Identifying pesticides in Hearnes Lake catchment waterways.

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Executive summary

Hearnes Lake catchment is situated on Gumbaynggirr Country north of Coffs Harbour on the east coast of NSW, Australia. It is a small Intermittently Closed and Open Lake or Lagoon (ICOLL) north of Coffs Harbour and is classified as a Habitat Protection Zone within the Solitary Islands Marine Park. It is surrounded by a series of integrated wildlife habitats that support many species listed as Threatened Species, two Endangered Ecological Communities and is a nursery ground for fish. Due to its intermittently closed nature, Hearnes Lake is highly sensitive to the accumulation and impacts of aquatic pollution. Historically, Hearnes Lake has been used by local communities for gathering oysters, prawning, crabbing, fishing, boating and swimming. Currently, 43.6% of the 6.6 sq km catchment of Hearnes Lake is agricultural. The associated agricultural runoff is a key issue affecting estuary health and social and recreational values of Hearnes Lake.

This study was undertaken by concerned members of the local Sandy Beach community to explore the type and extent of agricultural chemical contamination in tributaries feeding into Hearnes Lake during rain events. A community-based sampling methodology was produced and implemented by local residents, and water samples were collected during rainfall-induced flows at 5 sites in the catchment 3 times throughout the year.

A total of twelve different pesticides were detected during this project. Most of the chemicals detected are highly toxic to a variety of aquatic organisms, and some are highly toxic to humans and other mammals. Two are suspected of causing cancer. Seven are included in the National Toxics Network's list of Australia's most dangerous pesticides. Six of these are currently under review or proposed to be reviewed by the Australian Pesticides and Veterinary Medicines Authority. Eight of them are not approved for use in the European Union. One has been illegal to supply or use in Australia since 2006.

The most obvious and alarming pattern of contamination found was the repeated detection of multiple pesticides at one site. It took just an estimated 20 mm of rainfall to induce runoff laden with multiple pesticides at this site, which was immediately downstream of relatively high levels of intensive agricultural development, high slope and low vegetation or riparian cover. Over the year of the study alone, adequate rainfall to produce pesticide laden runoff from this site occurred 18 times.

Another significant pattern was the repeated spatial and temporal detection of imidacloprid, a neonicotinoid insecticide currently under review due to the unacceptable environmental risk for non-target organisms. These findings indicate widespread and possibly frequent contamination of the catchment waterways with this pesticide. The pattern of detections indicate the main source of imidacloprid may have been discharges from hothouses. Current accepted methods for management of this chemical appear inadequate to prevent continued pollution to downstream environments.

The most significant adverse effects of these pesticides are likely to be on those aquatic invertebrates that are closely related to target pest species. Macroinvertebrate assemblages, being comprised mostly of aquatic insects, are highly vulnerable. Because insects can play a “keystone role” in many ecosystems, the structure and composition of an entire ecosystem can be impacted. Two previous independent assessments of macroinvertebrate populations within the affected waterways demonstrated negative impacts on these populations, most likely due to both chemical and nutrient contamination arising from agricultural runoff. The impoverished nature of these macroinvertebrate assemblages would inherently disrupt the composition of the typical dissolved and particulate food sources being carried into Hearnes Lake. It would also significantly modify the movement of macroinvertebrates downstream and into Hearnes Lake, reducing this important source of food for many fish. An important component of the ecosystem of Hearnes Lake itself are the macroinvertebrates found in the soft sediment habitats. These are a vital food resource for higher level predators such as fish, crabs and birdlife. These important macroinvertebrate assemblages could also be greatly depleted by repeated exposure to this pollution.

Residues of neonicotinoids (such as imidocloprid) above the safe residue limits have been found in prawn flesh and in water in Hearnes Lake. Furthermore, recent studies on the impact of imidacloprid on prawns and oysters found sub lethal impacts at low concentrations. Bioaccumulation and biomagnification of pesticides may also occur via the transfer of pesticides through the food web. This would present a risk to predators such as the Threatened Eastern Osprey and the Endangered Little Tern. Aside from the environmental impacts, pesticide pollution of Hearnes Lake also presents a potential Public Health risk to community members who use the waterbody for swimming, fishing and boating, and to anyone eating seafood sourced from Hearnes Lake.

The potential loss of biodiversity through lethal and sub-lethal impacts on aquatic organisms both upstream and within Hearnes Lake will reduce the resilience of Hearnes Lake and its associated ecosystems, leaving them vulnerable to further degradation. However, the presence of healthy riparian vegetation around Hearnes Lake and sections of the freshwater creeks indicate that these ecosystems have the capacity to recover in the absence of chronic aquatic pollution. The protection and restoration of Hearnes Lake would ensure the maintenance of a healthy ecosystem and provide valuable recreational opportunities for our local communities, restoring opportunities for gathering oysters, prawning, crabbing, fishing, boating and swimming. Recreational fishers within the SIMP would also benefit from protection of fish nurseries in the longer term. In addition, it will contribute to the protection of the high biodiversity of the Flat Top Rock region of the SIMP.

The significant loads of pollution entering Hearnes Lake waterways is damning evidence of a failure of will or capacity of the responsible authorities, and the relevant agricultural industries, to act decisively to protect this section of the SIMP and its irreplaceable environmental and community values from pesticide pollution. One local researcher has recently been quoted as stating “Hearnes Lake isn’t dead but it’s nearly dead”. Hearnes Lake should not be sacrificed for the immediate profit of the few, but be protected and restored for the benefit and enjoyment of the many, its diverse environmental assets secured in perpetuity.

Introduction

Agricultural chemicals and pesticides have become ubiquitous in modern agriculture, to the point where community concern regarding their impacts is widespread. In a review conducted by the Environmental and Natural Resources Law in 2015, some of these concerns are summarised as follows:

Agricultural pollution is a major component of pollution in many parts of the world, due in large part to the reduction of pollution from other industries via regulation. While modern agriculture is increasingly reliant on pesticides to increase or maintain yields, much is unknown regarding the risks associated with pesticide use. Many pesticides are acutely toxic and are known to cause adverse effects on non-target mammals, birds, reptiles, amphibians, fish, and invertebrates, including sub-lethal effects on the organism by affecting life span, growth, physiology, behaviour, and reproduction. It is likely that the most significant adverse effects of pesticides are those to invertebrates that are closely related to target pest species. Insects play a “keystone role” in many ecosystems and frequently act as ecosystem engineers and soil modifiers. As such, insects can influence the structure and composition of an entire ecosystem (Environmental and Natural Resources Law, 2015).

Some studies have linked drastic declines in insect populations to the widespread use of agricultural pesticides (Mills, 2021). Even at levels deemed safe, pesticides have been shown to cause a loss of biodiversity, including reduced numbers of beneficial insects, as well as birds and amphibians (Oosthoek, 2013).

Pesticide runoff remains largely unmonitored in Australia. Previous studies undertaken in the Hearnes Lake catchment near Coffs Harbour, NSW, have identified significant agricultural pollution loads, including nitrogen (White et al., 2018), phosphorus and suspended solids (Conrad et al., 2018) discharging into Hearnes Lake. A wide variety of pesticides are used in the Hearnes Lake catchment, an area of high ecological value and part of the Solitary Islands Marine Park. Many are toxic to aquatic organisms including fish. An investigation of a fishkill in Hearnes Lake in 2018 by the NSW Environment Protection Authority found high levels of the pesticide chlorpyrifos in the dead fish (Watson, 2018), and an ensuing investigation uncovered 25 cases of non-compliance with chemical handling regulations within the Hearnes Lake catchment (Watson, 2019).

