PRIORITIZING WATERBODY MANAGEMENT IN THE LEICHHARDT CATCHMENT

ACTFR Report No. 07/20

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Using a Landsat TM archive to characterise water permanence and water clarity

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August 2007

Prepared for
Southern Gulf Catchments
Mt. Isa

Prepared by Leo Lymburner and Damien Burrows

Australian Centre for Tropical Freshwater Research
James Cook University
Townsville Qld 4811
Phone: 07 47814262
Fax: 07 47815589
Email: actfr@jcu.edu.au

TABLE OF CONTENTS

EXECUTIVE SUMMARY

There are 686 large (>1875m^2) waterbodies throughout the Leichhardt catchment. Prioritizing on-ground management for these waterbodies requires a 'whole-of-catchment' assessment of how waterbodies throughout the catchment are behaving over time. This report describes how three different remote sensing products have been combined to describe waterbodies throughout the Leichhardt catchment. An archive of dry season Landsat TM data was used to describe the size, distribution and permanence of individual dry season waterbodies. The same archive was also analysed to characterise the optical water quality dynamics of each waterbody, *i.e.* which water bodies are always clear in the dry season, and which waterbodies vary between being clear during one dry season and then turbid the next. Daily MODIS data were also used to map the extent and duration of inundation associated with the post Tropical Cyclone Larry flood event.

Each waterbody was assessed according to the following criteria:

- Permanence;
- Water clarity regime; and
- Wet season inundation.

These criteria were combined to assess the uniqueness of individual waterbodies and to identify priority waterbodies for on-ground management. The following waterbodies were identified as relatively unique and pending on-ground confirmation, priority candidates for on-ground management (by subcatchment)[1].

Upper Leichhardt

- The in-stream lagoon immediately upstream of the intersection of Saint Paul Creek and the Leichhardt River, and
- The in-stream lagoon downstream of the intersection of Eureka Creek and the Leichhardt River.

Mid Leichhardt

- Un-named waterbody at the intersection of Sandy Creek and Leichhardt River
- In-stream waterbodies on the main channel that vary between clear and turbid

Gunpowder Creek

- The water reservoir near Bar Creek, and
- Un-named waterhole on Dynamite Creek

Fiery Creek

- 16 Mile Waterhole,
- Un-named waterhole upstream of 16 Mile Waterhole

Alexandra River

- The largest of these waterbodies is 'The Lakes' on the road out to the Talawanta property.
- Un-named waterbody located on Seven Mile Creek.
- The other unique suite of waterbodies that are the 3 classified as always clear. They are shallow ephemeral waterbodies located just north of a line between Werna Hole Yards and Prickly Bush Holding Paddock.

Coastal Floodplain

- Off-channel waterbodies on the forested floodplain of the main channel, such as Goose Lagoon, Old Station Lagoon and Dingo Waterhole

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[1] The UTM coordinates of these wetlands are listed in the Recommendations at the end of this report (All coordinates are projected into **UTM Zone 54** on a **GDA 94** datum).

1. INTRODUCTION

There are thousands of wetlands within the Southern Gulf region including over 500 permanent waterbodies (QDNRW 2006) and covering an area of over 10 000km^2 (WWF). These wetlands include in-stream and off-stream riverine waterbodies, drinking water reservoirs, farm dams, swamps, and shallow ephemeral wetlands. These wetlands are important at a regional, national and international scale, with some wetlands aggregations under consideration for RAMSAR listing. Identifying which of these wetlands is in most urgent need of on-ground management presents a significant challenge. The aim of this report is to use cutting edge remote sensing techniques to address this challenge and provide new information to assist in the process of prioritizing on-ground works.

This report focuses specifically on wetlands that contain open water (as distinct from vegetated swamps, bogs, fens). Furthermore this project focuses on two aspects of open water bodies, permanence and water clarity. As a consequence of this the analysis places an emphasis on aquatic habitat and permanent aquatic habitat in particular. This means that the results of this analysis can be used to prioritise management actions aimed at protecting and restoring aquatic habitat and ecosystems, but is not intended to identify wetlands that may be important form an avian point of view (*i.e.* valuable local and migratory bird habitat) or from a social/cultural point of view. The approach used in this report is designed to classify waterbodies based on their degree of permanence and their long term water clarity dynamics. This approach captures two of the most important attributes that determine the aquatic ecosystem values of a waterbody. Permanence is a crucial attribute in determining aquatic ecosystem values, as permanent waterbodies provide the only refuge for aquatic organisms during the dry season, and by assessing permanence over a 16 year timeframe it is possible to identify permanence in terms of the waterbodies that persist during droughts too. Water clarity is also important because it determines the light climate within the waterbody, and this in turn determines the net primary productivity of the waterbody, and can have a large impact on the benthic productivity, aquatic vegetation and food-web-structure.

Based on the remote sensing approach used in this study water bodies can fall into the following classes:

- Ephemeral (inundated less than 50% of the time);
- Semi-permanent (inundated between 50% and 80% of the time);
- Frequently inundated (inundated between 80% and 99% of the time); and,
- Permanent (inundated 100% of the time).

The way in which these classes were determined, and the limitations of the approach used to identify these classes (both spatially and temporally) are discussed in detail in the Methods section of this report.

Waterbodies were also classified according to water clarity. Water clarity was divided up into three broad classes, turbid (secchi disk depth <0.5 m), clear (secchi disk depth >0.5m <1m) and very clear (secchi disk depth >1m). These classes were calculated for every available dry season Landsat TM scene, leading to a classification of water clarity regime (or temporal dynamics) that contained the following classes:

- Always very clear
- Varies between clear and very clear
- Always clear
- Varies between clear and turbid
- Always turbid.
- Varies between very clear and turbid

The two attributes of waterbodies permanence and clarity regime can be combined to generate classes such as permanent and always clear, or semi-permanent and varying between clear and turbid. These classes are analysed at a sub-catchment scale to identify unique or rare waterbodies, and it is these waterbodies that are considered as candidates for on-ground management. Daily satellite imagery of flooding of the post Tropical Cyclone Larry flood event analysed to further understand the dynamics of dry season water clarity (by assessing the relationship between wet season and dry season water clarity and assist in the identification of rare or unique waterbodies.

2. METHODOLOGY

The methodology is broken up into a series of sections that deal with the different products used in this project:

- Waterbody permanence;
- Water clarity regime;
- Wet-season inundation extent; and,
- Spatial analysis and rationale.

2.1. Waterbody Permanence

2.1.1. Image Processing

The image processing for the waterbody permanence layer was done by the Statewide Land and Tree Survey (SLATS) team at Queensland Department of Natural Resources and Water. The image processing techniques they used to generate this layer are as follows. The data is a polygon feature class containing all water bodies identified within Queensland, projected using GDA94. The water bodies were mapped using ERDAS Imagine to classify a time series of Landsat 5 & 7 images, ranging in date from 1986 to 2005, (typically winter imagery of 1988, 1991, 1993, 1995, 1997, and yearly from 1999 to 2005). Classification was based on thresholding a standardised multiple-regression water index, so that the number of pixels included with water was maximized, and errors of commission minimised. The individual year outputs of this process were converted to a mean extent for all years, excluding flooding events, and vectorised into the ArcGIS format to produce the polygon feature class. The number of years each water body feature had water in it has been calculated, along with a percent value which is an indicator of persistence (this attribute is cumulative and accounts for the first date the feature was captured and the number of years for which imagery was not available for that feature). Additional attributes, including the name, primary use and owner/s of dams, have been incorporated into the final dataset, by matching features to point features from a database provided by Dam Safety (Department of Natural Resources, Mines and Water), where features were within 100m of waterbodies derived from satellite imagery. Additionally features smaller than $1875m^2$ (a group of 3x25m pixels or less) have been excluded from the dataset, to meet the requirement of identifying large dams in Queensland.

By using an archive of Landsat TM data this dataset provides valuable insight into the distribution and permanence of waterbodies throughout Queensland. This in turn provides an essential input into any waterbody prioritization scheme.

2.1.2. Assumptions and Limitations

One of the limitations of this product is the minimum size of detection. A waterbody that is $1875m^2$ in size is relatively large, and there may be waterbodies smaller than this that require on-ground management, particularly in the upper reaches of catchments where small in-stream waterbodies that are smaller than this may provide refugia for the aquatic ecosystem in that part of the catchment. Waterbodies in these settings would require a different assessment technique consisting of higher spatial resolution remote sensing and land holder surveys. A further limitation of this means of detecting wetlands is that it relies on the presence of standing water. Wetlands that don't contain open standing water (*i.e.* vegetated swamps, ephemeral wetlands and bogs) are not detected using this method, and would need to be assessed using a different remote sensing methodology. An assumption of this technique is that waterbodies detecting during the mid to late dry season persist to the end of the dry season *i.e.* the first rains of the next wet. The images are typically dated from May through to October, whereas the first rains typically fall around mid to late November to early December. Given the minimum size criteria of $1875m^2$ it is likely that any waterbody that consistently met this criteria would probably persist until the next wet season.

2.2. Water Clarity Regime

2.2.1. *Background*

There are a range of techniques for using remote sensing to assess optical water quality. These techniques range from fairly basic (Nellis *et al*., 1998) , to highly sophisticated (Dekker *et al*., 1992). The more sophisticated techniques require extensive fieldwork and detailed laboratory analysis, and as such were beyond the scope of this project. The following approach was developed to meet the objectives of this project *i.e.* to characterize waterbodies based on their long term water clarity dynamics. Waterbodies were classified into three broad classes turbid (estimated secchi disk depth <0.5 m), clear (estimated secchi disk depth >0.5m <1m) and very clear (estimated secchi disk depth >1m). These secchi disk depth ranges were used because they are presumed to represent three different light climate regimes, and are likely to influence the ecological character of the waterbody. To identify these classes using remote sensing data a correlation between secchi disk depth and reflectance in the green wavelengths (Landsat TM band 2) was established (Figure 1). The relationship shown in Figure 1 was established using a series of lagoons along a flow path in the Burdekin Delta. The secchi disk measurements were made during 2004 dry season, and the satellite imagery from which the digital numbers were recorded was also collected during the 2004 dry season. Based on the relationship shown in Figure 1 the DN thresholds of >30 (turbid) >20<30 (clear) and <20 (very clear) were chosen. As a local reference point, Lake Moondarra has a digital number (DN) less than 25 in all dry season scenes indicating that it is clear in every dry season. A visual survey of wetlands within the study area also reveals that those that contain emergent and/or floating macrophytes (*i.e.* those that support benthic production) typically have DNs less than 30.

2.2.2. *Image Processing*

2.2.2.1. Identifying and characterizing waterbodies for each Landsat scene

An archive of Landsat TM scenes was used to quantify the long term water clarity dynamics of wetlands The waterbody polygons identified by the QDNRW database were used to segment up each individual Landsat TM imagery. The variable climate encountered within the Southern Gulf mean that waterbodies are not always the same size and shape, even at the same time of the year. A waterbody that covers 10 hectares in July of one year may only cover 4 hectares in July of the next year. To describe the long term

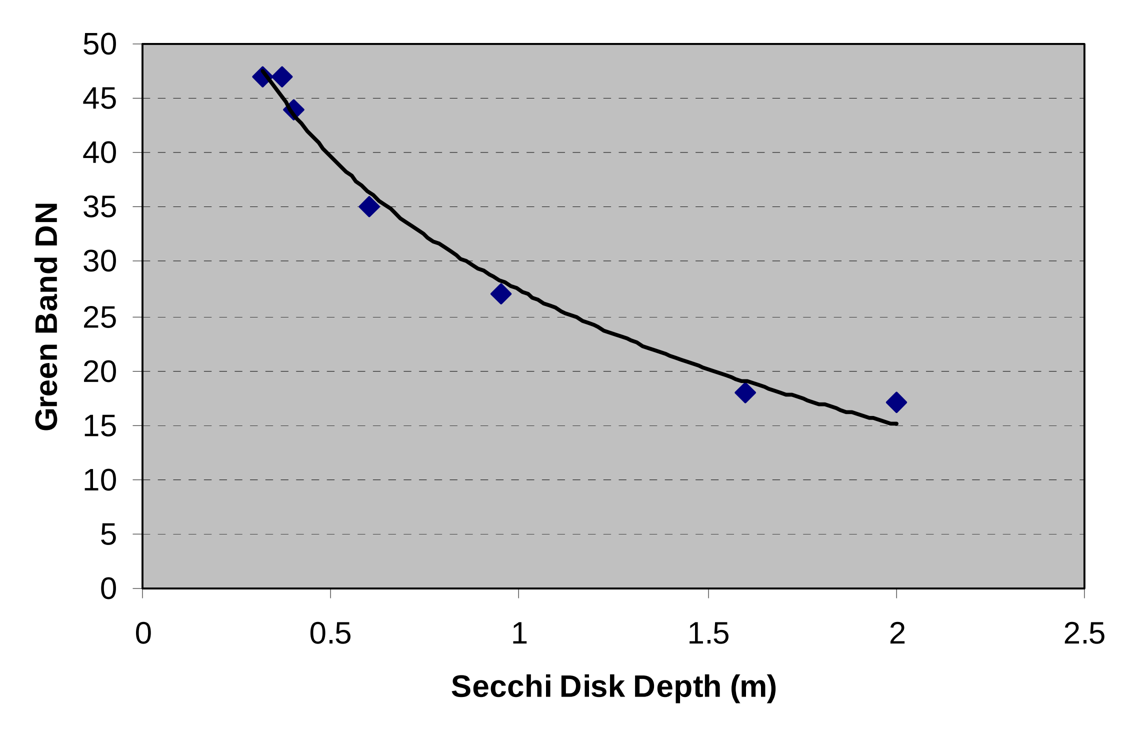

Figure 1 The correlation between secchi disk depth and Green Band digital numbers

water clarity dynamics of a waterbody it is vital to ensure that the reflectance being considered comes only from the waterbody (not the surrounding banks that may have dried out earlier in the year). To achieve this data within each waterbody polygon were segmented to identify areas that had similar spectral characteristics. Dry land has different spectral characteristics to water and would be identified as a separate segment. The standing water polygons, *i.e.* those areas within the QDNRW waterbody polygons that contained water in that scene were identified using a short wave infra red (Landsat TM Band 5) threshold. If a waterbody polygon, as defined by the QDRNW dataset contained no water, *i.e.* that waterbody was dry in that particular scene then the polygon was classified as not inundated. If it did contain water then it was classified as follows. The average green reflectance value for each standing water polygons identified using the previous steps was used to classify the polygon into one of the three classes: turbid (Band 2 DN>30); clear (Band 2 DN >20 but <30) or very clear (Band 2 DN <20). This approach does not take into consideration the inherent optical properties of each waterbody, however it does provide a simple means of comparing the relative water clarity of a large number of waterbodies for multiple satellite scenes.

