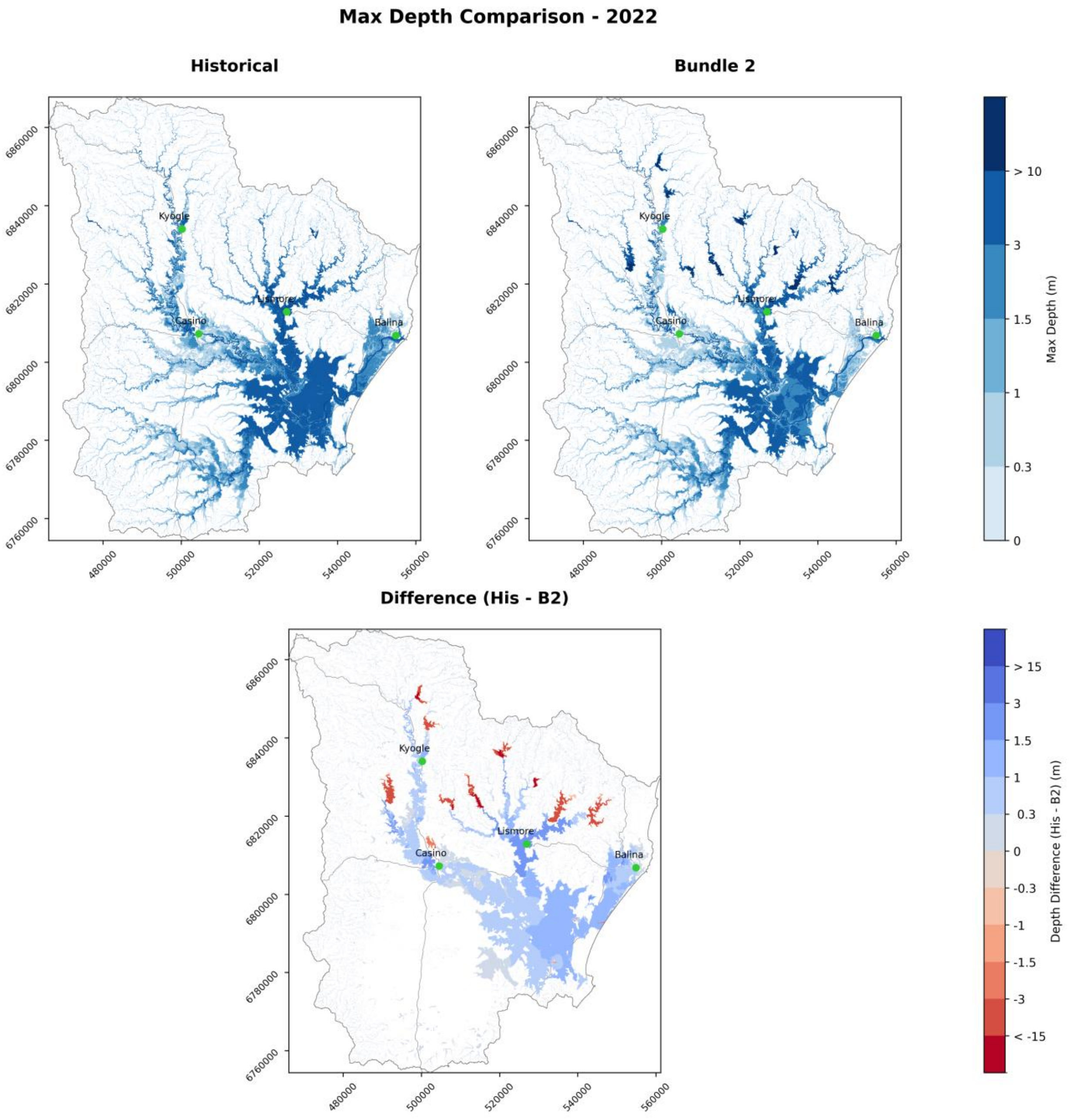

Figure 40 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for the Richmond River catchment for the 2022 flood event.

