OFFICE OF ENVIRONMENT AND HERITAGE

HUNTER RIVER HYDRAULIC ASSESSMENT – PATERSON RIVER LEVEE MODIFICATION

APRIL 2017

Level 2, 160 Clarence Street
Sydney, NSW, 2000

Tel: (02) 9299 2855
Fax: (02) 9262 6208
Email: wma@wmawater.com.au
Web: www.wmawater.com.au

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FINAL REPORT

APRIL 2017

Project **Hunter River Hydraulic Assessment – Paterson River Levee Modification**	**Project Number** **116035**
Client Office of Environment and Heritage	**Client's Representative** Richard Murphy
Authors Dan Morgan Rhys Hardwick-Jones	**Prepared by**
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LIST OF ACRONYMS

AEP	Annual Exceedance Probability
ARI	Average Recurrence Interval
ALS	Airborne Laser Scanning
ARR	Australian Rainfall and Runoff
EOT	Early Overtop
FFA	Flood Frequency Analysis
HRFRMS	*Hunter River Floodplain Rick Management Study and Plan*
HRFS	*Hunter River Branxton to Green Rocks Flood Study*
LOT	Late Overtop
mAHD	meters above Australian Height Datum
NSD	Newcastle Sewerage Datum
OEH	Office of Environment and Heritage
PMF	Probable Maximum Flood
PRFS	*Paterson River Flood Study*
TUFLOW	one-dimensional (1D) and two-dimensional (2D) flood and tide simulation software (hydraulic model)
WAE	Work-As-Executed
WBNM	Watershed Bounded Network Model (hydrologic model)

FOREWORD

The NSW State Government's Flood Policy provides a framework to ensure the sustainable use of floodplain environments. The Policy is specifically structured to provide solutions to existing flooding problems in rural and urban areas. In addition, the Policy provides a means of ensuring that any new development is compatible with the flood hazard and does not create additional flooding problems in other areas.

Under the Policy, the management of flood liable land remains the responsibility of local government. The State Government subsidises flood mitigation works to alleviate existing problems and provides specialist technical advice to assist Councils in the discharge of their floodplain management responsibilities.

The Policy provides for technical and financial support by the Government through four sequential stages:

1. ***Flood Study***
   - Determine the nature and extent of the flood problem.
2. ***Floodplain Risk Management***
   - Evaluates management options for the floodplain in respect of both existing and proposed development.
3. ***Floodplain Risk Management Plan***
   - Involves formal adoption by Council of a plan of management for the floodplain.
4. ***Implementation of the Plan***
   - Construction of flood mitigation works, and use of Local Environmental Plans to ensure new development is compatible with the flood hazard.

1. INTRODUCTION

The Office of Environment and Heritage (OEH) has modified part of the levee system on the Paterson River, including raising of existing levees and early overtops (EOT). The works were completed between February and March 2016. The extent of the modification works is along a stretch of approximately 4 km that begins approximately 1 km downstream of Dunmore Bridge and ends approximately 250 m downstream of Wallalong Road, on the eastern bank of the Paterson River. The extent of the works is shown in Image 1 and Figure 1.

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WMAwater was engaged by the Office of Environment and Heritage (OEH) to undertake a hydraulic assessment of the completed works to identify the effect on flood behaviour using available TUFLOW hydraulic models of the Lower Hunter River and Paterson River. These models were previously developed as part of catchment-wide flood studies (see Section 2.2 for details). WMAwater were engaged to undertake the assessment for Paterson River flooding in May 2016, and for joint Hunter River / Paterson River flooding in October 2016.

Image 1 - Extent of Levee Modification Works

WMAwater previously completed the *Hunter River Branxton to Green Rocks Flood Study* (HRFS, Reference 1) for Maitland Council and Cessnock Council and the *Hunter River*

Floodplain Risk Management Study and Plan (HRFRMS, Reference 2) for Maitland Council. The results supplied herein were prepared by utilising the hydraulic models developed for both studies.

WMAwater is currently undertaking the *Paterson River Flood Study* (PRFS, Reference 3), with the study at the public exhibition phase. The majority of the PRFS (including flood modelling) was completed before the levee modification works were undertaken. WMAwater became aware of the modification works in May 2016, at approximately the same time that a draft report was submitted to Council.

The modelling for the PRFS is based on conditions prior to the levee modification conditions and that study is not related to the modification works. The purpose of the PRFS is to understand existing flood risk on the Paterson River, and prepare modelling tools that can be used to assist in floodplain management decision making. The PRFS is currently on hold until an understanding of the levee modification works, community consultation, and any subsequent remediation works is resolved. It is likely that the design flood modelling and mapping for the draft PRFS will be revised at a later date to reflect the modification works and ay additional works that may occur.

Prior to modelling of the Hunter River flood mechanisms as part of this assessment, WMAwater completed an assessment of the effect of the levee works on flooding solely from the Paterson River, entitled *Hydraulic Assessment – Paterson River Levee Upgrade* (Reference 4).

2. BACKGROUND

2.1. Study Area

The Hunter River has a catchment of some 16,500 km^2 to Singleton and 17,600 km^2 to Maitland which is approximately 50 km straight line or 85 km river distance downstream. The Hunter River has experienced many floods in the past with the largest since European settlement recorded in February 1955. Subsequently large floods have occurred in February 1971, March 1977 and June 2007 (these events were large floods at both Singleton and Maitland)

For this assessment the study area that is of interest is located on the Hunter River between Oakhampton and Green Rocks and on the Paterson River between Dunmore Bridge and the confluence with the Hunter. The area of interest also includes the floodplains and flood affected areas in the suburbs of Bolwarra, Lorn, Pitnacree, Raworth, Phoenix Park, Woodville, Wallalong, Hinton, Duckenfield and Morpeth.

2.2. Previous Studies

2.2.1. Hunter River Branxton to Green Rocks Flood Study – Final 2010 (HRFS)

This HRFS (Reference 1), undertaken by WMAwater, determined Hunter River design flood levels for the entire Maitland City LGA, and superseded the 1998 Flood Study. Reasons for initiating the study and updating the design flood levels included:

- The use of a two-dimensional (2D) model to simulate flood behaviour, an advancement over one-dimensional (1D) techniques used in the previous study;
- The availability of detailed topographic data from Airborne Laser Scanning (ALS) has enabled the use of 2D models, an accurate definition of topographic features in the floodplain and the ability to provide accurate flood extent and depth mapping;
- The need to obtain design flood level estimates upstream of Oakhampton (not previously available);
- Advancements in flood frequency estimation, used to determine design flow rates on the Hunter River;
- The June 2007 flood was the third largest flood since February 1955 and over 30 peak levels were recorded by residents as well as at thirteen automatic water levels recorders within the study area. This event therefore provided suitable data for model calibration;
- The June 2007 event equalled the January 1971 event at Singleton, exceeded the 1971 peak at Greta (by 0.7 m) but was 0.4 m lower than 1971 at Maitland (Belmore Bridge). This apparent “anomaly” together with the relatively “slow” travel time of the flood peak from Singleton in 2007 was not well re-produced by existing models and required some further investigation; and
- There was a general need to review the results of the October 1998 Flood Study and establish a computer model for use in the evaluation of climate change scenarios as well as to investigate potential development options.

The following tasks were undertaken in the Flood Study:

- collection of historical flood data;
- flood frequency analysis for Oakhampton/Belmore Bridge;
- development of hydrologic (WBNM) and hydraulic (TUFLOW) models, calibrated against historical flood behaviour (June 2007, February 1971 and February 1955);
- design flood estimation (including the 50% AEP, 20% AEP, 10% AEP, 5% AEP, 2% AEP, 1% AEP, 0.2% AEP, and 0.5% AEP events as well as the PMF);
- assessment of provisional flood hazard (for the PMF and 1% AEP events).

The hydraulic model developed for HRFS study was the one primarily relied upon for this assessment.

2.2.2. Hunter River Floodplain Risk Management Study and Plan – Final 2015 (Reference 2)

The objectives of the study were to identify and compare various management options, including an assessment of their social, economic and environmental impacts. The primary aim of the Plan is to reduce the flood hazard and risk to people and property in the existing community and to ensure future development is controlled in a manner consistent with the flood hazard and risk. The management options that were investigated were:

- Flood Mitigation Measures:
  - Sharkies Lane Levee;
  - Private Trzecinski Bridge Levee;
  - Maitland Ring levee Upgrade;
  - Modify Spillway Levels;
  - Reinforce Oakhampton Road Control.
- Property Modification Levels:
  - House Raising / Flood Proofing / Amphibious Housing;
  - Voluntary Purchase;
  - Rezoning;
  - Development Control Planning and Flood Planning Levels.
- Response Modification Measures:
  - Upgrade Evacuation Route (existing Long Bridge);
  - Upgrade Evacuation Route (realigned Long Bridge);
  - Flood Warning and Evacuation Planning;
  - Public Information and Raising Flood Awareness.

2.2.3. Paterson River Flood Study (Draft) – 2016 (PRFS)

The PRFS (Reference 3) is currently being undertaken by WMAwater on behalf of Maitland Council, Port Stephens Council and Dungog Council, and is at the draft pubic exhibition phase. The Paterson River has a total catchment area of approximately 1200 km^2. The area of interest for this study is the floodplain from Vacy (near of the confluence of the Paterson and Allyn Rivers) to the confluence with the Hunter River at Hinton. This portion of the catchment has an area of approximately 105 km^2.

It should be noted that the PRFS was essentially completed without WMAwater having knowledge of the levee modification works. The levee survey and LiDAR data obtained and incorporated into the PRFS does not include the levee modification works, and therefore the results from the study are based on conditions prior to the works' completion.

The study is currently on hold. The PRFS is currently on hold until an understanding of the levee modification works and any subsequent remediation works is resolved. It is likely that the design flood modelling and mapping for the draft PRFS will be revised at a later date to reflect the modification works and ay additional works that may occur.

The components of the study are to:

- collate available historical flood related data;
- analyse historical rainfall and flooding data;
- undertake a community consultation program;
- develop robust computational hydrologic and hydraulic models and calibrate them against multiple historical events;
- undertake a flood frequency analysis based on the historical record
- determine the flood behaviour including design flood levels, velocities and flood extents within the catchments;
- to assess the sensitivity of flood behaviour to potential climate change effects such as increase in rainfall intensities
- to assess the floodplain categories in accordance with Council policy and undertake provisional hazard mapping; and
- to determine and map the flood planning area in accordance with the floodplain development manual

The study comprised two distinct modelling components:

- WBNM (Hydrologic) – The model was used to calculate the flow hydrographs for input into the TUFLOW model.
- TUFLOW (Hydraulic) – The 2D hydraulic model was used to assess the complex flow regimes of Paterson River and its tributaries and how these flows interact with the floodplain and levee system.

Two approaches were investigated to determine design flood magnitude. Flood Frequency Analysis and design rainfall modelling were both undertaken with similar results for peak flow at key gauges. The design rainfall approach was adopted as it provides a more holistic result for the entire study area, especially in regard to flood mapping of the Paterson River floodplains and tributaries.

The study included modelling of the 20%, 10%, 5%, 2%, 1%, 0.5%, 0.2% AEP and PMF design flood events, with mapping provided for peak flood depths and levels, peak velocities, hydraulic hazard and hydraulic categories.

2.2.4. Hydraulic Assessment – Paterson River Levee Upgrade – 2016

An initial assessment of the Paterson River levee modification works on the eastern bank was undertaken by WMAwater at the request of OEH (Reference 3). The extent of the modification works is along a stretch of approximately 4 km that begins approximately 1 km downstream of Dunmore Bridge and ends approximately 250 m downstream of Wallalong Road, on the eastern bank of the Paterson River.

The assessment was undertaken using the modelling package developed as part of the PRFS (Reference 3). The assessment primarily focused on the Paterson River design flood events that were modelled in PRFS. The design events investigated for the assessment were the 20% AEP, 10% AEP, 5% AEP, 1% AEP design events and the April 2015 historical event.

The April 2015 event was modelled as a calibration event for the PRFS. This event was modelled over a 72 hour period, with the rainfall and temporal patterns were determined from daily and pluviometer rainfall gauges in the catchment. This event was assessed for the levee modification assessment as it was the largest flood recorded on the Paterson with a peak flood level of 16.1 mAHD recorded at Gostwyck Bridge. This flood event is strong in the memory of local residents, and therefore useful in conveying the outcomes of the assessment as part of any ongoing consultation activity.

In order to undertake a reliable impact assessment of the levee modification works, the section of levee that was modified was isolated in the model so that only that section of the levee varies in the base case (before levee works) and post-modification (after levee works) scenarios. The only differences between the “base case” and “post modification” scenarios are the levee crest profiles along the extent of the works. Other areas in the model were left constant, even where there were slight discrepancies in the available survey data, to ensure that the impact assessment only identified the flood impacts of the modification works.

The levee works (including raising) that were undertaken on the eastern levee bank were found not to have a significant impact on flood behaviour or peak flood levels for events up to and including the 5% AEP event (for flooding of the Paterson River without significant Hunter River flooding). This is because the smaller Paterson floods would not overtop the affected sections of levee, with or without the modification works. This finding is only for smaller Paterson River floods without significant Hunter River flooding occurring in conjunction.

