Detecting stream health impacts of horse riding and 4WD vehicle water crossings in South East Queensland: an event based assessment

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Introduction

Horse riding in natural areas is an activity that has received significant attention in the scientific community and has spurred several recent reviews (Beavis 2000; Landsberg *et al.* 2001; Newsome *et al.* 2004, 2008; Pickering 2008; Abbott *et al.* 2010). These have been of particular interest in South East Queensland (SEQ), with the recent formation of the Horse Riding Trail Network (HRT Network) that was developed to facilitate the continuation of horse riding access to a number of former State forests that have been transferred to National Parks under the South East Queensland Forests Agreement (SEQFA). A literary review, conducted by Associate Professor Catherine Pickering, was undertaken to determine the direction and priorities for monitoring the impacts of horse riding on these trails (Pickering 2008) and highlighted the need for both social and biophysical monitoring programs.

Horse riding is considered a 'high impact' recreation activity (Beavis 2005; Carter *et al.* 2008), and has been identified as having a higher impact on most terrains compared to other activities that occur on trails, such as hiking and mountain biking (Torn *et al*. 2009; Pickering *et al*. 2010). This is primarily due to the large body mass of horses, specifically the body-bass to hoof-size ratio. The impact of horse riding appears to be more considerable on Australian terrain, which is adapted to non-hoofed animals (Beavis 2005). It must be noted however that this is not always the case, and is dependent on the substrate and vegetation types on which such activities occur (Whinam and Comfort 1996; Torn *et al.* 2009; Pickering *et al.* 2010).

The Horse Trails (HT) Scientific Monitoring Program (DERM 2010a) has been set up to study the direct social and biophysical impacts of horse riding on trails within SEQ. While several studies have investigated the potential impacts of horse riding in conservation areas, there is as yet no substantial research undertaken that is specific to the environs of SEQ. There is also a significant lack of research directly targeting the impact of horse riding on aquatic ecosystems. In her review of HRT Network monitoring needs, Pickering (2008) highlighted that "indicators on the impact of horse riding on aquatic ecosystems are required".

Horse riding can be considered a 'disturbance' activity, and any monitoring program needs to consider the potential impacts that might occur in such terms. Lake (2000) has categorised potential disturbance events into three types: pulse (short-termed and sharply delineated); press (may arise sharply, like a pulse, but then reaches a maintained, constant level); or ramp (when the strength of a disturbance increases over time). In the case of this project, it was theorised that horse riders crossing a stream would create a pulse event, with a potentially large impact that lasts a short amount of time. Highlighted in the literature, trampling by horses is known to cause soil erosion, and therefore it is likely that a high level of sediment will be deposited into aquatic systems during these pulse events (horse crossings). This deposition can be via dirt, seeds or weeds from their hooves, or directly from defecation (Pickering 2008). Mechanisms that increase sediment runoff can be considered a threat in the aquatic environment as it has been shown that increased sedimentation can lead to large changes and in the faunal composition of streams (Wood and Armitage 1997).

It is known that HRT horse trails are routinely used by both private individuals and larger groups (including tourism operators), and these regular trips could be considered small, individual pulse events. As with most natural areas, with the increase and spread of urban populations, there has been increased use of these trails, and such a trend is likely to continue. There are also several large events run by horse organisations within SEQ, in which a large number of horses use a trail over a short period of time. One such event is the Murrumba Endurance Ride, where over a hundred horse riders traverse a trail to participate in the equestrian event in the Moreton Bay region. Events such as the Murrumba Endurance Ride represent a larger pulse event corresponding to a larger environmental impact than smaller pulse events caused by individuals trail riders. Any impacts of horse riding on the aquatic environment are expected to be greatly exaggerated during a larger pulse event, and therefore easier to detect (see Figure 1 below).

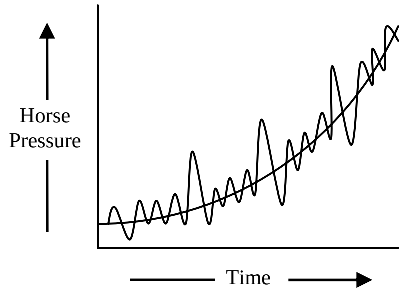

Figure 1 Conceptual diagram of horse pressure on stream crossings in natural areas. The wavy line represents pulses in horse pressure, whereas the trend line represents growing pressure over many years. The larger pulses represent the potentially increased pressure during horse 'events'.

Depending on the frequency of horses travelling on trails, a number of pulse events could become a press event if sediment was regularly being deposited and could even become a ramp disturbance if traffic on the trails increased over time with increasing levels of sediment continuously being deposited. Change from a pulse to a press or ramp disturbance would be something to consider in a larger, long term monitoring program. As the Horse Trails Scientific Monitoring Program is set up to run over 20 years, there is potential for future projects to address such issues.

This report forms part of the biophysical section of the HT Scientific Monitoring Program. Its primary focus is to observe and record the impacts of horse trail crossings on aquatic ecosystems and to ascertain if any of these impacts are of high concern. As was emphasised by Pickering *et al.* (2010) there have been no studies of the impacts of horse riding on streams within natural areas to date. This project will therefore add important knowledge to this understudied area of scientific research, and its findings will inform the direction of future monitoring.

Sampling Design

This project was undertaken by the Water Planning Ecology (WPE) group for the Department of Environment and Resource Management (DERM), in conjunction with Griffith University. It was designed as an event based assessment to determine the impacts of large horse event stream crossings such as the Murrumba Endurance Ride on aquatic ecosystem health, and for these sites to be relevant to the HRT Network. This represents a typical 'pulse' disturbance, albeit exaggerated compared to smaller more common pulse events, occurring on stream crossings throughout the HRT Network. This 'exaggeration' will increase the likelihood of detecting any impacts. As most of the horse trails in SEQ now exist as Forest Reserves within National Parks, they tend to fall along fire breaks, and are accessed by 4-wheel drive vehicles (4WDs) by Park Rangers for management use. Horse riding is therefore not the only high impact activity occurring along these trails, and it was determined that within this study the impact of horse riding should be compared to that of 4WDs crossing the same streams. This allowed a direct comparison of activities and the potential size of any impacts occurring. Sampling was designed to measure two events, one to measure the impacts of one 4WD, and a separate one for horse riding.

Pressure/Stressor/Response

The underlying study design was based on the Pressure-Stressor-Response (PSR) framework (Marshall *et al.* 2006) utilized by the WPE group on several of their long term monitoring programs (Negus 2009), such as their ongoing project the Stream and Estuary Assessment Program (SEAP). The PSR framework labels human activities that affect ecosystems as *pressures* (natural landscape elements, such as floods and droughts etc., are termed *natural drivers*). These pressures have the ability to modify the biophysical conditions experienced by ecosystems. The biophysical conditions that have been modified by pressures are termed vectors or *stressors* because they, in turn, elicit ecosystem *responses* (Marshall *et al.* 2006). It was determined that the pressures present in this project are both horse riders and 4WDs crossing streams, as these anthropogenic activities are likely to create a disturbance within the affected aquatic ecosystem.