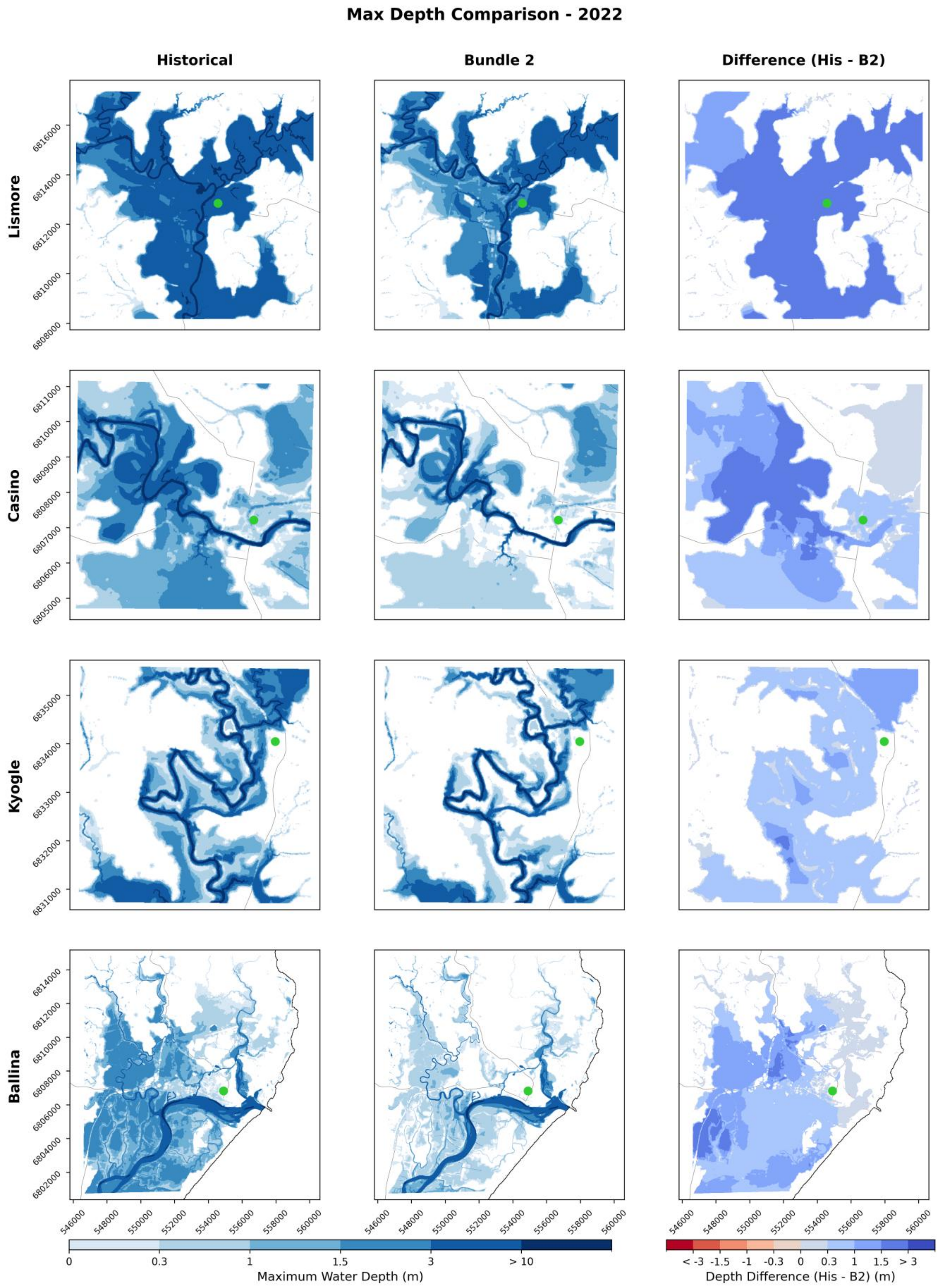

Figure 41 Comparison between the historical and scenario Bundle 2 simulated maximum water depth for four key locations in the Richmond River catchment for the 2022 flood event.