For larger floods, which would have overtopped the modified section of levee, it was found the levee modifications will alter flood levels in the river and on the surrounding floodplains. The magnitude of the increases and decreases in peak flood levels on the floodplains varies spatially but is in the order of ±0.1 m (for flooding of the Paterson River without significant Hunter River flooding). Flood levels will typically be increased upstream of the works, and decreased downstream of the works, for these larger flood events.

The assessment described above did not include consideration of the levee modifications on flooding from the Hunter River. The present report addresses the impacts of the works on Hunter River flood behaviour.

2.3. Hunter River Flood Behaviour

There is a constriction of the Hunter River at the Oakhampton railway bridge crossing. Downstream of this point, for large flood events, there are three main flow paths of the Hunter River:

- The Hunter River main channel, which contains all flow up to events of around the 10% AEP magnitude.
- The Oakhampton Floodway, which passes between Maitland and the high ground of Rutherford and Telarah in the west and discharges into a large flood storage area south of Maitland (the Wallis Creek and Swamp/Fishery Creek floodplains). This area drains back into the Hunter River at Wallis Creek, and at Porters Hollow via the East Maitland floodway.
- Bolwarra Floodway – Traverses the Bolwarra Flats and then discharges back into the Hunter River in the King Island and Phoenix Park areas or overtops the Paterson River and enters the Wallalong floodplain.

The HRFS indicated that flow is primarily in-bank for the Hunter River 50% AEP event with some shallow overbank flooding of low-lying areas on the Lower Paterson River and downstream of Morpeth. The 50% AEP event is large enough for the formation of an anabranch flow-path from Porters Hollow (just downstream of Harry Boyle Bridge), through Howes Lagoon, and re-joining the Hunter River immediately upstream of Morpeth.

In the 20% AEP event the Narrow Gut flowpath begins to operate with floodwaters from the Hunter River entering Narrow Gut and then flowing across the western Paterson River spillway and into the Paterson River. From there, floodwaters either overtop the spillway on the eastern Paterson levee bank and enter the Wallalong floodplain, or continue further down the Paterson River.

In the 10% AEP event the Oakhampton and Bolwarra Spillways are just overtopped (with only inconsequential impacts). In the 10% AEP event, the majority of rural floodplain areas downstream of Harry Boyle bridge are inundated, including Raworth, Largs/Kings Island, Phoenix Park, Woodville, Wallalong, Duckenfield, Millers Forest, and McClymonts Swamp.

In larger flood events between 5% AEP and 2% AEP magnitude, significant overtopping of the Oakhampton and Bolwarra Spillways will occur, with high hazard flow occurring in each of the respective floodways, resulting in widespread inundation throughout Louth Park and the Bolwarra Flats. The deck level of Long Bridge is overtopped between a 5% and 2% AEP flood. Wyburns Levee, which extends eastwards from the Wallis Creek floodgates to Morpeth Road near Reid Street, is overtopped in floods greater than the 5% AEP, resulting in flooding of the Pitnacree area.

In the 1% AEP event, most of South and Central Maitland is inundated, with depths exceeding 2.5 m in large areas of Horseshoe Bend, and along the railway corridor including Maitland railway station. The extent of inundation is up to 4 km wide at some points. While Lorn is protected from inundation by levees along the Hunter River, the flood level in the river is up to 3 m higher than average ground levels in the area. Low-lying areas at the east of Lorn are inundated by backwater flooding from the Bolwarra Flats.

3. DATA

3.1. Topography

3.1.1. LiDAR - HRFS

The LiDAR utilised for the HRFS was obtained for the Maitland LGA and part of Cessnock LGA from Photomapping Services, Melbourne. This data was verified against approximately 380 surveyed data points obtained across the Maitland LGA and the accuracy confirmed as:

- The standard deviation of the error between the aerial survey and ground survey is less than 0.15 m
- The mean of the error is less than +/- 0.1 m.

3.1.1. LiDAR - PRFS

Light Detection and Ranging (LiDAR) survey of the PRFS study area and its immediate surroundings was provided by Land and Property Information (LPI). The data for the Maitland area was collected in 2012 and the Raymond Terrace area in 2013. The accuracy of the ground information obtained from LiDAR survey can be adversely affected by the nature and density of vegetation, the presence of steeply varying terrain, the vicinity of buildings and/or the presence of water. The accuracy is typically ± 0.15 m for clear terrain.

3.1.2. Levee Survey 2011 (OEH)

OEH provided detailed survey of the Paterson River levee system. The levee survey begins at Tocal and continues through to the confluence with the Hunter River. This survey was used as the basis for refinement of the pre-modification scenario modelled by WMAwater.

3.1.3. Levee Survey 2016 (OEH)

OEH provided detailed survey of the levee system after completion of the modification works. The survey begins at Dunmore Bridge and continues through to approximately 500m past Wallalong Road. The location of the survey is shown in Figure 2, Figure 3 and Figure 4. This survey was used as the basis for refinement of the post-modification scenario modelled by WMAwater.

3.1.4. Hunter River Flood Mitigation Plans 1967 (Department of Public Works)

The original plans by Department of Public Works for the Hunter Valley Flood Mitigation – Woodville – Wallalong – Greenwattle – Levees were provided by OEH. The plans are attached in Appendix B.

3.2. Development of Hydrologic and Hydraulic Models

3.2.1. Hydrological Model

The hydrological approach was to utilise Flood Frequency Analysis (FFA) for the Hunter River and a WBNM hydrological model for the tributaries. The FFA determined the peak flows for design events on the Hunter River, with the hydrograph shape being based on the February 1955 historical flood event.

3.2.2. Hydraulic Model

The hydraulic model was developed using the TUFLOW 1D/2D modelling software (WMAwater, 2015). The catchment topography was based on LIDAR survey, bathymetric survey of the tidal zone, and detail survey of levee bank crests. A digital elevation model with a 10 m grid resolution was developed from these survey datasets. WMAwater calibrated the models to multiple events with a good match to recorded data being achieved across the full range of events. The calibration events were:

- February 1955
- February 1971
- March 1977
- June 2007

4. PATERSON RIVER LEVEE

A major levee system was constructed in the 1960s and 1970s by the Department of Public Works. The levee system is built on the major floodplains, beginning at the township of Tocal and continuing to the confluence of the Hunter River where it meets the Hunter River levee system. The levee system has a considerable influence on flood behaviour, especially in smaller events, where a large proportion of flow is contained within the river by the levee system.

The section of levee that is being investigated as part of this assessment is the eastern levee beginning approximately 1 km south of Dunmore Bridge and ending just south of Wallalong Road.

4.1. Levee Survey Data

There are two detail surveys of the levee that were used in this assessment with their profiles shown in Figure 5. The levee surveys form the basis of the assessment as they represent the levee topography before and after the modification works.

Levee Survey (2011)

The survey undertaken by OEH samples the levee topography at approximately 100 m intervals. The survey identifies the EOTs, but they would be more defined if the survey was undertaken at smaller intervals along the levee profile. The levee height differs from the 1967 design although the location of the EOTs are very similar. There could be multiple explanations for the discrepancy in levels:

- Subsidence of levee through natural soil and gravitational forces, vehicles traversing the levee and livestock grazing
- Erosion from flooding
- The levee not constructed exactly to the design plans.

Levee Survey (2016)

The survey undertaken by OEH samples the levee topography at irregular intervals ranging from 10 m to 160 m. The majority of the EOT sections have been filled by up to 0.5 m along the entire levee profile.

4.2. Historical Design Data

Woodville – Wallalong – Greenwattle – Levees (Design Plans 1967)

The design plans were developed in 1967 by the NSW Department of Public Works. The design plans detail the proposed eastern levee design beginning at Wallalong Road and finishing in the area south of Dunn's Creek. The plans consists of a detailed longitudinal section and plan of the proposed levee design. The plans were converted from imperial to metric and from the Newcastle Sewerage Datum (NSD) to the Australian Height Datum (mAHD). The conversion from NSD to mAHD was taken as -1.02 m (from Reference 5). The design displays multiple EOT sections along the stretch of the levee profile.

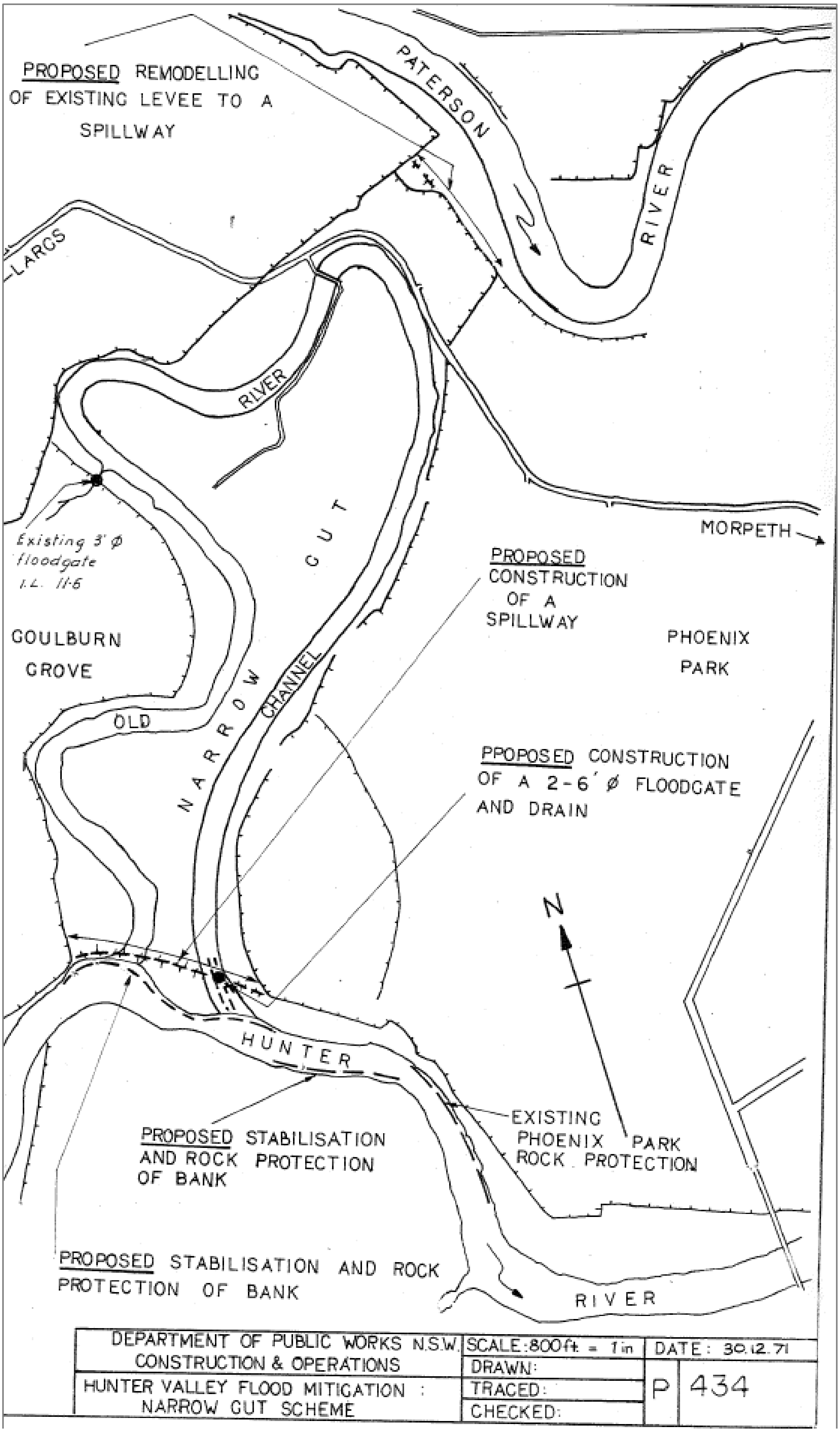
The historical design plans obtained from OEH detail how the proposed levee was intended to operate. There are approximately 15 early EOT sections in the design between Wallalong Road and Dunmore Bridge. The location of the EOT sections are also identified in the levee survey (2011) with a comparison profile shown in Figure 5. It is not known if the levee was built to the design as Work-As-Executed (WAE) drawings are not available, nor detailed survey of the levee post construction. The difference in levee topography may be due to many factors over the last 50 years, including natural subsidence, compaction due to vehicles traversing the levee, livestock grazing and erosion due to wind, rain or overtopping.

It is worth noting that the levee scheme was designed in the 1960's and 1970's without the benefit of computer models, with the design developed utilising hand calculations. The conclusions from the design process regarding flood behaviour and the protection each levee provides with regard to magnitude of flood event would differ from an analysis undertaken at the current time.

4.3. Narrow Gut Scheme

Initial plans developed in 1971 for the Narrow Gut Scheme (Reference 6) are shown in Image 2 and Appendix B. WAE drawings were not available, but the levee survey (2011) and the presence of the floodgate at Narrow Gut shown in Image 3 suggests the proposed works were undertaken in a similar fashion to the proposed design. The plans suggest the reasoning behind the Narrow Gut Scheme is to allow floodwaters from the Hunter River to spill into Narrow Gut, then be conveyed either, into the Paterson River and downstream towards Hinton, or over the Paterson River and spilling into the Wallalong floodplain through the EOT sections on the eastern levee. Figure 5 shows the location of the flowpath on the western levee and the EOT section on the eastern levee. It would normally be expected that the second flow mechanism mentioned above would be impeded by raising the spillway levels on the eastern levee, as is the case for the modification works that were undertaken.