Potential stressors of horse impact were assessed for their viability at an expert qualitative risk assessment workshop (DERM 2010b), which ranked stream health stressors with their relative risk (see table 1). Indicators of these stressors were then assessed for their applicability to the study (see table 2).

Table 1 Workshop qualitative risk assessment for horse impact stressors on stream health (DERM 2010b). Consequence given is the worst case scenario (e.g. not flowing water). Scales are local and short-term. Stressors highlighted in green were considered of greatest importance and were therefore considered as potential indicators in this project.

Stressor	Likelihood	Likelihood confidence	Consequence	Consequence confidence	Risk	Risk confidence	Worst case circumstance
Nutrients direct	5	2	4	3	20	6	non-flowing
Deposited sediment	5	3	4	2	20	6	non-flowing
Physical disturbance to riparian vegetation/banks	5	3	4	2	20	6	wet ground
Physical disturbance to bed	5	3	4	2	20	6	none
Changed light regime	5	2	3	2	15	4	non-flowing
Bacteria	5	3	3	1	15	3	non-flowing
Nutrients - resuspension	5	3	2	2	10	6	non-flowing
Nutrients - via transferred sediments	4	3	2	3	8	9	non-flowing
Weeds aquatic	2	2	4	3	8	6	
Physical disturbance waves	4	2	2	2	8	4	
Weeds riparian	3	1	2	2	6	2	
Horse drugs	3	1	2	1	6	1	
Litter	2	3	1	2	2	6	

Table 2 Potential Indicators as determined at an expert qualitative risk assessment **workshop (DERM 2010b).** Where Y = yes, N = No, H = High, M = Medium, and L = Low

Indicator	**Sensitivity**	**Specificity**	**Practicality**	**$**	**Relevance**	**Collection**
Scats counting (in or near stream, solid or not)	Y	Y	H	L	H	Field
Littoral vegetation (ref Erosion study): cover, change	Y	Y	H	L	H	Field
Pugging	Y	Y	H	L	H	Field
Light penetration	Y	Y	L	L	H	Field
Turbidity	Y	Y	H	L	H	Field
Algal biomass, Chl-a: substrate &/or water column	Y	Y	H	M	H	Lab
Sediment traps	Y	Y	M	M (2 visits)	H	Lab
Ash-free dry weight of biofilms (dirt)	Y	Y	M	M-	H	Lab
Ratio of carbon to ash-free dry weight of biofilms (C/dirt)	Y	Y	M	M-	H	Lab
Algal biomass on cobbles/other substrate	Y	Y	H	M	H	Lab
Pootering (suck up insects): coarse taxonomy, abundance/biomass	Y	Y	H	M	H	Lab
Macroinvertebrates - sensitive species loss	Y	Y	M (destructive?)	M	H	Lab
Macroinvertebrate composition	Y	Y	M (destructive?)	M	H	Lab
Macroinvertebrate functional groups / composition	Y	Y	M (destructive?)	M	H	Lab
Fcol/sterols (QHealth).	Y	Y	H	M	H	QHSS

To be scientifically defensible, the design of the project had to take into consideration meaningful effect sizes and the statistical power needed to detect a significant impact. In order to balance sample sizes with budget constraints fewer indicators were monitored but higher sample repetitions were implemented to increase the potential of detecting an impact. Following the workshop it was decided that only six indicators should be sampled: 1) nutrients direct (nutrients directly added to the stream system); 2) deposited sediments; 3) physical disturbance to the riparian zone; 4) physical disturbance to the stream bed; 5) changed light regime (turbidity of stream); and 6) bacteria added to the stream system. Measurement of these indicators would indicate whether horses were adding sediment and nutrients to the aquatic ecosystem, and what direct impact their hooves may have on the aquatic environment. The same indicators were used to capture the impact of 4WD crossings on the stream, as the same stressors were relevant, either by the transporting of soil and nutrients in the car tyres and undercarriage, or directly on the stream bed and banks by their tyres, when crossing.

Indicators were monitored via direct measures (such as water quality samples), rather than by studying the ecological response of the system (such as a change in the macroinvertebrate assemblage) due to time and budget restraints. It was determined that the potential addition of nutrients and bacteria to the system could be captured by sampling water quality. Changed light regime could also be detected via water quality samples by measuring turbidity. Deposited sediment, physical disturbance of riparian banks, and physical disturbance of the stream bed are all eroding processes, and were monitored using sediment traps. Sediment traps indicate how much erosion is occurring through sediment deposition at the impact site (Marshall 2001).

BACI Design

Initial monitoring employed a BACI (Before/After, Control/Impact) type design, as was originally described by Green (1979), and further developed by Berstein and Zalinski (1983) and Underwood (1991, 1994) whereby the

control and potentially impacted sites are sampled before and after the impact occurs, therefore utilizing both spatial and temporal variables.
The chosen indicators were sampled both upstream (at control sites) and downstream (at impacted sites) of a designated crossing site. Each site was sampled over several months to control for seasonal and other natural sources of variability within stream systems. The unimpacted difference between upstream and downstream sites was measured at the two test sites where the events would occur, as well as at four control sites, where no crossings would take place. The use of control sites gives a further understanding of the aquatic ecosystems within the monitoring area and the normal variability ranges typical to this region. Since each 'event' (Horse and 4WD) was expected to act as a large pulse disturbance, it was assumed that it would be quite apparent whether any impacts had occurred at the test sites during and after events, due to an acute discrepancy in indicator measurements between sites upstream and downstream of the crossing immediately preceding the event, followed by a relatively quick return to normal baseline levels (Glasby and Underwood 1996). Control sites were not expected to show any change outside of natural variance throughout the monitoring period, including during event days.

Site Selection and Locales

Several sections of the HRT Network have stream crossings and the ideal monitoring program would sample each crossing. The event based sampling design outlined above was chosen for use in this project however, due to environmental and practical constraints as well as the confounding issue of multiple users on the trails. The chosen sampling design allows for a much smaller, more controlled and focused study.

In order to find suitable sampling sites, scouting trips were conducted to find sites that had the following characteristics: sites needed to be unculverted (considered to be representative of the worst case scenario, as a lack of infrastructure could lead to greater erosion at the crossing site, and any potential impacts would be easier to detect); flowing (otherwise the spread of impact downstream could not be properly evaluated); and similar to each other in substrate type, flow, and local weather patterns (to attempt to alleviate confounding issues). A total of four control sites which met these characteristics were located in the South Coast Drainage basin in the Gold Coast Hinterland for use in this study (Figure 2).