The Hearnes Lake catchment has a high level of intensive plant agriculture with 16% of the catchment developed for horticultural purposes (Conrad et al., 2019b). Given the heavy reliance on pesticides of the intensive agricultural industry, the potential for pollution by pesticides is considered high. The movement of agricultural chemicals through the catchment to Hearnes Lake is a significant risk to the ecological health and recreational value of the lake. The potential loss of biodiversity through the lethal and sub-lethal impacts on aquatic organisms will likely reduce the resilience of Hearnes Lake and its associated ecosystems, leaving them vulnerable to further degradation.

Aims and Objectives

The objective of this project was to provide a preliminary understanding of the major types and sources of agricultural chemical pollution that may discharge into Hearnes Lake during rain events. This entailed the development and coordination of a community-based process for the collection of water samples.

The aim of the project was to facilitate the identification and removal of sources of chemical pollution in the catchment. This would lower the risk and severity of fish kills in Hearnes Lake and reduce the lethal and sublethal impacts of agricultural chemicals on aquatic life within and upstream of Hearnes Lake. It will also reduce potential Public Health risk to community members who use the lake for recreation by providing safer water quality for swimming, fishing and boating. Recreational fishers will also benefit from protection of fish nurseries in the longer term. In addition, it will contribute to the protection of the high rocky shore biodiversity of the Flat Top Rock region of the Solitary Island Marine Park (SIMP).

To achieve this aim, results from each sampling event were disseminated to appropriate authorities (NSW Environment Protection Authority (EPA) and Coffs Harbour City Council (CHCC)), for their information and action. Results can also enable agriculturalists to identify and rectify inadequacies in safe chemical management.

Methods

Study site

Hearnes Lake catchment is situated on Gumbaynggirr Country north of Coffs Harbour on the east coast of NSW, Australia. It is a small Intermittently Closed and Open Lake or Lagoon (ICOLL) north of Coffs Harbour and is classified as a Habitat Protection Zone within the SIMP. Hearnes Lake and surrounds are a series of integrated wildlife habitats that support many species listed as Threatened Species, including the Wallum Froglet, Black-necked stork, Osprey, Greater Broad-nosed bat, Eastern free tail bat, and Glossy Black Cockatoo (Sainty and Associates, 2006). There are also two Endangered Ecological Communities in the surrounds of Hearnes Lake, being Swamp Sclerophyll Forest and Coastal Saltmarsh communities. While the waterbody of Hearnes Lake is only 10 ha, its long foreshore perimeter (4.6 km) supports 4.5 ha of saltmarsh community (Beadle and Sanborn, 2021a). The extensive saltmarsh areas present prompted a recommendation for the estuarine vegetation communities to be included in SEPP 14 (Coastal Wetlands) legislation, in recognition of the regional importance of the Hearnes Lake wetlands area (BMT WBM, 2009).

Hearnes Lake also provides habitat for migratory and other birds and is a nursery ground for fish which populate the SIMP. When open to the ocean, the Lake discharges near Flat Top Point (also known as Flat Rock Point), which is one of the most highly biodiverse Rocky Shores of the SIMP and is protected by a Sanctuary Zone. Due to its intermittently closed nature, Hearnes Lake is highly sensitive to the accumulation and impacts of aquatic pollution.

Historically, Hearnes Lake has been used by local communities for gathering Sydney Rock oysters, prawning, crabbing, fishing, boating and swimming. While there is little written information available regarding the use by and significance of Hearnes Lake to local aboriginal populations, there is little doubt it would have played an important role in providing food and other resources. In recent times, some significant artefacts have been found in Hearnes Lake (Beadle and Sanborn, 2021b).

While the catchment of Hearnes Lake is only 6.6 sq km, 43.6% of the catchment area is agricultural (Beadle and Sanborn, 2021a). Catchment runoff has been identified as a major source of poor water quality, and the significant increase in intensive plant agriculture across the catchment over recent decades, the associated agricultural runoff and a lack of regulation of agricultural practices has been highlighted as a key issue affecting estuary health and social and recreational values of Hearnes Lake (Beadle and Sanborn, 2020).

The community-based sample collection process

Sample collection was undertaken by concerned members of the local community. Sample collection protocols were developed based largely on the NSW EPA's Environmental Sampling Guideline (See Appendix 1 for sampling protocols).

A call for volunteers was made through the Sandy Beach Action Group (SANDBAG) community group and through local community Facebook groups, and a total of 18 community members volunteered to assist in the sampling process. Two training events were conducted to talk volunteers through the purpose and methods of undertaking sampling, with a demonstration of the use of the sampling equipment, and a field visit to each of the sites to be sampled.

When rain was forecast and it appeared an opportunity to undertake a sample event was imminent, a text message was sent out to all volunteers asking for them to indicate their availability over the next hours. Visual assessments of instream turbidity were then conducted, with a sampling event triggered when at least one site in the upper catchment exhibited high turbidity. A follow up text was sent to all volunteers who were available, and a sample event proceeded. A visual assessment of relative flows and relative turbidity was recorded at the time of sample collection. Since these were relative values, and given that we had no baseline understanding of flow characteristics prior to the initiation of the project, flows during the initial sample collection event were not recorded. Site E was downstream of a confluence of two tributaries, one from the north and one from the south, so visual assessments were made for each of these tributaries.

Samples were then sent for analysis to ALS Environmental Sydney, a National Association of Testing Authorities (NATA) registered laboratory. Given the plethora of chemicals potentially used and the high cost of analysis, chemical groups to be analysed were chosen based on known or suspected use within the catchment, with a particular focus on those with high toxicity and/or high persistence in the environment.

Site selection and sample initiation

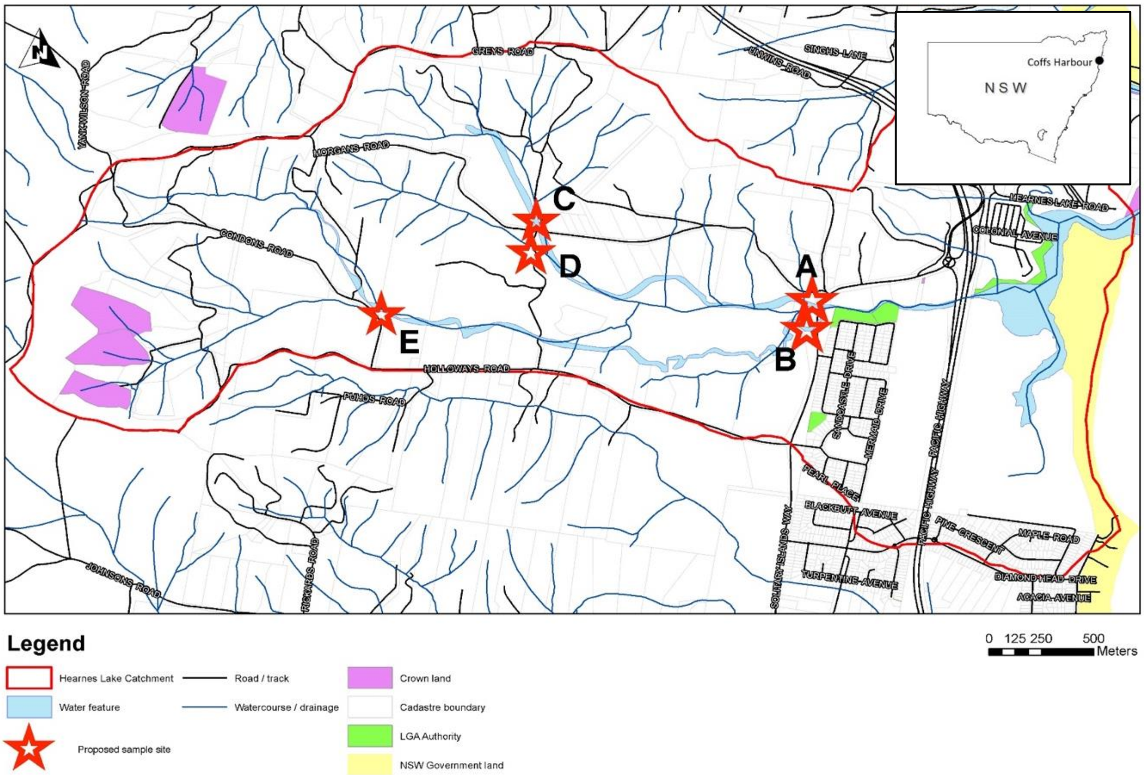
Water samples were collected during rainfall-induced flows at 5 sites in the catchment of Hearnes Lake, 3 times throughout the year, providing three snapshots of levels of chemical contamination in tributaries feeding into Hearnes Lake.