Image 2 – Plans for Narrow Gut Spillway and Flowpath



The Narrow Gut flow path has the potential to be affected by the levee modification works that have been undertaken, particularly in flood events where this flood runner is active but broader parts of the floodplain are not inundated. For example, in Hunter River flood events between 20% AEP magnitude and 10% AEP magnitude, the Narrow Gut flow path is the primary breakout on the northern side of the lower Hunter River floodplain, since the Bolwarra Spillway would not overtop in these events.

Image 3 – Narrow Gut Flood Gate

The interactions between the various flow paths in and adjacent to Narrow Gut and the major flow paths of the Hunter River and Paterson River are extremely complex and would vary considerably between each flood, due to the unique nature of coincident flooding between the two river systems.

The assessment tools available at the time of design were simple in nature compared to the tools available today and not sufficient to understand all of these interactions. The 2D modelling now available (as used for this assessment) provides a better understanding of how the scheme behaves as it was built and has operated for the last 50 years. To some degree the original design objectives are moot with regards to ongoing works on the scheme, unless there is a clear benefit from re-optimising the scheme, and the affected community is amenable to changes. Typically, changes would involve some members of the community becoming disadvantaged, which limits the scope and feasibility changes being carried out, even if they are in line with the original design objectives.

5. ASSESSMENT METHODOLOGY

5.1. Levee Topography

The original model topography developed for Reference 1 and Reference 2 was based on LiDAR aerial survey, without additional detail survey of levee crests. For this study, additional detail was included for the levees east of Morpeth Bridge based on the PRFS levee topography. This data included a combination of the detail survey from 2011/2012 (provided by OEH) and additional LiDAR survey undertaken by the NSW Department of Land & Property Information (LPI) in 2013/2014. The reasoning for this approach was to assess the same levee topography that was assessed in Reference 4 so that the results would be comparable.

For the levee assessment additional detail was required for the section of levee under consideration (that is, the reach between Dunmore Bridge and Hinton). The "base case" scenario was developed using the 2011/2012 detail survey to define the levee bank crests. The "post-modification" scenario was developed using additional detail survey collected by OEH in June 2016, which captured the levee crest profile after the modification works were completed. The survey covers a 5.8 km section of the levee system starting at Dunmore Bridge and concluding downstream of Wallalong Road. The extent of this survey is shown in Figure 2.

In order to undertake a reliable impact assessment of the levee modification works, all aspects of the modelling were consistent except for changes to the modified section of levee. The only differences between the "base case" and "post modification" scenarios are the levee crest profiles along the extent of the works. This methodology ensures that the impact assessment only identified the flood impacts of the modification works. The data sources for each scenario are illustrated on Figure 3 and Figure 4.

The difference of the levee topography between the base case (before levee works) and post-modification case (after levee works) is displayed in Figure 5.

5.2. Joint Flooding of the Hunter and Paterson Rivers

A comprehensive statistical analysis of coincident flooding on the Hunter River and Paterson River is not within the scope of this study. However there are several historical examples of significant Hunter and Paterson River floods occurring in conjunction, since the flood-producing rainfalls on these catchments are often generated by similar meteorological systems.

As no two floods are the same and to try and understand the effects of the levee works across a range of possible flooding combinations, 25 different hypothetical floods were modelled for this assessment. Each hypothetical flood was a combination of varying magnitudes of Hunter River flooding and Paterson River and tributary flooding. Additionally, the June 2007 historical flood was modelled since this involved significant flooding in both the Hunter River and Paterson River. The modelled flood events are summarised in Table 1.

Table 1 - Modelled Hunter River Floods

		Paterson River & Tributaries				
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Hunter River	20% AEP	✓	✓	✓	✓	✓
	10% AEP	✓	✓	✓	✓	✓
	5% AEP	✓	✓	✓	✓	✓
	2% AEP	✓	✓	✓	✓	✓
	1% AEP	✓	✓	✓	✓	✓

6. RESULTS

6.1. Impacts on Peak Flood Levels

The impact assessment of the levee modification works was undertaken for all 26 flood events modelled. The results are displayed on "impact maps," which show the difference in peak flood levels produced by the levee modification works, compared to the pre-modification scenario. The corresponding map number for each combination of Hunter River and Paterson River floods is shown in Table 2.

Table 2 – Impact Figures

		Paterson River & Tributaries				
		20% AEP	10% AEP	5% AEP	2% AEP	1% AEP
Hunter River	20% AEP	Figure 6	Figure 7	Figure 8	Figure 9	Figure 10
	10% AEP	Figure 11	Figure 12	Figure 13	Figure 14	Figure 15
	5% AEP	Figure 16	Figure 17	Figure 18	Figure 19	Figure 20
	2% AEP	Figure 21	Figure 22	Figure 23	Figure 24	Figure 25
	1% AEP	Figure 26	Figure 27	Figure 28	Figure 29	Figure 30

The figures show areas where peak flood levels would be increased or reduced. Areas where the difference is ±0.01 m are reported "no impact." This is consistent with the guidance from Engineers Australia (Reference 7), which indicates that typically "impacts less than 0.01 m are not reported, as they are considered to be within the precision of numerical model and data."

The maximum increases and minimum decrease in flood levels are shown in Table 3.

There are significant increases in peak flood levels across all events modelled with more pronounced increases in the smaller Hunter River events, especially in the Bolwarra floodway and the floodplain adjacent to Lorn. This is because in smaller Hunter River events the Bolwarra Spillway is not overtopped, and the Narrow Gut flood runner is the primary breakout location on the northern side of the Hunter downstream of Maitland. Raising of the Narrow Gut spillway on the eastern Paterson levee bank therefore obstructs flow through this area, resulting in a backwater effect through King Island and across the Bolwarra flats.

Discussion of the impacts for various combinations of Hunter River and Paterson River design event is discussed further below.

Table 3 – Increases and Decreases in Peak Flood Level

Hunter River Flood Event	Paterson River Flood Event	Max Increase in Flood Level (m)	Location	Min Decrease in Flood Level (m)	Location
20% AEP	20% AEP	+ 1.73 m	Largs	-3.20 m	Wallalong
	10% AEP	+ 0.92 m	Largs	-2.15 m	Wallalong
	5% AEP	+ 0.28 m	Largs	-0.87 m	Wallalong
	2% AEP	+ 0.11 m	Largs	-0.37 m	Four Mile Creek
	1% AEP	+ 1.21 m	Bolwarra	-0.13 m	Four Mile Creek
10% AEP	20% AEP	+ 0.24 m	Largs	-0.97 m	Wallalong
	10% AEP	+ 0.74 m	King Island	-0.17 m	Four Mile Creek
	5% AEP	+ 0.80 m	King Island	-0.18 m	Four Mile Creek
	2% AEP	+ 1.48 m	Bolwarra	-0.05 m	Four Mile Creek
	1% AEP	+ 0.78 m	Bolwarra	-0.27 m	McClymonts Swamp
5% AEP	20% AEP	+ 0.07 m	Largs	-0.03 m	Four Mile Creek
	10% AEP	+ 0.10 m	Largs	-0.02 m	Four Mile Creek
	5% AEP	+ 0.10 m	Largs	-0.02 m	McClymonts Swamp
	2% AEP	+ 0.15 m	Lorn	-	-
	1% AEP	+ 0.20 m	Lorn	-	-
2% AEP	20% AEP	+ 0.05 m	Largs	-0.03 m	Narrow Gut
	10% AEP	+ 0.05 m	Woodville	-0.03 m	Woodville
	5% AEP	+ 0.06 m	Largs	-0.03 m	Hinton
	2% AEP	+ 0.15 m	Lorn	-0.02 m	Hinton
	1% AEP	+ 0.19 m	Lorn	-0.02 m	Hinton
1% AEP	20% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	10% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	5% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	2% AEP	+ 0.05 m	Woodville	-0.02 m	Hinton
	1% AEP	+ 0.06 m	Woodville	-	-

6.2. Description of Changes to Flood Behaviour

Hunter River 20% AEP Event

For the Hunter River 20% AEP event, the most significant impacts occur in combination with the Paterson River 20% AEP event. There are increases in peak flood levels of up to 0.1 m on the Phoenix Park floodplain, 0.28 m in Four Mile Creek and 0.45 m in McClymonts Swamp. Modelling indicates the largest increase in peak flood levels would be on the Largs floodplain with impacts of up to 1.73 m. There is also a significant area between Narrow Gut and King Island that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of up to -3.2 m in on the Wallalong floodplain.

Hunter River 10% AEP Event

For the Hunter River 10% AEP event, the most significant impacts occur in combination with the Paterson River 2% AEP event. There are increases in peak flood levels of up to 0.25 m on King Island, 0.08 m on the Largs floodplain and 0.04 m on the Wallalong floodplain. Modelling indicates the largest increase in peak flood levels would be on the Bolwarra floodplain with impacts of up to 1.5 m. There is also a significant area of the Bolwarra floodplain that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of up to -0.01 m in Narrow Gut, -0.02 m in Hinton and 0.05 m in Four Mile Creek.

Hunter River 5% AEP Event

For the Hunter River 5% AEP event, the most significant impacts occur in combination with the Paterson River 5% AEP event. There are increases in peak flood levels of up 0.07 m on the Wallalong floodplain, 0.06 m on the Bolwarra floodplain, 0.01 m on the Phoenix Park floodplain, 0.1 m on the Largs floodplain and 0.26 m near Lorn. There is also a small area near Lorn floodplain that is newly flooded as a result of the levee modification.

There are decreases in peak flood level of -0.02 m at Hinton.

Hunter River 2% AEP Event

For the Hunter River 2% AEP event, the most significant impacts occur in combination with the Paterson River 2% AEP event. There are increases in peak flood levels of up 0.15 m on the Lorn Floodplain, 0.06 m on the Wallalong floodplain, 0.06 m on the Largs floodplain, 0.01 m on the Phoenix Park floodplain and 0.02 m on the Bolwarra floodplain.

There are decreases in peak flood level of -0.02 m at Hinton.

Hunter River 1% AEP Event

For the Hunter River 1% AEP event, the most significant impacts occur in combination with the Paterson River 1% AEP event. There are increases in peak flood levels of 0.06 m on the Wallalong floodplain, 0.06 m on the Largs floodplain, 0.02 m on the Bolwarra floodplain and 0.02 m on the Phoenix Park floodplain.

There are no decreases in peak flood level.

6.3. Summary of Impacts from the Levee Modification Works

The interaction of the Hunter River and the Paterson River with their subsequent levee systems is extremely complex and even more so when considering the variety of coincidence flooding between the two rivers that has occurred throughout history. Throughout historical records no two floods are exactly the same, therefore the river and levee systems do not behave in exactly the same manner from flood to flood. There is no single flow path, spillway, road or section of levee that can be isolated when describing the flood mechanisms that are affected due to the levee modifications. There are multiple flood mechanisms that are affected by the levee modification works. It is the shift in these flood mechanism that result in the increase in peak flood levels and peak flood extents. The food mechanisms that have been identified as being affected are as follows:

- The raised section of eastern levee prevents floodwater spilling into the Wallalong floodplain until the flood level is higher than was previously (0.5m in some sections of levee). This results in floodwaters overtopping the western levee at an earlier time than previously and with greater volume. This results in increased peak flood level in the Largs floodplain. The effect of the obstruction is most pronounced in the modelled Hunter River 20% and 10% AEP events when the Bolwarra spillway and floodway are not operational. Excess floodwater in the Largs floodplain is conveyed in a westerly direction into the Bolwarra floodway. In events larger than a 10% AEP event the impacts are less pronounced as the Bolwarra floodway is operational with floodwater already having overtopped the Bolwarra spillway.
- The increased levee topography obstructs the Narrow Gut flow path. Flow from the Hunter River is conveyed through Narrow Gut, with a portion of that flow conveyed over the Paterson River which then fills the Wallalong Floodplain. The effect of the obstruction is most pronounced in the modelled Hunter River 20% and 10% AEP events when the Bolwarra spillway and floodway are not operational. Floodwaters that would normally be conveyed through Narrow Gut over the Paterson River and into the Wallalong Floodplain are prevented from doing so or do so in a less efficient manner. This behaviour has two consequences for flood behaviour:
    - Additional floodwater is conveyed down the Paterson River overtopping the Hinton spillways and increasing the flood levels in Hinton and McClymonts Swamp
    - Floodwaters inundate the Largs floodplain and are conveyed in a westerly direction down the Bolwarra floodway. In events larger than the modelled 10% AEP event the impacts are less pronounced as the Bolwarra floodway is operational with floodwater already having overtopped the Bolwarra spillway.
- The Wallalong Road is a control point for the Wallalong floodplain at approximately 6 mAHD. As the Wallalong floodplain fills up flood waters could equalise their levels with the Largs floodplain up to a level of 6 m until they overtopped Wallalong Road and entered McClymonts Swamp. A large section of the modified eastern levee is now at or above 6 mAHD, this impedes floodwaters in the Wallalong floodplain equalising levels with the floodwaters in the Largs floodplain. This results in increased levels in Wallalong floodplain.

