Warrell Creek to Nambucca Heads

Giant Barred Frog Monitoring Annual Report – year three operational phase 2020/2021

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Project team:

Dr D. Rohweder (project management, survey, report writing)
Mr L. Andrews (field survey)
Dr B. Taylor (review)

Report prepared for:

Transport for New South Wales NSW

ABN: 82 084 096 828

PO Box 401
ALSTONVILLE NSW 2477
P 0401 195 480 | E **david@sandpipereco.com.au**

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1. Introduction

In 2015, Transport for New South Wales, in conjunction with Acciona Ferrovial Joint Venture (AFJV), commenced the upgrade of the Pacific Highway between Warrell Creek and Nambucca Heads (WC2NH). The WC2NH project was opened to traffic in two stages:

- Stage 2a - 13.5km section from Lower Warrell Creek Bridge to Nambucca Heads opened on 18 December 2017; and
- Stage 2b - 6.25km section from the southern end of the project to the Lower Warrell Creek bridge opened in late June 2018.

Approvals for the WC2NH upgrade required monitoring of several species and mitigation measures during the operational phase. Species monitored include koala (*Phascolarctos cinereus*), yellow-bellied glider (*Petaurus australis*), giant barred frog (*Mixophyes iteratus*), green-thighed frog (*Litoria brevipalmata*) slender marsdenia (*Marsdenia longiloba*), rusty plum (*Niemeyera whitei*) and Floyds grass (*Alexfloydia repens*). Mitigation measures monitored included green-thighed frog breeding ponds, fauna underpasses, vegetated median, and exclusion fence. Sandpiper Ecological Surveys (SES) has been contracted by Transport for NSW to deliver the WC2NH operational ecological and water quality monitoring program in accordance with the Warrell Creek to Nambucca Heads Operational Ecological and Water Quality Monitoring Brief (the Brief).

The following report details the methods and results of the summer year three operational phase giant barred frog population monitoring. The objective of giant barred frog monitoring, as outlined in the Giant Barred Frog Management Strategy (GBFMS), is “to demonstrate through the life of the Project that mitigation has maintained or improved population sizes and habitat of the giant barred frog. The use of preconstruction, during construction and post construction monitoring to measure frog distribution, abundance and habitat quality with defined thresholds will be used to measure the overall performance of the mitigation” (Lewis 2014).

1.1 Background

The giant barred frog is listed as ‘Endangered’ under both the NSW *Biodiversity Conservation Act 2016* (BC Act) and Federal *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act). The impact of the upgrade on giant barred frog was assessed in the Project Environmental Assessment (Sinclair Knight Merz [SKM] 2010). Following identification of potential giant barred frog habitat during the Project environmental assessment, Lewis Ecological conducted targeted surveys (in November 2011 and January/February 2013) (Lewis 2014). A population of giant barred frog was subsequently confirmed at Upper Warrell Creek and a management strategy prepared (see Lewis 2014).

Measures proposed to manage impacts on giant barred frogs included: population monitoring, pre-clearing surveys, temporary frog fencing during construction, clearing supervision, dewatering procedures (tadpole surveys) and permanent frog exclusion fence. Population monitoring was recommended to occur within a 1km transect in spring, summer and autumn of Year 1 and 3 of the construction phase and years 1, 3 and 5 of the operational phase using the methods applied during pre-construction baseline surveys.

Pre-construction baseline surveys for giant barred frog were conducted between 20 September 2013 and 2 April 2014. The baseline surveys recorded 47 individuals, including 22 adults (11 females & 11 males), 8 sub-adults, and 8 juveniles. Based on these results the population of giant barred frog at the Upper Warrell Creek site was calculated as 45 adults (with a 1:1 sex ratio), 19 sub-adults, and 16 juveniles (Lewis 2014b). Geolink (2018) recalculated population size for baseline (using the same data and methods as Lewis 2014b), year 1 and year 3 construction phase samples and obtained population estimates of 41 (2013/14), 7 (2015/16), and 8 (2017/18) respectively. The results suggest a substantial decline in population between

the baseline (2013/14) and year one of construction (2015/16).

During early construction work *Mixophyes* spp. tadpoles were recorded at Butchers Creek (Geolink 2015). There was some conjecture about the identification of tadpoles and targeted surveys for adult frogs and further consultation with frog specialists was undertaken in an attempt to confirm the identification. The final consensus was that the tadpoles were great barred frog (*Mixophyes fasciolatus*) and the giant barred frog was unlikely to occur at Butchers Creek (see Geolink 2015; Lewis 2015). Nonetheless, a precautionary approach was adopted and the Butchers Creek site was included in population monitoring (Geolink 2016). No giant barred frogs were recorded at Butchers Creek during the construction phase, or in year one of the operational phase (Geolink 2018; Sandpiper Ecological 2019).

1.2 Study area

The WC2NH project covers a total length of 19.75km and extends from Warrell Creek in the south to Nambucca Heads in the north (Figure 1). The alignment bypasses the town of Macksville and the northern section traverses Nambucca State Forest. The two sample sites, Butchers Creek and Upper Warrell Creek, are situated near the southern end of the alignment.

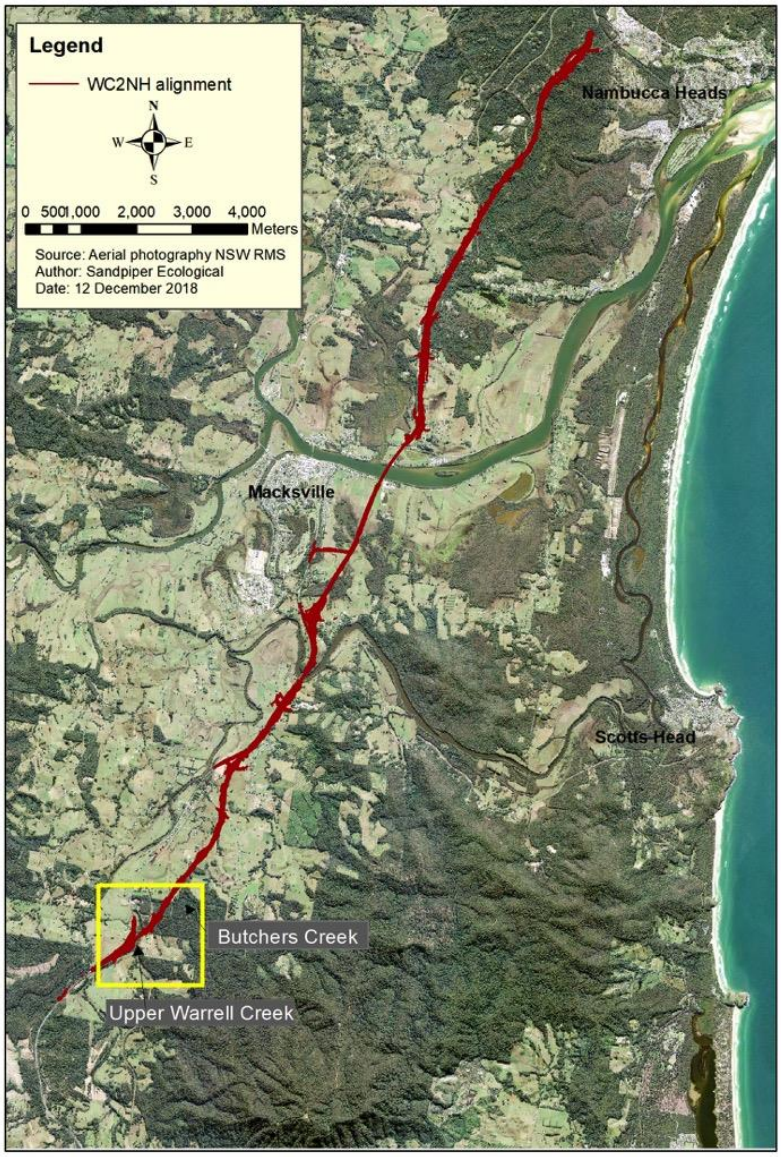

Figure 1: Location of giant barred frog sample sites in relation to the WC2NH alignment.

2. Methodology

2.1 Survey effort

Following completion of the spring year 3 operational phase survey (see Sandpiper Ecological 2020) it was agreed with TfNSW that during future surveys survey effort (i.e. person hours) should be re-distributed from Butchers Creek to Upper Warrell Creek, with effort at Butchers Creek limited to the minimum required to sample all zones. This approach was adopted in summer 2021. In autumn, the landowner at Butchers Creek refused entry as severe flooding had increased the risk of tree-fall. Consequently, Upper Warrell Creek was the only site sampled in Autumn 2021.

2.2 Frog survey

Frog surveys followed the method specified in the Brief and baseline population survey (Lewis 2014). The method involved:

1. Two ecologists conducted a nocturnal meandering foot-based traverse of each 50m survey zone on each side of the watercourse i.e. 40 zones at Upper Warrell Creek (20/side; Figure 2); and 16 zones at Butchers Creek (8/side; Figure 2).
2. Each ecologist was equipped with a 200-lumen spotlight and slowly traversed the riparian zone searching for frogs and listening for calls. Giant barred frog calls were broadcast through a 5-watt megaphone for five minutes within each zone. Both ecologists listened for call responses during and immediately after call broadcast.
3. All captured giant barred frogs were scanned with a Trovan Nanotransponder to determine if that frog had been previously pit-tagged. If the captured individual had not been pit-tagged and was deemed a sub-adult or older (i.e. >40mm snout-vent length) a tag was inserted beneath the skin on the left side and the insertion hole sealed with vet bond. The insertion point was swabbed with disinfectant prior to the tag being inserted. During operational surveys prior to autumn 2021 only frogs with a SV length greater than 60mm were PIT tagged. In autumn the size limit was reduced to 40mm to ensure consistency with baseline and construction phase surveys.
4. Data collected on each captured frog included: Survey zone (20x50m); Distance from the stream edge measured to the nearest 0.1m; Position within the microhabitat (i.e. under litter, above litter, exposed, on rock/log); Sex (male, female, unknown); Age class (adult=>60mm; sub-adult=40-60mm; juvenile=<40mm); Snout-vent length (mm); Weight (grams); Breeding condition:
    i. males assessed on the colouration of their nuptial pads (i.e. no colour, light, moderate, dark) in accordance with the classification developed by Lewis (2014b);
    ii. females assessed on whether they are gravid (i.e. egg bearing, with the typically adult weighing > 100 grams) or not gravid.
    iii. frogs with a snout vent length of <60 mm were classified as immature.

