Project 3

NSW Forest Monitoring and Improvement Program

Baselines, drivers and trends for forest water catchments

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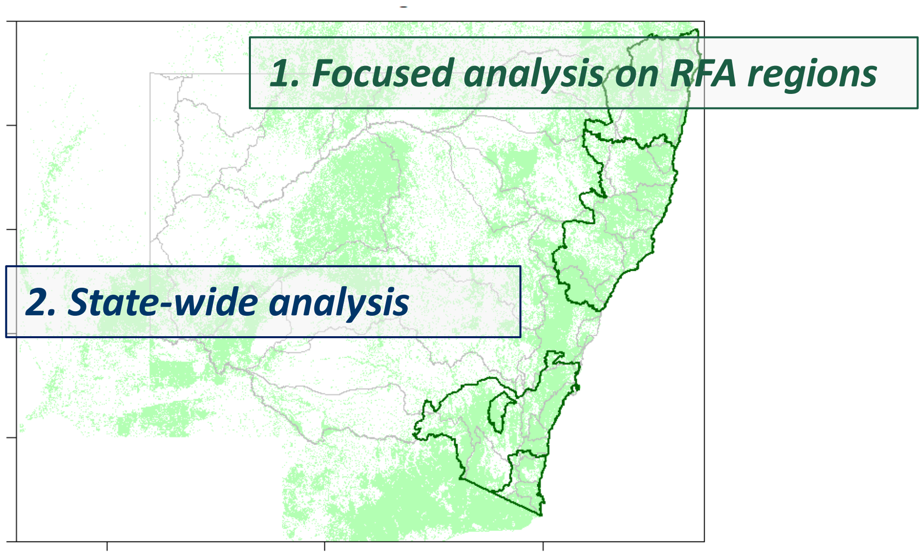
1. Project Overview

Stage 1 (2020-21)
Baselines, drivers and trends in water quality and quantity **within NSW Regional Forest Agreement (RFA) regions**

Extension (2021-22)
State-wide analysis and attribution of long-term trends in water quality and quantity

- Identify key indicators of water quantity and quality forested catchments
- Identifying long-term trends in key water quality/quantity indicators
- Attributing water quality/quantity trends to potential drivers including climate and disturbances



1. Project Highlights

Water data assessment across RFA and the entire state

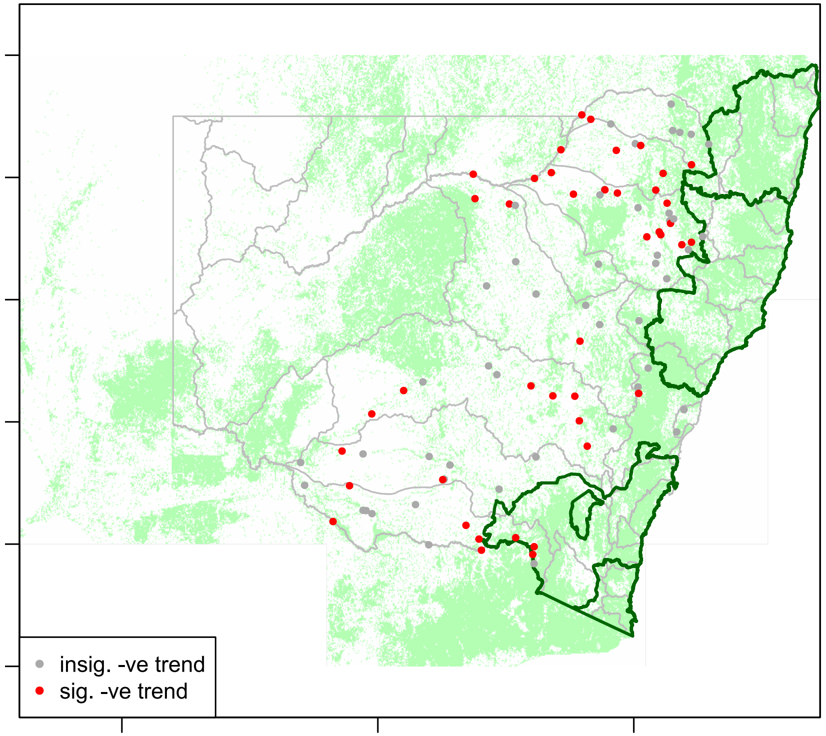
- Compiled water monitoring data across three agencies, including previously inaccessible archival data reaching back decades, in a form ready for analysis and interpretation

- Comprehensive assessed water data availability across the RFA areas – the outcomes are already being used across several NRC projects

Large-scale state-wide trend and attribution analyses

- Identified long-term trends in water quality and quantity across NSW, within focuses on 1) the RFA regions only and 2) a state-wide synthesis

- Identified novel statistical approaches to explain historical changes in water quantity and link them to key catchment disturbances of bushfire and climate variability



2. Data

Input data for water quality/quantity

Water quality and quantity data across NSW were extracted from:
WaterNSW, Forestry Corporation of NSW (FCNSW) and BoM Water Data Online (WDO)

Data variable extracted were informed by the key water quality/quantity indicators that we identified in project Stage 1

Water Quantity trend analysis (*Flow*) :

- Focusing on sites with >35 year high-quality daily streamflow data (>=350 days per year)

Water Quality trend analysis (*EC, WTemp, DO, pH, Turb, TP, TN*):

- Focusing on sites with >10 year high-quality data for each variable (>=4 records per year)

2. Data

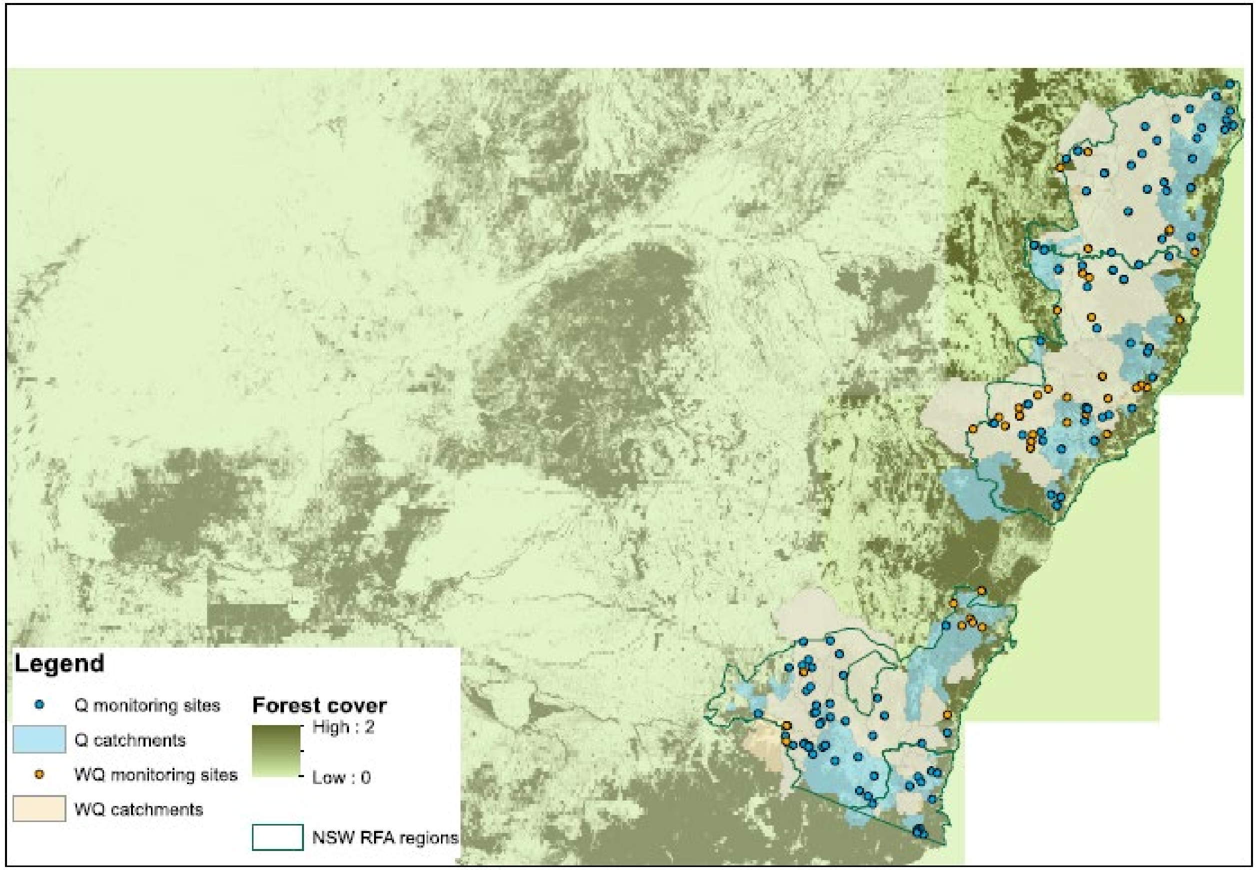
Long-term Water Monitoring Sites and their Contributing Catchments

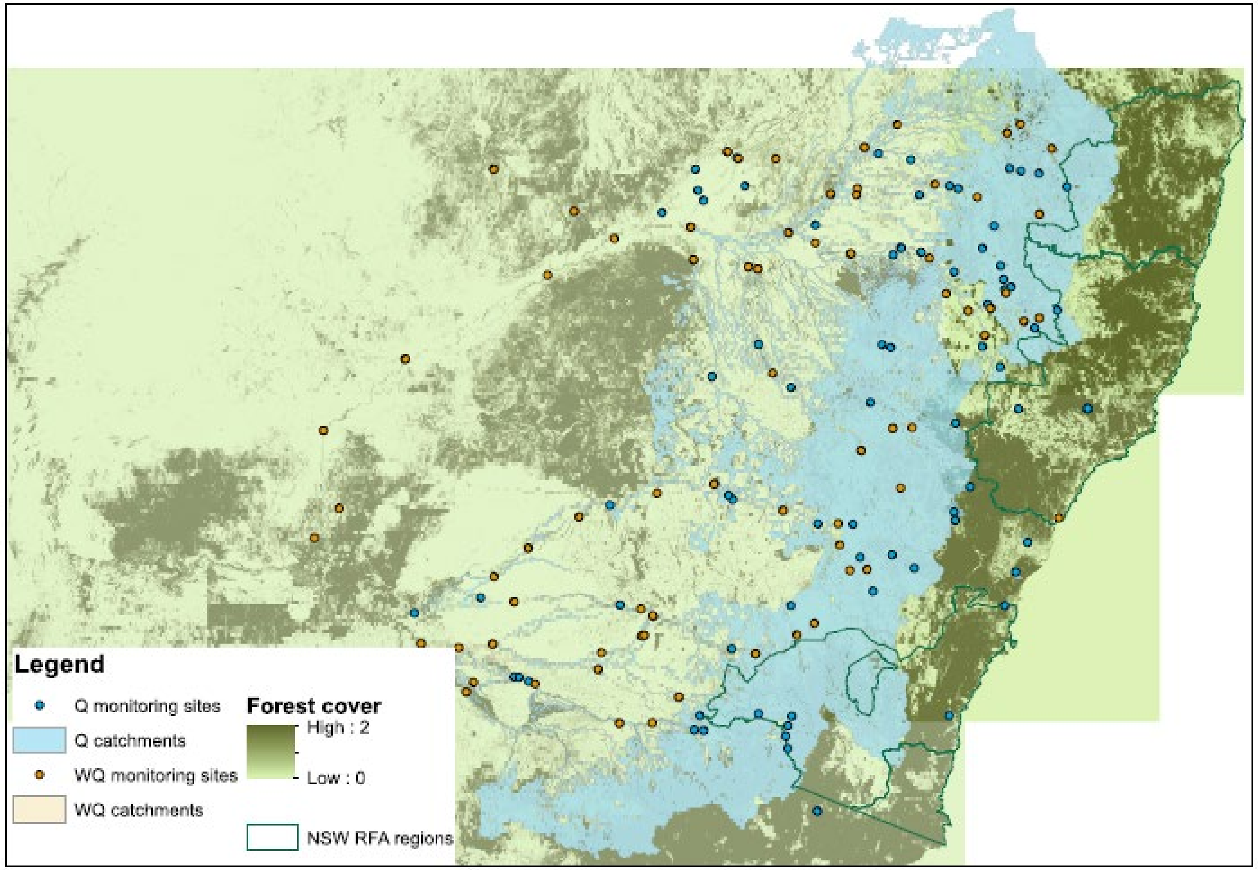
Within RFA:

- 75 long-term flow monitoring sites
- 42 long-term water quality monitoring sites

Outside RFA:

- 90 long-term flow monitoring sites
- 59 long-term water quality monitoring sites





3. Methods

Identifying key water quality/quantity indicators for NSW forested catchments

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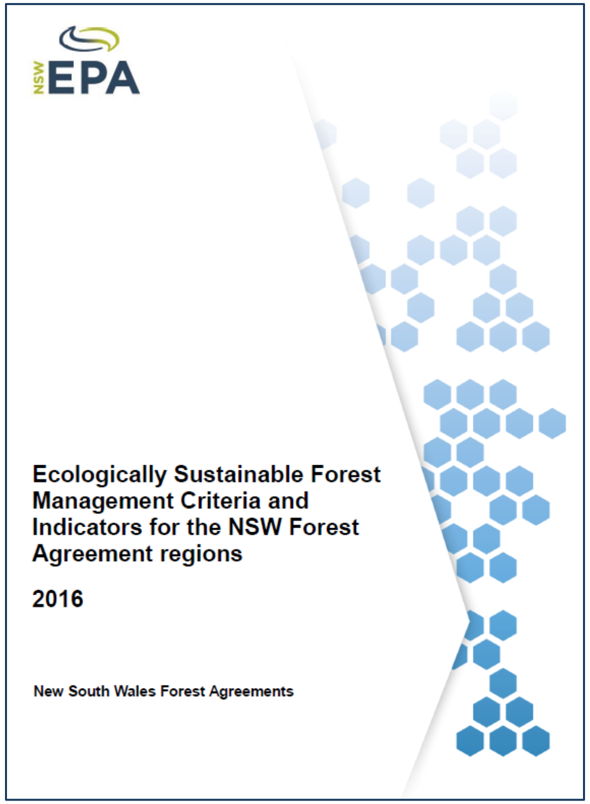
- A comprehensive literature review to identify the key indicators of water quality and quantity in NSW forested catchments, which should be considered in the trend analyses in the subsequent analyses.