In addition to the above characteristics, test sites were also chosen based on their potential as crossing points, as both 4WDs and horses needed access to both banks. Two sites were found. One test site was chosen because it was located on the HRT Network in Numinbah National Park. Access was restricted to horse riders and hikers due to fence infrastructure, although it was noted that trail bikes were able to gain access to the National Park. Park Rangers also had 4WD access, but were amenable to avoid driving through sites during the study. The second test site chosen was not an established crossing which ideally limited outside influencing factors, but was still accessible to both 4WDs and horses. Both test sites had a control site located upstream, so that sites were as comparable to test sites as possible.

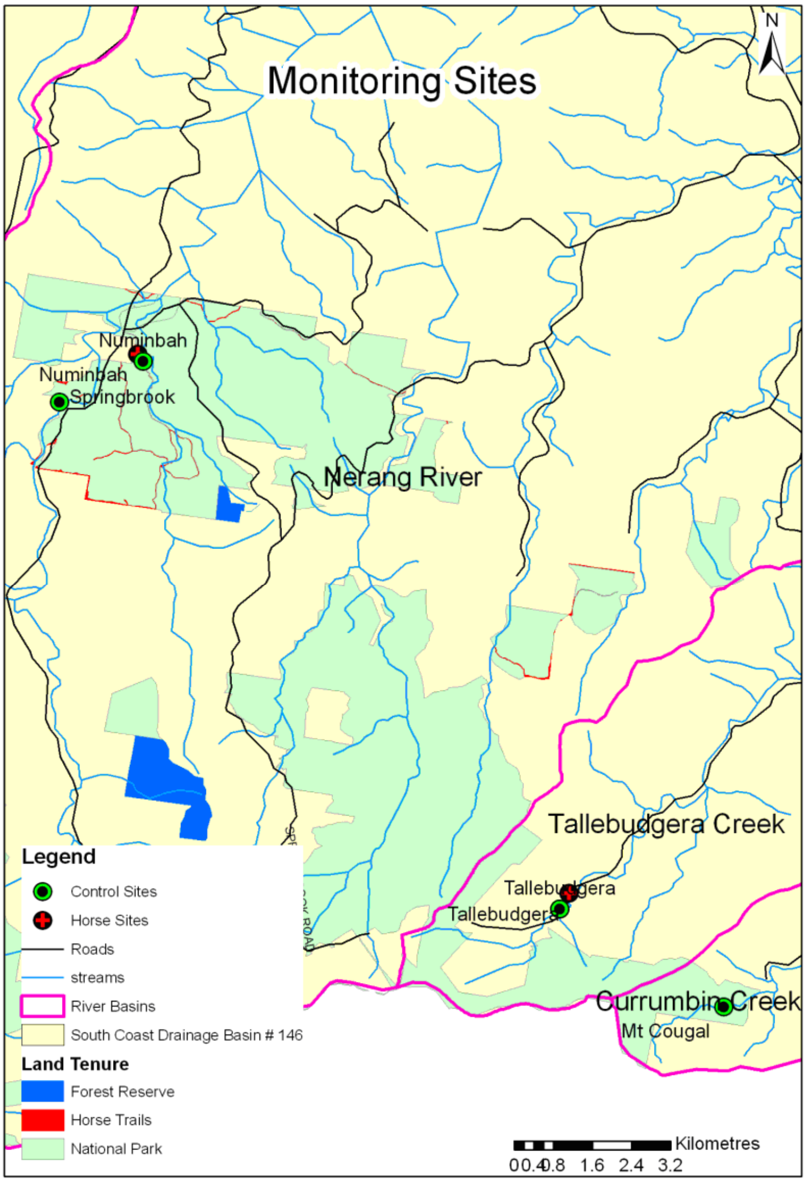

Figure 2 Map of study site locations on the Gold Coast Hinterland. Control sites: Mt Cougal, Tallebudgera, Numinbah and Springbrook are shown in three adjacent catchments. Both Tallebudgera and Numinbah test sites are located downstream of their corresponding control sites**.**

Sampling Protocol

Sampling took place over several months between October 2010 and March 2011 to provide a baseline dataset and an understanding of the normal fluctuations and variability of each site, before the event sampling occurred. Whilst similar, the protocol for baseline and event sampling varies slightly and are outlined separately below.

Baseline Sampling

Based on the BACI design implemented in this monitoring program, it was important to provide detailed information on the level of natural variation occurring in these aquatic systems across an extended time period, in order to determine whether any differences detected during the events were significant. Each site was revisited after the events to collect post-event recovery data to detect whether the systems had returned to their natural states.

GPS coordinates were recorded and photos taken for each selected site. Barometer and diver data loggers recording instream water temperature and pressure were installed discreetly in the vicinity of each site. When positioning instream loggers it was ensured that there were no tributaries entering the stream between the logger and the sampling area. This was to minimise the error between recorded pressure changes at the logger and the study site. Barometer loggers were placed in tubing and nailed discretely to a tree in the riparian vegetation. Diver loggers were attached to a stake, which was driven into the stream bed, as they had to be submerged throughout the sampling period. The diver logger data is compensated with the barometer data allowing stream depth to be calculated. These loggers were used to capture weather conditions and flow events such as floods during the study period, and were removed after the final post-event recovery data was taken. Data loggers were downloaded every other sampling trip, or more regularly if return trips were delayed due to inclement weather conditions.

Sites were first evaluated and defined. A potential crossing area was determined at each site (including control sites) and then marked by flagging tape. Flagging tape was used to mark sampling areas 1 metre upstream of the crossing, and 1 metre downstream. To determine the potential drift of any impacts detected it was decided that suspended sediment traps would also be set at 5 metres, 10 metres and 20 metres (or until a pool was reached due to their different hydrological features) downstream of the crossing, and these were also marked by flagging tape. These markers allowed for consistency over sampling periods and between field staff. Water quality was taken 1 metre upstream and 1 metre downstream of each potential crossing point. Figure 3 below illustrates how each site was set up. At both Tallebudgera Test and Numinbah Control, only 12 traps were set, as both sites became pools before they reached 20m.

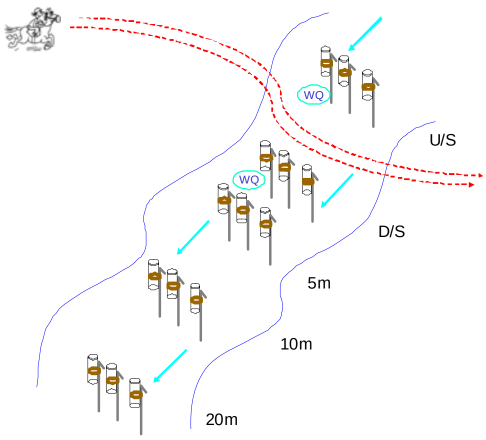

Figure 3 Site Set Up. Red lines indicate crossing. WQ = water quality collection points, downstream (d/s) and upstream (u/s). Suspended sediment traps were placed three abreast of the thalwag (deepest point of the stream), at 1m upstream, then 1m, 5m, 10m and 20m downstream.