Based on all the comparisons between the historical and scenario Bundle 1 and Bundle 2 maximum flood depth for the 2008, 2017 and 2022 flood events, it can be clearly seen that the scenarios can reduce the flood inundation depth in large areas across the Richmond River catchment. As expected, the reduction in maximum flood depth for Bundle 2 is larger than that for Bundle 1 as we are detaining a larger quantity of water.

4.1.3 Maximum flood depth comparison at key locations across the catchment

Maximum water depths at key locations across the Richmond River catchment were extracted from the historical and scenario Bundle 1 and Bundle 2 simulations to investigate the changes in flood depth for the flood mitigation scenarios for the 28 Feb 2022 flood event. These locations are randomly selected and spread across the catchment and represent the CBD areas of the key towns (note that these statistics can be extracted for any location/point within the Richmond River catchment/model domain). Table 8 below shows these comparisons.

Table 8 Statistics of comparison between the historical and scenario (Bundle 1 and Bundle 2) maximum water depth at key locations across the Richmond River catchment for the 28 Feb 2022 flood event.

Location	Coordinate	Historical Water depth (m)	Bundle 1		Bundle 2	
			Water depth (m)	Reduction (m)	Water Depth (m)	Reduction (m)
Kyogle Anzac Park (Anzac Dr)	153.00, – 28.62	1.78	1.38	0.4	0.88	0.9
Richmond Valley Council	153.05, – 28.87	0.39	0	0.39	0	0.39
AZA Motel (Keen St)	153.28, – 28.81	5.33	4.2	1.13	3.25	2.08
Coraki Riverside Park	153.29, – 28.98	1.52	1.26	0.26	1.08	0.44
Woodburn Information Centre	153.34, – 28.07	2.3	1.62	0.68	1.3	1
Ballina Moon St/ Tamar St	153.56, – 28.87	0.5	0.1	0.4	0	0.5

As can be seen from the numbers in Table 8, the maximum water depths at all these locations are reduced compared to the historical for both the scenario bundles. The reductions are higher for scenario Bundle 2 compared to Bundle 1 as we are detaining a larger quantity of water.

4.2 Discussion

The hydrodynamic model MIKE21 FM was developed for the entire Richmond River catchment and successfully implemented for five historical flood events (Vaze et al., 2025). The same model physical setup, parameters, historical climate (2008, 2017 and 2022), evaporation and spatial soil moisture status at the start of the events are used for the flood mitigation scenario Bundle 1 and Bundle 2 simulations. The only difference is the implementation of the flood mitigation measures as agreed with stakeholders in each of the scenario bundles. For implementing the scenarios in the model, we only applied the structure functions in the MIKE21 FM model, including dykes and gates at the detentions, one-way flow culverts, and modified model mesh at the Boundary Creek opening to represent the structural measures, and the rest of the model mesh remains the same as for the model implementation and validation analysis.

The scenario modelling results are compared against the baseline hydrodynamic modelling results for historical flood events (2008, 2017 and 2022) to investigate the ability of two flood mitigation bundles to influence flood impacts. This is done to investigate the ability of the implemented flood mitigation scenarios in influencing the water levels, maximum spatial inundation extents, maximum flooding depth and water depth at key locations for the selected historical flood events for scenario analysis.