- **Key topics/literature reviewed:**

1) Montreal Framework on sustainable forest management
2) Australian/NSW water quality guidelines – ANZECC water quality guidelines and NSW water quality objectives (WQO)
3) Existing literature on the key forest stressors on water quality and quantity


NSW EPA

Ecologically Sustainable Forest Management Criteria and Indicators for the NSW Forest Agreement regions

2016

New South Wales Forest Agreements

Australian Government Initiative

Australian & New Zealand GUIDELINES FOR FRESH & MARINE WATER QUALITY

Australian and New Zealand Guidelines for Fresh and Marine Water Quality

3. Methods

Identifying key water quality/quantity indicators for NSW forested catchments

- **Selection criteria for the key water quality/quantity indicators**

1) sensitivity to forest management
2) suitability and availability of data for landscape-scale assessment
3) statistical power of data analyses
4) effort required for future monitoring

Indicator (category and specific variable)	Link and sensitivity to forest stressors (summarised in Section 3.2)	Impacts on forest health concerns	Relevance at a landscape scale	Existing monitoring programs, preferably at a landscape scale	Known data statistical properties of indicator and implications on how well they represent forest health	Consistency of data type, resolution and analytical method with other indicators	Ease of data collection
TP (mg/L)	Forest wildfires can increase nutrient losses and soil erosion (Meyer et al., 2001), and pollutants loading (Martin et al., 2016). Also, vegetation mortality due to fires reduces canopy interception, ET, as well as nutrient and water uptake. Forest maturity: mature	High levels can lead to aquatic system impacts - Nuisance aquatic plants.	Suitable for landscape assessment – as recommended by both ANZECC and NSW WQO.	Within RFA regions: 33 sites have quarterly data over recent 10 years. Only spot-data available, on average 10 samples per year. (WaterNSW)	No notable issues with statistical representativeness. Note the need of removal of seasonal and streamflow effects for trend analyses.	Assessing compliance: Comparing with chemical guideline values Assessing trends: Simple trend analyses/ time-based regression models. Uncertainty on the trend	Often monitored with grab sampling and lab analyses – can be labour intensive and challenging to maintain over long term.

3. Methods

Identifying key water quality/quantity indicators for NSW forested catchments

- **Selected key indicators for subsequent analyses**

Water quality:

✓ *Total phosphorus (TP)*

✓ *Total nitrogen (TN)*

✓ *Dissolved oxygen (DO)*

✓ *pH*

✓ *Electrical conductivity (EC)*

✓ *Turbidity (Turb)*

✓ *Water Temperature (WTemp)*

Water quantity:

✓ *Signatures of continuous flow data (annual flow, flow quantiles 10^{th} and 90^{th})*

✓ *Indicators of climate-streamflow relationship (flow vs. rainfall relationship)*

✓ *Indicators of catchment storage and hydrologic regime (7-day low-flow/CTF days)*

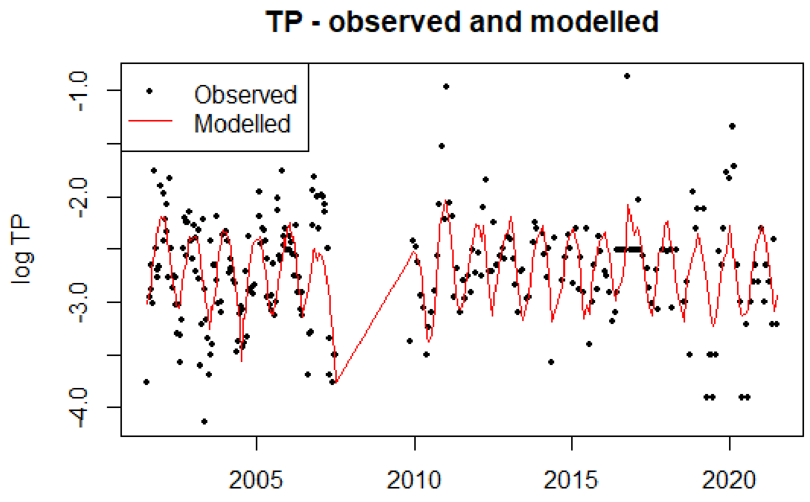
3. Methods

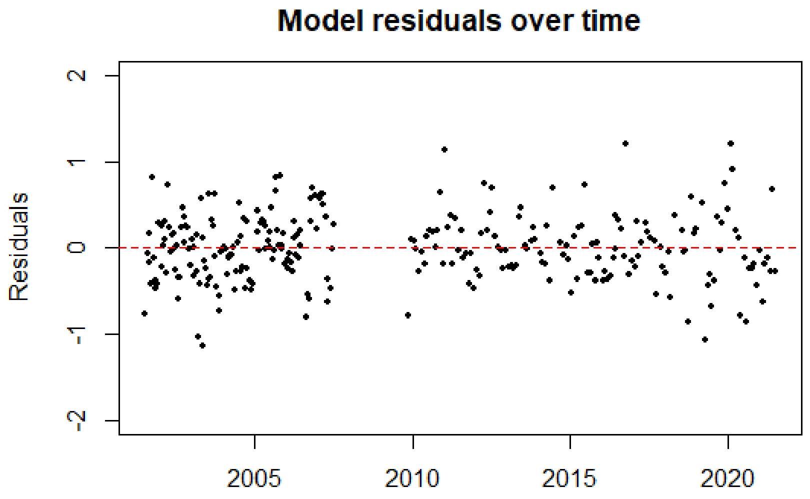
Statistical Analyses for Long-term Trends

Water Quality – Temporal Regression on the time-series of monitoring data

$$\log(C_t) = t \times \beta_{tC} + f(\log(Q_t)) \times \beta_Q + f(seasonality) \times \beta_{seasonality} + f(\varepsilon_C)$$

Direction & magnitude





Water quality indicators:

- ✓*Total phosphorus (TP)*
- ✓*Total nitrogen (TN)*
- ✓*Dissolved oxygen (DO)*
- ✓*pH*
- ✓*Electrical conductivity (EC)*
- ✓*Turbidity (Turb)*
- ✓*Water Temperature (WTemp)*

✓*The multi-regression model is capable to capture non-linear dynamics*

✓*Assumption of linear trend is carefully validated by residual checks*

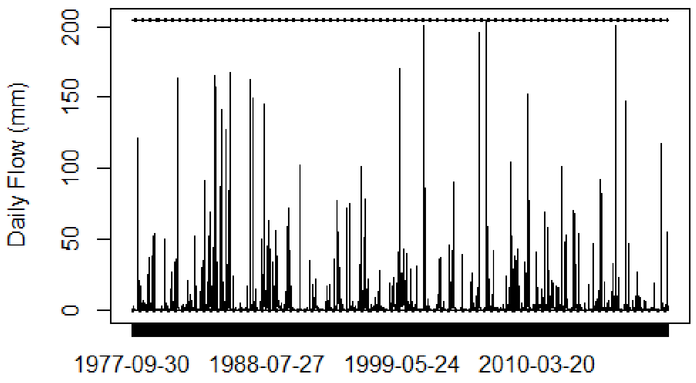
3. Methods

Statistical Analyses for Long-term Trends

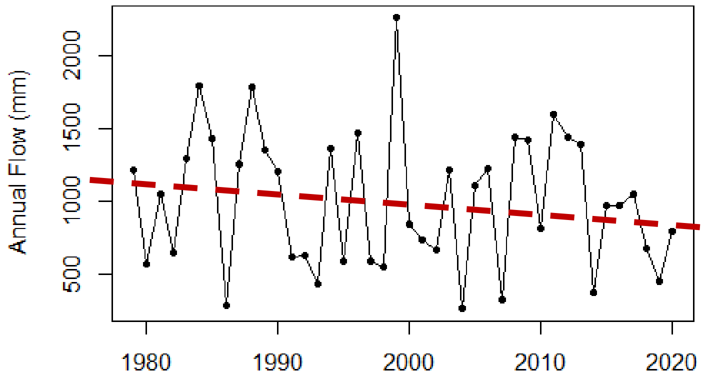
Water Quantity – Non-parametric Trend Tests performed in annual step (aggregated from daily).

- *Mann-Kendall (MK) (direction)*
- *Sen's Slope (magnitude)*

Raw Daily Flow Time-series



Annual Flow / Other Summaries…



Water quantity indicators:

- ✓ *Signatures of continuous flow data (annual flow, flow quantiles 10th and 90th)*
- ✓ *Indicators of climate-streamflow relationship (flow vs. rainfall relationship)*
- ✓ *Indicators of catchment storage and hydrologic regime (7-day low-flow/CTF days)*

✓*Annual scale is appropriate with respect to the long-term data we focus on*

✓*We consider different periods of assessment to overcome the limitation of this monotonic trend model*

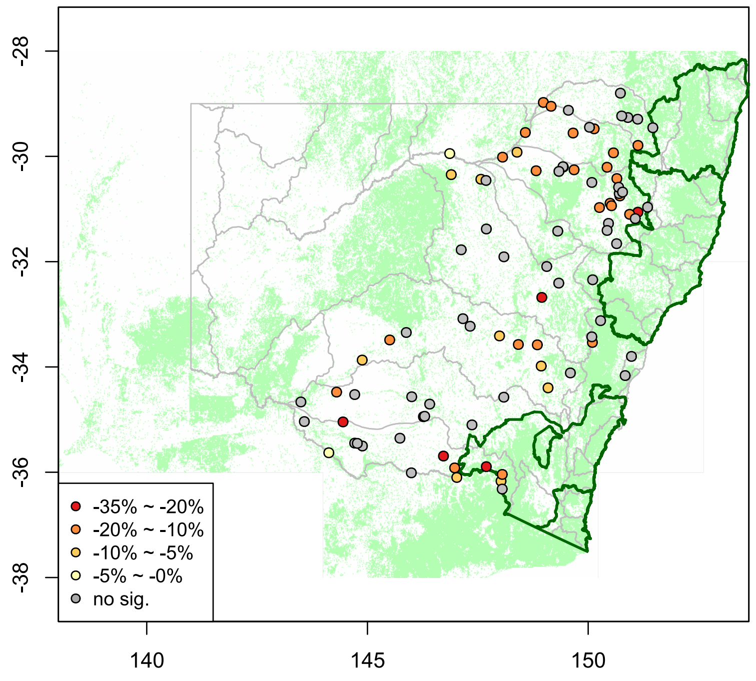
✓*These trend approaches are commonly used to summarize large-scale trend patterns*

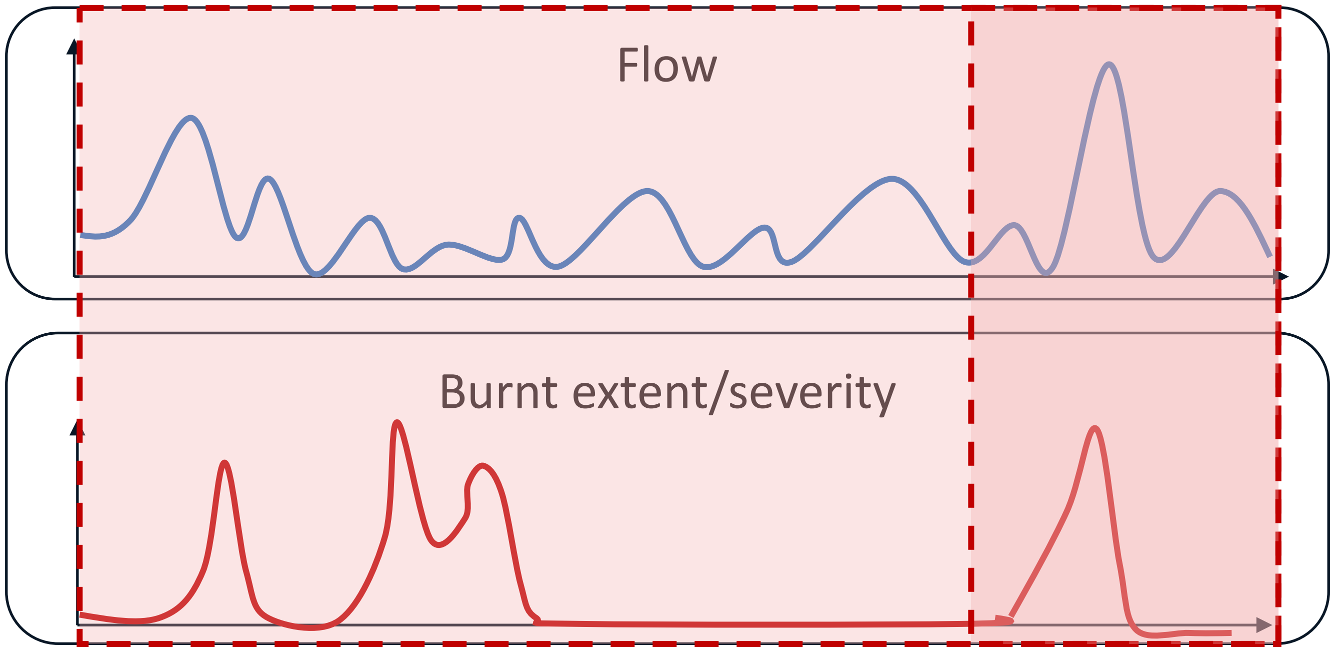
3. Methods

Trend Attribution

1. Linking spatial differences in flow trends to catchment characteristics
2. Assessing the impact of 2019/2020 fire on water quantity/quality
3. Linking historical temporal changes in flow to catchment disturbances

Trend magnitude (% flow decline/year)

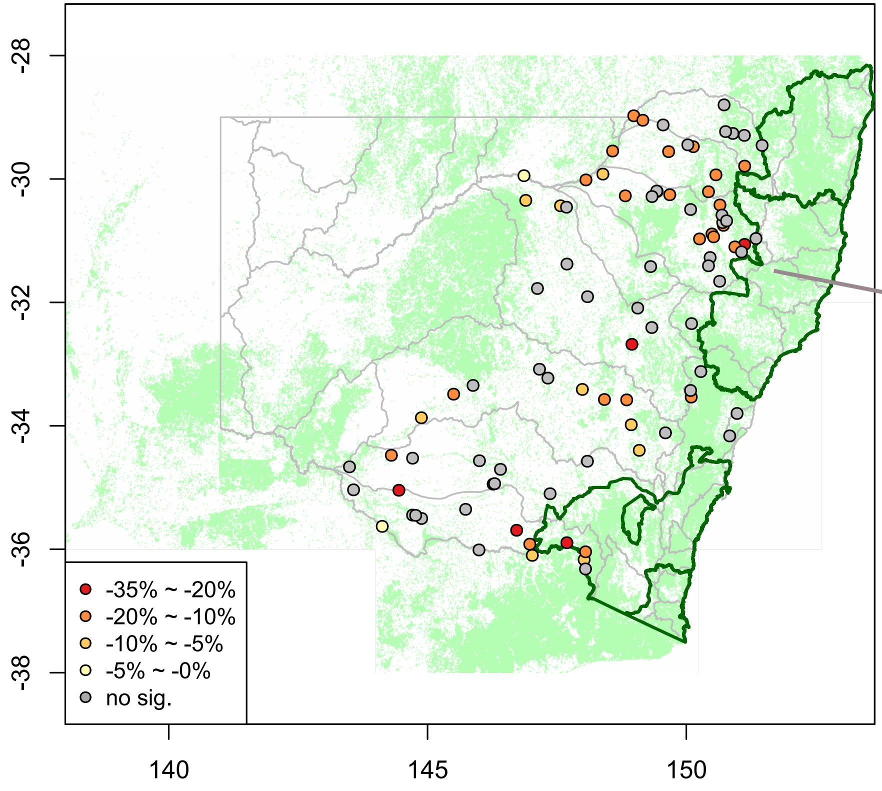




3. Methods

Trend Attribution – linking spatial differences in trends to catchment characteristics (for outside-RFA sites only)

Trend magnitude (% flow decline/year)



Multi-variate analysis to identify the most important drivers

(brute-force search for the best predictors of trends)

Catchment land use
(% grazing land, % agriculture, % plantation forest etc.)