2.2.2.2. Characterizing water clarity dynamics

For each waterbody a database was established, and the status (very clear, clear, turbid, dry) of that waterbody was recorded for every year of observation. For example, Lake Moondarra fluctuated between very clear (42%) and clear (58%) of all recorded years. The number of records for the Mt Isa Landsat tile was 12 years in total during the period from 1988 to 2005. The water clarity estimates were made from the same suite of images as the water permanence database, meaning that water clarity was estimated during the mid to late dry season. This means that waterbodies recorded as turbid are likely to have suspended sediments that persist into the dry season, as distinct from waterbodies that may be turbid for a short period of time immediately following flooding but then become clear. By looking at water clarity at the same time of year, *i.e.* mid-late dry season this provides an inter-annual assessment of water clarity dynamics.

2.2.2.3. Defining riparian zones and land cover

A 150 metre buffer layer was generated by buffering each waterbody, and this area was used to assess riparian land cover types. Google Earth Pro ™ was used to identify different vegetation structural classes: Closed Forest, Open Forest, Woodland, Open Woodland, and Grassland) *sensu* Specht (1970). In addition to these vegetation cover classes the land cover classes of bare soil/scald/gully and river sand were identified. Areas of each class were identified using the high spatial resolution scenes available through Google Earth ™ and independent areas were used to assess the accuracy of the classification.

2.3. Wet Season Inundation

2.3.1. Image Processing

The wet season inundation mapping was done using the daily 500 metre MODIS product MOD09GHK. This imagery was acquired from the Earth Observing System Data Gateway via the Land Processes Distributed Active Archive Center. Daily data was collected for the 2000/2001 wet season flood event and the 2006 post-tropical-cyclone-Larry flood event. The data were then processed using the MRT algorithm and imported into ENVI ™. A threshold classification was applied the short-wave infra-red band of each image to identified the inundated areas. A threshold value of 1000 was used to separate inundated from non-inundated areas. The inundated area for each day was then added together to form a map showing inundation extent and duration. This layer was used to identify whether waterbodies are likely to receive wet season floodwaters, or waters from their immediate surroundings.

2.3.2. Assumptions and Limitations

The main limitation of this approach is that optical sensors are unable to detect water beneath vegetation canopies, so that in areas where there are large floodplain forests this method will not detect the inundation of that portion of the floodplain. This limitation does not have a large impact on this project, as this project is primarily concerned with open waterbodies.

2.4. Spatial Analysis

The initial scope of this project was the entire Southern Gulf region, and initial image processing was undertaken with this scope in mind. However, during the accuracy assessment phase of the image processing it became apparent that there were spatial mismatches between the inundation frequency maps produced by the QDNRW and the Landsat mosaics used to characterise water clarity. The resulting products identified catchment scale trends, but were not accurate at the individual waterbody scale. As a consequence of this the analysis was re-done on individual Landsat scenes. The constraints of the budget only allowed for the analysis to be re-done on one of the Southern Gulf catchments, in this instance the Leichhardt.

The Leichhardt catchment was broken up into a series of sub-catchments. This was done to provide a template for summarising the data, and because the different sub-catchments have different geological and hydrological settings, and the uniqueness and rarity of waterbodies is determined by their local context. A map of the eight subcatchments is shown in Figure 2. Note that whilst the estuarine section of the catchment is included in the analysis, this report focuses on freshwater wetlands. The subcatchments are Alexandra River, Fiery Creek, Gunpowder Creek, upper Leichhardt, mid-Leichhardt, and coastal floodplain.

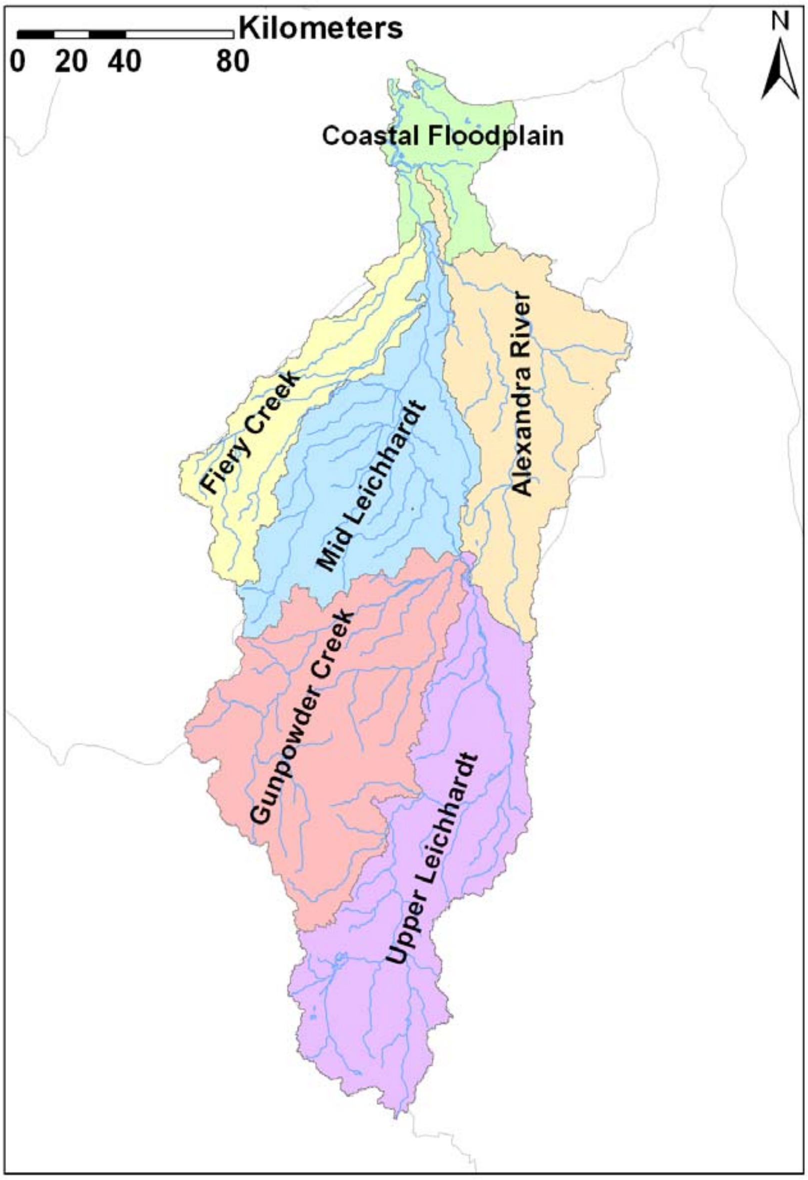

Figure 2 Subcatchments of the Leichhardt catchment

2.5. Prioritizing waterbodies based on permanence, size, water clarity and riparian vegetation

Prioritizing wetlands for on-ground management is a complex problem. This complexity stems from two sources. Firstly, rare or unique wetlands are likely to be of high priority, thus there is the problem of identifying which wetlands are rare or unique in a sub-catchment or catchment context. Secondly, there is the problem of identifying which waterbody types are likely to respond to management. For example, there is no point in spending thousands of dollars on a fencing project it the wetland condition will not respond to fencing, or show only a weak response to being fenced off.

In addition to this there are also social and cultural considerations when prioritizing on-ground works including identifying willing land-holders and addressing the needs/concerns of traditional owners. With this in mind this report presents a suite of data layers designed to assist in the prioritization process, on the understanding that the final list of priority wetlands will be developed in a workshop environment with these layers available to inform the decision making process. The layers presented in this report are:

- Waterbody Permanence;
- Water Clarity Regime;
- Riparian Vegetation and/or Land Cover immediately surrounding the dry season waterbody;
- Fluvial context (Resevoir, in-channel, off-channel (floodplain), off-channel (not-floodplain); and
- Wet season inundation extent and duration.

3. RESULTS AND DISCUSSION

3.1. Waterbodies in the Leichhardt catchment

3.1.1. Waterbody permanence in the Leichhardt catchment

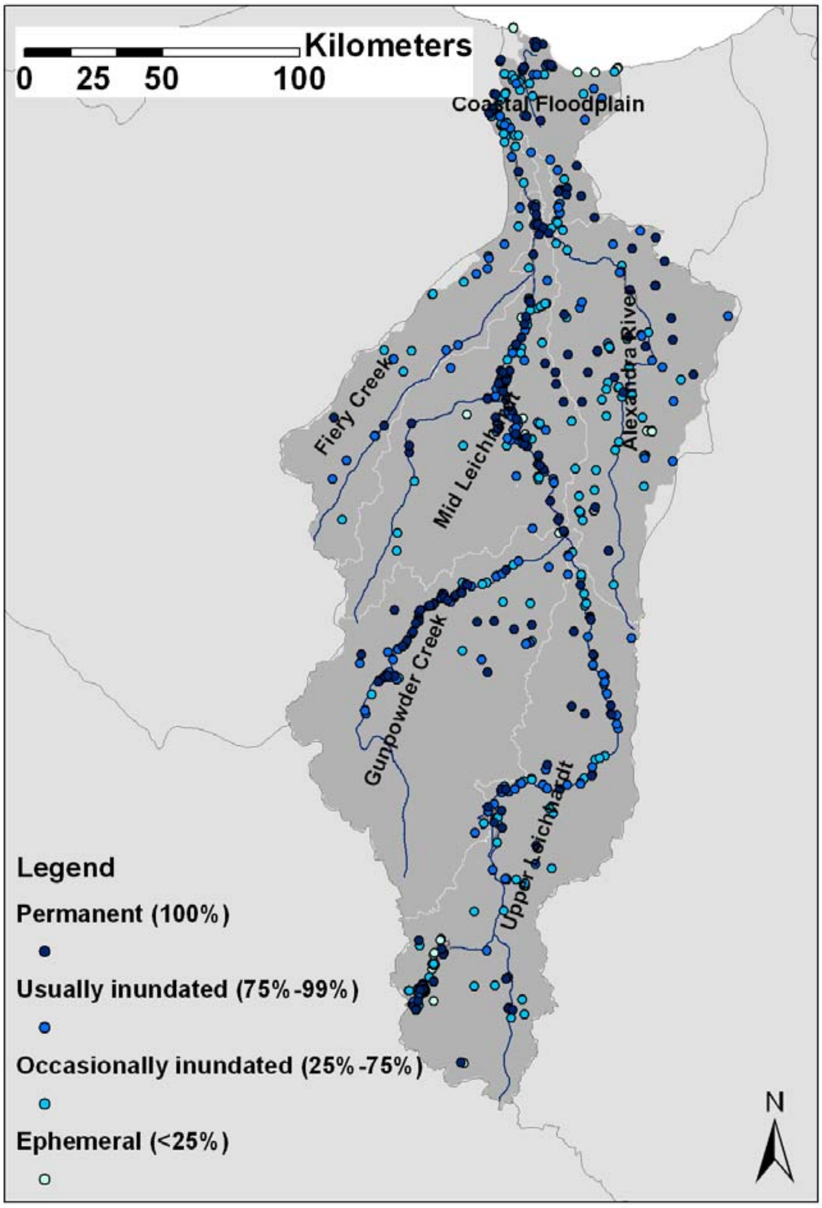

Figure 3 Permanency of waterbodies (>1875m^2) in the Leichhardt catchment

There are permanent waterbodies in all subcatchments of the Leichhardt catchment (Figure 3). These range from the large reservoirs that service Mt Isa and mining activities in the Upper Leichhardt and Gunpowder subcatchments through to permanent in-stream waterbodies in the northern part of the catchment. Some artificial cattle watering points are also identified as permanent waterbodies from the satellite imagery. Many of the semi-permanent waterbodies (usual and occasional class) are in-stream waterbodies that either dry out during the drier years or drop below the size detection limit of technique used to identify the waterbodies. The more ephemeral waterbodies (occasional and ephemeral classes) are typically off-stream waterbodies that contain water during the wetter years but are dry during drier years.