2.3 Tadpole survey

Tadpoles were sampled in spring and autumn only. In spring and autumn, a single tadpole trap (i.e. small bait trap) was set in each zone and baited with one slice of bread. Each trap was set for a minimum of three hours. Dip-netting for tadpoles was conducted by two ecologists, with a minimum of five dips in each zone. Dip-netting targeted accessible vegetated banks and rocky stream beds with a sufficient detritus layer.

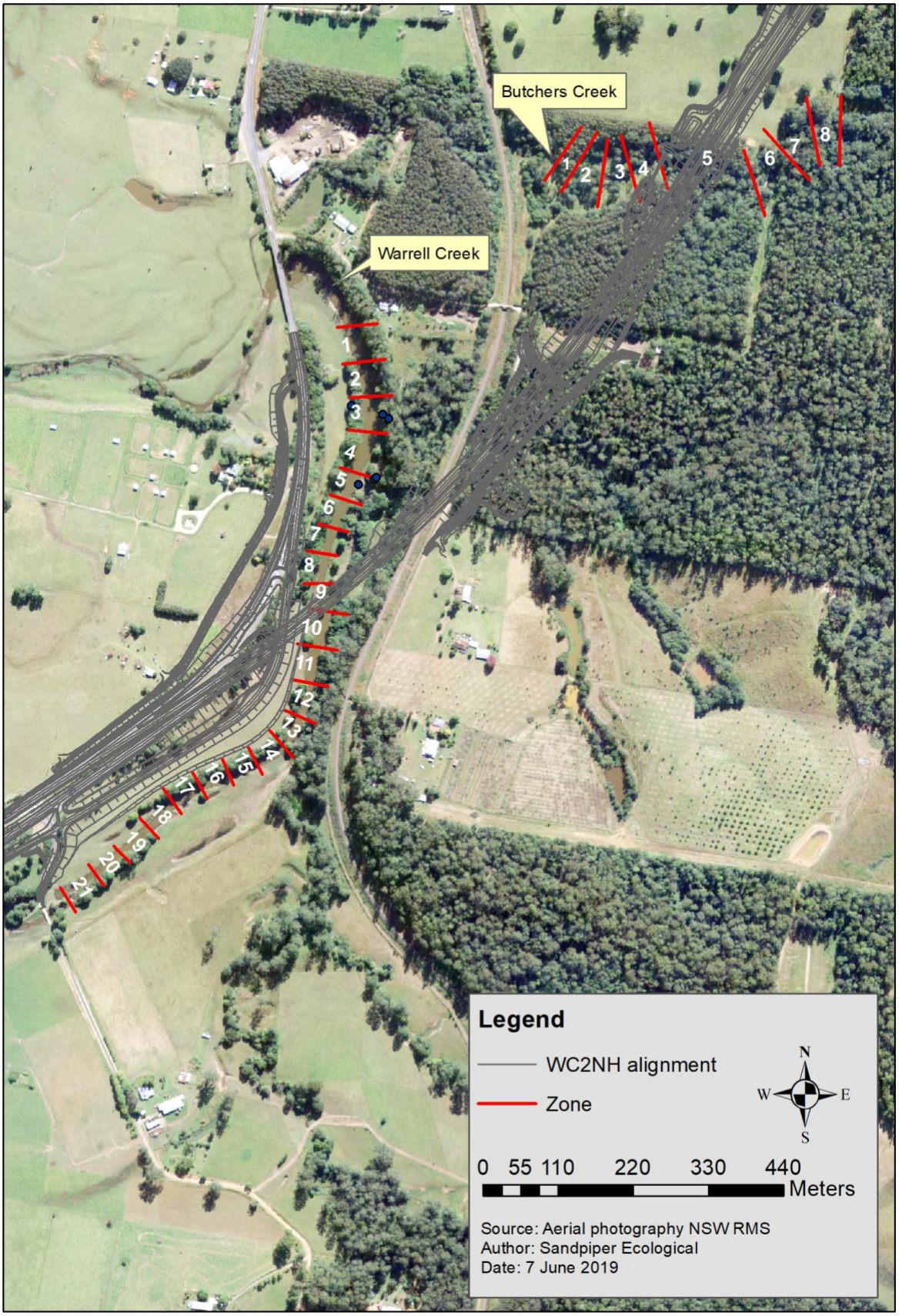

Figure 2: Survey zones within the Upper Warrell Creek and Butchers Creek sample sites.

2.4 Habitat assessment

Key habitat components in each survey zone are required to be sampled annually (i.e. once/year). Habitat sampling was conducted during the summer sample period. An ecologist conducted a meandering traverse of each zone at each site, including both banks. Habitat data recorded in each zone at each site included:

1. Land use: Description of existing land uses e.g. grazing, dairy, horticulture, conservation, private native forestry.
2. Broad vegetation type within the immediate riparian zone (primary stream bank): Riparian Rainforest, Dry Sclerophyll, Wet Sclerophyll, Sedgeland, Grassland or Cleared Land.
3. In stream physical characteristics including stream width and depth(metres), presence of pools and/or riffles, bed composition (sand, clay, rock, organic or other to be specified), and type of emergent vegetation, if present.
4. Stream bank characteristics including bank profile expressed as steep, benched or a gradual incline from the water's edge.
5. Foliage projective cover of overstorey, midstorey and ground layer vegetation on the stream bank.
6. Groundcover expressed as a percentage of vegetation, leaf litter, soil, and exposed rock.
7. Litter depth - Deep (>100 mm); Moderate (20-100 mm); Shallow (>0-20 mm); or Absent (0 mm).

2.5 Water quality

Water samples and field measurements were taken at approximate locations E: 489301 N: 6594447 at Upper Warrell Creek and E: 489642 N: 6594927 at Butchers Creek. One sample were collected at each site and placed immediately into an esky. Samples were analysed by the Environmental Analysis Laboratory (EAL), a NATA accredited laboratory, at Southern Cross University. Water quality parameters measured included:

1. Heavy Metals including arsenic, cadmium, chromium, copper, lead, mercury, nickel and zinc.
2. Nutrients including Nitrogen (as N), Suspended Solids and Total Phosphorus.
3. Turbidity and dissolved oxygen.
4. Hydrocarbons from the following groups:
    a. Naphthalene group including TRH>C10-C16, TRH>C10-C16 less Naphthalene (F2), TRH>C16-C34, TRH>34-C40, TRH C6-C10 and TRH C6-C10 LESS BTEX (F1).
    b. BTEX group including Benzene, Ethylbenzene, m&p-Xylenes, o-Xylene, Toluene and Xylenes – total.

Field physicochemical measurements including Conductivity, pH, and Temperature, were measured using a Horiba portable water quality meter.

2.6 Population estimate

The modified Petersen-Lincoln index method (that is the Petersen-Lincoln method with the Chapman estimator) was used to calculate a population estimate for year three operational phase. The method follows that applied during previous surveys (Lewis 2014; Geolink 2018; Sandpiper Ecological 2019). Juveniles, sub-adult, and non-captured individuals were not included in the equation which is consistent with the baseline and construction phase surveys. Population estimates were calculated using spring/ autumn and summer/autumn. The baseline population estimate was based on summer and autumn data. The equation and input data, included:

$$\hat{N} = \frac{(M+1)(C+1)}{(m+1)} - 1$$

N = population size
M = total captured in sample 1
C = total captured in sample 2
m = number recaptured in sample 2

To account for uncertainty around the population estimate the confidence interval of the standard error was determined. The confidence interval is the range of values that we expect the population estimate to fall between if the survey was conducted again. For this assessment the confidence level was set at 95%. The 95% confidence interval was calculated using the following formulae:

- 95% confidence interval = N ± (1.96)(SE)

The standard error (SE) of the estimate of N was calculated using the following formulae:

- SE = sqrt { [(M+1)(C+1)(M-R)(C-R)] / $(R+1)^2$(R+2) }

2.7 Data summary and analysis

Rainfall data for the year three survey and historical records were sourced from the Bellwood weather station. Individual frogs were identified by comparing PIT tag numbers recorded during this survey with those reported by Geolink (2018) and Lewis (2014). The number of individuals calculated for year one construction phase might be an underestimate as it does not include individuals captured during the first autumn sample (GeoLink 2018).

2.8 Temporal comparison

Data collected during year three operational phase were compared to the construction phase and baseline surveys to provide a temporal comparison of frog abundance. The number of giant barred frogs detected (i.e. captured and heard calling but not captured), and captured in each time period is presented using histograms. Population estimates derived during each survey are also compared.

3. Results

3.1 Survey timing, weather conditions and effort

The year three operational phase giant barred frog survey was conducted on 27/28 October 2020, 16/17 February 2021 and 14/15 April 2021. Weather conditions were suitable for giant barred frog surveys during all sample events (Table 1). Above average rainfall was recorded over the sample period (i.e. October 2020 to April 2021), with 870mm falling in the 30 days prior to the autumn survey. The study area experienced two flood events during the sample period, one in December 2020 and a major flood in March 2021. Air temperature ranged between 20.4^{0}C and 22.9^{0}C in October and February, and 16.8 to 17^{0}C in April. Temperatures in April 2021 decreased to 14^{0}C at 2200 hours on both sample days. Relative humidity ranged from 76-100% and wind was either absent or light (i.e. rustled leaves; Table 1). Rain or showers occurred during the spring and summer surveys. Survey effort at Upper Warrell Creek ranged from 12.5 person hours in spring to 17 person hours in autumn (Table 1).

Table 1: Weather conditions and survey effort recorded during the year 3 2020/21 giant barred frog survey. PH = person hours; Wind categories = 0 - no wind, 1 - rustles leaves, 2 - branches moving, 3 - canopy moving; RH = relative humidity; Rainfall = mm; Temp = ^{0}C; Dew Point = ^{0}C

Season	Site	Date	Start/ Finish	Observers	PH	Rainfall	Rainfall (prev 24hr)	Rainfall (prev 7 days)	Rainfall (prev 30 days)	RH	Temp	Dew point	Wind
Spring 2020	Butchers Creek	27/10/20	2000/2230	BT/NM	5	Nil	0	22	28	85	22.9	21.1	0
		28/10/20	2145-2200	DR/LA/NM/ BT	1	Present	35	57	63	88	21.7	20.9	2
	Warrell Creek	27/10/20	2000-2230	DR/LA	5	Nil	0	22	28	85	22.9	21.1	0
		28/10/20	1940-2130	DR/LA/NM/ BT	7.5	Present	35	57	63	88	21.7	20.9	2
Summer 2021	Butchers Creek	17/2/21	2000-2045	DR & LA	1.5	Showers	17	60	94	95	20.4	20.4	1
	Warrell Creek	16/2/21	2000-0015	DR & LA	8.5	Showers	16	44	77	84	23.1	20.5	1
		17/2/21	2100-0045	DR & LA	7.5	Showers	17	60	94	100	21.3	20.4	0
Autumn 2021	Warrell Creek	14/4/21	1845-2245	DR & LA	8	Nil	0	73	870	84	17	16	1
		15/4/21	1800-2230	DR & LA	9	Nil	0	56	847	76	16.8	14.7	0

3.2 Frog surveys

3.2.1 Abundance

A total of 21 giant barred frogs were recorded at Upper Warrell Creek during the year three operational phase surveys (Tables 2 & 3). No giant barred frogs were captured at Butchers Creek. Captures included nine adults (Snout-vent length >60mm), nine sub-adults (S-V length 40-60mm), and three juveniles (S-V length <40mm). Three of the recorded individuals were not captured. This included, two calling (adult) males and one juvenile. The two un-captured adult males were both recorded calling from concealed positions on the opposite creek bank to that being sampled and the juvenile escaped capture.