The detention gate shut water levels for a particular detention storage are fixed at a water level that remains constant for all the flood events for a scenario bundle (but different for Bundle 1 and Bundle 2 to get the optimum reduction in water levels). This is necessary as we will never know at the start of any flood event what the maximum magnitude that event peak will reach in advance, and so the water detentions have to start holding at a water level where we are sure to reduce the impacts downstream. The detention gate opening water levels can be different for the same detention for different flood events and for the two scenario bundles. The decision of times and volumes to release water at each of the detentions will be based on the quantity of water detained in each detention and the combination of controlled release to ensure the flow stays in-bank and avoids any flooding downstream. The release times also need to allow the detentions to empty as soon as possible so that they are fully available for holding water back if another flood follows.

The maximum water detained values for the two bundles and the three flood events show that different detentions detain different amounts of water for each flood event. Bundle 2 can always detain larger volumes in total for an event due to the availability of extra detentions. The results also clearly show that all the detention storages can be completely emptied safely for the three flood events and the two bundles within about two weeks after water is released from them. The time taken to empty the detentions is dependent on the amount of total water detained and other contributing tributaries influencing the downstream water level. As expected, the maximum time for releasing all detained water was for the 28 Feb 2022 flood event, where almost all storages were completely full.

During the controlled release of detained water, the time required to reach below minor flood level following flood event peak clearly shows that we can reduce the water levels after a flood peak for the selected events and scenarios to below minor flood levels at the control gauges within 5.5 to 17 days, depending on the total water detained for a flood event. The results also show that we can completely empty all the detentions even after the 28 Feb 2022 flood event (the maximum observed peak , for which most of the storages were full in both bundles) in a maximum of 15.0 days from the start of the controlled release, and they are fully available to detain water for the 31 Mar 2022 flood event. This is the reason that we can detain water for the 31 Mar event to keep the flood peak below the Lismore CBD levee.

The time series water level plots for historical and all the scenarios, and the statistics for water level reductions for the flood peaks, clearly show that both the scenario bundles can reduce the flood peak at all eight internal flow gauges. For the 2008 flood event, the flood peak at the Casino gauge can be reduced by 2.7 m for scenario Bundle 1 and 2.76 m for Bundle 2. The 2017 flood event, which is a major flood for Lismore, the flood peak at the Lismore gauge for scenario Bundle 1 can be reduced from 11.72 m (overtopping the Lismore CBD levee) to 10.75 m for Bundle 1 (still overtopping the Lismore CBD levee) and to 10.32 m for Bundle 2 (below the Lismore CBD levee by about 0.4 m). For the first flood peak of 28 Feb 2022, which is the largest observed flood peak for Lismore, the flood peak at Lismore gauge for scenario Bundle 1 can be reduced from 14.87 m (overtopping the Lismore CBD levee) to 13.75 m for Bundle 1 (still overtopping the Lismore CBD levee) with a reduction in water level of 1.12 m, and to 12.80 m for Bundle 2 (still overtopping the Lismore CBD levee) with a reduction in water level of 2.07 m. For the second flood peak of 31 Mar 2022, which is a major flood for Lismore, the flood peak at Lismore gauge for scenario Bundle 1 can be reduced from 11.02 m (overtopping the Lismore CBD levee) to 10.10 m for Bundle 1 (below the Lismore CBD levee) and to 9.30 m for Bundle 2 (under the Lismore CBD levee by more than 1 m).

The MIKE21 FM simulated historical maximum inundation extents for the three selected flood events were compared against the scenario Bundle 1 and Bundle 2 simulated inundation extents at maximum overland flooding. These comparisons are undertaken to investigate and demonstrate whether the flood mitigation scenarios can reduce the maximum extent of overland flooding across the Richmond River catchment. The comparison results are presented for the entire Richmond River catchment as well as four key locations across the catchment. The results clearly show that the flood mitigation scenarios investigated in this analysis can substantially reduce the maximum extent of flooding in some areas. As expected, the reduction in maximum flooding extent for Bundle 2 is larger than that for Bundle 1, as a larger quantity of water is detained in Bundle 2.