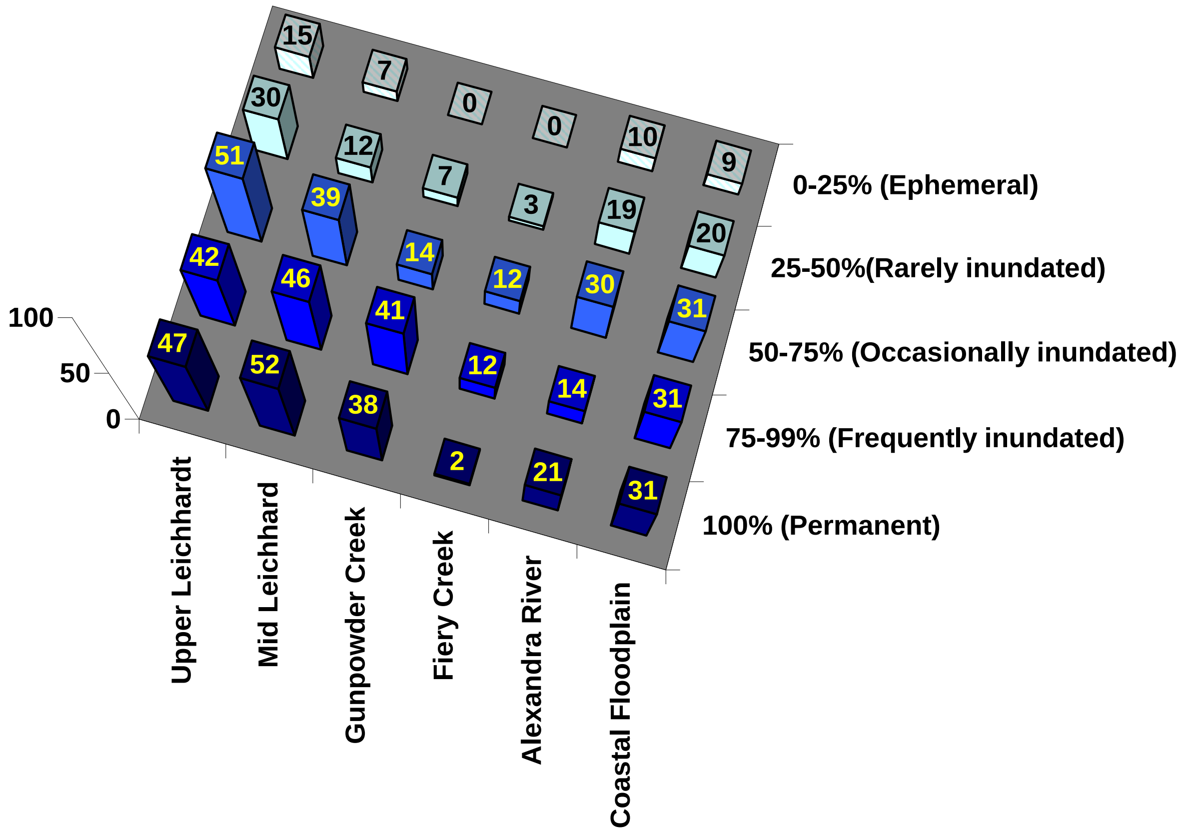

Figure 4 Distribution of waterbodies according to permanency classes for each subcatchment

The results (Figure 4 and Figure 5) show that there are a large number of permanent and frequently inundated waterbodies in the upper and mid-Leichhardt subcatchments, and the Gunpowder Creek subcatchment. The floodplain dominated subcatchments of Fiery Creek and Alexandra River have a higher proportion occasional, rarely inundated and ephemeral waterbodies. The coastal floodplain represents a combination of both, in the sense that it has a large number of permanent of frequently inundated waterbodies in the main river channel, as well as a large number of ephemeral and rarely inundated floodplain waterbodies.

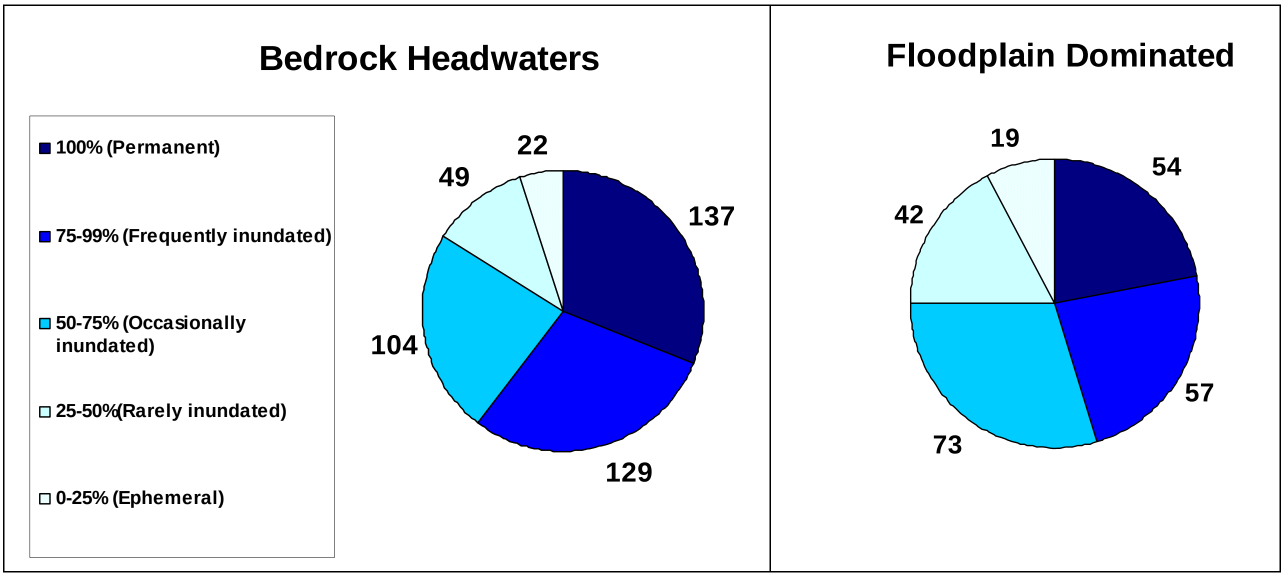

Figure 5 Distribution of waterbody permanence classes for two broad subcatchment types

3.1.2. *Water Clarity Dynamics in the Leichhardt catchment*

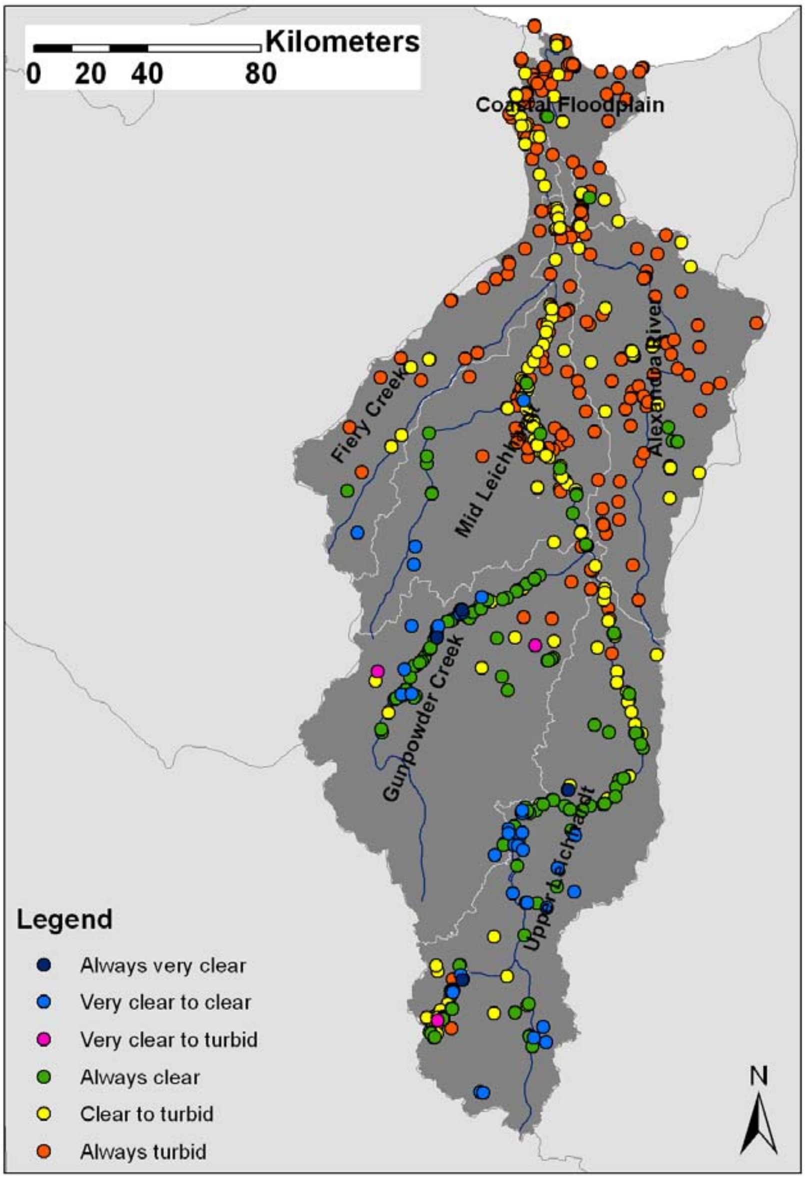

Figure 6 The spatial distribution of the water clarity regime classes for waterbodies of the Leichhardt catchment

The water clarity dynamics show a range of informative patterns at the whole-of-catchment scale (Figure 6). In the granite and metamorphic dominated southern parts of the catchment the waterbodies are typically very clear to clear with a few exceptions associated with mining activities. In the northern part of the catchment the off-stream floodplain waterbodies are always turbid, whereas the in-stream waterbodies vary between turbid and clear with many of the main-channel waterbodies receiving clear base flow from further up in the catchment. These patterns are even more striking when overlaid with a geology layer and this is explored for each subcatchment in the subsequent sections.

In the context of the water clarity dynamic product the term 'always' means 'in all scenes analysed'. This means that a waterbody classified as 'always turbid' was turbid in every scene analysed. It is possible for a waterbody to have had a different water clarity class earlier or later during the year that was not observed using this technique. This technique also fails to discriminate between the following three scenarios: shallow clear water with a bright substrate (sandy bottom), algal bloom, high concentrations of suspended matter. All three of these scenarios would be classified as 'turbid' using this technique. In future this technique will be refined to discriminate these scenarios. The secchi disk depths of several waterbodies were recorded by Hogan and Vallance (2005), and their data were used by way of validation. Hogan and Vallance (2005) recorded secchi disk depths at nine waterbodies throughout the catchment. The technique used in this study correctly predicted the secchi disk depth class (*i.e.* very clear, clear, turbid) of seven of the nine waterbodies. Of the two that were misclassified, one was misclassified as clear (predicted class clear, observed class turbid) because it was experiencing an algal bloom (and may otherwise have been clear earlier or later in the year), the other was predicted as clear and observed as very clear. In this instance the observed secchi disk depth falls into the 'very clear class' because the observed secchi disk depth was 1.1 metres. This is very close to the 1 metre threshold value between clear and very clear and is considered as an acceptable error for the purposes of this study. In future a field campaign to measure secchi disk depths across a large number of waterbodies would provide additional validation for this product.

It is difficult to validate this product due to a lack of appropriate datasets *i.e.* historical records of secchi disk depth variation with time for a range of waterbodies throughout the Leichhardt catchment.

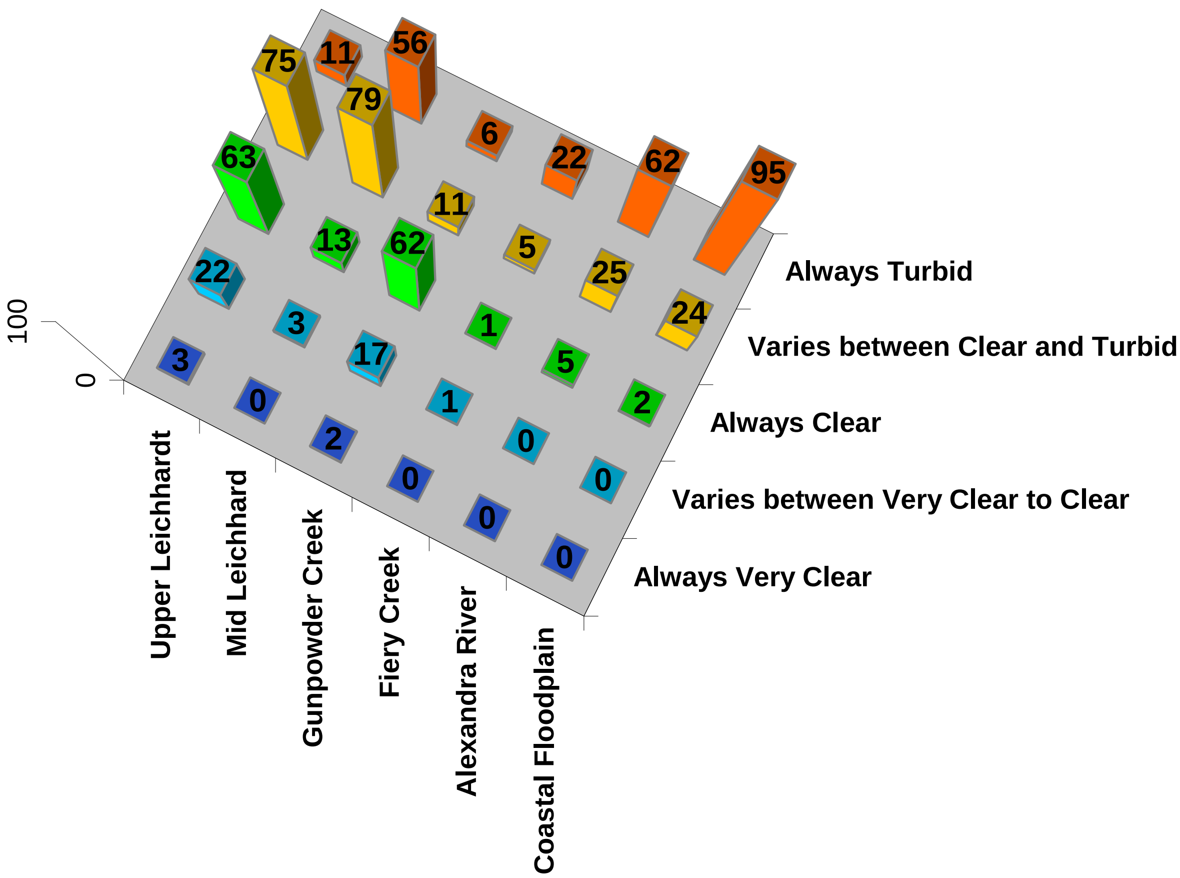

Figure 7 Distribution of water clarity regime classes for each subcatchment

The results (Figure 7) show the change from the predominantly clear or variable classes in the bedrock dominated upper parts of the catchment (upper and mid-Leichhardt, and Gunpowder Creek) towards the more turbid waterbodies that dominate in the floodplain dominated subcatchments (Fiery Creek, Alexandra River and coastal floodplain. This is particularly evident for the always very clear class that only occurs in bedrock reaches of the bedrock dominated subcatchments.

