Franklin Vale Catchment

Monitoring and Evaluation Plan 2021-2026

Prepared by:

Joseph McMahon, Rebekah Grieger, Anna Petrova, Hannah Franklin, Wade Hadwen, Kathleen McLay and Samantha Capon

Australian Rivers Institute, Griffith University, Brisbane

For:

Ipswich City Council to inform the Franklin Vale Creek Catchment Initiative

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Approvals

Author signature: ____________.. Date ....14/10/21.............

Author Name: Joseph McMahon

Internal reviewer signature: Date 26.9.21

Internal reviewer name: Professor Michele Burford

Author contact details

0401 218 899

s.capon@griffith.edu.au

https://www.griffith.edu.au/australian-rivers-institute

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1. Introduction

1.1 Context

The Franklin Vale catchment is a relatively small catchment (~ 138 km^2) situated approximately 35 km south-west of Ipswich in southeast-Queensland. Franklin Vale Creek drains into the Bremer River (via Western Creek) which, in turn, is a tributary of the Brisbane River. The catchment is currently home to a small community of landholders and supports a range of land uses including grazing, cropping, forestry and conservation. Significant vegetation clearing has occurred in the catchment since it was settled by Europeans in the mid 1800s. A lack of vegetation, especially in riparian areas, in combination with steep slopes and grazing pressure have been associated with bank instability and erosion in the catchment's waterways, as well as gully erosion in the broader catchment (Alluvium, 2014a, b). While instability in the catchment was identified as being high compared to other catchments within the Ipswich City Council (Council) area, such instability is unlikely to be major contributor to sediment loads in the lower Bremer River (Alluvium, 2014a, b).

To address concerns associated with the degradation of water quality and the ecological values of the Franklin Vale catchment and its receiving waters, as well as the catchment's agricultural productivity, Council has established the *Franklin Vale Creek Catchment Initiative*. This programme seeks to restore and enhance the ecological condition of the Franklin Vale Creek and catchment by working with landholders to mitigate threats and rehabilitate and renew degraded areas through the implementation of on-ground actions (e.g., revegetation). The Initiative is funded by Council's stormwater quality offsets scheme.

In late 2020, Council engaged a project team from the Australian Rivers Institute at Griffith University to develop a catchment restoration plan to inform the design and development of the *Franklin Vale Creek Catchment Initiative*.

1.2 Purpose

The main purpose of the Franklin Vale catchment restoration plan is to support decision-making regarding the selection, prioritisation and implementation of restoration actions in the Franklin Vale catchment. More specifically, the aims of the plan are to:

- synthesise existing knowledge concerning the ecology of the Franklin Vale catchment;
- assess current ecological conditions of the Franklin Vale catchment, including its key values and threats to these;
- provide a strategic plan for prioritising on-ground actions; and
- identify monitoring and evaluation needs to assess the effectiveness of these interventions and guide future adaptive management.

1.3 Approach

To develop a catchment restoration plan for the Franklin Vale catchment, three work packages were completed as follows.

1. *Catchment condition assessment:*
    - compilation of an information log for the catchment
    - synthesis of available relevant knowledge
    - an evaluation of key ecological values of the catchment
    - an assessment of the major risks and vulnerabilities facing the catchment

2. *Strategic Plan development:*
    - co-design of restoration objectives for the Franklin Vale catchment
    - compilation of a catalogue of potential on-ground interventions
    - identification of priority actions to address restoration goals

3. *Monitoring and Evaluation guidelines:*
    - design and testing of rapid field condition assessment methods
    - intervention monitoring methodology
    - water quality monitoring protocols
    - longer-term catchment-scale condition monitoring and evaluation

To support the development of this catchment restoration plan, thorough literature searches of published and unpublished literature were conducted and existing sources of relevant regional data (e.g., LiDAR, satellite imagery, regional ecosystem mapping) were identified. This knowledge was then synthesised and analysed to describe the status of key catchment components with respect to five themes (land, water, plants, animals and people) and to identify appropriate restoration approaches. A comprehensive information log and detailed methods of the spatial data analysis is provided in the *Catchment Condition Assessment* package, Appendices 1 and 2.

Additionally, field surveys were conducted at 30 sites along Franklin Vale Creek and main tributaries to provide a rapid condition assessment of these waterways including bank condition and erosion, riparian vegetation cover and condition (including exotic species), water quality and stream condition (sedimentation, aquatic vegetation), animal habitat (instream and terrestrial) and infrastructure. Detailed methods are provided in the *Catchment Condition Assessment* package, Appendix 3.

Two community workshops were also held during the project to ascertain community values and collate local knowledge regarding the condition of the catchment and its vulnerability as well as interest and support for various management approaches. A summary of each event is provided in the *Catchment Condition Assessment* package, Appendix 4.

It should be noted that this project was initially designed during the 2020 Covid-19 lockdown period. Consequently, neither field work nor face to face community events were included in the budget or timeline but were conducted as the opportunity arose.

1.4 Structure of this document

This document presents the outputs of the third work package – a monitoring and evaluation plan for the Franklin Vale catchment. The first section presents recommendations regarding water quality monitoring as this is a critical focus of the *Franklin Vale Creek Initiative* for which there is currently no information (beyond that collected during the current project). The second section describes an approach to ongoing condition monitoring to enable the condition of the catchment to be reassessed in the future, building on the approach taken in this project (see accompanying Catchment Condition Assessment report). The third section focuses more specifically on recommendations for targeted monitoring of specific restoration interventions implemented under the *Franklin Vale Creek Catchment Initiative*. Finally, some recommendations for priority research to address key knowledge needs are presented.

2. Water quality monitoring

Monitoring is a key part of the catchment restoration process needed to confirm whether restoration actions have resulted in improved water quality. Documenting the long-term outcomes of restoration projects is essential to evaluating the effectiveness and value of the program, as well as apply the lessons learned to further river restoration.