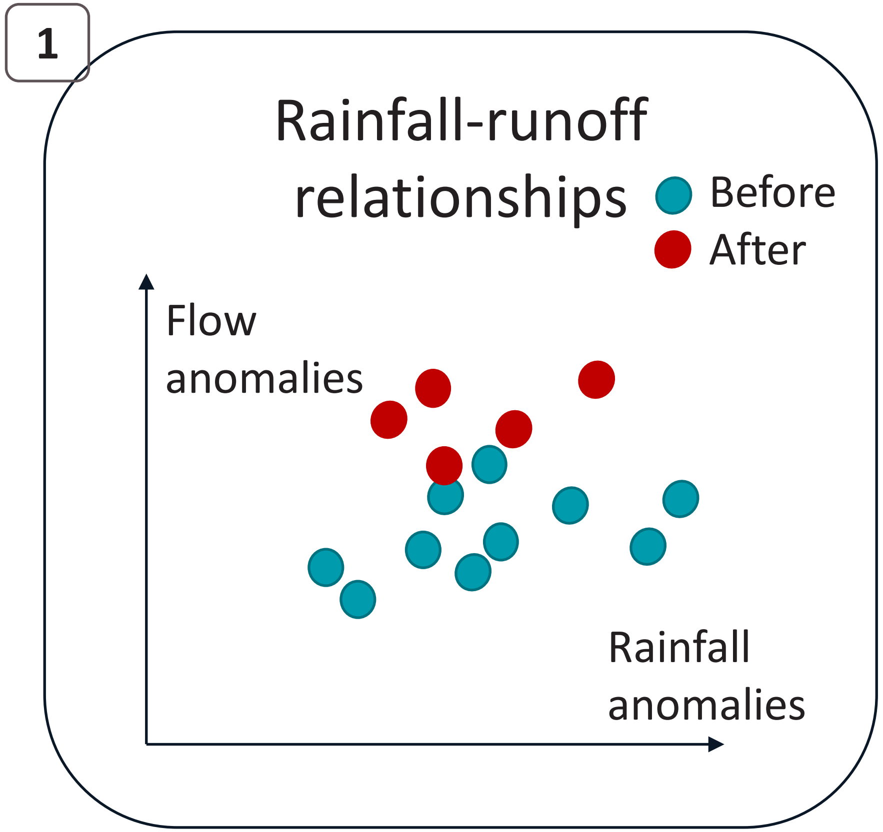
Catchment tenure
(% private, % state forest etc.)

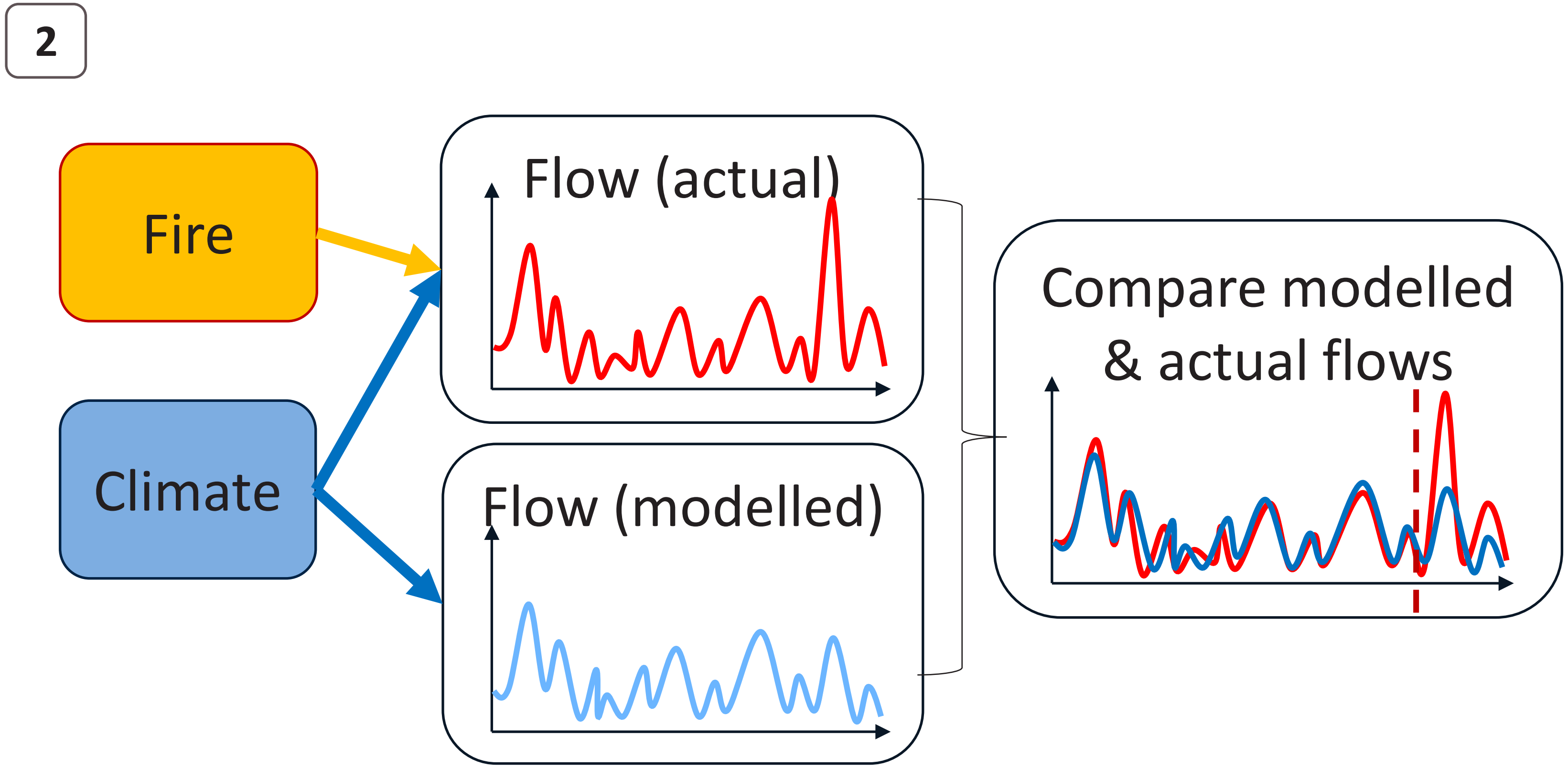
Catchment land cover
(forest or non-forest, NDVI)

Catchment climate/hydrology
(mean annual flow, mean annual rainfall etc.)

3. Methods

Trend Attribution – assessing the impact of 2019/2020 fire



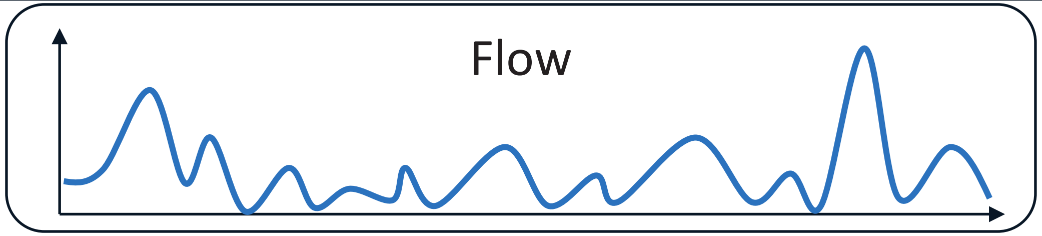


- Using both direct data-interpretation and a model-based approach to identify changes in rainfall-runoff relationship across pre/post fire periods
- Focusing only on 9 undisturbed catchments with the highest fire intensity & largest areas burnt in 19/20 event
- There was very limited water quality data on severely burnt catchments – investigated with individual case studies comparing flow, concentration and fire occurrence

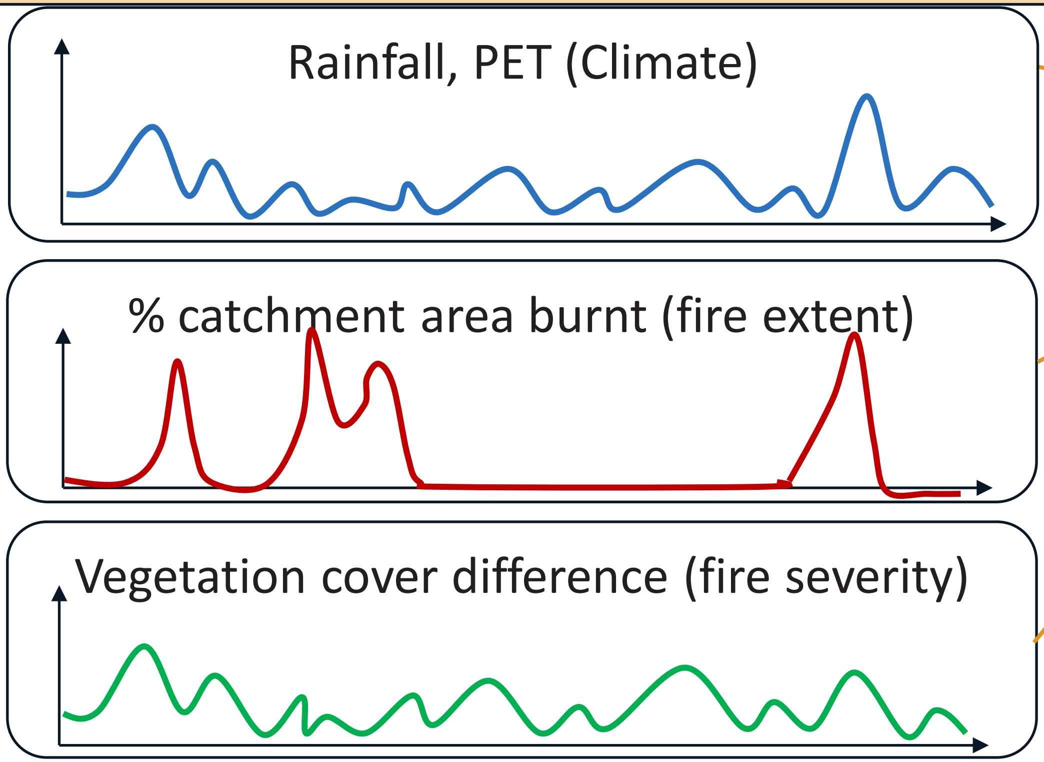
3. Methods

Trend Attribution – linking temporal changes to catchment disturbances

Temporal changes of interest



Driving variables



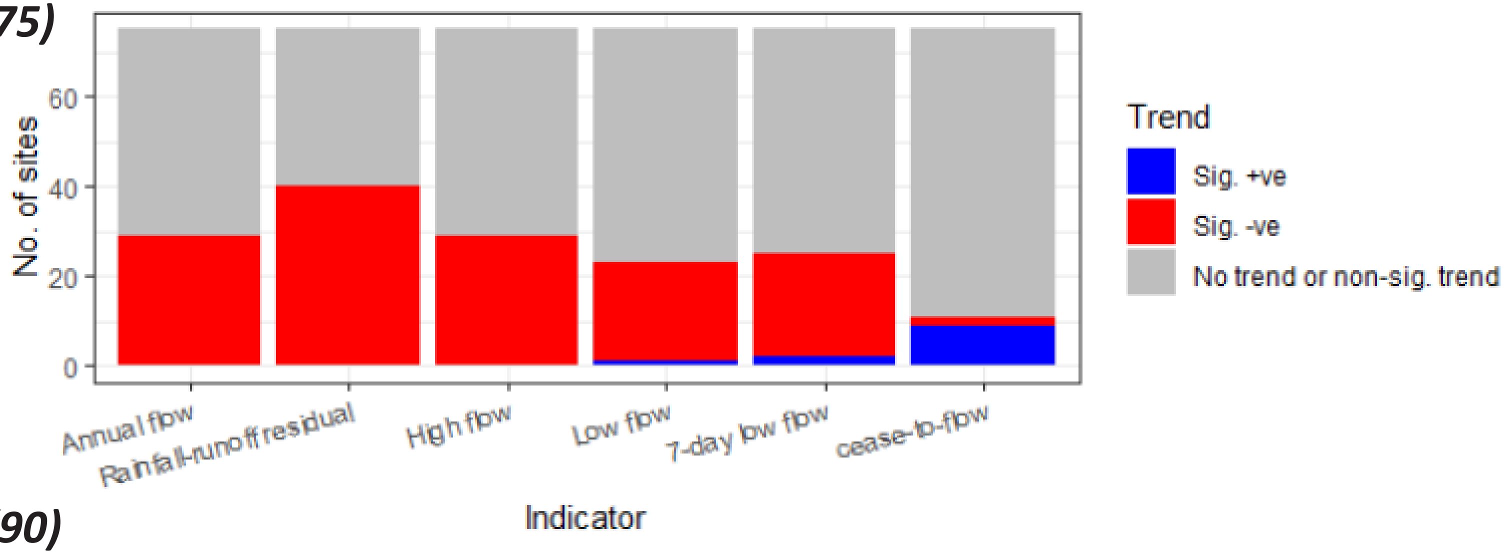
Multi-variate analysis (e.g., Random forest) to identify importance and impact of each driver

- The analysis is focusing on 12 undisturbed catchments with the greatest areas burnt in historical fire events

