Hydrosphere Consulting

TWEED SHIRE COUNCIL

Water Quality Assessment – Tweed River Upper Catchment

Final Report

March 2017

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15-023 – WATER QUALITY ASSESSMENT – TWEED RIVER UPPER CATCHMENT

REV	DESCRIPTION	AUTHOR	REVIEW	APPROVAL	DATE
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EXECUTIVE SUMMARY

Tweed Shire Council (TSC) monitors water quality at a number of sites in the Upper Tweed Catchment to assess catchment health and risks to drinking water supply. Council requires review of water quality data to draw out information to better understand the water supply catchment including: the key water quality risks; mitigating catchment factors; spatial and temporal trends across and between sub-catchments; and the influence of natural factors such as rainfall and streamflow.

The project had two stages:

- **Stage 1:** involved analysis of the existing dataset collected at a number of sites in the upper catchment since the KEC Science (1999) report and spanned the 15 years from 1999 to 2015. The existing monitoring program was reviewed and a modified sampling program was recommended to be carried out over a trial 12 month period. Results of Stage 1 are reported in *Report 1: Review of Water Quality Information 1999-2015* (Hydrosphere Consulting, 2015); and
- **Stage 2** (this report): includes review of the data collected during the additional sampling period from January 2016 to January 2017, and considers the overall results of monitoring. Final recommendations are made for an on-going monitoring program that will accurately inform decision making in the catchment and fulfil requirements under the Australian Drinking Water Guidelines (ADWGs).

A summary of key findings of Stage 2 are provided below:

Water Quality Compliance 2016

Overall percentage compliance with water quality objectives (WQO's) for aquatic ecosystem health was assessed at each sample site (refer Figure 9, page 16). Four sites scored an 'A', achieving over 76% compliance across all parameters and were located in Doon Doon Creek, Crystal Creek, the Upper Rous River and along the Lower Oxley River (CAT23) just upstream of Eugella. Apart from CAT23 (mid Oxley River), these sites are all located in the upper catchment and reflect a healthy functioning aquatic ecosystem system at these locations. Nutrients, particularly Total Phosphorus (TP) and *Escherichia coli* (*E. coli*) were occasional issues for compliance at these sites.

The majority of sites were assigned a 'B' score (between 66-75% overall compliance) reflecting increasing influence of agricultural runoff, wastewater discharges (both on-site systems and centralised sewage systems), and decreasing riparian vegetation at these sites. Nutrients, *E. coli* and Dissolved Oxygen (DO) often exceeded guidelines with occasional exceedances of Chlorophyll *a* triggers.

Site CAT21 located at the outlet of the Pumpembil Creek sub-catchment received a 'C' score (i.e. between 51-65% overall compliance) with elevated nutrients, *E. coli* and reduced DO levels reflecting the impact of intensive dairy land use in this catchment. Site CAT10, located immediately downstream of dairying operations in the Pumpenbil Creek sub-catchment displayed the poorest water quality, receiving the only 'D' grade (<50% overall compliance) in the Upper Tweed Catchment. Elevated nutrient and Chlorophyll *a* concentrations were significant issues indicating frequent eutrophication at this site. High *E. coli* levels and low DO were also substantial issues indicating poor ecosystem health and a high level of disturbance from a natural state.

Temporal variability

Some temporal trends were identified throughout the year including clear seasonal trends in temperature and strong associations to rainfall identified for conductivity, turbidity, total suspended solids (TSS), and to a lesser extent, nutrients. No clear temporal trends were identified for DO, pH, Chlorophyll *a* and *E. coli* throughout 2016, with a high degree of variation on monthly timescales.

Spatial variability

Water quality varies considerably throughout the catchment. Cluster analysis (Section 3.4.1) performed on 2016 data divided the monitoring sites into five groups based on water quality information. Site CAT10 on Pumpenbil Creek was assigned its own cluster and the analysis indicates water quality at this site is highly degraded and considerably different to any other site in the Upper Tweed Catchment. Other clusters included sites in the same geographical areas such as in the Lower and Upper Oxley River (Cluster 2); sites in the north-west portion of the Upper Tweed Catchment (Cluster 3); and sites with overall better water quality than other sites, such as in the Mid and Upper Tweed River (Cluster 5).

Analysis of paired sites produced mixed results. Analysis of CAT10 (downstream of a large dairy on Fowlers Creek); CAT21a (upstream of the dairy on Pumpenbil Creek) and CAT21 (downstream of the dairy on Pumpenbil Creek) showed several statistically significant differences in water quality, all indicating that dairying operations in the Pumpenbil Creek sub-catchment are having considerable adverse impacts on Pumpenbil Creek. This is consistent with long-term findings assessed for 1999-2015 (Hydrosphere Consulting, 2015).

Analysis of sites located in the vicinity of dairy located on Tyalgum Creek did not show the same level of impact as in Pumpenbil Creek, but did indicate dairy operations in this location were having an impact on pH and nitrogen levels in Tyalgum Creek.

Sites CAT25 and CAT5, located upstream and downstream of the village of Uki on the Mid Tweed River, did not reveal any statistically significant differences between the two sites for any of the parameters analysed. The similar water quality results indicate that land use between the two sites, including Uki WWTP, residential areas and wastewater reuse areas, are not significantly impacting water quality.

Sites CAT23 and CAT1 are located on the Lower Oxley River and between them are areas of grazing land, sugarcane and an area which was subject to bank erosion remediation works in 2016. Analysis demonstrated a clear deterioration in water quality between CAT23 and CAT1, although due to the multiple land use types between the two sites, it was difficult to attribute degradation to any particular source. Further work could seek to investigate sources of water quality decline in this area, with more spatially intensive monitoring of the potential land uses impacts.

Results of comparing sites CAT17, CAT18 and CAT17a indicated that discharge from Jackson Creek is of a poorer quality than water in the Upper Rous River and is adversely impacting the overall water quality in the Upper Rous River. Future work should consider investigations in Jacksons Creek to identify sources of pollution.

Review of the modified sampling program and recommendations for ongoing sampling

The modified sampling regime undertaken in 2016 has achieved several of the program objectives including:

- Better characterisation the Upper Tweed Catchment by sampling at all sub-catchment outlet sites;
- Capturing a number of high risk 'wet' events at key sites in the catchment, an issue identified as a significant gap in pre-2016 monitoring. Targeted event sampling is considered a key component of effective ongoing sampling to adequately assess high risk periods;
- Streamlining the modified sampling program to better assess parameters of concern without unnecessary analysis; and
- Confirming suspected sources of water quality degradation in the catchment in several locations.

Recommendations for ongoing sampling are:

- Continue sampling at all sub-catchment outlet sites to characterise sub catchments through time, and to identify any emerging issues on a sub-catchment basis;

- Discontinue sampling at CAT28 as trial sampling did not identify specific issues CAT7 is a nearby site to characterise the Upper Tweed sub catchment;
- Continue targeted event sampling;
- Continue sampling modified parameter suite; and
- Consider further investigation of potential sources of water quality decline identified by this report (refer Section 4.4).

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TABLES

FIGURES

1. INTRODUCTION

Water quality monitoring has been undertaken in the Upper Tweed Catchment by Tweed Shire Council (TSC) since the late 1980's to assess catchment health and risks to drinking water supply. While source water quality is assessed continuously as part of water supply management, the last systematic review of catchment water quality data was completed in 1999. This assessment focused on water quality data collected over 10 years from 1988-1998 (KEC Science, 1999).

The focus of the present engagement is the assessment of water quality data collected at a number of sites in the upper catchment since the KEC Science (1999) report, and spans the 16 years from 1999 to 2016. Council requires review of the existing dataset to better understand the water supply catchment including: the key water quality risks; mitigating catchment factors; spatial and temporal trends across and between sub-catchments; and the influence of natural factors such as rainfall and streamflow. This study aims to identify water quality problems, and priority areas that TSC can develop, targeted by sub-catchment, as well as site based management plans to address key risks to the drinking water supply.

The key drivers for this work are twofold:

1. The protection of the Tweed Shire drinking water supply, and implementation of a risk identification and management process consistent with the Australian Drinking Water Guidelines (ADWG). To comply with the ADWG, Council needs to better understand the water supply catchment including:
    - risk based identification and prioritisation of landuses, including both human and livestock sources of contamination (completed through the sanitary survey recently completed by Council, refer Section 1.2.2); and
    - water quality drivers within the water supply catchment, with a focus on identifying sources and levels of contaminants. Emphasis is on turbidity, pathogens and nutrients.
2. Monitoring and assessing the condition of the catchment and aquatic ecosystem health throughout the waterways to assist in achieving more effective restoration and rehabilitation.

This is a joint project being implemented by Tweed Shire Council's Natural Resource Management and Water Units, in recognition of the inherent link between water supply protection and the ecosystem health of catchments and particularly the condition of riparian zones.

The present engagement was completed in two stages:

- **Stage 1:** the first stage of the project involved the analysis of the existing dataset collected at a number of sites in the upper catchment since the KEC Science (1999) report and spans the 15 years from 1999 to 2015. The existing monitoring program was reviewed and a modified sampling program was recommended to be carried out over a trial 12 month period. Results are reported in *Report 1: Review of Water Quality Information 1999-2015* (Hydrosphere Consulting, 2015).
- **Stage 2** (this report): includes review of the data collected during the additional sampling period from January 2016 to January 2017, and considers the overall results of monitoring. Final recommendations are made for an on-going monitoring program that provides data that will accurately inform decision making in the catchment and fulfil requirements under the ADWGs. Recommendations to improve efficiency, scientific rigour, spatial extent and cost-effectiveness are made wherever possible.

1.1 Study Area

The study area is the Upper Tweed Catchment (approximately 698km^2) incorporating the freshwater reaches of the Tweed, Oxley and Rous Rivers. The study area has been divided into 15 sub-catchments based on topography (Figure 1).

The Tweed Shire Water Supply is derived from the Tweed and Oxley Rivers and there are three drinking water treatment plants (WTP) within the study area. Both Uki and Tyalgum WTPs draw flow from relatively small, discrete areas, however the Bray Park WTP receives flow from the total combined catchment area. Figure 1 shows the WTP catchments within the study area. The Clarrie Hall Dam is an on-line storage facility within the catchment of

Doon Doon Creek, from which water is released to flow down the Tweed River for extraction at Bray Park Weir and subsequent treatment.

The Rous River does not form part of the drinking water supply and there was no ongoing monitoring of water quality in the catchment up to 2016. However, as the Rous River is known to contribute to water quality issues in the Tweed Estuary (refer Section 1.2.1 below), key sites were selected for water quality assessment as part of the trial 12 month monitoring program in 2016.

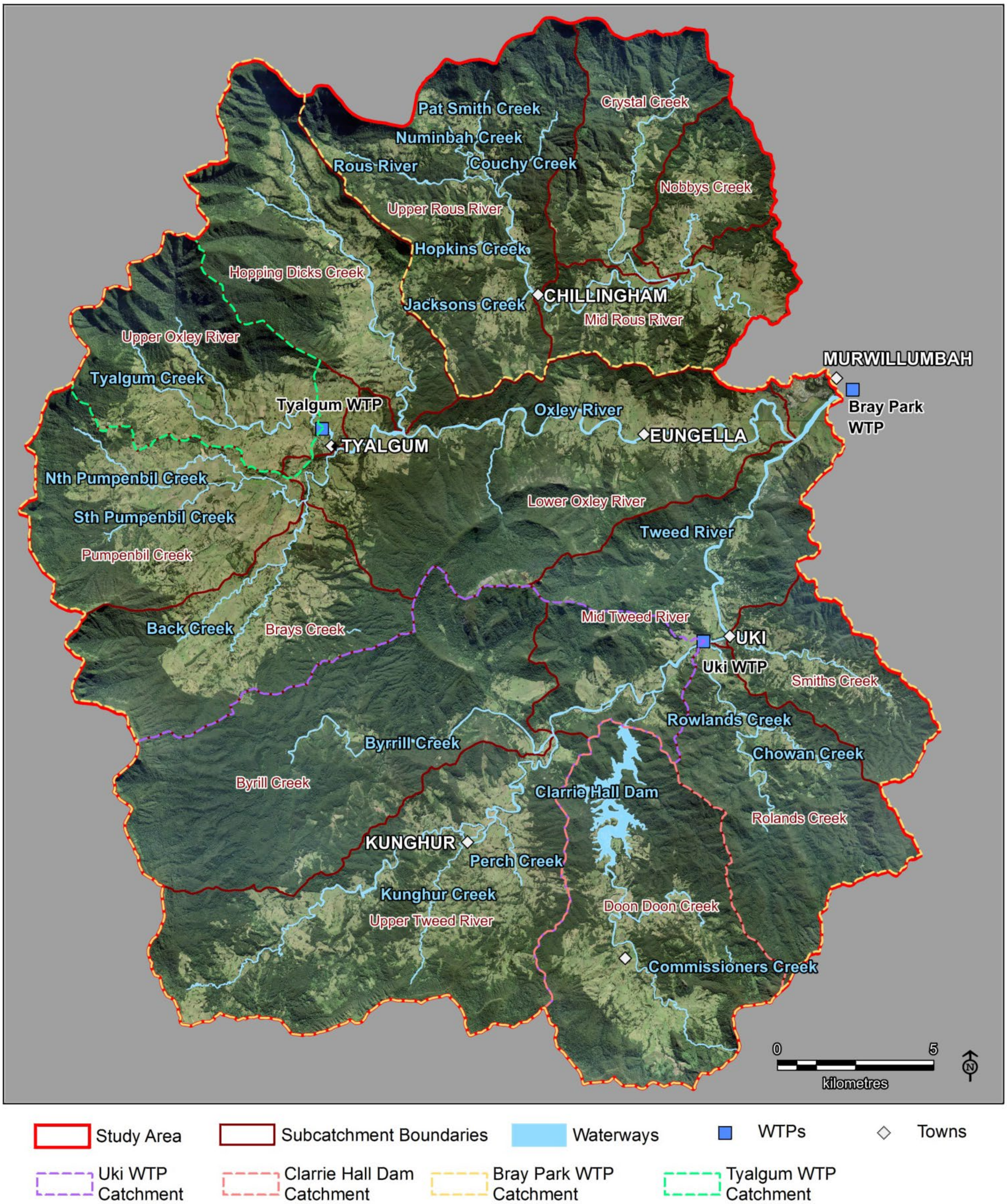

Figure 1: The Upper Tweed Catchment Study Area

1.2 Background

1.2.1 Previous water quality studies

KEC Science (1999) completed an assessment of water quality in the Upper Tweed Catchment using data collected from 1988-1998. The study assessed compliance with *Australian and New Zealand Guidelines for Fresh and Marine Water Quality* (ANZECC & ARMCANX, 2000) (ANZECC Guidelines). The study found that concentrations of nutrients (particularly nitrogen), pathogens, Chlorophyll *a*, and suspended solids all exceeded ANZECC guidelines for aquatic ecosystem protection at a number of sites. All sites reported pH concentrations within guideline levels. The study determined that poor water quality was linked to increasing rainfall, and estimated that the impact of runoff accounted for 70-90% of the variation in water quality at two sites examined in detail. High density animal husbandry, urban areas and areas where stock readily accessed waterways were identified as having the greatest impact on pathogen and nutrient concentrations, with elevated levels consistently observed downstream of these land uses. KEC Science (1999) also implicated these land uses in the occurrence of nuisance algal growth. Soil erosion was determined to be the primary source of suspended solids in the catchment. Recommendations for catchment management focussed on the reduction of nutrient and sediment exported to waterways through improved land management practices such as stock control, control of soil erosion and reducing point source effluent discharge. The review recommended increasing sampling frequency to monthly samples, and formalising program objectives and reporting.

Water quality in the Tweed Estuary is also monitored by Council, and has been comprehensively assessed several times, most recently in 2012, (ABER 2012). This report found that water quality objectives (WQO's) for nutrients, dissolved oxygen (DO), chlorophyll *a* and turbidity are regularly exceeded in the Tweed Estuary. Catchment runoff and discharge of treated sewage effluent were identified as the primary causes of poor water quality in the estuary. River bank erosion was also an issue of concern. In the upper catchment, issues of concern included high levels of nutrients in runoff, (particularly nitrogen) as well as sediment, algae and bacterial contamination. Nitrogen input was stimulating algae growth in estuary reaches, the decomposition of which was leading to depressed levels of dissolved oxygen. The Upper Tweed River (above Bray Park Weir) was seasonally affected by serious blue green algae blooms (ABER, 2012).

Council does not routinely monitor water quality in the Rous River catchment. A spatially intense water quality monitoring project was undertaken in the Rous River in 1997 (Eyre and Pepperell, 1997). Three point sources, the Murwillumbah Sewage Treatment Plant (STP), a dairy shed, and horse stables were found to have the largest impact on water quality in the Rous River catchment. Most water quality parameters assessed greatly exceeded ANZECC guidelines immediately downstream of these point sources. The impact of the dairy shed and horse stables was localised with an improvement in most water quality parameters further downstream due to dilution and assimilation. However nutrient loads from the STP were more persistent. Eyre and Pepperell (1997) attributed these loads to the stimulation of algal growth throughout most of the Rous River estuary. Non-point sources of most concern were cane land with elevated nutrient concentrations and temperature in cane drains contributing to algal growth and high turbidity. High instream oxidised nitrogen (NOx)concentrations were attributed to the use of nitrate based fertilisers leaching from upstream banana plantations. Catchment-wide water quality (excluding cane and horticultural areas, and downstream of point sources) was generally good for aquatic ecosystem health, but poor for human health. Elevated pathogen levels were detected at most sites and were attributed to cattle access to waterways

1.2.2 The Australian Drinking Water Guidelines and catchment management

Australian drinking water guidelines emphasise the importance of protecting water sources (catchments). The Australian Drinking Water Guidelines (ADWG) (NHMRC/NRMMC, 2004) provide overarching guiding principles and statements, including: "*prevention of contamination provides greater surety than removal of contaminants by treatment, so the most effective barrier is protection of source waters to the maximum degree practical*."

The principles in the ADWG imply the following:

- Multiple barriers are required to protect drinking water quality;
- The most effective barrier is the protection of source waters;

- Source waters should be protected to the maximum degree practical;
- Water quality should be maintained at the highest practicable quality; and
- Water quality should not be degraded even if it complies with guideline values by a safe margin.

1.2.3 Tweed Drinking Water Management System

The TSC Water Unit has developed a Drinking Water Management System (DWMS) that fulfils the requirements of the ADWG.

The DWMS is a quality assurance program from catchment to consumer. A critical part of the DWMS is the assessment of catchment water quality, catchment hazard identification, risk assessment and specification of control measures.

All of the TSC raw water sources were found to have high nutrient levels capable of sustaining algal blooms at problematic levels given suitable environmental conditions. Toxigenic, taste and odour causing algae were identified and there was evidence of rainfall-related faecal contamination. Source waters were also high in turbidity, colour, iron and manganese. The maximum risk, without treatment, was elevated for all systems for these hazards (TSC, 2014a; TSC, 2014b).

The DWMS highlighted that one of the key influences on water quality was high runoff rates from the catchment due to the steep landform in the upper catchment and short stream lengths in the lower catchment. Peak flows carry high levels of runoff contaminants which can be quickly transported to waterways and potential overwhelm treatment barriers (TSC, 2014). The DWMS also identified potential for other water quality risks such as protozoa and bacteria generated by cattle grazing adjacent to the waterway, and human pathogens from any failing on-site sewage management systems (OSSMs).

1.2.4 Tweed Shire Council Sanitary Survey

The Sanitary Survey is the first step in undertaking a source water assessment. In 2014, Council completed a sanitary survey in the water supply catchments in preparation for implementation of Health Based Targets (HBT’s) (refer Section 1.2.5). The key outputs of the Sanitary Survey provide an understanding of:

- Pathogen sources arising from the presence of people and livestock;
- The intensity of these developments/activities;
- Proximity to feeder streams and water storage; and
- Presence of control measures such as riparian vegetation, fencing, etc.

The Sanitary Survey identified both diffuse and specific contamination sources within the catchment. Both types have been mapped by TSC and this is shown in (Appendix 1).

The main diffuse sources were identified as broad-scale grazing and wildlife in National Parks and Nature Reserves. These landuses account for over 60% of the land area. Horticulture accounts for less than 0.3% of the catchment including areas of bananas and sugarcane.

Specific contamination sources include:

- Wastewater Treatment Plants: there are two in the catchment, Tyalgum WWTP and Uki WWTP. Both have wastewater reuse in place where effluent is used to irrigate plantation or pasture, with no direct discharge to waterways except during extended wet weather;
- Camping Grounds and Recreation Areas with OSSMs;
- OSSMs distributed throughout rural properties in the catchment. The villages of Uki, Tyalgum and urban areas of Bray Park are served by centralised sewage;
- Intensive agriculture: three diaries and two piggeries remain in the catchment. Significant work has been done at the diaries adjacent to Bray Park Weir and Fowlers Creek, including improved effluent management systems, riparian vegetation and fencing to exclude cattle from waterways, and provision of off-stream watering; and
- Flying Fox Colonies – there are two permanent colonies, one within a wetland that drains to Bray Park Weir and one at Uki adjacent to the Tweed River.

1.2.5 Tweed Shire Council Health Based Targets Assessment

The National Health and Medical Research Council (NHMRC) is currently trialling Health Based Targets (HBT's) for drinking water supply management, which when approved, will be integrated into the ADWG and then into Councils DWMS.

This assessment focused specifically on sources of pathogens (bacteria), viruses and protozoa. Results of the source vulnerability assessment are as follows:

- Bray Park Water Supply- Category 4 (Unprotected catchment);
- Uki Water Supply – Category 4 (Unprotected catchment); and
- Tyalgum Water Supply - Category 4 (Unprotected catchment).

Based on these results, minimum pathogen reduction requirements were generated for the three supply systems.

2. SAMPLING PROGRAM

2.1 Monitoring Sites and Sample Collection

The TSC Upper Tweed Catchment water quality monitoring program (1999-2015) involved *in-situ* monitoring and collection of samples for laboratory analysis at a total of 35 water quality sampling sites monitored for some, or all of the period from 1999-2015. Stage 1 of this study focussed on detailed analysis of catchment surface water quality at 19 representative sites (refer Hydrosphere Consulting, 2015). The sites comprised 16 catchment sites and three WTP intake sites.

Based on the Stage 1 review of existing data, an optimised sampling program was recommended for a trial 12 month period which was subsequently undertaken between January 2016 and January 2017. The sampling program included:

1. Discontinuing redundant sites (11 sites);
2. Re-locating sites to better represent catchment waterways and areas of interest (2 sites);
3. Sampling of new sites to provide better spatial resolution including the Rous River upper catchment (16 new sites);
4. Routine monthly sampling at all 24 catchment sites;
5. Sampling at the three WTP intake sites to continue at weekly intervals and monthly intervals for catchment health parameters;
6. Targeted rainfall event sampling;
7. Changes to sample frequency to better assess trends and sources of variation; and
8. Changes to parameters analysed to better target indicators of concern.

Table 1 lists the 27 sampling sites (24 catchment sites and 3 WTP sites) proposed by the Stage 1 review and details of changes from the previous program. Figure 2 shows the location of sampling sites. Details of the sampling program including frequency and parameters monitored are provided in: Table 2 (WTP weekly sampling); Table 3 (WTP monthly sampling); Table 4 (routine monthly sampling at catchment sites); and Table 5 (events sampling at targeted sites).