6.4. Flood Profiles

Peak flood level and levee profiles for the Paterson River from Dunmore Bridge to the end of the modification works are shown in Figure 31 to Figure 38. The water level profiles were obtained from the PRFS (Reference 3) and the HRFS (Reference 1). The profiles demonstrate the different flood behaviour that is possible due to the very complex flood mechanism at work, resulting from the interaction of the Hunter and Paterson Rivers and their corresponding levee systems and floodplains. The profiles will provide valuable information in any levee design process. The figures are as follows:

- Figure 31 & Figure 32 – Peak level profiles for the design events from PRFS;
- Figure 33 & Figure 34 – Peak flood levels for the modelled historical events from PRFS;
- Figure 35 & Figure 36 – Peak level profiles for the design events from HRFS;
- Figure 37 & Figure 38 – Peak flood levels for the modelled historical events from HRFS.

7. CONCLUSIONS

7.1. Summary of Impact Assessment

The modelling undertaken indicates that the levee modification works significantly affect peak flood levels across a wide range of flood events, and cause a significant increase in flood extent Hunter River events of around 20% AEP to 10% AEP magnitude. The levee modification works cause the most pronounced impact to peak flood levels and extents in the modelled 20% AEP and 10% AEP Hunter River events when the Bolwarra floodway is not overtopped. The mechanisms at play are the raised section of the eastern levee preventing floodwaters spilling into the Wallalong floodplain until the flood level is higher than previously (0.5 m in some sections of levee) and the Narrow Gut floodway not operating as effectively and efficiently as previously.

The modification works will significantly change flood behaviour and peak flood levels in Woodville, Wallalong, Largs, Bolwarra, Lorn, King Island, Narrow Gut, Phoenix Park, McClymonts Swamp, Hinton and Four Mile Creek. In some instances the increases in peak flood level are relatively minor in comparison to the flood depths that would have occurred before the works. However, this does not necessarily mean the increases are insignificant. Any increase in flood levels has the potential to damage property, buildings, machinery and crops that may previously not have been damaged previously, or damaged less severely. Increases in inundation can also increase the duration of flooding, which can also increase tangible and intangible damages from flooding.

Significant works on the floodplain such as the alteration of levee schemes are typically undertaken under the NSW Flood Risk Management Program (e.g. as part of a Floodplain Risk Management Study and Plan). Modification of levee crest heights has the potential to significantly redistribute flood flows and flood levels. Consequently, planning for levee works requires these impacts to be assessed and communicated to all stakeholders. Such planning should generally include:

- Pre-construction surveys;
- hydraulic assessment of flood impacts (including strategic assessment of the impact of cumulative changes, not just modifications to individual sections – this may include consideration of original design heights);
- engagement with stakeholders to communicate impacts and provide opportunity for comment;
- development of detailed construction drawings;
- cost-benefit analysis of proposed works; and
- surveillance of contractor activities.

7.2. Recommendations

WMAwater considers that remediation works are required to redress or mitigate the adverse impacts caused by the levee modification works.

Returning the 4 km section of levee back to the pre-modification levels would be one way to restore flood behaviour to previous circumstances, but such a comprehensive remediation would potentially be unnecessarily costly. It may be possible to produce very similar behaviour by making more localised adjustments, with an emphasis on EOT sections and other parts of the levee system where the majority of overtopping flow occurs.

Such options would require further 2D hydraulic modelling investigation. The investigation is critical to ensure the mitigation works return flood behaviour and peak flood levels to as close to pre-modification conditions as possible. Community engagement and consultation are recommended to ensure transparency of the process, and to facilitate widespread stakeholder acceptance of the remediation works.

To summarise, WMAwater make the following recommendations.

- The 4 km stretch of levee that has been modified should preferably be returned to pre-modification levels (January 2016), however such comprehensive remediation works are likely to be cost-prohibitive and similar outcomes could potentially be achieved with more carefully targeted remediation works.
- Community consultation should be undertaken to understand the concerns of landholders and other stakeholders in the area.
- The interaction of Hunter River and Paterson River with their subsequent levee and flood mitigation systems is extremely complex, and 2D hydraulic modelling is required to adequately understand the potential impacts of the changes on flood behaviour. It is highly recommended that any future proposed modifications to the Lower Hunter Valley Flood Mitigation Scheme should be first assessed by detailed hydraulic assessment utilising calibrated 2D hydraulic modelling.
- A comprehensive overview assessment of the entire Lower Hunter Valley Flood Mitigation Scheme should be undertaken in order to define the existing system of levees, spillways and gates, and review which elements of the scheme have the most significant influence on flood behaviour. The scheme is a valuable asset to the community both economically and socially, and it is important to ensure it continues to function effectively. It has been over 50 years since many elements of the scheme were designed or constructed, and the design intentions are in some cases not well understood. Furthermore, modern computational flood assessment tools provide a significant increase in our ability to analyse and predict the complex flood interactions between different parts of the scheme.

  As part of such an assessment, the levee system could be analysed using existing aerial survey to create a database of crest levels, which could be used as the basis for future restorative maintenance works. There is ongoing maintenance cost for the levee system so it would be prudent to identify whether there are redundant sections of the system that provide no significant benefit. Reducing maintenance costs for these sections of the system could be redirected to the critical sections that provide the most significant benefit in reducing flood risk, or to future mitigation options that have been assessed to provide benefit to the community.

WMAwater recommends that the original drawings for the scheme to be used to set an upper bound for the design of any future levee profile. Additional lowing, from the original design profile, may be required if flood impacts are not in line with community expectations. This recommendation is based on the following considerations:

- The 1967 design EOT profile is close to the pre-modifications levels form chainage 1200m to 2400m. Between chainage 2500m and 4500m there are six locations where the profile is higher, with the range in height between 100mm and 250mm. This may be due to many factors over the last 50 years, including natural subsidence, compaction due to vehicles traversing the levee, livestock grazing and erosion due to flooding.
- However these considerations apply to all other parts of the levee system as well. If the eastern levee is returned to 1967 design conditions then an argument could be raised to return the western levee to 1967 design conditions which has the possibility to exacerbate the issues even further, and similar demands could reasonably be made about each element of the entire scheme.
- Any major changes to the levee system have the potential to produce significant changes to the flood behaviour that has been assessed as part of recent flood studies undertaken as part of the NSW Floodplain Risk Management Program. These studies are relied upon by Council to undertake their floodplain management and planning responsibilities, and the information from these studies is what is currently used to assess the suitability of development proposals in the floodplain. Changes to the established flood behaviour could potentially undermine these planning decisions.
- There is no way of determining if the levee was constructed as per the design drawings. Work-as-Executed plans or survey of the completed levee are not available to undertake a topographic comparison.
- This approach is in line with the recommendations from the ‘Hunter Valley Flood Mitigation Lower Hunter River Datum Conversion report, March 2017 (Reference 5), which recommends “*A conservative approach to design for future levee upgrades knowing that there is a level of uncertainty in the original datum adopted*”.

8. REFERENCES

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3. Maitland Council and Port Stephens Council
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5. Hunter Valley Flood Mitigation – Lower Hunter River Datum Conversion
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6. Flood Mitigation in the Lower Hunter Valley - Volume 1 - Flood Mitigation Works
Department of Public Works NSW, 1974.

7. Department of Climate Change and Energy Efficiency
Australian Rainfall and Runoff Revision Project 15: Two Dimensional Modelling Urban and Rural Floodplains
Engineers Australia, 2012.

Figures

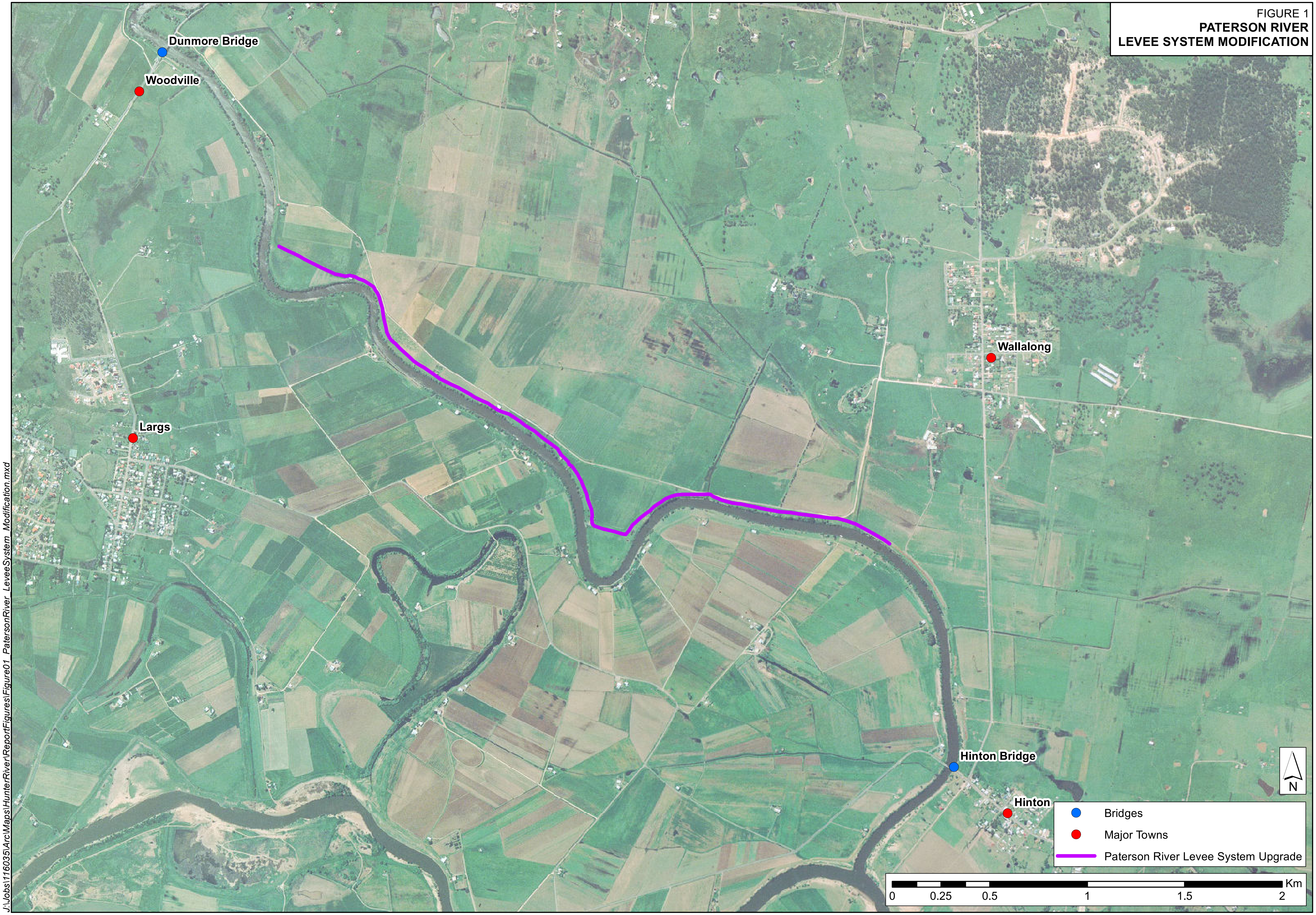

FIGURE 1
PATERSON RIVER LEVEE SYSTEM MODIFICATION

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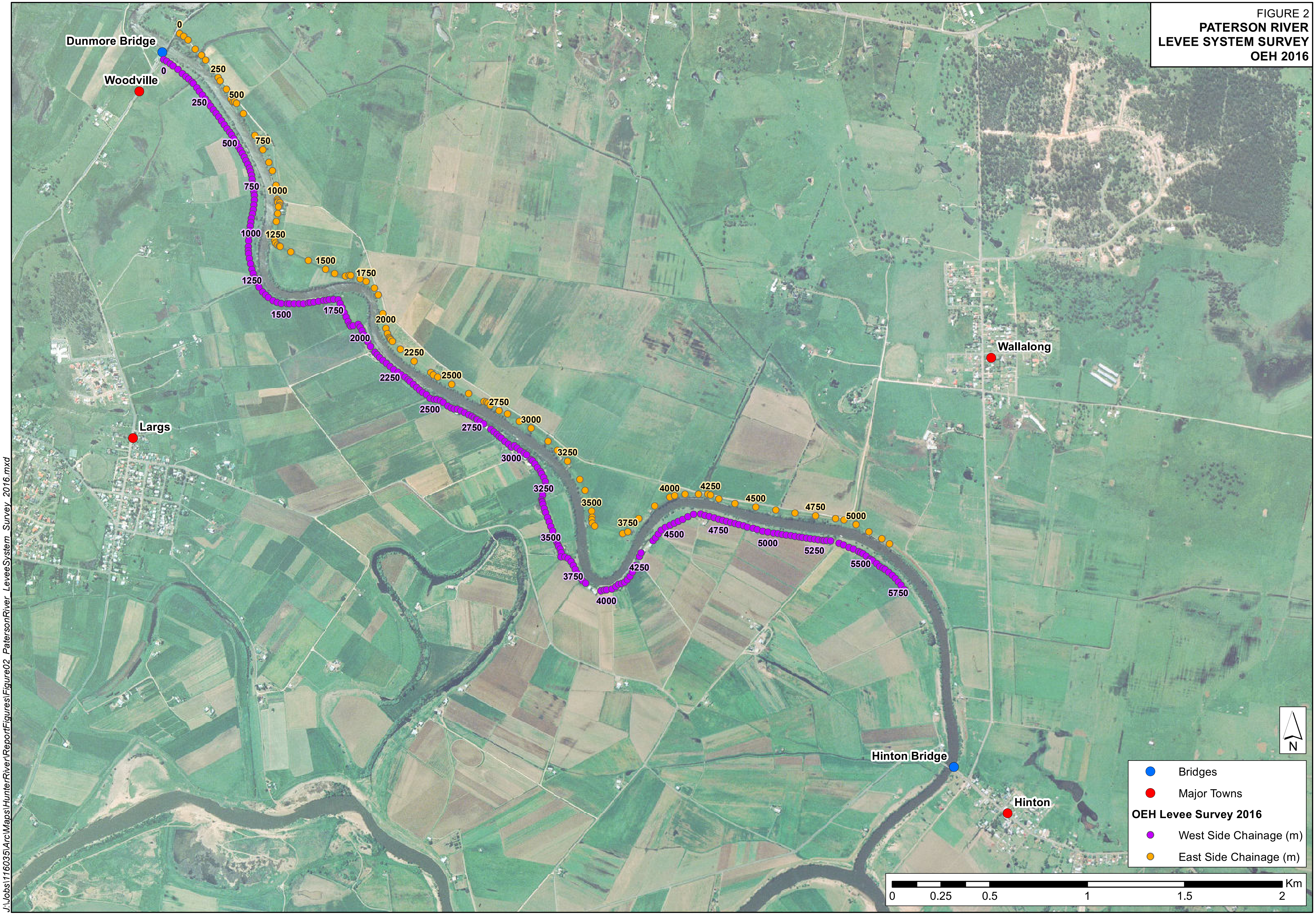