The age of frogs was biased towards immature frogs with 12 of the 21 individuals falling in the immature class (i.e. S-V <60mm). A further three individuals had a S-V length <70mm, and these individuals may have only moved into the adult size class in early autumn 2021 (Table 3). The number, sex and age-class of individuals recorded during each survey included:

- three (2M & 1F all adults) in spring 2020;
- six (1 adult male, 3 sub-adult & 2 juvenile) in summer 2021; and
- 12 (5 adult 1M &1F (3 individuals recently attained adult size), 6 sub-adult, 1 juvenile) in autumn 2021.

Table 2: Data recorded for Frog # 1-9 captured or heard calling during the year 3 (spring 2020 to autumn 2021) operational phase monitoring surveys. NC = not captured; NA = not applicable

Variable	Frog 1	Frog 2	Frog 3	Frog 4	Frog 5	Frog 6	Frog 7	Frog 8	Frog 9
Capture date	27/10/20	27/10/20	28/10/20	17/2/21	17/2/21	17/2/21	17/2/21	17/2/21	17/2/21
Zone	6	6	20	8	6	6	16	17	17
Creek side	Mid (on island)	North	North	South	South	North	South	South	South
GPS location	489323.6594415	489352.6594444	490654,6597518	489261,6594336	489285,6594410	489283,6594403	489108,6594022	489050,6593989	489050,6593989
Distance from stream edge (nearest 0.1m)	1.2	4	5	0.2	0.5-1m	4	3.5	4.5	5
Position in micro-habitat*	Beneath ferns, dense leaf litter	On leaf litter - exposed	On leaf litter - exposed	On exposed leaf litter	On bank	On leaf litter exposed	Leaf litter scattered	Scattered with leaf litter	Scattered with leaf litter and exposed soil
Sex**	M	F	M	Immature	Male - HC	Immature	Immature	Immature	Immature
Age***	Adult	Adult	Adult	Sub-adult	Adult	Juvenile	Sub-adult	Sub-adult	Juvenile
S/V length	83.7	98.7	75.3	51.4	NC	36.1	42.6	44.2	39.4
Weight	85	141	58	15		<5	10	10	6
Breeding condition#	Moderate	Gravid	Moderate	N/A	NC	N/A	N/A	N/A	N/A
Microchip ID (new or re-capture)	Re-capture-00077E8FEF	Re-capture-00078Abbf2	Re-capture - 991001000620121	N/A	NC	N/A	N/A	N/A	N/A
Original capture & recapture details	1. 6/11/17; 69gr; 72mm SV 2. 26/2/19; 85gr; 83.8mm SV 3. 20/3/19; 85gr; 81.8mm SV	1. 5/2/18; 152gr; 100mm SV 2. 26/2/19; 141gr; 101.5mm SV 3. 20/3/19; 165gr; 99.5mm SV	1. 19/3/19; 53gr; 75.9mm SV	N/A	NC	N/A	N/A	N/A	N/A
Capture locations	1. 489302; 6594439 2. 489322, 6594426 3. 489320, 6594428	1. 489327, 6594425 2. 489354, 6594451 3. 489342, 6594424	1. 489323, 6594584						

*Microhabitat: under leaf litter, under veg, on leaf litter, exposed, on a log/rock etc.
**Sex: Frogs >78mm were deemed female unless heard calling.
***Age: >60mm = adult, 40-60mm = sub, <40mm = Juv.
#Breeding: Males: colour of nuptial pads; light/moderate/dark/no colour. Females: Gravid, typically weighing >100g. Immature: SV length <60mm.

Table 3: Data recorded for Frog # 10-21 captured or heard calling during the autumn 2021 survey at Upper Warrell Creek. HC – heard calling; NC – not captured; NR = not recorded

Variable	Year 3 frog number											
	Frog 10	Frog 11	Frog 12	Frog 13	Frog 14	Frog 15	Frog 16	Frog 17	Frog 18	Frog 19	Frog 20	Frog 21
Date	14/4/21	14/4/21	14/4/21	14/4/21	15/4/21	15/4/21	15/4/21	15/4/21	15/4/21	15/4/21	15/4/21	15/4/21
Zone	3	3	6	10	8	6	5	5	5	4	4	4
Creek side	North	North	North lateral bar	North	South	South	South	South	South	South	South	South
GPS location	489376: 6594541	489393: 6594551	489324: 6594405	489299: 6594221	489261: 6594325	489283: 6594411	489307: 5594430		489302: 6594450	489307: 6594478	489307: 6594481	489302: 6594475
Distance from stream edge (nearest 0.1m)	5	0.4	4	8	2	2.5	4	NR	3	3	7	8
Position in micro-habitat*	Under flood debris	bare earth base of tree	bare scoured earth	leaf litter	Bare earth under grass tussock	Bare earth under tree	Bare earth	NC	Leaf litter	Base of tree	Bare ground	Leaf litter
Sex*	Immature	Immature	Immature	Immature	Immature	Immature	Unknown	Male heard calling plus eye shine	Female	Unknown	Unknown	Immature
Age*	Sub-adult	Juvenile	Sub-adult	Sub-adult	Sub-adult	Sub-adult	Adult	Adult	Adult	Adult	Adult	Sub-adult
S/V length	56	38-40~	59.2	59.7	59.2	52.2	63.4	NC	94	68.3	63.1	59.7
Weight	22	NC	25.3	24	25.5	15	33	NC	123	50	26	30.5
Breeding condition*		NC						NC		Dark nuptials		
Microchip ID (new or re-capture)	911001000620123	NC	991001000620129	956000010433861	956000010454091	956000010434396	956000010427097	NC	956000010433901	Dorsal photo	Dorsal photo	Dorsal photo

Plate 1: Dorsal pattern of Frog #19.

Plate 2: Dorsal pattern of Frog #20.

Plate 3: Dorsal pattern of Frog #21

Only two adult female frogs were recorded. The three un-sexed adults recorded in autumn (S-V 63.1 to 68.3mm) had only recently reached the adult size class of >60mm and therefore determining sex was difficult. Seven frogs were PIT tagged, all during the autumn sample. An additional three individuals (frogs 19, 20 & 21) had their dorsal pattern photographed as the field team ran out of tags (Plates 1-3). Three sub-adult frogs (i.e. S-V 40-60mm) captured in summer were not tagged due to miss-interpretation of the minimum tagged size class, see Sandpiper Ecological (2021) for further explanation.

3.2.2 Capture location

All frogs were captured within riparian forest on the primary bank. The capture distance from water ranged from 0.2m to 8m with a mean of 3.75m. There was no notable difference in the mean capture distance from water for the three age classes. Mean values were 3.5m for adults, 4.2m for sub-adults and 3.13m for juveniles. All individuals were captured on bare earth, scattered leaf litter or leaf litter (Tables 2 & 3).

3.2.3 Distribution

In year three, giant barred frogs were recorded in nine of the 21 survey zones, with individuals distributed from zone 3 to zone 20 a distance of approximately 900m (Figure 3). The highest number of frogs was recorded in zone 6 (6 frogs), followed by zones 4 and 5 (3 frogs each). Two individuals were recorded in zones 3, 8 and 17. Sixteen of the 21 individuals were recorded downstream of the alignment, with individuals distributed across both the north and south banks.

Three recaptures (frogs 1, 2 & 3) were recorded during the survey, all in spring 2020. Frog number 3, an adult male, was recaptured in zone 20, 880m upstream from its original capture point in zone 3. Frogs two and three were initially tagged during the construction phase, and have been captured on four occasions. Both individuals have always been captured in zone 5 or on the boundary of zones 4 and 5.

3.2.4 Population estimate

The adult giant barred frog population estimate for Upper Warrell Creek in year three operational phase using the spring and autumn samples was estimated at 19 with a 95% confidence interval of 21.5 (Table 4). This suggests there is a 95% chance that the adult population within the 1km transect at Upper Warrell Creek is between zero and 40 individuals. As seven adult frogs were recorded in year three the range for population size is more accurately presented as 7-40 individuals.

The population estimate using the summer and autumn data was four with a 95% confidence interval of zero. A confidence interval could not be calculated as no adult frogs were recorded during the summer survey. The spring/autumn population estimate is considered more reliable, although it is likely affected by emigration and immigration (refer to the Discussion for more details).

Table 4: Population estimate, standard error and 95% confidence interval after the conclusion of year one operational phase giant barred frog monitoring at Upper Warrell Creek.