Despite the growing number of restoration projects worldwide aimed at reducing downstream sediment flux, only a small portion of them is typically monitored for sufficient time and at a sufficiently large scale to give information about the project's outcomes. Of about 320 rivers restored in Europe to improve their aquatic ecosystem conditions, for example, less than 27 % reported monitoring outcomes (Nones, 2016). The scarcity of post-restoration monitoring is typically related to the lack of project funds for monitoring water quality, and the limited timeframe over which these funds can be spent. To overcome this problem, we suggest including a long-term monitoring programme in planning and budgeting phase of future projects wherever possible.

2.1 Considerations when designing a monitoring programme

Water quality monitoring should take into account the scale and time frame over which changes are expected to occur and consider the catchment characteristics which may confound links between changes in water quality and the restoration action. Some key considerations when designing a monitoring programme are:

- Adjust expectations - before designing a water quality management program it is important to set realistic expectations regarding the time frame for which improvement in each parameter of interest is likely to occur;
- Goal setting – where background water quality condition is known or guideline values exist short term, mid-term and long term reduction in sediment/nutrient goals can provide a framework for monitoring (Cape York NRM and South Cape York Catchment, 2016);
- Understanding catchment hydrology is important as this drives the movement of pollutants and will help decide which locations to monitor and the frequency sufficient to detect change with reasonable sensitivity;
- In cases where understanding the effects of a restoration program on water quality is a critical goal, lag time can be minimized by focusing monitoring on sub-catchments or sites close to restored areas sources;
- Supplementing spatial water quality monitoring with monitoring localised restoration case studies can help understand the causes for delayed water quality improvement downstream, and help explain these delays to stakeholders;
- Choose indicators of success that are likely to respond quickly to monitor first. For example, improvements in stream biota may come much more slowly than some water quality parameters and may be beyond the time frame of many monitoring efforts.

2.2 Appropriate indices to monitor for water quality

Restoration of Franklin Vale catchment aims to improve water quality in terms of the total sediment, nutrient and pathogen loads exported from the catchment into Western Creek and then the Bremmer River. Key parameters of interest therefore are as follows. An indicative cost associated with analysis for each parameter per sample at a commercial laboratory is provided, this should be used as a guide only.

1. Total suspended sediment ($20-30)
2. Total nitrogen and phosphorus (sediment bound N and P) ($35-45)
3. Dissolved nitrate, ammonium, and phosphate ($20-25)
4. Pathogens: Faecal coliforms and *Escherichia coli* ($45-$60)
   Other pathogens: *Salmonella enterica, Campylobacter jejuni*, adenovirus, and *Cryptosporidium* oocysts (>$100 per analyte)

Other water quality parameters of interest to Council may include temperature, dissolved oxygen, pH and salinity, which influence the suitability of water for biota such as invertebrates, fish and platypus. These could be monitored in persistent pools which may provide refuge for biota during low flow.

In addition to monitoring the concentrations of these key parameters it would also be beneficial to monitor river discharge so that “empirical load” can be calculated for each parameter. This can be estimated using a stage height (river water level) logger installed at an appropriate location where a flow rating curve is established by hydrologists.

There are a range of logistic and economic limitations of collecting samples and analysing for these key parameters which may prevent data collection at the frequency necessary to adequately understand spatial and temporal variation (Leigh et al., 2019). In intermittent systems it is important to understand changes in pollutant concentration across flow events, but manual collection of sufficient samples may be cost-prohibitive and dangerous. Monitoring of surrogate parameters either manually or via *in situ* sensors provides a lower-cost alternative to assess these parameters. However, *in situ* sensors require regular servicing and maintenance by a qualified technician to be effective, which may prohibitive if the project budget is short-term. Sensors installed in the river provide high-frequency data needed to understand variation in water quality in rivers. Continuous surrogate data (e.g. turbidity) can then be correlated with data from periodic field samples of the parameters the surrogate represents (e.g. suspended sediment), to predict continuous pollutant concentrations or loads through time. Table 1 provide a list of common surrogate parameters and the constituents they represent.

Table 1. Surrogate parameters that are low-cost when measured in grab samples or can be measured semi-continuously using in situ sensors, and the constituents they represent

Surrogate	Constituent represented
Turbidity or other manual measures of water clarity such as black disc visibility	Total suspended sediments Total N or P Total organic C Sediment bound metals or organic pollutants *E. coli, total coliforms*
Specific conductance	Dissolved nitrate, ammonium, and phosphate Alkalinity, Other dissolved elements e.g. Chloride, Calcium, Potassium, Sodium, Magnesium
fDOM (Fluorescent Dissolved Organic Matter)	Dissolved organic carbon

2.3 Tailored water quality monitoring approaches for restoration of Franklin Vale Creek

A range of possible monitoring approaches have been applied in previous projects to assess the effectiveness of interventions at improving water quality, these are outlined in Appendix 1. We suggest the following possible approaches to water quality monitoring are most appropriate for Franklin Vale Creek:

End of catchment monitoring and event monitoring

End-of-catchment monitoring aims to detect the combined impact of all upstream restoration actions and management improvements on the quality of water leaving the catchment. An end-of-catchment monitoring site would be located at the downstream end of the catchment, where the discharge can be accurately gauged.

Water samples are collected manually or using an automatic sampler at set time intervals and more intensively during events for many years during and after catchment restoration. This data is paired to continuous measurements of river discharge and turbidity or other surrogate data.

This would have a high initial set up cost but can provide a robust way to quantify and monitor changes in the load of suspended sediments and nutrients exported from the catchment as restoration projects proceed. However, this approach does not provide information about the effectiveness of specific restoration actions within catchment and may have a lag time before impact is detected.