FIGURE 2
PATERSON RIVER LEVEE SYSTEM SURVEY OEH 2016

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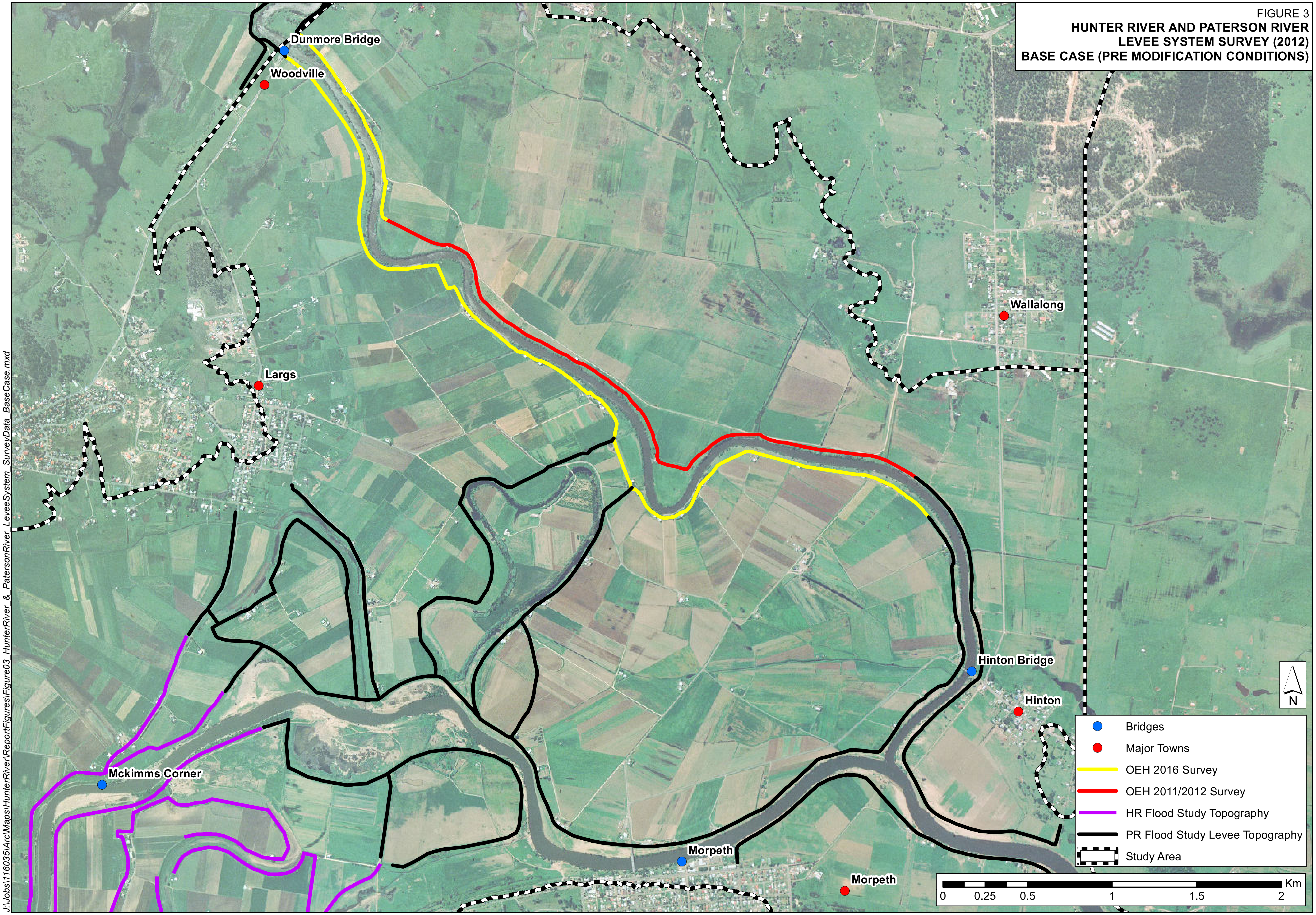
FIGURE 3
HUNTER RIVER AND PATERSON RIVER LEVEE SYSTEM SURVEY (2012) BASE CASE (PRE MODIFICATION CONDITIONS)



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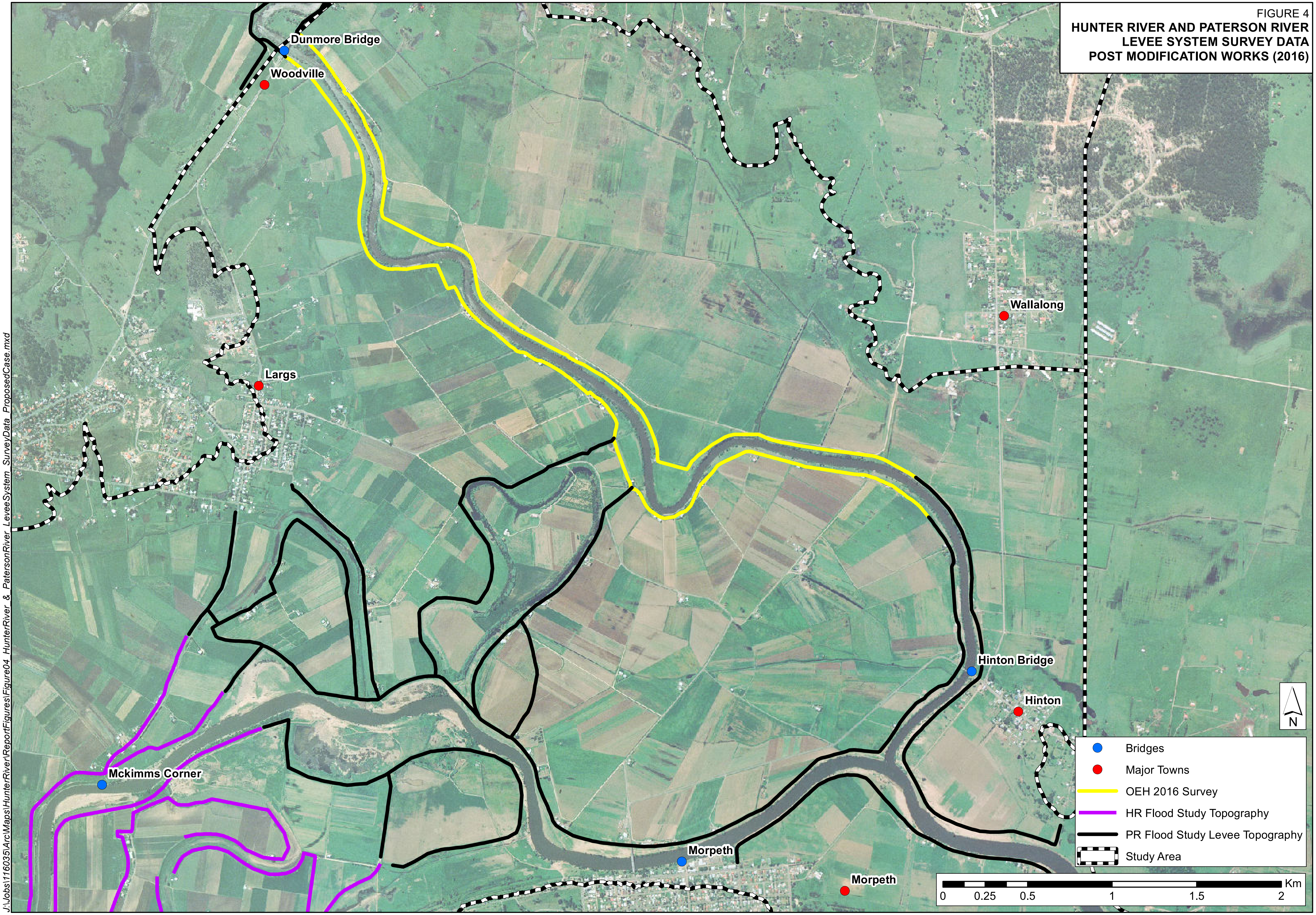

FIGURE 4
HUNTER RIVER AND PATERSON RIVER
LEVEE SYSTEM SURVEY DATA
POST MODIFICATION WORKS (2016)
Dunmore Bridge
Woodville
Wallalong
Largs
Hinton Bridge
Hinton
Mckimms Corner
Morpeth
Morpeth
N
Bridges
Major Towns
OEH 2016 Survey
HR Flood Study Topography
PR Flood Study Levee Topography
Study Area
0
0.25
0.5
1
1.5
2
Km
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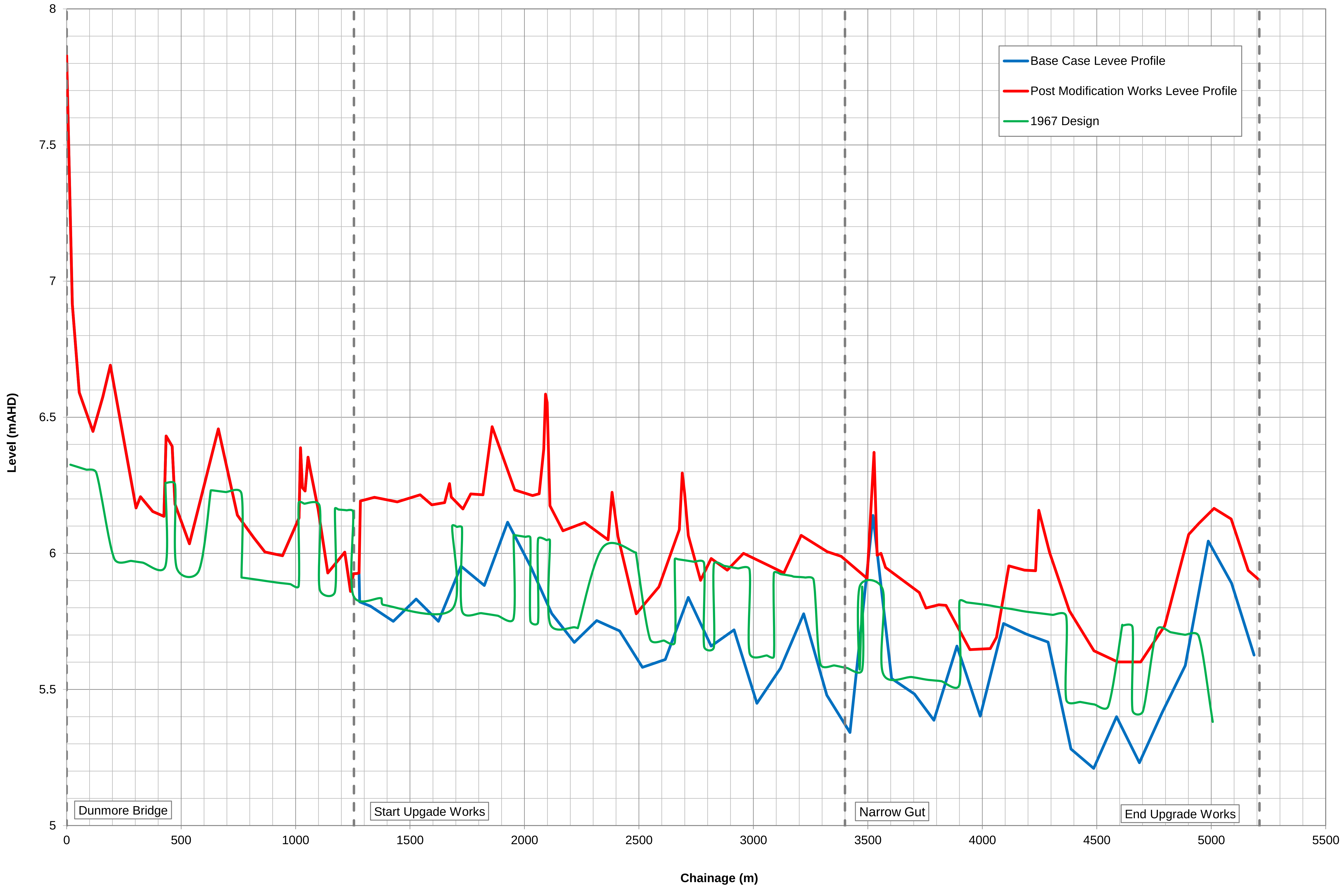
FIGURE 5