3.1.3. Floodplain inundation for the Leichhardt catchment post-Tropical Cyclone Larry

A total of six days of MODIS 250 metre data were analysed to assess floodplain inundation after Tropical Cyclone Larry. This represents with the largest flood on record for this catchment (Bureau of Meteorology, 2006), and the imagery was captured at the peak of the flood and over the subsequent five days. The red dots in Figure 8 represent dry season waterbodies and the yellow lines represent the main rivers within the catchment. The blue tones represent the number of days of inundation that occurred subsequent to the post TC Larry flood event. Based on this imagery there are extensive floodplains within the Alexandra, mid-Leichhardt and coastal floodplain subcatchments. This imagery was used to identify which waterbodies were subject to floodwaters during flood events.

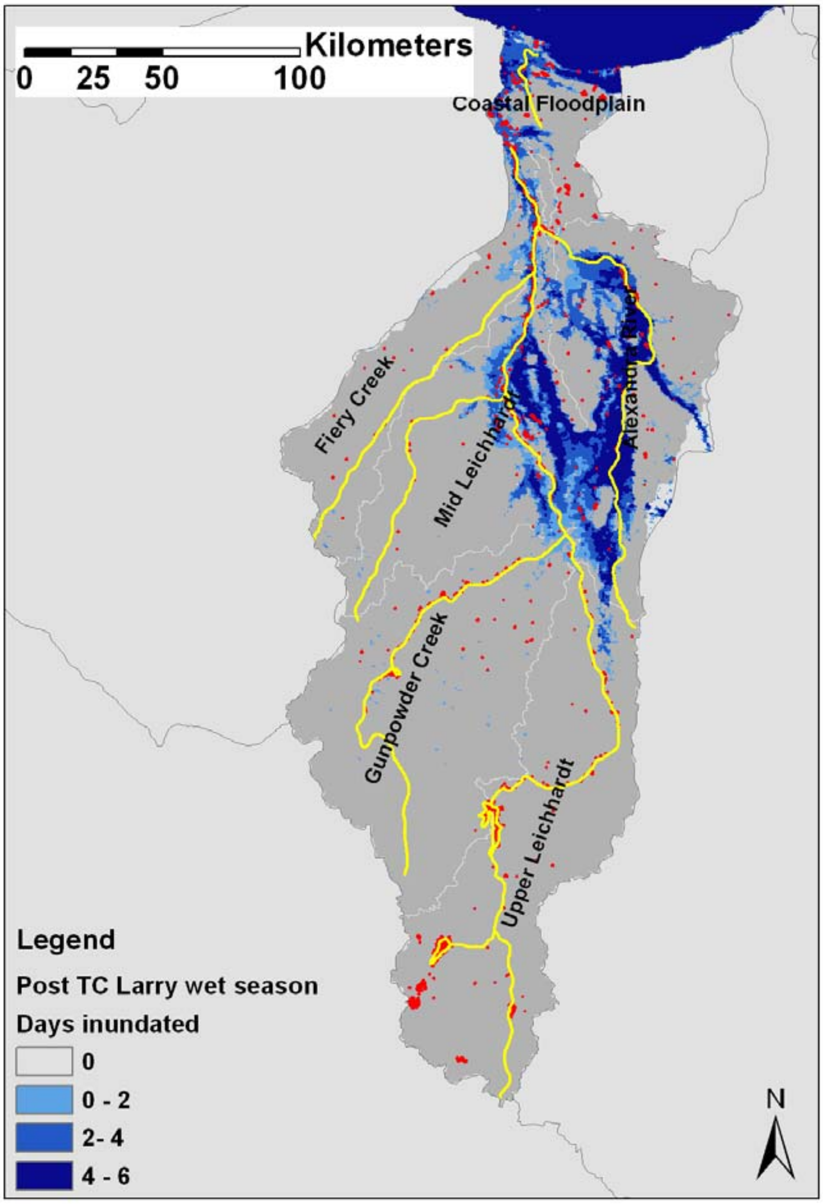

Figure 8 Duration of inundation during the flood event that followed TC Larry

3.2. Alexandra River

3.2.1. Waterbody Permanence in the Alexandra River subcatchment

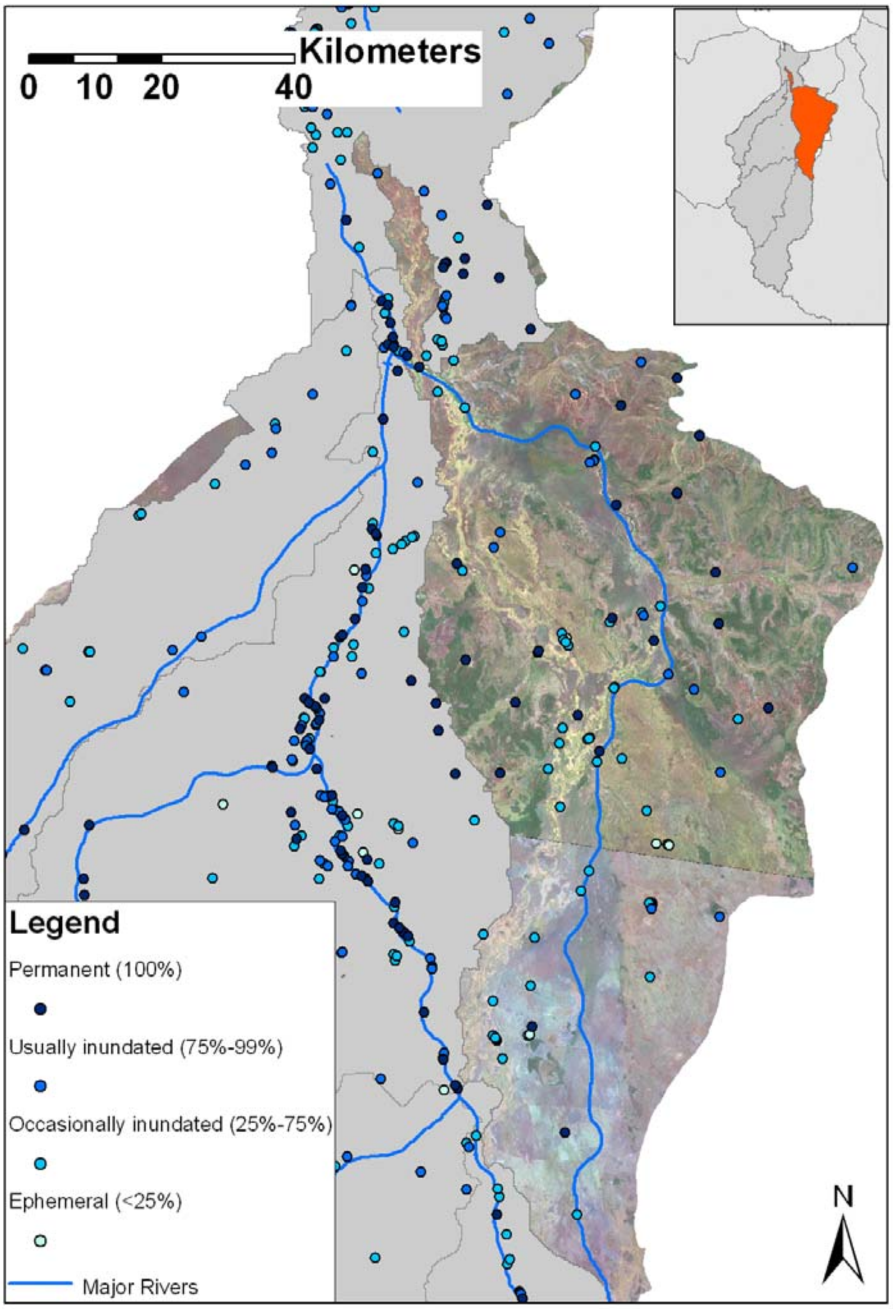

Figure 9 Waterbody permanence for waterbodies in the Alexandra River subcatchment (shown in true colour, other subcatchments grayed out)

The Alexandra River subcatchment has a large number of ephemeral and occasionally inundated waterbodies (relative to other sub-catchments in the Leichhardt) (Figure 9). These are typically off-channel shallow depressions on the floodplain that fill during flood events and persist during wet years and dry out in the drier years. The permanent waterbodies in this sub-catchment include off-channel cattle watering points, dams, and in-stream waterbodies. Some of the waterbodies on the main channel (blue line) are not permanent, indicating that the main channel itself is ephemeral (as distinct from the main channel of the Leichhardt which has predominantly permanent waterbodies.

3.2.2. Water clarity dynamics for the Alexandra River subcatchment

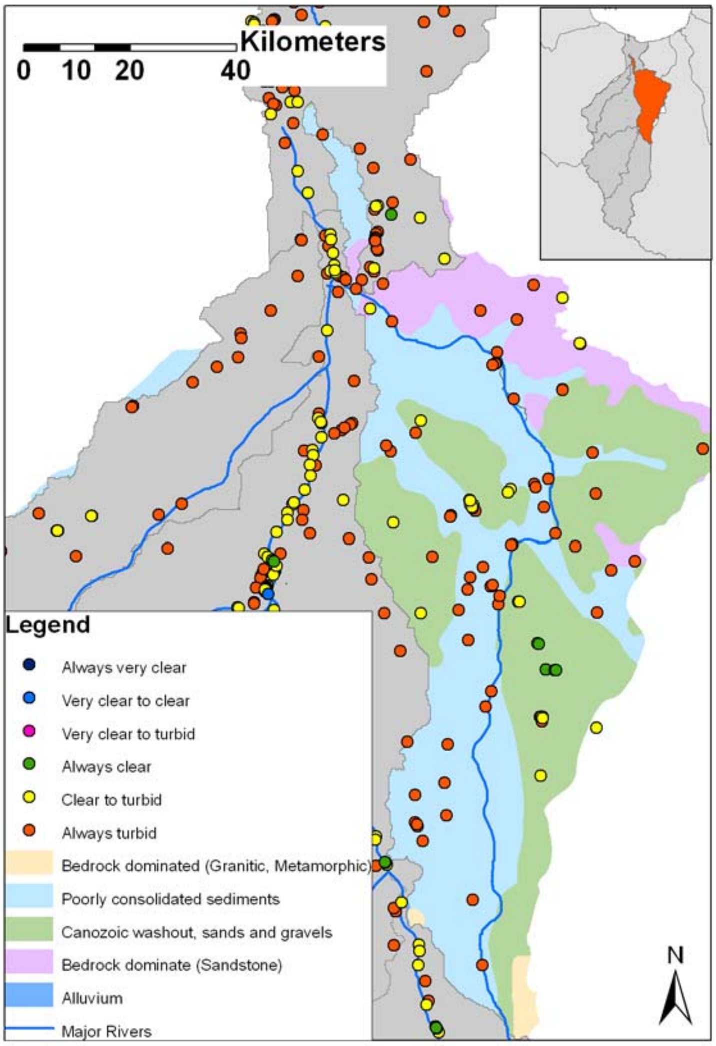

Figure 10 Water clarity regime for waterbodies in the Alexandra river subcatchment (other subcatchments grayed out)

The relationship between water quality regime and geology is striking in this sub-catchment (Figure 10). All of the floodplain waterbodies (located in the pale blue region) are always turbid, whereas waterbodies on Canozoic floodout sediments include waterbodies from the always clear and clear to turbid classes. The absence of significant base flow/ low flow in the main channel also means that the main channel waterbodies remain turbid (as distinct from the main channel waterbodies of the Leichhardt which typically clarify as a result of baseflow). Of the 94 waterbodies in this catchment, 21 are permanent, and of these 15 are always turbid and 6 vary between clear and turbid. It's possible that the 6 that vary between clear and turbid may be candidates for management actions such as fencing. The largest of these waterbodies is 'The Lakes' on the road out to the Talawanta property. The remainder are un-named waterbodies, one of which is located on Seven Mile Creek.

The waterbody known as 'The Lakes' and the un-named cluster of waterbodies located at (408795E, 7940843N) are unique in the sense that 'the Lakes' are relatively large (9.8 ha) is subject to an extended period (3 days) of inundation during the post TC Larry flood event (shown next page), but, unlike other floodplain waterbodies they have become clear on at least one occasion.

The other unique suite of waterbodies are the 3 classified as always clear. They are shallow ephemeral waterbodies and are un-named but are located just north of a line between Werna Hole Yards and Prickly Bush Holding Paddock. They are located at 422551E, 7910423N, 424343E, 7910302N, and 421169E, 7915283N.