Low-cost option: stage height logger and turbidity sensor, with manual grab samples collected when possible

High-cost option: full gauging station with autosampler attached

Spatially explicit regular and event monitoring

This strategy consists of a network of monitoring sites spread throughout the catchment which aim to detect changes in water quality at different scales and understand spatial variability in pollutant loads, e.g. which tributaries produce the most sediment

The network may combine nested paddock, property, sub-catchment, and catchment scale monitoring. Sites are often positioned strategically to monitor locations particular current or future restoration projects, i.e. upstream and downstream of action to detect impact. Control sites on unrestored sections of river can be built into the sampling design.

Stage height loggers and turbidity meters installed at all or a subset of sample points and supplemented with spot measurements and grab water samples during low and high flow when possible.

This is a high-cost option but may provide robust information on both the effect of individual projects (if sites are situated upstream and downstream) and information on end of catchment loads. It would also provide baseline information for reaches in the catchment that are yet to be restored.

Measuring erosion rates as a surrogate for water quality

Rates of soil erosion measured within each restored reach, paired with measurements at adjacent unrestored sites with similar aspect and soil type could provide a surrogate for impact on water quality. This could be assessed visually in the field. Drone photos of restored sites and adjacent non-restored areas taken each year may be used to chart growth of vegetation and changes in bank structure. Repeat analysis of lidar data at appropriate intervals in the future could also help establish the effectiveness of restoration to reduce erosion.

Citizen science water quality assessment

This approach would involve landowners monitoring the condition of the river in key locations (e.g. important refugia pools) where their property borders the creek seasonally or annually under baseflow conditions. Landowners could also be given water collection bottles and requested to collect water from the creek during or directly following events when safe to do so. These samples could be frozen until collection by Council and samples sent for analysis. It would be difficult for landowners to assess flow rate however this could be estimated if they record the time of sample collection and this is compared to stage height data recorded at the downstream end of the catchment. Photographs of the river at the time of sampling could also be used to estimate wetted width.

3. Condition monitoring

We recommend that the condition assessment of the Franklin Vale catchment conducted during this project (see accompanying Catchment Condition Assessment Report) be updated approximately every five years to assess the overall trajectory of the catchment's land, water, plants, animals and people in response to the *Franklin Vale Creek Catchment Initiative* as well as other drivers, and to incorporate new information.

We recommend that this catchment condition assessment comprises:

1. Spatial data analyses to assess trends in geomorphic stability, erosion, vegetation cover and condition and land use; and
2. Rapid field assessment.

3.1 Spatial data analyses

The spatial data analysis method used during this project, and recommended for future condition assessments, is based on the authors' prior experience with prioritising catchment rehabilitation interventions (Olley et al., 2010a; Olley et al., 2010b; Olley et al., 2009) and LiDAR data analyses (McMahon et al., 2017; McMahon et al., 2020). It is designed to inform a catchment scale estimate of relative erosion rates and the distribution of canopy cover in different height classes, without requiring the additional time required to derive estimates of absolute erosion volume (in m^3 for example).

The method could be completed again when new LiDAR data becomes available. If possible, it is recommended that this new data be captured approximately every 5 years, or after large flood events. If more time were available to error check the remotely sensed data, it would give more confidence in the magnitude and distribution of erosion volume, and the proportion of vegetation canopy cover in different height categories.

Future analyses should involve the following steps:

1. Using a Digital Elevation Model (DEM) of the study area define

   a. Slope in degrees

   b. Waterways based on flow accumulation

2. Using the waterways layer identify Strahler stream orders

3. Define geomorphic process zones based on coarse scale changes in slope, geology and soils

4. For each of the geomorphic process zones, calculate the proportion of different native vegetation types present currently, and at the time of European settlement, as indicated by the Queensland Herbarium.

5. For each of the stream orders, visually inspect aerial imagery to determine the most appropriate riparian buffer width in the catchment, e.g. 15 m, 20 m etc.

6. Using the most up to date LiDAR data available, extract canopy height model (CHM) data for 1-5 m and >5 m height categories.

7. Calculate the percent canopy cover of each vegetation height category in each stream order buffer

8. If two LiDAR captures are available, subtract the latter DEM from the earlier DEM to estimate erosion between the two time periods. Only look at erosion greater than a threshold of 0.5m to give increased confidence in erosion estimates.

9. Divide the volume of erosion in each stream order segment by the area of that segment to derive a m^3/m^2 erosion rate.

10. Visually inspect erosion in stream order segments to determine if errors have been introduced from dense vegetation cover or changes in water levels.

11. Extract the canopy cover of different height categories and erosion stream order data within each geomorphic process zone. Use erosion intensity as the primary factor driving rehabilitation priorities, followed by current vegetation extent.

Evaluation should investigate trends in relation to the current condition assessment presented in the accompanying Catchment Condition Assessment Report.

3.2 Rapid field assessments

The method developed and applied during this project is based on several rapid assessment methods that are widely used by natural resource managers to assess stream and riparian condition (e.g. protocols developed in Queensland; rapid appraisal of riparian condition – Jansen et al., 2005, State of the Rivers - Land and Environment Assessment, 2003; and the a national rapid assessment protocol for streams and rivers developed in New Zealand (Clapcott and Young, 2015). The method is designed to be comprehensive and rigorous, yet easily applicable at a variety of sites, rapid, and transferrable between catchments. Data sheets used to collect information during the rapid field assessment of sites in this project are provided in Appendix 2.

Desktop analysis

Prior to fieldwork, conduct a desktop analysis of the catchment to select sites suitable for the assessment. Sites at road creek crossings can be selected using satellite images, stream network information and analysis of road networks. Additional sites can also be selected in consultation with landholders who agree to property access.