The five sampling sites were selected giving consideration to public access, volunteer safety while undertaking sampling and with a view to reflect the quality of water flowing from different sub-catchments (see Figure 1).

Sample sites were as follows:

Site A	Site B	Site C	Site D	Site E
Double Crossing Creek near Solitary Islands Way	Houp Gully near Solitary Islands Way	Double Crossing Creek on Morgans Rd	Unnamed tributary of Double Crossing Creek on unnamed road off Morgans Rd	Houp Gully near Condons Rd

Figure 1 – Sampling locations



Upstream sites were sampled first, contrary to usual practice. Downstream sites are usually sampled first to avoid any contamination from disturbed upstream sites, however previous work indicated that the upper catchment headwaters have been the main source of metals and nutrients, and it was preferable to sample upstream sites first, as, in the steep headwater reaches of the catchment, rain events cause sediment runoff and turbid plumes that will disappear faster than downstream (Conrad et al., 2021). The aim was to catch the first flush, the initial period of stormwater runoff during which the concentration of pollutants is substantially higher than during later stages (Conrad et al., 2020).

Ideally, samples would be collected when there had been chemical use in the few days previous, and preferably after a period of little or no rain. Unfortunately, reports of active spraying in the catchment were never followed by a suitable rain event. Rainfall patterns during the sampling period consisted of long periods of virtually continual rain followed by long periods of no or little rain. As a result, each sample event was ultimately undertaken during or immediately after a runoff inducing rain event that occurred after a period of no rain.

Ultimately, chemical classes chosen for analysis included organophosphorus pesticides (which would detect, among others, dimethoate, malathion and chlorpyrifos), synthetic pyrethroids (targeting bifenthrin), and multiresidue pesticides (including benomyl, boscalid, cyprodinil, fipronil and iprodione).

The requirement for the analysis for synthetic pyrethroids was discontinued after the first sample run due to funding limitations. Synthetic pyrethroids were chosen to discontinue since none had been detected in our initial samples and there was only one main target chemical (Bifenthrin) in this category.

Results

Table 1 – Pesticide detections at five sites in the Hearnes Lake catchment on 17/04/2021

Parameter	Site A DCC	Site B HG	Site C DCC/ Morgans	Site D DCC trib/ unnamed	Site E HG/ Condons	
Flow (visual)				Deep with slow flow		
Turbidity (visual)	very low	low	medium	medium	high (south trib) medium (north trib)	
Chemical (ug/L)						Guideline Level*
Benomyl	0.02	0.03			0.03	banned December 2006 (#)
Boscalid					0.08	n/a**
Dimethoate					0.03	0.15***
Fipronil					0.03	n/a**
Iprodione	0.28					n/a**
Methomyl					22.8	3.5***
Imidacloprid	0.02	0.06		0.02	0.11	n/a**

Table 2 – Pesticide detections at five sites in the Hearnes Lake catchment on 29/06/2021

Parameter	Site A DCC	Site B HG	Site C DCC/ Morgans	Site D DCC trib/ unnamed	Site E HG/ Condons	
Flow (visual)	fast	low	medium/ high	none	high and fast	
Turbidity (visual)	medium	low/ medium	medium	slightly milky	high (both tributaries)	
Chemical (ug/L)						Guideline Level*
Malathion	0.03					0.05***
Boscalid					3.8	n/a**
Pyraclostrobin					0.1	n/a**

Fipronil					0.10	n/a**
Propiconazole					0.82	n/a**
Cyprodinil					0.06	n/a**
Imidacloprid	0.05	0.01	0.43		0.2	n/a**

Table 3 – Pesticide detections at five sites in the Hearnes Lake catchment on 30/09/2021

Parameter	Site A DCC	Site B HG	Site C DCC/ Morgans	Site D DCC trib/ unnamed	Site E HG/ Condons	
Flow (visual)	low	low	low	low	medium	
Turbidity (visual)	low	low	high	high	high (north trib) medium (south trib)	
Chemical (ug/L)						Guideline Level*
Boscalid					0.6	n/a**
Fipronil					0.01	n/a**
Propiconazole					1.46	n/a**
Cyprodinil					0.10	n/a**
Methomyl					1.19	3.5***
Dimethoate					0.10	0.15***
Omethoate					0.04	n/a**

https://apvma.gov.au/node/12391
* *ANZG 2018. Australian and New Zealand Guidelines for Fresh and Marine Water Quality. Australian and New Zealand Governments and Australian state and territory governments, Canberra, ACT, Australia.*
** no guideline level developed
*** for slightly to moderately disturbed ecosystems, 95% level of species protection

Discussion

Pesticide detections

A total of twelve different pesticides were detected in waters of the Hearnes Lake catchment during this project. Most of the chemicals detected are highly toxic to a variety of aquatic organisms (see Table 4). Methomyl is highly toxic to humans and other mammals, such as dogs. Iprodione is suspected of causing cancer, as is benomyl.

Dimethoate, fipronil, iprodione, methomyl, malathion, propiconazole and omethoate are all included in the National Toxics Network's list of Australia's most dangerous pesticides (Immig, 2010). Of these, the use of dimethoate, fipronil, methomyl, malathion, propiconazole and omethoate are currently under review or proposed to be reviewed by the Australian Pesticides and Veterinary Medicines Authority (APVMA) (Immig, 2010). Benomyl, dimethoate, fipronil, imidacloprid, iprodione, methomyl, omethoate and propiconazole are all not approved for use in the European Union (European Commission, 2022). Benomyl has been illegal to supply or use in Australia since 2006 (APVMA undated). Both registrants (DuPont (Australia) Ltd and Farmoz Pty Ltd) sought voluntary cancellation of the APVMAs approvals for their benomyl products prior to this (APVMA undated), possibly in response to potential foetal teratogenicity effects, after a woman who had been exposed to Benlate (benomyl) gave birth to a son with no eyes (Health Council of the Netherlands, 2004).