Comparison	Population estimate	95% confidence interval
Spring and Autumn	19	21.46
Summer and Autumn	4	0

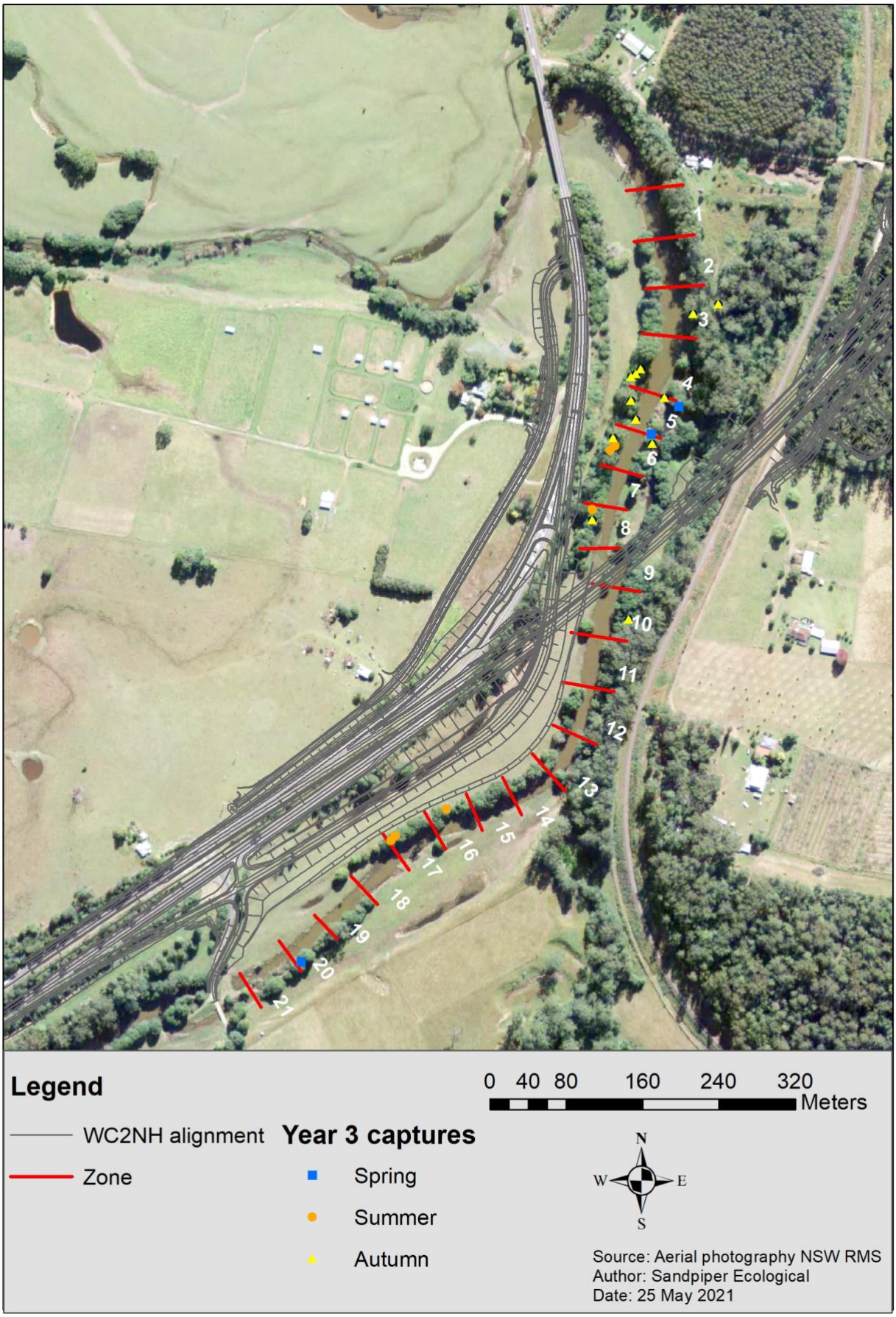

Figure 3: Location of frogs captured during the summer 2021 giant barred frog survey at Upper Warrell Creek.

3.2.5 Tadpole surveys

No giant barred frog tadpoles were detected at either Butchers Creek or Upper Warrell Creek during year three operational phase monitoring. During the spring survey 32 great barred frog (*M. fasciolatus*) tadpoles were captured at Butchers Creek, 22 in bait traps, 17 in Zone 8, and five in Zone 7, and 10 in Zone 3 during dip netting (Plate 4). All tadpoles were between development stages 35 to 41 and would have hatched from eggs laid the previous autumn.

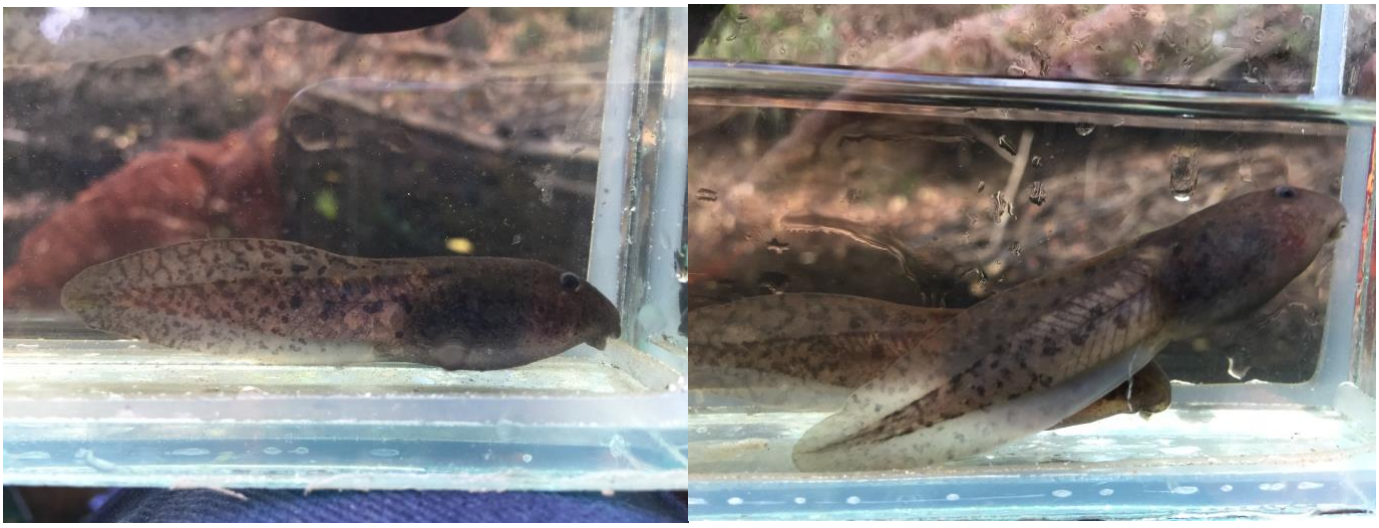

Plate 4: Great barred frog tadpoles recorded at Butchers Creek during the spring 2020 survey.

3.3 Habitat

3.3.1 Upper Warrell creek

Habitat at Upper Warrell Creek ranged from grassland to moderate quality riparian and wet sclerophyll forest with a dense litter layer (Appendix A). Parts of the Upper Warrell Creek study area contained fragmented riparian forest that is grazed, whilst the remainder consisted of a narrow riparian strip bordered by agricultural land. The width of riparian vegetation varied throughout the site but was mostly restricted to the bank and did not exceed 30m wide. Leaf litter cover ranged from high (>75%) in areas with an intact riparian zone to low (<40%) in cleared and grazed areas. Creek bank topography varied throughout the transect, with a steep bank on both sides downstream of the alignment (i.e. Zones 1-6), and on the north bank upstream of the alignment (zones 11-13), a flatter bank profile occurred on the north bank near the alignment (Zones 7-11), and upstream, Zones 14-18.

One notable aspect of concern was growth of pigeon grass (S*etaria sphacelata*) and broad-leaved paspalum (*Paspalum mandiocanum*) on the north bank in zones 5, 7 and 8. Pigeon grass also dominated the south bank of zones 10, 11, 19, 20 and 21. Whilst giant barred frogs have been recorded in broad-leaved paspalum (Sandpiper Ecological 2019a), dense grass represents a barrier to movement. Geolink (2015, 2018) recorded paspalum and/or pigeon grass in zones 7, 8 and 10, and images presented by Geolink (2018) show pigeon grass in zones 8 and 10. Based on available information, it seems likely that pigeon grass was present at commencement of construction, however grazing by stock may have kept grass under control and the exclusion of stock, particularly on the south bank, has enabled grass to grow and form a barrier to movement. TfNSW has implemented some work (i.e. slashing & some planting) to reduce grass density in Zones 7 and 8 although more intensive work is required.

Work to control pigeon grass and paspalum in zones 7, 8, 9 and 10 commenced in July 2021. The programmed works include targeted weed control aimed at reducing the extent / density of pigeon grass and paspalum followed by planting of 60 *Waterhousia floribunda* (on the southern bank of Warrell Creek in zones 9 & 10 and the northern bank in zones 7,8 & 9) to form a canopy and connect existing

remnant canopy trees. Additional wetland plant tube-stock to bolster the now established wetland plantings will also be planted in the area (Zone 9 on the northern bank under the bridge and as needed to repair flood damage). The scope of works has been developed in consultation with and endorsed by the EPA.

A severe flood in March 2021, shortly before the autumn survey, had a noticeable impact on habitat. Several trees in the riparian zone were pushed over, areas of grass and regrowth were scoured or flattened, and leaf litter was washed away, leaving bare earth. Impacts appeared most severe downstream of the bridge, and between zones 1 to 13 groundcover composition changed between the spring and autumn surveys. The primary change was a reduction in litter cover and an increase in the amount of woody debris.

3.3.2 Butchers Creek

Habitat at Butchers Creek was not inspected in autumn and the following description is based on data collected during the spring 2020 survey. Flooding in March 2021 is likely to have impacted habitat at Butchers Creek. Habitat at Butchers Creek varied substantially between zones. The west side of the alignment was characterised by a narrow degraded riparian zone that was predominantly cleared immediately prior to the spring 2018 survey. In spring 2020, previously cleared areas were dominated by pigeon grass with some regrowth lantana (*Lantana camara*) and small-leaved privet (*Ligustrum sinense*). East of the alignment habitat was characterised by wet sclerophyll forest that extended well beyond the riparian zone. The substrate consisted of rock and gravel with a steep bank and gravel bars. Leaf litter cover varied from 25 to 80% and ground vegetation cover from 10 to 60%. Water was restricted to three small pools.

Habitat at Butchers Creek did not contain the moist microclimate that is typical of many giant barred frog habitats. The site lacks continuous overhanging riparian vegetation and the thick dense leaf litter and ground vegetation required to create moist ground conditions and in addition the creek is highly ephemeral. Based on surveys in 2018/19 and spring 2020 we conclude that Butchers Creek is unsuitable for giant barred frog. This conclusion is supported by the absence of confirmed records despite regular surveys since 2011 (Lewis 2014; Geolink 2015, 2018; Sandpiper Ecological 2019b). Lewis (2014) surveyed Butchers Creek on two occasions in summer 2011 and on three occasions in spring 2013. No giant barred frogs were recorded during these surveys and Butchers Creek was not included in the WC2NH Giant Barred Frog Management Strategy (Lewis 2014).