The flood mitigation scenarios investigated in this analysis can control water coming from upstream through a river/stream, but they have no control over the local area runoff generated within the catchment landscape downstream of the detentions, which can still cause some flooding depending on the rainfall intensity, duration and antecedent soil moisture conditions. This is evident from the results for 2017 scenario Bundle 2, where the peak water level at Lismore gauge is reduced to 10.32 m and it stays well below the Lismore CBD levee however the flooding around the CBD (mostly in the 'Basin – the lowest-lying area of the Lismore CBD') is caused by local area generated runoff, which cannot be controlled by any detentions upstream. There are already measures in place across most of the Richmond River catchment to mitigate local area runoff, such as pump stations and pressure gates.

The model simulated historical maximum inundation depths for the three selected flood events were compared against the scenario Bundle 1 and Bundle 2 simulated maximum inundation depths. This comparison is undertaken to investigate and demonstrate whether the flood mitigation scenarios can reduce the maximum depth of overland flooding across the Richmond River catchment and for four key locations across the catchment. The overall results clearly show that both scenario bundles can reduce the maximum flood inundation depth in large areas across the Richmond River catchment. As expected, the reductions in maximum flooding depth for Bundle 2 are higher than those for Bundle 1, as we are detaining a larger quantity of water.

The results for comparison between the maximum water depth at key locations across the Richmond River catchment for the historical and scenario Bundle 1 and Bundle 2 simulations for the 28 Feb 2022 flood event show that the maximum water depth at these key locations is reduced compared to historical for both the scenario bundles. The reductions are higher for scenario Bundle 2 compared to Bundle 1, as we are detaining a larger quantity of water. These locations are randomly selected and spread across the catchment and represent the CBD areas of the key towns, but these statistics can be extracted for any location/point within the Richmond River catchment.

Although the upgrade of the Tuckean Swamp pressure gate and the Boundary Creek opening show minimal impact for the flood events in 2008 and 2017 (both caused minimal flooding in these areas), these mitigation measures contribute to reducing the flood inundations upstream of Bagotville, allowing flood water overflowing from Wilson River into the Tuckean Swamp to escape earlier to the ocean through Boundary Creek, and overall reducing the flooding downstream in Wardell and Ballina.

Barlings Creek drains a catchment largely located north and northeast of Casino and flows into Tomki Creek upstream of its confluence with the Richmond River which is located downstream of the Casino CBD. During extreme flood events, elevated water levels in the Richmond River restrict discharge from Tomki Creek, causing backwater effects that propagate upstream. Under these conditions, inflows from Barlings Creek are unable to drain efficiently and spill onto adjacent low-lying floodplain areas, resulting in overland flooding north of the Casino CBD. While Barlings Creek does not contribute directly to the flood inundation of the Casino CBD coming from overbank flows from the Richmond River, it does contribute to tributary-driven overland flooding in the northern parts of the town. By attenuating peak flows from the Barlings Creek catchment, the Barlings Detention would reduce inflows to Tomki Creek during flood events, thereby reducing backwater effects and the extent of overland flooding north of the Casino CBD.

As can be seen from the comparisons presented and discussed above, all the comparisons between model simulated historical and flood mitigation scenario Bundle 1 and Bundle 2 time series of hourly water level plots across the Richmond River catchment, the statistics for water level reductions at the peak of all the flood events and the spatial comparisons for overland maximum flood extents, maximum flood depth and maximum water level at key locations clearly demonstrates that the flood mitigation scenarios formulated with the stakeholders and implemented in this analysis for the entire Richmond River catchment can reduce historical flood peaks as well as spatial inundation extents and depth reasonably substantially. The multiple lines of evidence used to demonstrate the effectiveness of the flood mitigation scenarios provide confidence in the modelling results.