Table 4 – Type, toxicity and possible use of pesticides detected in the Hearnes Lake catchment

Chemical	**Type**	**Use (list is incomplete)**	**Toxicity**	**Toxicity reference**
Benomyl	benzimidazole fungicide	Banned for sale or use in Australia since 2006	Very toxic to aquatic organisms Possible human carcinogen, liver toxicity, foetal development toxicity, reproductive toxicity	National Center for Biotechnology Information (2022) US EPA (2001) Benomyl RED Facts
Boscalid	carboxamide fungicide	berries* cucumber^+ tomato-	Moderately-to-highly toxic to fish and aquatic invertebrates	Aubee, C. and D Lieu, (2010)
Cyprodinil	anilinopyrimidine fungicide	berries* cucumber^+	Very toxic to aquatic life, with long lasting effects	Cayman Chemicals Cyprodinil Safety Data Sheet (2021)
Dimethoate	organophosphate insecticide	berries* bananas~ cucumber+	Adversely impacts many organisms,	Van Scoy, A., Pennell, A., and

		tomato-	including plants and birds; aquatic organisms expected to be highly impacted	Z. Xuyang (2016)
Fipronil	N-phenylpyrazole insecticide	bananas~	Very toxic to aquatic life, with long lasting effects	Genfarm fipronil 200 insecticide Safety Data Sheet (2020)
Imidacloprid	neonicotinoid insecticide	bananas~ berries* cucumber+ tomato-	Acutely hazardous to bees	National Registration Authority for Agricultural and Veterinary Chemicals (1994)
Iprodione	dicarboximide derivative fungicide	berries* cucumber^ tomato-	Very toxic to aquatic life; also suspected of causing cancer	Safety Data Sheet for 'Apparent' Iprodione 500 fungicide (2019)
Malathion	organophosphate insecticide	cucumber+ tomato-	Highly toxic to many fish and aquatic invertebrates	ANZG (20180
Methomyl	oxime carbamate insecticide	berries* cucumber^ tomato-	Moderately to highly toxic to fishes and very highly toxic to aquatic invertebrates; highly toxic to birds and mammals; highly toxic to humans Fatal if swallowed, very toxic to aquatic life with long lasting effects	Van Scoy, A., Yue, M., Deng, X., and R. S. Tjeerdema (2013) European Chemicals Agency (2021)
Omethoate	organophosphate insecticide, also a breakdown product of Dimethoate	bananas~	Toxic to bees, very toxic to aquatic life with long lasting effects	4Farmers Omethoate 290 insecticide Safety Data Sheet (2017)
Propiconazole	triazole fungicide	berries* bananas~	Very toxic to aquatic organisms; may	4Farmers Propiconazole 500 systemic

			cause long term adverse effects in the aquatic environment	fungicide Safety Data Sheet (2015)
Pyraclostrobin	carbamate fungicide	berries* bananas~	Highly toxic to aquatic organisms	Huang, X., Yang, S., Li, B., Wang, A.,Li, H., Li, X., Luo, J., Liu, F. and Mu, W. (2021)

* Simpson, M. (2019). Berry Plant Protection Guide. NSW Department of Primary Industries, a part of NSW Department of Industry.
^ Anon. (2020). Cucumber. Strategic Agrichemical Review Process (SARP). September 2020. Hort Innovation Project – VG 18004.
~ Anon. (undated). Australian Pesticides and Veterinary Medicines Authority. Public Chemical Registration Information Search "bananas"
+ Anon. (undated). Australian Pesticides and Veterinary Medicines Authority. Public Chemical Registration Information Search "cucumber"
- Anon. (undated). Australian Pesticides and Veterinary Medicines Authority. Public Chemical Registration Information Search "tomato"

Imidacloprid, a neonicotinoid insecticide, was detected on the first and second sampling events at four of five sites each event. It is one of a group of neonicotinoids currently under review by the APVMA focussing on the potential for unacceptable environmental risk for non-target invertebrates (including pollinators), birds and small animals, toxicity to fish and aquatic degradation (APVMA, 2019). It has a wide variety of uses, including in horticulture and termite control. Van Dijk et al. (2013) used extensive available monitoring data on the abundance of aquatic macro-invertebrate species, and on imidacloprid concentrations in surface water in the Netherlands to show a significant negative relationship between macro-invertebrate abundance and imidacloprid concentration. Chronic contamination by a pesticide with such wide ranging and unacceptable environmental impacts can only have a degrading effect on the integrity of both the aquatic and terrestrial ecosystems impacted.

Fipronil was detected on all three sampling occasions at Site E, as was boscalid and methomyl. Of these, boscalid is the most benign, being considered moderately-to-highly toxic to fish and aquatic invertebrates. However, boscalid degrades slowly in aquatic systems and may persist in water (Aubee and Lieu, 2010), posing a threat to the downstream aquatic life including Hearnes Lake. Both fipronil and methomyl are very toxic or very highly toxic to some components of aquatic life, and both have long lasting effects**.** The repeated detection of methomyl and especially, on one occasion at a concentration nearly seven times that of the ANZECC Guidelines (for a 95% level of species protection in slightly to moderately disturbed ecosystems) (ANZG, 2018) is particularly concerning given it is highly toxic to birds, mammals and humans as well as aquatic life. Laicher et al (2022), in a recent study of pesticides in the Houp Gully waterway, also detected methomyl over the Guideline value, at 5.6 µg/L.

Omethoate is a pesticide in its own right, but is also the major degradation product of dimethoate (Van Scoy et al., 2016). Both are highly toxic to honey bees, birds and freshwater invertebrates (US EPA, 2006). For mammals, omethoate is about 10 times more toxic and a more potent cholinesterase inhibitor than dimethoate (FAO/WHO, 1997; Hassan et al., 1969).

Knowledge of the occurrence and toxicity of pesticide degradation products, known as transformation products (TPs), is limited. While some pesticide transformation products are known to persist in the environment, there is generally a lack of toxicity data (van Zelm et al., 2010). Mahler et al. (2021) found more TPs than parent pesticides (116 vs 108) in their study involving 3700 samples from 442 small urban streams in the USA, and the breakdown products of fipronil was one of the most frequently detected. They concluded that the potential aquatic effects of pesticide TPs could be underestimated by an order of magnitude or more. While many TPs are less toxic to aquatic life than the parent, some are more toxic (USGS, 2021). Chenyang et al. (2020) found approximately 50% of the TPs of four pesticides (including Malathion) exhibited stronger endocrine disrupting effects than their corresponding parent compounds. Benomyl is primarily metabolised to the more toxic carbendazim (Chapin, 2014). Menger et al. (2021) found some TPs at higher concentrations than their parent pesticides, and some TPs present in the environment without the co-occurrence of their parent pesticide, which may indicate a higher persistence or mobility of TPs. The presence and toxicity of other TPs in the waterways of Hearnes Lake is unknown.

Propiconazole, Cyprodinil, Dimethoate were all detected twice at site E, with Omethoate, Benomyl and Pyroclostrobin being detected once. In total, ten different pesticides were detected at this site over the three sampling events. Pesticides are known to interact with each other in various ways, including by influencing each other's toxicity, and the joint effects may deviate from the additive predictions (Hernández et al., 2017). For example, Zhang et al. (2022) found combinations of chlorpyrifos, imidacloprid and thiamethoxam showed additive or synergistic effects, and their research showed that the mixed toxicity of those insecticides had a significant effect on bumblebees. It is reasonable to expect that the mixture of pesticides found at this site would have both additive and unpredicted synergistic effects on the toxicity of each other.

Patterns of pesticide detection

There are several factors contributing to the type, frequency and distribution of pesticide detections. Timing and type of pesticide application, and the environmental behaviour of each pesticide, eg water solubility, adsorption to sediments, and photo degradation rates determine which pesticides may be present when a rain event occurs. Slope, geology and vegetation cover will all influence the amount of runoff caused by a rain event to enter a waterway. And the timing of the rain event (in relation to previous pesticide application) and amount and intensity of rain received on the catchment will determine whether and when overland runoff will occur and whether the runoff will contain pesticides.