PATERSON RIVER LEVEE PROFILE
BASE CASE vs POST MODIFICATION WORKS
vs 1967 DESIGN



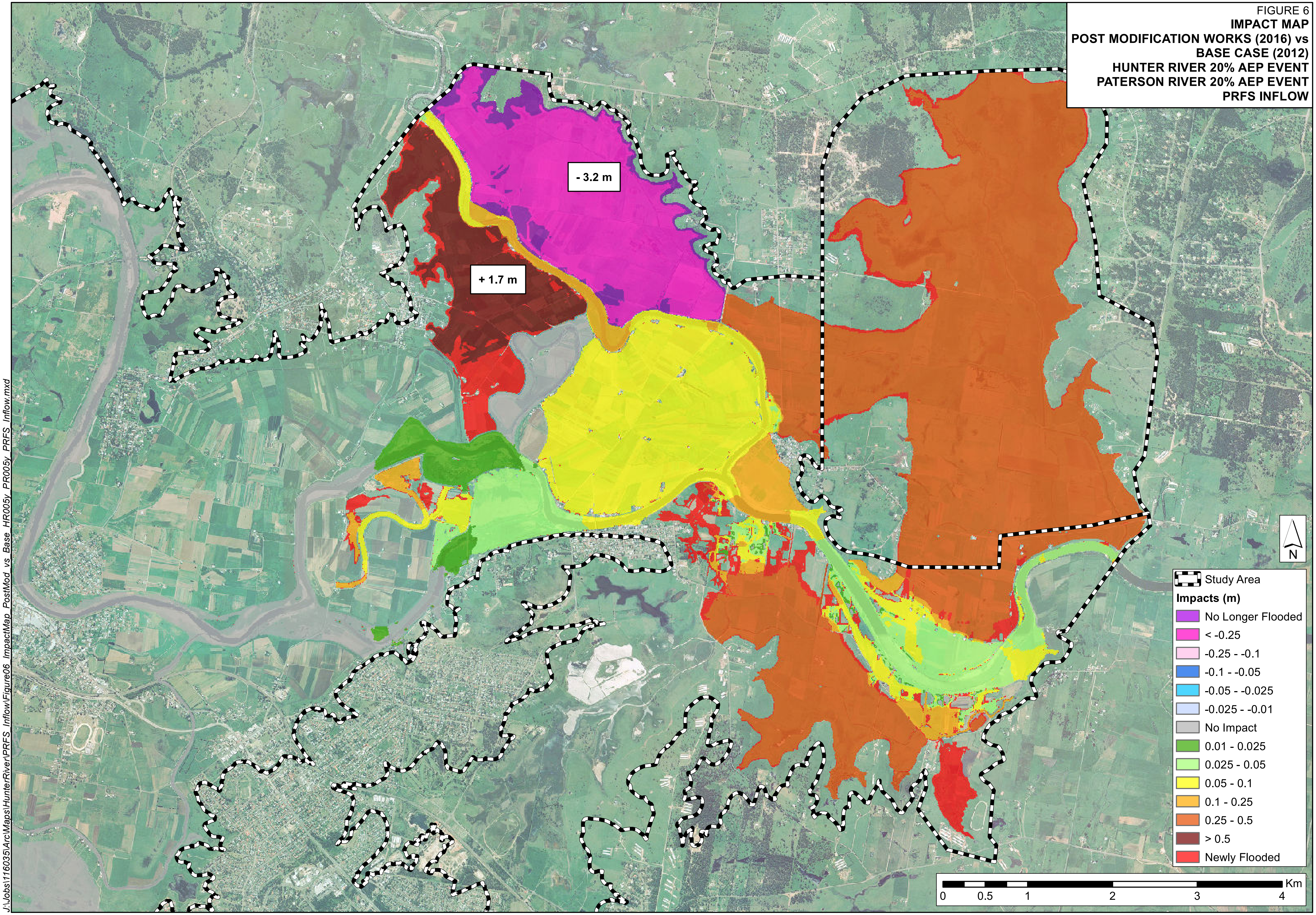


FIGURE 6
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 20% AEP EVENT
PRFS INFLOW
- 3.2 m
+ 1.7 m
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0
0.5
1
2
3
4
Km
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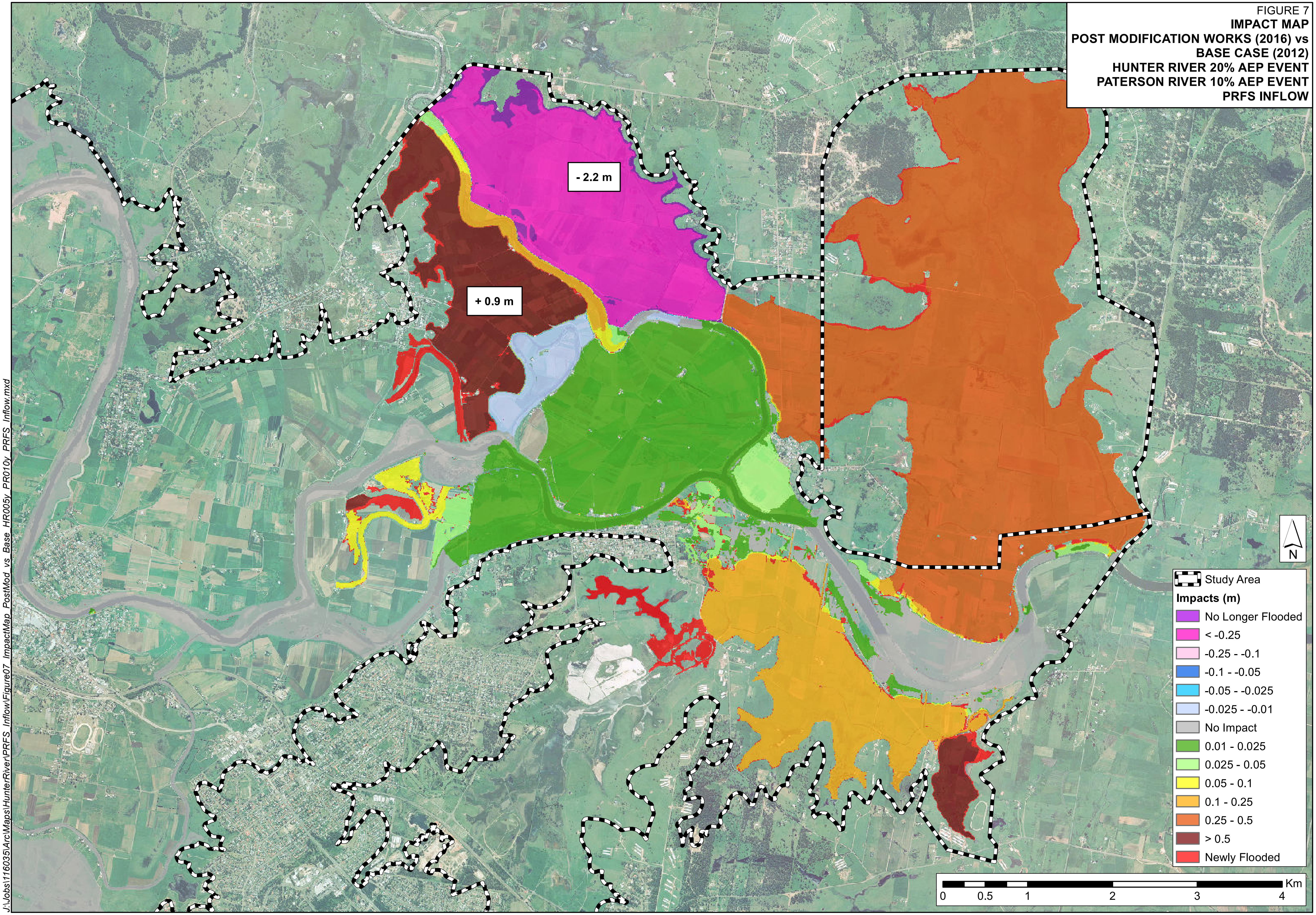

FIGURE 7
IMPACT MAP
POST MODIFICATION WORKS (2016) vs BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW

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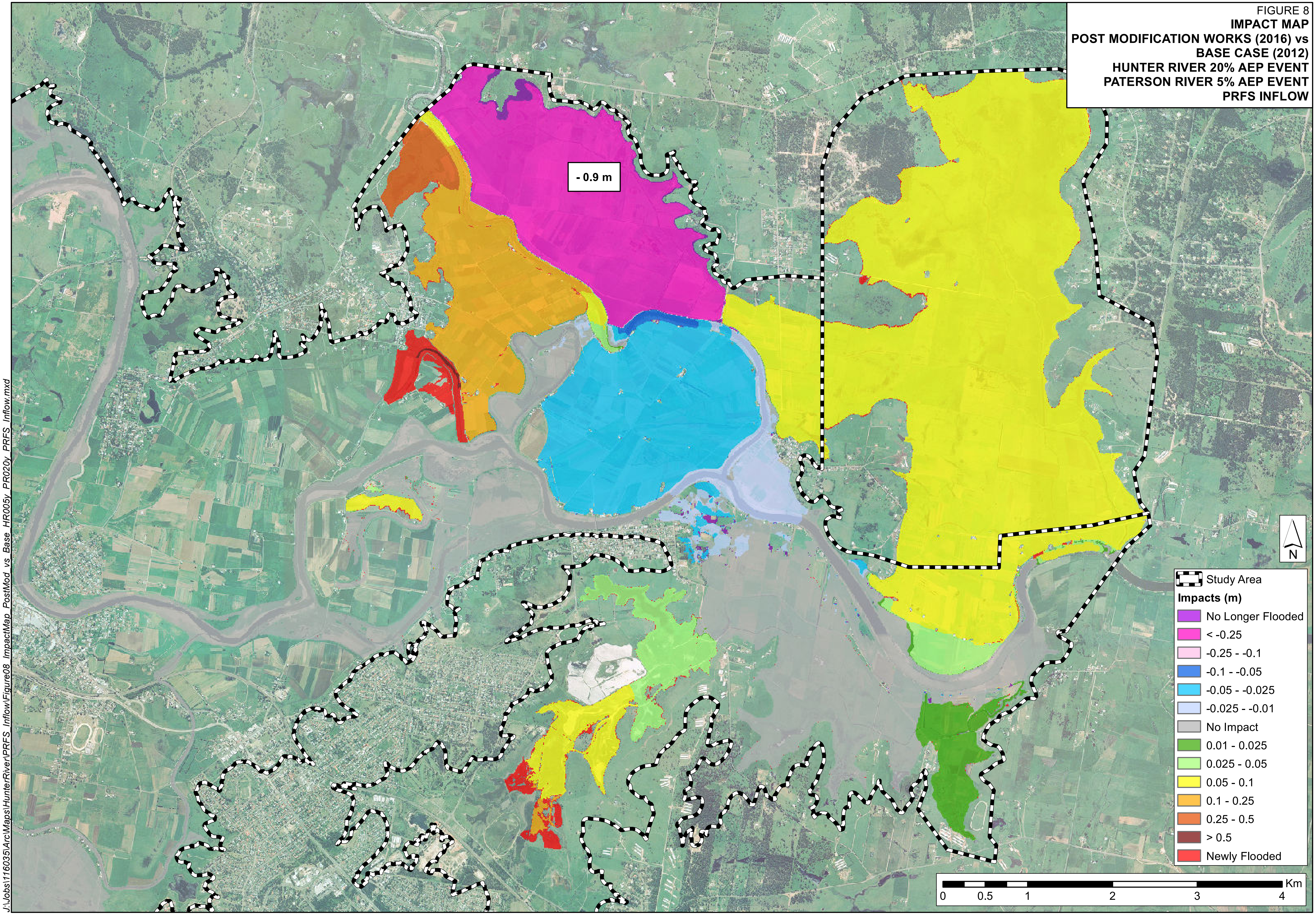