The procedure for order of sampling was important for both the water quality and the suspended sediment trap method, in order to eliminate contamination from the sampling team. After arriving at a site during baseline sampling, water quality was taken first d/s, then u/s so as not to sample water which had already been stirred up. Suspended sediment vials were then set upstream first, and in sequence downstream, so that they would not collect any sediment that might be stirred up whilst setting. On collection of sediment traps, streams were entered downstream of the last set of vials, which were then collected whilst walking upstream.

At paired control/test sites, order of sampling was imperative due to the added complication of both sites occurring on the same stream. Since test sites were downstream of their corresponding control sites, water quality was collected first at test sites (d/s, then u/s), then at the control sites. After both sets of water quality samples were taken, sediment traps were set first at the control site, starting upstream and working downstream, and then at the test site. Sediment traps were first collected at the test site, then at the control site.

Event Sampling

Two separate 'events' were created: one for 4WDs passing through the stream crossing, and a second event for horses. To mitigate as many outside influences as possible, sampling for each event occurred at both test sites simultaneously. There was, however, a time lag between the two event types. Sampling was consistent between event types.

Under baseline protocol, sediment traps were set and left overnight, to be collected the following day. Due to the importance of the events, field staff remained at the site to ensure no site disturbance occurred, and sediment traps were collected shortly after the event.

On the morning of the event day, water quality and suspended sediment traps were collected and set at all sites as per the baseline protocol outlined above. At the two test sites the crossing (impact) occurred at midday during each event. Midway during the crossing, water quality was collected to capture what was happening whilst the disturbance was in progress. At 2pm, at all sites, suspended sediment traps and water quality were collected (water quality samples were taken after the d/s sediment traps were collected, and before the u/s sediment traps were collected, being careful not to disturb the u/s samples). Where a control site was located upstream of a test site, to prevent disturbance the control site was collected soon after 2pm, following test site completion.

4WD Event

At Tallebudgera, both scientists were involved in driving and directing their 4WD through the crossing and because of this, water quality was taken after the disturbance had occurred, which was not ideal. At Numinbah, due to extra personnel, water quality was able to be taken whilst the 4WD was driven through the crossing, in line with protocol.

Horse Event

Horses for the event were provided by the team at the Numinbah Valley Adventure Trails for the Numinbah Test site, and were arranged by Peter Gamble and the Queensland Horse Council for Tallebudgera. As this event was based on the Murrumba Endurance Ride, where it is expected that over a hundred horses might pass through one stream crossing, the target was to imitate such an event. Therefore if ten horses were provided, they would be asked to pass through the stream ten times each, simulating a crossing of one hundred horses. At Numinbah, four horses were available on the day, and crossed the stream twenty-five times in total. A cross was considered as going once through the stream, and the return pass was considered a second crossing. Water Quality was sampled during the twelfth and thirteenth pass. At Tallebudgera, only two horses were available on the specified day, and also crossed their stream twenty-five times, giving a simulated fifty horse crossing. Water Quality was also taken midway through the crossing.

Water Quality Sampling

All collected water quality samples were processed by the Queensland Health Forensic and Scientific Services (QHFSS, formerly QHSS), and sampling followed the protocol as set out in the Department of Natural Resources and Water guideline, '*Water quality sampling: of surface water, groundwater and aquatic biota (WMO018)*' (NRW 2009). Based on the above protocol, there were four water quality tests conducted: Bottle A – Major Ions, Bottle D – Unfiltered Nutrients, Bottle E – Filtered Nutrients, and Bottle J – Bacteria. These four water quality tests were sampled twice at each site, once downstream, and once upstream.

Suspended Sediment Traps

Suspended sediment was initially collected over five baseline sampling trips (Runs 1-5). The 4WD Event (Run 6) was then held followed by a baseline sampling trip (Run 7) to determine whether the stream had recovered from the event. This was followed by the Horse Event (Run 8), and a final baseline sampling trip (Run 9). In total, there were seven baseline sampling trips (two of which was post-event recovery trips, one after each event), and two events (9 Runs in total). Water quality samples were taken during each Run.

Each trap consisted of a glass vial, which was attached upright to a tent peg via two rubber bands. A piece of flagging tape was tied around the tent peg to allow for easier detection of the trap during collection. The sediment trap was set by ramming the tent peg tightly and securely into the stream bed. The mouth of the vial was always submerged and positioned upright. These collection methods were based on a modified version of the experimental design outlined by Marshall (2001).

Sediment traps were generally collected 24 hours after setting. The exceptions to this were Run 4, which was set for 48 hours, and the 'Event' Runs (6 and 8), which were each set for 7 hours. Each lid was labelled with the date, site, location in stream, where +1 indicated 1m upstream, and subsequent numbers indicated downstream locations (1, 5, 10, 20), as well as its position in the stream: left (L), middle (M), or right (R). To collect traps, they were approached from downstream, and labelled lids were attached while the traps were in-situ. The sediment traps were then dismantled and the vials were refrigerated, ready for processing.

Filtration of Suspended Sediment Traps

Filtration protocol was based on the American Public Health Association sStandard mMethods (APHA, 1995). Each vial containing a suspended sediment sample was first filtered, and then weighed to determine the mass of each sample. Whatman glass microfiber filters (47µm) were pre-ashed in a muffle furnace at 450^{0}C for two hours and then placed in a desiccator until weighed. After weighing they were placed in individual, numbered foil wrappers. Foil crucibles were each numbered and pre-ashed at 450^{0}C for two hours and then placed in a desiccator until weighed. All weights were recorded.

Each filter was removed from its foil wrapper and placed into position on the filter tower using tweezers. The vial containing one sediment sample was shaken to resuspend sediment, and then poured into a measuring cylinder to calculate volume. Whilst the volume of each vial was recorded, it was later decided that it was unimportant since each vial was completely submerged in the stream and the sediment collected at the bottom of the vial.

After measuring, the sample was emptied into the filter tower and allowed to filter through, catching any sediment on the filter paper. The measuring cylinder, vial and vial lid were all then rinsed twice to catch any sediment residue that might have been left behind.

The filter paper was removed from the filter tower using tweezers and placed into a correspondingly labelled crucible which was then placed into a tray. One tray took twelve samples and once full a lid was placed on top to avoid disturbance of samples. A complete tray was then put in a soil dryer at 60^{0}C for 2 hours with its lid removed.