Rainfall records from the Australian Bureau of Meteorologies' Lower Bucca rainfall observation station (Appendix 2), situated approximately 8 km west of Hearnes Lake catchment, show antecedent rain patterns and the rain events which triggered overland flows and thus sample collections. February and March were quite wet months, then in April there was a period of dry weather then a fairly short rain event which triggered the first sampling. The rain had ceased by the time sampling was completed. Lower Bucca recorded 20 ml on that day, and, while rainfall in the area can be extremely localised, this amount is consistent with 2 of 3 community members' home rain gauge recordings (with the third recording less than 20 ml). This demonstrates how small rainfall events cause overland runoff to reach the creek system, at least at Site E, whose high turbidity triggered the sampling event. Both the sample in June and the one in September followed a month or so of little and infrequent rain before sample collection was triggered. Lower Bucca recorded 37.2 ml and 36.2 ml respectively at 9 am on the days after sample collection, however, since samples on these dates were collected at approximately 9 pm the previous evening, some of this rain may have fallen after sample collection.

The most obvious and alarming pattern was the repeated detection of multiple pesticides (at least 6 per sample) at Site E. This site always exhibited a high turbidity, at least in one of two branches immediately upstream of the sample site, and was always the trigger for the initiation of a sampling event. Our results are consistent with those of Laicher et al (2022) who detected 9 pesticides at a site upstream of Site E. Aerial photos show significant agricultural development upstream of this site, most of which has been identified as blueberry farms (Conrad et al., 2019a). There also appears to be minimal riparian buffer zones present. Other catchment conditions, including slope and soil type may also influence the excessive flushing of pesticides at this site during rain events. It is possible that this type of landscape is not suitable for intensive agricultural practices.

Site A had the next most contaminated sample, with 3 pesticides detected on the first sampling run. This was despite the turbidity level being recorded as 'very low'. Site A is further down the catchment than Site E and on a different arm (Double Crossing Creek rather than Houp Gully), is some distance from any intensive agriculture and has much more extensive riparian vegetation immediately upstream of the site. As this sampling event was triggered by very little rain (20 ml at South Bucca), it is possible that any overland runoff originating in farmed land upstream had not had time to reach this site prior to sample collection (as suggested by the low turbidity), and the pesticides that were detected may have originated from hothouse discharges. This contrasts with Laicher et al (2022) who found a potential relationship between turbidity and concentrations of imidacloprid.

A difficulty in interpreting and comparing results from Site E and Site A is inherent in the sampling process used. These sampling events detect the concentration of pesticides in the stream at a singular point of time. Pesticide concentrations may well have been higher at any of the sites during the runoff event, either before or after sample collection.

Another significant pattern was the repeated spatial and temporal detection of imidacloprid, indicating widespread and possibly frequent contamination of the catchment waterways with this pesticide. Laicher et al (2022) also detected imidacloprid most frequently (alarmingly, at a maximum of 294 µg/L), at 5 out of 6 study sites during their summer/autumn sampling in 2019, and at two sites (including at a site upstream of our Site E) both before and after a single rain event in spring 2019. These were also the only two sites within close proximity to hothouse horticulture, however, during their summer autumn sampling period imidacloprid (and methomyl) was detected at five of their six sites including their two most downstream sites, which are not in close proximity to any active farming or horticultural activities. This is consistent with our findings and suggests that imidacloprid is persisting in the waterway at least until near the upstream entrance to Hearnes Lake estuary. Further research on the origins of imidacloprid (and, in respect to the results of Laicher et al, dimethoate and methomyl), the quantity of these pesticides that reaches Hearnes Lake, and the impacts of these pesticides in Hearnes Lake are required.

A subsequent study conducted by the EPA in response to our findings found low levels of imidacloprid in the Houp Gully tributary of Hearnes Lake (NSW EPA, 2022), but no other pesticides were detected. This is in contrast with the multiple pesticides detected by us at every stormwater sampling event at the Houp Gully site (Site E). The EPA samples were collected on 30 November 2021. Rainfall data (Appendix 2) shows just 2 mm falling on the three day period (28^{th} to 30^{th}) preceding the day of sample collection. It is possible that EPA samples were collected during baseflow conditions and the source of imidacloprid could have been discharges from hothouses. This scenario may also explain the multiple detections of imidacloprid found across the catchment in this study. This is supported by the results of Laicher et al (2022) who found imidacloprid (and dimethoate) not just across several sites in summer autumn but also, they were the only two pesticides detected during their dry season (spring) samples collected before and after rain.

Environmental impact considerations

Information on the aquatic ecosystem condition or the impacts of pesticides entering the catchment waters of Hearnes Lake is limited, however, assessments of the macroinvertebrate assemblages at two sites in the Hearnes Lake catchment waterways have been undertaken.

Aquatic macroinvertebrates are comprised mostly of aquatic insects (including aquatic larval stages) but also include crustaceans, molluscs, and worms which live at least part of their life within a body of water. They are important members of aquatic foodwebs, feeding on bacteria, algal and plant material and other animals, and becoming food for others such as fish and aquatic birds. Macroinvertebrates can live in a river reach for an extended period of time, and as a result their health reflects the impacts on the ecosystem over an extended period of time (Ryder et al., 2016). This makes them highly suitable as an indicator of chronic pollution.

An assessment of macroinvertebrate populations in one study conducted from 2018 to 2020 at a site approximating Site E, demonstrated negative impacts on the local macroinvertebrate communities from both toxic and nutrient contamination (Judy Davies, pers. comm.).

At a site further downstream and much closer to Hearnes Lake (approximately just downstream of Sites A and B), macroinvertebrate assemblages were collected in autumn and spring 2015. The site was also assessed for habitat condition, and rated very highly, particularly due to vegetation:channel width ratio, proximity to larger tracts of remnant native vegetation, large and hollow-bearing trees, and the presence of all structural layers. However, the site was rated very low for macroinvertebrate condition. It was concluded that this indicated the water quality and habitat conditions in the freshwater reaches of Hearnes Lake were in very poor condition (Ryder et al., 2016).

The value of the contribution of macroinvertebrates to aquatic ecosystem function is underappreciated. They are a variety of different organisms, and they have a variety of feeding techniques, and may be grazers, shredders, gatherers, filterers, or predators. They will utilise food washed downstream or growing within the stream and convert it into other forms which other organisms rely on as a food source, and can have an important influence on nutrient cycles, primary productivity, decomposition, and translocation of materials (Wallace and Webster, 1996).

The impoverished nature of macroinvertebrate assemblages in Houp Gully and Double Crossing Creek would inherently disrupt the composition of the typical dissolved and particulate food sources being carried by freshwater flows downstream and into Hearnes Lake. It would also significantly modify the contribution of benthic drift to downstream ecosystem function. Benthic drift is a means of recolonising downstream environments through being washed by the currents to new downstream sites. Since macroinvertebrates also constitute an important source of food for many fish, this would not only reduce the food transformation capacity of downstream benthic assemblages, it would also reduce the quantity of food available for those organisms that predate on macroinvertebrates. These impacts would extend into the Hearnes Lake environment.

An important component of the Hearnes Lake ecosystem are the macroinvertebrates found in the soft sediment unvegetated habitats. These are a vital food resource for higher level predators such as fish, crabs and birdlife. Ryder et al. (2016) show that despite having very high quality habitat at their site just upstream of Hearnes Lake, it supported a very poor assemblage of macroinvertebrates. This may be the result of ongoing repeated pesticide (and nutrient) pollution pulses washing through the waterways to Hearnes Lake, as repeated pesticide pulses have been found to increase harmful effects on stream macroinvertebrate biodiversity and function (Wiberg-Larsen et al., 2021). It is not unreasonable therefore to consider that the important macroinvertebrate assemblages within Hearnes Lake could also be similarly greatly depleted by repeated exposure to pollution. In addition to deleterious impacts on population numbers and diversity of all the aquatic organisms in Hearnes Lake (and the predators that feed on them), bioaccumulation and biomagnification of pesticides may also occur via the transfer of pesticides through the food web. This would present a risk to predators such as the Threatened Eastern Osprey and the Endangered Little Tern, a colony of which nests near the shore of Hearnes Lake in summer. The Little Tern eats small fish, insects, crustaceans and other invertebrates, and prefers to feed over shallower coastal waters, making Hearnes Lake a perfect feeding ground.