During construction, *Mixophyes* tadpoles were captured in Butchers Creek and identified as giant barred frog (Geolink 2015). Subsequently, Lewis (2015) conducted additional nocturnal frog and diurnal tadpole surveys. No giant barred frogs were recorded during these surveys, however, adult and juvenile tadpoles of the great barred frog (*M. fasciolatus*) were recorded. Two tadpoles were retained and grown-out and these were identified as great barred frog. Despite evidence to the contrary, TfNSW adopted a precautionary approach and included Butchers Creek in the Giant barred frog monitoring program. Subsequent population monitoring surveys in 2016, 2017, 2018, 2019 and 2020 (Geolink 2016, 2018; Sandpiper Ecological 2019, this study) have not detected giant barred frog. The overwhelming evidence suggests that Butchers Creek does not support giant barred frog.

3.4 Water quality

Most water quality parameters were within the ANZECC trigger values for freshwater ecosystems in south eastern Australia (Table 5). Exceptions were:

- Total phosphorus, which exceeded the ANZECC thresholds for freshwater ecosystems at both sites during all surveys,
- Total nitrogen, which slightly exceeded the threshold value at both sites during the spring survey,

- Dissolved oxygen, which was lower than the ANZECC trigger value at both sites during all samples.

Findings are broadly consistent with the year one operational phase survey and most likely reflect normal fluctuations associated with changes in water level and runoff. Importantly, all BTEX and Total Recoverable Hydrocarbon (TRH) levels were below ANZECC trigger levels. In autumn 2021 the concentration of all heavy metals sampled was well below the ANZECC thresholds. Based on water sample results in year 3 there is no evidence to suggest that frogs could be detrimentally affected by elevated TRH's or heavy metals. The nature of water quality sampling, that is, one-off samples months or years apart, is unlikely to provide data representative of water quality at either site.

Table 5: Results of water sample analysis for Upper Warrell creek and Butchers Creek. ID = insufficient data to derive a reliable trigger value (ANZECC 2000); NS – parameter not sampled due to access restriction; NR – parameter not recorded.

Parameter	Spring		Summer		Autumn		ANZECC/ARMCANZ Trigger value for freshwater (95% species level of protection)
	Warrell Creek	Butchers Creek	Warrell Creek	Butchers Creek	Warrell Creek	Butchers Creek	
Temperature (^{0}C)	24.6	19.7	22.3	21.1	14.23	NS	
pH	7.07	6.2	6.31	6.19	5.58	NS	6.5-8.0
Conductivity (us/cm)	0.396	0.212	0.171	0.108	0.246	NS	125-2200
Dissolve oxigena (mg/L O_2)	NS	0.54	6.23	6.51	5.79	NS	9-10.5
Total Suspended Solids (mg/L)	4	4	<1	4	5	NS	
Turbidity (NTU)	0.258	0.138	4.7	11.6	8.8	NS	6-50
Total Phosphorus (mg/L P)	0.03	0.03	0.05	0.04	0.05	NS	0.025
Total Nitrogênio (mg/L N)	0.37	0.43	0.24	0.10	0.1	NS	0.35
BTEX							
Benzene (µg/L or ppb)	<0.5	<0.5	<0.5	<0.5	1	NS	950
Toluene (µg/L or ppb)	<0.5	<0.5	<0.5	<0.5	1	NS	ID
Methylbenzene (µg/L or ppb)	<0.5	<0.5	<0.5	<0.5	1	NS	ID
m+p-Xylene (µg/L or ppb)	<1	<1	<1	<1	2	NS	200
o-Xylene (µg/L or ppb)	<0.5	<0.5	<0.5	<0.5	1	NS	350
Naphthalene (µg/L or ppb)	<0.5	<0.5	<0.5	<0.5	1	NS	16
Total Recoverable Hydrocarbons (TRH)							
C6-C9 Fraction (µg/L or ppb)	NS	NS	<40	<40	10	NS	ID
C10-C14 Fraction (µg/L or ppb)	<50	<50	<50	<50	50	NS	ID
C15-C28 Fraction (µg/L or ppb)	<100	<100	<100	<100	100	NS	ID
C29-C36 Fraction (µg/L or ppb)	<50	<50	<50	<50	100	NS	ID
C10-C16 Fraction (µg/L or ppb)	<60	<60	<60	<60	50	NS	ID
C10-C16 less Naphthalene Fraction (µg/L or ppb)	NR	NR	NR	NR	50	NS	ID
C16-C34 Fraction (µg/L or ppb)	<200	<200	<200	<200	100	NS	ID
C34-C40 Fraction (µg/L or ppb)	<100	<100	<100	<100	100	NS	ID

Parameter	Spring		Summer		Autumn		ANZECC/ARMCANZ Trigger value for freshwater (95% species level of protection)
	Warrell Creek	Butchers Creek	Warrell Creek	Butchers Creek	Warrell Creek	Butchers Creek	
Sum C10-C36 Fraction (µg/L or ppb)	<100	<100	<100	<100	NS	NS	ID
Heavy Metals							
Silver (mg/L)	<0.001	<0.001	NS	NS	0.001	NS	0.05
Aluminium (mg/L)	0.099	0.012	NS	NS	0.01	NS	55
Arsenic (mg/L)	0.001	<0.001	NS	NS	0.001	NS	24
Cadmium (mg/L)	<0.001	<0.001	NS	NS	0.0001	NS	0.2
Chromium (mg/L)	<0.001	<0.001	NS	NS	0.001	NS	1.0
Copper (mg/L)	<0.001	<0.001	NS	NS	0.001	NS	1.4

3.5 Temporal comparison

3.5.1 Frog surveys

The total number of giant barred frogs captured during each sample period declined substantially between baseline and year one of the construction phase. A more gradual decline is evident from year one construction phase, where 16 detections occurred, to year one operational phase, where 12 detections occurred. Captures during the operational phase have increased from 12 in year one to 21 in year 3 (Figure 4).

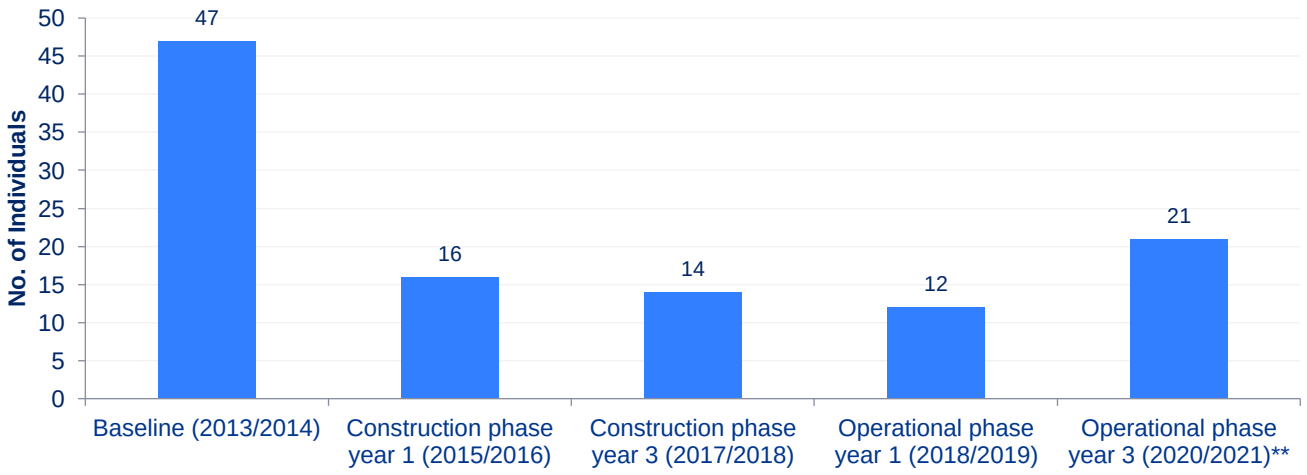

Figure 4: Total number of giant barred frog recorded in each of five sample periods at Upper Warrell Creek. Values include multiple recaptures of the same individual and calling males that were not captured. ** could include recapture of unmarked sub-adults from summer survey.

The number of individual frogs captured between baseline and year one construction phase surveys declined from 38 to eight and remained stable over the construction and year one operational phase surveys. The number of individual frogs increased to 21 during the year three operational phase survey (Figure 5).

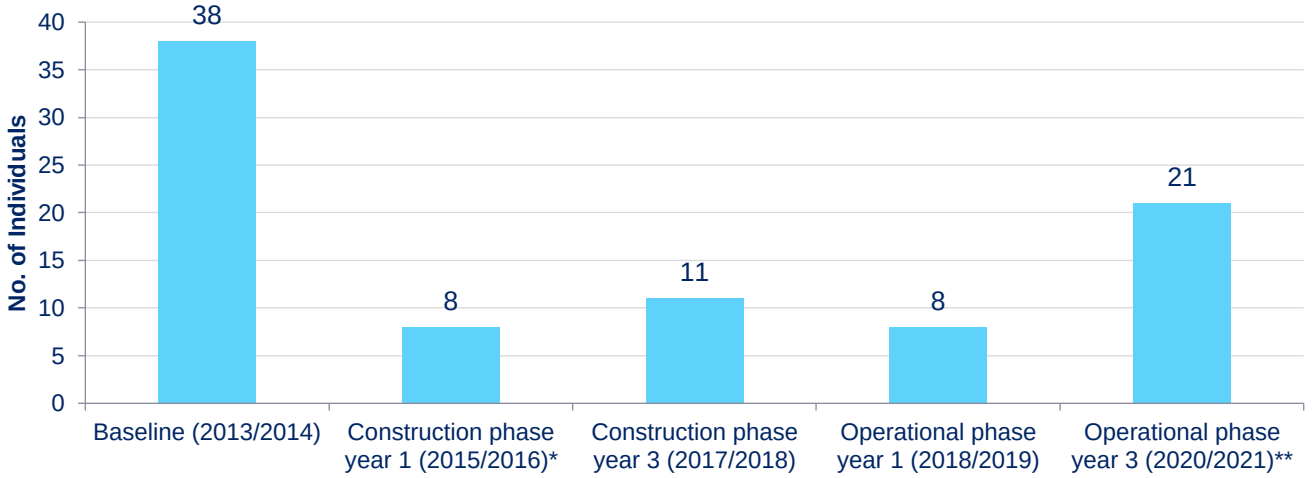

Figure 5: Number of individual giant barred frogs recorded over five sample events at Upper Warrell Creek. *Year one construction phase number may be an underestimate as it does not include frogs recorded in autumn 2015 (GeoLink 2018); ** could include recapture of unmarked sub-adults from summer survey.