Fieldwork

At selected locations, at least a 30 m transect is assessed for the survey. Sites at road crossings are assessed approximately 10 m either side of the road or within the road buffer before fencing restricted access. Sites on private property are established as 30 m along the stream. Five categories of stream condition are assessed: land, water, flora, animals, and people. Photographs are taken at each location for future references.

i. **Land.** Riparian width (width of woody vegetation from banks to the end of the riparian zone – determined by fencing or clear delineation between riparian and upland) and presence or absence of a fence and its functionality (quality) are recorded. Banks' slope (vertical, steep, moderate, low, and flat) and shape (concave, convex, stepped, wide lower bench, or undercut) are determined, any evidence of active erosion is assessed (see data sheet for reference pictures). Erosion is presented in four categories: nil to minor (minimal exposed bank, no evidence of recent gullying), minor to moderate (small areas of ripped bank, not continuous along bank), significant less than 2m (ripped banks and strong visible evidence of erosion along lower banks), and significant more than 2m (strong visible evidence of major erosion along all banks). Stock grazing pressure (none, low to moderate, high) and stock type are identified, as well as any evidence of heavy stock usage.

ii. **Plants.** The continuity of riparian vegetation within the transect on each bank (estimated percentage of bank covered with continuous canopy vegetation - greater than 2m) is measured, and a number of significant discontinuities (breaks in canopy cover) recorded. Total canopy, understory, and ground cover for both banks are estimated, with an additional indication of a percentage of native and introduced (exotic) species for each stratum. Any additional vegetation features of interest (e.g. identified species, thickets of invasive plants, native regrowth, large native or exotic trees etc.) are described.

iii. **Water.** The wetted stream width and depth for three to five chosen points distributed evenly along the transect are recorded. The percentage of shading of the stream bed and stream's visible depth are estimated. When water was present in the creek, turbidity, conductivity, pH, and dissolved oxygen at three points of the transect are measured with a YSI multiprobe. When water is not turbid or not present, a percentage of fine sediment covering the stream bed is estimated. Three quadrats (1m x 1m) are set up to examine sediment composition, and the percentages of rocks, cobbles, pebbles, gravel, sand, and silt are recorded.

iv. **Fauna.** Aquatic habitat features rather than presence of animals are assessed. The leaf litter within stream channel at every site is recorded in percentage, while individual submerged logs, twigs, branches, log jams, and root overhang are tallied. The continuity for fish passage is investigated and possible obstructions in the waterway (e.g., high dam, weir or waterfall, cascade rapid, log jam, culvert, logs, but also low features like sand bars, etc.) identified and recorded as presence/absence. The presence of terrestrial and aquatic habitat features is indicated: leaf litter cover on banks, the presence of hollow bearing trees and a presence of fallen logs. Any fauna seen at a site is counted and recorded, as well as indicators of its presence (e.g., nests, scats, mark on tree bark etc.).

v. **People.** Any infrastructure present at a site (e.g., bridge, weir, artificial bank protection structure, fencing) is described, and its photo reference taken.

Data analyses and evaluation

The collected data is summarised for the whole catchment, as well as within each process zone and stream order, with average calculated for quantitative variables. Points are mapped by site location and colour coded by attribute score. Future assessments should focus on describing trends in indicators in relation to those describe in the current project and presented in the accompanying Catchment Condition Assessment Report.

4. Intervention monitoring

4.1 Types of intervention monitoring

Collection and evaluation of information in the following categories would help understand the overall effectiveness of the *Franklin Vale Creek Initiative*:

1. **Success of on ground actions, for example:**
   - Assessment of plant survival, establishment and growth paired with information on care given to the plants and environmental conditions (rainfall and temperature).
   - Assessment of structural integrity of fences, hardened crossings, or off stream watering points through time, paired with construction details.
2. **Water quality** – monitoring to understand the effectiveness of restoration actions to reduce the load of sediment, nutrients and pathogens exported from Franklin Vale Creek
3. **Community and landowner perceptions** of the catchment and restoration programme
4. **Cost-effectiveness** – detailed record keeping of the costs associated with each project combined with data in the above categories could be used to undertake cost-benefit analysis.

4.2 Targeted intervention monitoring for water quality

Targeted intervention monitoring can be implemented to track changes in sediment and nutrient movement through restored riparian areas or constructed features where water is diverted. Monitoring sites are established to measure pollutant loads in water exiting (and if possible, entering) restored land areas, e.g., overland flow through riparian planting and restored gullies, or where water is channelled through artificial wetlands or swale. The aim is to quantify the local effectiveness of discrete restoration projects and study changes in runoff water quality through time. Sampling is typically using automatic monitoring stations equipped with turbidity and water height or velocity sensors, but may be conducted manually during events. Sediment traps may also be installed to collect time-integrated data.

This approach would help detect change at a local scale which is likely to occur in a shorter time frame than changes in downstream locations. To be successful monitoring sites need to be installed along well-defined hydrological flow paths through the restored area. Sites for targeted intervention monitoring also require unrestricted access so that samples can be collected during or immediately following events

Targeted intervention monitoring can also include river water quality sampling at paired sites directly upstream and downstream of a restored riparian area. The aim here is to detect change in water quality passing the site due to the reduction in inputs through the restored area during rainfall events. These methods may be useful to detect improvement when high runoff expected through the restored area, e.g. subtraction of upstream to downstream can tell you the portion that is entering along that reach during events, and improvement monitored as a site establishes. This approach is best suited where a large riparian area and long section of river has been restored (e.g. multiple kilometres) and an effect is unlikely to detect effects where short stretch of river is restored. It may also take some time for the effect of restoration to become apparent in water quality data using the technique.

The approach chosen for post-restoration water quality monitoring should be tailored to the individual project and its goals. A range of previous approaches are reported in literature which vary in spatial and temporal intensity of measurements. These approaches are outlined in Table 1 along with their potential drawbacks and a description of situations they may be well suited to monitoring.