Hearnes Lake is also home to prawns and oysters, and research by Southern Cross University marine science professor Kirsten Benkendorff has found residues of neonicotinoids (such as imidocloprid) above the safe residue limits in prawn flesh and in water in Hearnes Lake (Davies 2022). Furthermore, recent laboratory studies on the impact of imidacloprid on prawns and Sydney Rock Oysters found sub lethal impacts at around 1 to 5 ug/l, resulting in nutritional deficiency and reduced flesh quality in black tiger prawns, and weakening of the immune system in Sydney Rock oysters (Honan 2020). The research also showed that the imidacloprid accumulates in the flesh of prawns and oysters, potentially then being eaten by a myriad number of species across the food chain in the Hearnes Lake estuary and environs, including unaware human consumers.

As an ICOLL, Hearnes Lake is often blocked from tidal exchange with the ocean, making it especially vulnerable to pollutant accumulation. It has been recognised that the lack of regulation of agricultural practices across the upper catchment has resulted in detrimental impacts to water quality and sedimentation across the ICOLLs north of Coffs Harbour, including Hearnes lake (Beadle and Sanborn, 2020). The impacts of this persistent pollution on the biological assets of the Lake are unknown.

Hearnes Lake is classified as a Habitat Protection Zone within the SIMP. Habitat protection zones are zones intended to conserve marine park values by protecting physical and biological habitats through the control of high impact activities. While this zoning recognises the value of the Hearnes Lake habitat, there is no recognition of the potentially severe damage from water pollution and no mechanism to protect the high value habitat of Hearnes Lake from water pollution.

Hearnes Lake, when open to the ocean, discharges just south of Flat Top Point. Flat Top Point has the highest relative diversity of any coastal Rocky Shore in the SIMP, is the site of the most southerly coastal record of the giant clam and is also rich in molluscs (Marine Parks Authority NSW, 2008). Flat Top Point has been classified as a Sanctuary Zone within the SIMP, which is intended to provide the highest level of protection to this habitat and its biodiversity. This is achieved through controls placed on activities within the zone, but there is no capacity to provide protection from sources of water pollution.

For high conservation or ecological values ecosystems, such as Flat Top Point, ANZECC Guidelines recommend there should be no change in biodiversity, and where possible, no change in water/sediment physical and chemical properties, including toxicants (ANZG, 2018). The levels of toxicants passing through Hearnes Lake from the upper catchments, and discharging at Flat Top Point, has not been assessed.

Conclusions and recommendations

Sampling and analytic process
The community-based process of monitoring stormwater for pesticides in local waterways proved effective, requiring at least one person to lead, manage paperwork and collate and disseminate results, a back-up person capable of taking over organisational responsibilities when necessary, and enough committed volunteers to ensure that at least two people are available for sampling (a sampling event may be triggered at any time). The community-based sample collection process developed for this project could easily be adapted by other community groups who are concerned about the possible presence of pesticides in their local waterways, however some improvements can be made.

Site selection
The two patterns of pesticide detection in this study (ie, many pesticides at one site, and one pesticide (imidacloprid) repeatedly at many sites) point to sites worth focusing on in other catchments. Areas with high levels of intensive agricultural development, high slope and low vegetation or riparian cover; and hothouse discharges are both implicated by the results of this study as sources of chronic pesticide discharge.

Sample event triggers
Several factors need to be considered when deciding whether sample collection should be initiated by a stormwater runoff event. These include antecedent rain, seasonal chemical use patterns, and known chemical use events. Ideally, samples would be collected from a runoff event when there had been known chemical use in the few days previous, and after a period of little or no rain.

An idea of seasonal chemical use patterns requires identifying crops and/or varieties grown in the catchment. Documentation outlining pesticide type and use patterns is available for some crops. For example, the 'Berry Plant Protection Guide' (Simpson, 2019), produced by the NSW Department of Primary Industries, provides information on pests and diseases on various berry types, their seasonal impact in the growth cycle (i.e. flowering, harvest and post-harvest), and recommendations of pesticide use. In the absence of documentation, discussions with people within the industry can assist. Even a stroll through the local farm supplies shop can help identify which pesticides could be being used in the area.

Observations of spraying activity in the catchment can prompt a sample event especially if a suitable rain event occurs in the few days post application. It may also be beneficial to time sampling to occur after known spraying events even if a suitable rain event doesn't occur (Laicher et al., 2022).

If a pesticide is being discharged from hothouses, its presence in catchment waters may be independent of rain events and possibly present throughout the period of hothouse use. Thus the timing of sampling events targeting hothouse discharges can be determined through knowledge of crop type, growth cycles and pesticide requirements. This will also make it easier to organise and undertake sampling, as the timing will not be dependent on rain events.

Pesticide results
Twelve different pesticides were detected in waters of the Hearnes Lake catchment during this project. Most of the chemicals detected are highly toxic to a variety of aquatic organisms,

and some to honey bees, birds, humans and dogs. One substance banned since 2006, suspected to cause foetal abnormalities, was detected. One substance, considered highly toxic to humans, was found at nearly 7 times the ANZECC water quality guideline (for a 95% level of species protection in slightly to moderately disturbed ecosystems). One site contained a mixture of at least 6 different pesticides on every sampling event, posing additive and synergistic risks of increased toxicity.

It is alarming that it took just an estimated 20 mm of rainfall to induce runoff laden with multiple pesticides at one site. This implies the possibility that every time 20 ml or more rain falls on this part of the catchment, a cocktail of pesticides is entering Houp Gully. A minimum of 20 ml of rain (preceded by at least one dry day) was recorded 18 times at the Lower Bucca site in 2021 (see Appendix 2), giving rise to the possibility of 18 pollution events that year alone.

The presence of imidacloprid at several sites in both Double Crossing Creek and Houp Gully on one date suggests multiple sources of this pesticide. Current accepted methods for management of this chemical appear inadequate to prevent ongoing pollution to downstream environments.

If a pesticide is being discharged from hothouses, its presence in catchment waters will be independent of rain events and possibly present throughout the period of hothouse use. Further monitoring for imidacloprid independent of rainfall events, and during the appropriate growing season, is recommended. Concurrently, analysis for nutrient loads may be considered since levels of excess fertilizer may also be being discharged.

The load of pesticides being carried towards Hearnes Lake cannot be calculated since the duration and peak of contamination, and the flow volume at the time, is unknown. Since sample collection where Double Crossing Creek discharges into Hearnes Lake could not be undertaken due to access and safety issues, the level of contamination reaching Hearnes Lake is unknown. To successfully sample in Hearnes Lake, however, would require an accurate prediction of flow times between potential pesticide source and the sampling site, or a continuous, multiple sample collection process aimed at capturing the first flush of the rain event.

Environmental implications

The range and frequency of pesticide detection in this study is highly concerning. The most significant adverse effects of these pesticides are likely to be on those invertebrates that are closely related to target pest species. Macroinvertebrate assemblages, being comprised mostly of aquatic insects, are highly vulnerable. Because insects can play a “keystone role” in many ecosystems, the structure and composition of an entire ecosystem can be impacted. The poor condition of macroinvertebrate assemblages found at sites in Houp Gully and Double Crossing Creek demonstrates the impact of ongoing pesticide pollution in the catchment, but the consequences of those impacts on the ecology of the catchment waters and Hearnes Lake are unknown. However, the potential loss of biodiversity through the lethal and sub-lethal impacts on aquatic organisms both upstream and within Hearnes Lake will likely reduce the resilience of Hearnes Lake and its associated ecosystems, leaving them vulnerable to further degradation.