Table 1: Sampling sites for monitoring in the Upper Tweed Catchment Jan 2016- Jan 2017

Sub-catchment	Site Code	Site Description
Byrill Creek	CAT6a	Re-location of old CAT6 site to Byrill Creek and better representation of catchment
Doon Doon Creek	CAT9a	Doon Doon Creek, upstream of Dam. Re-location of old CAT9 site for better representation of catchment
Smiths Creek	CAT13	Uki, Smiths Creek Bridge - Smiths Creek, bottom of Smiths Creek sub-catchment, downstream of Uki WWTP
Upper Tweed River	CAT7	Tweed River downstream of Kunghur Creek junction, upstream of Perch Creek junction and Byrill Creek junction, 400m dowsntream of Kunghur Village
	CAT28	Perch Creek, Bridge on Kyogle Road. Covers good size catchment of Perch and Midginbil creeks
Mid Tweed River	UWTP	Uki Raw Water Supply at WTP, Tweed River upstream of Uki Village
	CAT5	Tweed River 400m downstream of junction of Smiths Creek, 800m downstream of Uki Village
	CAT4	Tweed River 1.75km upstream of Byangum Bridge
	BPWTP	Bray Park Raw Water Supply at WTP Tweed River downstream of Oxley River junction
	CAT25	Palmers Rd crossing upstream of Doon Doon Ck junction and road cutting
Pumpenbil Creek	CAT21a	Kerrs Lane. South Pumpenbil Creek, upstream of dairy
	CAT10	Fowlers Creek upstream of Pumpenbil Ck junction. Small creek near dairy
	CAT21	Pumpenbil Creek at Larkins Road, just upstream from confluence with Brays Creek. Provides whole of Pumpenbil sub-catchment coverage
Upper Oxley River	TWTP	Tyalgum Raw Water Supply at WTP, Upper Oxley River dowsntream of Tyalgum Creek junction
	CAT26	Tyalgum Creek, Buttlers Road Immediately downstream of Stoddarts Dairy
	CAT27	Tyalgum Creek, Stoddarts Road Immediately upstream of Stoddarts Dairy
Lower Oxley River	CAT3a	Brays Creek at Tyalgum Bridge, downstream of Pumpenbil Creek junction
	CAT1	Oxley River at Sharp's Crossing
	CAT23	Oxley River at Tyalgum Rd bridge upstream of planned erosion remediation works
Upper Rous River	CAT17	Hopkins Creek Road. Includes Upper Rous, Numinbah and Couchy Creek
	CAT18	Jackson Creek. Take steps down off road to waterhole. Opportunity to sample Jackson Creek which was more turbid in appearance than crystal creek
Mid Rous River	CAT17a	Chilcots Road. Picks up village of Chillingham and Jackson creek infow
	CAT15	Old road crossing upstream of boatharbour bridge, off Numinbah Rd. Approx. tidal limit
Crystal Creek	CAT16	Upstream of Upper Crystal Ck bridge, swimming hole
Hopping Dicks Creek	CAT19	Boormans Rd crossing. Upstream of crossing
Brays Creek	CAT20	Larkins Road, takes in whole of Brays Creek Catchment
Rowlands Creek	CAT24	Rolands Creek Road, opposite no. 21 Rolands Ck Road

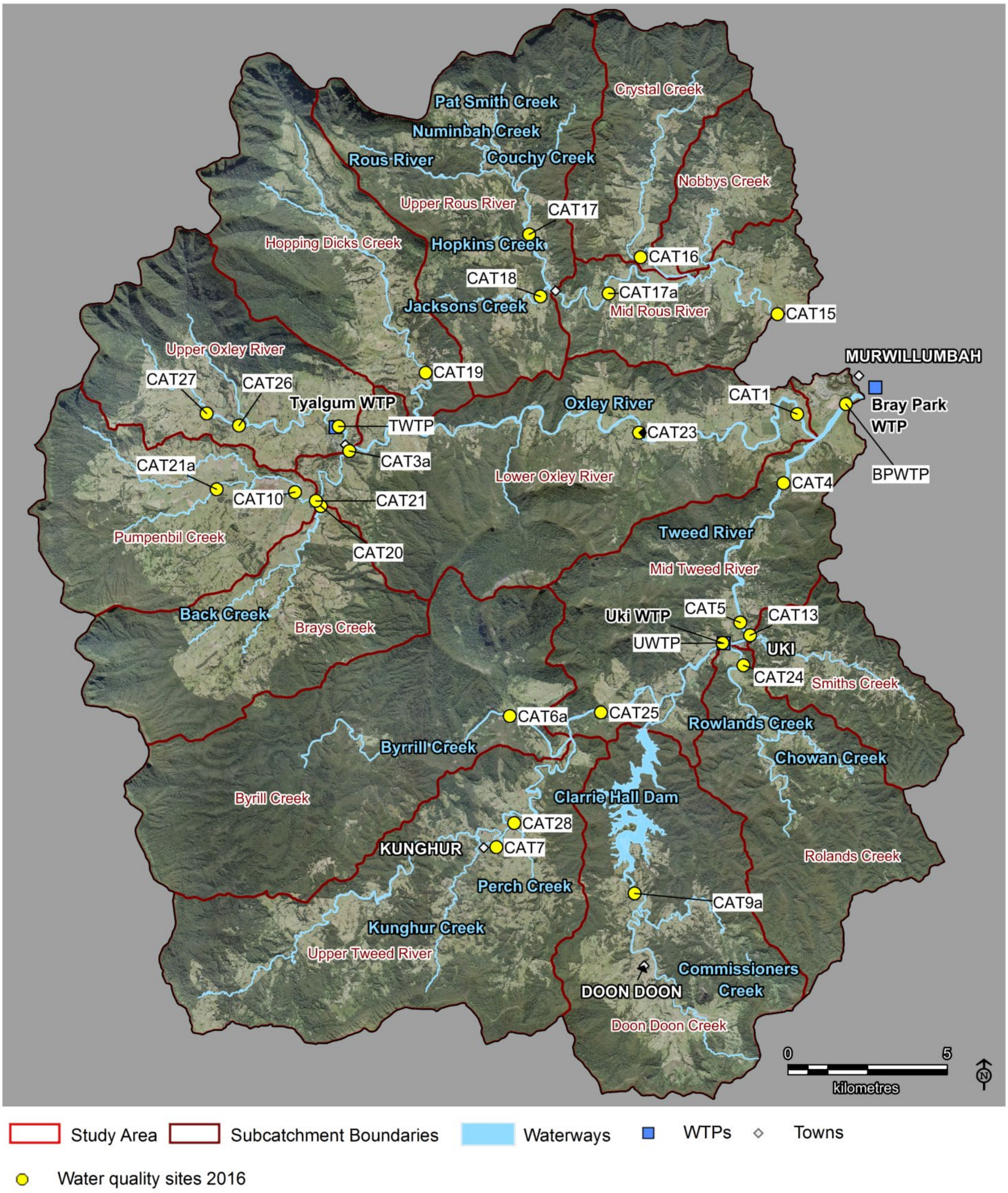

Figure 2: Sampling site locations for water quality monitoring Jan 2016 – Jan 2017

Table 2: Weekly WTP raw water sampling

Sample type:	WTP intakes
Sites:	BPWTP, UWTP, TWTP
Frequency:	Weekly sampling
Parameters:	PHYSICO-CHEMICAL: pH (pH units), Conductivity (µScm^{-1}), Turbidity (NTU), WATER SOURCE SPECIFIC: Alkalinity (mg/L as $CaCO_3$), Total Dissolved Solids (TDS(by calc)@180°C) (mg/L), Total Hardness (mg/L as $CaCO_3$), Hardness Calcium (mg/L as $CaCO_3$), Total Calcium (mg/L), True Colour (TCU), Apparent Colour (Colour Units), Total Iron (mg/L), Soluble Iron (Sol Fe) (mg/L), Total Manganese (mg/L), Soluble Manganese (Sol Mn) (mg/L), Soluble Silica (mg/L). BACTO: Thermotolerant coliforms (cfu/100mLs), Total Coliforms (cfu/100mLs), *Escherichia coli* (*E. coli*) (cfu/100mLs) ALGAE: Algae suite of samples

Table 3: Monthly WTP raw water intake sampling

Sample type:	WTP intakes
Sites:	BPWTP, UWTP, TWTP
Frequency:	Monthly sampling
Parameters:	NUTRIENTS: Total Nitrogen (TN) (mg/L), Ammonia (NH_4) (mg/L), Nitrate (N mg/L), Nitrite (N mg/L), Nitrogen Oxidised (NOx) (mg/L), Total Kjeldahl Nitrogen (TKN) (mg/L), Total Phosphorus (TP) (mg/L), Orthophosphate (mg/L). WATER SOURCE SPECIFIC: Flouride (mg/L), Total Organic Carbon (TOC) (mg/L), Dissolved Organic Carbon (DOC) (mg/L), Total Aluminium (mg/L), Total Suspended Solids (TSS) (mg/L) BACTO: *Clostridium perfringens, Somatic coliphage* ALGAE: Chlorophyll *a* (µg/L)

Table 4: Routine sampling at all catchment sites

Sample type:	Routine Sampling at all Catchment Sites
Sites:	CAT6a CAT9a CAT13 CAT7 CAT28 CAT5 CAT4 CAT25 CAT21a CAT10 CAT21 CAT26 CAT27 CAT3a CAT1 CAT23 CAT17 CAT17a CAT18 CAT15 CAT16 CAT19 CAT20 CAT24
Frequency:	Monthly sampling for 12 month period. Ongoing monitoring frequency to be determined following 12 months data collection and analysis.
Parameters:	PHYSICO-CHEMICAL: Dissolved Oxygen (DO) Membrane (mg/L), DO % Saturated (%), Biochemical Oxygen Demand (BOD) (mg/L), Conductivity (μScm^{-1}), pH (pH units), Temperature (°C), TSS (mg/L), Turbidity (NTU) NUTRIENTS: TN (mg/L), NH_4 (mg/L), Nitrate (N mg/L), Nitrite (N mg/LNOx (mg/L), TKN (mg/L), TP (mg/L), Orthophosphate (mg/L). BACTO: Thermololerant coliforms (cfu/100mLs) ALGAE: Algae suite of samples

Table 5: Event sampling

Sample type:	Event Sampling at selected (bottom of sub-catchment) sites (total 14 sites)
Sites:	CAT1 (Lower Oxley), BPWTP (Mid Tweed), CAT13 (Smiths), CAT24 (Rolands), CAT9a (Doon Doon), CAT6a (Byrrill), CAT20 (Brays), CAT21 (Pumpenbil), UWTP (Mid Tweed), CAT26 and CAT27 (Tyalgum), CAT19 (Hopping Dicks), CAT17a (Upper Rous), CAT15 (Mid Rous)
Frequency:	Wet event triggers will be determined by observing 3 rain gauges within the catchment, nominally a gauge in the south, mid and north arms of the Tweed. A sampling event will be triggered when 2 out of 3 rain gauges show >50ml rain over three days.
Parameters:	PHYSICO-CHEMICAL: Dissolved Oxygen Membrane (mg/L), DO % Saturated (%), BOD (mg/L), Conductivity (μScm^{-1}), pH (pH units), Temperature (C),TSS (mg/L), Turbidity (NTU) NUTRIENTS: TN (mg/L), NH_4 (mg/L), Nitrate (N mg/L), Nitrite (N mg/L), NOx (mg/L), TKN (mg/L), TP (mg/L), Orthophosphate (mg/L). BACTO: Thermololerant coliforms (cfu/100mLs), *E. coli* (cfu/100mLs) ALGAE: Chlorophyll *a* (μg/L)

2.2 Rainfall Data

Rainfall data for the 1999 to 2016 period was obtained from the Bureau of Meteorology (BOM) and Silo Data Drill at three locations in the catchment: Bray Park (Murwillumbah), Uki and Tyalgum. The Silo data provides a patched dataset for any given location by interpolating rainfall data from nearby BOM rainfall stations. The Silo data was obtained for the three locations in the catchment and averaged to produce a daily rainfall record with no data gaps. Figure 3 shows the annual rainfall totals for the Upper Tweed Catchment from 1999-2016 compared to long-term average annual rainfall. Figure 4 shows monthly rainfall totals for 2016 compared to long-term average monthly totals. Figure 5 shows daily rainfall from Jan 2016 - Jan 2017. Variation in annual rainfall is apparent over the period of this study (Figure 3) with most years from 1999-2008 (except 1999 and 2004) recording below average rainfall and above average rainfall experienced from 2008-2013. Average monthly rainfall for 2016 shows considerable departure from long-term averages (Figure 4) with below average rainfall occurring in all months except for March, June and August where rainfall was significantly greater than long-term monthly averages. Daily rainfall also shows considerable variation with maximum daily rainfall totals up to 183mm experienced on occasion (Figure 5).

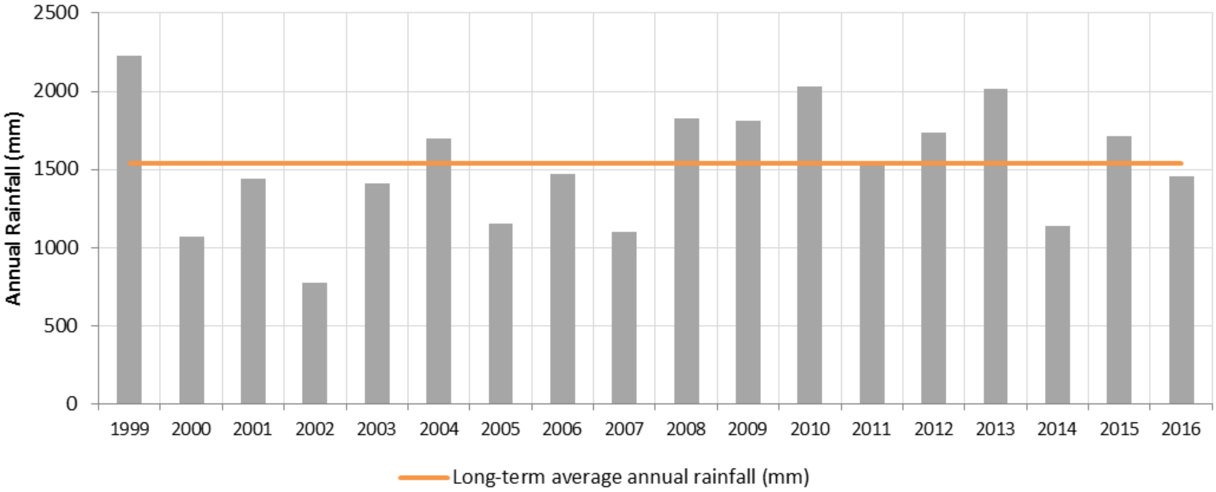

Figure 3: Annual rainfall for the Upper Tweed Catchment 1999-2016 compared to long-term averages (Source: BOM, 2017 and Silo Data Drill, 2017)

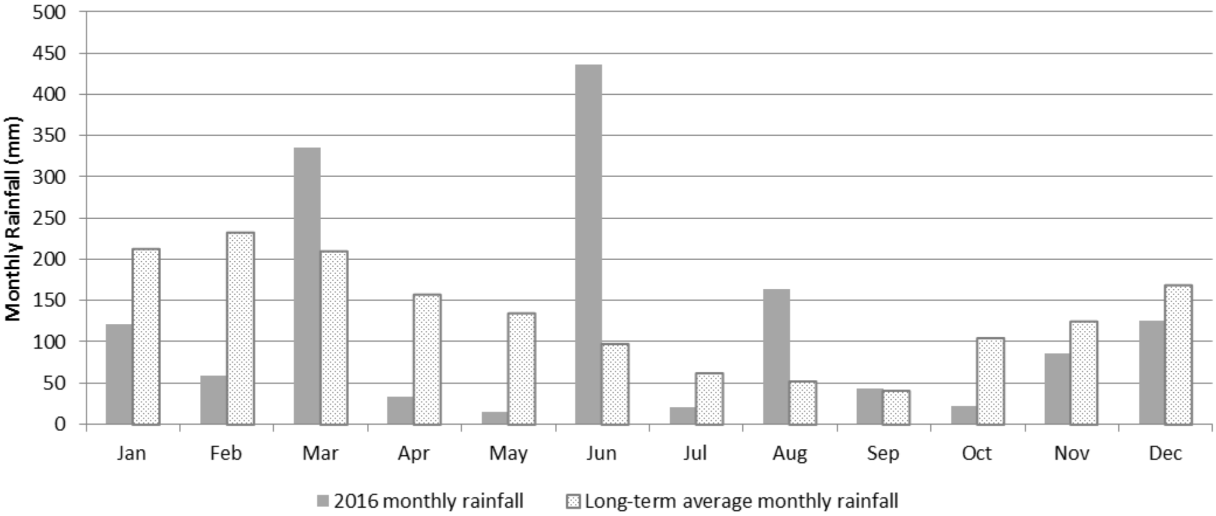

Figure 4: Average monthly rainfall for the Upper Tweed Catchment showing the study period (2016) compared to long-term averages (Source: BOM, 2017 and Silo Data Drill, 2017)

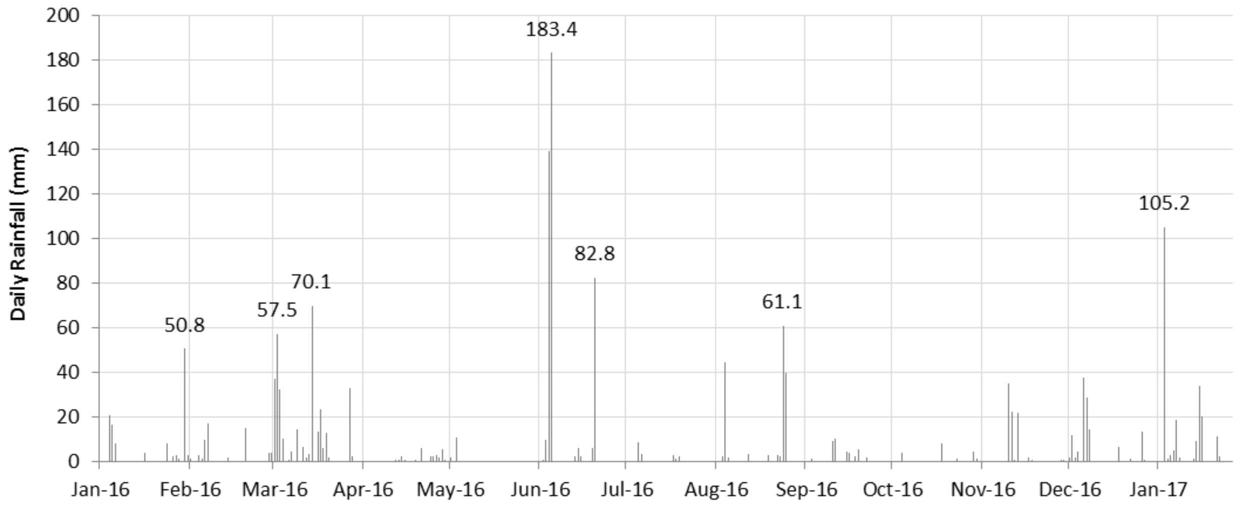

Figure 5: Daily rainfall for the Upper Tweed Catchment Jan 2016 – Jan 2017 (Source: BOM, 2017 and Silo Data Drill, 2017)

3. WATER QUALITY RESULTS

3.1 Water Quality Compliance

Compliance was measured against water quality objectives for the Tweed River Catchment (Lowland Rivers <150m AHD) (OEH, 2015). Compliance was assessed for a key range of indicators against the objectives for aquatic ecosystem health (pH, Conductivity, DO, Turbidity, TN, TP and Chlorophyll *a*) and human health (thermotolerant coliforms). The median value at each site for the period of record was used to assess compliance in accordance with ANZECC guidelines for water quality assessment (ANZECC and ARMCANZ, 2000).

Figure 7 and Figure 8 presents the data for all sites as box plots showing the spread of results in 2016. The median, minimum, maximum, upper and lower quartiles and outliers are shown on box plots (refer to box plot explanation, Figure 6). Where available, water quality objectives (upper and lower limits) have also been plotted for a visual assessment of compliance. The sites have been grouped by sub-catchment to provide an overview of spatial trends in the Upper Tweed Catchment.

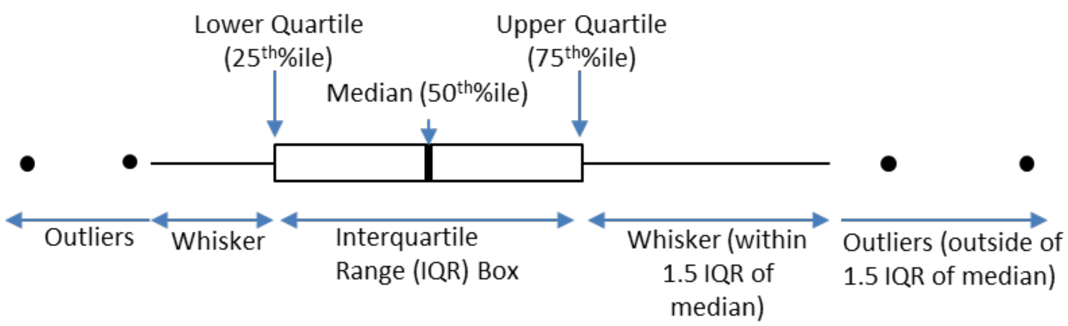

Figure 6: Explanation of box plots

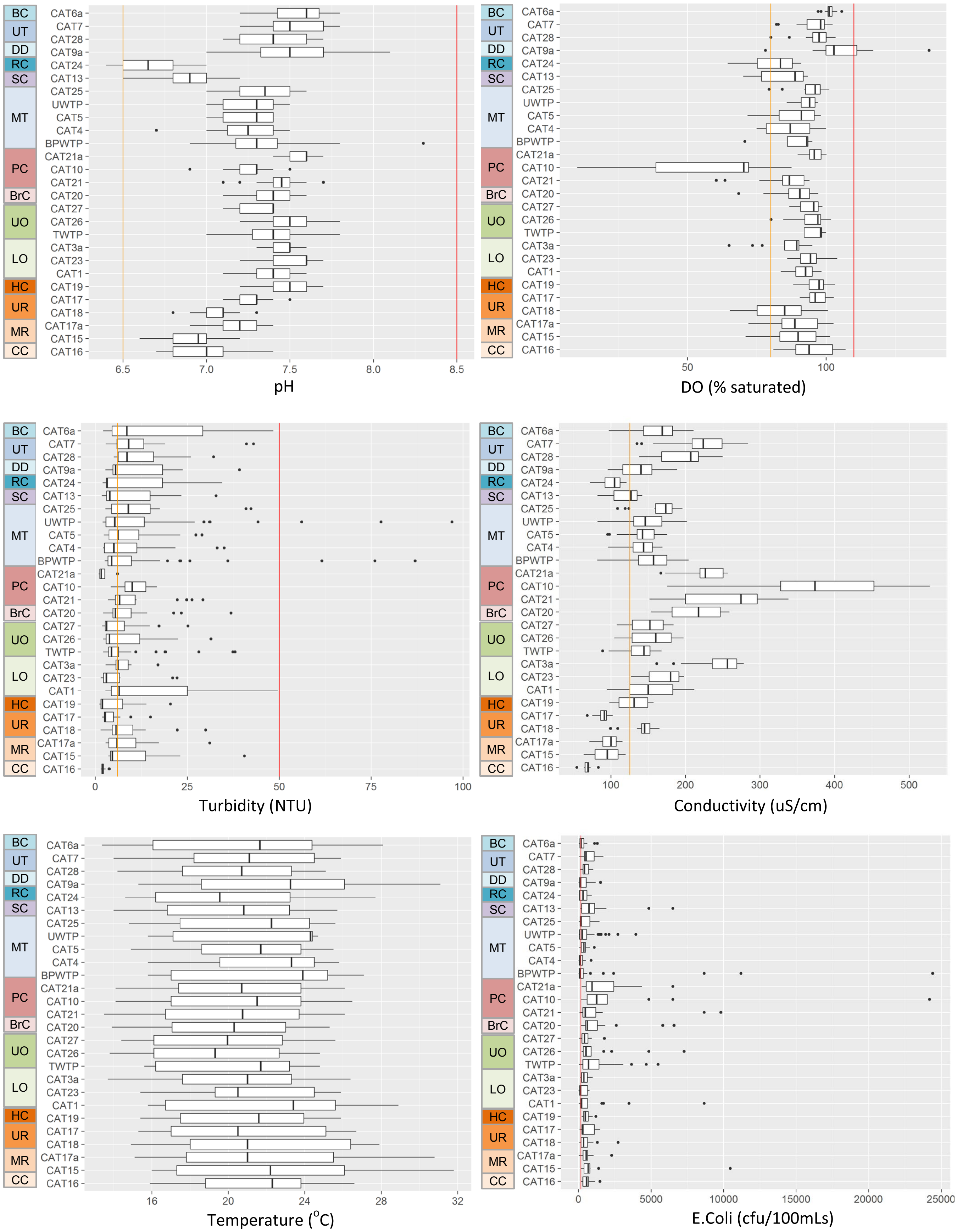

Figure 7: Box Plots presenting water quality results for pH, DO, turbidity, conductivity, temperature and *E. coli* grouped by sub-catchment* from Jan 2016 - Jan 2017

* Sub-catchment abbreviations: BC-Byrill Creek; UT – Upper Tweed River; DD – Doon Doon Creek; RC – Rowlands Creek; SC – Smiths Creek; MT – Mid Tweed River; PC – Pumpenbil Creek; BrC – Brays Creek; UO – Upper Oxley River; LO-Lower Oxley River; HC – Hopping Dicks Creek; UR - Upper Rous River; MR: Mid Rous River; CC – Crystal Creek.

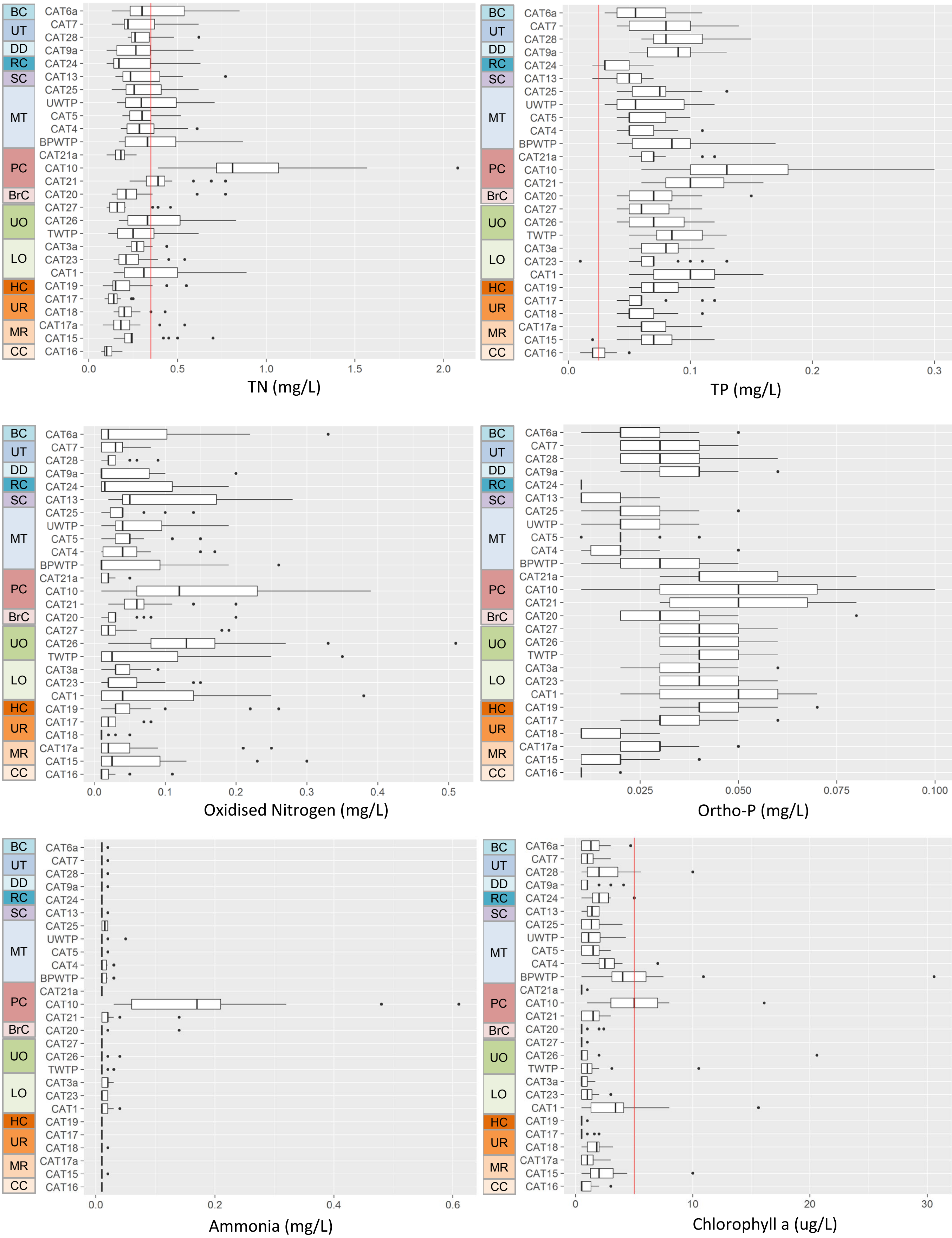

Figure 8: Box Plots presenting water quality results for TN, TP, NOx, Ortho-P, ammonia and Chl *a* grouped by sub-catchment* from Jan 2016 - Jan 2017

* Sub-catchment abbreviations: BC – Byrill Creek; UT – Upper Tweed River; DD – Doon Doon Creek; RC – Rowlands Creek; SC – Smiths Creek; MT – Mid Tweed River; PC – Pumpenbil Creek; BrC – Brays Creek; UO – Upper Oxley River; LO-Lower Oxley River; HC – Hopping Dicks Creek; UR - Upper Rous River; MR: Mid Rous River; CC – Crystal Creek.

Table 6 provides a summary of compliance for selected parameters, showing sites where consistent exceedances of water quality objectives over the data period were observed.

Table 6: Median water quality levels for selected parameters at each site from Jan 2016 - Jan 2017, showing compliance with Tweed River water quality objectives (OEH, 2015).