3.5.2 Population estimate

Comparison of adult population estimates across the five sample periods shows a decline at the Upper Warrell Creek site from baseline through the construction phase and into year one of the operational phase (Table 6, Figure 6). The population estimate of 43 adult frogs in 2013/14 declined to seven in year one of the construction phase with estimates of eight and seven recorded in year 3 construction phase and year one operation phase respectively (Table 6, Figure 6). The population appears to have re-bounded in year three of the operational phase with a population estimate of 19 adults.

Table 6: Population estimates of adult giant barred frog at Upper Warrell Creek prior to construction (Lewis 2014), during construction (GeoLink 2018) and operational phase (Sandpiper 2019). GBF = giant barred frog.

Parameter	Baseline (2013/2014)	Year 1 Construction phase (2015/2016)	Year 3 Construction phase (2017/2018)	Year 1 Operational Phase (2018/2019)	Year 3 Operational phase
GBF population estimate	43	7	8	7	19
95% confidence interval	26.6	9.77	10.46	4.8	21.46

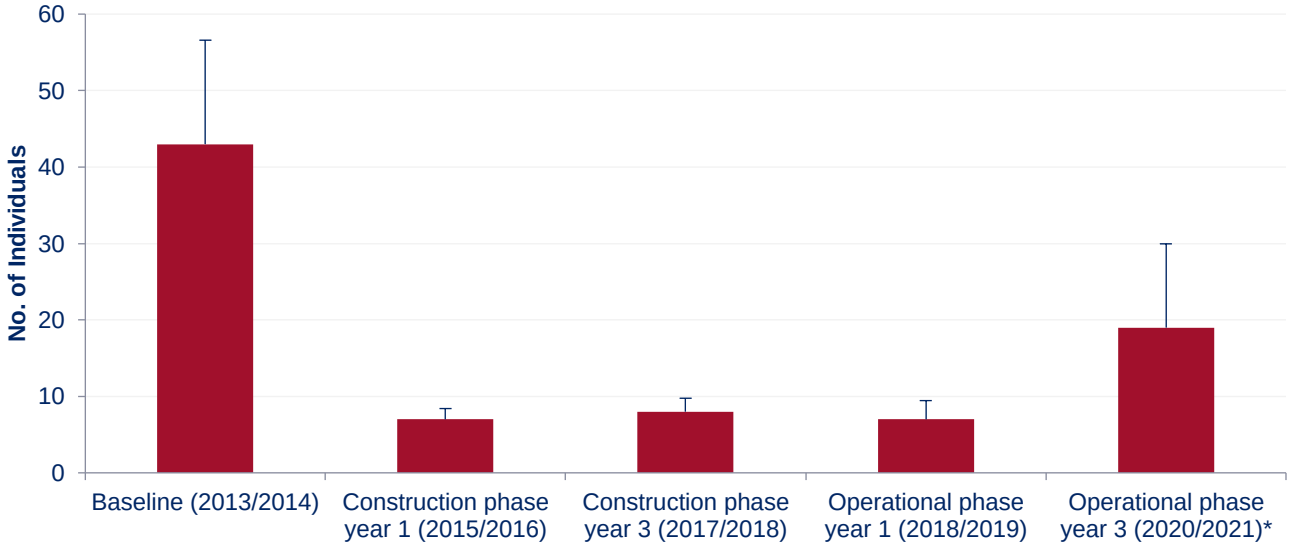

Figure 6: Adult population estimates (+ standard error) at Upper Warrell Creek during baseline (Lewis 2014), construction phase (GeoLink 2018), year one operational phase (Sandpiper Ecological 2019), and year three operational phase monitoring (this study). Note: Operational phase year 3 is based on spring/autumn data, whilst all others based on summer/autumn data.

4. Discussion

4.1 Giant barred frog population

No giant barred frogs were recorded at Butchers Creek during the year three surveys. This result is consistent with construction phase and year one operational phase surveys and further highlights the likelihood that giant barred frogs do not occur at that site. The following discussion relates solely to the Upper Warrell Creek site.

Findings of the year three operational phase giant barred frog surveys suggest that the population at Upper Warrell Creek has rebounded following substantial declines through the construction phase and year one of operation. A cohort of similarly sized immature frogs dominated samples in summer and autumn 2021. In summer, snout-vent length ranged from 36-51mm (*n*=4) and in autumn S-V length ranged from 52-68mm (*n*=9). This age cohort is suspected to have hatched as tadpoles in autumn 2020 and metamorphed in late spring 2020. The suggested timing of key events and growth during the sample period is consistent with the observation of Maas and Passioura (1999) that giant barred frogs reach maturity at the end of their first year. A high abundance of invertebrates, the main prey item (Lemckert & Shoulder 2008), over the previous 12 months (pers obs), is likely to have increased growth rates. Based on growth rates the age cohort recorded in 2021 may breed in the 2021/22 breeding season.

There is some uncertainty about the origins of the sub-adult age cohort. Whilst breeding conditions between January 2020 and April 2021 have been ideal for insitu recruitment, movement of juveniles into the study area by floods in December 2020 and March 2021 cannot be discounted. Juvenile frogs may be more susceptible to flood transportation due to their smaller size (Koch & Hero 2007). The denuded nature of creek banks and lack of a structurally complex ground layer for shelter at Upper Warrell Creek may increase the incidence of flood transportation.

The flood transportation hypothesis of juvenile frogs is supported by the size distribution of frogs recorded in 2021, the low level of breeding activity (i.e. calling males) within the study area, absence of tadpole captures, and the occurrence of juvenile and sub-adult frogs in areas where no adults have been recorded (i.e. south bank of zones 16 and 17) and where there is low quality habitat. Contrary to this hypothesis are the findings of Lewis (2014) who recorded eight juvenile and eight sub-adult frogs in the study area during the 2013/14 breeding season in the absence of any flood events. Lewis (2014) recorded clusters of juvenile frogs on the south bank in Zones 9 and 18. This finding is broadly consistent with the year three results when juveniles were recorded on the south bank in Zones 16 and 17, and throughout zones 4-8 (Figure 3). Lewis (2014) linked the juvenile clusters to back channels that occurred in both zones 9 and 18. Sandpiper Ecological (2019a, 2020) highlighted the importance of back channels for breeding and suggested that the population declines recorded since the baseline may be due to modification of these channels.

The absence of recaptures in summer and autumn 2021 is contrary to the year one operational phase surveys when recaptures accounted for 50%, 75% and 33% of all captures in spring, summer and autumn respectively (Sandpiper Ecological 2019a). Indeed, all individuals captured in spring 2020, prior to flooding, were recaptures (Sandpiper Ecological 2020), including two individuals that had been captured within the same zone on several occasions since the construction phase. The absence of recaptures in summer and autumn suggests that these individuals could have been washed out of the study area.

The possibility that frogs moved into or out of the sample population during the sample period raises concerns about validity of the population estimate. A key assumption of the population estimate procedure is limited immigration, emigration and mortality during the sample period (Fowler *et al.* 1999). Repeat sampling in consecutive years both within and upstream of the study area is required to determine how floods and insitu recruitment influence local abundance.

4.2 Distribution and movement

Movement of giant barred frogs beneath the highway was confirmed during year three monitoring. A male frog, initially tagged in autumn 2019, was recaptured 880m upstream in spring 2020. Whilst giant barred frogs have been recording moving up to 200m in a night average nightly movement distance is typically less than 25m (Lemckert and Brassil 2000). The smaller (i.e. <50m) movements recorded by other recaptured individuals at Upper Warrell Creek is consistent with published studies (Lemckert & Brassil 2000; Koch & Hero 2007).

Movement of frogs along the transect is likely to be hampered by dense pigeon grass (*Setaria* spp.), which occurs on the north bank in zone 7, 8, and 14-18, and on the south bank in zones 10, 11 and 19-21. The flood in March 2021 removed some pigeon grass, however, it is likely to have regrown by the 2021/22 breeding season. Photographs taken in February 2015 suggest that grass on the creek banks was substantially shorter prior to construction, presumably due to grazing by stock (Plate 5). Regeneration beneath the alignment has been slow and frogs need to traverse approximately 40m of exposed scour protection or soil to cross the alignment.

Plate 5: Grassland at Upper Warrell Creek in February 2015, prior to construction (Source: TfNSW).

The presence of frogs in nine of the 21 zones in 2020/21 indicates that the species continues to occur throughout the study area, albeit in fewer zones than baseline surveys. The majority of records occurred within zones 1-8, which is consistent with all previous surveys (Lewis 2014, Geolink 2016, 2018; Sandpiper Ecological 2019). In the three surveys since construction commenced 83% of all records have occurred within zones 2-8, downstream of the alignment.

4.3 Temporal comparisons

4.3.1 Stream morphology – aerial photographs

Sandpiper Ecological (2020) reviewed historical aerial photographs and found that aerials from 2010 and 2013, prior to construction, showed that stream morphology within the alignment was different to the present (Figures 7 & 8). Both images reveal a more complex stream morphology within and immediately downstream of the alignment prior to construction. In 2010 and 2013, there was an obvious back channel with lateral bar on the south bank in zone 8, and a channel on the north bank that created a large island. The northern channel may have functioned as a flood channel with water level receding to pools outside of flood events. Both features would have provided good quality breeding habitat outside the main channel. Both the 2010 and 2013 images coincided with high rainfall events and may not be indicative of normal stream flow.

Back channels in zones 8 and 18 are evident in aerial images used by Lewis (2014) and were referred to as breeding habitat in that report. The large size of the waterbody at Upper Warrell Creek and presence of predatory fish, such as Australian bass (*Macquaria novemaculeata*), means that back channels and flood channels may be preferred breeding sites. Combined, these habitat features likely represented important breeding habitat within the 1km sample area. This is reflected by the findings of baseline surveys when 44% of captures occurred in zones 8 and 9 (Lewis 2014). It is possible that the decline in frog abundance can be linked to removal and modification of primary breeding habitat.

Bridge construction modified the back channel in zone 8 and permanently removed part of the northern channel (Figure 9). Whilst the back channel in zone 8 is still present, rocks, imported during construction, dominate the upstream section and it is likely that construction altered the finer scale morphology of that channel (Plate 6). The northern channel presently receives water during large flood events only.

Figure 7: 2010 aerial photograph of the section of Upper Warrell Creek crossed by the WC2NH alignment.

Figure 8: 2013 aerial photograph of the section of Upper Warrell creek crossed by the WC2H alignment

Figure 9: 2017 aerial photograph of the section of Upper Warrell creek crossed by the WC2H alignment

4.3.2 Flood events

To determine if flood events could have transported tadpoles and juvenile frogs into the study area and thereby contributed to the number of individuals recorded in the baseline we have summarised annual rainfall, breeding season (October to March) rainfall and number of rain days = or >5mm during the breeding season (Figures 10 & 11). There is no obvious trend in annual rainfall between 2008 and 2021, although there were more high rain events (>200mm in 3 days) between 2008 and 2014 (8 events) than between 2015 and 2021 (5 events). High rain events would flood back channels and are generally indicative of high rainfall years.