Once dried, each tray was removed from the dryer. After its lid was replaced it was then taken back to the scales and each sample was immediately put into a desiccator before weighing. All dry weights were recorded.

Samples were returned to their tray. After the lid was replaced they were taken to the muffle furnace. After removing the lid, each tray was then placed in the furnace at 450^{0}C for 2 hours. Once combusted, the tray was removed using gloves and allowed to cool. The lid was once again replaced and the tray was taken back to scales. Each sample was put immediately into a desiccator and then weighed. All ashed weights were recorded. The inorganic and organic weight of each sample was then calculated.

To ensure quality control of the entered data, all sediment and water quality results were entered twice into excel, the two datasets compared, and discrepancies checked and resolved. All suspended sediment sample results were weighted to seven hours, ensuring that results from different sites and different runs were comparable.

The primary focus of the event crossings was to identify whether there was an impact occurring downstream of the disturbance, so the proportional difference between 1m downstream and 1m upstream suspended sediment samples was calculated for each site, for each run ([downstream-upstream]/upstream). This was done for both the inorganic and organic weights, as well as for water quality samples. The data from the seven baseline sampling trips was then run through an ANOVA program on SAS® Software for Microsoft® Windows® for both.

Results

Significant results of the indicators sampled during events are highlighted below. The suspended sediment samples can be seen as distinct to the results of the water quality tests and will be presented separately.

Suspended Sediment

Generally, suspended sediment traps appeared variable during normal baseline sampling runs, particularly at Tallebudgera, whilst Numinbah sediment deposits were much more consistent, and indicate the normal stream activity and natural variation of both sites. During both event runs, there is a clear differentiation between u/s and d/s samples at Numinbah, with samples appearing to grow lighter (less sediment) at each position downstream (potential tapering of impact). Tallebudgera also shows a clear differentiation between u/s and d/s during the horse event, but less so during the 4WD event. Samples further downstream are quite variable.

Photos were taken during both events and also give a qualitative perspective of sediment dispersal during the crossings. Photos below (Figures 5 and 6) were taken at Numinbah during the 4WD and Horse events respectively.

Figure 5
Sediment Runoff during 4WD Crossing at Numinbah test site

Figure 6
Sediment Runoff during Horse Crossing at Numinbah test site

Inorganic Suspended Sediment

Table 3 below presents the proportional difference for inorganic suspended sediment. High proportional differences can be seen at test sites during the 4WD and horse events.

Table 3 Proportional difference of inorganic suspended sediment deposits between upstream and downstream of stream crossings. Where SC = Springbrook Control, NT = Numinbah Test, NC = Numinbah Control, MC = Mount Cougal Control, TT = Tallebudgera Test, TC = Tallebudgera Control. Colour Scale indicates strength of difference, grading from 0% to 500%, where highest contrast is above 500%. Test sites are outlined in bold for clarity, as are event runs. *Note that during Run 4, a television program was being filmed between the Tallebudgera test site and its upstream control site. Therefore the high value can be accredited to numerous 4WDs being driven through the stream crossing between our 2 sites, and potentially through the actual crossing at the test site as well. (Outliers: Run 4, TT; Run 5, NT; and Run 9, TC)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	**4WD Event**	Run 7	**Horse Event**	Run 9
SC	-3.53%	-17.51%	116.30%	-22.43%	-27.33%	**190.94%**	-25.18%	**5.26%**	-44.79%
NT	**-78.39%**	**-45.57%**	**-19.41%**	**8.99%**	**-11.93%**	**558.05%**	**-24.91%**	**949.79%**	**78.02%**
NC	-11.23%	6.64%	-23.45%	-44.87%	213.61%	**40.09%**	-5.88%	**-76.90%**	71.98%
MC	30.51%	47.48%	46.64%	-52.41%	-51.03%	**-14.48%**	6.48%	**58.23%**	1.77%
TT	**7.75%**	**32.35%**	**14.00%**	***308.51%**	**-18.38%**	**169.29%**	**-18.61%**	**2038.78%**	**-49.65%**
TC	-73.00%	-7.42%	-53.17%	3.29%	-5.20%	**-33.80%**	-43.47%	**-71.43%**	234.59%

After running the ANOVA program, a confidence interval test was conducted and it was determined that any values outside the range of -78.64% - 94.40% (rounded to two decimal places) would be considered outside normal variance. (3 outliers were removed during analysis due to their extremely high values in comparison to what was considered normal for each site. As sediment traps were left out over night, it is highly likely that these discrepancies were due to circumstances or crossings occurring outside the control of the experiment). Whilst the coefficient variance (degrees of freedom) was extremely high, 550.1881%, this was expected due to the variable nature of the data, and small sampling size. The data was also not normally distributed. Therefore the 6 sigma principle was applied, whereby when data is not normally distributed, anything greater than 6 standard deviations outside the interval test range could be considered significant. There were four data points that fell into this category: both the 4WD and horse event crossings at the Numinbah Test Site, the horse crossing at Tallebudgera Test, and the sample taken whilst a film crew was onsite at Tallebudgera.

Organic Suspended Sediment

A confidence interval test was also run on the organic suspended sediment data (see Table 4 for the proportional difference between u/s and d/s for each site, over each run), and it was determined that the confidence interval was between -8.83% - 86.82%. Again the 6 sigma rule was applied and four significant results were found: both NT and TT during the Horse Event, as well as Run 3, TT and Run 9, TC. It was noted that Run 9, TC was extremely abnormal for both inorganic and organic samples.

Table 4 Proportional difference of organic suspended sediment deposits between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 100%, where highest contrast is above 100%. Test sites are outlined in bold, as are event runs. *Note a film crew had disturbed this site during this Run, but had no visible effect on organic sediment deposit. (Outliers: Run 1, TT; Run 3, TT; Run 3, MC; Run 5, NC; Run 9, TC)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	**4WD Event**	Run 7	**Horse Event**	Run 9
SC	-14.63%	-16.59%	65.75%	-55.54%	-25.11%	**8.88%**	-14.79%	**6.92%**	-42.36%
NT	**-2.78%**	**-28.07%**	**-43.49%**	**1.14%**	**-21.17%**	**129.11%**	**-15.77%**	**231.41%**	**10.25%**
NC	-32.92%	-2.67%	-36.03%	-63.87%	85.42%	**-10.51%**	-17.02%	**-51.02%**	18.51%
MC	7.80%	-43.59%	86.11%	-11.42%	-40.94%	**-9.07%**	-0.16%	**-5.40%**	-17.78%
TT	**-156.82%**	**-8.05%**	**3054.55%**	**0.38%**	**-72.12%**	**-8.30%**	**-52.19%**	**414.29%**	**-57.72%**
TC	-84.74%	1.97%	-48.37%	10.64%	-53.58%	**-8.84%**	-45.98%	**-50.13%**	285.16%

Also of interest is that whilst there was a significant difference between upstream and downstream inorganic sediment at Tallebudgera when the film crew was onsite, there was no indication from the organic data that this disturbance had occurred. This was also the case when the 4WD was driven through Tallebudgera Test.