4.3 Challenge of detecting change in water quality associated with restoration

Time lag effects

Restoration projects which aim to improve water may fail to meet targets due to a time lag between restoration actions and detectable improvement in water quality (Meals et al., 2010). This time lag comes from the time required for an effect to be delivered from the intervention. For example, it may take years for vegetation to grow sufficiently to reinforce soils with roots preventing erosion or contribute leaf litter to rivers providing habitat for invertebrates. The time required for the waterway to respond to the effects of restoration may also induce a time lag. For example, riparian planting may reduce sediment inputs to rivers, but sediment accumulated in the river from past events may continue to be resuspended and transported downstream for a period.

The extent of time lag time is catchment and pollutant specific, but may be months to years for contaminants such as bacteria that are relatively short lived, or longer for sediment accumulated in river systems (Meals et al., 2010).

Spatially connected nature of rivers and non-point source pollution inputs

Restored reaches receive water from upstream sites which may confound interpretation of water quality changes through that site. Water quality improvements driven by restoration of specific upstream areas may be obscured at the downstream end of a catchment by high pollutant loads delivered lower in the catchment. In this case water quality monitoring close to the restoration site or catchment wide may be required to understand the effect of restoration. It is important to understand which tributaries or channels within anabranching rivers contribute or transport the greatest load of pollutants, so that restoration positioned in an optimal position to intercept pollution.

Lack of baseline data

There is no baseline water quality data available of the historic or current condition of water quality in Franklin Vale Creek. This is typical of many small and intermittent rivers world-wide. Without baseline data it can be difficult to establish improved conditions, however this can be dealt with by regular monitoring at strategic locations in future and showing a trajectory through time. Even when no baseline data have been established prior to restoration, this research showed monitoring can demonstrate the effectiveness of riparian restoration (Collins et al., 2013).

Intermittent or flashy rivers

The term "intermittent rivers" has been used to refer to all temporary, ephemeral, seasonal, and episodic streams and rivers with defined channels (Datry et al., 2014). We might expect increased intermittency under future climate projections (Leigh et al., 2010). Monitoring the response of intermittent rivers to restoration is complicated by the fact that water only flows during part of the year, or only flows substantially during rainfall events which may be infrequent and unpredictable.

During dry or low flow periods, sediment and organic matter are stored in intermittently flowing channels. During these high flow events, large amounts of sediment, nutrients, organic matter, and other pollutants stored in river channels and on the land are transported downstream within short time periods (Leigh et al., 2013). It is during these wet periods that the majority of the sediment, nutrient and pathogen load is delivered downstream, but it is logistically difficult to collect samples to monitor these events.

Such events occur infrequently and unpredictably, which leads to uncertainty about the amount and frequency of monitoring required to reflect the full range events which may occur (Leigh et al., 2013).

5. Research priorities

Key knowledge needs to support the development, implementation and evaluation of the *Franklin Vale Creek Initiative* are provided in the accompanying Catchment Restoration Plan. To address, these we recommend the following priority research projects:

- A comparative analysis of all the catchments draining into the Bremer River (not only those within the Ipswich City Council area) to identify regional erosion hotspots. This could be achieved with the methods used to assess the Franklin Vale catchment in this study (see section 3.1). Once identified, collaborative work with regional bodies, such as the Resilient Rivers Initiative or Healthy Land and Water, could be undertaken to improve the spatial prioritisation of water quality interventions. If more time and/or funding was available, an estimate of erosion magnitude in absolute (i.e. m^3) rather than relative terms could be derived, which would allow the contribution of riverbank erosion to regional suspended sediment loads to be estimated.

- There is a need to understand how water and sediment move through Franklin Vale catchment, especially during high rainfall and flood events. Which sub-catchments contribute the most sediment and how does this change as restoration of the catchment proceeds? This could be a citizen science project to gather data from sufficient locations during rainfall events. A data station installed at the downstream end of the catchment to monitor flow and turbidity through events would also be valuable.

- In additional to understanding sub-catchment contributions in terms of sediment load, information on which areas of Franklin Vale Catchment contribute sediment with the highest nutrient content and bioavailability would be useful. Nutrient bioavailability indicator and bioassay techniques have recently been developed to rapidly assess sediments and identify those likely to have the greatest impact in downstream ecosystems (see Garzon-Garcia et al. 2017, Franklin et al. 2018). These techniques could be applied to detect nutrient “hotspots” within the catchment and combined with information on zones of high erosion potential to prioritise restoration most effectively.

- How long does water remain in Franklin Vale Creek following flow events, where is it retained and how does water quality in pools change after receiving flows? This information would be useful to work out what type of interventions could help retain water and which locations these should target.

- There is a need for improved understanding of the regenerative capacity of key vegetation communities in the catchment including riparian forests and woodlands, extirpated floodplain woodlands, as well as that of weeds (e.g., propagule pressure, seed banks), to inform the selection and design of appropriate vegetation management and restoration strategies.

- Improve understanding of wildlife in the catchment, including aquatic fauna, and habitat quality. This could include identification of key aquatic refuges (e.g. waterholes) and mapping of habitat connectivity to inform restoration priorities.