There is some evidence of lower breeding season rainfall between 2013/14 and 2019/20. Average breeding season rainfall between 2008/09 and 2012/13 was 1098mm (n=5) compared to 717mm (n=7) between 2013/14 and 2019/20 (Figure 11). This was supported by a similar reduction in the number of rain days =/>5mm, with an average of 38.6 recorded between 2008/09 and 2012/13 and 31 between 2013/14 and 2019/20. The highest number of rain days >5mm and total breeding season rainfall was recorded in 2020/21 (Figure 11).

Rainfall data suggests that breeding conditions were superior prior to baseline surveys than during the construction and early operational phases (i.e. between 2015 and 2019). This may explain the higher number of frogs recorded during the baseline and the lower abundance recorded during the construction and early operational phases but does not explain the substantial decrease in abundance recorded between baseline and year 1 construction.

There is no evidence to support the hypothesis that the large number of frogs recorded during the baseline was due to flood related immigration, with only one large rain event recorded in 2013, and that occurred nine months prior to commencement of sampling. Whilst flood movement cannot be discounted as the cause of increased abundance in 2020/21 other issues are likely to have caused the decline in abundance between baseline and year one construction. Rainfall has a strong influence on frog breeding and abundance, however, giant barred frogs are known to survive severe drought (Lollback *et al.* 2021) and it is likely that historically frogs would have persisted in years of below average rainfall.

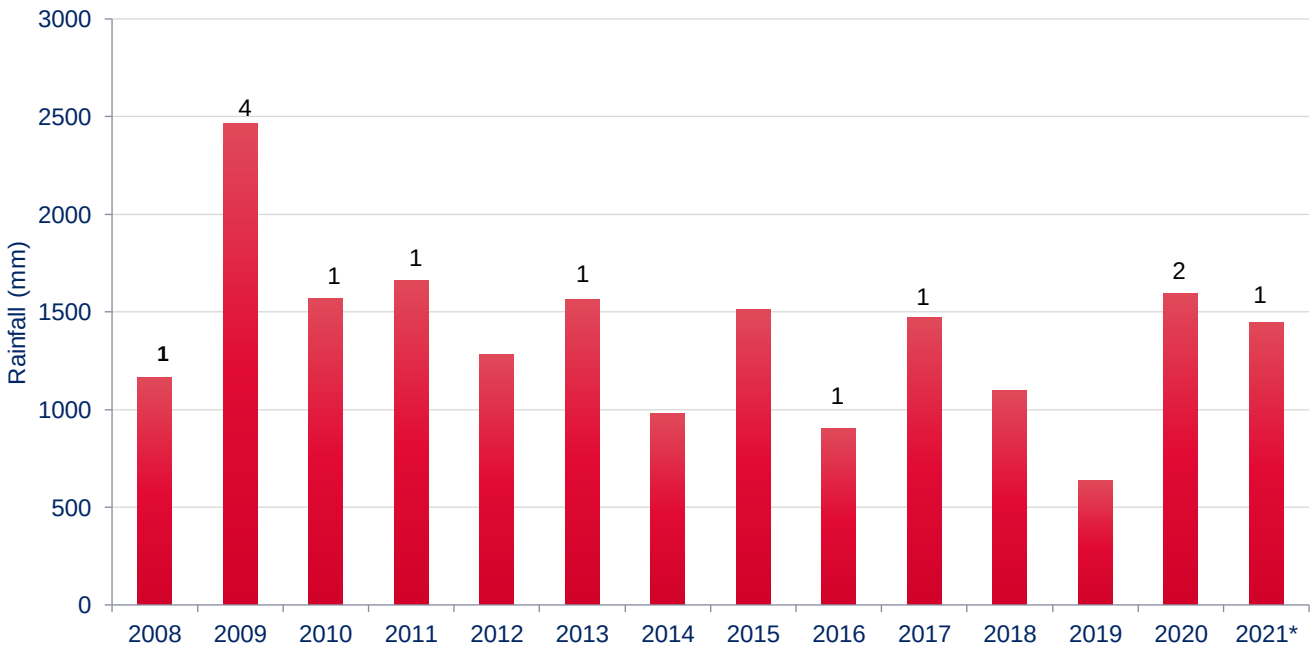

Figure 10: Total annual rainfall at the Bellwood weather station from 2008 to 2021. Numbers above bars represent number of flood events (i.e. >200mm in 3 days). * = Jan-April only.

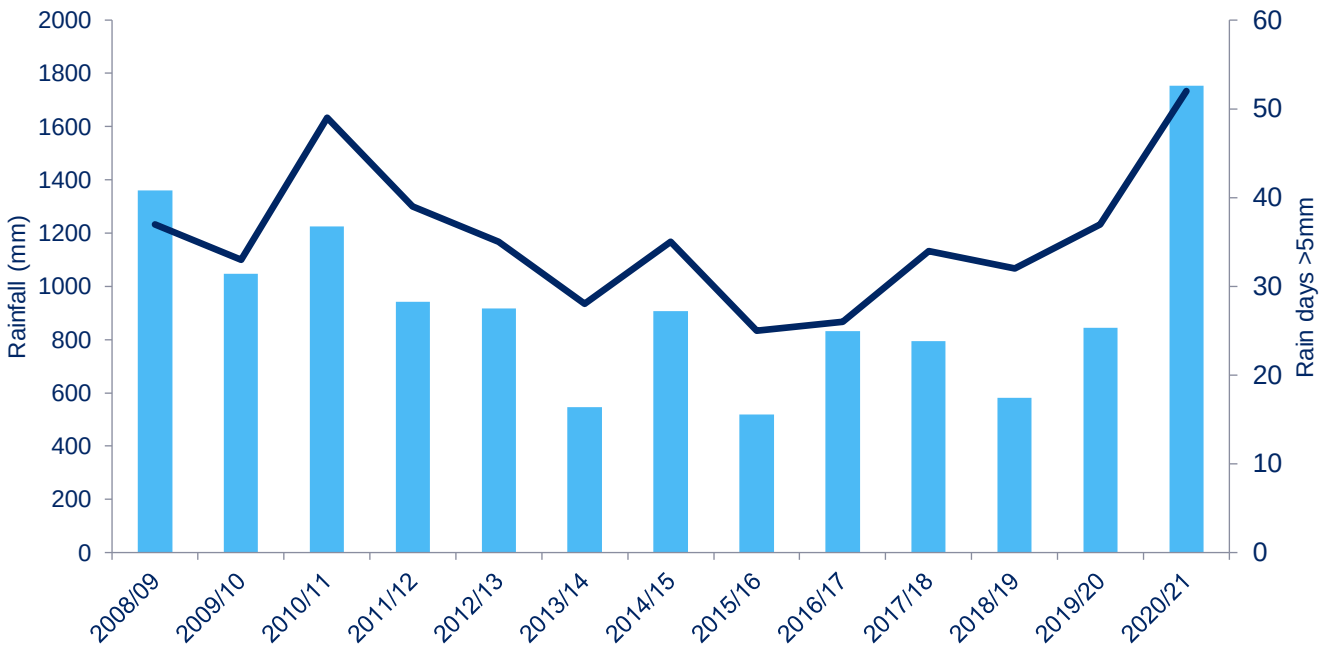

Figure 11: Total rainfall during the breeding season (October – March) and number of rain days =/>5mm during the breeding season recorded at the Bellwood weather station between 2008/09 and 2020/21.

4.3.3 Population estimates

Giant barred frog population estimates at Upper Warrell Creek declined from 43 during the 2013/14 (baseline) breeding season to seven during the 2015/16 breeding season (year 1 construction phase). The population remained reasonably constant between 2015/16 and 2018/19 and increased to 19 individuals during the 2020/21 breeding season. Reasons for the 84% population reduction that occurred over a period of 20 months between March 2014 and November 2015 warrant further consideration. There are several possible reasons for the observed reduction, including:

- Direct construction impacts – construction of a temporary crossing, and bridge platform removed and modified breeding habitat. Direct mortality of some adults was also probable based on the distribution of frogs during the baseline when 21 individuals were captured in zones 8 and 9. GeoLink (2018) also suggested that construction of a concrete causeway and bridge piling platforms had a direct impact on giant barred frog abundance. Plate 6 shows the temporary crossing as viewed from the south bank. The area in the left side foreground of the photograph is the southern back channel identified as important breeding habitat by Lewis (2014). It is plausible that construction caused direct mortality, and changes in habitat have suppressed breeding activity and local recruitment. The absence of recaptures during the year one construction phase survey is not entirely attributable to construction impacts as frogs were distributed along the 1km transect during the baseline survey and construction had a direct impact on <100 m of this area.
- Chytrid fungus (*Batrachochytrium dendrobatidis*) – The response of frogs to Chytridiomycosis infection (i.e. chytrid fungus) is complex and dependent on several factors (Lips 2016). The worst case is substantial and rapid population decline and in some cases extinction (Lips 2016). There is evidence that populations can recover following initial infection (Newell *et al.* 2013) and infected populations can develop some resistance to the pathogen and survive with the pathogen present in the population (Retallick *et al.* 2004). At Upper Warrell Creek chytrid fungus was detected in one frog during the baseline survey and in three of 21 frogs tested during the construction phase (Lewis 2014; Geolink 2018). One individual tested during the construction phase had recovered by the time of the second sample (Geolink 2018). Research on chytrid related mortality suggests that it can result in sudden population declines (Retallick *et al.* 2004), with localised impacts in some cases (Penman *et al.* 2008). A rapid decline in frog abundance fits with the findings at Upper Warrell Creek. No obvious signs of chytrid infection (i.e. lethargy, discolouration etc) have been recorded during the

operational phase surveys, which suggests that if present the population may have developed some resistance. The absence of a population level response has not occurred due to other compounding impacts.