Sub-catchment	Site	DO (% sat)	pH	Turb (NTU)	Cond (ug/L)	TN (mg/L)	TP (mg/L)	Chl-*a* (ug/L)	*E. coli* (cfu/100ml)
Byrill Creek	CAT6a	101	7.6	8.6	169	0.30	**0.06**	1.3	**177**
Upper Tweed River	CAT7	98	7.5	9.0	224	0.22	**0.08**	1.0	**513**
	CAT28	98	7.4	8.6	207	0.26	**0.08**	2.0	**405**
Doon Doon Creek	CAT9a	103	7.5	5.5	140	0.27	**0.09**	1.0	146
Rowlands Creek	CAT24	**84**	6.7	3.2	105	0.17	**0.03**	2.0	**301**
Smiths Creek	CAT13	89	6.9	3.9	127	0.24	**0.05**	1.4	**717**
Mid Tweed River	CAT25	96	7.4	9.0	174	0.26	**0.08**	1.4	**168**
	UWTP	94	7.3	5.3	146	0.30	**0.06**	1.1	**240**
	CAT5	91	7.3	6.1	142	0.30	**0.05**	1.5	**355**
	CAT4	87	7.3	5.0	144	0.29	**0.05**	2.5	109
	BPWTP	93	7.3	4.5	157	0.33	**0.09**	4.0	100
Pumpenbil Creek	CAT21a	87	7.5	6.6	274	**0.39**	**0.10**	1.5	**461**
	CAT10	**70**	7.3	10.0	374	**0.81**	**0.13**	5.0	**1250**
	CAT21	87	7.5	6.6	274	**0.39**	**0.10**	1.5	**461**
Brays Creek	CAT20	91	7.4	5.4	218	0.21	**0.07**	0.5	**591**
Upper Oxley River	TWTP	98	7.4	4.4	144	0.25	**0.09**	1.0	**691**
	CAT26	97	7.5	3.8	160	0.33	**0.07**	0.5	**512**
	CAT27	95	7.4	3.1	152	0.16	**0.06**	0.5	**404**
Lower Oxley River	CAT3a	89	7.5	6.1	256	0.27	**0.08**	0.5	**359**
	CAT23	94	7.6	3.0	180	0.21	**0.07**	1.0	138
	CAT1	93	7.4	6.5	150	0.31	**0.10**	3.4	**201**
Hopping Dicks Creek	CAT19	98	7.5	1.9	131	0.15	**0.07**	0.5	**462**
Upper Rous River	CAT17	96	7.3	2.7	91	0.14	**0.06**	0.5	**288**
	CAT18	85	7.1	5.6	145	0.20	**0.05**	1.8	**345**
Mid Rous River	CAT17a	89	7.2	5.9	100	0.18	**0.06**	1.0	**522**
	CAT15	90	7.0	4.6	95	0.24	**0.07**	2.0	**664**
Crystal Creek	CAT16	94	7.0	2.0	69	0.10	0.02	0.5	**548**
Tweed River Water Quality Objectives (OEH, 2015)									
Upper limit		110	8.5	50	2220	0.35	0.025	5	150
Lower limit		85	6.5	6	125				

Notes:

1. nd – no data.
2. Results outside of the range of Tweed River water quality objectives are shown in **red**, excluding the exceptions below.
3. Turbidity less than the lower limit but not considered to indicate poor health as not in conjunction with low pH.
4. Conductivity less than the lower limit but not considered to indicate poor health and more likely to be indicative of local conditions.

Sub-catchment Mapping of Percentage Compliance

Percentage compliance is defined as the percentage of samples that achieved the guideline value over the measurement period (Jan 2016-Jan 2017). The term 'percentage compliance' with water quality objectives has been used in this report as an indicator to gain a relative and absolute indication of water quality at a site. Mapping of percentage compliance for sites within each sub-catchment was also undertaken to assess spatial trends and assist is identifying potential sources of water quality issues in the catchments. This was undertaken by examining compliance in relation to adjacent and upstream catchment characteristics such as land use, vegetation coverage and potential point and non-point sources. Figure 9 shows the overall compliance scores at each site (created by the average of compliance score across all parameters); sub-catchment scale maps are included in Appendix 1.

Sites with an 'A' score achieved over 76% compliance across all parameters in 2016 and were located in Doon Doon Creek, Crystal Creek, the Upper Rous River and along the Lower Oxley River (CAT23) just upstream of Eugella. Apart from CAT 23, these sites are all located in the upper catchment and reflect a healthy functioning aquatic ecosystem system at these locations. Nutrients (particularly TP) and E. coli were occasional issues for compliance at these sites.

The majority of sites were assigned a 'B' score (i.e. between 66-75% overall compliance) reflecting an increasing influence of agricultural runoff, wastewater discharges (on-site systems and centralised sewage systems), and decreasing riparian vegetation at these sites. Nutrients, E.Coli and DO often exceeded guidelines with occasional exceedances of Chlorophyll *a* triggers.

Site CAT 21 located at the outlet of the Pumpembil Creek sub-catchment received a 'C' score (i.e. between 51-65% overall compliance) with elevated nutrients, E.Coli and reduced DO levels reflecting the impact of intensive dairy land use in this catchment. Site CAT10 located immediately downstream of dairying operations in the Pumpembil Creek sub-catchment displayed the poorest water quality, receiving the only 'D' grade (i.e. <50% overall compliance) in the Upper Tweed Catchment. Elevated nutrient and Chlorophyll *a* concentrations were significant issues indicating frequent eutrophication at this site. High E.Coli levels and low DO were also substantial issues indicating poor ecosystem health and a high level of disturbance from natural state. There was a clear deterioration of water quality evident from upstream of the dairy (CAT 21a achieving 'B' score) to downstream of the dairy (CAT 21 'C' score).

Table 7: Water Quality percentage compliance for each site from Jan 2016 - Jan 2017 broken down by parameter and overall scores.

Sub-catchment	Site Code	DO	pH	Turb	Cond	TN	TP	Chl a	E.Coli	Overall % compliance	Overall Compliance Score
Byrill Creek	CAT6a	100	100	100	100	61	0	100	35	75	B
Doon Doon Creek	CAT9a	94	100	100	100	83	0	100	59	80	A
Smiths Creek	CAT13	61	100	100	100	72	6	100	12	69	B
Upper Tweed River	CAT7	85	100	100	100	69	0	100	8	70	B
	CAT28	92	100	100	100	77	0	85	17	71	B
Mid Tweed River	UWTP	no data	100	95	100	61	0	100	42	71	B
	CAT5	69	100	100	100	77	0	100	25	71	B
	CAT4	57	100	100	100	64	0	93	67	73	B
	BPWTP	no data	100	95	100	50	0	69	60	68	B
	CAT25	79	100	100	100	64	0	100	50	74	B
Pumpenbil Creek	CAT21a	100	100	100	100	100	0	100	0	75	B
	CAT10	8	100	100	100	0	0	54	0	45	D
	CAT21	72	100	100	100	39	0	100	11	65	C
Upper Oxley River	TWTP	no data	100	100	100	67	0	92	14	68	B
	CAT26	89	100	100	100	58	0	93	0	68	B
	CAT27	100	100	100	100	85	0	100	11	75	B
Lower Oxley River	CAT3a	77	100	100	100	85	0	100	15	72	B
	CAT1	95	100	100	100	52	0	87	33	71	B
	CAT23	100	100	100	100	82	6	100	50	80	A
Upper Rous River	CAT17	100	100	100	100	100	0	100	15	77	A
	CAT18	54	100	100	100	92	0	100	23	71	B
Mid Rous River	CAT17a	71	100	100	100	88	0	100	11	71	B
	CAT15	67	100	100	100	78	6	93	0	68	B
Crystal Creek	CAT16	88	100	100	100	100	53	100	0	80	A
Hopping Dicks Creek	CAT19	100	100	100	100	84	0	100	0	73	B
Brays Creek	CAT20	79	100	100	100	84	0	100	0	70	B
Rowlands Creek	CAT24	45	85	100	100	75	20	100	35	70	B

Key:

Score	% Compliance Overall
D	0-50
C	51-65
B	66-75
A	76-100

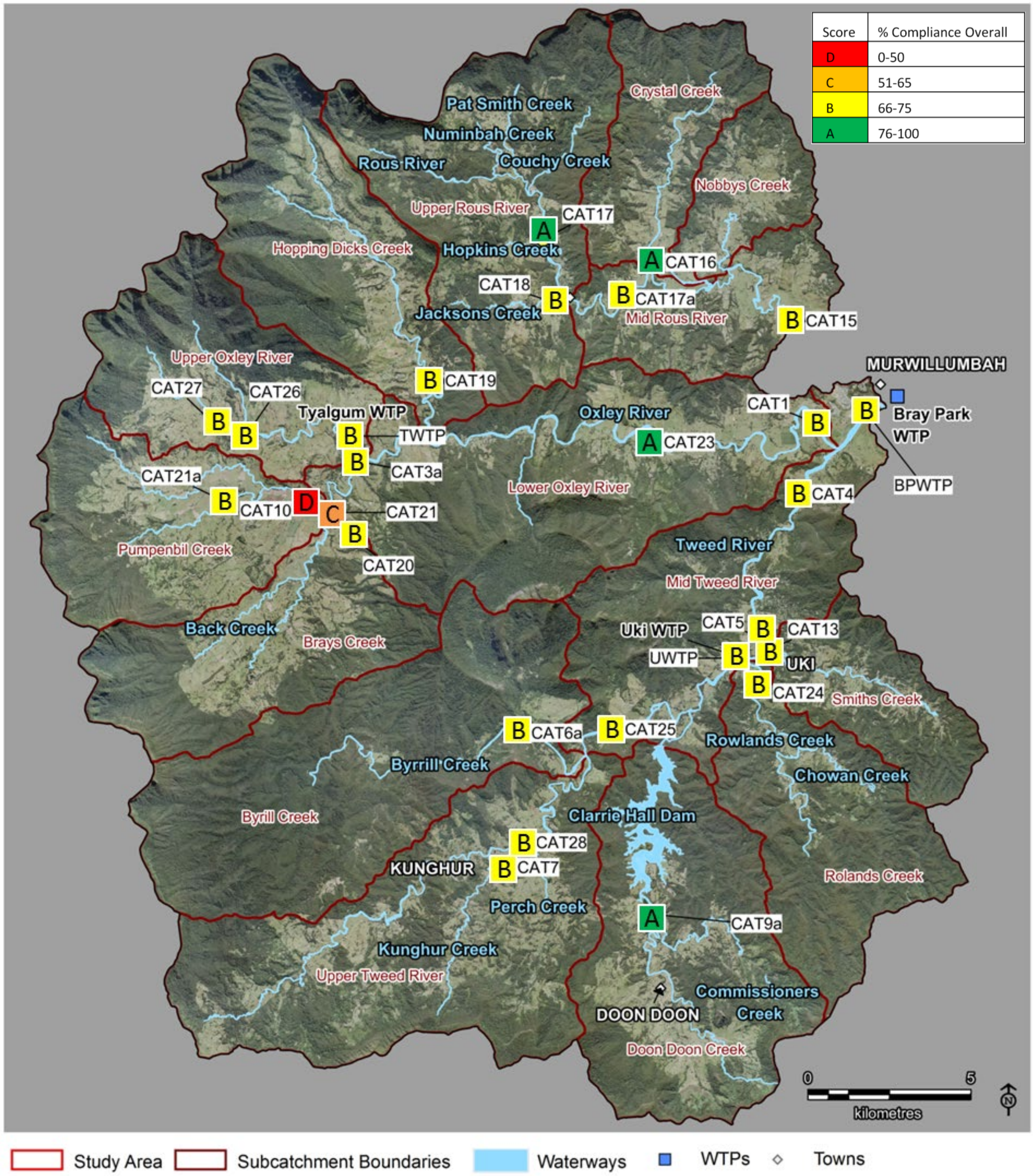

Figure 9: Overall compliance scores at each site in the Upper Tweed catchment from Jan 2016 - Jan 2017

3.1.1 pH

Levels of pH were within recommended guidelines for ecosystem health (pH 6.5-8.5) at all sites. There were occasional occurrences of pH<6.5 at CAT24 on Rowlands Creek, which had an overall compliance rate of 85% for pH (Table 7). All remaining sites achieved over 100% compliance with the pH objective for 2016.

3.1.2 Dissolved Oxygen

Median dissolved oxygen (DO) levels were below the lower guideline (85% saturation) at two sites: CAT24 (Rowlands Creek) and CAT10 (Pumpenbil Creek sub-catchment). CAT10 experienced the lowest DO overall with a median value of 70% saturation and a range of values from 10%-88% saturation. Compliance with aquatic ecosystem guidelines was only achieved by 1 of the 13 samples taken throughout the year, indicating poor aquatic health almost all the time in 2016. The median DO value at CAT24 on Rowlands Creek was just below the guideline at 84% saturation and compliance with guidelines achieved for less than half of samples throughout 2016 (45% compliance). Low levels of DO compliance were also observed at CAT18 (Jackson Creek, Upper Rous River 54% compliance), CAT 4 (Mid Tweed River, 57% compliance) and CAT13 (Smiths Creek, 61% compliance).

At CAT9a, DO was elevated over the upper limit of 110% saturation on occasion (indicated by outliers in Figure 7), which can indicate increased productivity in the system such as potential algal blooms. However, Chlorophyll *a* measurements at this site were within normal ranges, indicating elevated DO was likely caused by other factors (e.g. increased flow, aeration due to increased turbulence etc.).

It should be noted that while DO is an important indicator for ecosystem health, when measured as part of routine sampling, interpretation of the data can be difficult due to the variability of DO throughout the day. Sampling in the morning will typically produce lower DO concentrations as this is when aquatic plants respire and consume oxygen from the water column. Conversely, sampling in the middle of the day will yield higher overall DO when plants are actively photosynthesising and producing oxygen. While an indication of overall health can be gleaned from routine samples over a long period, sampling DO over daily cycles is the only reliable method to get a handle on DO status at any particular site.

3.1.3 Turbidity

The maximum recommended guideline for median turbidity (50 NTU) was not exceeded at any site over the monitoring period indicating good overall water clarity throughout the catchment. Overall, the percentage compliance for turbidity was also good with 95-100% compliance across the catchment. There were occasional exceedances of the guideline at BPWTP and UWTP intake sites, shown as outliers in Figure 7, which were all associated with high rainfall events. These results indicated that the waterways do experience turbid conditions at times associated with rainfall/runoff events. CAT10, showed consistently higher turbidity levels than other sites with a median value of 10 NTU. Maximum turbidity detected at the water supply intake sites is unlikely to be due to any specific issue at these sites, but prather the greater frequency of sampling at these sites (weekly compared to monthly at catchment sites) being more likely to pick up the extreme events. A number of sites showed turbidity levels below the lower limit recommended for ecosystem health (i.e. 6 NTU), however as these results were not associated with other risk factors, such as acid drainage, these low levels were not considered likely to be an indicator of poor health in the Upper Tweed catchment. For this reason only the upper limit was considered in the assessment of percentage compliance shown in Appendix 1.

3.1.4 Chlorophyll *a*

Median Chlorophyll *a* levels were below the maximum guideline (5ug/L) at all sites throughout 2016, indicating that all sites achieved the guidelines for ecosystem health in 2016 during most conditions. Median values at CAT10 were the highest recorded and were equal to the maximum guideline value. On occasion, measured concentrations were up to 30ug/L at BPWTP, 20ug/L at CAT26 and 16ug/L at CAT10 and CAT1. So while overall chlorophyll *a* at monitoring sites is at acceptable levels for ecosystem health for this time period, the data indicate that high concentrations do occur at some sites from time to time.

3.1.5 Total Nitrogen

Total Nitrogen (TN) median concentrations for 2016 exceeded guidelines at CAT10 (0.81mg/L) and CAT21 (0.39mg/L), located immediately downstream. None of the individual samples taken at CAT10 achieved the aquatic ecosystem guideline for TN (i.e. 0% compliance). This is in contrast to CAT21a, located upstream of CAT10 on Pumpenbil Creek, which had some of the lowest TN levels in the Tweed Catchment, achieving 100% compliance with aquatic ecosystem guidelines. These results indicate a clear point source of nitrogen in the vicinity of CAT10 (dairying operations).

Site CAT16 in Crystal Creek recorded the lowest levels of TN (median 0.10mg/L) and achieved 100% compliance overall, which is likely to reflect the low level of disturbance in this catchment compared to other sub-catchments.

3.1.6 Total Phosphorus

Total Phosphorus (TP) concentrations exceeded guidelines at all sites except for CAT16 (Crystal Creek) throughout the monitoring period. In terms of percentage of compliance, TP was the worst performing indicator with 53% compliance, the highest level achieved (at Site CAT16). Most sites recorded a 0% compliance for TP in 2016. The highest overall TP levels were recorded at CAT10 (median was 0.13 mg/L, over 5 times the upper limit) and CAT21 (0.10 mg/L) compared to upstream levels at CAT21a (0.7mg/L), again indicating nutrient sources impacting water quality in the vicinity of CAT10.

As noted in Stage 1 reporting, high TP levels, which were reported even for the upper catchment sites with limited disturbance, tends to suggest that there may be natural catchment factors such as geology and soil type contributing to TP levels above the general OEH water quality objectives. Further exploration of deriving local objectives for TP could be undertaken to determine if more relevant WQOs can be defined for the Tweed Upper Catchment.

3.1.7 Faecal Indicator Bacteria (*E. coli*)

Levels of *E. coli* were in excess of recommended guideline levels for primary contact recreation at the majority of sites in 2016 (Figure 7), indicating that pathogen sources are present at most locations. Site CAT10 showed the highest levels of *E. coli* (median 1250 cfu/100ml), over 8 times the guideline, and with nosamples taken in 2016 achieving compliance with primary contact recreation guidelines. BPWTP had the lowest levels of *E. coli* with a median concentration of 100 cfu/100mL in 2016 and 67% compliance overall.

3.2 Rainfall and Hydrological Variability

In natural river systems, water quality is supported by a variable flow regime whereby each flow component (e.g. high flows, low flows, cease to flows) fulfils particular functions to restore or maintain water quality and a range of ecological and geomorphological functions (Bunn and Arthington, 2002). For instance, low flows provide warm, clear conditions suitable for nutrient cycling and primary production. Higher flows provide dilution of ions and toxins and entrainment of a fresh supply of nutrients and carbon to support ecological functions. Cease to flow periods in temporary streams can dry out the sediments, releasing carbon and nutrients that enable new life to flourish when flows return.

Extremes in flow variability, which occur during severe droughts and major floods, often cause extremes in water quality. Although such extreme events have a low frequency of occurrence, when they do occur, they often have major consequences for water quality in aquatic systems. Water quality impacts from such extreme events can compromise the availability and suitability of water resources for its environmental values and beneficial uses.

A substantial proportion of the mobilisation and downstream transportation of the nutrients and suspended sediments during the wet season occurs during the rising limb of the hydrograph of the first high flow events and may last only short periods (several days) with fluctuating concentrations (Butler and Burrows, 2006). The amount of particulate matter in suspension during the rising stages of early flow increases with stream order, and concentrations may exceed extremely high levels (10,000 mg/L) for brief durations in large river catchments with erosion-prone soils (Butler, 2008).

3.2.1 Assessment of water quality variation due to rainfall

Rainfall information was assigned to the Upper Tweed Catchment dataset retrospectively by calculating three day rainfall leading up to each sampling event. Three day rainfall prior to sampling is considered to be a good indicator of the occurrence of runoff generation. The samples were then categorised using the following method:

- Wet: >50mL of rainfall in three days prior to sampling;
- Dry: <10mL of rainfall in three days prior to sampling; and
- Moderate: between 10mL and 50mL of rainfall in three days prior to sampling.

The percentage of samples in each rainfall category based on the above classification is presented in Table 8. Also included in the table is the percentage breakdown of rainfall conditions over the entire sampling period (Jan 2016-Jan 2017). The majority of samples (65%) have been collected during dry conditions, with 13% collected during moderate rainfall conditions. Wet or 'Event' samples comprise approximately 22% of the dataset, which is a marked improvement on the 1999-2015 sampling, where only 7% of samples were 'wet' samples. Based on this classification, it appears that the program has sampled water quality under a range of rainfall conditions and has collected data during a number of high risk 'wet' events at key sites. At the water supply intake sites which have weekly sampling, all conditions are well represented.

Table 8: Sample counts at each site classified by pre-sampling rainfall condition compared to all days from Jan 2016 to Jan 2017

Site	**Dry**	**Moderate**	**Wet**
BPWTP	40	7	9
CAT1	10	2	9
CAT10	10	2	1
CAT13	9	2	7
CAT3a	10	2	1
CAT4	10	2	2
CAT5	9	2	2
CAT7	9	2	2
TWTP	40	7	9
UWTP	40	7	9
CAT24	10	2	8
CAT25	9	3	2
CAT28	9	2	2
CAT6a	9	2	7
CAT9a	9	2	7
CAT15	10	3	5
CAT16	13	2	2
CAT17	10	2	1
CAT17a	10	2	5
CAT18	10	2	1
CAT19	11	2	6
CAT20	12	2	5
CAT21	10	2	6
CAT21a	10	2	1
CAT23	12	3	2
CAT26	11	2	6
CAT27	12	2	6
Grand Total	364	72	123
% of total samples	**65%**	**13%**	**22%**
% of all days Jan 2016 - Jan 2017	**74%**	**15%**	**11%**

3.3 Temporal Change in Water Quality

Temporal change is the change in water quality observed over time. Trends are identified where the change attributed to time is found to be statistically significant. Trends in water quality data are often difficult to determine due to the confounding influences of seasonal variation (e.g. peaks in summer), cyclic variation (e.g. long-term rainfall patterns) and natural variation in the variable (e.g. noise). Stage 1 of this study included a comprehensive analysis of temporal trends over 16 years from 1999-2015 including; seasonal decomposition time series analysis to identify seasonal trends and isolate underlying trends; and regression analysis to identify any statistically significant trends in water quality through time. As this report analyses the 12 month period of additional data (Jan 2016 to Jan 2017), there is not yet adequate data to repeat the longer-term statistical analyses completed for Stage 1. Therefore a simpler descriptive form of analysis has been undertaken to present the data over the 12 month period as time series plots for key parameters at each site.

3.3.1 Temporal Trends throughout Jan 2016 to Jan 2017

pH

There were no clear temporal trends in pH during the 13 month study period (Figure 10). Consistently lower pH measurements were observed at the Rowlands Creek site (CAT24) and may indicate either landuse impacts or natural characteristics such as soil type in this catchment. At this site pH dipped below levels considered suitable for aquatic ecosystem health (pH 6.5) during two major rainfall events (June 2016 and Jan 2017). All other pH measurements were within aquatic ecosystem health guidelines at all sites.

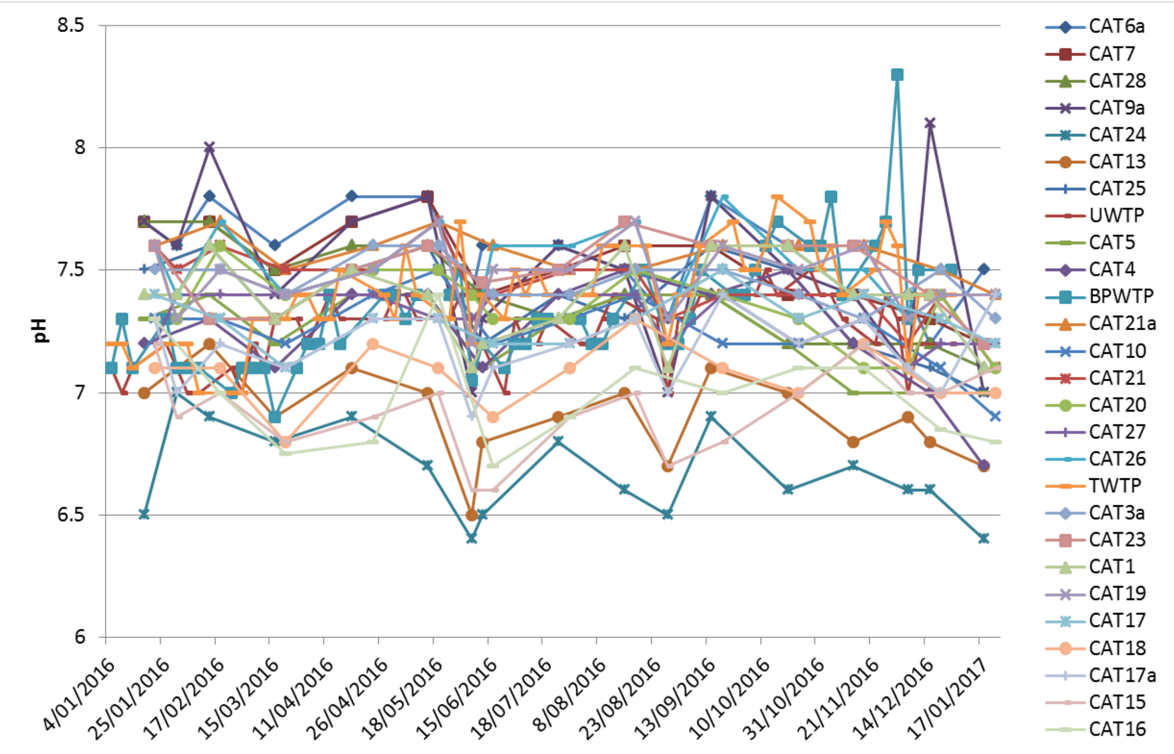

Figure 10: Temporal variation in pH from Jan 2016 - Jan 2017

Conductivity

There was a clear relationship with rainfall events and deceased conductivity at all sites in 2016 (Figure 11). All conductivity measurements were within maximum aquatic ecosystem health guidelines at all sites (<2200 µS/cm). However, consistently higher conductivity measurements were observed at CAT 10, which were elevated above the upstream site on Pumpenbil Creek (CAT21a), indicating land use impacts affecting water quality at this location (i.e. wastewater discharges, fertiliser runoff etc.)

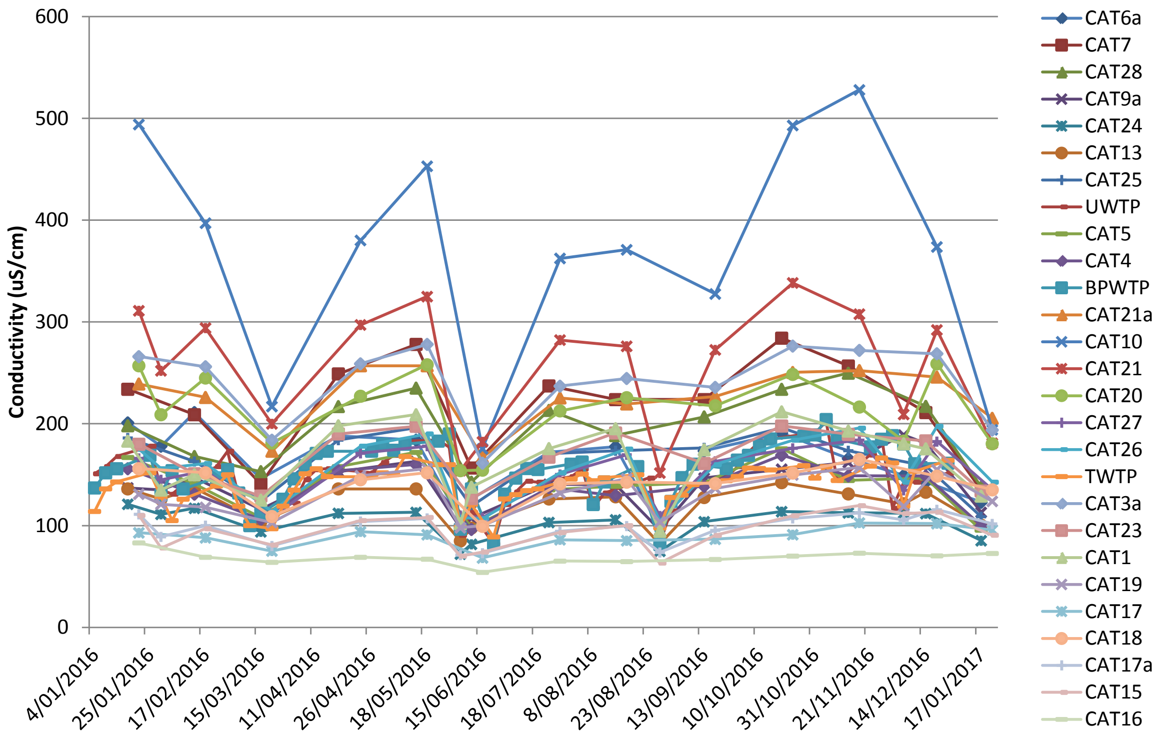

Figure 11: Temporal variation in Conductivity from Jan 2016 - Jan 2017

Dissolved Oxygen

No clear temporal trends were detected for DO in 2016. DO at CAT10 was consistently lower than all other sites, indicating poor ecosystem health at this site.