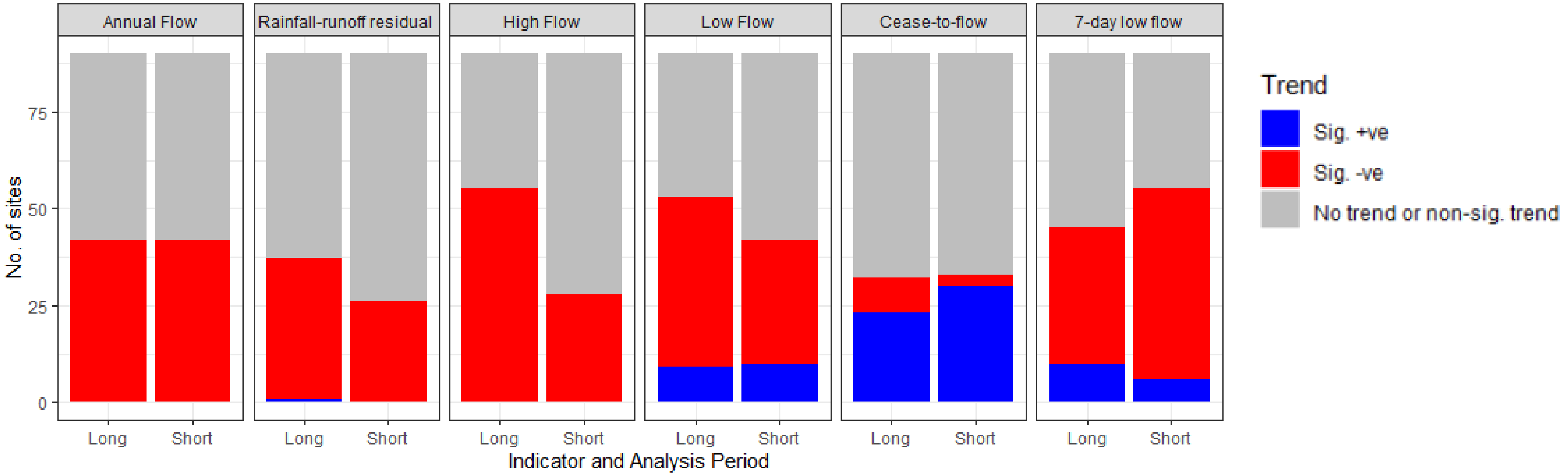
3.1 Water Quantity Trends

Summary

Within RFA catchments (75)



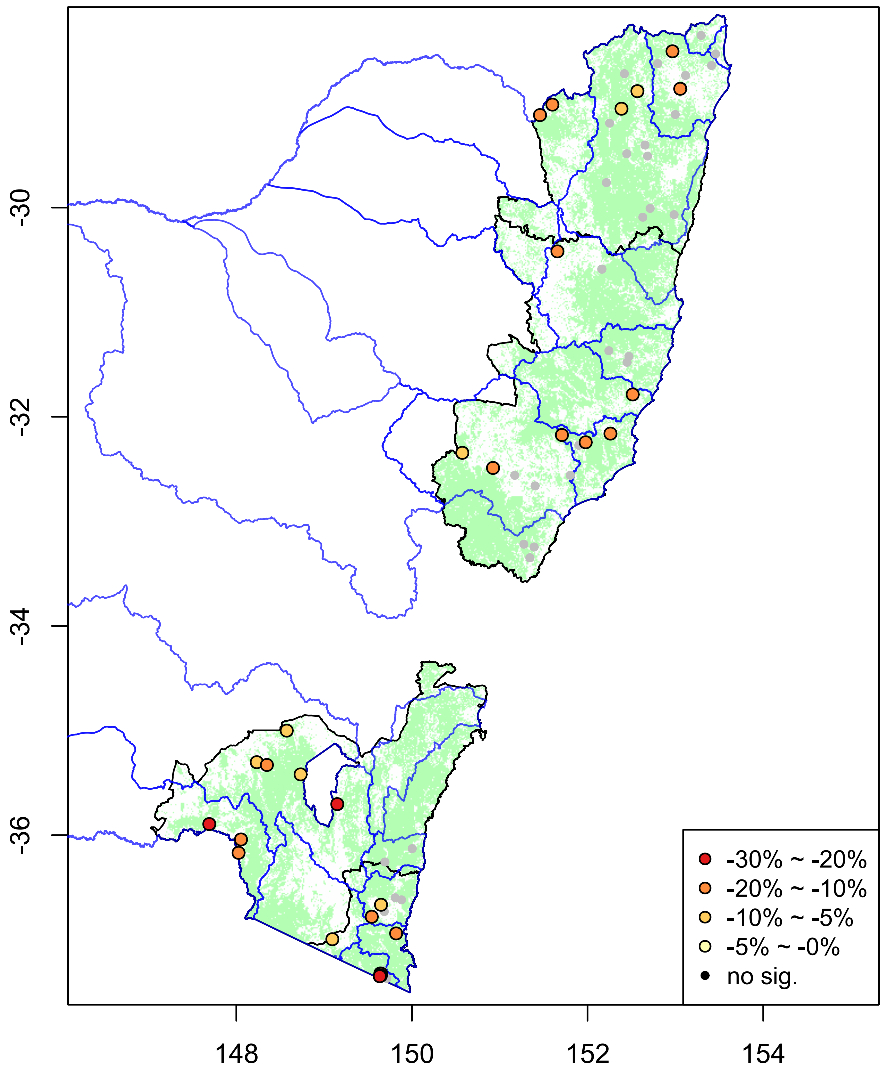
Outside RFA catchments (90)



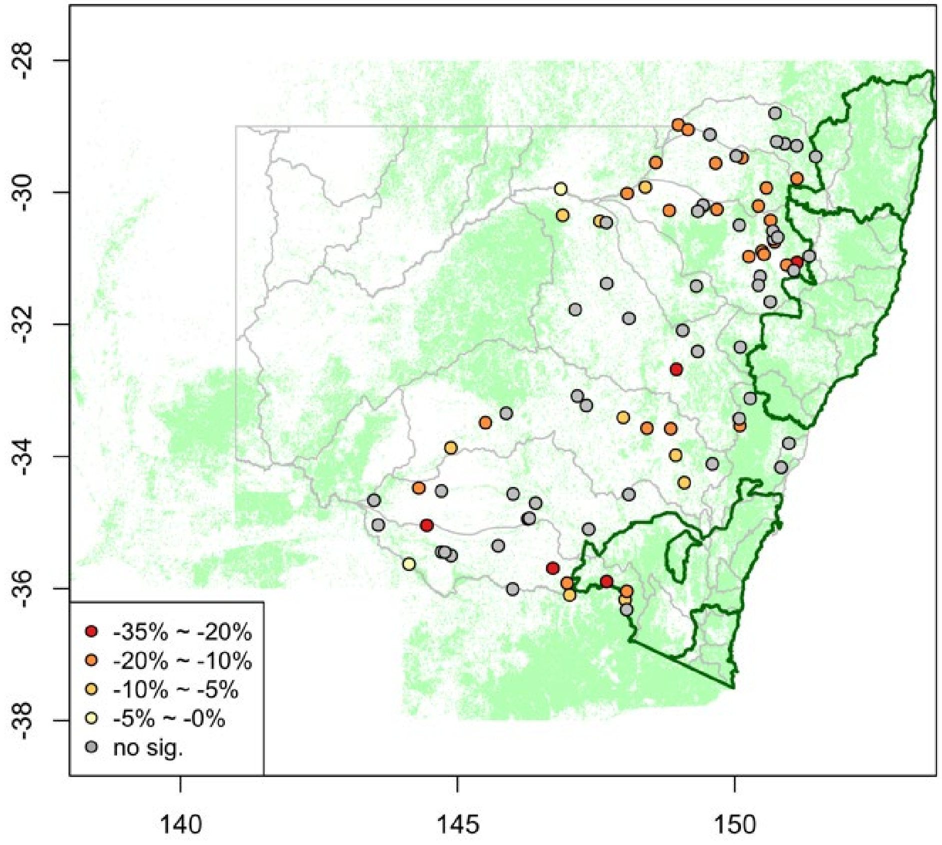
3.1 Water Quantity Trends

Maps of Trends in Annual Flow

Within RFA catchments (75)



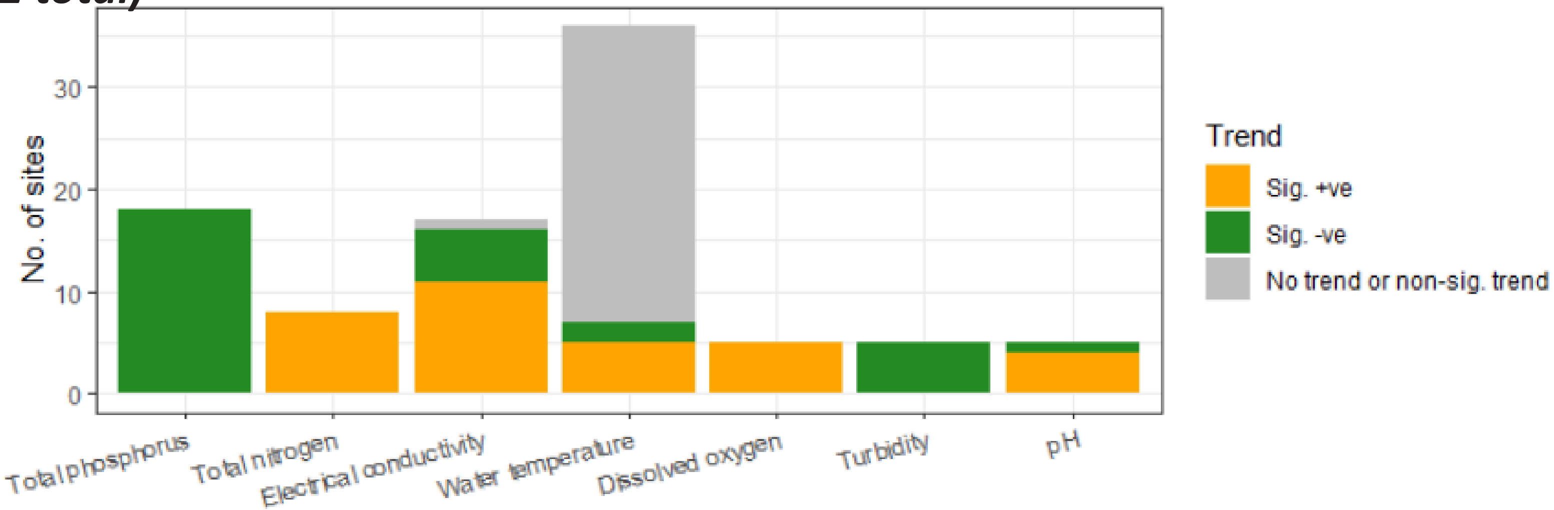
Outside RFA catchments (90) – over full historical period



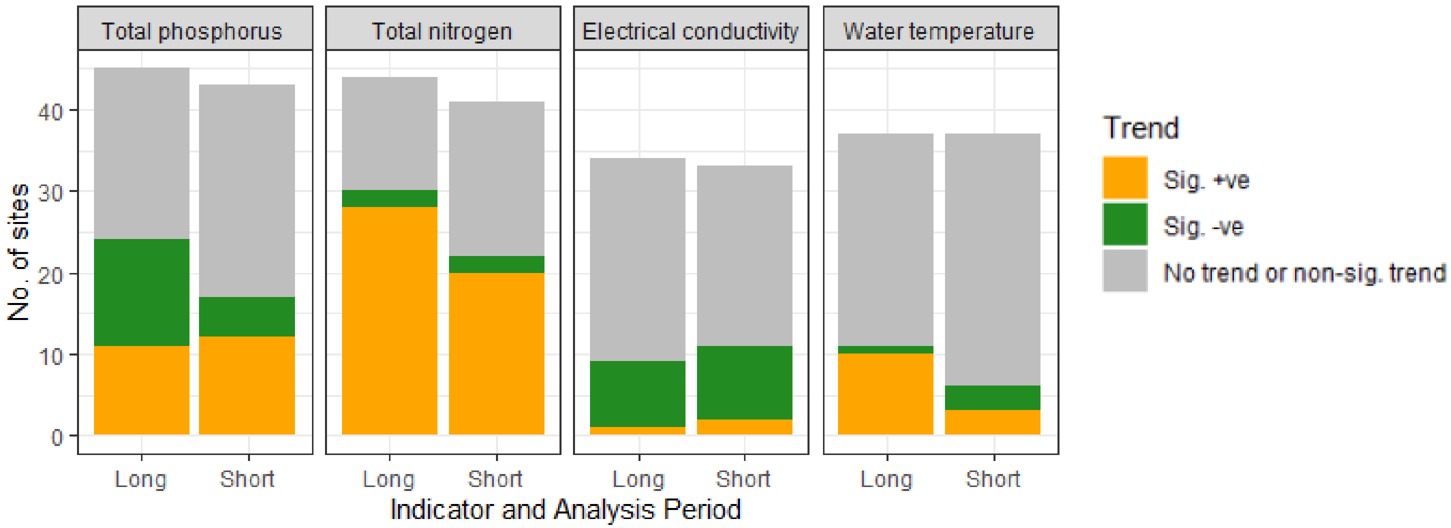
3.2 Water Quality Trends

Summary

Within RFA catchments (42 total)



Outside RFA catchments (59 total)



4.1 Trend Attribution: *linking trend magnitudes with catchment attributes*

Wetter catchments and catchments with more % grazing area generally show greater declining trends in flow