3.2.3. Floodplain inundation for the Alexandra River subcatchment

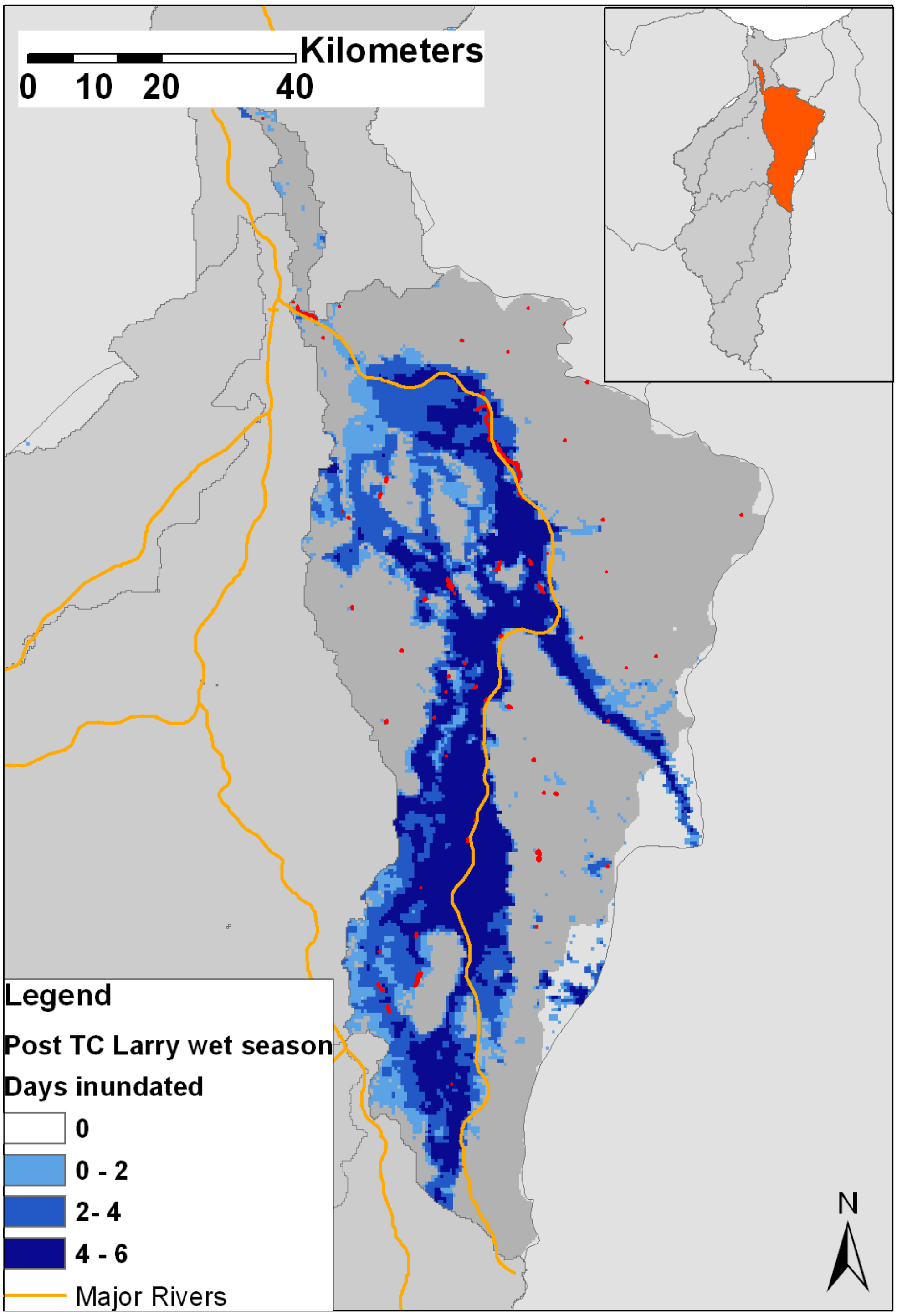

Figure 11 Extent and duration of flooding in the Alexandra River subcatchment

The flood event that followed TC Larry was the biggest flood on record for the Leichhardt catchment. The Alexandra river catchment contains extensive floodplains and received water from further up in the Leichhardt catchment. Large portions of the catchment were inundated for an extended period of time, and all floodplain waterbodies shared a common water source during this event. As expected there is a close relationship between the inundated area shown above the geology class 'poorly consolidated sediment' shown on the previous page.

3.3. Fiery Creek

3.3.1. Waterbody permanence for the Fiery Creek subcatchment

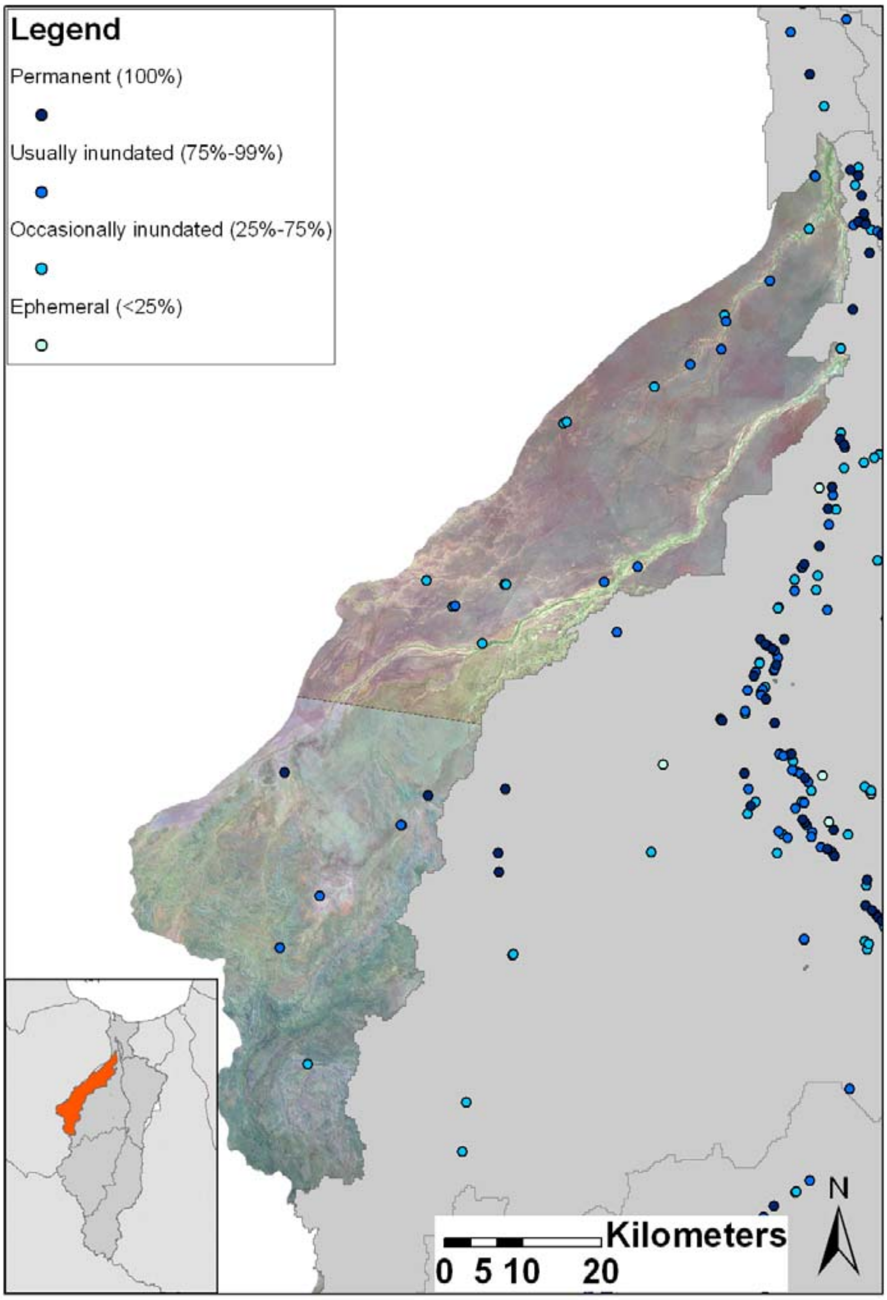

Figure 12 Waterbody permanence classes for the waterbodies in the Fiery Creek subcatchment

The Fiery Creek subcatchment contains relatively few waterbodies (29) of which only two are permanent (Figure 12). The catchment is dominated by semi-permanent floodplain waterbodies with only four waterbodies located in bedrock dominated geologies.

3.3.2. *Water clarity dynamics for the Fiery Creek subcatchment*

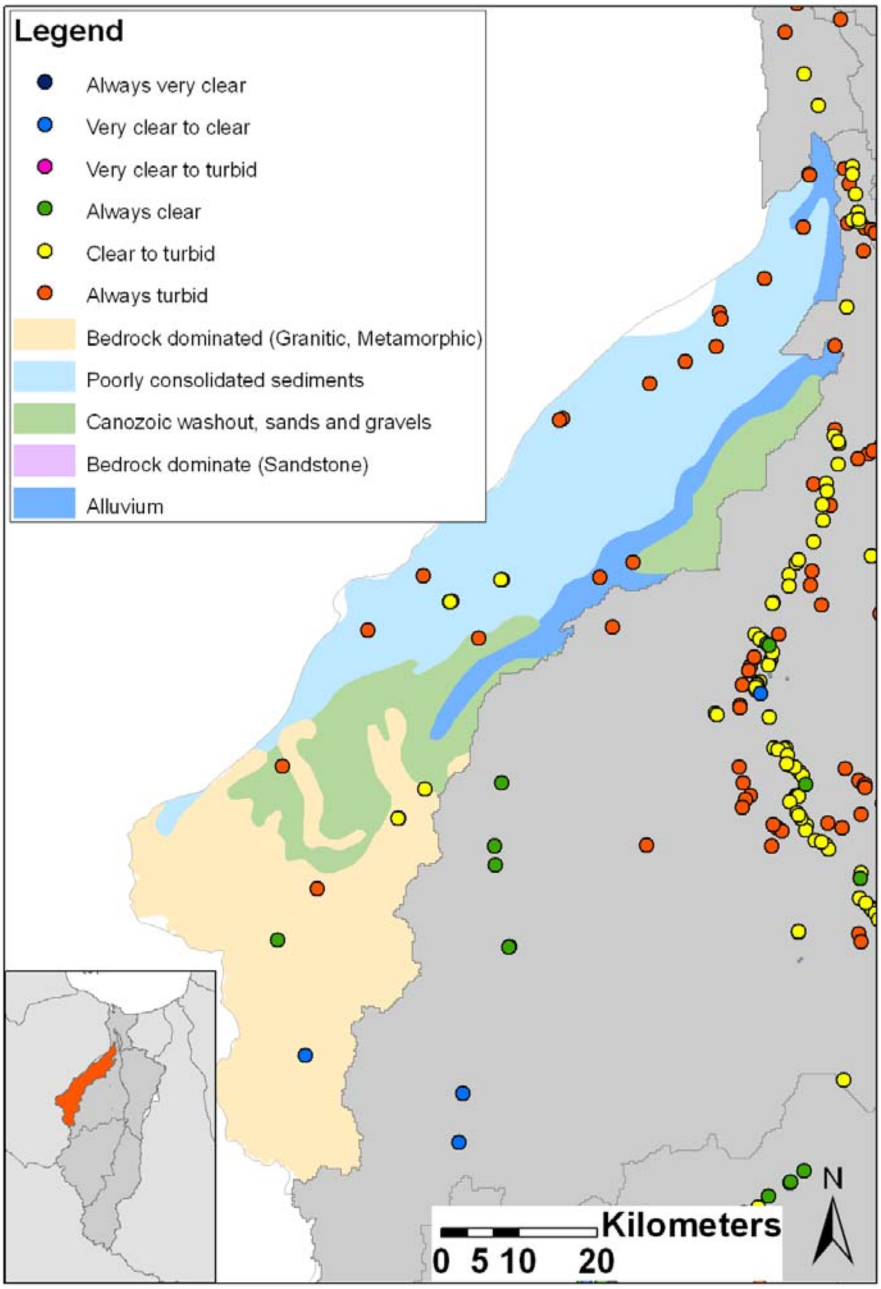

Figure 13 Water clarity regime for waterbodies in the Fiery Creek subcatchment

The relationship between water clarity regime and geology seen previously in the Alexandra River also exists here (Figure 13). The waterbodies located on bedrock geology include very clear-clear class, always clear, two clear to turbid and two always turbid. Conversely, all floodplain waterbodies (except two) are always turbid. Of these two 16 Mile Waterhole is the only permanent one. Both this waterhole and the un-named waterhole upstream of it (that also goes clear 330465E, 7936474N) would be good candidates for management. The other areas that may be worth management (pending on ground investigation) would be the always turbid and clear-turbid waterbodies located on bedrock geology. These are all ephemeral, and may be less important than other waterbodies within the whole Leichhardt catchment.

3.4. Gunpowder Creek

3.4.1. Waterbody permanence for Gunpowder Creek

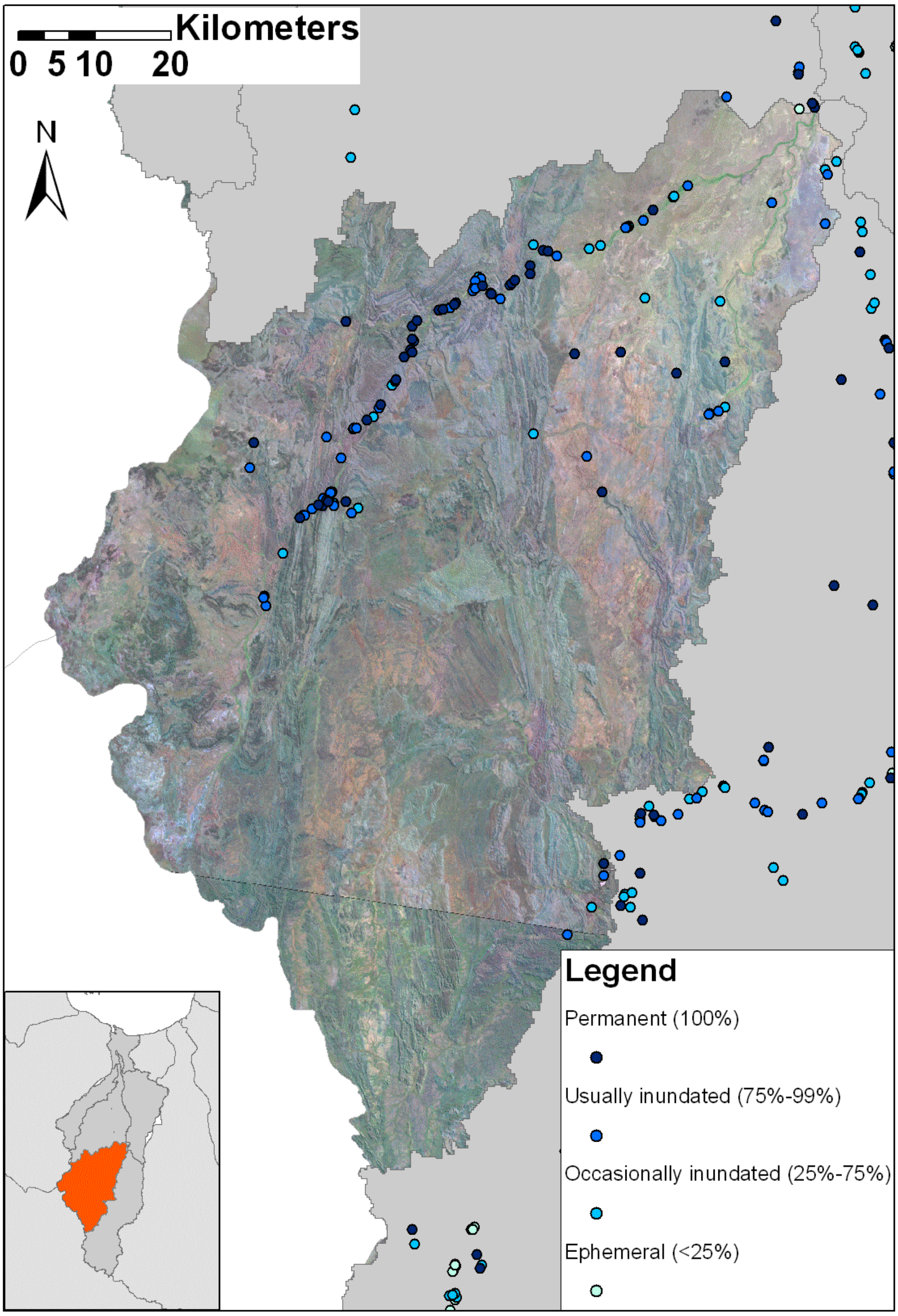

Figure 14 Permanence classes for waterbodies in the Gunpowder Creek subcatchment

There are 100 waterbodies within the Gunpowder Creek subcatchment (Figure 14) of which 38 are permanent and all are inundated more than 25% of the time. Unlike the floodplain dominated subcatchments the majority of these waterbodies typically fall into the very clear and clear classes.