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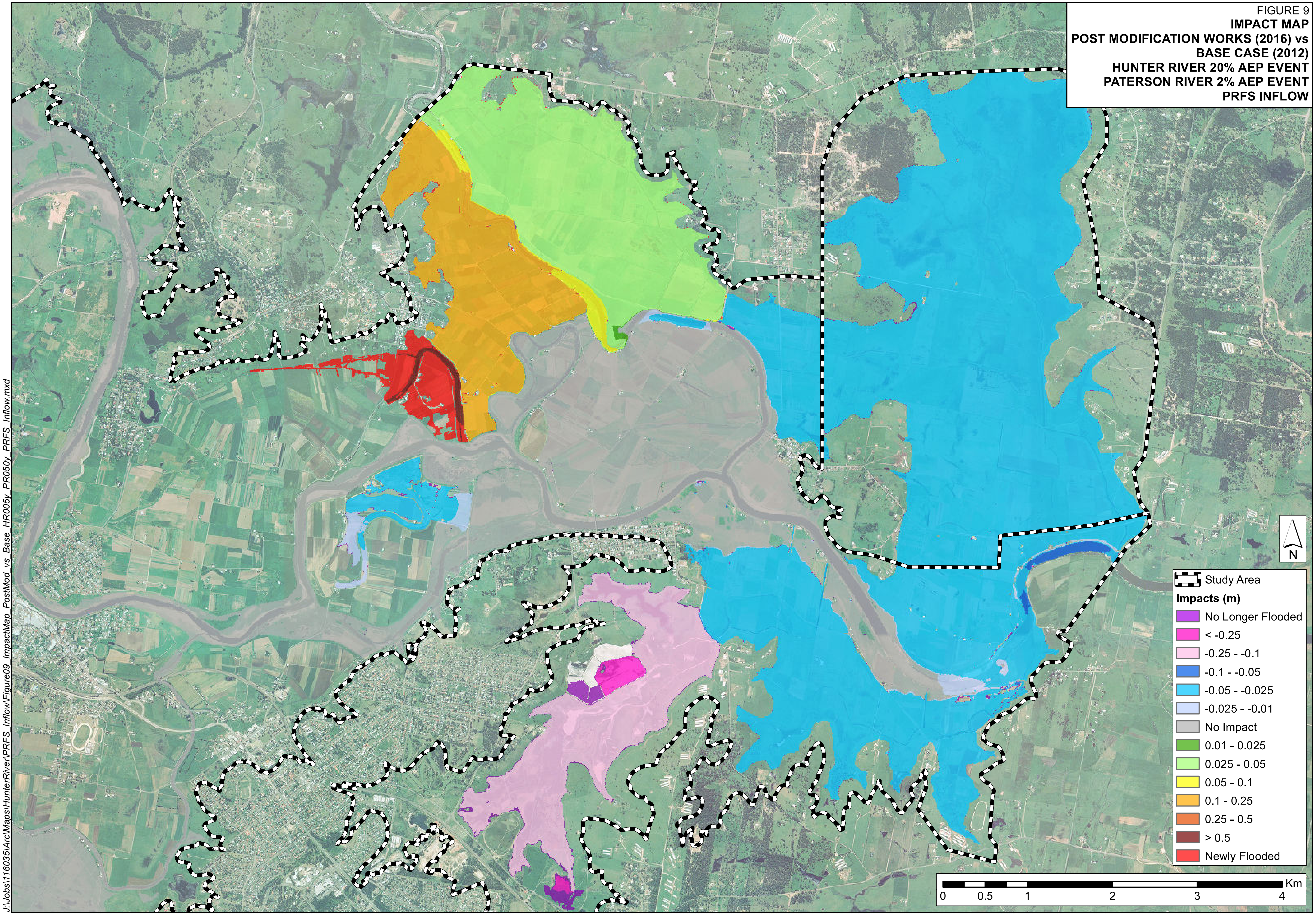

FIGURE 9
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 20% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW

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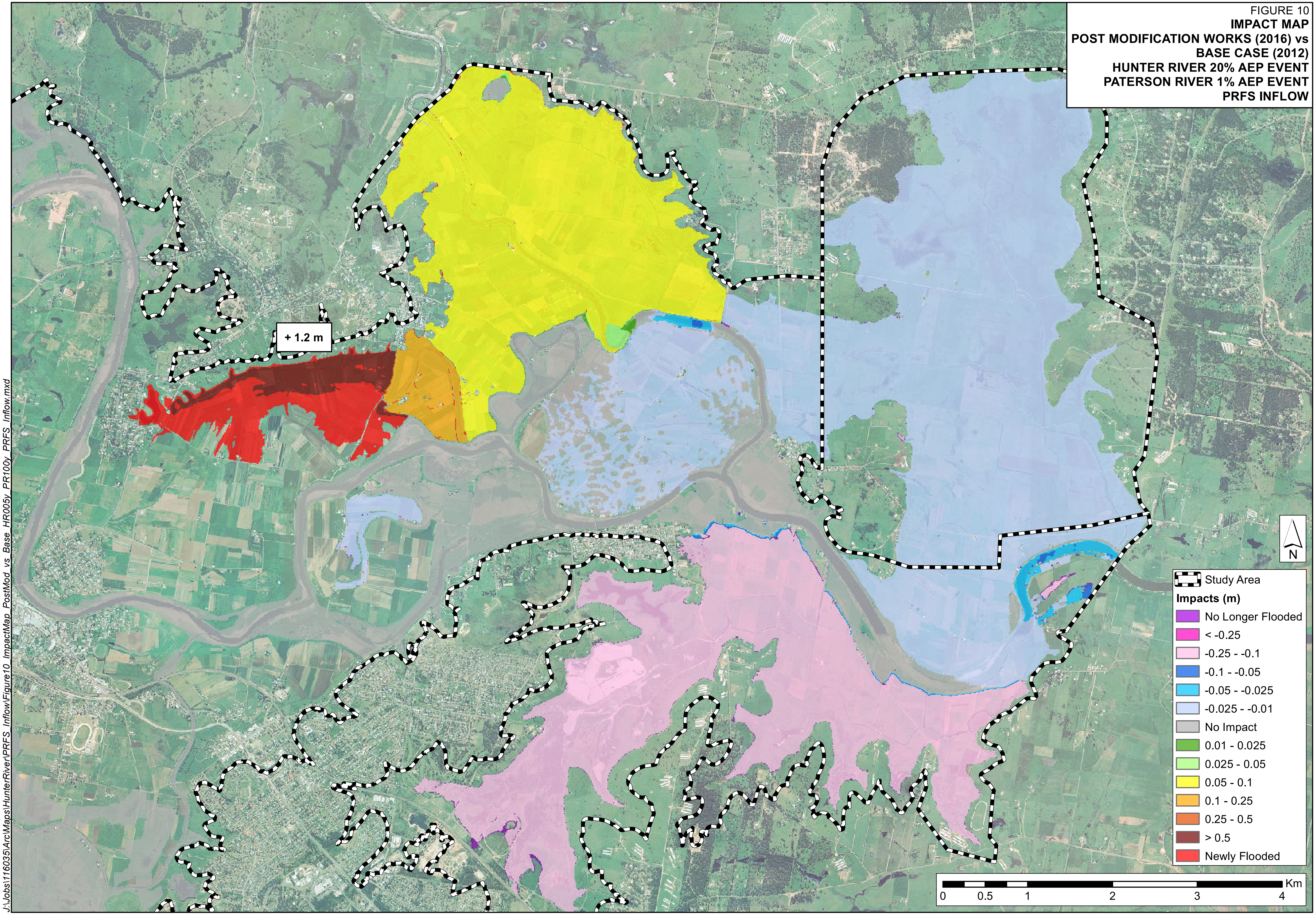

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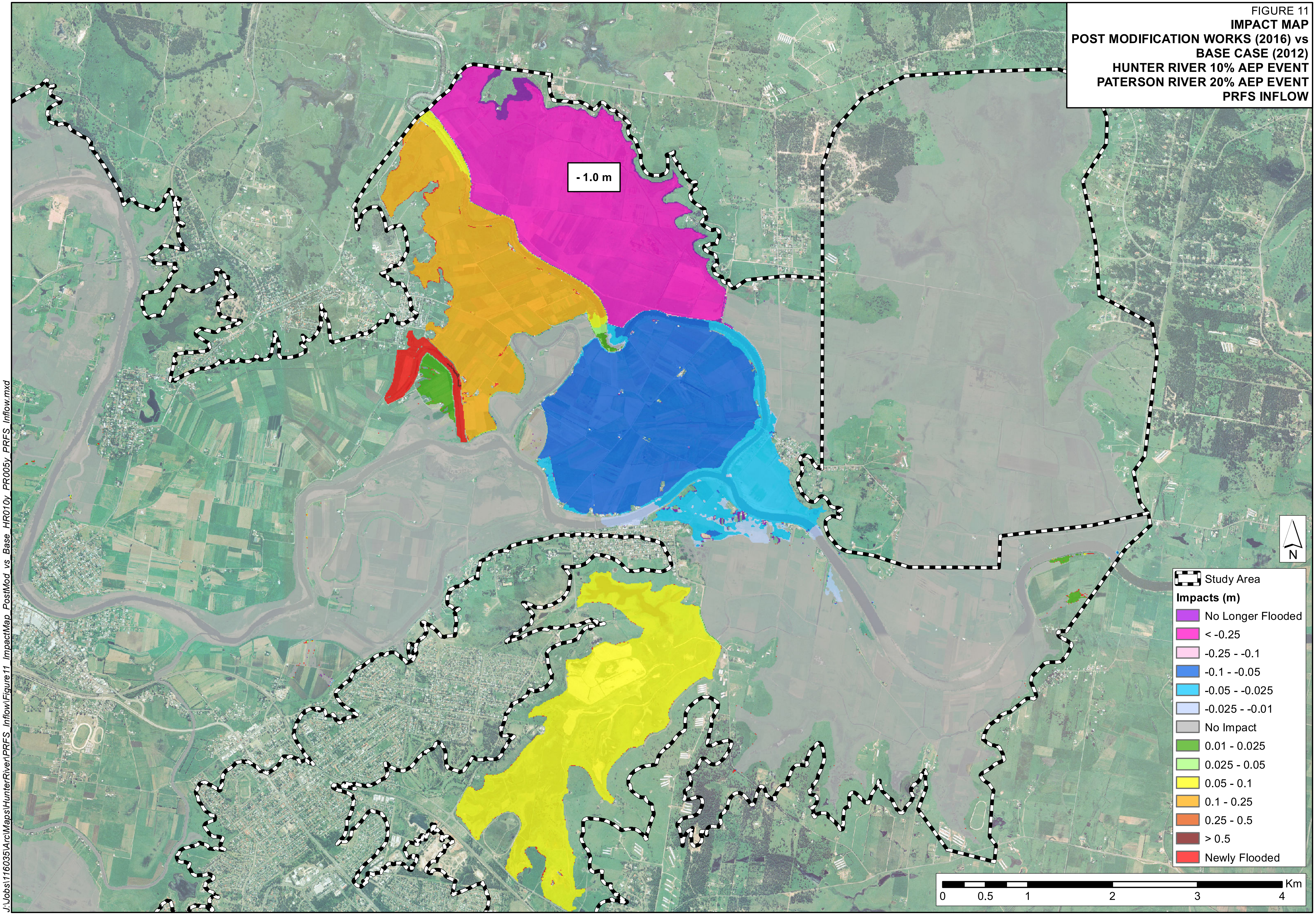

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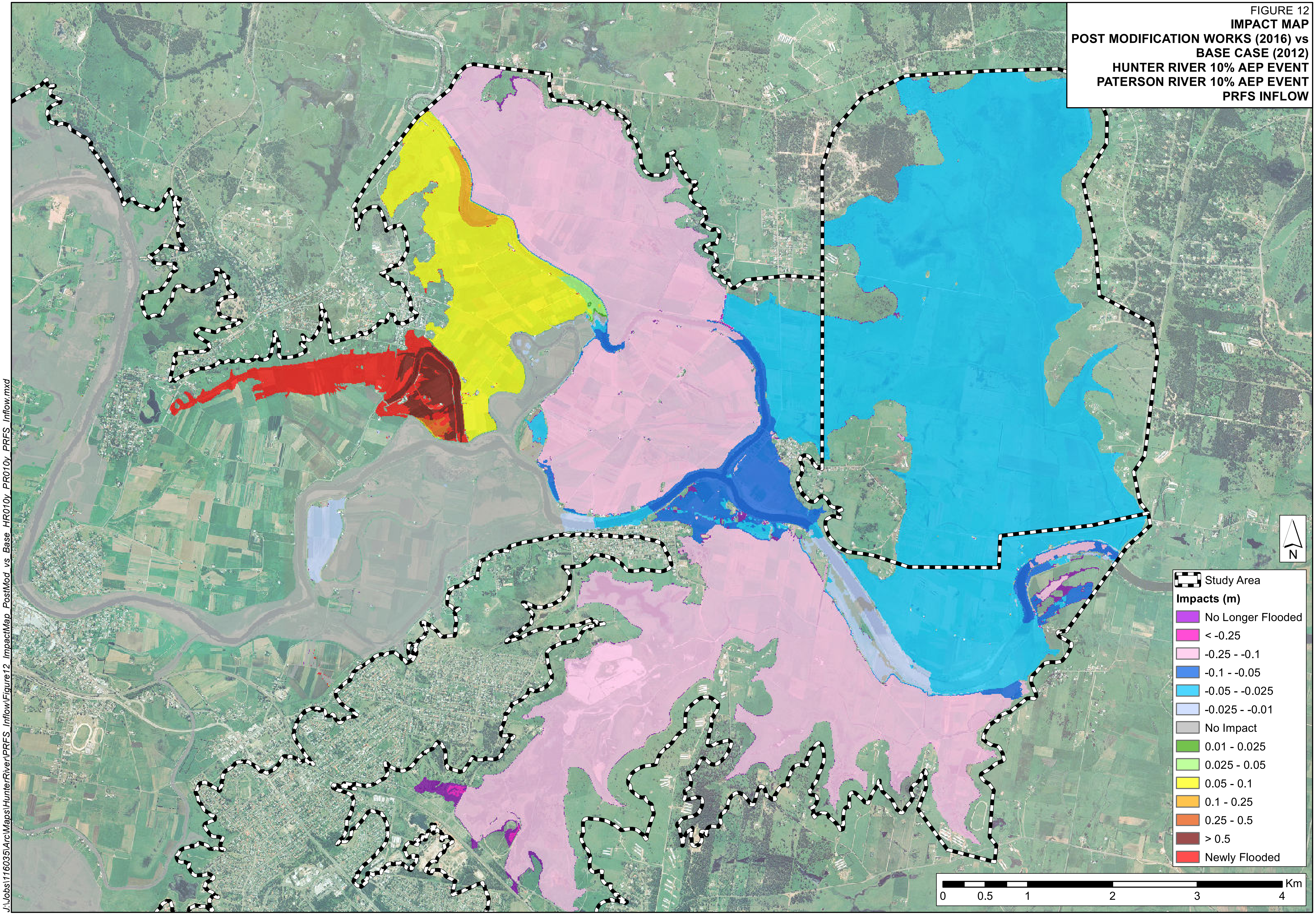