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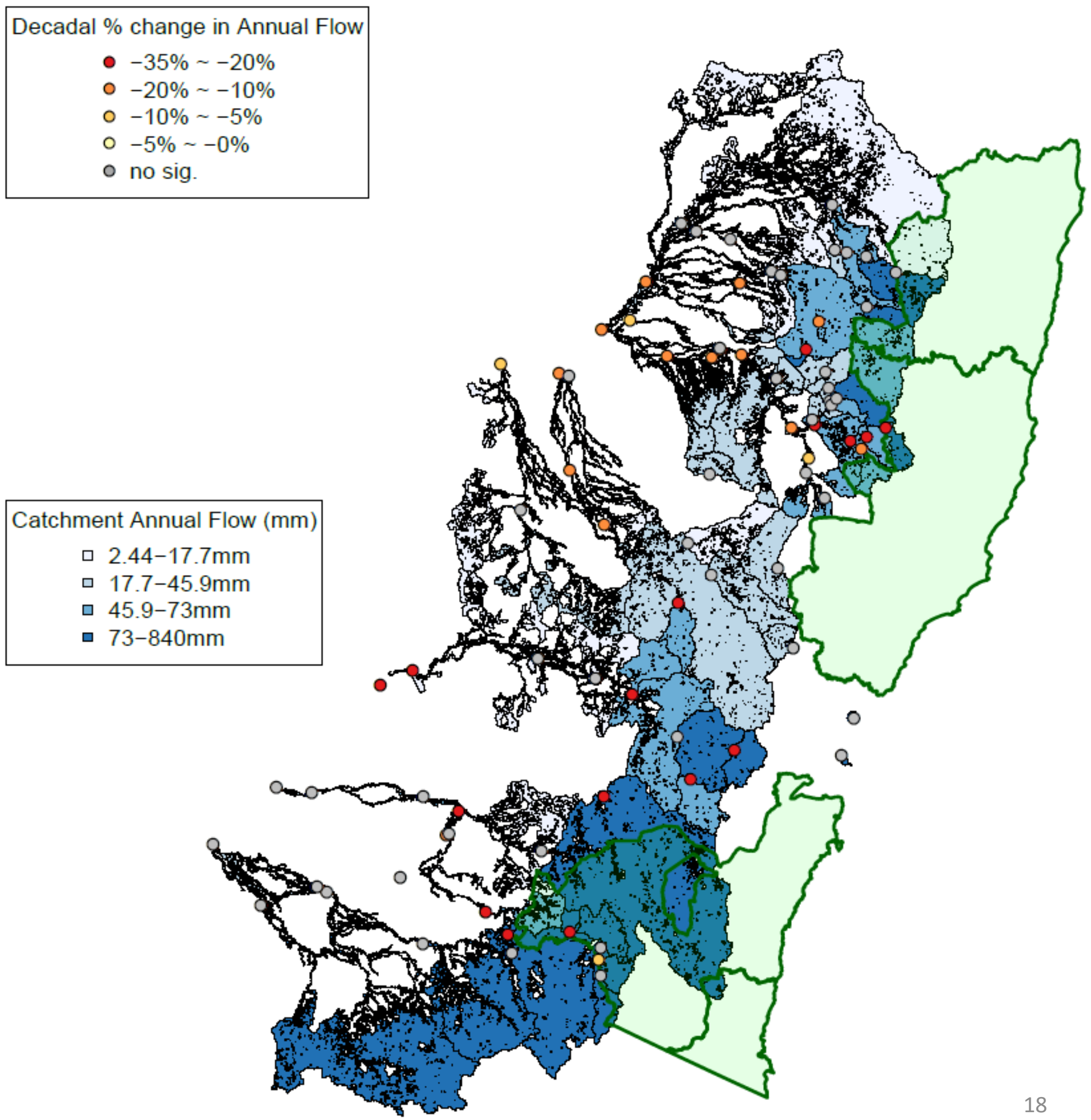
Amongst a number of catchment attributes, a brute-force search for the best predictors of site-level trends suggests:

16% spatial difference in Long Trends is explained by:

- *Mean annual flow (🡑 - greater decline),*
- *% catchment area as Plantation Forest (🡑 - greater decline),*
- *% catchment area as Grazing Land (🡑 - greater decline).*

31% spatial difference in Short Trends is explained by:

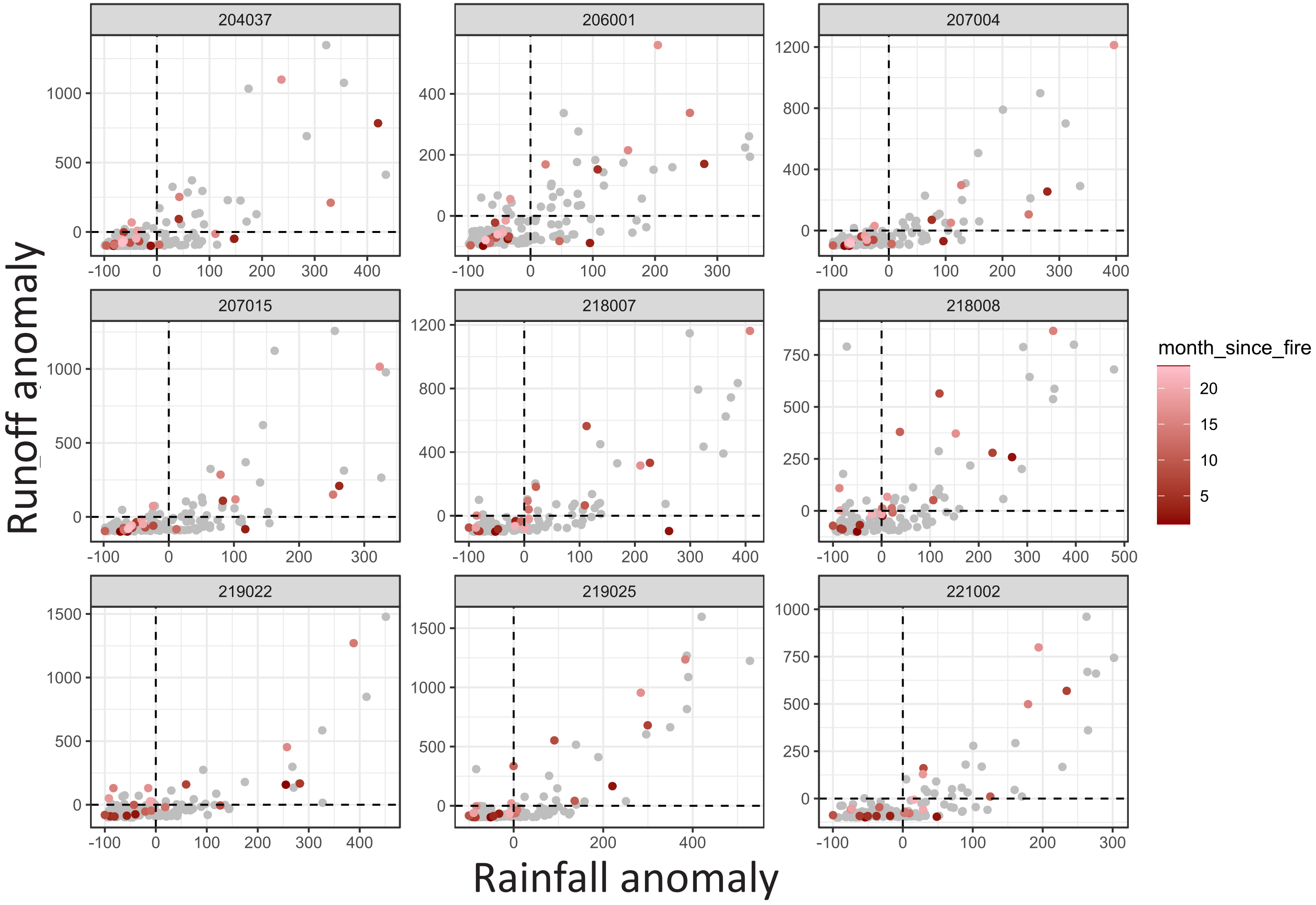
- *Mean annual flow (🡑 - greater decline),*
- *% catchment area as Forest (🡑 - smaller decline),*
- *% catchment area as Natural Land (🡑 - greater decline),*
- *% catchment area as Plantation Forest (🡑 - greater decline),*
- *% catchment area as Grazing Land (🡑 - greater decline),*
- *% catchment area as National Park (🡑 - smaller decline).*



4.1 Trend Attribution: *2019/2020 fire impact on flow*

Compared to the recent 5-10 years, there has been a clear shift in rainfall-runoff relationships after the 2019/20 fire i.e., more runoff than expected given rainfall

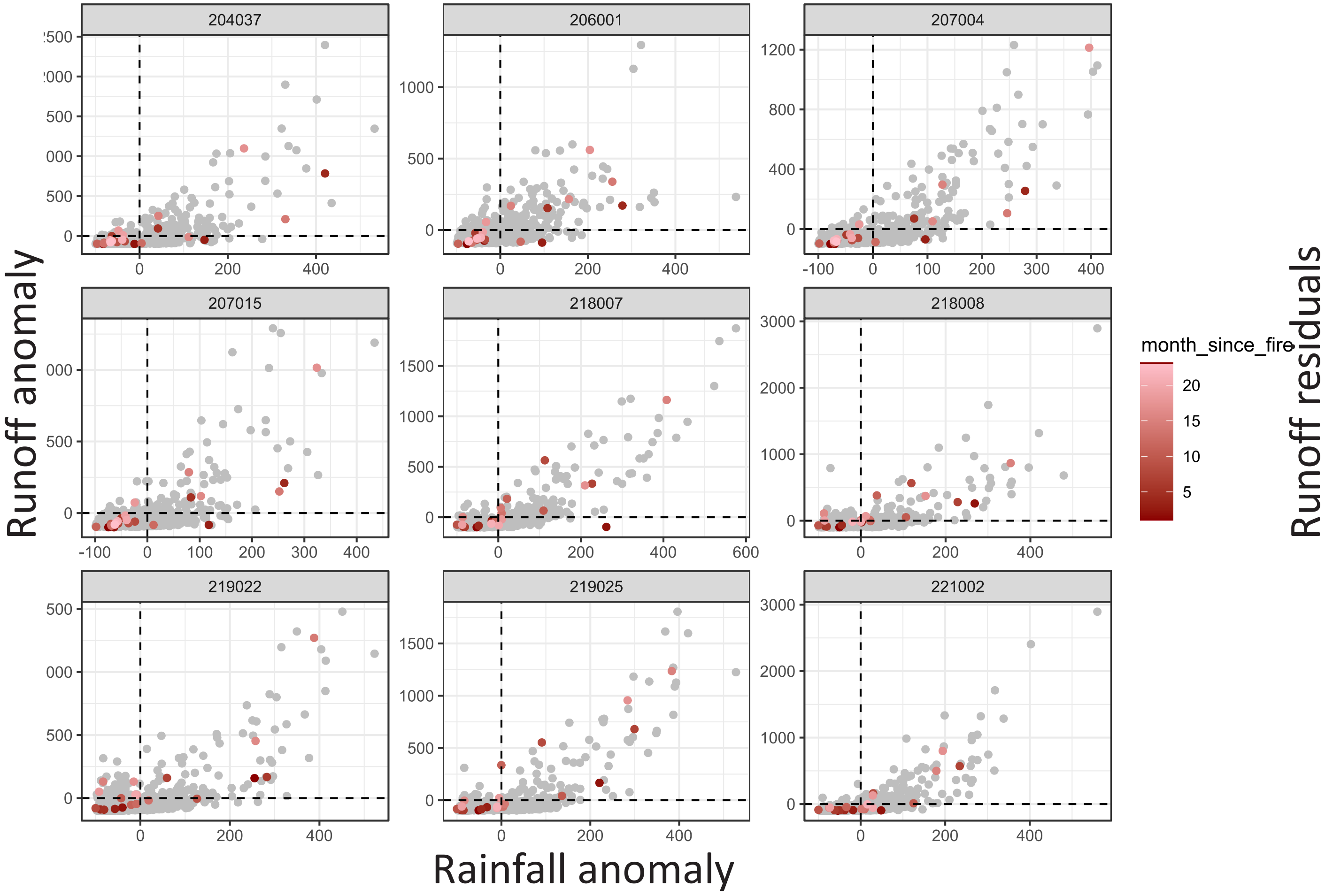
Monthly anomalies of runoff vs. rainfall since 2010, before and after fire



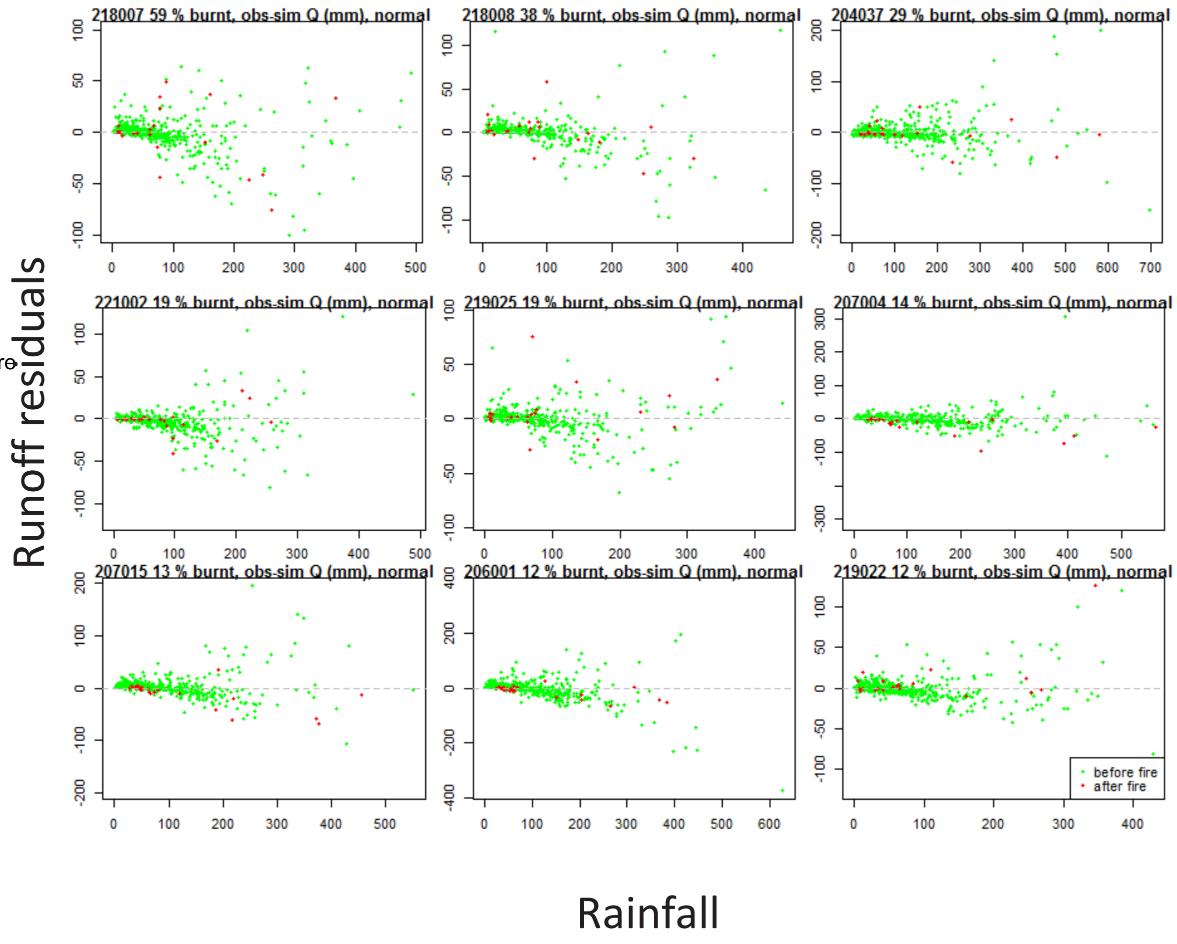
4.1 Trend Attribution: *2019/2020 fire impact on flow*