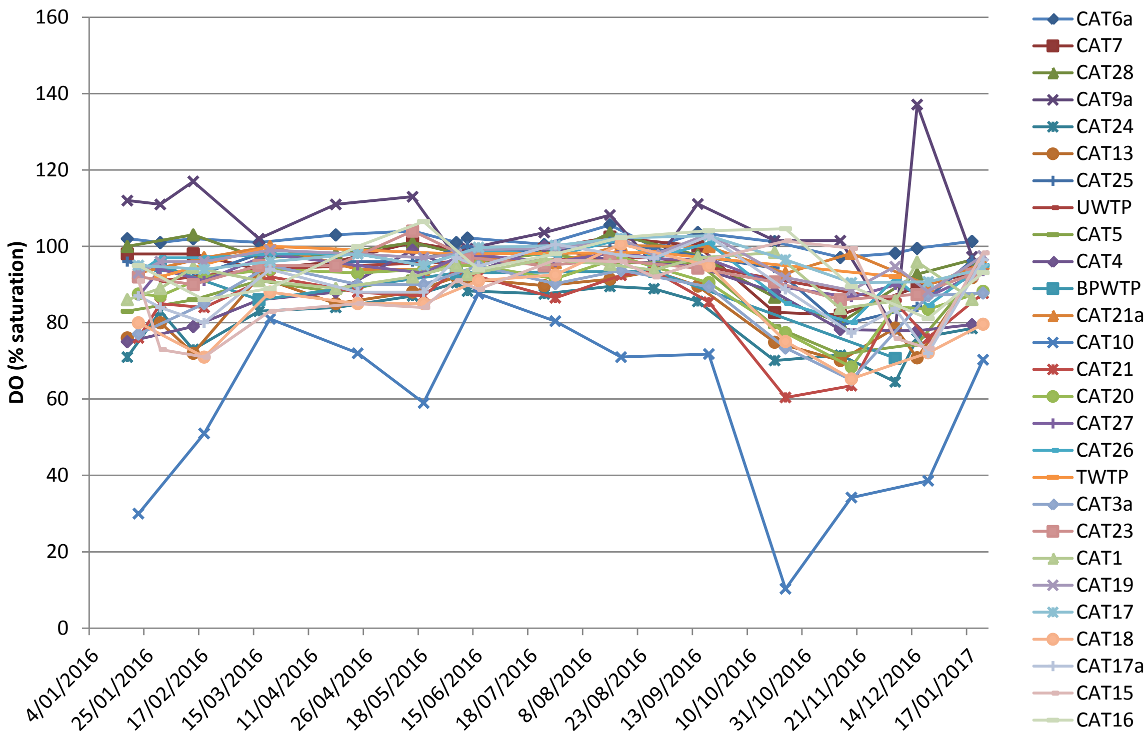

Figure 12: Temporal variation in dissolved oxygen from Jan 2016 - Jan 2017

Temperature

There was a strong seasonal pattern to temperature with summer maximum water temperatures reaching 32ºC and winter minimum temperatures reaching 13ºC (Figure 13).

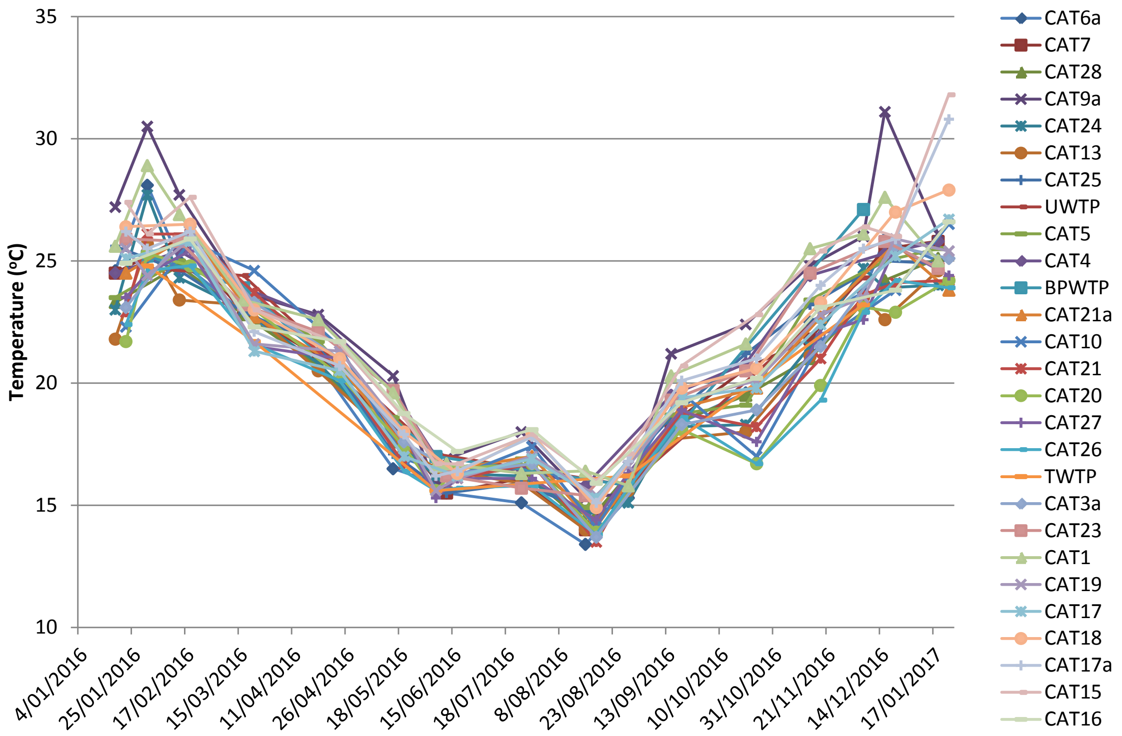

Figure 13: Temporal variation in temperature from Jan 2016 - Jan 2017

Turbidity

The results for turbidity show strong association with rainfall events, with elevated levels recorded during all 5 rainfall events sampled in 2016. Highest levels were observed during rainfall events, recorded at BPWTP and UWTP.

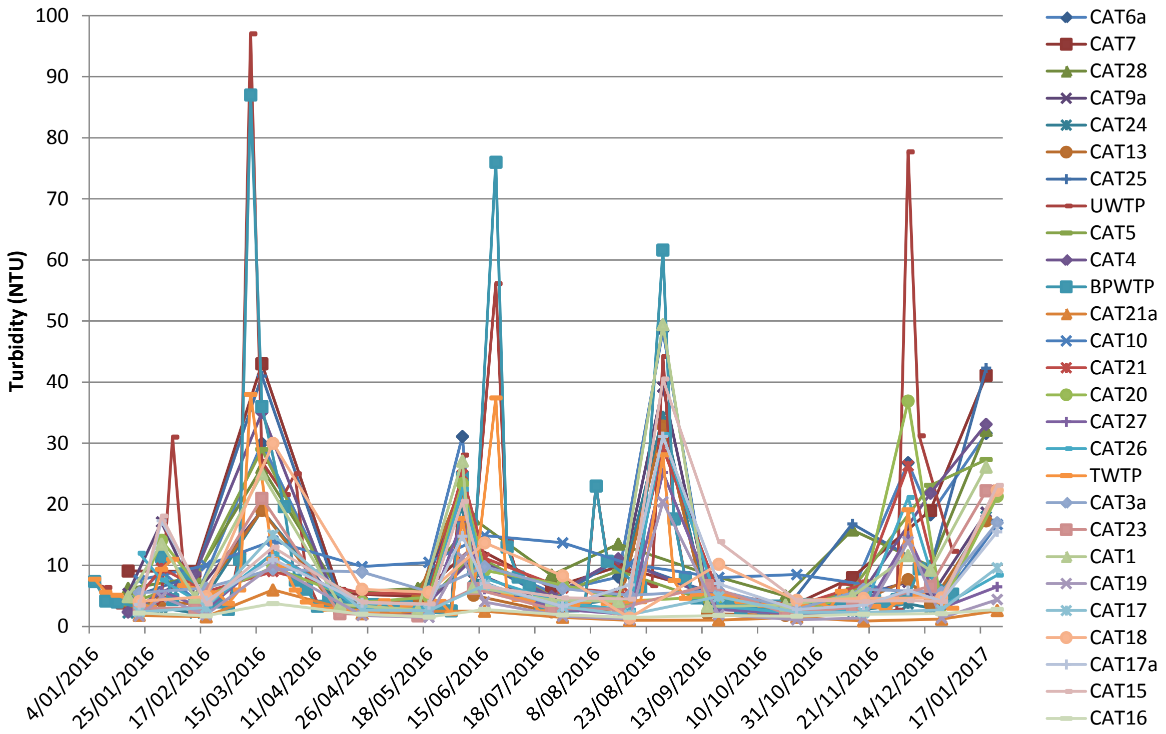

Figure 14: Temporal variation in turbidity from Jan 2016 - Jan 2017

Total Suspended Solids

The results for TSS also show strong association with rainfall events, with elevated levels recorded during all 5 rainfall events sampled in 2016. There was also a notable spike in TSS at CAT10 in October 2016 which was not associated with rainfall but coincides with high nutrient and chlorophyll a values indicating an algal bloom at this time contributing to high TSS. Highest TSS levels were observed during rainfall events, recorded at BPWTP and UWTP.

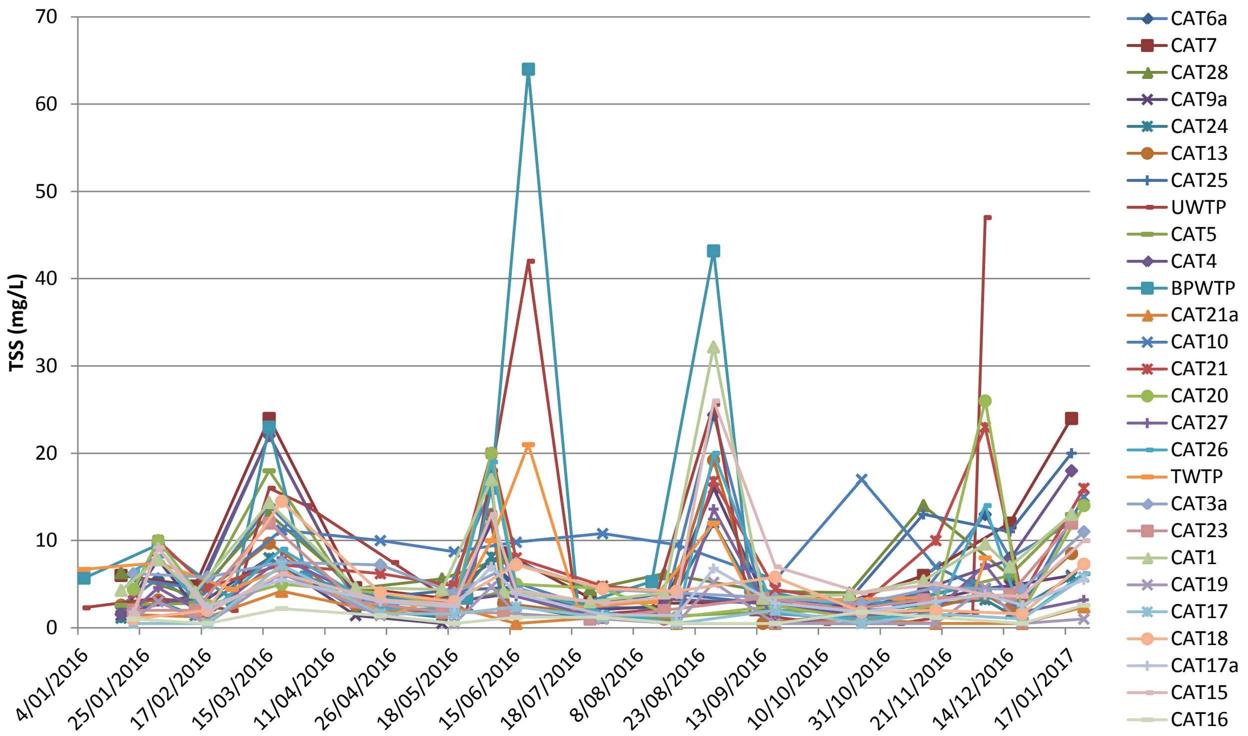

Figure 15: Temporal variation in total suspended solids from Jan 2016 - Jan 2017

Total Nitrogen

Higher concentrations of TN were observed during high flow times indicating sources of nutrient in runoff from land surfaces (Figure 16). Spikes in TN at CAT10 in May, August and October all occurred during 'dry' conditions (<10mL rainfall in 3 days leading up to sampling) indicating a point source of nitrogen in this vicinity such as wash-down wastewater discharge from dairy operations. Figure 18 shows that the majority of TN sampled in May and October was made up of ammonia and oxygen levels were also very low, potentially reflecting discharge from an anaerobic wastewater pond or holding tank.

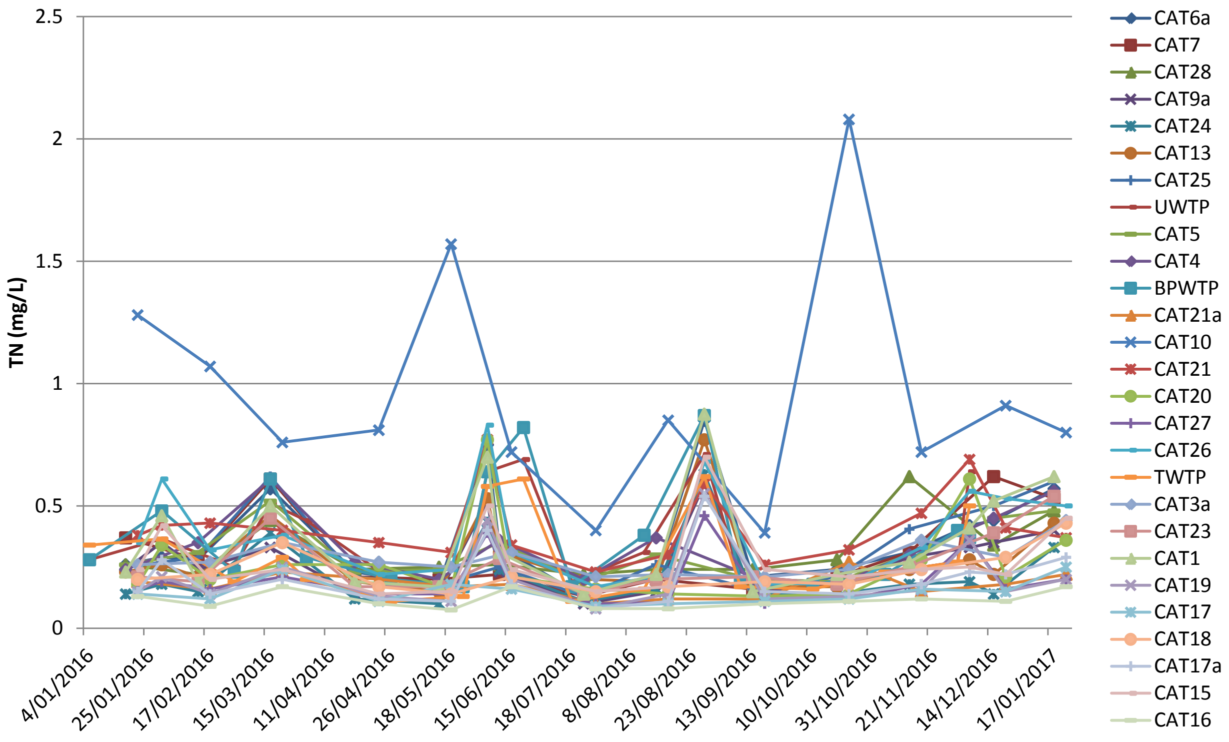

Figure 16: Temporal variation in total nitrogen from Jan 2016 - Jan 2017

Oxidised Nitrogen

There was some association with elevated NOx and rainfall events during 2016. CAT26 (downstream of dairy operations in Upper Oxley River) showed some of the highest recorded levels of NOx in 2016. Some of these spikes occurred during rainfall events (e.g. 6th June 2016) and others occurred during dry periods (e.g. 15th Dec 2016) indicating runoff from land surfaces during rainfall and also occasional point source discharges occurring during dry times.

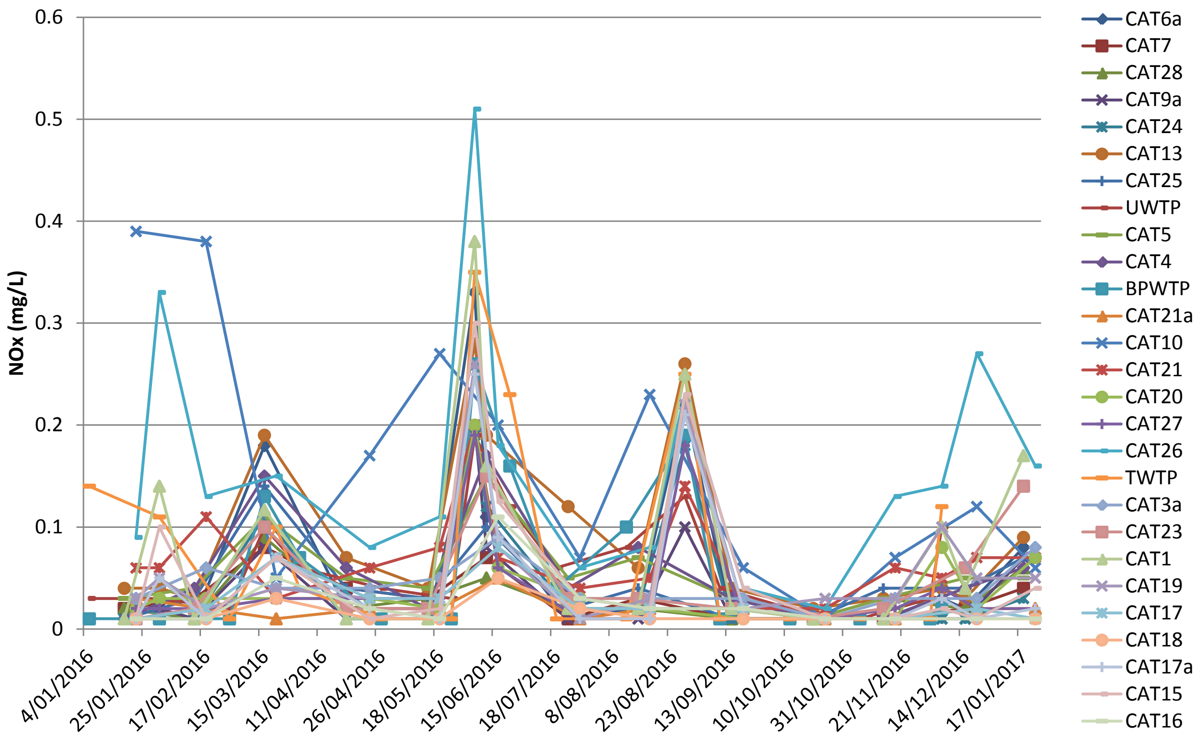

Figure 17: Temporal variation in oxidised nitrogen from Jan 2016 - Jan 2017

Ammonia

There were no clear temporal trends in ammonium during 2016. CAT10 was a significant source of ammonia in the catchment and spikes occurred during dry periods indicating some form of wastewater discharge to the waterway.

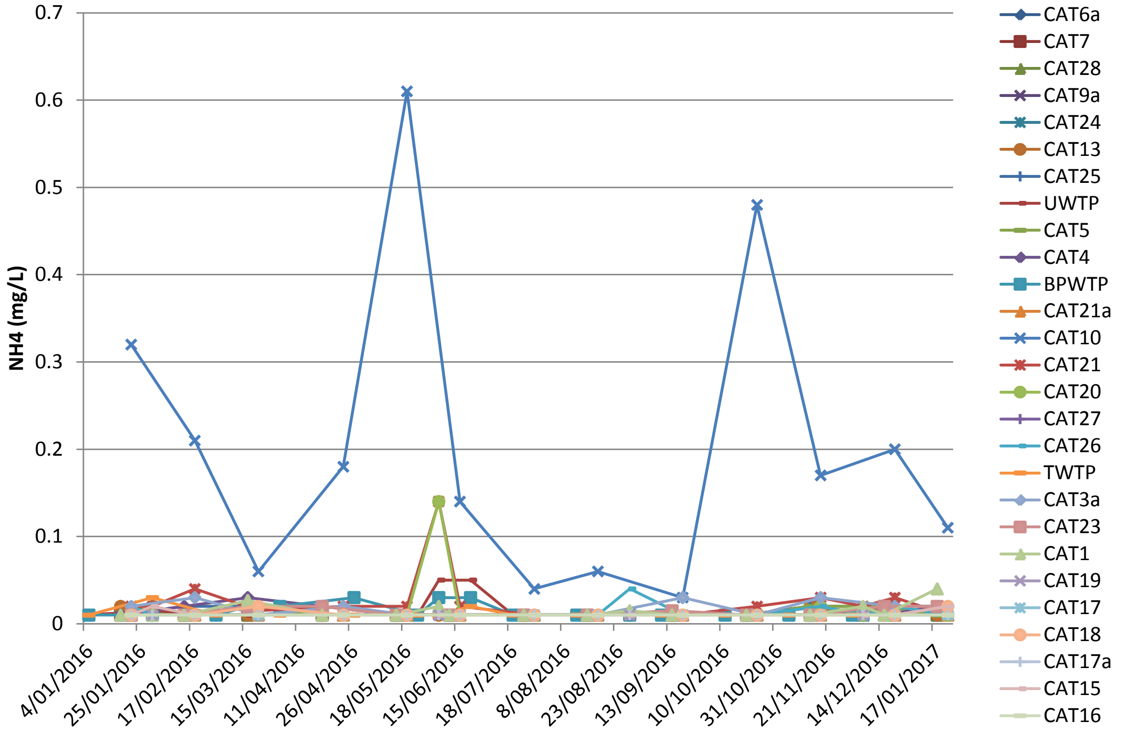

Figure 18: Temporal variation in NH_4 from Jan 2016 - Jan 2017

Total Phosphorus

There was some association with elevated TP and rainfall events during 2016 at most sites (Figure 19). Again, elevated concentrations at CAT10 did not always coincide with rainfall indicating wastewater discharge in the vicinity.

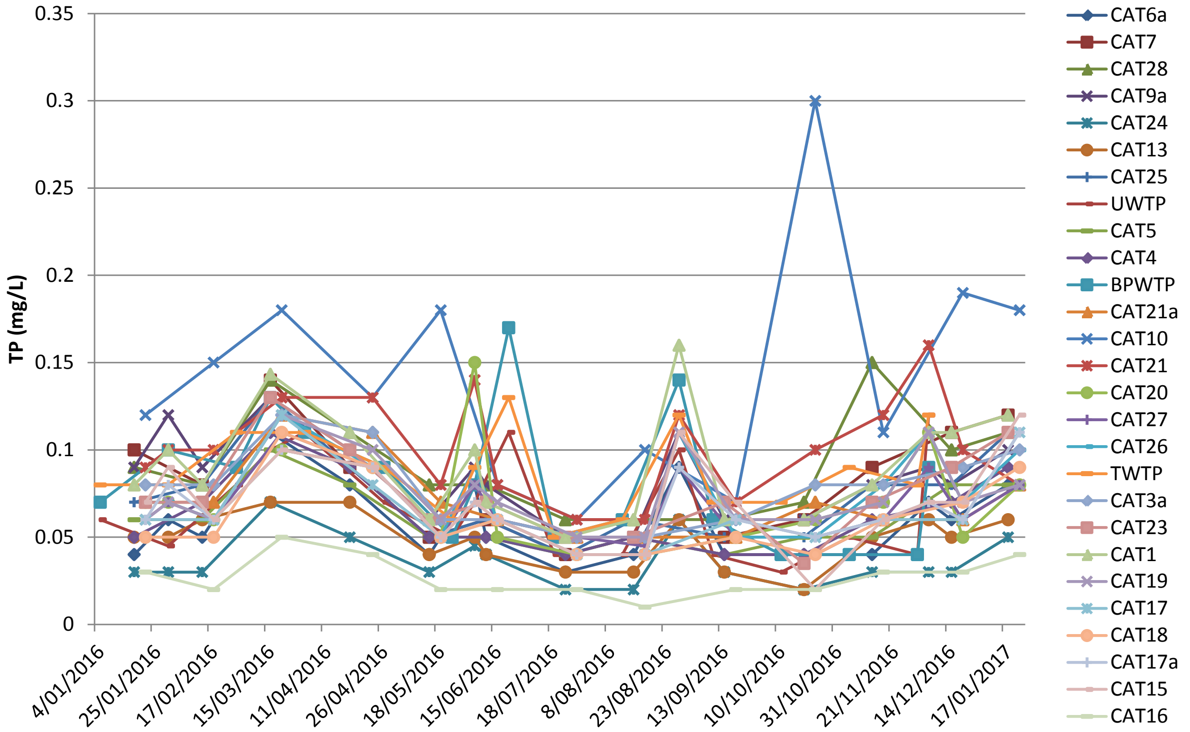

Figure 19: Temporal variation in total phosphorus from Jan 2016 - Jan 2017

Ortho-Phosphorus

There was no clear temporal trends in Ortho-P during 2016, with a high degree of variation from month to month, likely reflecting the rapid uptake and cycling of this bioavailable indicator in the aquatic ecosystem.