FIGURE 12
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 10% AEP EVENT
PRFS INFLOW
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0
0.5
1
2
3
4
Km
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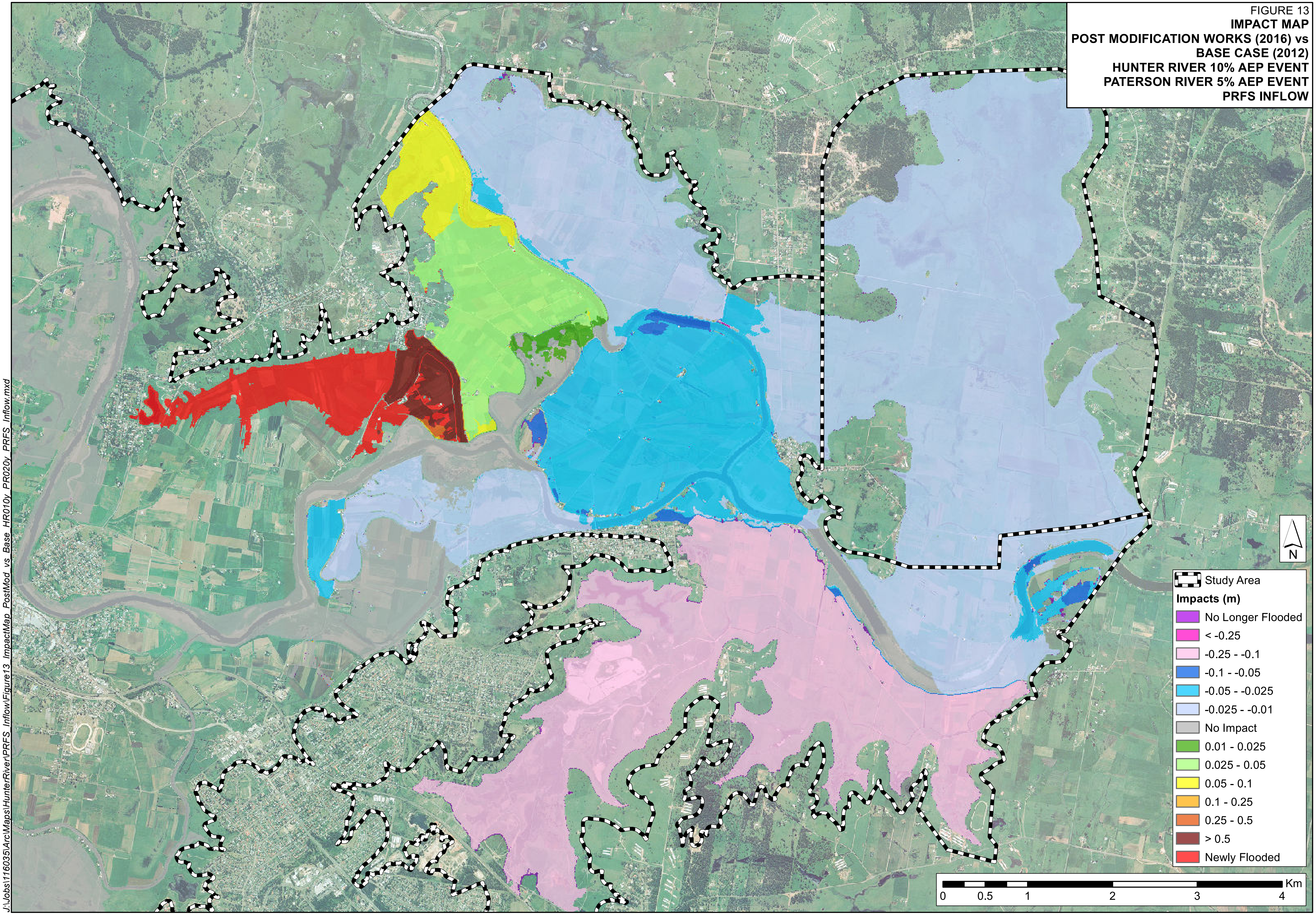

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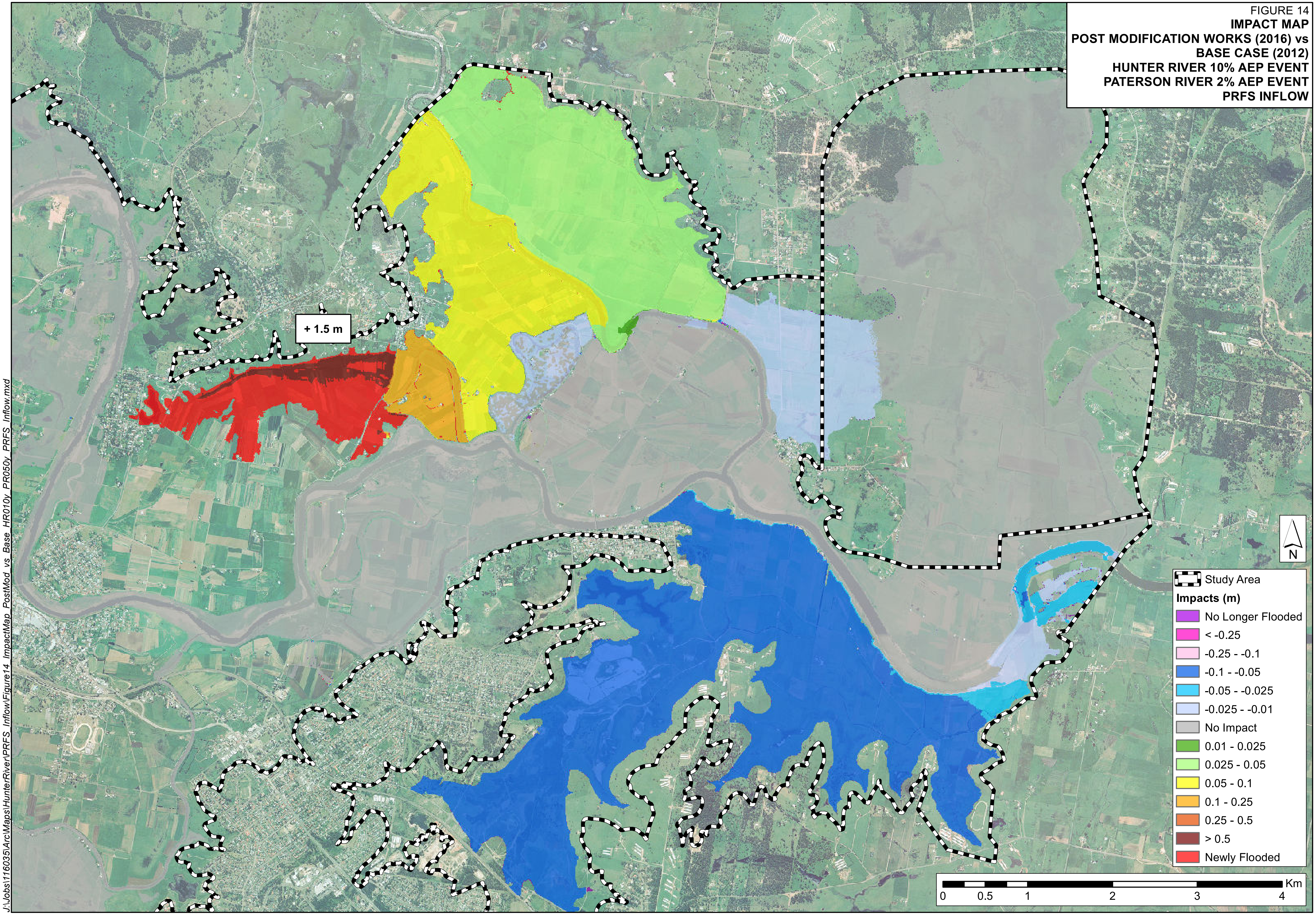
FIGURE 14
IMPACT MAP
POST MODIFICATION WORKS (2016) vs
BASE CASE (2012)
HUNTER RIVER 10% AEP EVENT
PATERSON RIVER 2% AEP EVENT
PRFS INFLOW
+ 1.5 m
N
Study Area
Impacts (m)
No Longer Flooded
< -0.25
-0.25 - -0.1
-0.1 - -0.05
-0.05 - -0.025
-0.025 - -0.01
No Impact
0.01 - 0.025
0.025 - 0.05
0.05 - 0.1
0.1 - 0.25
0.25 - 0.5
> 0.5
Newly Flooded
0 0.5 1 2 3 4
Km
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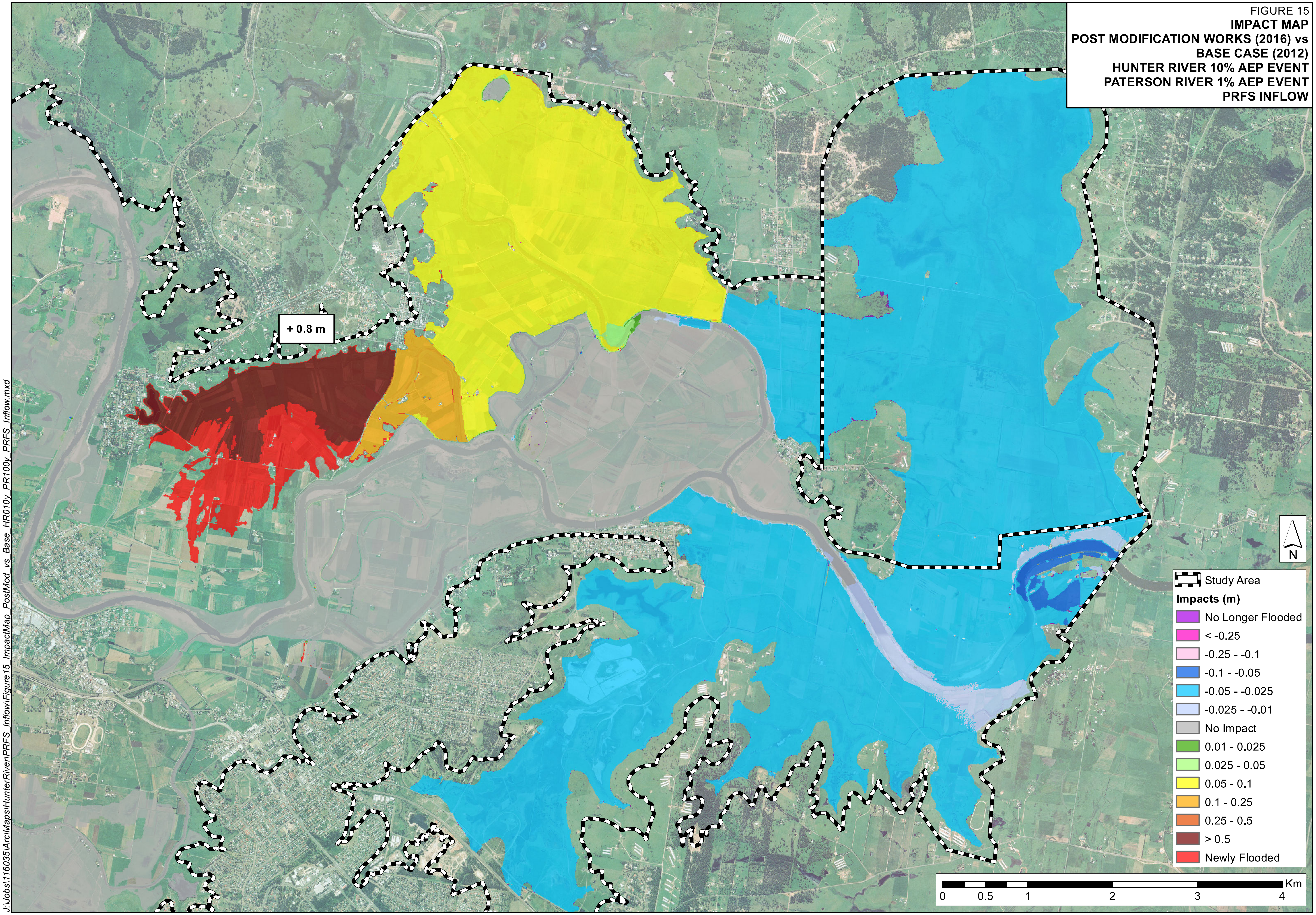

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