3.4.2. Water clarity dynamics for the Gunpowder Creek subcatchment

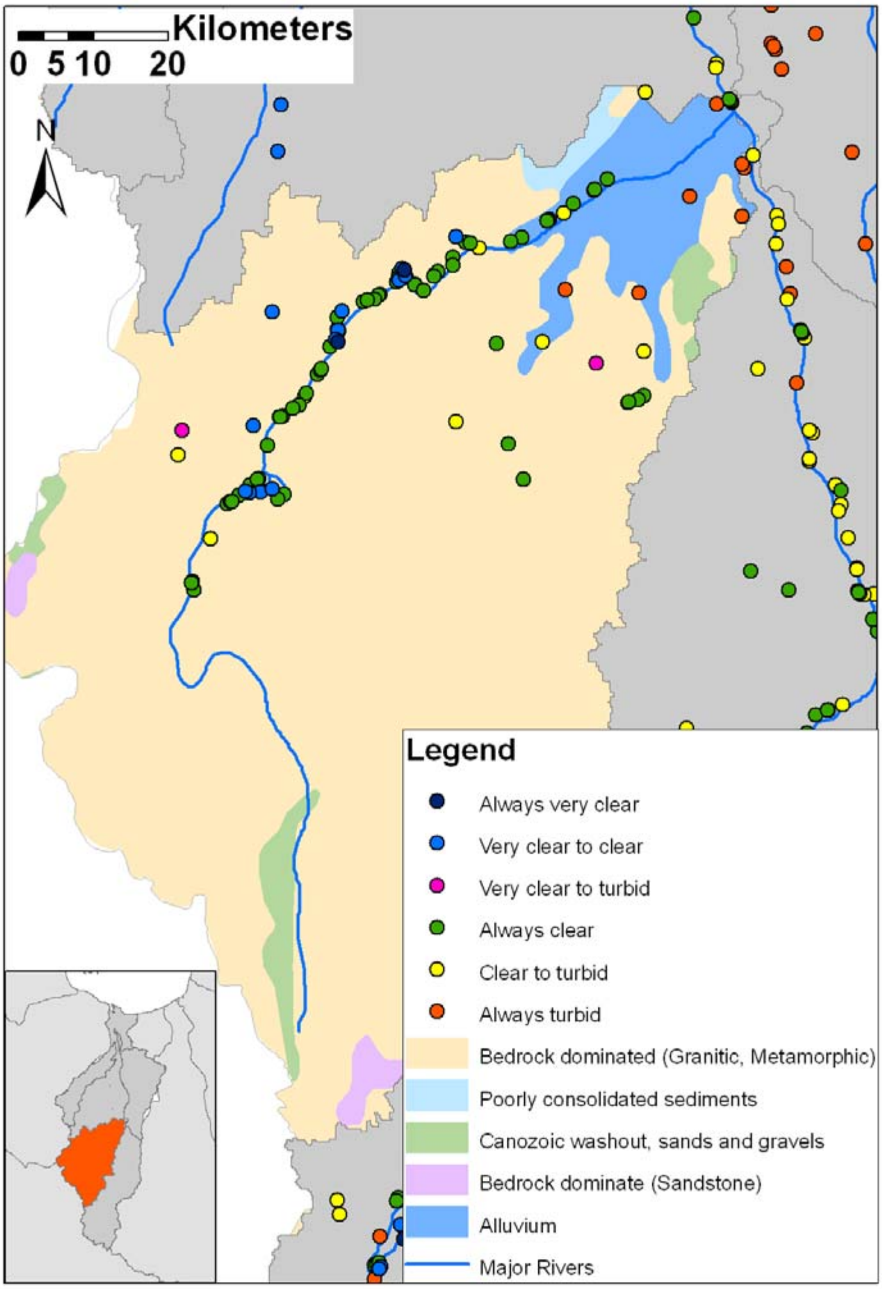

Figure 15 Water clarity regime for waterbodies in the Gunpowder Creek subcatchment.

The majority of waterbodies fall into the three clearest classes, reflecting the bedrock geology and water source (Figure 15). The two waterbodies that vary between very clear and turbid are unusual in this class occurs in only a few places. These two waterbodies are the water reservoir near Bar Creek and an un-named waterhole on Dynamite Creek (374318E, 7838612N). It's possible that this class represents an algal bloom, this would explain why a very clear waterbody experienced a large increase in green reflectance in one of the scenes.

Identifying a waterbody that would be suitable for management in this catchment is problematic, because the majority of in-stream waterbodies are already in the clear classes and may not respond to actions such as fencing. The waterbodies that fluctuate between clear to turbid are generally small un-named waterbodies, however these, particularly the off-stream waterbodies, may be candidates.

3.5. Upper Leichhardt

3.5.1. Waterbody permanence in the upper Leichhardt subcatchment

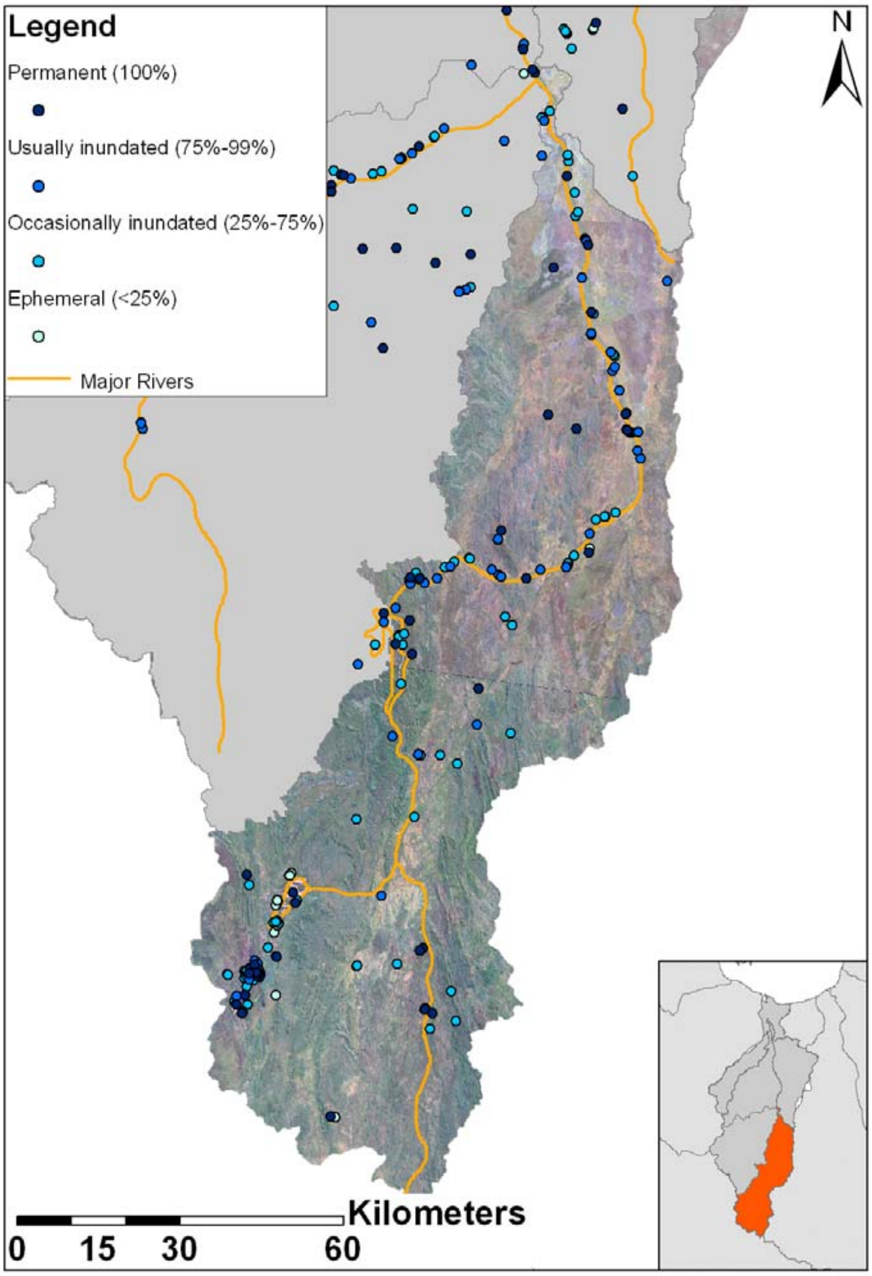

Figure 16 Permanence classes for the waterbodies in the upper Leichhardt.

There are 176 waterbodies in the upper Leichhardt, of which 47 are permanent. These include large reservoirs such as Lake Mary Kathleen, Lake Julius and Lake Moondarra. In the upper (southern) part of the catchment many of the off-channel waterbodies are only occasionally inundated. Whereas downstream of Lake Julius most waterbodies are either usually inundated or permanent.

3.5.2. *Water clarity dynamics for the upper Leichhardt*

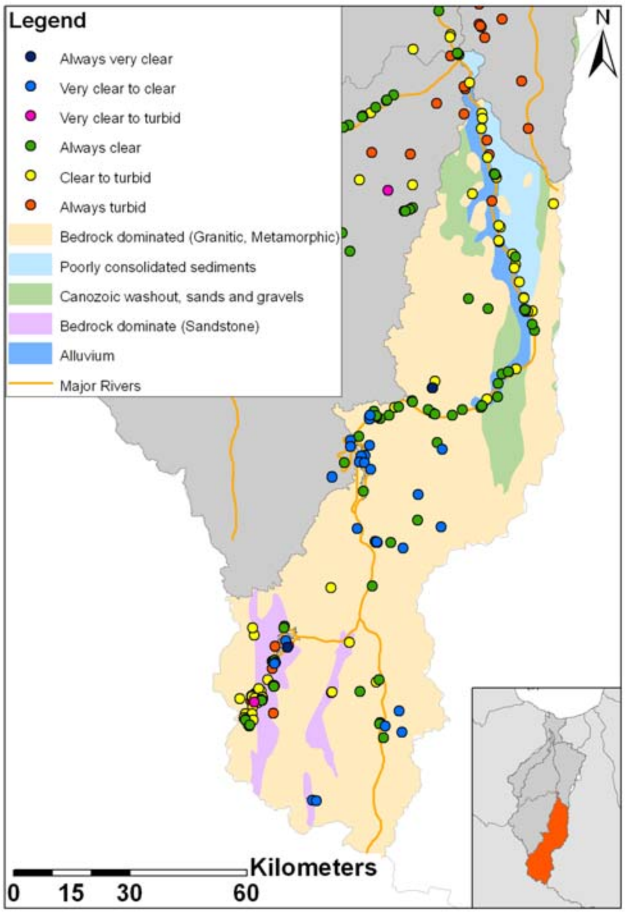

Figure 17 Water clarity regime for waterbodies in the upper Leichhardt.

The relationship between water clarity dynamics and geology in the upper Leichhardt is similar to that seen elsewhere within the catchment, *i.e.* waterbodies on a bedrock geology are typically clear or vary between clear and turbid, and waterbodies on alluvial sediment at the northern end of the catchment are more likely to have been turbid at least once (clear to turbid class). The exception to this is the waterbodies associated with mining activity around Mt Isa. This is not surprising given that the water clarity dynamics are being driven by different processes than encountered elsewhere within the catchment. Whilst these waterbodies are 'unique' they are not considered for the purposes of this report because they are managed to meet the needs of mining activities rather than the aquatic ecosystem. Of the 47 permanent waterbodies in the catchment 21 fall into the class that may respond to common management actions such as fencing (from a water clarity point of view) *i.e.* those that vary from clear to turbid. Of these 21 the majority are associated with mining activities with three located in the main channel of the Leichhardt river at the northern end of the catchment. These three waterbodies were clear in all but one year (although it's a different year for each waterbody). This could be indicative with localised algal blooms or localised cattle effects, *i.e.* if it had been a 'shallow water, bright sand' scenario both waterbodies would have gone 'turbid' in the same year). This would indicate that these waterbodies may respond to fencing. These waterbodies are the in-stream lagoon immediately upstream of the intersection of Saint Paul Creek and the Leichhardt River (402962E, 7829455N), and the in-stream lagoon downstream of the intersection of Eureka Creek and the Leichhardt River (402329E, 7841915N). Any fencing project for these two waterbodies would need to consider the propensity for floodwaters to damages any fencing projects. There is a dam at 396083E, 7837751N, that goes clear on two occasions. Closer inspection using Google Earth indicates that this is a moderate sized farm dam with evidence of macrophyte beds at one end. This waterbody would be a candidate for fencing, if the landholder was interested in the water clarity of the water.