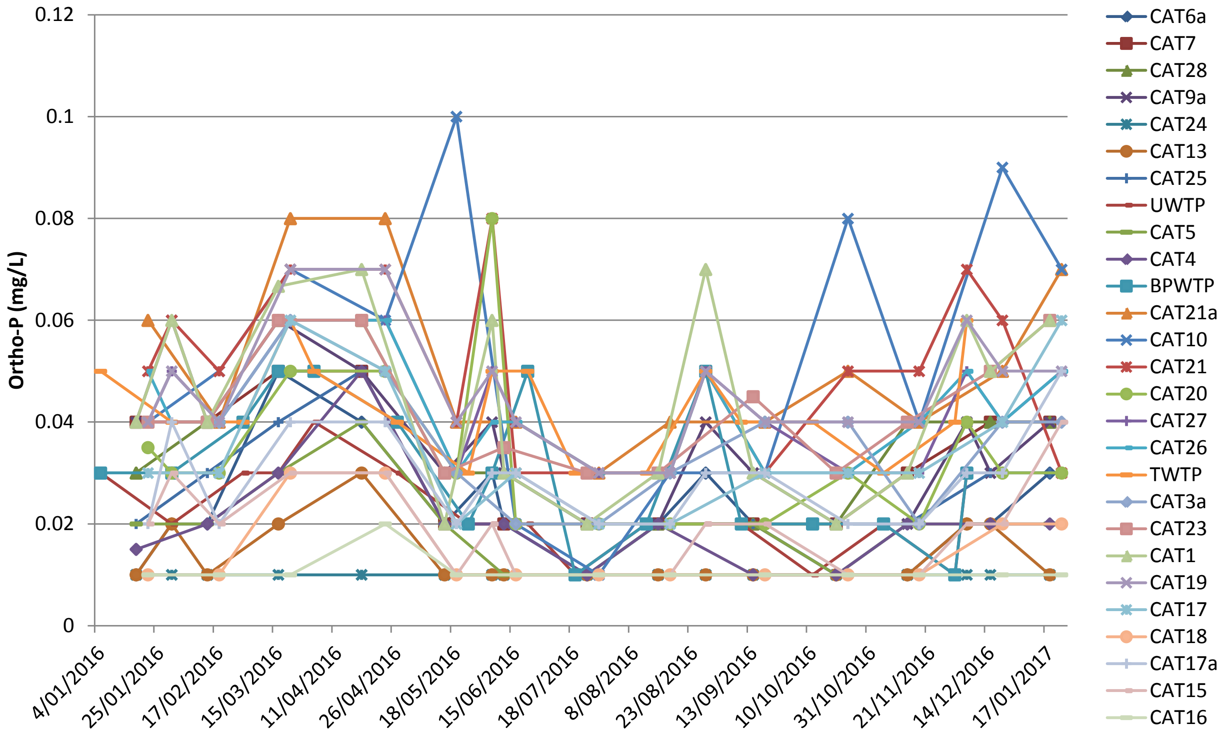

Figure 20: Temporal variation in Ortho-phosphorus from Jan 2016 - Jan 2017

Chlorophyll *a*

There was a high level of variation in Chlorophyll *a* concentrations on monthly timescales, most likely reflecting the boom-bust nature of phytoplankton blooms in freshwater systems. Generally higher concentrations of Chlorophyll *a* were experienced at several sites in late 2016 and early 2017 coinciding with summer when light conditions and nutrient supply (freshwater inflows) are greatest. Highest levels were recorded at BPWTP in January 2016 and this is consistent with TSC observations of occasional algal blooms occurring at this location. Consistently higher levels were observed at CAT10 which is consistent with similar patterns in nutrients at this site.

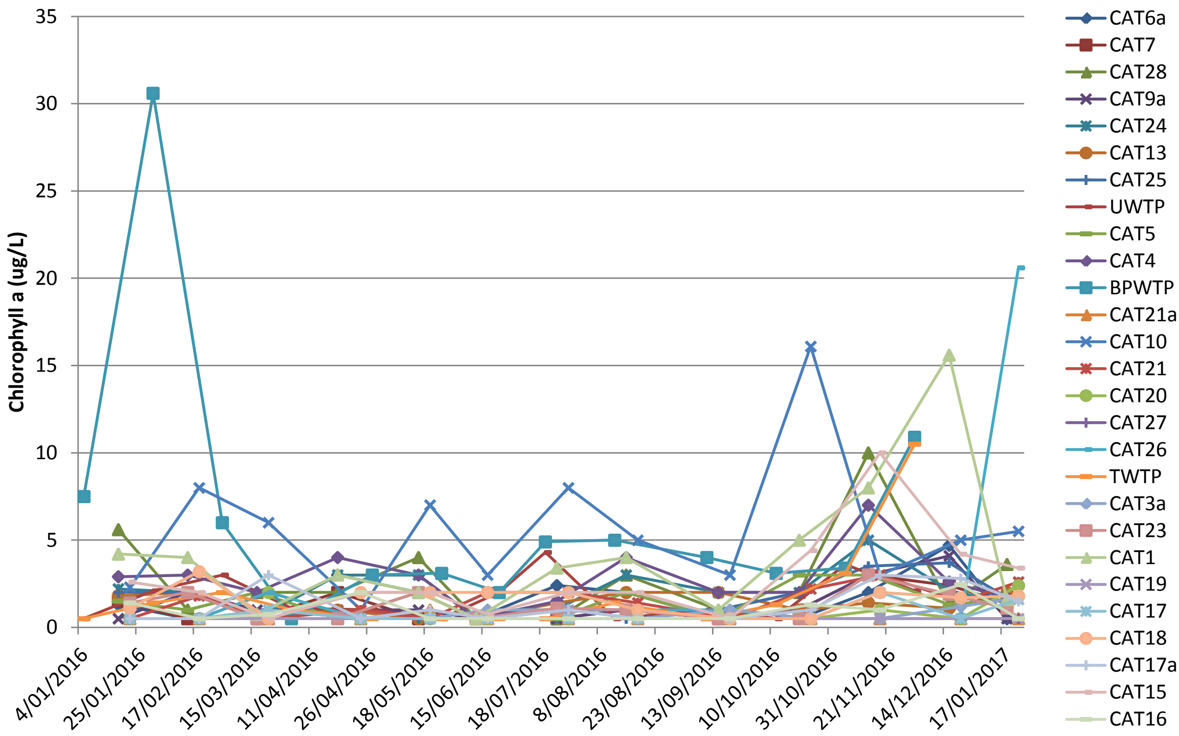

Figure 21: Temporal variation in chlorophyll *a* from Jan 2016 - Jan 2017

E.Coli

There were no clear temporal trends evident in *E. coli*, although results show association with some rainfall events (e.g. Feb and March 2016, and June 2016 at BPWTP). Spikes in *E. coli* at CAT10 in August 2016 and again in October 2016 were not associated with rainfall events and could indicate wastewater discharge.

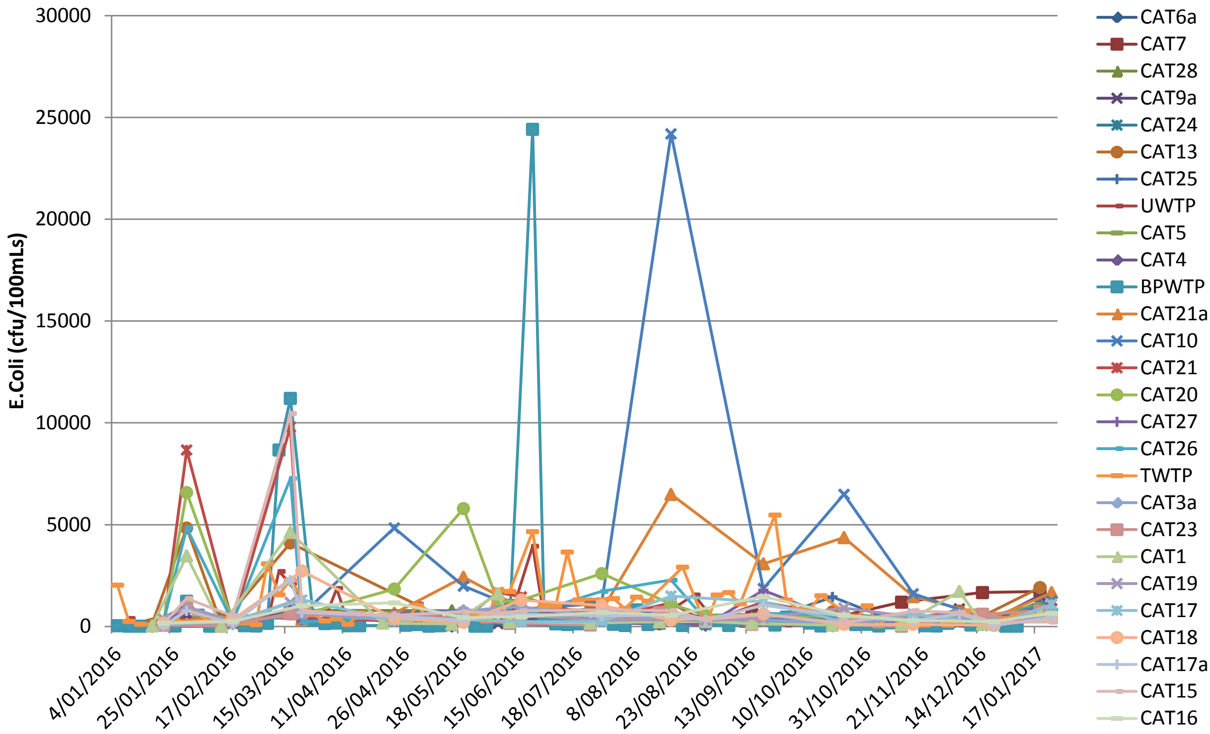

Figure 22: Temporal variation in E.Coli from Jan 2016 - Jan 2017

3.4 Spatial Change in Water Quality

3.4.1 Cluster Analysis

Cluster analysis is the task of grouping a set of objects in such a way that objects in the same group (called a cluster) are more similar to each other than to those in other groups. Connectivity based clustering, also known as hierarchical clustering, is based on the core idea of objects being more related to nearby objects than to objects farther away. The standardised mean of water quality data is used in this analysis as it allows for comparison across parameters of all units. Figure 24 provides a comparison of the standardised means showing differences in water quality collected during 2016.

Five distinct clusters formed based on the data from 2016 (Figure 23). The sites making up these five groups are therefore bound by the similarities and differences in water quality. Cluster 1 (CAT10 – Pumpenbil Creek sub-catchment) was determined to be highly different from any other site in the Upper Tweed Catchment. Figure 24 shows that CAT10 had greatly elevated concentrations across all nutrient parameters, Chlorophyll *a,* turbidity, conductivity, BOD, thermotolerant coliforms and *E. coli* compared to other sites. CAT10 also showed average concentrations of dissolved oxygen much lower than the other sites, all indicating poor waterway condition. Cluster 2 grouped sites in the Upper and Lower Oxley River and including CAT21 in Pumpenbil Creek together, which were geographically similar. This cluster tended to have slightly higher bioavailable nutrients, pH and conductivity than other sites. Cluster 3 was made up of a number of sites all located in the north-west portion of the Upper Tweed Catchment including upper Pumpenbil Creek (CAT21a), Brays Creek, Upper Rous, Mid Rous, Hopping Dicks Creek and the Upper and Lower Oxley River sites. This cluster was distinguished by slightly higher DO levels and lower nutrient concentrations than other clusters as well as low colour, soluble iron (Sol Fe) and TOC. Cluster 4 comprised a mixture of sites from various catchments including the Mid Tweed River, Upper and Mid Rous River, Smiths Creek, Rowlands Creek and Crystal Creek. The key differences for this cluster were slightly lower pH, higher colour, soluble iron and manganese (Sol Mn). Cluster 5 sites were differentiated by overall better water quality than other sites, with higher DO and pH, and lower nutrient concentrations compared to the other clusters, although turbidity was elevated. The sites were also geographically similar, located along the upper and mid Tweed River or tributaries.

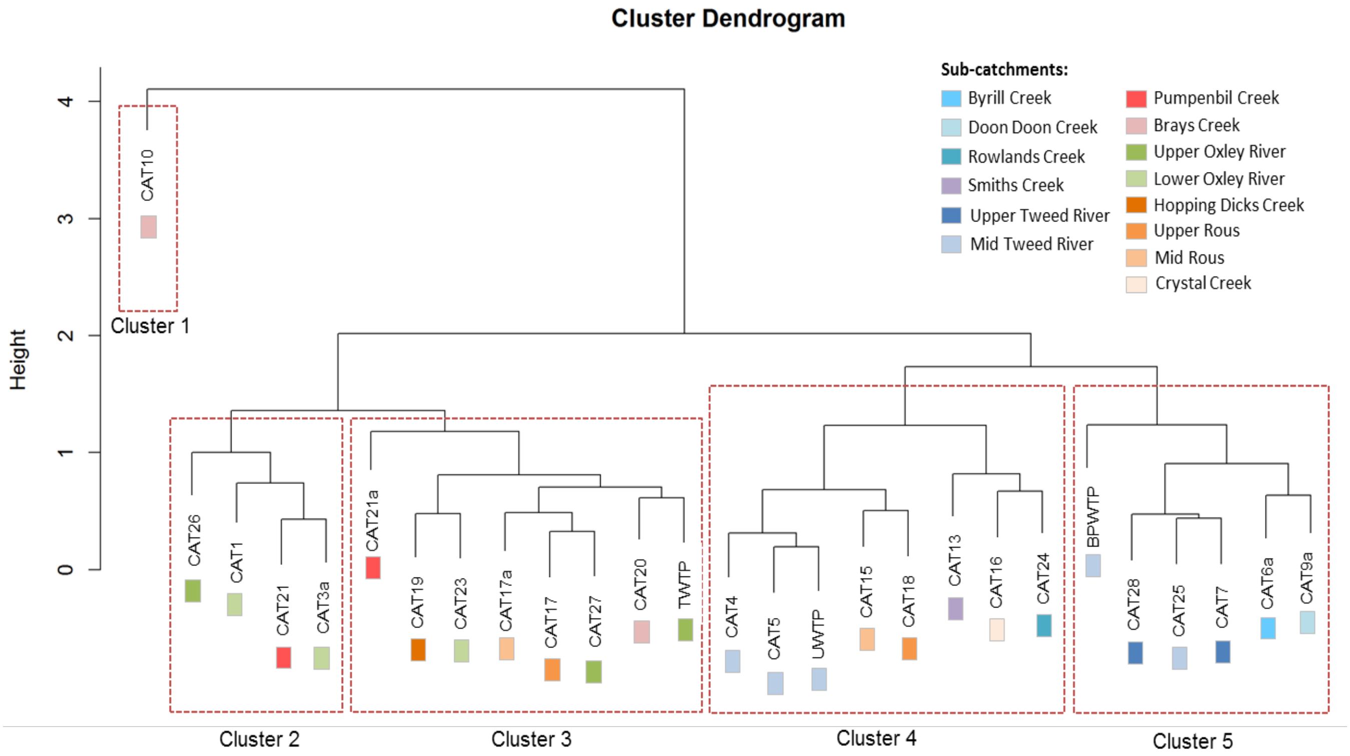

Figure 23: Cluster dendrogram generated using data across key water quality parameters (Colour, BOD, Conductivity, pH, DO, Turbidity, TOC, TN, NH_4, NOx, TKN, TP, Ortho-P, Sol Mn, Sol Fe, Total Coliforms, E.Coli).

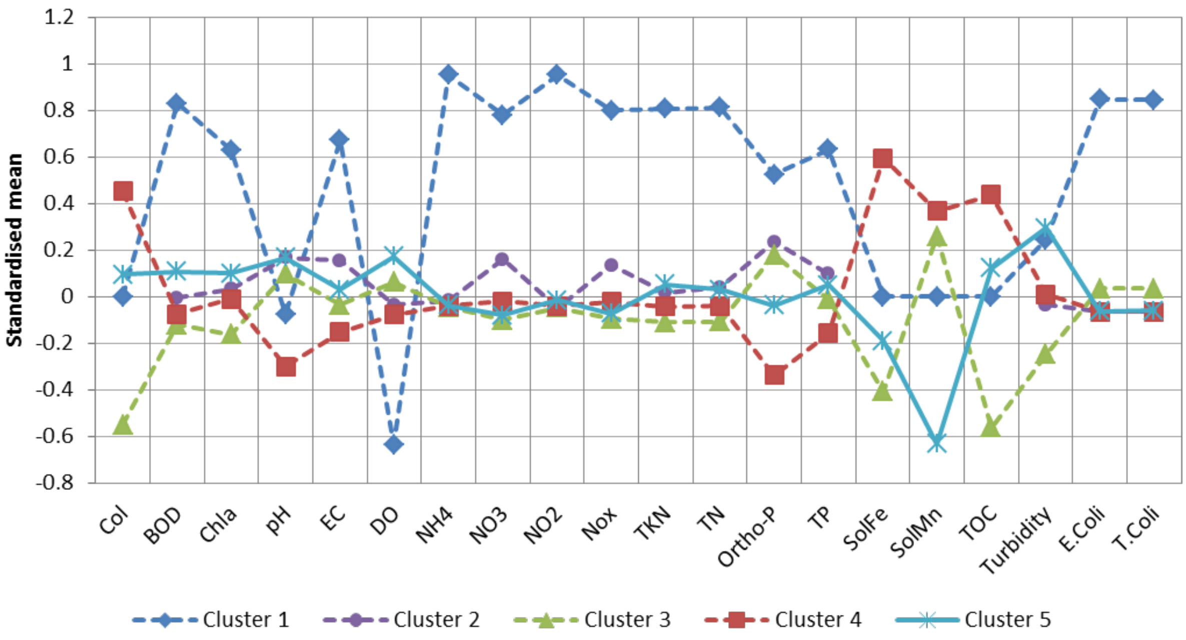

Figure 24: Comparison of standardised means showing differences in water quality among the five clusters.

3.4.2 Paired sites

Certain sites are positioned in a paired arrangement, upstream and downstream of potential sources of water quality pollution. Water quality data from paired sites was assessed to determine if there were any statistically significant differences observed between the two sites. A number of statistical techniques were employed to illustrate and assess these differences including:

- Time series plots of data comparing the behaviour of water quality at the paired sites through time;
- Summary box plots at the two sites to highlight long-term differences overall; and
- Regression analysis / analysis of variance (ANOVA) statistical tests were applied to determine if the observed differences were statistically significant.

Paired sites are listed and assessed separately below. Charts are shown only where statistically significant differences were detected. Refer to Appendix 2 for statistical results.

Pumpenbil Creek sub-catchment sites CAT 21a, CAT10 and CAT 21

CAT21a is located on Pumpenbil Creek upstream of a large dairy (refer Appendix 1 for site locations). CAT10 is located on Fowlers Creek immediately downstream of the dairy. CAT21 is located on Pumpenbil Creek downstream of where Fowlers Creek joins Pumpenbil Creek. The key parameters of concern are faecal indicators, DO, pH, turbidity, TSS and nutrient concentrations. CAT21a received a “B” overall compliance score while CAT10 received a “D” and CAT 21 received a “C”, reflecting clear deterioration in water quality from upstream to downstream (refer Figure 9 and Appendix 1). CAT10 was separated from all other sites in the cluster analysis indicating it is substantially different to all other sample sites and temporal analysis over the year highlighted a number of consistently poor water quality observations through time including low DO and high nutrients, particularly bioavailable forms. While overall conductivity, turbidity and pH appear to be compliant with WQOs at all sites, nutrients, DO and faecal indicators were generally in exceedance of WQOs and are significantly poorer at sites downstream of the dairy (CAT10 and CAT21). When ANOVA was applied, significant differences were found for TN ($p<0.001$); TP ($p<0.01$); Turbidity ($p<0.001$); TSS ($p<0.001$); and where values at CAT10 were significantly greater than at the upstream site CAT21a (Figure 25). DO ($p<0.001$) and pH ($p<0.001$) values were found to be markedly lower at CAT10 than CAT21a and this was also a statistically significant result. Similarly, ANOVA detected statistically significant differences for TN ($p<0.001$); TP ($p<0.01$); Turbidity ($p<0.01$); and TSS ($p<0.001$) where values at CAT21 were significantly greater than at the upstream site CAT21a on Pumpenbil Creek and DO (p<0.002) and pH (p<0.01) were significantly lower. While E.Coli was generally higher at CAT10, this was not a statistically significant result. The results of both long-term (refer Report 1) and short-term (2016) monitoring indicate that dairying operations at this location are having considerable adverse impacts on Pumpenbil Creek.

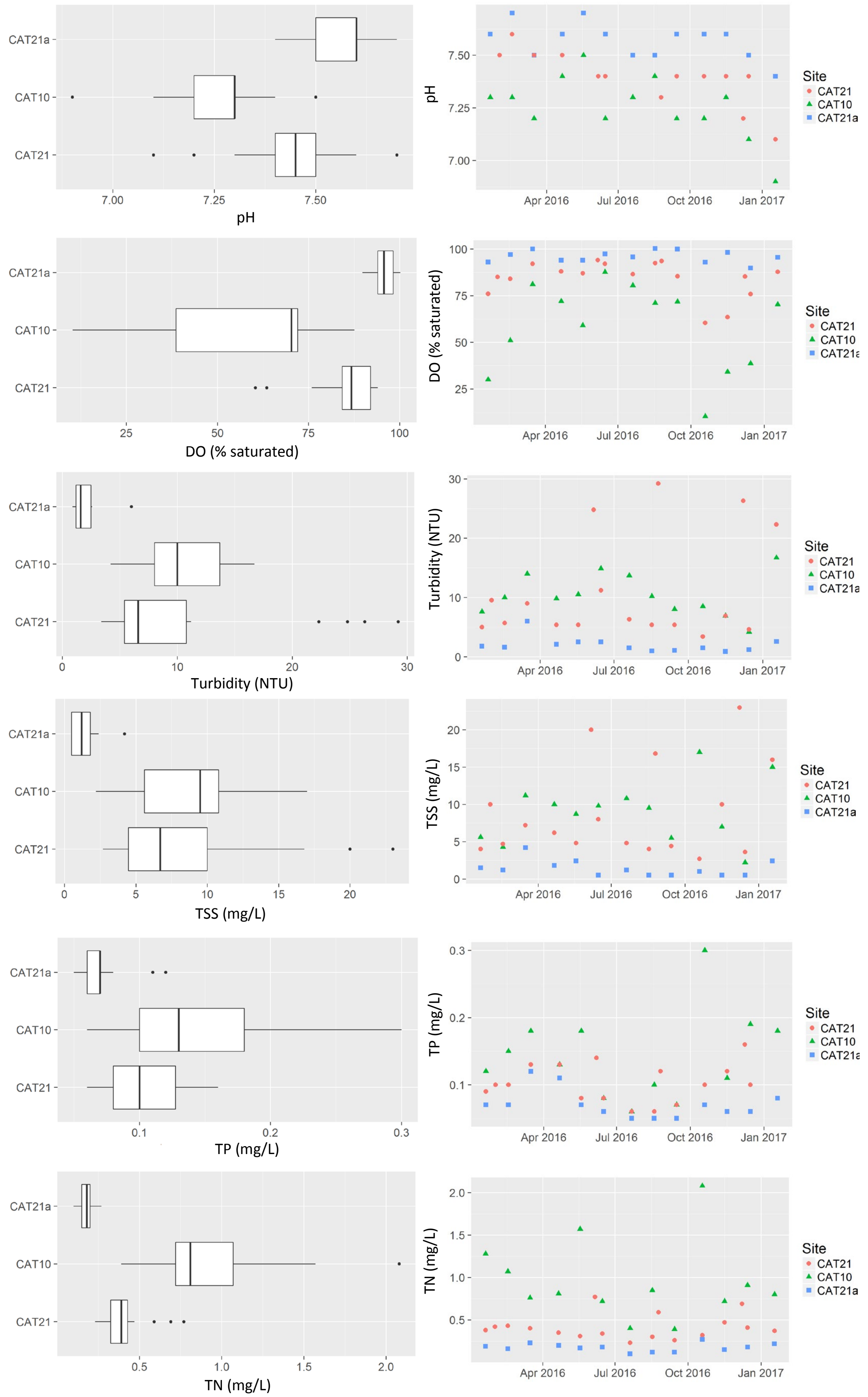

Figure 25: Statistically significant differences in water quality between CAT21a (upstream of dairy) and CAT10 (immediately downstream of dairy) and CAT21 (downstream of dairy).

Upper Tweed River sub-catchment sites CAT 27 and CAT26

Site CAT27 is located on Tyalgum Creek upstream of a large dairy in the Upper Oxley River sub catchment (refer Appendix 1 for site locations). CAT26 is located on Tyalgum Creek immediately downstream of the dairy. The key parameters of concern are faecal indicators, DO, pH, turbidity, TSS and nutrient concentrations. Both sites received a “B” overall water quality compliance score (refer Figure 9 and Appendix 1). E.Coli and TP levels were consistently poor at both sites with TN levels occasionally exceeding guidelines at CAT26. Temporal analysis over the year did not highlight any significant issues at either site. When ANOVA was applied, significant differences were found for TN ($p<0.001$) and pH ($p<0.001$) where values at CAT26 were significantly greater than at the upstream site CAT27 (Figure 26). These results indicate dairy operations are having an impact on pH and nitrogen levels in Tyalgum Creek.

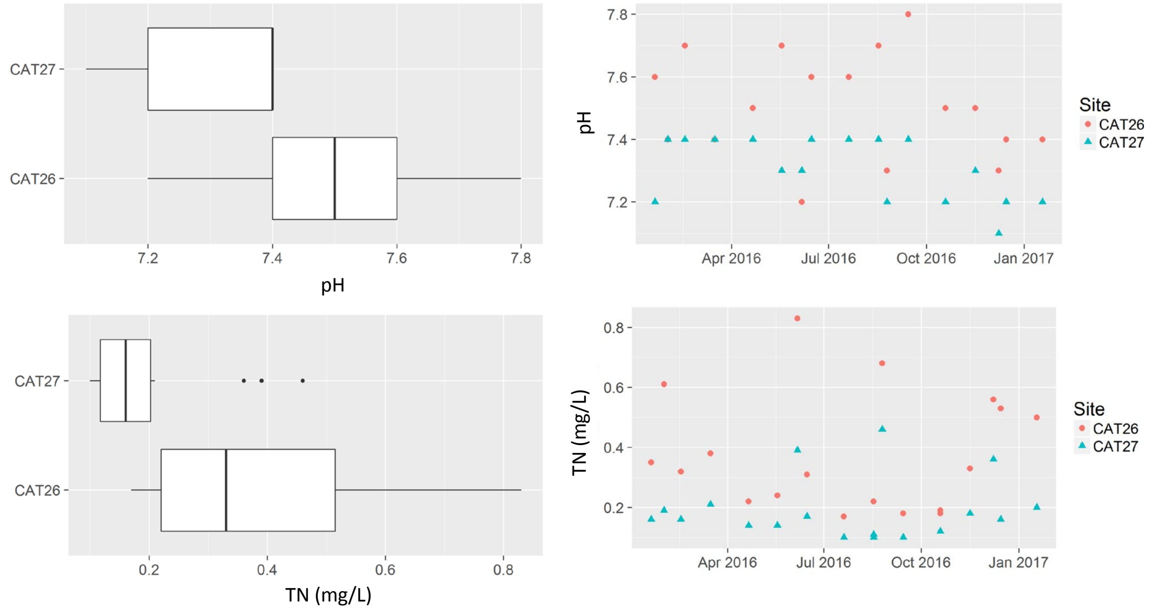

Figure 26: Statistically significant differences in water quality between CAT27 (upstream of dairy) and CAT26 (downstream of dairy).

Mid-Tweed River sub-catchment site CAT 25 and CAT5

Site CAT25 is located on the Mid Tweed River upstream of the village of Uki. CAT5 is located on the Mid Tweed River downstream of the village of Uki, Uki WWTP and also downstream of the junction of Rowlands Creek and Smiths Creek with the Tweed River. The key parameters of concern are faecal indicators, DO, pH, turbidity, TSS and nutrient concentrations. Both sites received a “B” overall water quality compliance score (refer Figure 9 and Appendix 1). E.Coli and TP levels were consistently poor at both sites with DO levels occasionally exceeding guidelines at CAT5. Temporal analysis over the year did not highlight any significant issues at either site. When ANOVA was applied, there were no significant differences found for any parameter between the sites indicating that neither Uki village, Rowlands Creek or Smiths Creek catchments were impacting on water quality in the Mid Tweed River in 2016.