The modelling undertaken in this study clearly shows that the impact of large floods can be reduced across the Richmond River catchment with strategically located water detentions and other flood mitigation measures tested in this study. Further investigation of the results also indicates that putting one or two additional detentions on Gradys Creek on the Casino/Kyogle side and Tuntable Creek upstream of Lismore may potentially further reduce the flood levels across the Richmond River catchment. These measures were not suggested or discussed during stakeholder consultations but were identified after completing the simulations. If these additional measures are to be assessed, they need to be implemented in the model together with Bundle 2.

These results clearly indicate that, when new infrastructure is appropriately represented in the model setup, the model can reliably estimate flow changes associated with infrastructure development across the catchment. This demonstrates the suitability of the model for assessing a range of structural interventions and alternative flood mitigation scenarios. Simulations of future climate, flow scenarios, or design flood events require modification of the input climate only, whereas assessment of major infrastructure interventions beyond those considered in this study would require additional changes to the model mesh and setups.

This scientific investigation of flood mitigation scenarios undertaken using a well-implemented, detailed hydrodynamic model and credible science has demonstrated the feasibility of different flood mitigation options in the Richmond River catchment. The effectiveness of the flood mitigation options is ultimately dependent on the detailed design of the structures and the implementation on the ground. Further analysis is required before any on-ground implementation, including but not limited to a detailed business case, cost-benefit analysis, environmental approvals, geotechnical analysis, detailed structural design, state and Australian government policy clearance, as well as budget availability. All these aspects are outside the scope of the Northern Rivers Resilience Initiative project.

5 Summary and recommendations

An exceptional flood event affected the Northern Rivers region in NSW between the end of February and the beginning of March 2022. The region was severely impacted, especially in some parts where the flood was unprecedented. The government wanted to analyse what happened during this flood and investigate possible ways of mitigating it in the future. NEMA engaged CSIRO to undertake the Northern Rivers Resilience Initiative to develop and implement a catchment-scale model and use it to test multiple flood mitigation scenarios. The first report for Phase 2 of NRRI described the development and implementation of a detailed hydrodynamic model for the entire Richmond River catchment in the NSW Northern Rivers region to reproduce the past flooding history to investigate flood mitigation scenarios. This report is for the second part of Phase 2 of NRRI, which tested two bundles of flood mitigation measures with three flood events (six scenarios) as suggested by and agreed with the stakeholders to investigate the possibility of reducing the impact of major floods across the Richmond River catchment.

The CSIRO, NEMA and NSWRA teams conducted a series of councils and community consultation workshops in July-August 2025 in the Northern Rivers region for the first round of stakeholder engagements to formulate and finalise the flood mitigation scenarios. The consultations aimed at identifying the broad flood mitigation measures supported by the Richmond River catchment councils and community to guide CSIRO team in the design of flood mitigation scenarios to be tested with the hydrodynamic model. In parallel to these face-to-face consultation workshops with the local community, NEMA allowed for feedback forms to be submitted online until mid-August 2025.

The CSIRO team analysed all the suggestions provided by the councils and community during this first round of engagements and refined the flood mitigation measures to be tested in a scenario analysis. Based on this further analysis and refinement, the CSIRO team formulated six scenarios, which are a combination of three climates and two bundles of multiple flood mitigation measures. These refined scenarios were taken back to the community and councils to get their agreement and further refine/revise if there were more suggestions to make the scenarios better. The second round of face-to-face consultations in the region took place in September 2025.

The stakeholder engagements in both the first and second rounds were extremely useful in understanding all the views and thinking of the community and councils towards flood mitigation. The engagements were attended by all sections of the community, representing locals, businesses, professionals, farmers, etc. Given the frequency of floods in the region and the on-ground experience of the devastating floods of 2022, most council and community members had a practical and realistic approach towards flood mitigation. They wanted the CSIRO team to test scenarios where there is a possibility of reducing the impact of the large floods across the region.