Water Quality

There were five water quality results of note: 1) *Escherichia coli* (*E. coli*), 2) Dissolved Organic Carbon as NPOC, 3) Total Organic Carbon as NPOC, 4) Total Nitrogen, and 5) Total Phosphorous. The proportional difference was again determined for each site over each run. ANOVAs were performed on each dataset, using only the baseline sampling runs. As water quality was taken in the morning of each event, this was also considered a baseline sample, as no disturbance had yet occurred, and was therefore included in the ANOVA. There was therefore data from 9 runs for each test, excepting *E. coli*. due to complications with processing samples, both Run 1, and Run 7 (baseline sample between the two Events) were not processed. Outliers were selected when a sample was clearly outside the normal parameters of that site. All confidence intervals were rounded to two decimal places.

- ***Escherichia coli***

The table below shows the proportional difference of the abundance of *E. coli* between upstream and downstream of each site crossing (impact site). It was found that the confidence interval was -80.89% – 115.59%. There were three samples that were greater than 6 standard deviations outside this interval: both 4WD Test sites, during the crossings, as well as at Tallebudgera during the horse crossing.

Table 5 Proportional difference of abundance of *Escherichia coli* between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 300%, where highest contrast is above 300%. Test sites are outlined in bold for clarity, as are event runs. (Outliers: Run 2, TT)

Site	Run 2	Run 3	Run 4	Run 5	4WD Event			Horse Event			Run 9
					BEFORE	DURING	AFTER	BEFORE	DURING	AFTER	
SC	66.67%	31.25%	30.77%	0.00%	16.00%		46.67%	-33.70%		14.89%	41.94%
NT	33.33%	-5.26%	-27.27%	77.78%	9.09%	78081.82%	33.33%	144.44%	135.29%	-23.53%	-25.00%
NC	18.75%	30.00%	-7.41%	-19.09%	-81.82%		66.67%	-58.90%		-17.65%	-29.17%
MC	90.91%	0.00%	78.95%	42.86%	28.00%		72.22%	9.09%		69.57%	40.00%
TT	233.33%	-56.25%	25.81%	-10.84%	33.33%	320.00%	-23.08%	-16.00%	661.90%	-50.00%	133.33%
TC	0.00%	-21.05%	12.00%	17.78%	100.00%		200.00%	0.00%		61.54%	-9.09%

- ***Dissolved Organic Carbon as NPOC***

Dissolved organic carbon had a confidence interval of -11.46% - 26.37%. As Table 6 below would suggest, there was only one sample that was significant, which was at the Numinbah Test Site, during the horse crossing.

Table 6 Proportional difference of Dissolved Organic Carbon as NPOC between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 80%, where highest contrast is above 80%. Test sites are outlined in bold for clarity, as are event runs. (Outliers: Run 4, NC; Run 5, MC; Run 6, TT)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	4WD Event			Run 7	Horse Event			Run 9
						BEFORE	DURING	AFTER		BEFORE	DURING	AFTER	
SC	3.33%	10.53%	22.73%	-28.13%	-18.52%	-3.85%		-25.00%	-8.33%	0.00%		-28.57%	-10.00%
NT	-6.25%	15.38%	0.00%	-9.09%	-14.29%	-12.90%	0.00%	-35.71%	0.00%	14.29%	80.00%	0.00%	-25.00%
NC	11.76%	0.00%	9.09%	-47.06%	6.67%	-15.00%		0.00%	6.67%	0.00%		40.00%	0.00%
MC	7.41%	0.00%	11.11%	10.00%	42.86%	10.53%		-22.22%	-7.14%	-16.67%		-28.57%	0.00%
TT	-4.35%	-24.00%	-3.85%	7.41%	10.00%	33.33%	0.00%	-6.67%	11.11%	-14.29%	40.00%	0.00%	15.38%
TC	15.79%	-8.70%	-6.67%	-10.00%	0.00%	11.11%		-3.85%	5.88%	-10.00%		16.67%	-17.65%

- ***Total Organic Carbon as NPOC***

As with Dissolved Organic Carbon, and highlighted below in Table 7, there was only one significant response for Total Organic Carbon. This was also at Numinbah, during the horse crossing event. The confidence interval was -22.6% - 24.05%.

Table 7 Proportional difference of Total Organic Carbon as NPOC between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 100%, where highest contrast is above 100%. Test sites are outlined in bold for clarity, as are event runs. (No outliers)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	4WD Event			Run 7	Horse Event			Run 9
						BEFORE	DURING	AFTER		BEFORE	DURING	AFTER	
SC	-2.63%	8.57%	3.45%	-21.43%	-1.49%	-13.16%		0.00%	-18.75%	0.00%		-23.08%	-30.00%
NT	0.00%	-11.11%	-3.70%	-15.63%	0.00%	5.00%	8.70%	-7.50%	-41.67%	-7.69%	240.00%	0.00%	0.00%
NC	4.35%	4.00%	7.69%	11.11%	0.00%	16.00%		0.00%	20.00%	0.00%		30.00%	-8.33%
MC	-2.78%	-3.85%	13.64%	-3.45%	12.12%	-3.57%		0.00%	12.50%	40.00%		-23.08%	-9.09%
TT	-7.41%	0.00%	6.67%	-13.16%	5.26%	17.39%	-2.63%	3.70%	4.76%	0.00%	30.00%	0.00%	12.50%
TC	16.67%	-5.56%	-8.82%	-9.76%	0.00%	2.38%		-2.44%	-14.29%	0.00%		30.00%	-5.26%

- ***Total Nitrogen***

As Table 8 below indicates, there was a significant difference between upstream and downstream levels of nitrogen during the horse event at both Test sites. The confidence interval was found to be -15.20% - 18.82%, and there was in fact a third sample that was greater than 6 standard deviations outside this interval. This was during the afternoon sample of Tallebudgera, after the 4WD event. Notably, there was no response at the crossing, during the actual disturbance, which could suggest sampling error.