Lower Oxley River sub-catchment sites CAT 23 and CAT 1

Site CAT23 is located on the Lower Oxley River upstream of Eungella (refer Appendix 1 for site locations). CAT1 is located approximately 7kms downstream of CAT23 on the Lower Oxley River immediately downstream of an area of sugarcane cropping land. There is also an area along this stretch (between the two sites) where bank erosion remediation works have been carried out in 2016. The key parameters of concern are DO, pH, turbidity, TSS and nutrient concentrations. CAT23 received an “A” overall water quality compliance score for 2016, while CAT1 received a “B” (refer Figure 9 and Appendix 1). E.Coli and TP levels were consistently poor at both sites with TN levels occasionally exceeding guidelines at CAT1. When ANOVA was applied, significant differences were found for TN ($p<0.05$); TP ($p<0.05$); Turbidity ($p<0.05$) and TSS ($p<0.01$) where values at CAT1 were significantly greater than at the upstream site CAT23 (Figure 27). pH ($p<0.05$) values were found to be markedly lower at CAT1 than

CAT23 and this was also a statistically significant result. From these results it is clear that water quality deteriorated between CAT23 and CAT1, although due to the multiple land use types between the two sites it is difficult to attribute degradation to any particular source. Further work could seek to investigate sources of water quality decline in this area with more spatially intense monitoring of the potential land uses impacts.

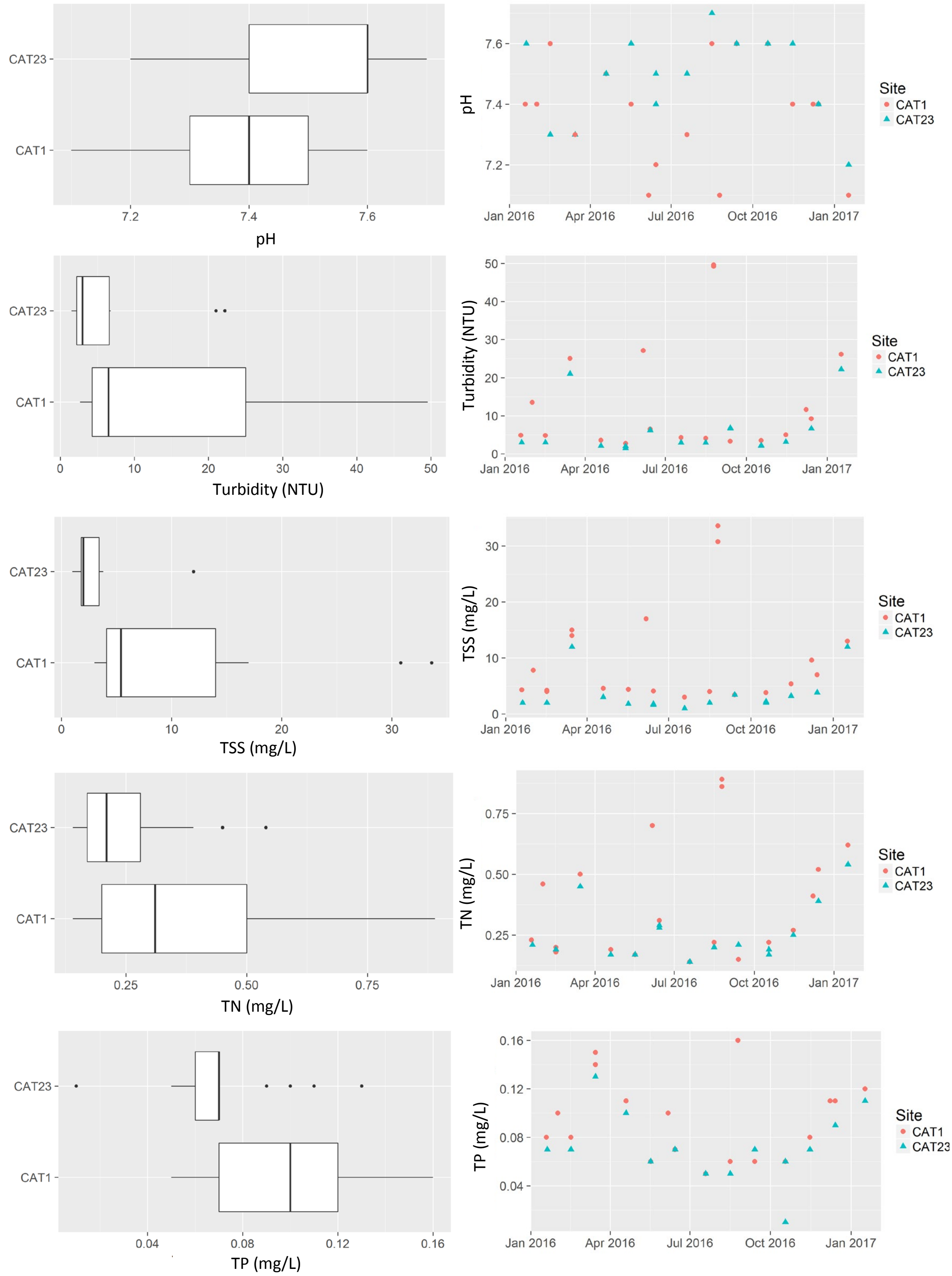

Figure 27: Statistically significant differences in water quality between CAT23 and CAT1.

Upper Rous River and Mid Rous River sub-catchment sites CAT17, CAT18 and CAT17a

Site CAT17 is located on the Upper Rous River upstream of Chillingham and the junction with Jackson Creek (refer Appendix 1 for site locations). CAT18 is located on Jackson Creek approximately 300m upstream of the junction with the Rous River above Chillingham. CAT17a is located on the Mid Rous River approximately 2kms downstream of Chillingham. During site visits in 2015, it was noted that water quality coming from Jackson Creek was noticeably (visually) more turbid that water in the Rous River and this prompted sampling of CAT18 in 2016. The key parameters of concern are faecal indicators, DO, pH, turbidity, TSS and nutrient concentrations. CAT17 received an “A” overall water quality compliance score for 2016, while CAT18 and CAT17a both received “B” scores (refer Figure 9 and Appendix 1). E.Coli and TP levels were consistently poor at all sites and DO levels occasionally exceeded guidelines at CAT18 and CAT17a. When ANOVA was applied to CAT 17 and CAT18, significant differences were found for TN ($p<0.01$) and TSS ($p<0.001$) where values at CAT18 were significantly greater than at the upstream site CAT17 (Figure 28). DO ($p<0.001$) and pH ($p<0.001$) values were found to be markedly lower at CAT18 than CAT17 and this was also a statistically significant result. Similarly, ANOVA detected statistically significant differences for TSS ($p<0.05$) and TN ($p<0.01$); where values at CAT18 were significantly greater than at the upstream site CAT17 on the Rous River and DO ($p<0.001$) and pH ($p<0.001$) were significantly lower. The results indicate that discharge from Jackson Creek is of a poorer quality than water in the Upper Rous River and is adversely impacting the overall water quality in the Upper Rous River.

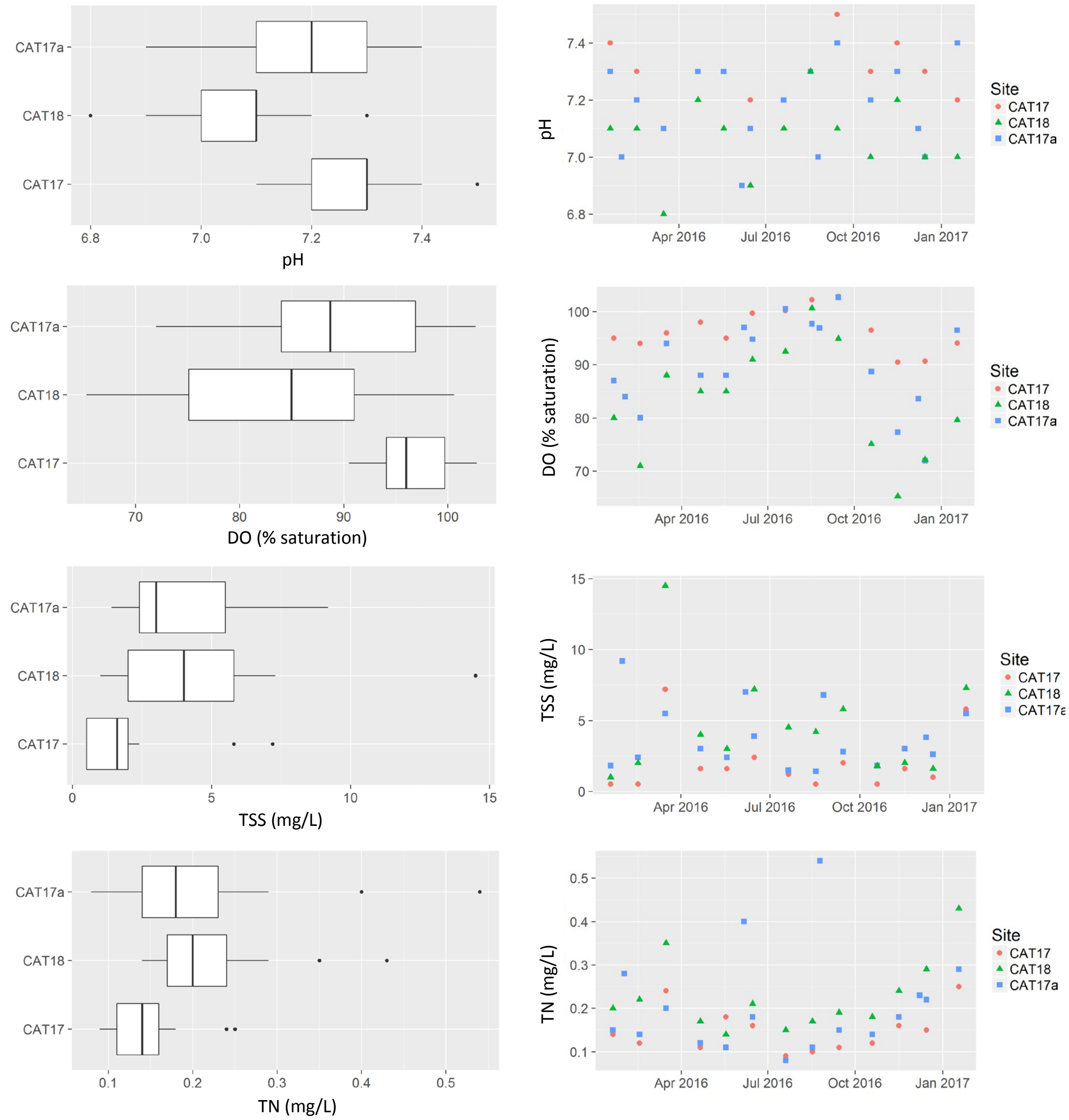

Figure 28: Statistically significant differences in water quality between CAT17a, CAT18 and CAT17. Note one exception: differences in TN between CAT17 and CAT17a were not statistically significant.

4. RECOMMENDATIONS FOR ONGOING SAMPLING

From this review of water quality data collected as part of the modified water quality sampling program 2016, recommendations for ongoing monitoring are discussed below.

4.1 Targeted event sampling

Targeted event sampling has been successful in capturing a number of high risk 'wet' events at key sites in the catchment, an issue identified as a significant gap in pre-2016 monitoring. Event sampling is considered a key component of effective ongoing sampling and it is recommended that this sampling continue.

4.2 Sample frequency

As discussed in Report 1, quarterly sampling frequency at catchment sites (pre-2016) was considered insufficient to assess water quality variability due to seasonal influences and rainfall and lack of replication of seasonal data. During 2016, routine monthly sampling was conducted at all catchment sites in addition to event sampling. Over time, such sampling will allow for accurate characterisation of seasonal trends and a clearer definition of underlying trends in water quality through time. It is recommended that routine monthly sampling continue as per the modified sampling program.

4.3 Parameters assessed

The modified sampling regime recommended changes to the parameters assessed to focus on:

- WTP intake sites for weekly sampling of water source specific parameters;
- Monthly sampling of aquatic ecosystem health parameters (to match catchment sites) and algae; and
- Monthly sampling of aquatic ecosystem health parameters at catchment sites (refer Section 2.1for details).

The changes have been effective in streamlining the modified sampling program to better assess parameters of concern without unnecessary analysis and it is recommended that monitoring is continued.

4.4 Assessment of additional sites created as part of the modified sampling program in 2016

New sampling sites were sampled in 2016 to gain better resolution throughout the Upper Tweed River Catchment. The aim was to better represent the catchment, including the Rous River, which was not previously sampled and to target potential sources of poor water quality. Table 9 provides a summary of what was achieved through monitoring of new water quality sampling sites in 2016 and provides recommendations for ongoing monitoring. Overall, the modified sampling regime achieved its aim of better characterising the Upper Tweed Catchment. Budget-permitting it would be desirable to continue all sampling at sub-catchment outlet sites (with the exception of CAT28) to characterise sub catchments through time, and to identify any emerging issues on a sub catchment basis. The modified program was also successful in confirming suspected sources of water quality degradation in the catchment in several locations, and recommendations have been made for further consideration of potential sources.

Table 9: Summary of new water quality sampling sites sampled in 2016

Site Code	Sub-catchment	Location Description	Rationale	Results from 2016 monitoring	Recommendations for ongoing monitoring
CAT15	Mid Rous River	Old road crossing upstream of Boatharbour Bridge, off Numinbah Rd	Outlet of Mid Rous River sub-catchment	Fair water quality. Key issues – nutrients, DO and bacteria.	Continue - for characterisation of Mid Rous River sub catchment.

Site Code	Sub-catchment	Location Description	Rationale	Results from 2016 monitoring	Recommendations for ongoing monitoring
CAT16	Crystal Creek	Upstream of Upper Crystal Ck bridge, swimming hole	Outlet of Crystal Creek sub-catchment	Excellent water quality. Key issues – TP and bacteria	Continue - for characterisation of Crystal Creek sub catchment
CAT17	Upper Rous River	Hopkins Creek Road	Takes in Upper Rous, Numinbah and Couchy Creek. Upstream of Jacksons Creek	Excellent water quality. Key issues - TP and bacteria Assisted in identification of Jackson Creek as source of poor water quality	Continue - for characterisation of Upper Rous River sub catchment and upstream of identified pollutant source (Jackson Creek)
CAT18	Upper Rous River	Zara Road	Takes in Jacksons Creek	Indication that Jacksons Creek is source of poor water quality and is impacting the Rous River (Section 3.4)	Continue – monitor impact of Jackson Creek Consider further investigation in Jacksons Creek to identify sources of pollution
CAT 17a	Upper Rous River	Chilcotts Road	Picks up village of Chillingham and Jackson creek infow	Fair water quality. Key issues – TP, DO and bacteria. Assisted in identification of Jackson Creek as source of poor water quality	Continue - monitor impact of Jackson Creek
CAT19	Hopping Dicks Creek	Boormans Rd crossing. Up-stream of crossing	Takes in Hopping Dicks sub catchment	Fair water quality. Key issues – TP and bacteria	Continue - for characterisation of Hopping Dicks Creek sub catchment
CAT20	Brays Creek	Larkins Road	Takes in Brays Creek sub catchment	Fair water quality. Key issues – Nutrients, DO and bacteria	Continue - for characterisation of Brays Creek sub catchment
CAT21a	Pumpenbil Creek	Kerrs Lane	Upstream of large dairy	Fair water quality. Key issues – TP and bacteria Assisted in confirmation of dairy as source of poor water quality	Continue - monitor impact of dairy
CAT21	Pumpenbil Creek	Larkins Road	Upstream from confluence with Brays Creek. Provides whole of Pumpenbil sub-catchment coverage	Fair water quality. Key issues – Nutrients, DO and bacteria Assisted in confirmation of dairy as source of poor water quality	Continue - monitor impact of dairy
CAT23	Lower Oxley River	Tyalgum Rd bridge	Upstream of planned erosion remediation works	Excellent water quality. Key issues - Nutrients and bacteria Water quality deteriorated between CAT23 and CAT1 although due to the multiple land use types between the two sites it is difficult to attribute degradation to any particular source	Continue. Further work could seek to investigate sources of water quality decline in this area with more spatially intense monitoring of the potential land use impacts between CAT23 and CAT1

Site Code	Sub-catchment	Location Description	Rationale	Results from 2016 monitoring	Recommendations for ongoing monitoring
CAT26	Tyalgum Creek	Buttlers Road	Immediately downstream of dairy	Fair water quality. Key issues – nutrients and bacteria Assisted in identification of dairy as source of TN to Tyalgum Creek and also impacting pH (Section 3.4)	Continue - monitor impact of dairy
CAT27	Tyalgum Creek	Stoddarts Road	Immediately upstream of dairy	Fair water quality. Key issues – nutrients and bacteria Assisted in identification of dairy as source of TN to Tyalgum Creek and also impacting pH (Section 3.4)	Continue - monitor impact of dairy
CAT24	Rowlands Creek	Rowlands Creek Road, opposite no. 21 Rolands Ck road	Takes in Rowland Creek sub catchment	Fair water quality. Key issues – Nutrients, DO, pH and bacteria	Continue - for characterisation of Rowlands Creek sub catchment
CAT28	Upper Tweed River	Bridge on Kyogle Road	Covers good size catchment of Perch and Midginbil Creeks	Fair water quality. Key issues – TP and bacteria	Discontinue – no specific issues detected at CAT28 and CAT7 can characterise the Upper Tweed sub catchment

5. REFERENCES

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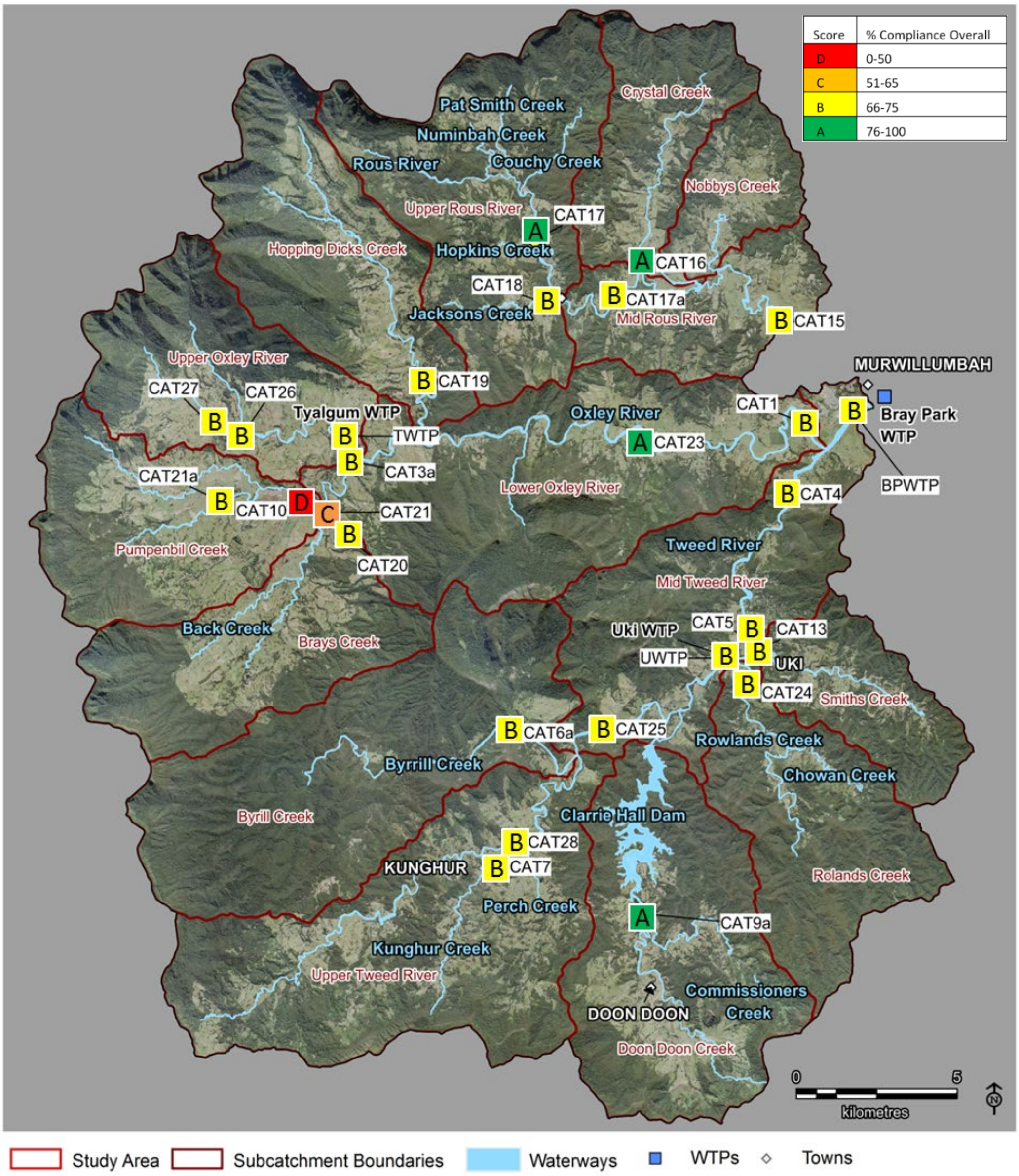
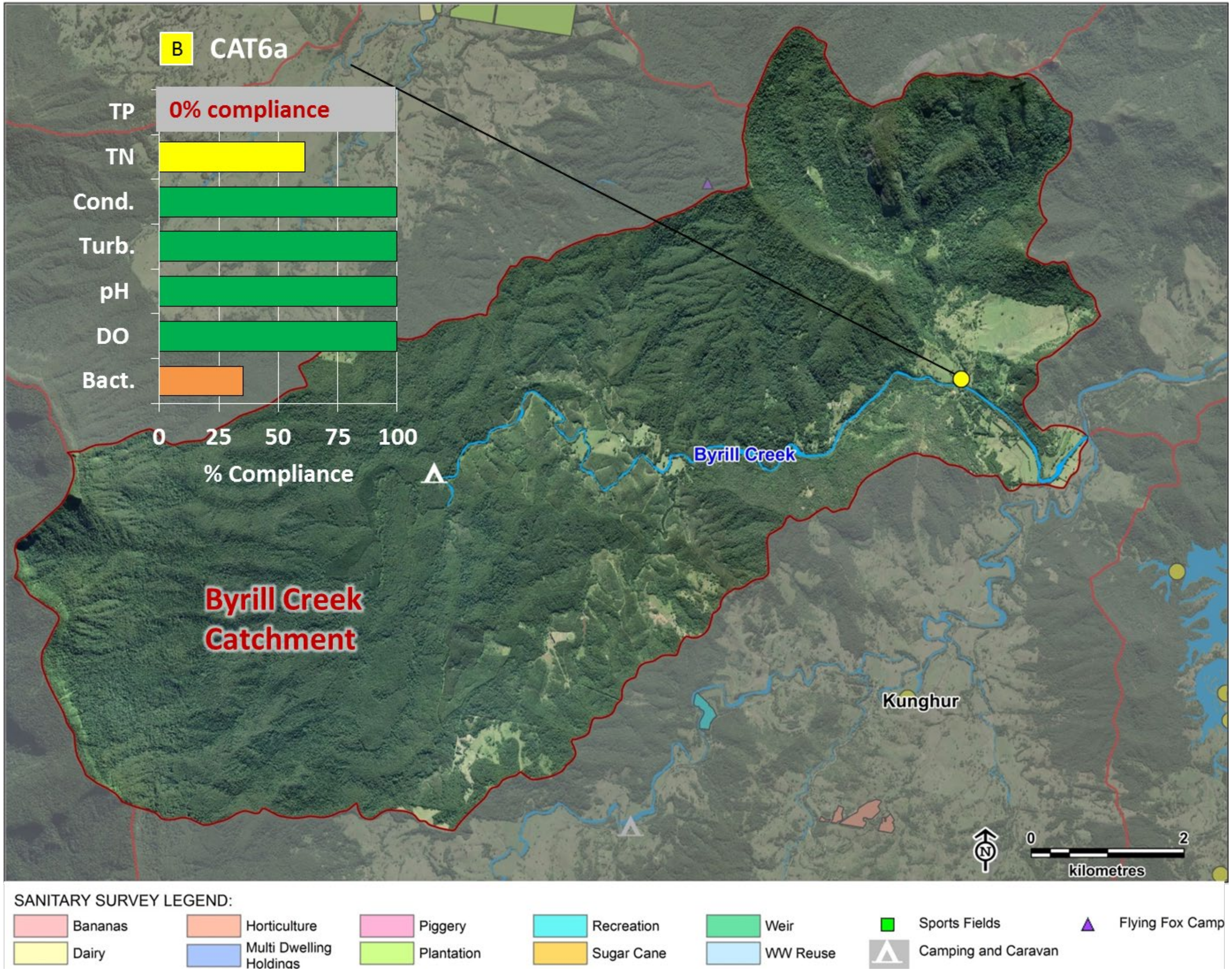
APPENDIX 1: SUB-CATCHMENT COMPLIANCE MAPPING



Sub-catchment	Site Code	DO	pH	Turb	Cond	TN	TP	Chl a	E.Coli	Overall % compliance	Overall Compliance Score
Byrill Creek	CAT6a	100	100	100	100	61	0	100	35	75	B
Doon Doon Creek	CAT9a	94	100	100	100	83	0	100	59	80	A
Smiths Creek	CAT13	61	100	100	100	72	6	100	12	69	B
Upper Tweed River	CAT7	85	100	100	100	69	0	100	8	70	B
	CAT28	92	100	100	100	77	0	85	17	71	B
Mid Tweed River	UWTP	no data	100	95	100	61	0	100	42	71	B
	CAT5	69	100	100	100	77	0	100	25	71	B
	CAT4	57	100	100	100	64	0	93	67	73	B
	BPWTP	no data	100	95	100	50	0	69	60	68	B
	CAT25	79	100	100	100	64	0	100	50	74	B
Pumpenbil Creek	CAT21a	100	100	100	100	100	0	100	0	75	B
	CAT10	8	100	100	100	0	0	54	0	45	D
	CAT21	72	100	100	100	39	0	100	11	65	C
Upper Oxley River	TWTP	no data	100	100	100	67	0	92	14	68	B
	CAT26	89	100	100	100	58	0	93	0	68	B
	CAT27	100	100	100	100	85	0	100	11	75	B
Lower Oxley River	CAT3a	77	100	100	100	85	0	100	15	72	B
	CAT1	95	100	100	100	52	0	87	33	71	B
	CAT23	100	100	100	100	82	6	100	50	80	A
Upper Rous River	CAT17	100	100	100	100	100	0	100	15	77	A
	CAT18	54	100	100	100	92	0	100	23	71	B
Mid Rous River	CAT17a	71	100	100	100	88	0	100	11	71	B
	CAT15	67	100	100	100	78	6	93	0	68	B
Crystal Creek	CAT16	88	100	100	100	100	53	100	0	80	A
Hopping Dicks Creek	CAT19	100	100	100	100	84	0	100	0	73	B
Brays Creek	CAT20	79	100	100	100	84	0	100	0	70	B
Rowlands Creek	CAT24	45	85	100	100	75	20	100	35	70	B