3.6. Mid-Leichhardt

3.6.1. Waterbody permanence in the mid-Leichhardt subcatchment

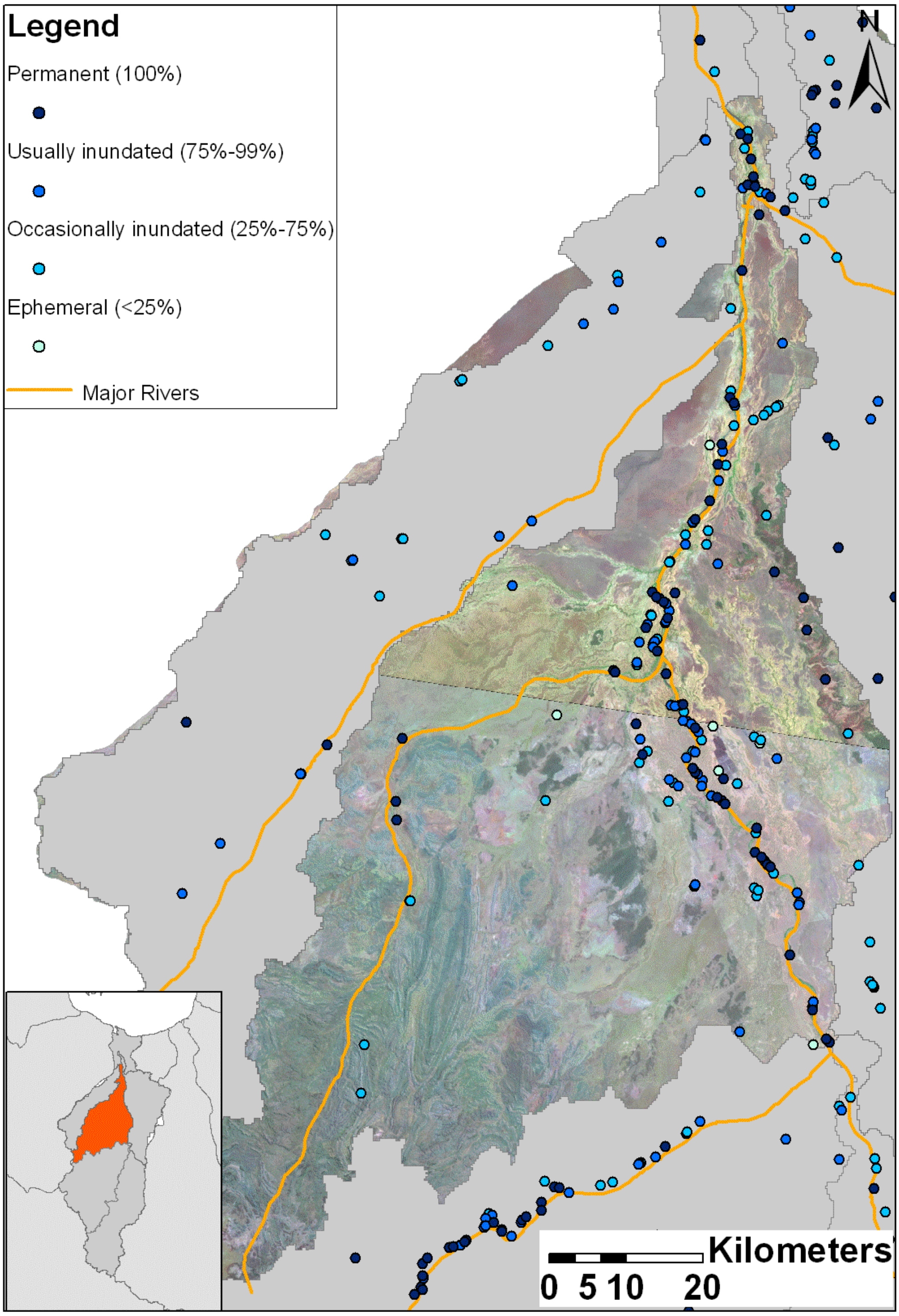

Figure 18 Permanence characteristics of waterbodies in the mid-Leichhardt subcatchment.

There are 156 waterbodies in the mid-Leichhardt, of which 52 are permanent, with the bulk of these being in-stream waterbodies or off-channel floodplain lagoons (Figure 18). There are also three permanent waterbodies on the main arm of Sandy Creek. The remaining waterbodies are primarily semi-permanent or ephemeral off-channel floodplain lagoons.

Water clarity regime for the mid-Leichhardt subcatchment

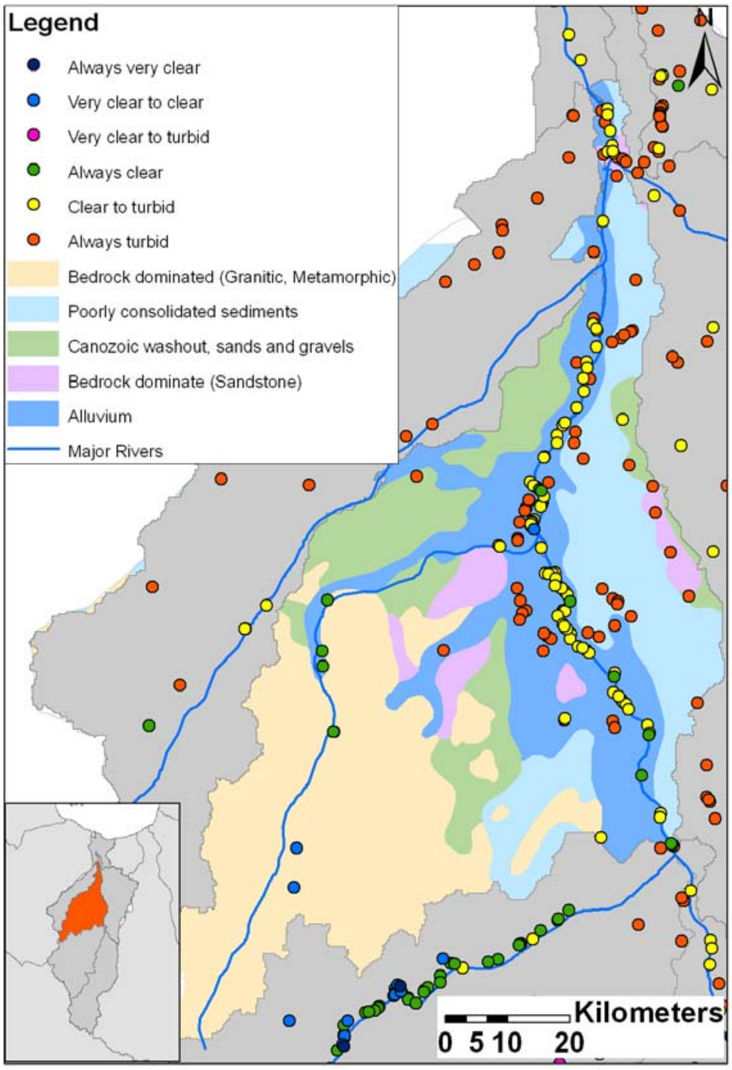

Figure 19 Water clarity regime for waterbodies in the mid-Leichhardt subcatchment.

The relationship between water clarity regime and geology is the same as encountered in other subcatchments, however there is another influence on water clarity that occurs in this catchment. The waterbodies on the main channel of the Leichhardt are all classified as always clear, or clear to turbid. Despite the fact that they're located on alluvial material, the clear base flow or low flow water from higher up in the bedrock dominated portion of the catchment displaces the more turbid floodwaters along the main channel. This phenomenon is emphasized by the very clear to clear waterbody that exists at the intersection of the Leichhardt and Sandy Creeks (370258E, 7924649N). This is the only instance of a very clear-clear waterbody anywhere within the alluvial or poorly consolidated geology classes and is unique as a result of this. The dual water sources for this waterbody are likely to make it fairly resilient, in other words there are other waterbodies that may benefit more from fencing. However this site would be a candidate for a more detailed assessment of it's aquatic flora and fauna. The other waterbodies that may be worth fencing are the in-stream waterbodies on the main channel that vary between clear and turbid. The effectiveness of the fencing would be determined by whether it is local processes (*i.e.* cattle access/cattle related biophysical processes) that are causing the change in water clarity, or whether the water clarity is being influenced by catchment scale influences (influx of nutrients from upstream followed by low flow periods providing the conditions required for algal blooms to occur. This uncertainty could make this sort of fencing project a lower priority than other projects within the catchment

3.6.2. Floodplain inundation in the mid-Leichhardt subcatchment

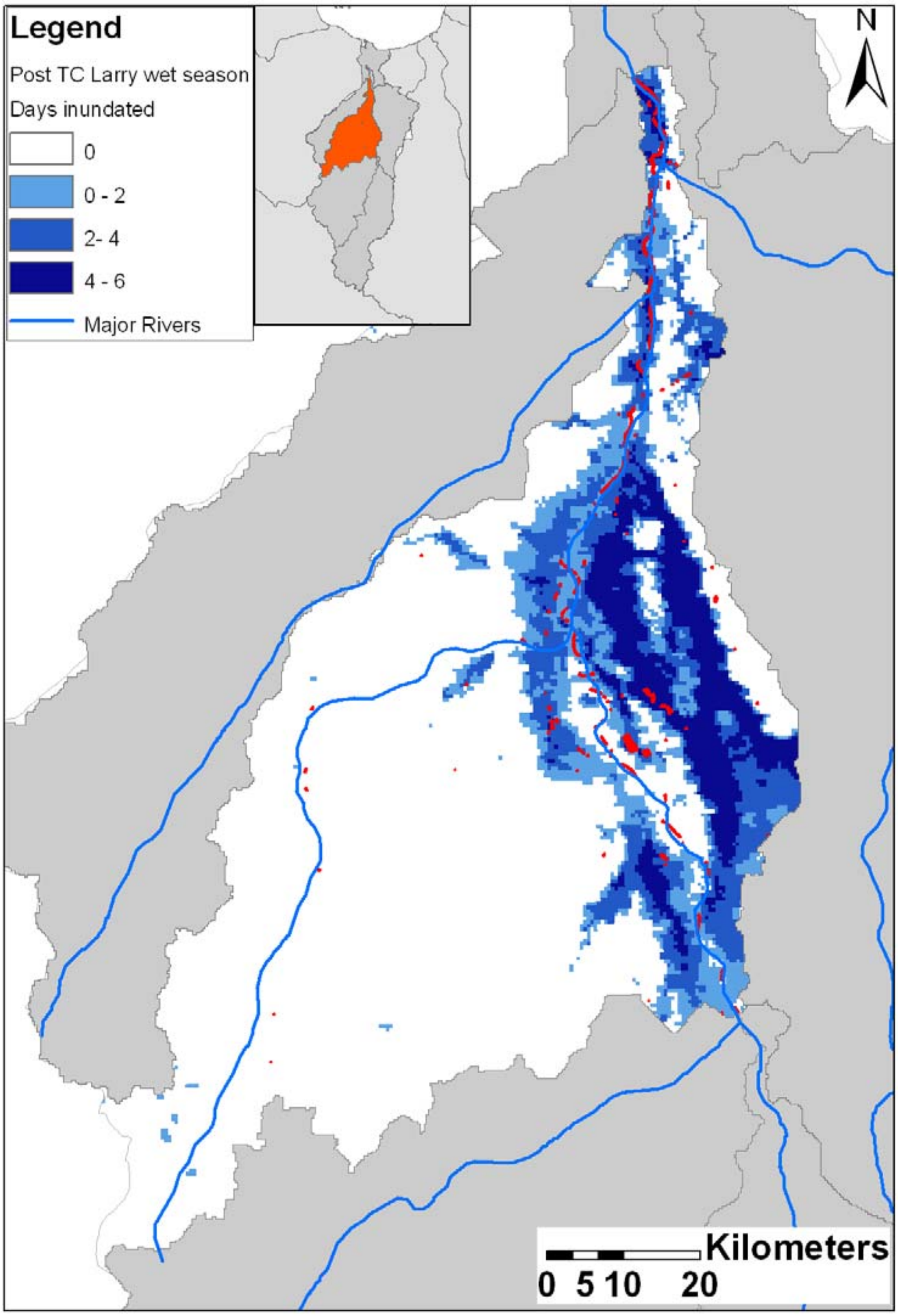

Figure 20 Extent and duration of inundation during the flooding that followed TC Larry.

The mid-Leichhardt was subjected to extended periods of flooding during the post TC Larry flood event (Figure 20). During this period the mid-Leichhardt and Alexandra River subcatchments shared a common water source. It is also worth noting that with the exception of the bedrock areas along Sandy Creek almost all of the waterbodies in the mid-Leichhardt received floodwaters and in many instances were inundated for two or more days.