Aside from the environmental impacts, pesticide pollution of Hearnes Lake also presents a potential Public Health risk to community members who use the waterbody for swimming, fishing and boating, and to anyone eating seafood sourced from Hearnes Lake.

Ryder et al (2016) assessed the condition of the riparian vegetation in Hearnes Lake as good. Previous work has identified a rich diversity of estuarine habitats in Hearnes lake, including mangroves, saltmarsh and fringing sedgelands and saltmarsh, and has noted that areas immediately fringing the lake mostly contain native vegetation (BMT WBM, 2009). The presence of healthy riparian vegetation around Hearnes Lake and sections of the freshwater creeks indicate that these ecosystems have the capacity to recover in the absence of chronic aquatic pollution. The protection and restoration of Hearnes Lake would provide valuable recreational opportunities for our local communities, restoring opportunities for gathering oysters, prawning, crabbing, fishing, boating and swimming. Recreational fishers within the SIMP would also benefit from protection of fish nurseries in the longer term. In addition, it will contribute to the protection of the high biodiversity of the Flat Top Rock region of the SIMP.

There is a lack of adequate governing mechanisms to prevent ongoing pollution to Hearnes Lake and the SIMP. Neither the NSW Marine Parks Authority, who manage the SIMP, or the CHCC appear to have a mechanism to prevent pollution of Hearnes Lake and its waterways. While the NSW EPA can prosecute for detected discharges of pesticides into the waterways of Hearnes Lake, they can only do so by specifically targeting sites and allocating time and resources into the collection, handling and processing of samples and the application of the appropriate legislation. This process in no way ameliorates the negative impacts of those pesticide pollution events, and our results indicate that there are in all probability many pesticide pollution events that remain undetected. The solution doesn't lie in actions taken after the pollution event, but in preventing those events from occurring.

One mechanism which may be effective in reducing pesticide contamination of waterways would be the implementation of a CHCC requirement for Development Applications for intensive plant horticulture and hothouse horticulture. These could stipulate protective mechanisms such as adequate riparian buffer zones, setback limits on proximity of infrastructure to waterways and on-site water recycling systems.

This, however, would not address ongoing contaminations from already established farms. Improving current on-farm management, including the capture and treatment of all wastewater, ensuring chemical mixing sheds and storage areas are well away from waterways, and a change to the use of safer, newer pesticides with less environmental impacts would also assist greatly.

Mechanisms introduced to eliminate pesticide contamination of the Hearnes lake catchment waterways would contribute to the protection of the SIMP, Hearnes Lake and its tributaries from pesticides, and also act to reduce the additional extensive pollution by nutrients and sediments identified in previous research.

The significant loads of pollution entering Hearnes Lake waterways demonstrate that current management and methods of Intensive Plant Production make it an unsustainable agricultural pursuit in the catchment. Rather, this form of agriculture is a current and on-going threat to the integrity of the Lake ecosystem, and thus both its important natural and community values. One local researcher (Proff. K. Benkendorff) has been quoted as stating

“Hearnes Lake isn’t dead but it’s nearly dead” (Davies 2022). This situation is damning evidence of a failure of will or capacity by the responsible authorities, and the relevant agricultural industries, to act decisively to protect this section of the SIMP and its irreplaceable environmental and community assets. Hearnes Lake should not be sacrificed for the immediate profit of the few, but be protected and restored for the benefit and enjoyment of the many, its diverse environmental values secured in perpetuity.

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Personal Communications

Judy Davies is conducting macroinvertebrate assessments in waterways of the Coffs Harbour region, including Hearnes Lake, supported by Coffs Harbour City Council Environmental Levy funding.

APPENDIX 1

HEARNES LAKE CATCHMENT SAMPLING PROTOCOLS

PURPOSE

A wide variety of chemicals, including pesticides, herbicides and fungicides are used in the Hearnes Lake catchment. Many are toxic to aquatic organisms including fish. An investigation of a fish kill in Hearnes Lake in 2018 by the NSW EPA found high levels of the pesticide chlorpyrifos in the dead fish, and an ensuing investigation uncovered 25 cases of non-compliance with chemical handling regulations within the Hearnes Lake catchment.

This project aims to identify types and sources of agricultural chemical pollution flowing into Hearnes Lake during rain events, to inform and prompt more effective chemical management.

This will be achieved by taking water samples from streams discharging into Hearnes Lake (5 sites 3 times through the year) during or immediately after rain events and analysing for a suite of agricultural chemicals (OP Pesticides, Synthetic Pyrethroids by GCMS and Pesticides by LCMSMS). Health and safety requirements will be maintained by always sampling in pairs, wearing hi vis vests and carrying mobile phones, and assessing sites for risks prior to each sampling event. Results will be provided to the NSW EPA with a request to follow up on detected pollution. Results will also be provided to the CHCC and to local agricultural industry representatives to facilitate targeting and encouraging more effective chemical management practices.

SITE SELECTION AND TIMING

Sites were selected at several locations upstream of Hearnes Lake, and located where possible immediately upstream of confluences from both converging streamflows, giving an opportunity to more closely identify the source area of any contaminants found.
All sites are on publicly accessible land, often where a road crosses a waterway. Most sites are a very short distance from vehicle access.

Sites are located as follows:

Site A: Double Crossing Creek at Solitary Islands Way -30.13613 153.18707°
Site B: Houp Gully at Solitary Islands Way -30.13723 153.18765°
Site C: Double Crossing Creek at Morgans Rd -30.13308 153.17583°

Site D: Double Crossing Creek Tributary at unnamed rd -30.13448 153.17578°
Site E: Houp Gully at Condons Rd -30.13678 153.16895°

See map for further details.

INFORMATION FOR SAMPLERS: FIELD SAMPLING PROTOCOLS

All volunteers involved in sampling are to be taken through training on appropriate sampling methodologies, safety considerations and paperwork management.

SAFETY

Sites were assessed for safety and chosen to avoid steep, slippery or heavily vegetated banks. Other potential hazards have been considered and risk control measures implemented for each identified risk, as follows:
Slip trip or fall – wear sturdy boots with non slip soles, move slowly, do not sample if site cannot be reached safely
Stings or bites – use insect repellent
Weather – wear wet weather gear
Fatigue – do not sample if tired, allow another volunteer to undertake the sampling
Contamination from sample handling – wear disposable gloves
Manual handling – bend knees when lifting eskies, although they shouldn't be too heavy
Working alone – Never work alone
Public harassment – always carry a phone, do not engage with harasser, never sample alone.
Drowning – flows are quite small and shallow
Vehicles – wear hi vis vests

SAMPLING EQUIPMENT

Clean sample bottles have been provided by the NATA registered laboratory that will perform the analysis, and are a suitable type and size for the required analysis.

Before undertaking a sampling event, check the following field equipment checklist to ensure you have all the equipment.

Field Equipment Checklist
Map of site locations
Field data sheet
Clipboard and waterproof pen/pencil
Extendable sampling pole and sampling pole bottle
Esky with ice bricks for transport
Bottles – 2 orange label and 1 green label per site
First aid kit
Disposable gloves
Mobile phone, charged

COLLECTION

Before undertaking sampling, reassess the site for risks. Do not proceed if there are risks that cannot be sufficiently mitigated.
Always have a contact person you can ring in case of safety problems occurring.