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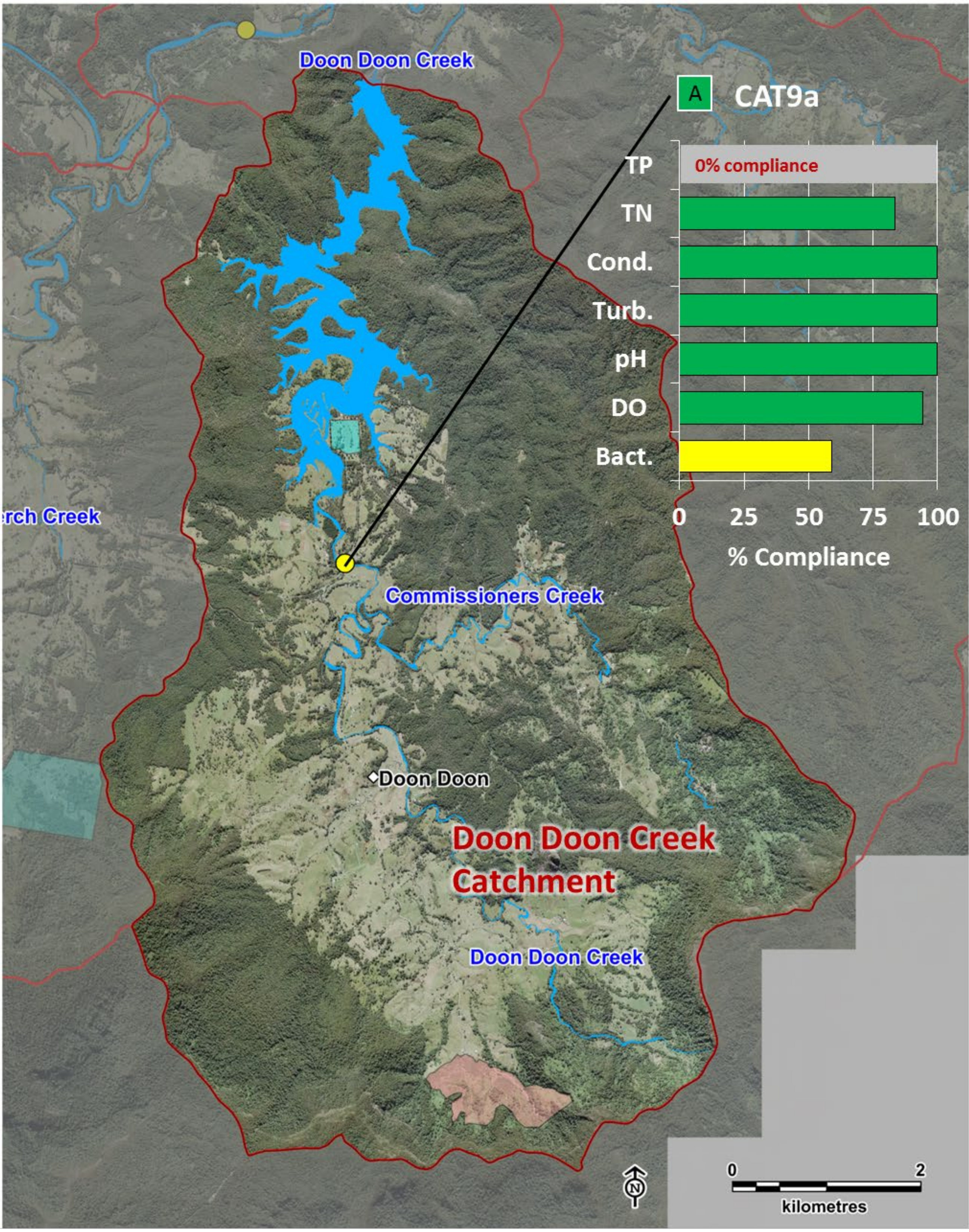
Sports Fields
Camping and Caravan
Flying Fox Camp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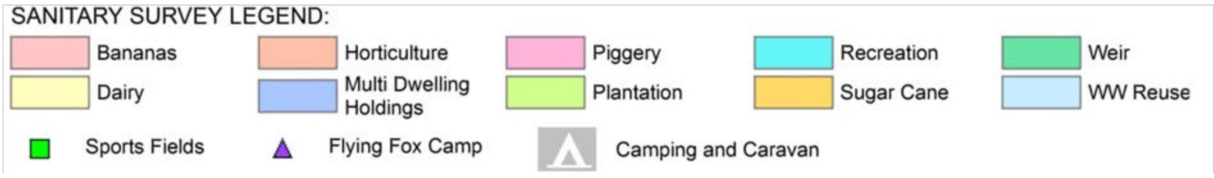
SANITARY SURVEY LEGEND:
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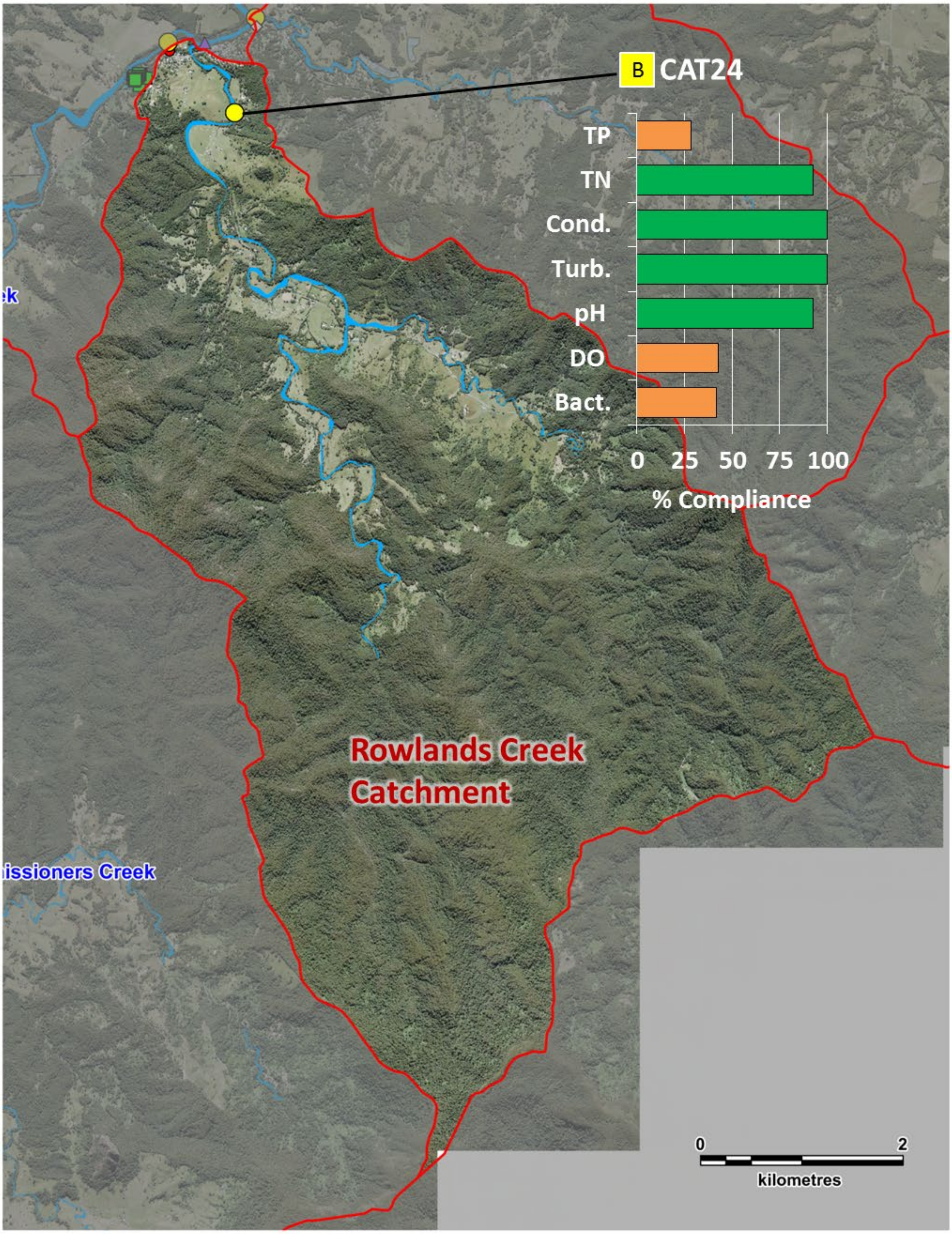

SANITARY SURVEY LEGEND:

Bananas
Horticulture
Piggery
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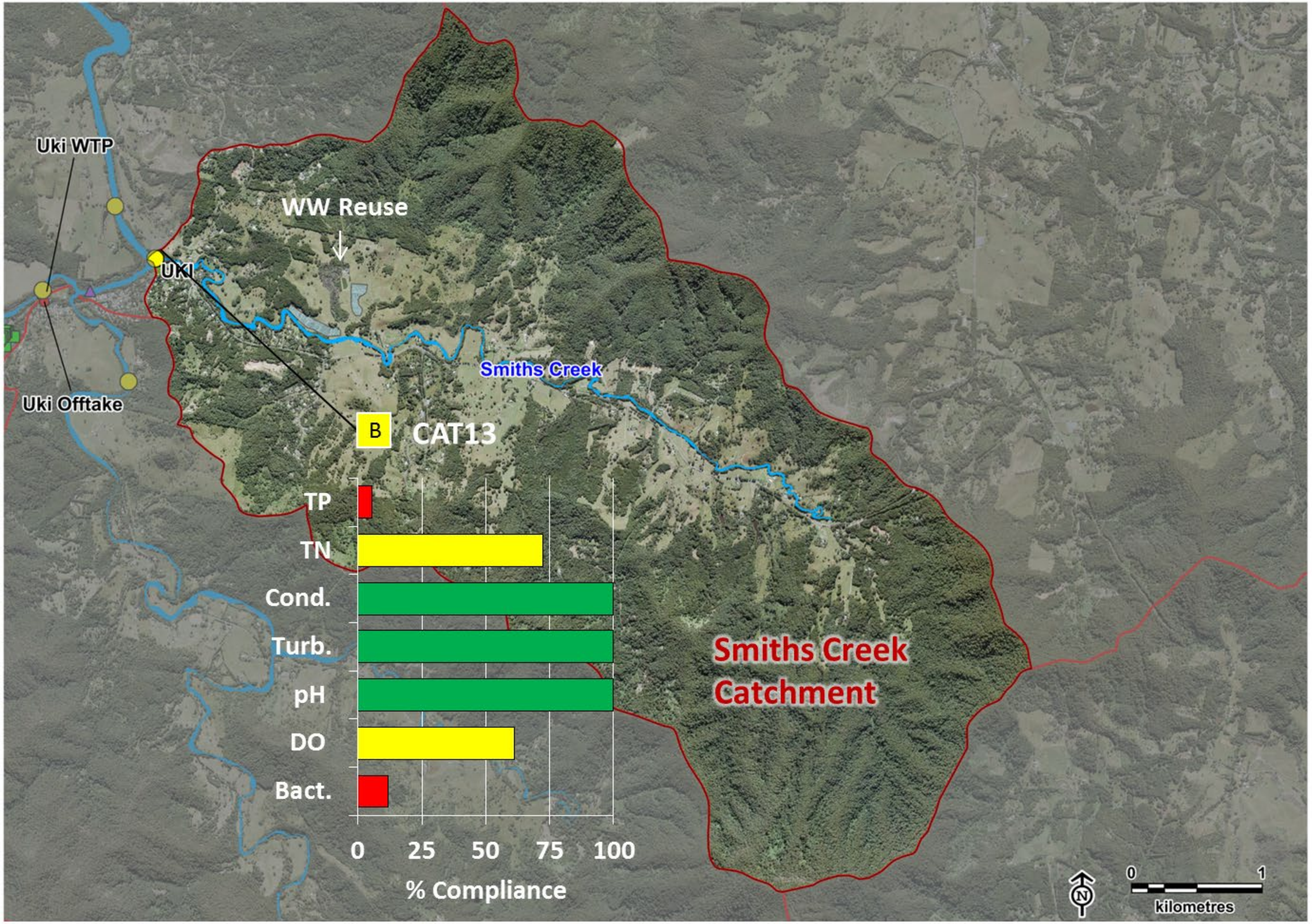
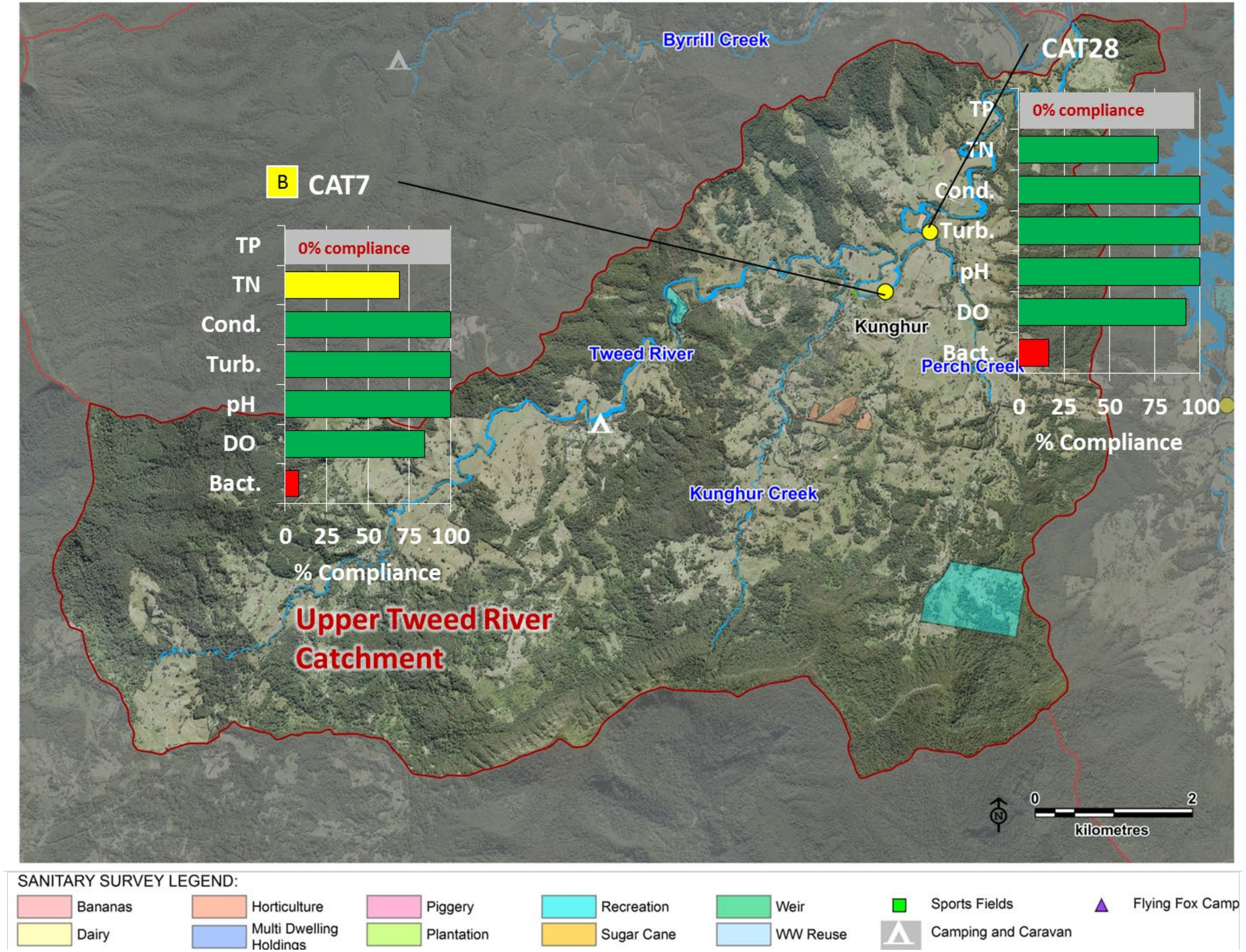
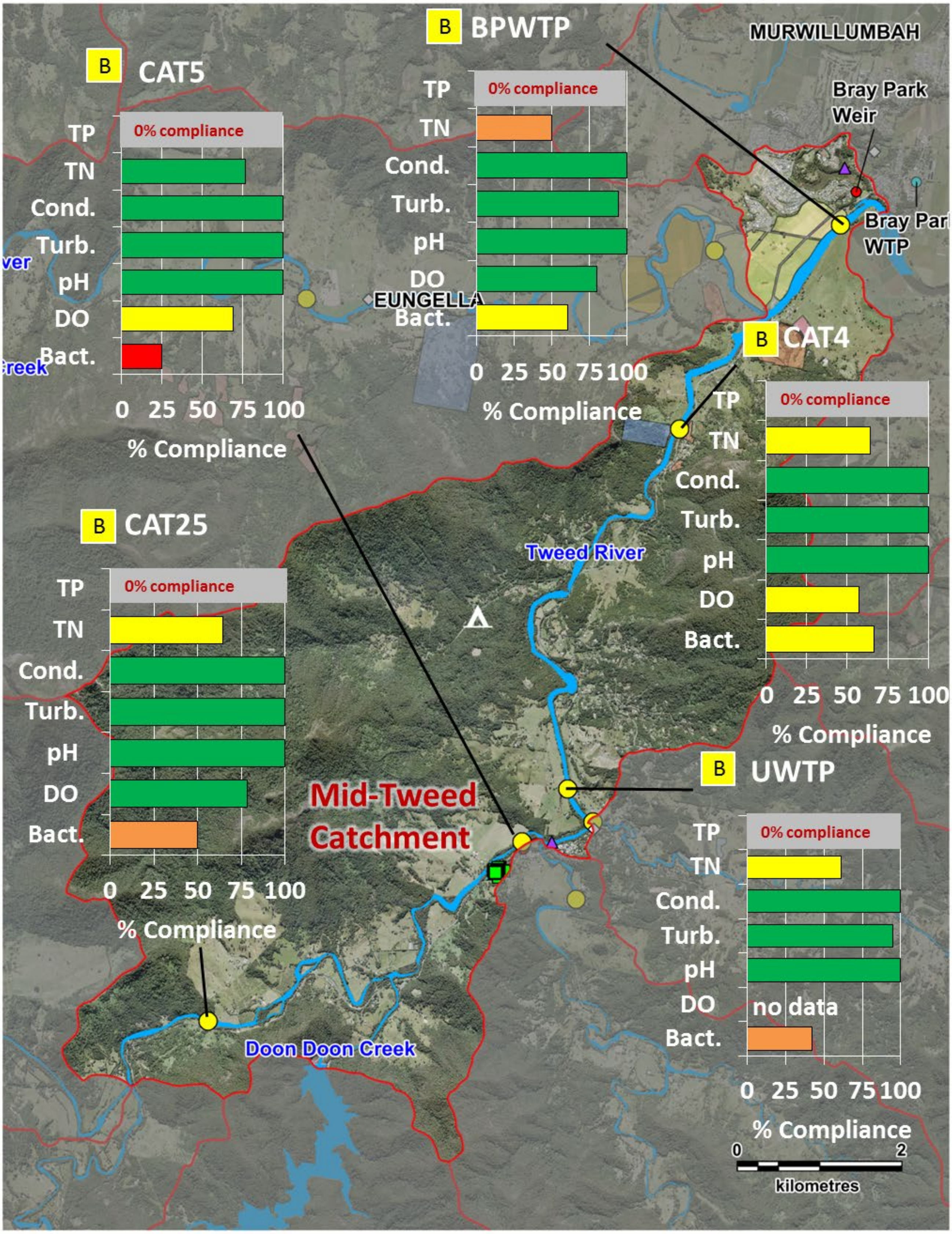
Weir
Dairy
Multi Dwelling Holdings
Plantation
Sugar Cane
WW Reuse
Sports Fields
Flying Fox Camp
Camping and Caravan



SANITARY SURVEY LEGEND:

Bananas	Horticulture	Piggery	Recreation	Weir	Sports Fields	Flying Fox Camp
Dairy	Multi Dwelling Holdings	Plantation	Sugar Cane	WW Reuse	Camping and Caravan	


Byrrill Creek
CAT28
TP
0% compliance
TN
Cond.
Turb.
pH
DO
Bact.
0 25 50 75 100
% Compliance
B
CAT7
TP
0% compliance
TN
Cond.
Turb.
pH
DO
Bact.
0 25 50 75 100
% Compliance
Kunghur
Tweed River
Perch Creek
Kunghur Creek
Upper Tweed River Catchment
0
2
kilometres
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp

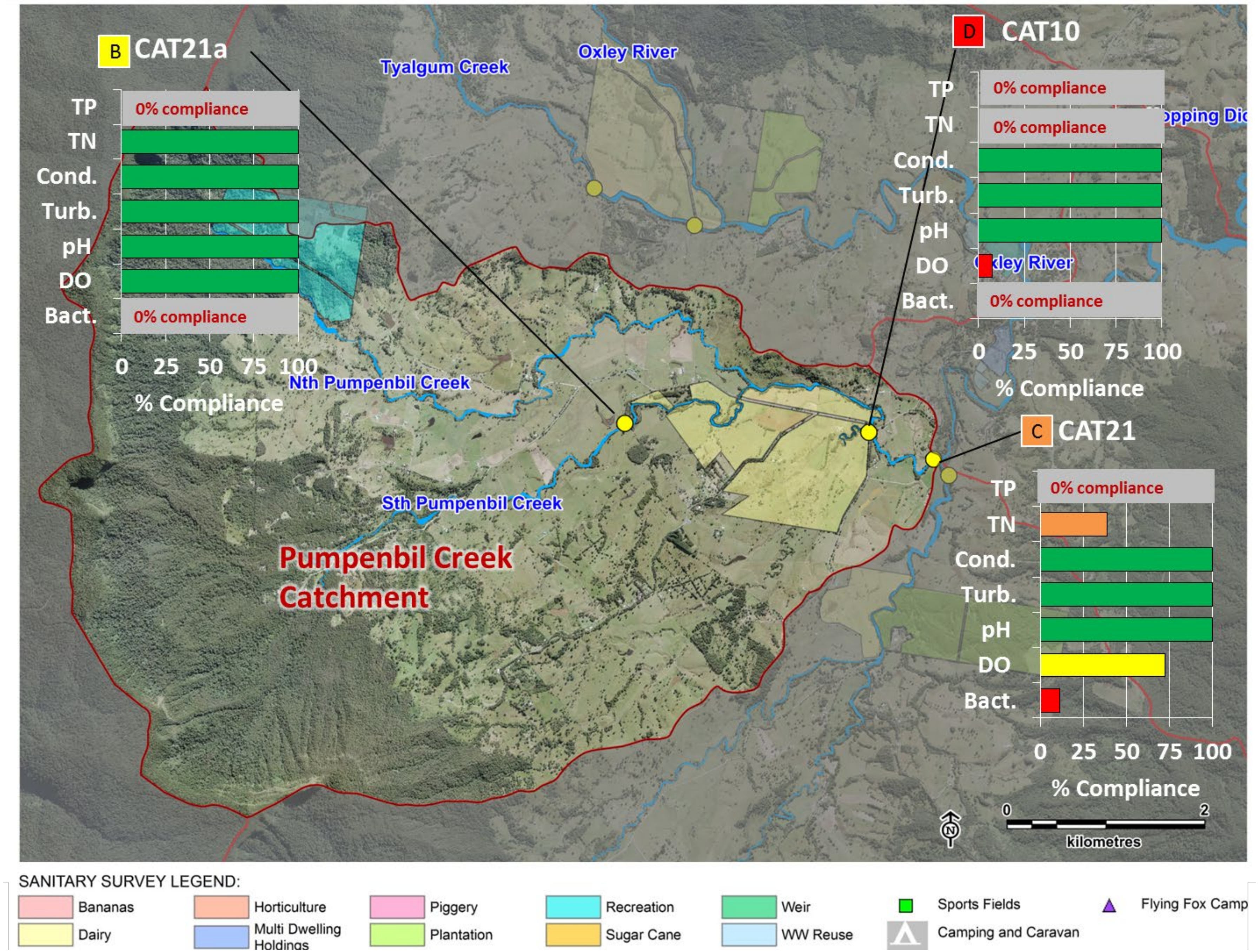


SANITARY SURVEY LEGEND:

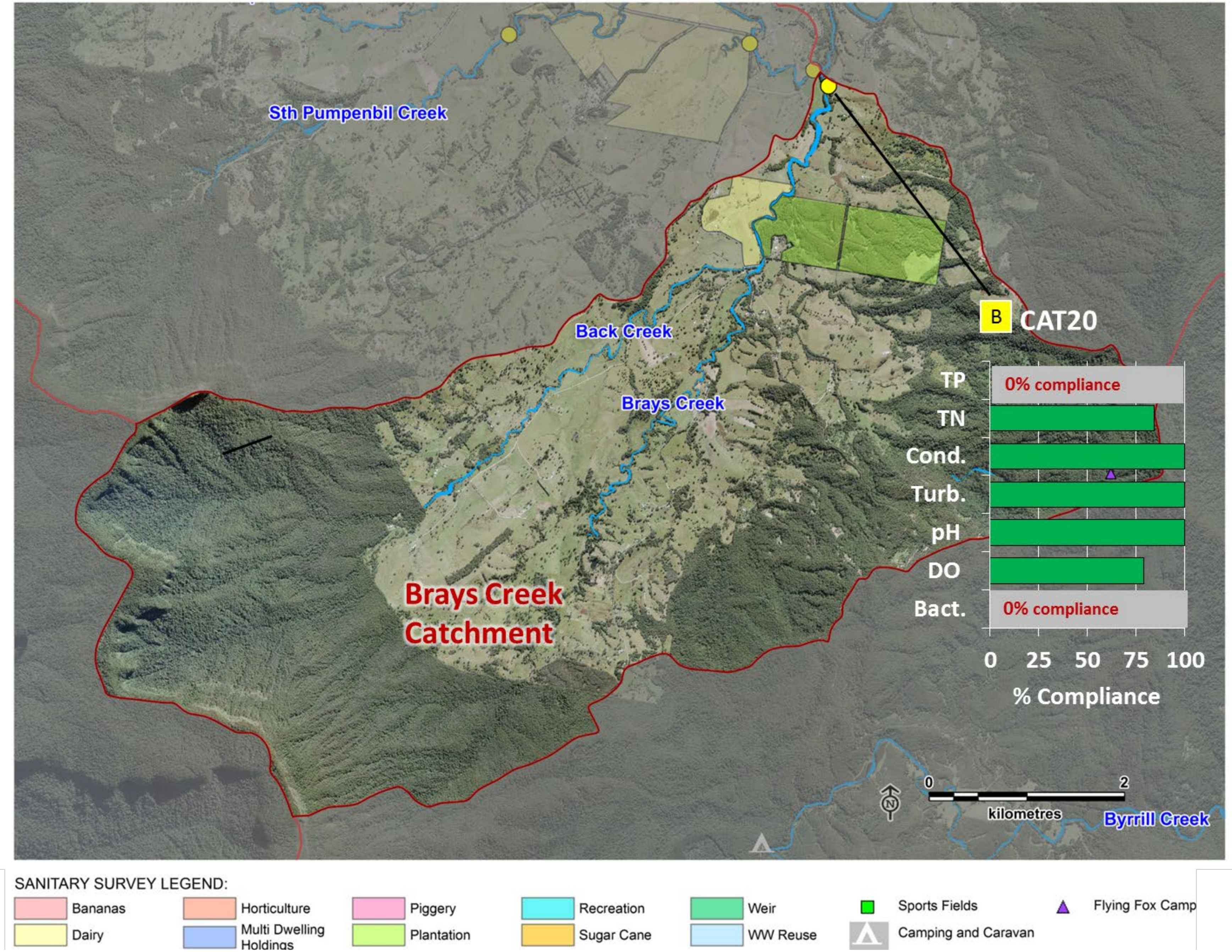
Bananas, Horticulture, Piggery, Recreation, Weir