3.7. Coastal Floodplain

3.7.1. Waterbody permanence on the coastal floodplain

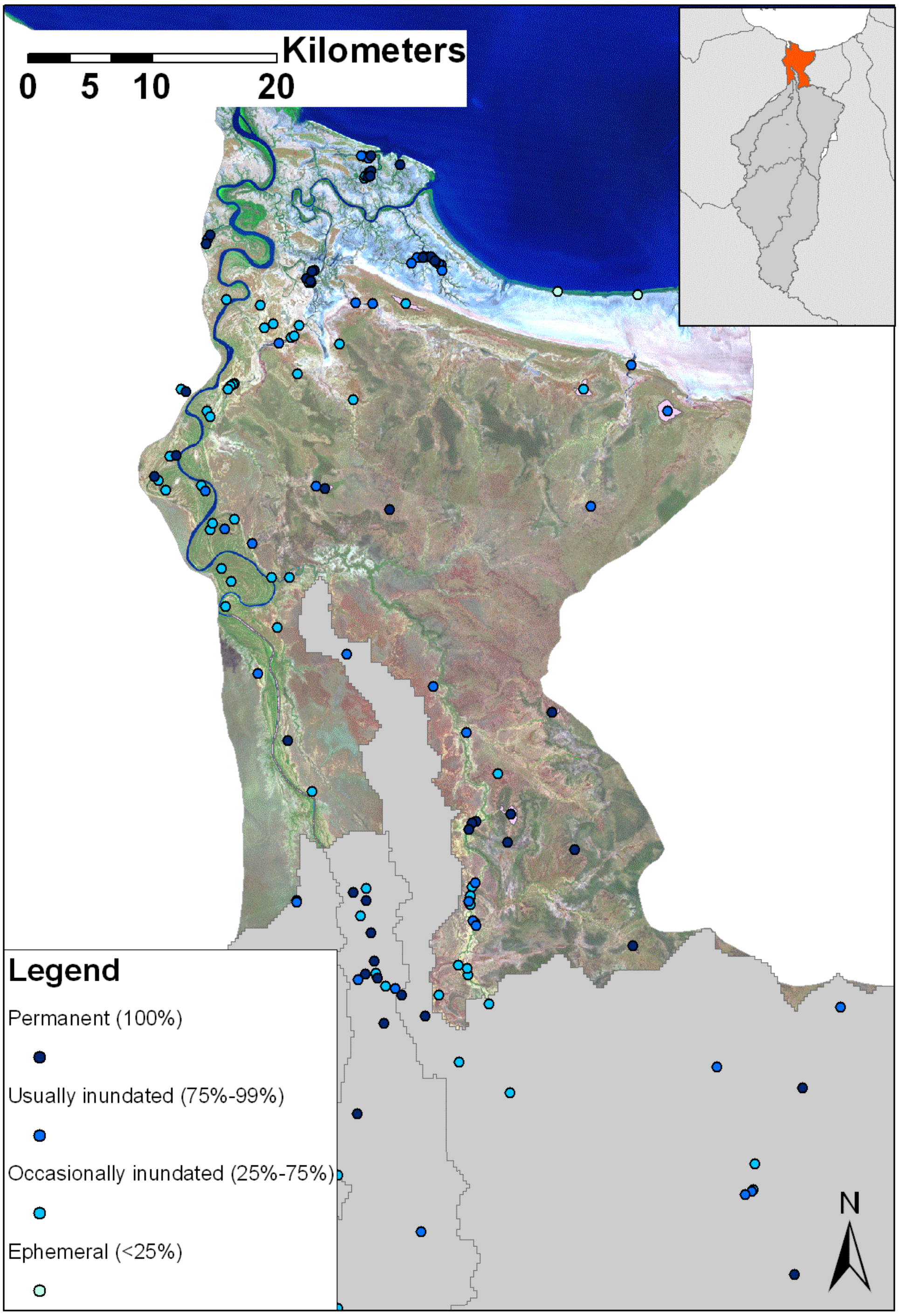

Figure 21 Permanence characteristics of waterbodies on the coastal floodplain.

There are 122 waterbodies in the coastal floodplain subcatchment, of which 31 are permanent (Figure 21). These include in-stream waterbodies, off-channel floodplain waterbodies and small farm dams. The semi-permanent and ephemeral waterbodies also include coastal salt pan and clay pan wetlands.

3.7.2. Water clarity regime for the coastal floodplain

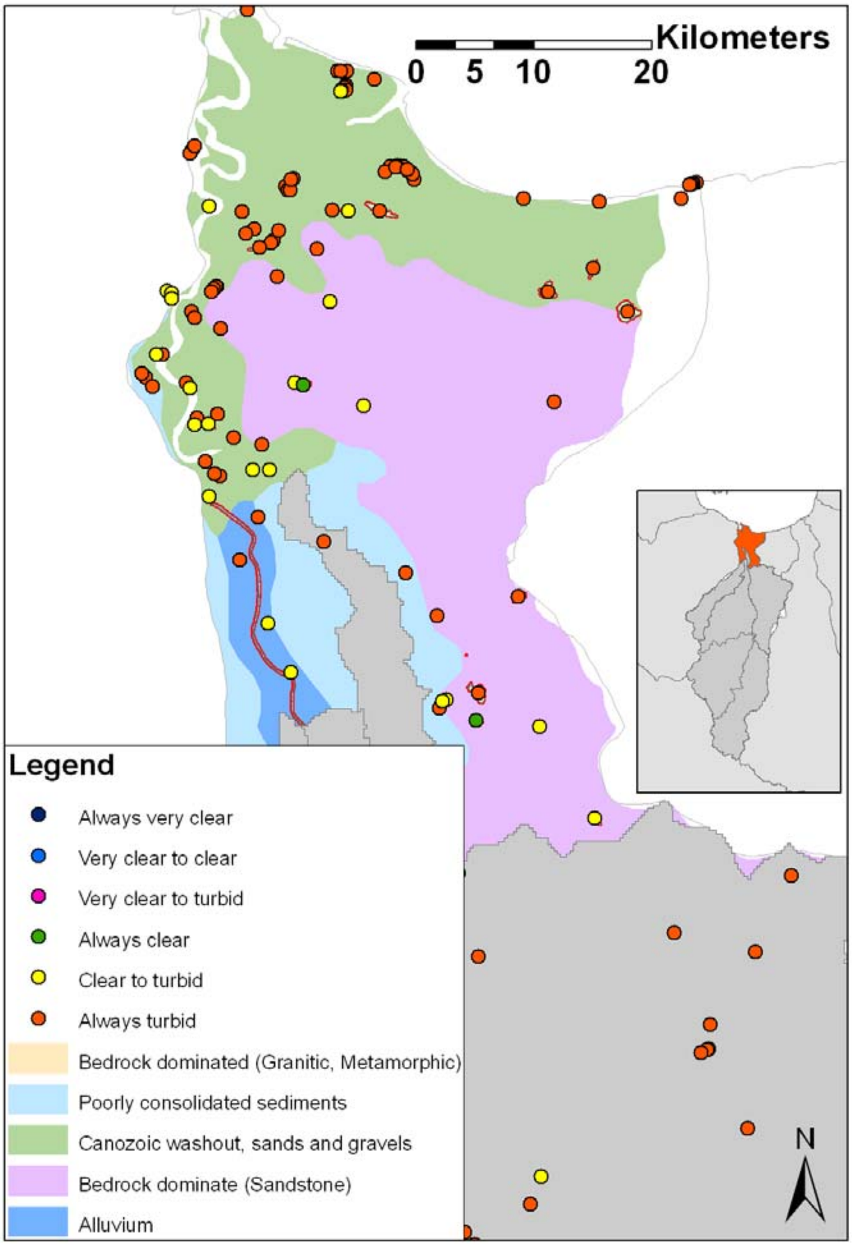

Figure 22 Water clarity regime for waterbodies on the coastal floodplain

The relationship between water clarity and geology follows the same pattern observed in other subcatchments, including the base flow flushing of main-channel water bodies. However there are number of waterbodies located on bedrock (sandstone as distinct from the granite/metamorphic bedrock encountered elsewhere within the catchment) that are always turbid (Figure 22). Of all the permanent waterbodies, only one is always clear (the remainder going turbid on at least one occasion). That waterbody is the dam on Johhnies Plain to the north east of Johhnies Yard (378742E, 8024558N). In terms of candidates for fencing, the off-channel waterbodies on the forested floodplain of the main channel would be suitable areas (For example, Dingo Waterhole and un-named waterholes at 370679E, 8021295N, and 370763E, 8015090N). These waterbodies receive floodwaters during high flow, yet some of them go clear on more than one occasion. Whether fencing would influence their water clarity is something that would have to be investigated on-ground either by site visit or landholder survey.

3.7.3. Floodplain inundation of the coastal floodplain

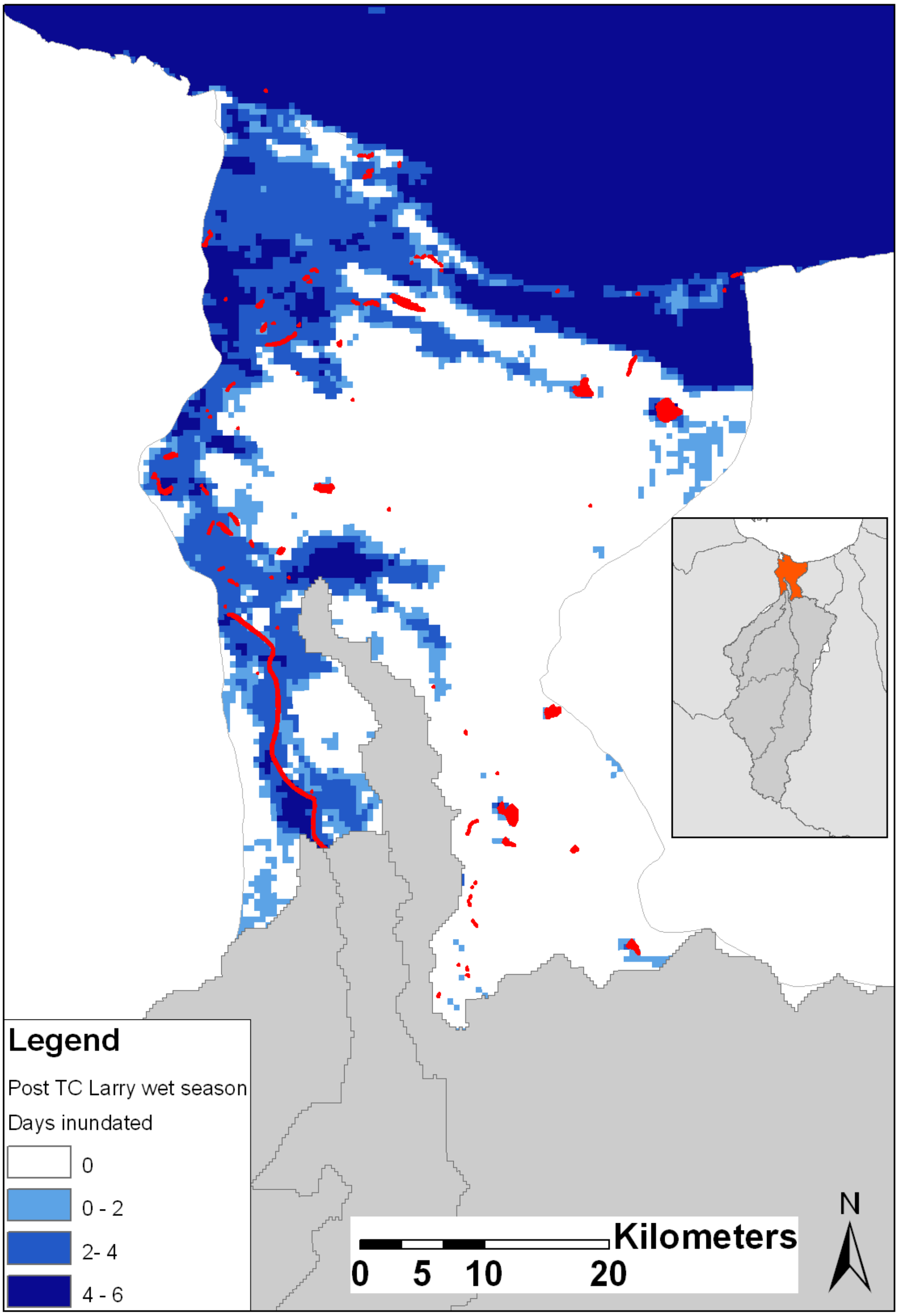

Figure 23 Extent and duration of inundation during the flood event post TC Larry

The alluvial portion of the coastal floodplain was subject to extensive flooding during the post TC Larry flood event, and all main-channel and off-channel floodplain waterbodies received floodwater inputs for more than 2 days (Figure 23).

4. RECOMMENDATIONS

Three different remote sensing products have been combined to describe waterbodies throughout the Leichhardt catchment according to the following criteria:

- Permanence;
- Water clarity regime; and
- Wet season inundation.

These criteria were combined to assess the uniqueness of individual waterbodies and to identify priority waterbodies for on-ground management. The following waterbodies were identified as unique and likely to respond to on-ground management (by subcatchment).

Upper Leichhardt

- The in-stream lagoon immediately upstream of the intersection of Saint Paul Creek and the Leichhardt River (402962E, 7829455N[2]) and
- The in-stream lagoon downstream of the intersection of Eureka Creek and the Leichhardt River (402329E, 7841915N).

Mid-Leichhardt

- Un-named waterbody at the intersection of Sandy Creek and Leichhardt River (370258 E, 7924649N).
- In-stream waterbodies on the main channel that vary between clear and turbid

Gunpowder Creek

- The water reservoir near Bar Creek, and
- Un-named waterhole on Dynamite Creek (374318E, 7838612N)

Fiery Creek

- 16 Mile Waterhole,
- Un-named waterhole upstream of 16 Mile Waterhole (330465E, 7936474N)

Alexandra River

- 'The Lakes' on the road out to the Talawanta property.
- Un-named waterbodies located at (408795E, 7940843N).
- The other unique suite of waterbodies that are the 3 classified as always clear. They are shallow ephemeral waterbodies located just north of a line between Werna Hole Yards and Prickly Bush Holding Paddock (422551E, 7910423N, 424343E, 7910302N, and 421169E, 7915283N).

Coastal Floodplain

- Off-channel waterbodies on the forested floodplain of the main channel, such as Goose Lagoon, Old Station Lagoon and Dingo Waterhole.
- Dam near Johhnies Yard (378742E, 8024558N).

[2] All coordinates are have a **UTM Zone 54S** projection on a **GDA94** datum.

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