The rainfall-runoff relationship post the 2019/20 fire does not change significantly from historical periods

Monthly anomalies of runoff vs. rainfall over full record, before and after fire



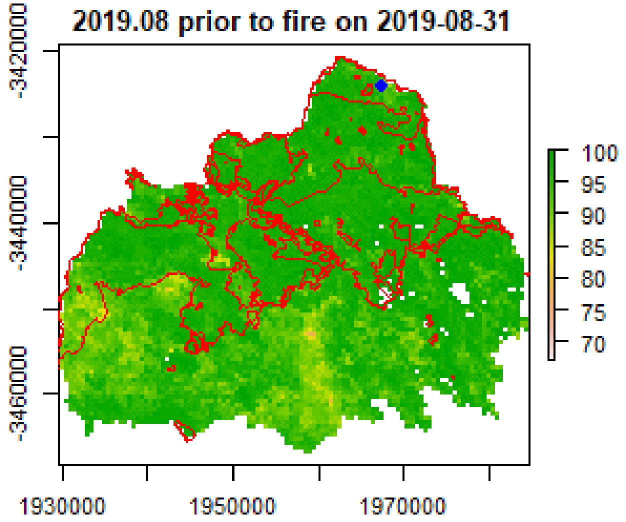
Runoff model residuals (Qobs – Qmod) vs. rainfall over full record, before and after fire

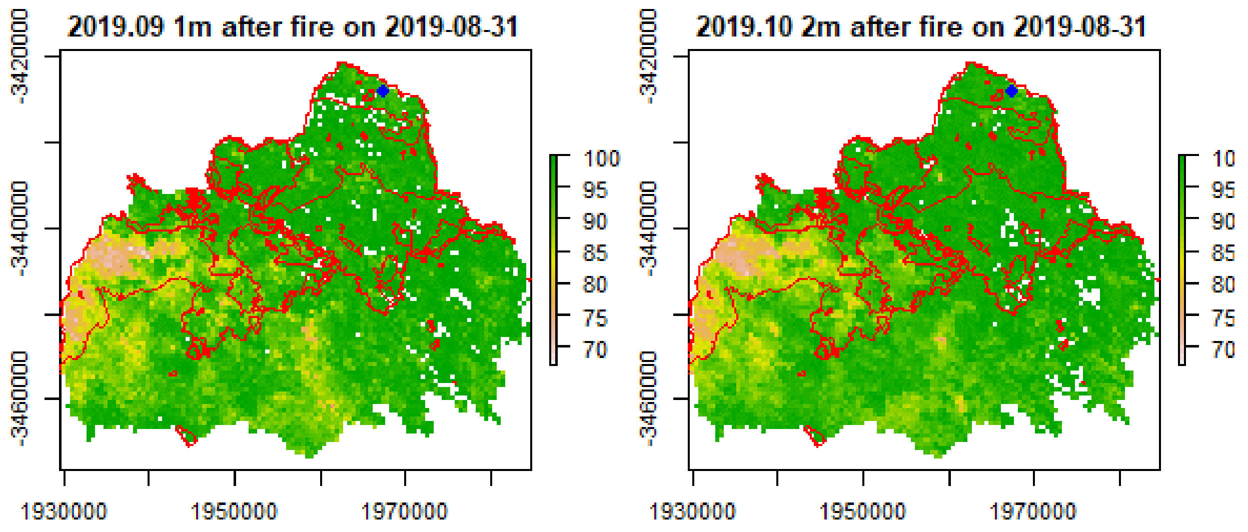


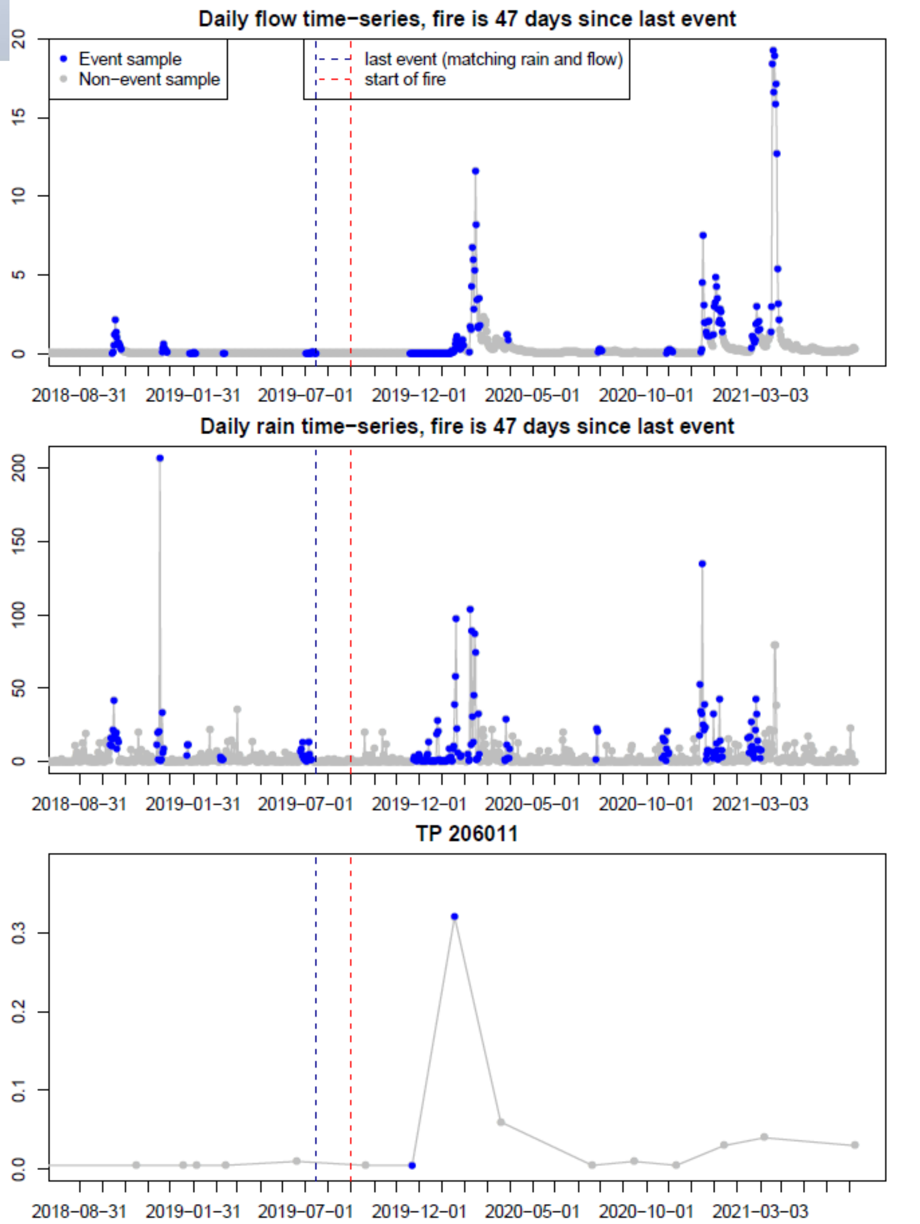
4.2 Trend Attribution: *2019/2020 fire impact on water quality*

The impact on water quality is highly catchment specific, and also influenced by the timing of rainfall and flow events following the fire

WQ change Example 1: *Phosphorus at 206011 (9980 km²)*



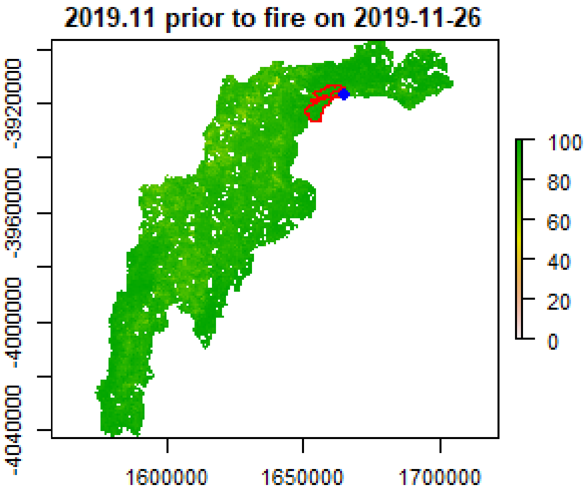


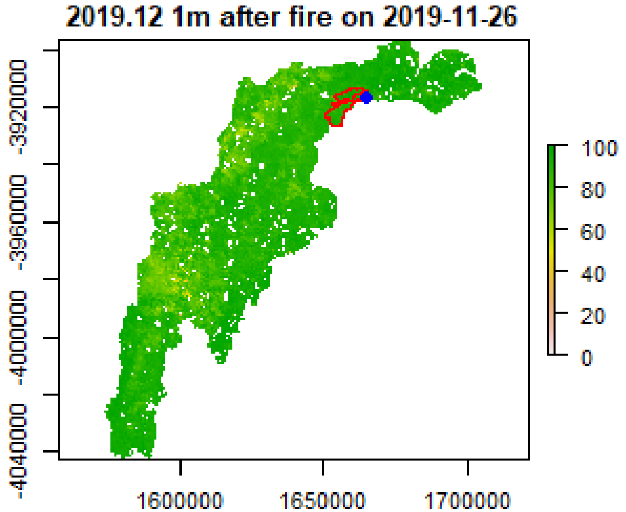


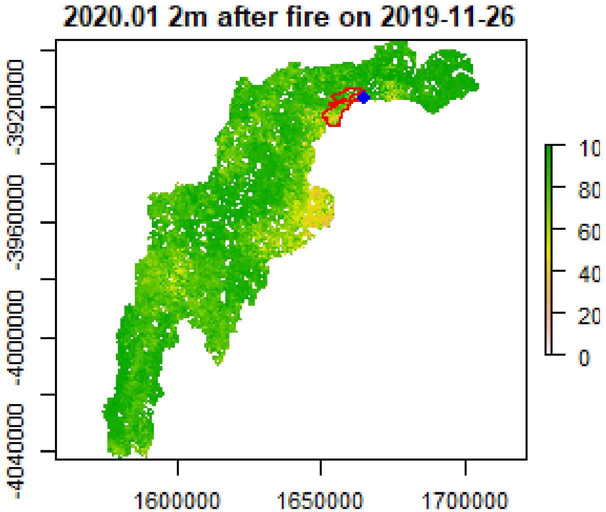
4.2 Trend Attribution: *2019/2020 fire impact on water quality*

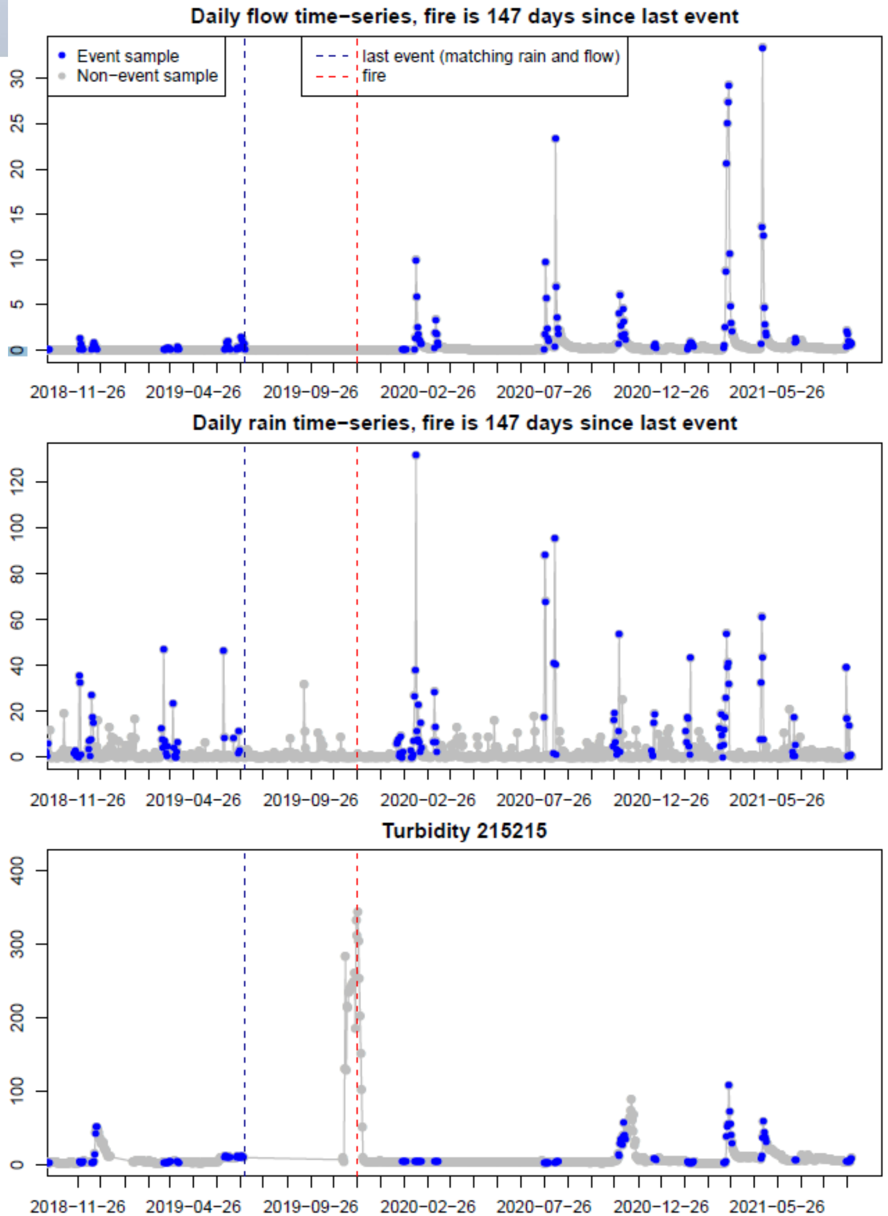
The impact on water quality is highly catchment specific, and also influenced by the timing of rainfall and flow events following the fire