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Appendix 1. Approaches for monitoring impacts of interventions on water quality

Table A1. Key approaches to intervention monitoring that have been used previously to track impacts of restoration on water quality, example cases for each, as well as potential drawbacks and situations suitable for use of each approach

Approach	Description	Drawbacks	Situations suited to approach
End-of-catchment sampling	• Designed to detect the impact of all upstream restoration actions and management improvements combined on the quality of water leaving a catchment, i.e. entering a downstream water body • End-of-catchment monitoring sites are located at the lowest point on a creek or river, where the discharge can be accurately measured, often where gauging stations are already established • Water samples are collected manually or using automatic sampler at set time intervals and more intensively during events. This data is paired to continuous measurements of river discharge and turbidity or other surrogate data • Provides field data to calibrate and validate catchment models	• Does not provide information about the effectiveness of specific restoration actions within catchment • A long time lag may occur before impact is detected • High cost of running and maintaining gauging stations, e.g. at the upper end of the cost scale annual running costs of a GBR "super gauge" estimated at $47,000/year for field and laboratory analysis (Cape York NRM and South Cape York	• Ideal for use where understanding impact on downstream ecosystems is the focus of restoration, e.g. rivers entering GBR • Whole catchment restoration projects where a similar restoration technique is applied across the catchment

Approach	Description	Drawbacks	Situations suited to approach
	• **Example:** A network of "super gauges" monitor hydrology and water quality at end-of-catchment locations in rivers entering the Great Barrier Reef (GBR) lagoon. This high-quality data aims to detect effects of changing land use on pollutant loads delivered to the GBR over the long-term (Cape York NRM and South Cape York Catchment, 2016).	Catchment, 2016). However, lower cost designs are possible	
Catchment wide or spatially explicit	• This strategy consists of a network of monitoring sites spread throughout the catchment which aim to detect changes in water quality at different scales and understand spatial variability in pollutant loads, e.g. which tributaries produce the most sediment • The network may combine nested paddock, property, sub-catchment, and catchment scale monitoring. Sites are often positioned strategically to monitor locations of discrete current or future restoration projects, i.e. upstream and downstream to detect impact. • Control sites on unrestored sections of river can be built into the sampling design	• Large number of sites increases programme cost • Some sites may be redundant for long periods of time, i.e. prior to restoration	• Useful when high spatial variation throughout catchment is expected which may confound interpretation of impact of individual restoration actions • Information required on end of catchment loads and effects of restoration occurring in specific areas • When sequential restoration is planned throughout a catchment. Some sites may be

Approach	Description	Drawbacks	Situations suited to approach
	• Paddock or small sub-catchment monitoring may detect short-term benefits of restoration prior to changes at end of catchment • **Example:** Currently used to provide data on the effect of improved land management on GBR water quality (Cape York NRM and South Cape York Catchment, 2016) • **Example:** 16 sites established throughout Tarland catchment, Scotland, to monitor changes in water quality through time in response to incremental restoration (Bergfur et al., 2012)		sampled less frequently prior to restoration to provide baseline information
Longitudinal (downstream) transect	• The effects of restoration treatments evaluated by comparing water quality at multiple points along the downstream transect of a restored section of river • Samples are typically collected seasonally or annually to detect change water quality as the restored river re-establishes healthy ecological processes • **Example:** Ten sample points along 2.5 km of the Kwacza River in Poland, which was restored using groynes, semi-palisades, and stone islands. Samples collected prior to	• Labour intensive • If restored section is upstream does not give information about pollutant load leaving the catchment • Provides trajectory information but no "control" data to account for background changes in water quality	• When long sections of river have been restored helps understand role of restoration in changing in-stream nutrient cycling and establish the length of restoration required to induce changes • Where different types of restoration are conducted within a continuous river reach

Approach	Description	Drawbacks	Situations suited to approach
	restoration and during 6 years post-restoration (Mrozińska et al., 2018).		this may be used to identify those leading to greatest water quality improvement
Upstream and downstream points	• Paired sample points established directly upstream and downstream of the restored area, to detect change in water quality passing through in baseflow or reduction in inputs through the site in high flow. • **Example**: Sampling at downstream end of restored reaches on streams in Lake Ellesmere catchment New Zealand, paired with sampling at control sites, without planted native vegetation, positioned at least 500 m upstream (Collins et al., 2013)	• Unlikely to detect effects where short stretch of river is restored, e.g. no difference in nutrient retention between vegetated and unvegetated reaches in Gwydir River catchment, New South Wales (Stewart, 2012). • If restored section is upstream does not give information about pollutant load leaving the catchment • No "control" data to account for background changes in water quality	• Useful to detect improvement when high runoff expected through the restored area, e.g. subtraction of upstream to downstream can tell you the portion that is entering along that reach during events, and improvement monitored as the site establishes • Best suited where a large riparian area or long section of river has been restored

Approach	Description	Drawbacks	Situations suited to approach
Before-after control-impact (BACI)	• Similar to “upstream downstream point” or “longitudinal transect” approaches but includes a reference control site and before and after treatment sampling • In the Before-after control-impact (BACI) design paired sites are selected with similar hydrogeomorphic and ecological conditions (reference and a restored stream). These are sampled before and sequentially after restoration • A subset of points within the “catchment wide” approach can be used as BACI sites • **Example**: 8-years of water quality data (8 months before) collected in BACI design across a reference stream and a stream with passive restoration in a rural Normandy, France (Muller et al., 2016) • **Example**: BACI sites selected from “catchment wide” sites in Waikato, New Zealand. Used to detect effects of integrated catchment management (cattle exclusions and riparian planting) in sub-catchments, including 6-years pre-treatment data (Hughes and Quinn, 2014).	• Unlikely to detect effects where short stretch of river is restored • If restored section is upstream does not give information about pollutant load leaving the catchment • Labour intensive - not possible to monitor many restored sites	• Provides robust information when understanding and quantifying the impact of discrete restoration projects is required