Table 8 Proportional difference of Total Nitrogen between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 80%, where highest contrast is above 80%. Test sites are outlined in bold for clarity, as are event runs. (No outliers)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	4WD Event			Run 7	Horse Event			Run 9
						BEFORE	DURING	AFTER		BEFORE	DURING	AFTER	
SC	6.67%	0.00%	-12.50%	0.00%	0.00%	5.88%		0.00%	30.77%	0.00%		-6.67%	-5.00%
NT	-6.67%	0.00%	0.00%	0.00%	-11.76%	0.00%	15.38%	0.00%	-15.38%	0.00%	88.24%	-7.69%	0.00%
NC	0.00%	0.00%	0.00%	0.00%	0.00%	0.00%		0.00%	0.00%	0.00%		-14.29%	-8.33%
MC	31.25%	0.00%	-7.14%	-10.00%	5.88%	0.00%		10.53%	10.53%	5.00%		0.00%	9.52%
TT	8.33%	14.29%	0.00%	7.69%	0.00%	0.00%	0.00%	57.89%	6.25%	0.00%	72.22%	0.00%	0.00%
TC	0.00%	25.00%	0.00%	0.00%	6.25%	0.00%		0.00%	6.25%	5.56%		5.26%	-10.71%

- ***Total Phosphorous***

The confidence interval for Total Phosphorous was found to be -9.65% - 12.72%. Table 9 clearly shows the 3 significant responses, which were similar to the results for total nitrogen. Both test sites had a significant proportional difference between upstream and downstream during the horse crossing. Mt Cougal also had a significant response during Run 1.

Table 9 Proportional difference of Total Phosphorous between upstream and downstream of stream crossings. Colour Scale indicates strength of difference, grading from 0% to 100%, where highest contrast is above 100%. Test sites are outlined in bold for clarity, as are event runs. (Outlier: Run 1, MC)

Site	Run 1	Run 2	Run 3	Run 4	Run 5	4WD Event			Run 7	Horse Event			Run 9
						BEFORE	DURING	AFTER		BEFORE	DURING	AFTER	
SC	2.17%	5.56%	0.00%	-3.03%	0.00%	-13.21%		0.00%	15.00%	-2.33%		0.00%	-3.92%
NT	0.00%	-2.63%	0.00%	0.00%	1.92%	2.08%	0.00%	4.08%	0.00%	2.22%	71.43%	2.33%	2.44%
NC	0.00%	0.00%	0.00%	-1.69%	-3.70%	2.04%		1.92%	0.00%	0.00%		-2.13%	-2.33%
MC	94.74%	6.25%	0.00%	11.11%	0.00%	5.00%		-4.76%	11.76%	0.00%		0.00%	3.70%
TT	4.76%	0.00%	-11.11%	0.00%	0.00%	4.76%	0.00%	0.00%	16.67%	0.00%	111.54%	4.17%	-3.45%
TC	-4.35%	0.00%	-5.56%	5.00%	10.00%	0.00%		0.00%	5.56%	0.00%		-3.85%	20.69%

Discussion

The aquatic impact that horses may potentially impose on the environment has, until now, been distinctly ignored. It is reasonable to assume they would have some degree of effect, but to what extent, and in what way was previously undefined. This represents a knowledge gap which impedes the implementation of effective management of stream crossings, and the determination of what infrastructure is necessary. Contrarily, it may also have been previously assumed that horses have such inconsequential impacts on stream crossings, that further study and management consideration was unnecessary.

This monitoring program was designed to determine whether horses have any detectable impacts on stream crossings. Findings add invaluable knowledge to this area of scientific research and will also help future planning and management of the SEQ Horse Trail Network.

4WDs vs. Horse Riding

As was discussed during the design of this project, horse riders are not the only high impact users along the HT Network. Most of the trails are made up of stretches of forest reserve that park rangers use as either fire breaks or as access points through the national parks, and therefore stream crossings along these trails are as likely to be impacted by heavy vehicle use as they are by horse riding. It was therefore determined that the study design would incorporate two events, both a horse crossing and a 4WD crossing, to create a genuine comparison.

From the results it can be seen that there were two distinct pressures exerted by horses on stream crosses: mechanical and nutrient loading. In comparison, 4WDs appeared to present only a mechanical pressure on the aquatic environment. Notably, during the horse crossing sediment erosion and displacement occurred primarily at the edges of the stream, whereas during the 4WD crossing whilst disturbance was also higher near the stream banks, erosion was also more evenly spread through the width of the stream. This is something to consider when designing a new project, as our sediment traps were set in the thalweg (deepest section of the stream), rather than at the edges, and therefore may not have been a true capture of each disturbance.

Mechanical Pressures

As was expected from the qualitative risk assessment, the data indicates that both horses and 4WDs do exert some degree of mechanical pressure and cause erosion within aquatic environments at stream crossings. This is particularly evident from inorganic suspended sediment, such as small rocks and sediment particles, which had a particularly high proportional difference between upstream and downstream at all test sites for each event, excepting the 4WD crossing at Tallebudgera. 4WD impact was however recorded during a baseline sample run, where it was observed that 4WDs were being driven back and forth through the crossing at Tallebudgera during the filming of a television series, while the sediment traps were still set. In this case the proportional difference between upstream and downstream suspended sediment samples from the 4WD crossing was statistically outside of the levels of variation natural at Tallebudgera. This particular site data was excluded from the baseline dataset as an outlier.

Whilst there was a statistically significant increase of organic sediment deposits at both Numinbah and Tallebudgera during the horse event, this suggests it is actually a result of nutrient loading, as it was not significant during the 4WD event. Since 4WDs managed to stir up inorganic sediment, it would be expected that any organic matter that was in the sediment, would be swept downstream as well. As this was not the case, it could be hypothesised that the organic suspended sediment collected during the horse events was actually material that was added to the aquatic system via the horses, and did not occur during the 4WD crossings. Alternatively, the lower organic runoff at Tallebudgera could be because there are no cows upstream, unlike Numinbah, so less organic matter is likely to enter the system from upstream. That would suggest that there would be less to stir up during a disturbance of the bed. Tallebudgera had very little algae, and was primarily pebbles or leaves, whereas there was a large amount of algae at Numinbah. Whilst not significant, there was a much higher organic runoff during the 4WD event at Numinbah, than there was during either the 4WD event at Tallebudgera, or whilst the film crew were onsite, despite their large impact on the inorganic runoff. Hypothetically this could suggest that 4WDs only act as a mechanical pressure, eroding and releasing only what is already in the system.

Another anomaly in the data was the proportional difference in release of large levels of *E. coli* downstream of both horse (135.29% and 661.90%) and 4WD crossings (78081.82% and 320.00%). This could be seen as a mechanical pressure as it has been documented that *E. coli* can live in sediment deposits on stream beds, to be re-released during disturbance of the bed. The extremely high level of *E. coli* at Numinbah Test during the 4WD crossing was so high as to suggest a potential mistake in the data, or a coincidence, as there was no significant response during the subsequent horse crossing. As *E. coli* lives in the sediment of stream beds, the smaller response seen during the horse event could be because the majority of it was released during the 4WD crossing. Due to several months of heavy flooding and high flow during the sampling period leading up to the 4WD event, a high level of deposited *E. coli* could have built up. This would have been released during the first high impact crossing of the site, (during the 4WD event), leaving much less stored in the sediment to be released during the next disturbance. This is purely hypothetical, and would have to be tested by allowing a similar build up of sediment (and potentially *E. coli*), followed by an assessment which tested horses crossing first, and then a subsequent 4WD event, to see if a similar pattern were to occur.