WQ change Example 2: *Turbidity at 215215 (5357 km^2)*









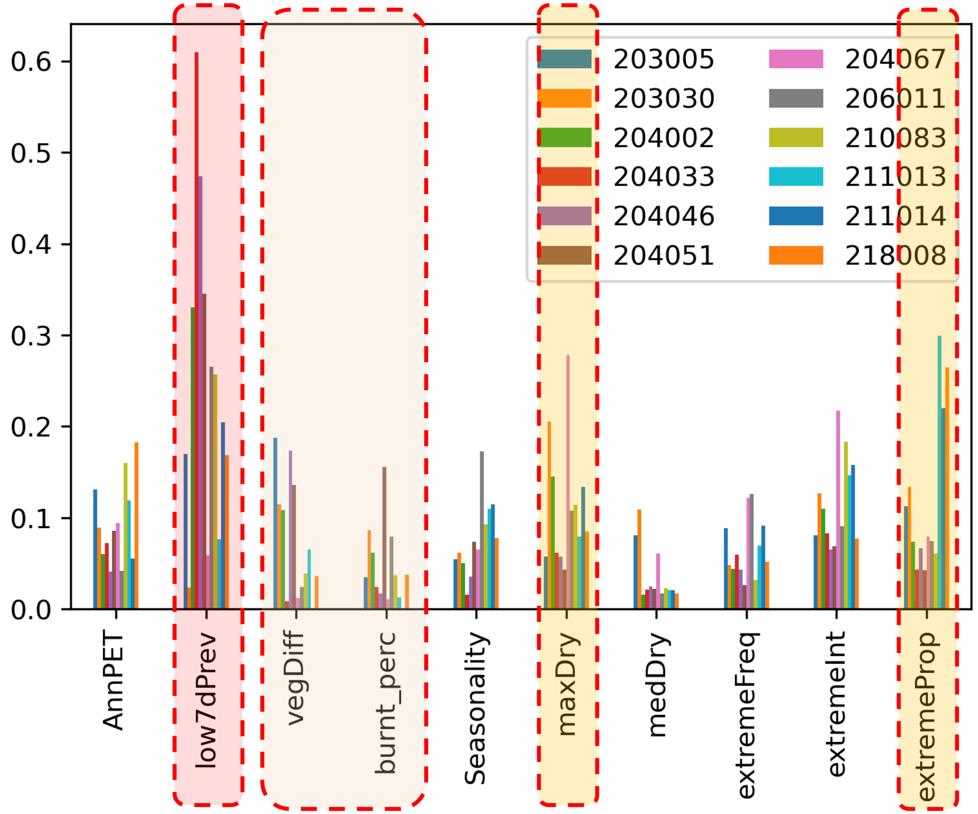
4.3 Trend Attribution: *Linking changes to catchment disturbances (WIP)*

Historical fire events have some influences on flow, but are generally not as big as climatic drivers

Across these 12 catchments analysed which experienced severe fire in history:

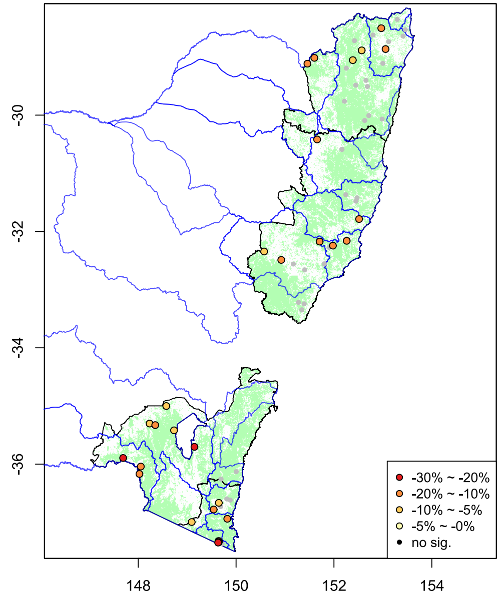
- ***Climatic indicators*** *i.e., catchment PET and storage from previous year generally have the highest impacts*
- ***Fire indicators*** *i.e., change in catchment veg cover before/after fire and catchment area burnt in each fire event are showing relatively minor effects*

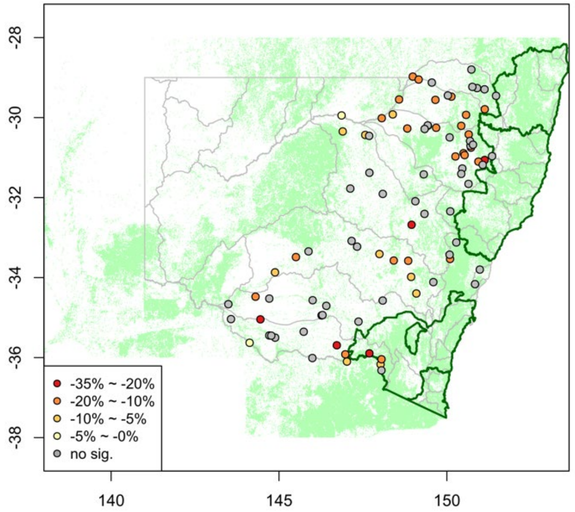
Importance of potential predictors on the flow residuals at 12 individual catchments



Key findings – water quality/quantity trends in NSW forested catchments

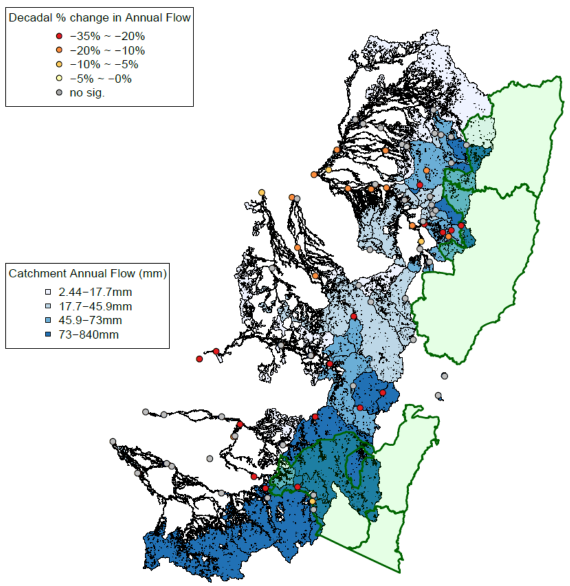
1. NSW forested catchments have experience a **large-scale decrease in flow (water quantity)**
2. The **magnitudes of flow decline are mostly around 10 to 20% per decade** relative to the long-term mean annual flow.
3. Water quality has mixed trend directions which lack regional consistency and also vary by indicators. Also, water quality variables generally have insufficient data to conclude large-scale patterns in trend.

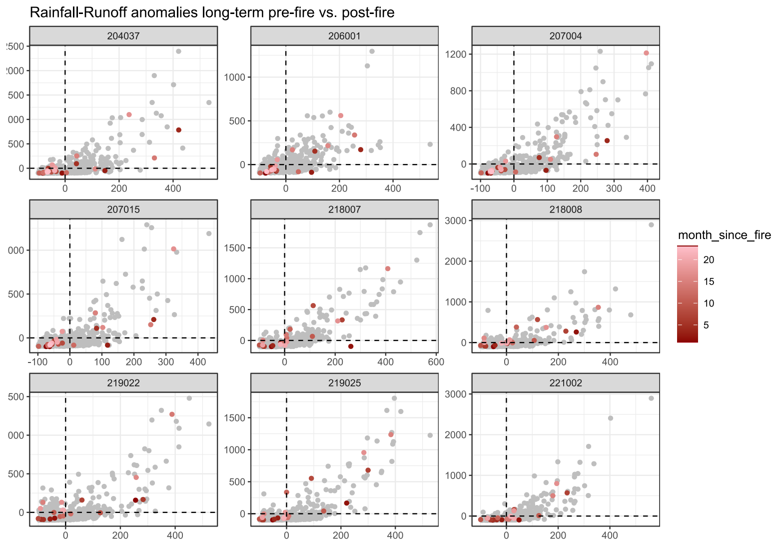


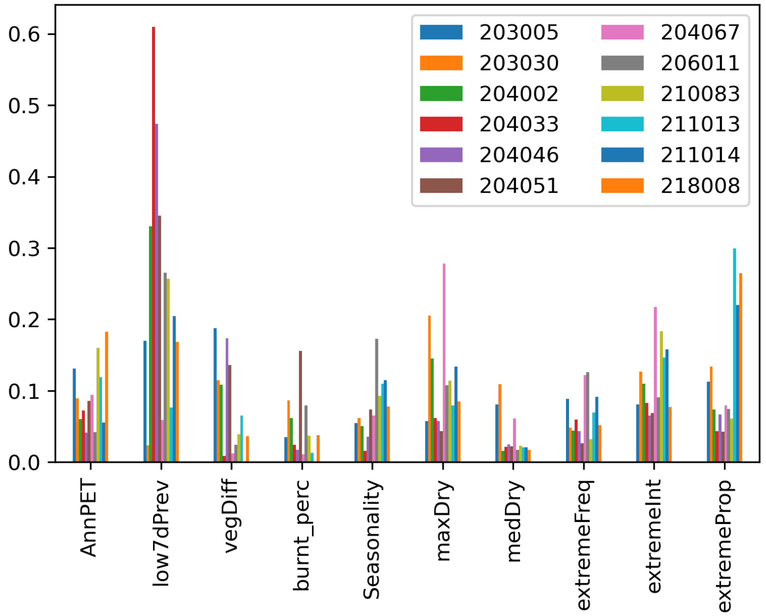


Key findings – attributing flow trends to fire and climate

1. **Wetter** catchments and catchments with **greater percentage area used for grazing land** show **greater percentage decline in flow**
2. Existing data show **small impact of the 2019/20 fire** on flow compared with long-term climate
3. There is very limited data to understand the impact of the 2019/20 fire on water quality; existing data suggests small, case specific impacts which also depends on timing of recent rainfall/flow events
4. **Over the longer term, the impact of historical fire events on flow is smaller** compared with climatic drivers







3.1 Annual Flow Trends within RFA

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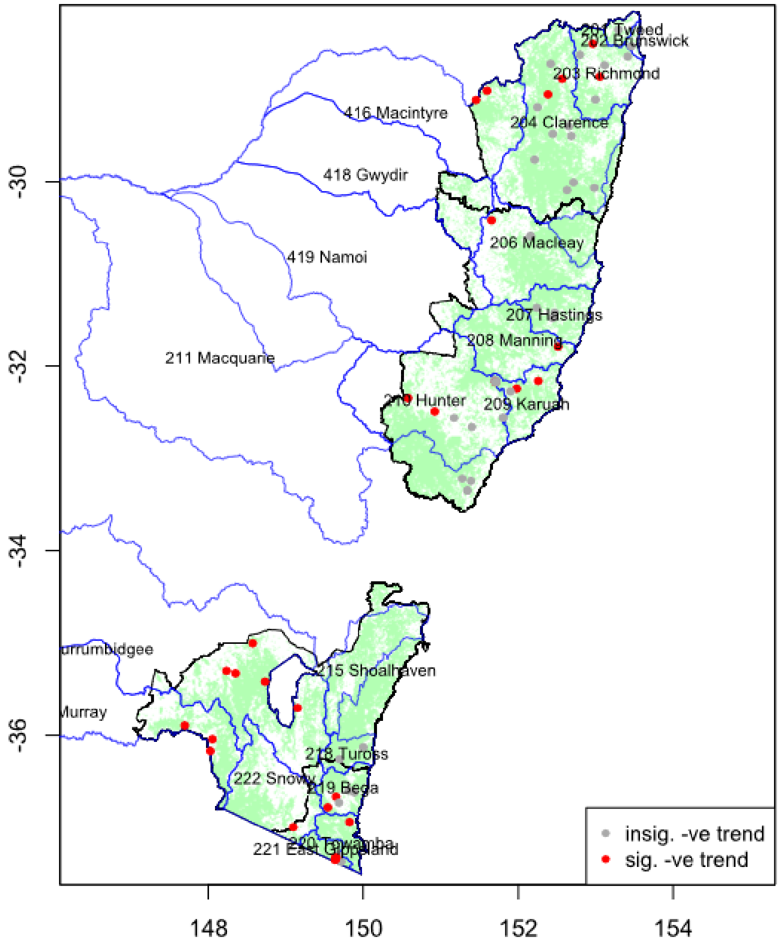
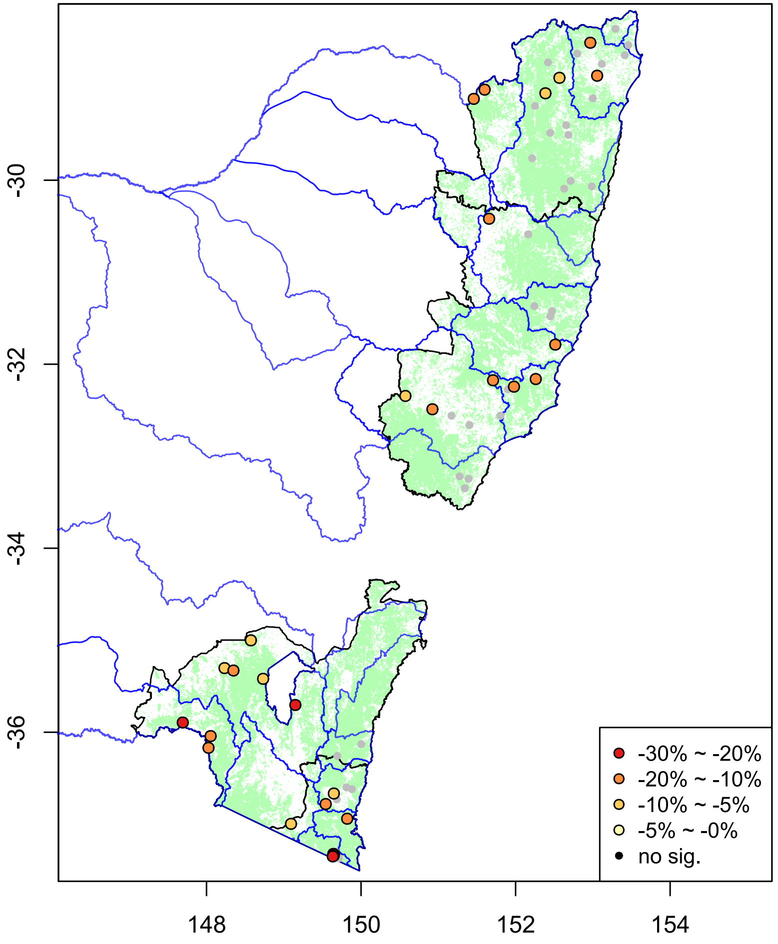
Trend direction and significance