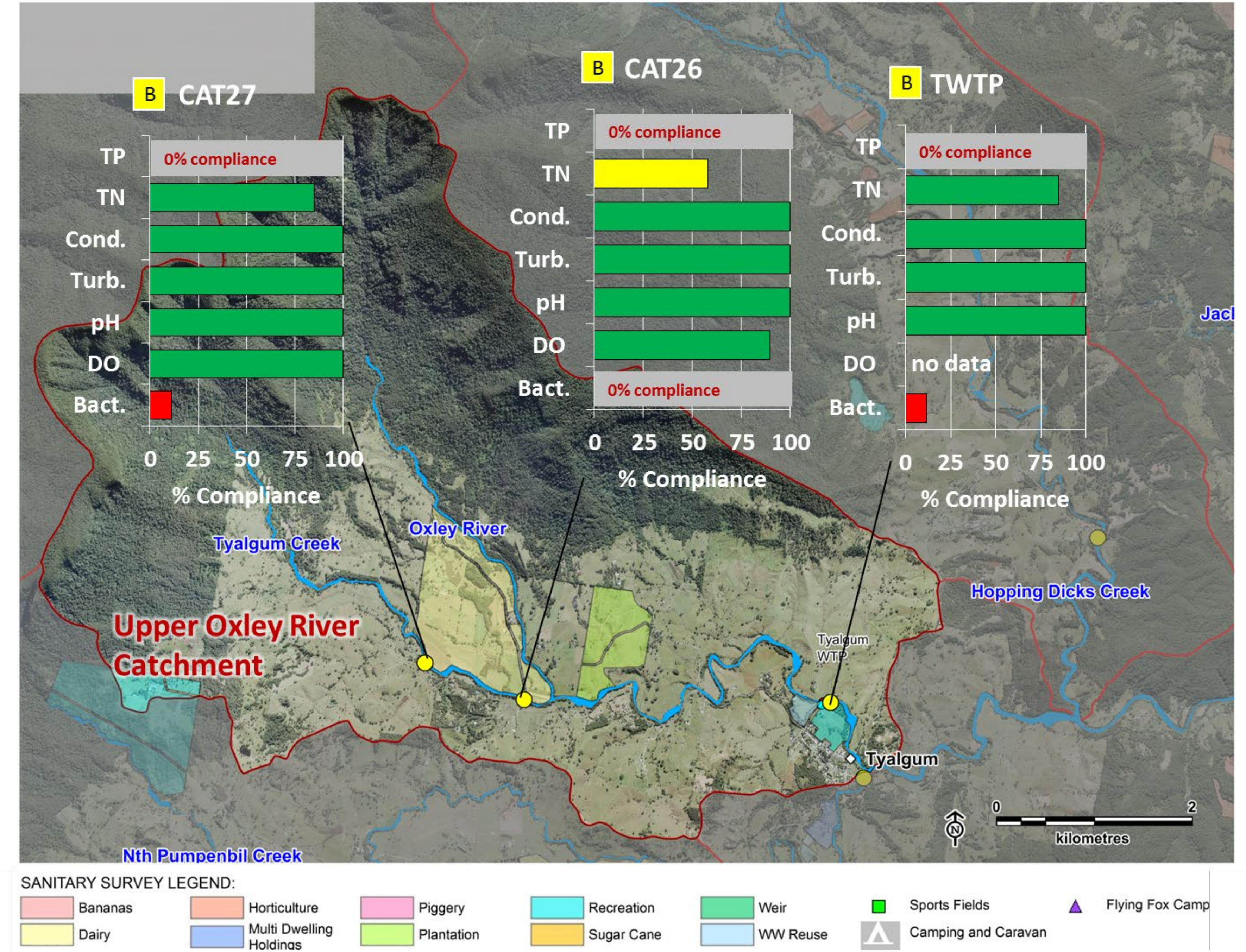
Dairy, Multi Dwelling Holdings, Plantation, Sugar Cane, WW Reuse

Sports Fields, Flying Fox Camp, Camping and Caravan

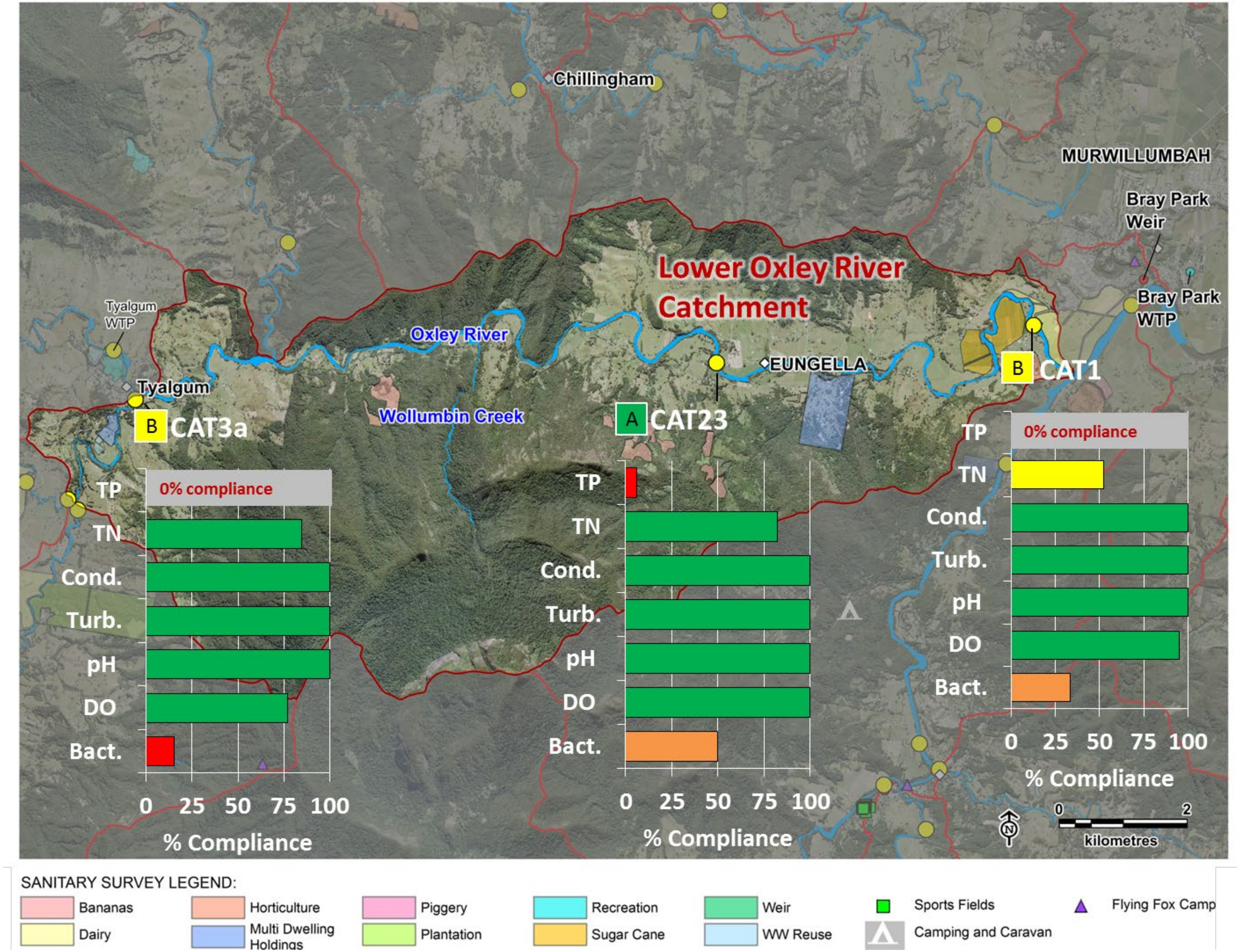


B CAT21a
TP 0% compliance
TN
Cond.
Turb.
pH
DO
Bact. 0% compliance
0 25 50 75 100
% Compliance
D CAT10
TP 0% compliance
TN 0% compliance
Cond.
Turb.
pH
DO
Bact. 0% compliance
0 25 50 75 100
% Compliance
C CAT21
TP 0% compliance
TN
Cond.
Turb.
pH
DO
Bact.
0 25 50 75 100
% Compliance
Tyalgum Creek
Oxley River
Nth Pumpenbil Creek
Sth Pumpenbil Creek
Pumpenbil Creek Catchment
0 2
kilometres
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp

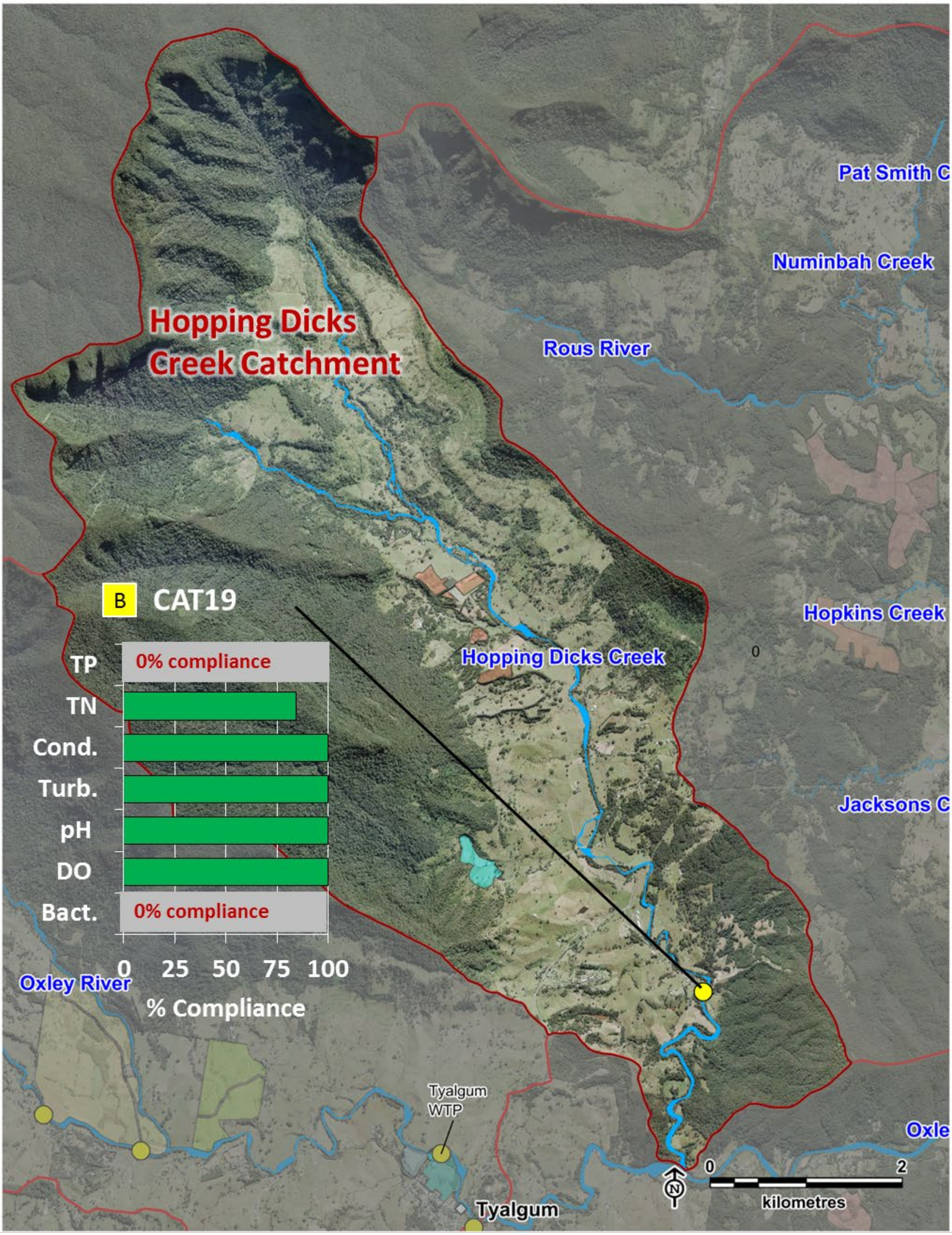

Sth Pumpenbil Creek
Back Creek
Brays Creek
Brays Creek
Catchment
B
CAT20
TP
TN
Cond.
Turb.
pH
DO
Bact.
0% compliance
0% compliance
0
25
50
75
100
% Compliance
0
2
kilometres
Byrrill Creek
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp



B CAT27
TP
TN
Cond.
Turb.
pH
DO
Bact.
0% compliance
0 25 50 75 100
% Compliance
B CAT26
TP
TN
Cond.
Turb.
pH
DO
Bact.
0% compliance
0% compliance
0 25 50 75 100
% Compliance
B TWTP
TP
TN
Cond.
Turb.
pH
DO
Bact.
0% compliance
no data
0 25 50 75 100
% Compliance
Jacl
Oxley River
Tyalgum Creek
Hopping Dicks Creek
Upper Oxley River Catchment
Tyalgum WTP
Tyalgum
Nth Pumpenbil Creek
0
2
kilometres
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp

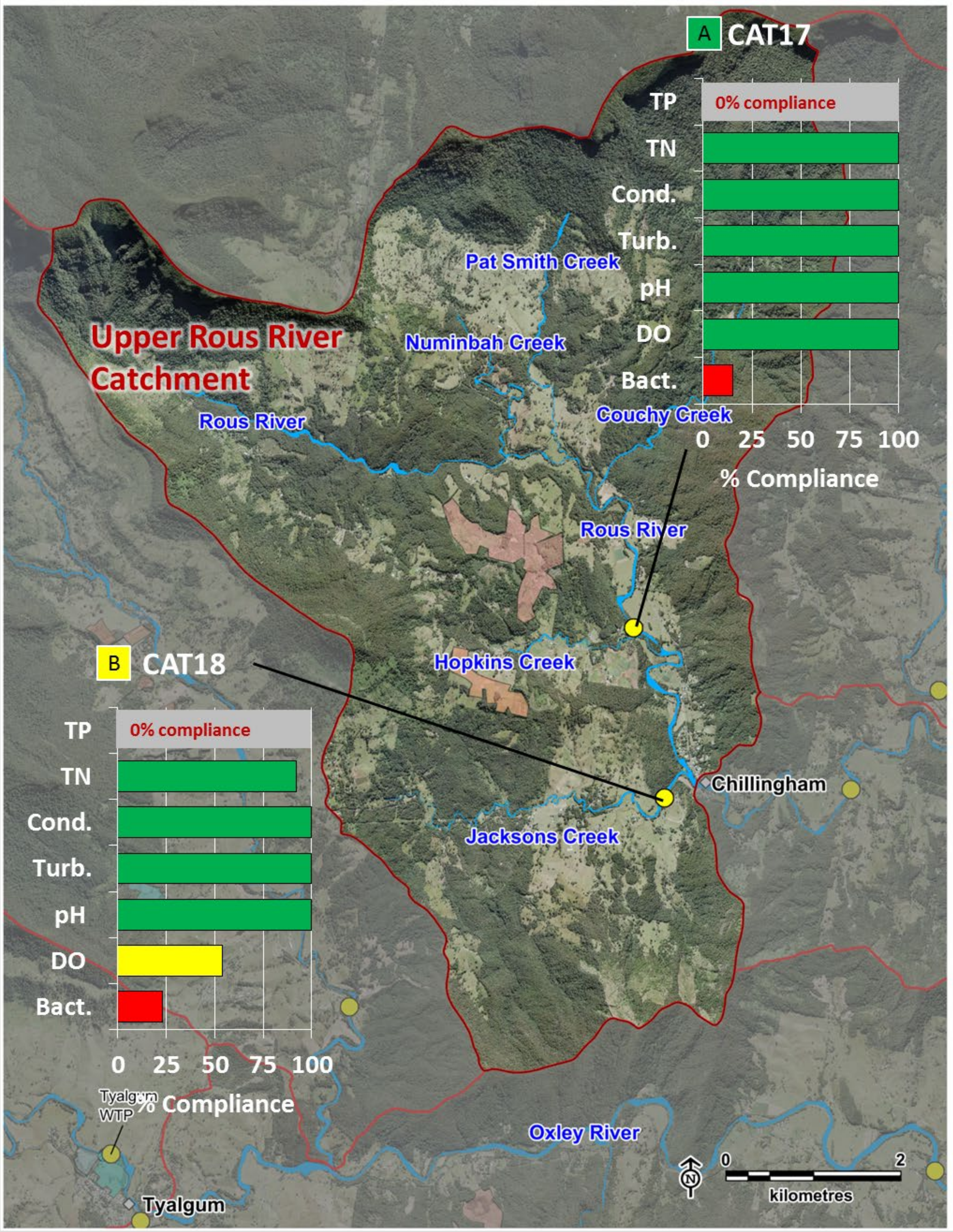


Chillingham
MURWILLUMBAH
Bray Park Weir
Bray Park WTP
Lower Oxley River Catchment
Tyalgum WTP
Tyalgum
Oxley River
EUNGELLA
Wollumbin Creek
B CAT3a
A CAT23
B CAT1
0% compliance
TP
TN
Cond.
Turb.
pH
DO
Bact.
0 25 50 75 100
% Compliance
0 2
kilometres
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp



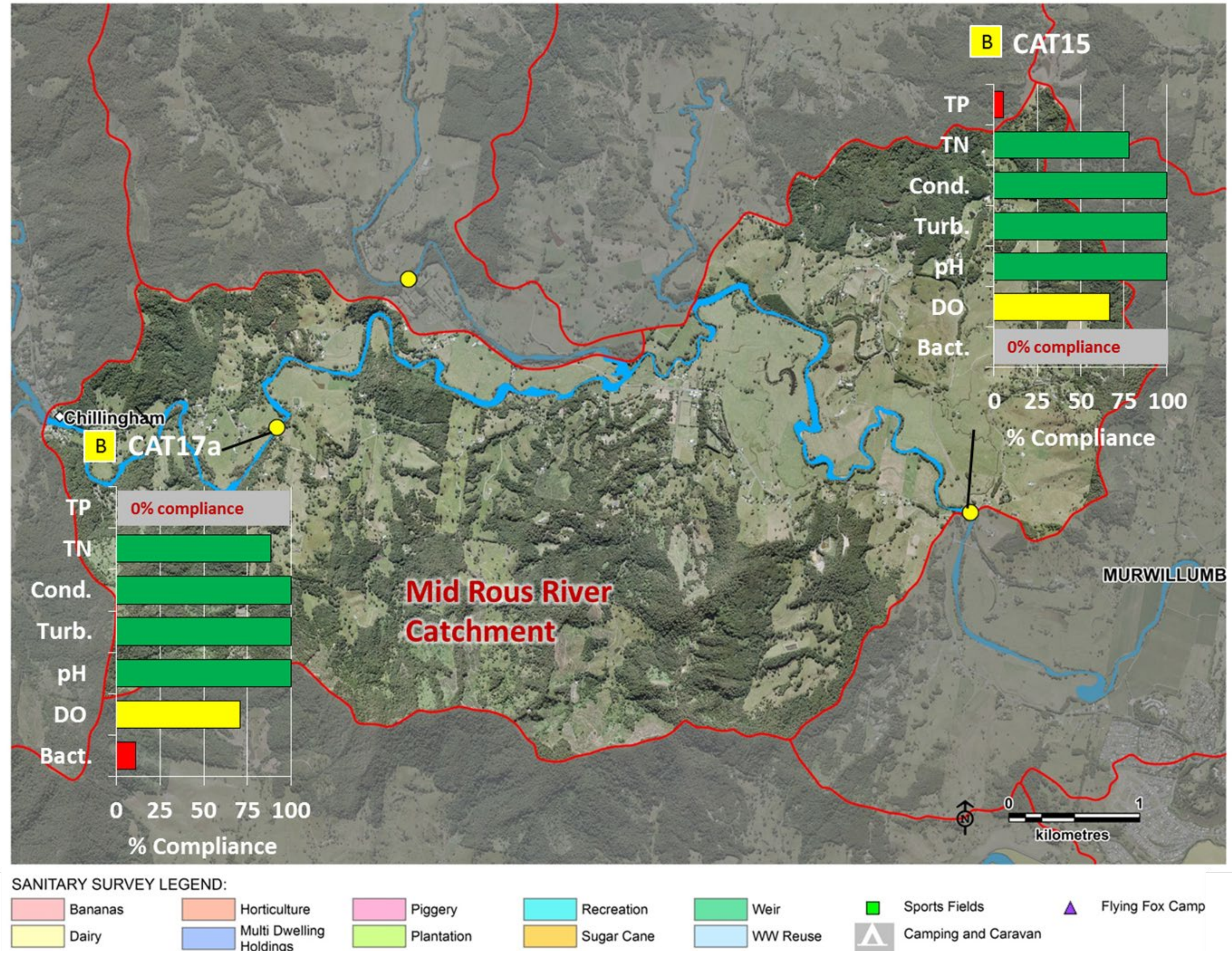
SANITARY SURVEY LEGEND:

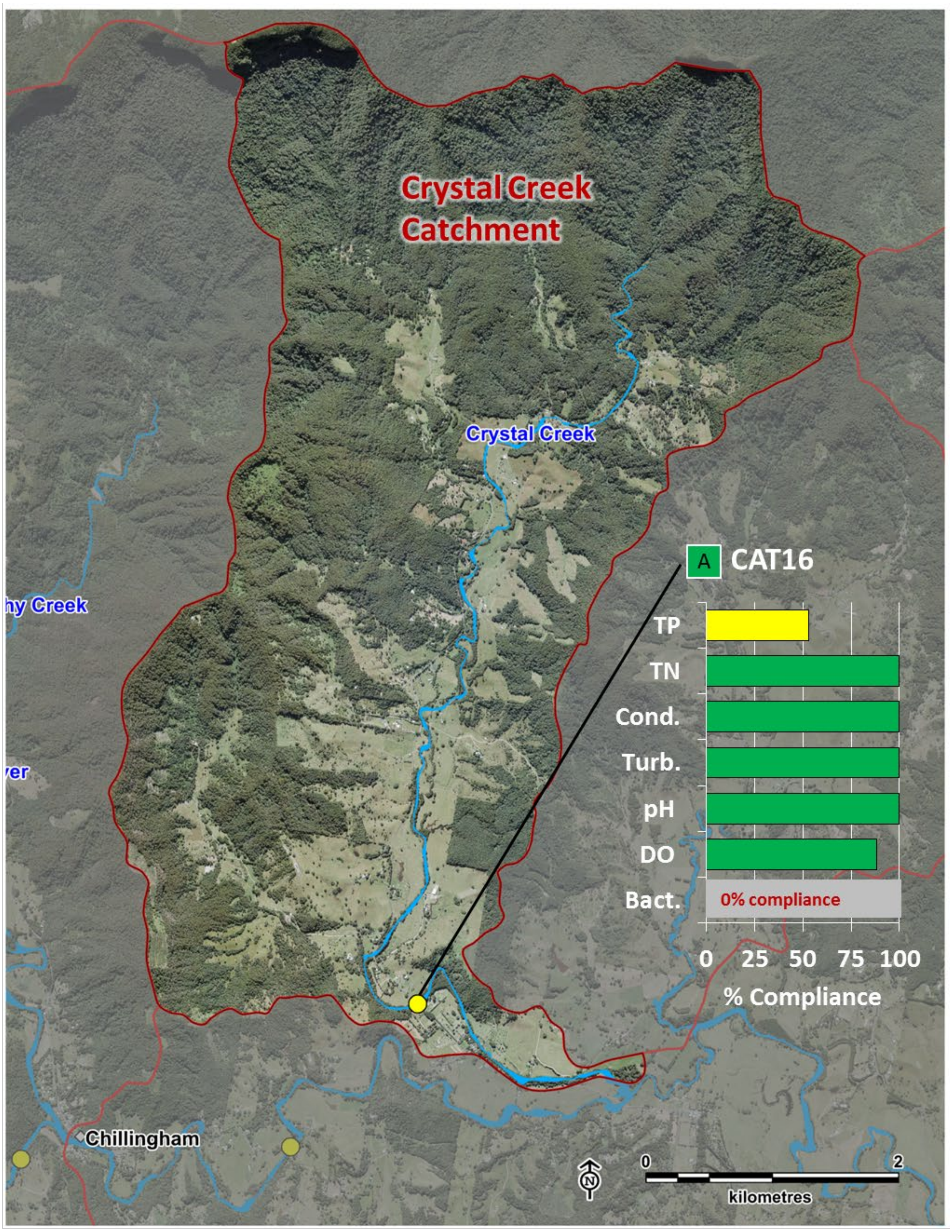
Bananas	Horticulture	Piggery	Recreation	Weir
Dairy	Multi Dwelling Holdings	Plantation	Sugar Cane	WW Reuse
Sports Fields	Flying Fox Camp	Camping and Caravan		



SANITARY SURVEY LEGEND:

Bananas	Horticulture	Piggery	Recreation	Weir
Dairy	Multi Dwelling Holdings	Plantation	Sugar Cane	WW Reuse
Sports Fields	Flying Fox Camp	Camping and Caravan		


B CAT15
TP
TN
Cond.
Turb.
pH
DO
Bact.
0% compliance
0 25 50 75 100
% Compliance
Chillingham
B CAT17a
TP
0% compliance
TN
Cond.
Turb.
pH
DO
Bact.
0 25 50 75 100
% Compliance
Mid Rous River
Catchment
MURWILLUMB
0 1
kilometres
SANITARY SURVEY LEGEND:
Bananas
Dairy
Horticulture
Multi Dwelling Holdings
Piggery
Plantation
Recreation
Sugar Cane
Weir
WW Reuse
Sports Fields
Camping and Caravan
Flying Fox Camp



SANITARY SURVEY LEGEND:

Bananas	Horticulture	Piggery	Recreation	Weir
Dairy	Multi Dwelling Holdings	Plantation	Sugar Cane	WW Reuse
Sports Fields	Flying Fox Camp	Camping and Caravan		

APPENDIX 2: STATISTICAL RESULTS OF PAIRED SITE ANALYSIS

P-value

Site	Turbidity	DO	TN	TP	E.Coli	pH	TSS
CAT21a & CAT10	0.000	0.000	0.000	0.001	0.375	0.000	0.000
CAT21a & CAT21	0.001	0.003	0.000	0.002	0.806	0.006	0.000
CAT26 &27	0.378	0.838	0.000	0.352	0.099	0.000	0.242
CAT25 & 5	0.567	0.075	0.853	0.145	0.776	0.106	0.205
CAT23 & 1	0.026	0.137	0.025	0.011	0.252	0.012	0.007
CAT 17 & 17a	0.091	0.016	0.104	0.783	0.957	0.033	0.038
CAT 17&18	0.077	0.000	0.009	0.678	0.943	0.000	0.043