Approach	Description	Drawbacks	Situations suited to approach
Space for time	• Point or longitudinal transect style monitoring of water quality at sites where restoration was initiated across a range of time periods • In lieu of collecting long-term time-series data to study to the trajectory of water quality following restoration an alternative is spatial data substituted for temporal data • **Example**: Water quality measured within nine riparian restoration zones in New Zealand that were fenced and planted 2 to 24 years prior to the study. These were compared to unrestored control points upstream (Parkyn et al., 2003). • **Example**: Impact of vegetation restoration on soil nutrient retention compared between paired degraded and historically restored sites in Baroon Pocket Dam catchment, southeast-Queensland (Laceby et al., 2017).	• Limited application to catchments with restoration sites established across a suitable range of time periods	• Useful to understand impact of previous restoration where no background data is available • When understanding the time lag prior to restoration effects being detected is a priority
Event-based monitoring	• Monitoring stations placed either at the end of catchment or upstream and downstream of restored sections of river. These are triggered during events to record continuous data on water height/flow and turbidity and may also collect water samples via an autosampler	• Does not provide data on baseflow conditions which exist most of the time therefore are likely to influence conditions for instream biota	• Suitable for intermittent or flashy rivers where most pollutant load moves downstream in flood events • Where impact of restoration on pollutants

Approach	Description	Drawbacks	Situations suited to approach
	• Monitoring station data can also be paired with grab samples collected manually for analysis of pollutants across the course of events • **Example:** High frequency sampling with "super gauges" on rivers entering the GBR are used to calculate empirical loads of pollutants delivered in events (Cape York NRM and South Cape York Catchment, 2016)	• A long-time lag may occur before impacts of upstream restoration are detected at end of catchment	loads delivered to downstream ecosystems is the focus
Targeted intervention monitoring	• Monitoring sites established to measure pollutant loads in water exiting (and if possible, entering) restored land areas, e.g. overland flow through riparian planting and restored gullies, or where water is channelled through artificial wetlands or swales • Aims to quantify the local effectiveness of the various treatment options and study changes in runoff water quality through time • Sampling typically using automatic monitoring station equipped with turbidity and water height or velocity sensors, but may be conducted manually during events • Sediment traps may also be installed to collect time-integrated data	• Does not provide info about effect of restoration on instream or downstream processes • Installation of autosamplers may be expensive • In areas where runoff does not occur in channelised zones it may be difficult to collect inflow and outflow water	• When aim is to detect change at a fine scale and short time frame, which can then be scaled up • Monitoring restoration of areas where hydrological flow paths are well defined • Sites with unrestricted access so that samples can be collected during or immediately following events • Suitable for intermittent or flashy rivers where

Approach	Description	Drawbacks	Situations suited to approach
	• **Example**: Sites set up at entrance and outflow of both restored and unrestored gullies in GBR catchments to investigate effectiveness of different restoration techniques (Bartley et al., 2019)		most pollutant load moves downstream in flood events • When understanding the impact of discrete restoration projects is required

Appendix 2. Rapid field assessment data sheets

Site Description

Site number:	Date and Time:	Recorders:
GPS location	Upstream: Downstream:	Photo point GPS location: Photo reference No.:
Does the site have a history of restoration activity? *(if yes, please give a brief description):*		

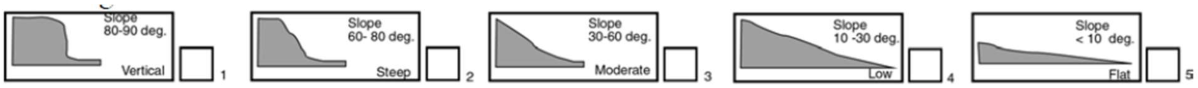
Section 1: Land

Riparian width |*The width (m) of the riparian buffer constrained by vegetation, fence or other structure(s).*

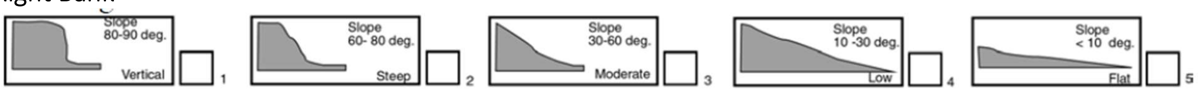
	Left Bank	Right Bank
Riparian Width (m)		
Is there a fence constraining the Riparian boundary? If yes, provide a brief description of the fence (e.g. barbed wire) ____ ____	☐	☐
If a fence is present, indicate the condition of the fence	☐ Good ☐ Moderate ☐ Poor	☐ Good ☐ Moderate ☐ Poor

Bank slope | *Indicate the percentage of the site represented by each slope type.*

Left Bank

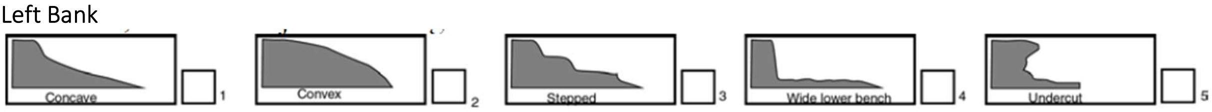


Right Bank

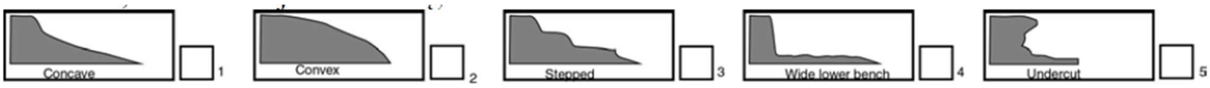


Bank shape | *Indicate the percentage (%) of the site represented by each shape type.*

Left Bank



Right Bank



Evidence of active erosion |*Select the option that most accurately reflects the erosion condition at the site.*

	Left Bank	Right Bank
Significant active erosion and bank recession on banks >2m high	☐	☐
Significant active erosion and bank recession <2m high	☐	☐
Minor to moderate active erosion or bank recession	☐	☐
Nil to minor active erosion or bank recession	☐	☐

Bank features | *Describe any notable features (e.g. gullies, rills, tunnel) that are present at the site that may contribute to erosion.* ***Take a photograph***