After completion of the two rounds of stakeholder engagements, the CSIRO team finalised the flood mitigation scenarios. A total of three historical flood events (2008, 2017 and 2022) and two bundles of flood mitigation measures were designed to provide six flood mitigation scenarios. The three flood events were chosen as they caused large-scale floodplain inundation and damage in different parts of the Richmond River catchment. The two bundles of flood mitigation measures are implemented to represent fewer interventions in the first bundle and a larger number of interventions covered in the second bundle. The main aim here is to temporarily detain water upstream of towns (detention storages) where the water is held only during the flood and released completely, keeping it in-bank once the flood peak has passed, so that the river can flow normally during non-flood times.

All the comparisons between model simulated historical and flood mitigation scenario Bundle 1 and Bundle 2 time series of hourly water level plots across the Richmond River catchment, the statistics for water level reductions at the peak of all the flood events and the spatial comparisons for overland maximum flood extents, maximum flood depth and maximum water level at key locations clearly demonstrates that the flood mitigation scenarios formulated with the stakeholders and implemented in this analysis can reduce historical flood peaks as well as spatial inundation extents and depth substantially. The multiple lines of evidence used to demonstrate the effectiveness of the flood mitigation scenarios provide confidence in the modelling results.

The modelling undertaken in this study clearly shows that the impact of large floods can be reduced across the Richmond River catchment with strategically located water detentions and other flood mitigation measures tested in this study. Further investigation of the results also indicates that putting one or two additional detentions on Gradys Creek on the Casino/Kyogle side and Tuntable Creek upstream of Lismore may potentially further reduce the flood levels at key locations.

These results clearly indicate that, when new infrastructure is appropriately represented in the model setup, the model can reliably estimate flow changes associated with infrastructure development across the catchment. This demonstrates the suitability of the model for assessing a range of structural interventions and alternative flood mitigation scenarios. Simulations of future climate, flow scenarios, or design flood events require modification of the input climate only, whereas assessment of major infrastructure interventions beyond those considered in this study would require additional changes to the model mesh and setups.

The hydrodynamic model developed here and used for the scenario analysis covers a large area and a very complex terrain with very steep to low gradients. The model is set up to represent the entire modelling domain and is suitable for understanding the water level variations and floodplain dynamics at the scale of the modelling domain. The modelling is undertaken to get the overall river water levels and the reductions in water levels for scenario analysis at all gauges across the catchment without focusing on any gauge or areas.

Recommendations: The investigation undertaken in the study clearly demonstrates that the flood mitigation scenarios formulated with the stakeholders and implemented in this analysis for the entire Richmond River catchment can reduce historical flood peaks as well as spatial inundation extents and depth reasonably substantially across the Richmond River catchment. The multiple lines of evidence used to demonstrate the effectiveness of the flood mitigation scenarios provide confidence in the modelling results.

The modelling undertaken in this study shows that the impact of large floods can be reduced across the Richmond River catchment with strategically located detentions and other flood mitigation measures tested in the analysis. Further investigation of the results also indicates that putting one or two additional detentions in addition to Bundle 2 on Gradys Creek on the Casino/Kyogle side and Tuntable Creek upstream of Lismore may potentially further reduce the flood levels across the Richmond River catchment. The modelling results show that Bundle 2 is the most effective in reducing impacts of floods across the Richmond River catchment for all three historical flood events and that further investigation needs to be undertaken.

This scientific investigation of flood mitigation scenarios undertaken using a well-implemented, detailed hydrodynamic model and credible science has demonstrated the feasibility of different flood mitigation options in the Richmond River catchment. The effectiveness of the flood mitigation options is ultimately dependent on the detailed design of the structures and the implementation on the ground. Further analysis is required before any on-ground implementation, including but not limited to a detailed business case, cost-benefit analysis, environmental approvals, geotechnical analysis, detailed structural design, state and Australian government policy clearance, as well as budget availability. All these aspects are outside the scope of the Northern Rivers Resilience Initiative project.

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