Bottle labels are already affixed and include the following information:

- Client/ref:
- Sampled by:
- Sample ID:
- Date/time:

Fill out bottle labels with a waterproof pen prior to sampling to avoid the label being too wet to write on.

Samples should be collected at near surface (<0.2m) toward the middle of the streamflow if possible, without disturbing bottom sediments. Avoid pooled areas, backwaters and areas of excessive turbulence.

The sampling procedure is:

- Put on gloves
- Face upstream and work well in front or to the side of your body
- Rinse the pole downstream of the sampling site before use at each location

- Take care not to disturb the work area, avoid collapsing any part of the bank or stirring up sediment on the bottom. Sample well in front or to the side of your body to avoid self-contamination
- Collect a sample in the sampling pole bottle twice and dispose of downstream, before taking a third and final sample (this is to wash the sampling pole bottle)
- Take your glass sample bottle, remove lid and hold bottle near base
- Fill bottle almost to the top and put the lid on quite tightly
- Don't touch the inside of bottles or lids
- Keep hands away from the mouth of the bottle
- Don't place lids on the ground face down
- Only have the lid off the container for the time it takes to collect the sample
- Remember to clean the pole when back at base (using tap water and distilled water rinse)

SAMPLE STORAGE, TRANSPORT AND ANALYSIS

During the sampling process

All samples are to be placed with ice bricks in an esky and transported to the laboratory as soon as possible, via Startrack couriers. The cost is paid by the laboratory and the receiver address is prefilled. The Sender address needs to be filled out, the label attached to the top of the esky and delivered to the couriers (or a pick up booked)

Quality control of water chemistry samples is maintained with the laboratory by the use of standard analytical methods and use of NATA accredited laboratories.

Basic preservation

- Put the samples into an esky with 2 ice bricks. (or fridge)
- Let the contact person in the laboratory know that samples will be arriving soon
- Get the samples to the laboratory quickly (the samples must be analysed within 7 days, the laboratory prefers about 3-4 days to undertake analysis, and the samples are delivered to the laboratory the day after sending)

Note that where samples would otherwise be despatched on a Friday by overnight courier you should discuss the situation with the laboratory before despatch as other arrangements may need to be made.

Storage and Transport

When using coolers (and fridges) to store and transport samples:

- Have bottles in an upright position
- Use packing (e.g. bubble wrap) where necessary to keep bottles upright and prevent excessive movement (especially were glass bottles are involved)

Tape up esky before delivery/pickup by courier.

- Documentation must be delivered with the samples. If delivering by courier, documentation can be sealed inside a plastic zip-lock bag and taped to the inside of the lid. Retain the senders copy of courier's despatch slip

Cleaning & Decontamination Procedures

Decontamination of sampling equipment between samples and at the completion of the sampling event is critical. It is important to consider the likely contaminants to ensure your chosen decontamination method is adequate and – importantly – does not interfere with planned analyses.

1. Rinse the equipment thoroughly using tap water, twice.
2. Rinse the equipment thoroughly using deionised water.

DOCUMENTATION

For each sampling event, the following form was completed:

Hearnes Lake Catchment Sampling Event Data Sheet

Date:________________________________

Site A: Double Crossing Creek at Solitary Islands Way   Sample start time:_______________

Site B: Houp Gully at Solitary Islands Way   Sample start time:_______________

Site C: Double Crossing Creek at Morgans Rd   Sample start time:_______________

Site D: Double Crossing Creek Tributary at unnamed rd   Sample start time:_______________

Site E: Houp Gully at Condons Rd   Sample start time:_______________

Field Sampling Personnel ____

Start Time (24 hr) _______________________ End time (24hr) ________________

Rainfall: ☐ nil ☐ light ☐ moderate ☐ heavy in last ☐ 24 hours ☐ 2-5 days

Comments on water condition (eg clarity, odour, presence of rubbish, flow height, velocity):

____

____

____

____

Other Comments

____

____

____

Samples delivered to Courier on Date _______________at Time________________________

REFERENCES

Ryder, D. and C. Sbrocchi (2010) Ecohealth Sampling Protocols: Coffs Harbour City Council LGA.

Anon. (2019). Environmental Sampling Guideline. State of NSW and the NSW Environment Protection Authority.

APPENDIX 2

Daily Rainfall (millimetres)

LOWER BUCCA

Station Number: 059006 · State: NSW · Opened: 1901 · Status: Open · Latitude: 30.16°S · Longitude: 153.10°E · Elevation: 112 m

2021	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
1st	0	0	0	0	5.8	0	9.6	0	0	36.2	0	44.6
2nd	58.4	0	0.4	6.2	12.2	0	16.2	1.6	5.0	1.2	0.6	0
3rd	4.6	0	2.8	0	2.0	0	1.4	13.4	2.0	1.8	0	0
4th	0	0	26.2	1.8	0	4.0	0	2.0	0	0	0	0
5th	0	0	0	6.0	4.2	0	0	0	0	0	4.6	14.6
6th	6.0	0	0	15.2	17.4	0	0	0	1.6	0	2.2	37.4
7th	38.0	2.4	0	31.6	0	0	0	0	0	0	0	4.8
8th	11.8	0	0	27.6	0	0	0	0	0	0	11.8	37.0
9th	5.0	3.0	7.6	14.4	0	7.6	6.8	10.6	0	0	10.2	13.8
10th	20.2	0	2.0	0	19.6	0	1.4	0	0	0	0	20.2
11th	2.8	8.2	24.0	0	0	0	0	0	0	0.4	12.2	0
12th	0	0	0	0	1.2	0	0	0	0	35.2	12.8	0
13th	0	0	0	0	13.8	0	0	2.0	0	61.8	0	1.6
14th	0	27.4	0	0	0	0	0	0	0	15.6	0	0
15th	0	0	13.0	0	0	0	0	4.0	0.4	3.6	0	0
16th	0	11.6	0	0	0	0	6.4	0	0	5.0	0	0
17th	0	39.0	9.2	0	0	1.6	0	0	0	0	0	18.0
18th	0	20.2	28.0	20.0	0	0	0	0	0	0	0	1.0
19th	19.8	38.2	138.2	0	0	0	0	0	0	5.6	1.4	0
20th	15.6	16.6	19.6	0	0	0	0	0	0	0.8	0	0
21st	8.0	0	198.2	0	0	0	0	0	6.2	14.0	18.0	0
22nd	0	4.6	98.0	0	0	4.4	0	0	0	4.4	27.8	0
23rd	0	0	30.4	0	4.0	1.2	0	0	0	0	7.4	25.2
24th	0	66.8	0	0	0	0	1.2	4.0	0	0	41.4	29.4
25th	0	216.4	0	0	0	2.8	0	0	0	0	12.2	0
26th	0	48.0	0	0	0	1.2	0	0	0	0	6.8	16.4
27th	0	0	0	0	0	0	0	0	4.6	0	17.0	0
28th	5.0	13.4	0	2.2	0	0	0	0	0	0	0	11.6
29th	0.2		0	0	0	9.4	1.2	0	0	4.0	1.2	2.0
30th	3.6		1.8	0	0	37.2	0	0	5.6	20.0	0.8	2.8
31st	1.2		4.4		0		0	0		1.2		3.4
Highest daily	58.4	216.4	198.2	31.6	19.6	37.2	16.2	13.4	6.2	61.8	41.4	44.6
Monthly Total	200.2	515.8	603.8	125.0	80.2	69.4	44.2	37.6	25.4	210.8	188.4	283.8

Annual total for 2021 = *2384.6*mm

↓ This day is part of an accumulated total

Quality control: 12.3 Done & acceptable, *12.3* Not completed or unknown