Nutrient Loading

Only the horse crossings added nutrients to the aquatic system to a significant degree, excepting a couple of variant baseline data points. This was true for both dissolved and total organic carbon at Numinbah Test, and nitrogen and phosphorous loading at both Numinbah and Tallebudgera test sites during the crossing. This could potentially indicate that only horses add nutrients to the aquatic system during crossings, whilst 4WDs act as a mechanical pressure only. To what extent this nutrient loading may affect the ecological response of the system still needs to be assessed. It is also unclear exactly how and why horses may be adding nutrients to the aquatic system, if they do not directly defecate whilst crossing through the stream. It was qualitatively noted that while no horses at Numinbah defecated whilst actually in the water, did, they did at Tallebudgera, suggesting a lack of a clear rule of thumb. There were however numerous scats on the either side of both crossings however, from the horses at the event, which they could easily have then walked into the stream. It can therefore be considered that in this case horses add to the system, whilst 4WDs only resuspend what is already there. This however will not be the case for all 4WD crossings as they are likely to be transporting material (including faecal matter) in their tyres and undercarriage.

Natural Drivers vs. Anthropogenic Pressures

Another important factor to consider is the strength of any incurred impacts of horse riding or 4WDs through stream crossing in comparison to natural drivers or the aquatic system. Natural drivers such as storms can appear to have much greater impact than one off horse events, as seen throughout our study in the extreme weather that occurred during the study period. The particular sampling period of this project occurred during a particularly strong wet season and included several floods during this time at some of the monitored stream systems. This not only impinged sampling trips, but also served to show the intensity of natural drivers and the impacts they can have on aquatic systems.

Whilst the data was skewed to detail the proportional difference between upstream and downstream to highlight potential disturbances occurring during each impact, it was noted that suspended sediment traps captured a greater amount of sediment during high flow (flood) periods. Water quality also appeared to be affected by high flow, especially at Numinbah and Springbrook where the streams first flowed through pasture and residential areas before reaching the National Parks. This was less likely to happen at Mt Cougal or Tallebudgera as the stream mouths were situated in rainforest. Both Mt Cougal and Tallebudgera however attracted much human attention due to their pristine states, and therefore pressures such as swimming hiking, and mountain bike riding could also have impacted some of the samples during the baseline monitoring.

The affect of increased flow will need to be further investigated using the data collected via the Barometer and Diver data loggers for the duration of the sampling period, to see if it correlates to suspended sediment weights, or high nutrient loads (see Appendix 1 for graphs depicting data collected via the data loggers).

Budget, in-situ monitoring programs and potential future scientific investigations

As can be expected when working in real life environmental scenarios, there were many issues to be faced when designing and implementing such a monitoring program:

- It would have been ideal to always set and collect each day, to account for as many potential outside influences as possible – not only impractical over baseline sampling, as too personnel intensive, but also too expensive to maintain for long sampling periods
- The use of discrete video cameras at sites whilst sediment traps were set to capture any potential disturbances that may occur could have provided valuable information
- Selection of test sites was a challenge. It was very hard to find two test sites, that were suitably similar, as well as providing safe and maneuverable room on either side of the bank for horses and 4WDs to access, whilst also not being a designated, or busy crossing
- Tallebudgera was accepted as a test site due to its appropriateness as a crossing, but not enough consideration was given to the numerous the riffles and deep pools directly downstream of the crossing. In hindsight, this was not an ideal test site since variability in data was too high due to the stream's

hydrology. It would be highly recommended to find a new test site, were this program were to be repeated.

- Springbrook was also not ideal, as there were too many visitors, and potential unknown disturbances. This was a problem for Mt Cougal, as it was particularly popular with swimming tourists (potentially impacting monitoring sites).
- Regarding statistical analyses - the coefficient variance was too high, for most of the datasets, due to the variable nature of the data, as well as the limited sample set. This is expected in natural systems where limited resources determine size and scope of projects. The current data set could be built upon by repeating the monitoring program and both the 4WD and Horse Events. Several further actual Events would also create a firmer picture of what is actually happening during each disturbance event.
- Future study should also consider sediment traps at nearer to the bank of the streams in order to fully capture all disturbance occurring.

Conclusion and Recommendations

This study has shown that horse trail crossings are a pulse impact on water quality. We found that there are several impacts occurring to the aquatic system when horses and 4WDs cross through streams. For horses there were increases in both organic and inorganic sediment, *E. coli*, nitrogen, and phosphorus. Of these, organic and inorganic sediment, and *E. coli* were also elevated by the 4WD crossing. This is invaluable knowledge, as hereto with we could only make informed assumptions.

There are, however, several areas that still need assessing. Whilst impacts have been detected, their intensity is determinate on the number and regularity of potential disturbance events. This is of particular interest in relation to the management of the HRT Network, as small numbers of horse riders along a particular trail could be considered pulse events, with little long term impact, whilst increased traffic and frequency could lead to ramp events, and potential degradation of crossings. As part of the Scientific Monitoring Program, the use of some trails is being assessed, and this information could be useful in determining which stream crossings may need further assessment and management.

The team at Numinbah Valley Trails were consulted, as they run regular large horse trail groups on their own property. They are able to monitor and maintain each trail separately, and will avoid certain trails if a particular stream crossing is becoming too highly impacted. This high level of monitoring is achievable, as they are the only users along their trails, and they are able to make informed and timely management decisions. The HRT Network however, has numerous individual and group users, and are managed by park rangers, that are responsible for much larger areas than the Network alone. They therefore, are unable to provide such a high level of management along each trail. This means that if detrimental impacts occur, they may not be caught in time.

An assessment of each stream crossing on high-use trails in the HRT Network is recommended. Any trail that has organized horse events should certainly have baseline monitoring undertaken. This would determine whether any infrastructure is currently needed, and allow for regular re-assessment that could detect deterioration of any crossing. Unfortunately, due to the hydrology of streams, most sediment and nutrient runoff will float downstream till it reaches the first pool. This therefore, is the area that is likely to receive the most impact, and where aquatic health monitoring should be focused, as this deposited sediment can smother macroinvertebrate habitat. Assessment of stream crossings should therefore also include any pools immediately downstream.

Finally, although impacts were found, the runoff during storms and floods, especially in National Parks that are downstream of pastures and residential areas, was potentially much greater than anything that occurred during the anthropogenic disturbances captured during the events. Therefore, as long as careful monitoring is maintained, horse riding along these trials should be allowed to continue.

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