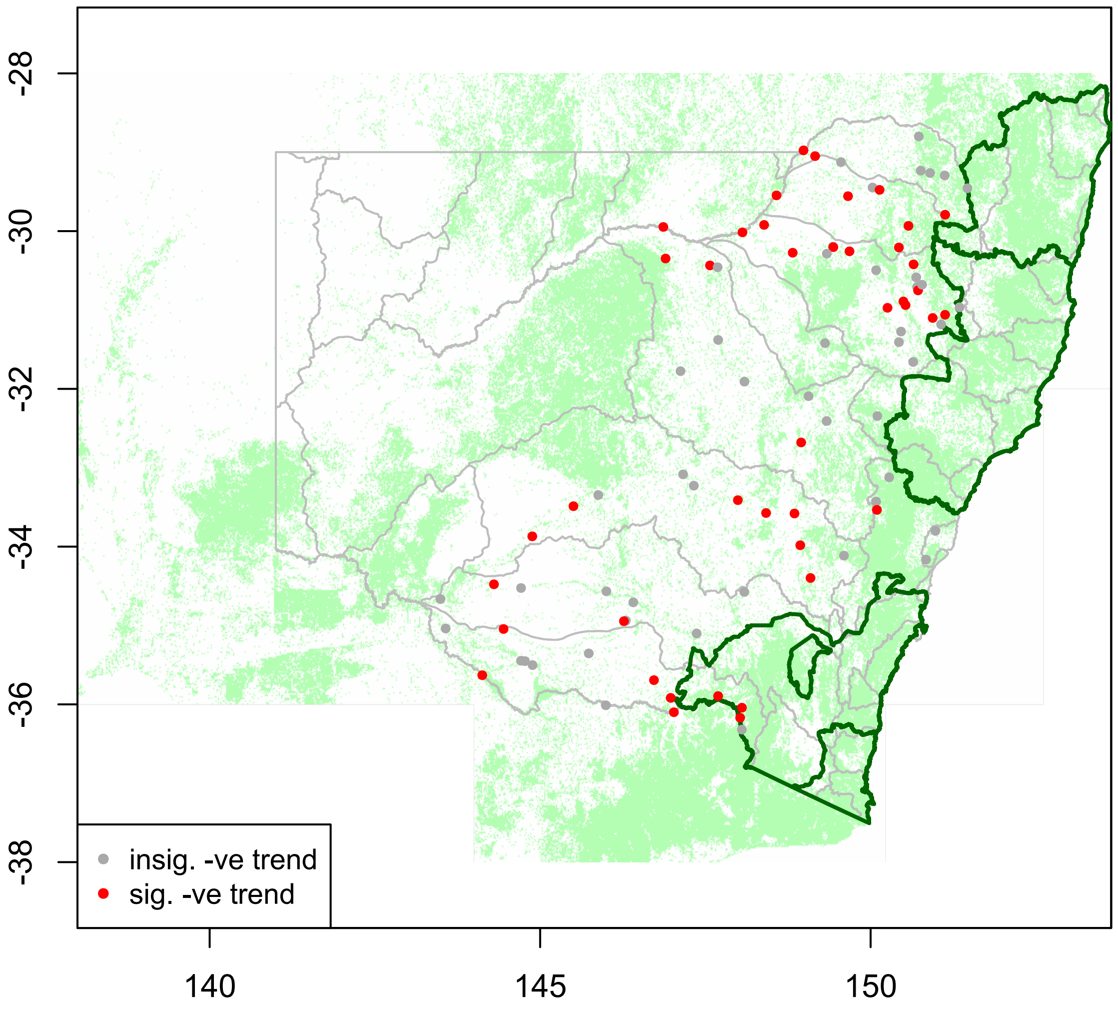


Trend magnitude (% change per decade)

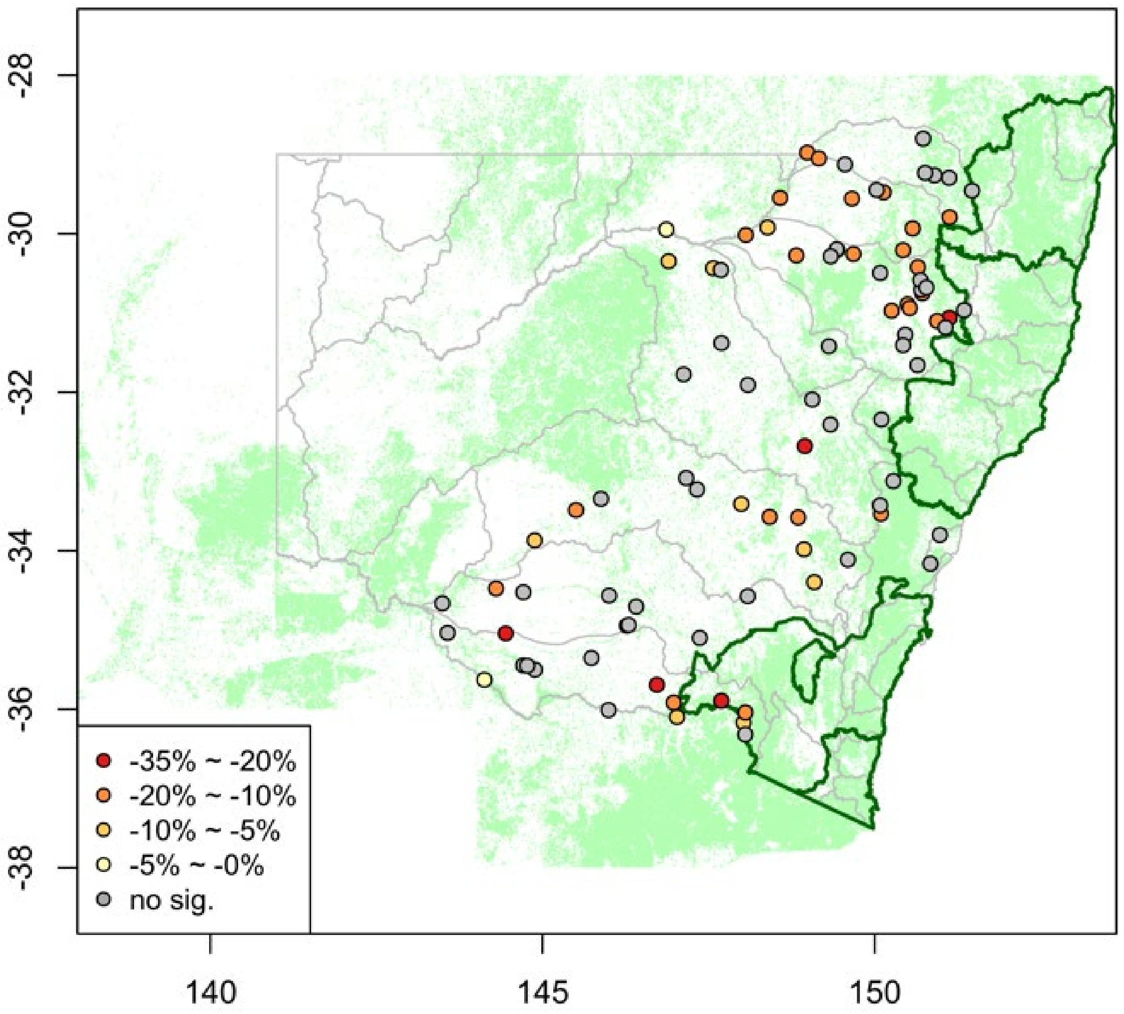


3.1 Annual Flow Trends outside RFA – full record period

Trend direction and significance

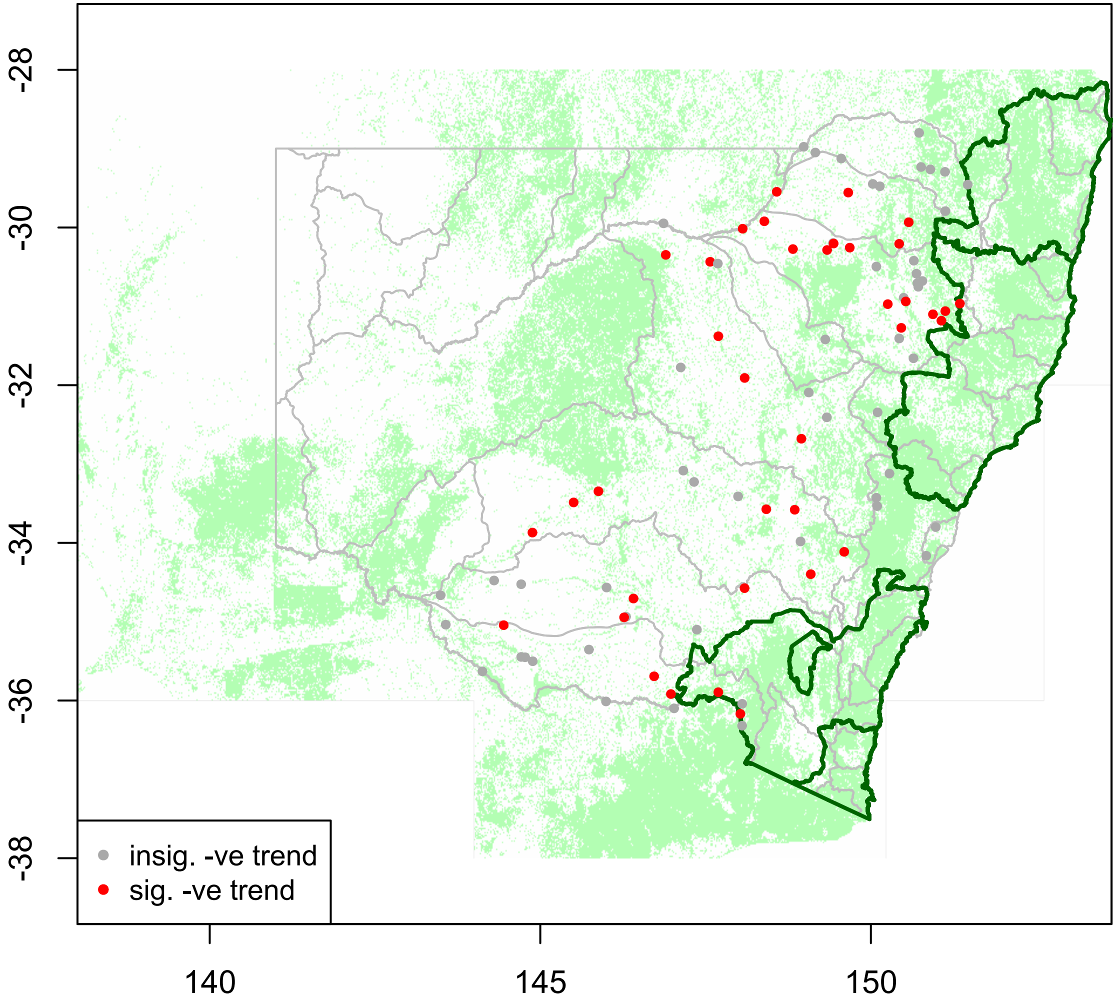


Trend magnitude (% change per decade)

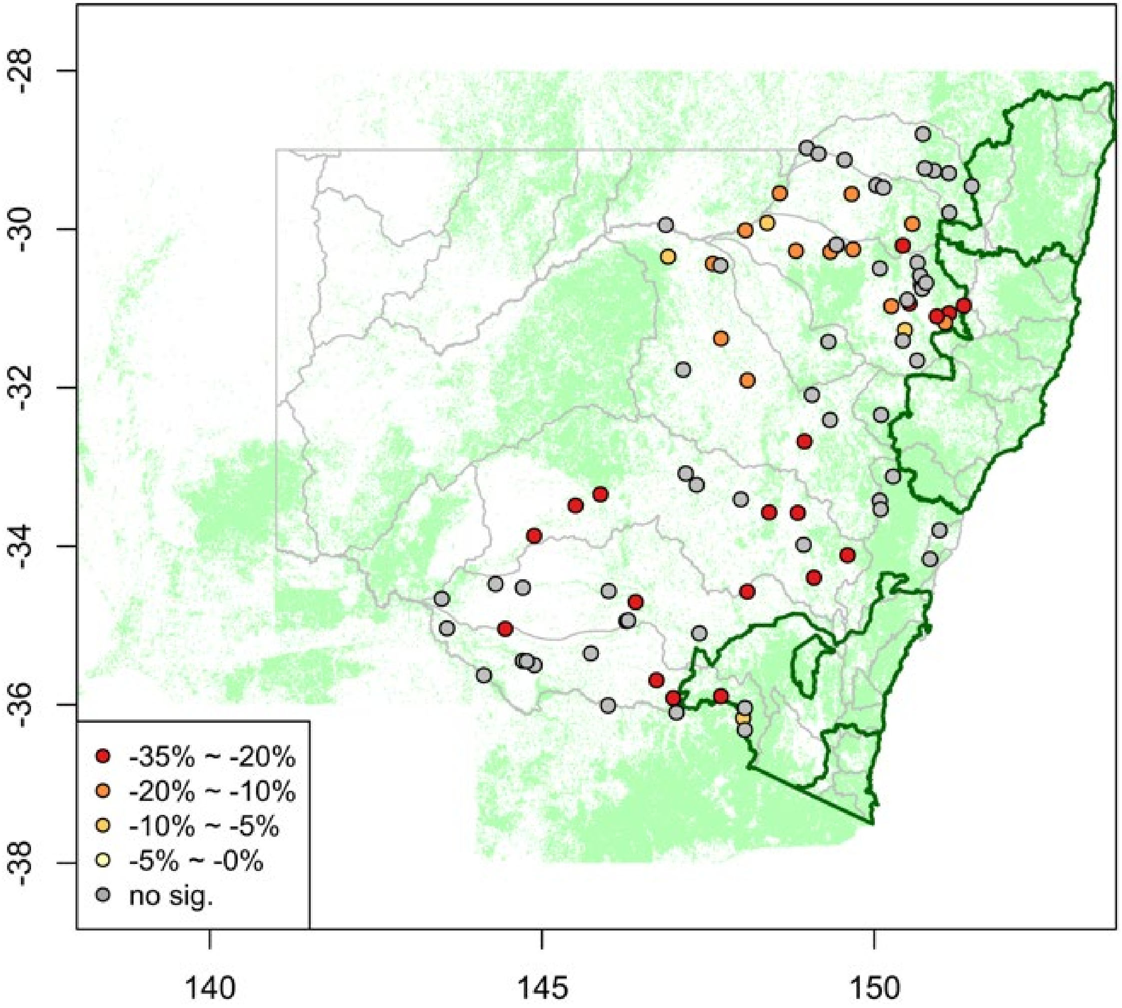


3.1 Annual Flow Trends outside RFA – since 1984

Trend direction and significance



Trend magnitude (% change per decade)



3.1 Water Quantity Trends (outside RFA)

Annual Flow – Trend Differences due to Analysis Period