____

____

____

____

Photo Reference: ___________

Stock access |*Assess the area and choose from the below three categories of stock grazing pressure using the below photos as a guide.*

Heavy usage   Light to moderate usage   Controlled access (fenced)

Stock grazing pressure	Left Bank	Right Bank
Evidence of heavy stock usage	☐	☐
Evidence of light to moderate stock usage	☐	☐
Stock access controlled by fencing	☐	☐
Stock type	**Left Bank**	**Right Bank**
Cattle / dairy cows	☐	☐
Other (horses, sheep, goats)	☐	☐

Section 2: Plants

Continuity of riparian vegetation | *Indicate the length of each bank covered by continuous vegetation.*

	Left Bank	Right Bank
Percentage (%) of Bank covered by continuous vegetation		
Number of significant discontinuities *(gaps in canopy of greater than __m long)*		

Vegetation structure and complexity | *For each structural type, assess the cover it provides to the riparian area. Each structural type is assessed independently of the others and is out of 100%. (source: Jansen et. al. Rapid Assessment of Riparian Condition 2005 and DES State of the Rivers Field Manual 2003) Use the following photographs as a guide to canopy cover.*

15 % canopy

50 % canopy

90 % canopy

30 % canopy

70 % canopy

	Left Bank	Right Bank
Canopy *(> 5 m tall)* percentage (%) cover		
Understory *(1–5 m tall)* percentage (%) cover		
Ground *(<1 m tall)* percentage (%) cover		

Presence of native vs. exotic species | *Indicate what percentage (%) cover for each structural type is provide by native species.*

	Left Bank	Right Bank
Canopy *(> 5 m tall)* percentage (%) of natives		
Understory *(1–5 m tall)* percentage (%) of natives		
Ground *(<1 m tall)* percentage (%) of natives		

Vegetation features | *Describe any notable vegetation features that are present at the site. This may include thickets of invasive species (e.g. lantana), native regrowth, large native trees or any other significant vegetation.* *Take a photograph*

____

____

____

____

Photo Reference: ___________

Section 3: Water

Wetted stream width/depth | *Record the width of the wetted area and maximum water depth of five transects perpendicular to the direction of flow.*

Transect #	1	2	3	4	5
Width (m)					
Depth (m)					

Riparian shade | *The percentage of shading of the stream bed throughout the day due to vegetation, banks or other structure(s).*

	Percentage (%)
Percentage (%) of Streambed covered by shade	

Visible depth | *The depth to which you can see into the water.*

To what depth you can see into the water (m)	

Water quality |*At three locations randomly selected within the site, take measurements of turbidity, conductivity, pH and dissolved oxygen concentration.*

	Reading		
Turbidity			
Conductivity			
pH			
Dissolved oxygen concentration			

Deposited sediment | *The percentage of the stream bed covered by fine sediment.*

	Percentage (%)
Water too turbid for observation of percentage (%) cover	☐
Percentage (%) of Streambed covered by fine sediment	

Sediment composition |*Set up a 1m x 1m quadrat and indicate the percentage (%) of the wetted riverbed covered by each of the following at three locations randomly selected within the site. If the water is too turbid to observe percentage cover, only indicate present/absent.*

	Percentage (%)		
Water too turbid for observation of percentage (%) cover	☐	☐	☐
Cobbles			
Pebbles			
Gravel			

Sand			
Other *Please Describe:*			

Aquatic vegetation | *For each aquatic vegetation structural type indicate percentage (%) cover of wetted area. If the water is too turbid to observe percentage cover, only indicate that the structural type is present or absent.*

	Percentage (%)
Water too turbid for observation of percentage (%) cover	☐
Percentage (%) cover of submerged vegetation	
Percentage (%) cover of floating vegetation	
Percentage (%) cover of emergent vegetation	

Channel habitat class | *For each habitat identified in the reach indicate what proportion of that reach is made up of those habitats out of 100%.*

Habitat Class	Percentage (%)
Riffle (*Depth 0.1 – 0.3m, gradient 1-3 degrees, moderate currents, surface unbroken but unsmooth)*	
Run (*Depth >0.3m, gradient 1-3 degrees, small but distinct and uniform current, surface unbroken)*	
Pool (*Depth >0.5m where stream widens or deepens and current declines)*	
Dry bed (*Depth = 0)*	
Other *Please Describe:*	

Section 4: Fauna

Aquatic habitat features | *Leaf litter and debris may be present on the water surface or submerged.*

Percentage (%) cover of leaf litter	
Submerged logs present	☐
Submerged twigs and smaller branches present	☐
Submerged log jams present	☐
Root overhang present in waterway	☐
Other *Please Describe:* (e.g. notable den sites for platypus etc.)	

Continuity for fish passage | *Are there obstructions in the waterway that would prevent fish passage.*

Indicate all obstruction types that are present at the site:	
High dam, weir or waterfall	☐
Cascade rapid or log jam	☐
Low weir, pipe, culvert, ford or bridge	☐
Single log, branch, log or pile	☐
Low features, easily bypassed (e.g. sand bars)	☐
No obstructions observed	☐
Other *Please Describe:*	

Terrestrial habitat features| *Indicate the presence of the following habitat features at the site.*

(%) Percentage cover of leaf litter on banks	
Count of hollow bearing trees	
Count of fallen logs	

Fauna observations | *Make a note of any fauna or indicators of fauna presence (e.g. nests and scats) observed at the site. If you cannot provide a description,* ***take a photograph***

Species/description	Count

Species/description	Count

Photo Reference: __________

Section 5: People

Infrastructure | *Provide a description of any other infrastructure present at the site (e.g. bridge, weir, artificial bank protection structures, offtake pipes or pumps)* *Take a photograph*

Photo Number/Reference: ___________