- Rainfall – Rainfall during the 2015/16 breeding season was equivalent to 2013/14 season and followed average rainfall in 2014/15. Rainfall is unlikely to be responsible for population decline between the baseline and year one construction phase survey.
- Emigration and mortality – Recapture rate of tagged frogs between survey years is low, suggesting a high mortality or emigration rate. For example, none of the 36 frogs tagged during the baseline were recaptured during the construction phase despite a gap of only 20 months between samples. In contrast, two individuals (or 29% of total new captures) tagged during the year three construction phase survey were recaptured in spring 2020 and 25% of frogs tagged during the first operational phase survey (2018/19) were recaptured in spring 2020. Whilst these sample sizes are small the results show that individuals can persist in the study area for several years. The lifespan of giant barred frogs may be 10 years, with a generation length of 4-5 years (Department of Agriculture, Water and Environment 2020). Mortality due to old age is unlikely to explain the absence of recaptures between baseline and construction. Giant barred frogs also display strong site fidelity (Koch & Hero 2007) and consistent movement away from the study area is unlikely.
- Tag failure - Geolink (2018) discussed the possibility of PIT tag failure, however, this seems unlikely and tags can often be observed under the skin.

Plate 6: Temporary crossing constructed over Upper Warrell Creek following a rain event on 9 November 2015. The back channel breeding site in zone 8 is situated on the left side of the photo. Note the large rock and high flows. (Source: TfNSW)

4.4 Survey logistics

The 2020/21 survey was influenced by several issues, however, the overall effect of these on results is considered to be minor. Issues that may have affected the survey include:

- Heavy rain on the second night of the spring survey session – heavy rain may affect activity of all individuals, but particularly juveniles, which are at greater risk of being washed away.
- Failure to tag sub-adult frogs during the summer survey – it is possible that some of the individuals captured during the summer survey could have been captured during the autumn survey and therefore double-counted. There is a low likelihood that this occurred and recaptures would not have affected the population estimate as it only considers adults.
- Cooler nighttime minimums during the autumn survey – the autumn survey coincided with a cold front that resulted in temperatures of between 14 and 18 degrees. Koch and Hero (2007) found that adult male giant barred frogs were less active once nighttime temperatures reach 18 degrees, although temperature had less effect on activity of juvenile frogs. Whilst temperature may effect behaviour rain is regarded as a stronger driver of activity (Lewis 2014). Twelve frogs were captured in autumn despite the cooler temperature. Although only one calling male was recorded in autumn this is consistent with the spring and summer survey results.

4.5 Performance criteria

Lewis (2014b) states the main goal of population monitoring as “To collect data to demonstrate that mitigation has maintained or improved population sizes and habitat of the giant barred frog”. Results suggest that this goal has not been achieved to date, although 2020/21 results are encouraging. Performance thresholds do not relate directly to the stated goal and include:

- Giant barred frog recorded along the monitoring transect;
- The detection of chytrid fungus; and
- No breaches in fauna exclusion fence.

All performance thresholds have been achieved, however, the population has undergone substantial decline. Importantly, whilst chytrid fungus has not been detected during the operational phase targeted sampling is not required. Corrective actions include an opportunity to “Modify, if appropriate, design of existing measures where feasible and reasonable.” This action allows for the population monitoring method to be amended if required.

5. Conclusion and Recommendations

5.1 Conclusion

The year three operational phase giant barred frog survey recorded an increase in abundance, with a total of 21 individuals recorded, including 12 immature frogs. The adult population was estimated at 19 individuals, which is the highest since baseline surveys in the 2013/14 breeding season. Whilst the exact reason for the increase is unclear, high rainfall and invertebrate abundance between January 2020 and April 2021 are likely to be key factors. The possibility that frogs were transported into the study area by floods in December 2020 and March 2021 cannot be discounted, however, floods do not appear to have contributed to abundance recorded during the baseline.

Exact reasons for the decline in abundance from baseline to construction are unclear, although direct impacts on breeding habitat and modification of stream morphology in zones 8 and 9 are likely contributing factors. The absence of recaptures in the first construction phase survey suggests a substantial decline occurred in the 20 months between end of baseline and start of construction phase monitoring. Whilst construction likely contributed to the decline by impacting important breeding habitat it is unlikely to have affected frogs across the entire 1km study area. A pathogen or severe pollution event may have contributed to the decline. Chytrid fungus cannot be discounted as a causal factor and in combination with construction impacts could explain the low frog abundance recorded during the construction and early operational surveys.

The critical question at present is to confirm if the study area can still support a population of giant barred frogs given the modified conditions. It is particularly important to closely monitor the existing cohort of frogs to see how the population fluctuates in the next 3 years. If the existing monitoring scheduled is followed and the number of frogs has declined by the year five operational phase survey then additional monitoring is likely to be recommended at that time. To circumvent that possibility it is recommended that an additional years monitoring occur in year four of the operational phase (i.e. 2021/22 breeding season) and that sampling continue in year five as programmed. Further monitoring would be dependent on results of year four and five surveys.

5.2 Recommendations

Recommendations are presented in Table 7.

Table 7: Recommendations based on findings of the year 3 operational phase (2020/21) giant barred frog monitoring program.

Number	Recommendation	Transport for NSW Response
1.	Continue river bank restoration on the north bank of Zones 7, 8 & 9 at Upper Warrell Creek. Additional planting and maintenance of *Waterhousia floribunda* and understorey shrubs, and control of grass is required to improve connectivity.	The scope of works was developed in consultation with, and endorsed by the EPA. The work commenced in July 2021.
2.	Continue to focus survey effort at Upper Warrell Creek as agreed following the summer 2021 population survey.	Agreed and adopted
3	Undertake additional population monitoring at Upper Warrell Creek during the 2021/22 breeding season to enable the existing cohort of immature frogs to be more closely monitored. Monitoring would occur during the 2022/23 breeding season (i.e. year 5) as programmed. The additional year four monitoring survey (i.e. 2021/22) should include frog surveys along the 1km transect at Upper Warrell Creek and targeted dip netting for tadpoles only. No bait trapping, habitat assessment, or water sampling is recommended in the additional sample year.	Agreed and adopted
5.	Undertake chytrid sampling of frogs at Upper Warrell Creek during the 2021/22 additional sample year. Chytrid fungus is a likely explanation for the sudden decline in frog abundance between baseline and construction. Determining the present	Agreed and adopted

	infection status of the population would assist with interpreting population trends.	

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Appendix A

Autumn habitat data – Upper Warrell Creek

Table A1: Habitat data collected in each zone at Upper Warrell creek in autumn 2021

Zone	Landuse (E&W)	Broad veg community (E&W)	In-stream physical characteristics (logs, boulders etc)	Stream width	Stream depth	Presence of pools or riffles	Bed composition	Emergent veg	Stream bank characteristics
1	Agriculture	Wet sclerophyll	Silt & sand; occ logs	40m	>1m	P	Uk	Absent	High bank on nth; clumping vegt ; undercuts; cleared south bank
2	Agriculture	Wet sclerophyll	Silt & sand; occ logs	40m	>1m	P	Uk	Absent	High bank on nth; clumping vegt ; undercuts
3	Agriculture	Riparian/ wet sclerophyll	Silt & sand; occ logs	40m	>1m	P	Uk	Absent	High bank on nth; clumping vegt ; undercuts
4	Agriculture	Riparian/ wet sclerophyll	Silt & sand; occ logs	40m	>1m	P	Uk	Absent	Grassy patches, large fallen trees
5	Agriculture	Riparian	Silt & sand; occ logs	40m	>1m	P	Uk	Absent	Grassy patch; established riparian vegt, logs and fallen veg
6	Road reserve/ cons	Riparian	Lateral vegetated bar; occ logs o/h vegt	35m 0.000s	>1m	P	Uk	Absent	Clumps of lomandra, logs, grasses and litter
7	Road reserve	Riparian	Occ logs; overhanging veg;	40m	>1m	P	Uk	Absent	Clumps of lomandra, logs, grasses and flood debris
8	Road reserve	Riparian/ cleared	Boulders; occ logs	25-40m	>1m	P/R	Uk	Absent	Rock, grasses,
9	Road reserve	Cleared land	Boulders; occ logs	25-40m	>1m	P/R	Uk	Absent	Rock & grasses
10	Agriculture / road reserve	Riparian / cleared	Occ logs	45m	>1m	P	Uk	Absent	Undercuts; clumping vegt
11	Utility corridor	Wet sclerophyll/ grassland	Occ logs & fallen trees; prob silty substrate	25m 0.000s	>1m	P	Uk	Present	Undercuts; clumping vegt; artificial rock
12	Utility corridor	Wet sclerophyll/ grassland	Freq logs & fallen trees; prob silty substrate	25m 0.000s	>1m	P	Uk	Present	Silty, undercuts, mat rush; some erosion of inside bank, woody and grassy flood debris
13	Utility corridor	Riparian	Occ logs & fallen trees; prob silty substrate	20m	>1m	P	Uk	Present	Silty, undercuts, mat rush, woody and grass flood debris
14	Utility corridor	Riparian	Logs, fallen trees, lomandra on bank, bank slumping,	20m	>1m	P	Uk	Absent	Silty, undercuts, mat rush, o/h vegt
15	Agriculture / road reserve	Riparian / grassland	Rare logs; persicaria & grasses & mat rush on bank;	25-30m	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared; cleared bank benched
16	Agriculture / road reserve	Riparian / grassland	Rare logs; persicaria & grasses & mat rush on bank;	25-30m	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared; cleared bank benched
17	Agriculture / road reserve	Riparian / grassland	Rare logs; persicaria & grasses & mat rush on bank;	25-30m	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared; cleared bank benched
18	Agriculture / road reserve	Riparian / grassland	Occ logs; persicaria & grasses on bank; back channel	30m 0.000s	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared
19	Agriculture / road reserve	Riparian / grassland	Occ logs; persicaria & grasses on bank; back channel	20m	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared
20	Agriculture / road reserve	Riparian / grassland	Occ logs; persicaria & grasses on bank; back channel	20m	>1m	P	Uk	Absent	Silty, o/h vegt, narrow rip zone, one bank cleared
21	Agriculture / road reserve	Riparian / grassland	Occ logs; occ lomandra clumps; back channel	20m	>1m	P	Uk	Absent	Silty, sparse vegt

Zone	Bank profile	Bank vegetation cover	Groundcover composition	Depth of leaf litter	Tadpoles (trap) weight, sex, location.	Tadpoles (dip net) weight, sex, location.
1	Steep	40.0%	30% vegt; 40%litter; 30%bare	30mm	Nil	Nil
2	Steep	60.0%	25% vegt; 40% litter; 35%	30mm	Nil	Nil
3	Steep both banks	60.0%	25% vegt; 70% litter; 5% bare	20mm	Nil	Nil
4	Sloping - moderate	60.0%	20%Veg, 20% flood debris and fallen trees, 20%litter, 30%water, 10% bare ground	30mm	Nil	Nil
5	Benched on nth; steep on Sth	50%	40% veg; 20% dead veg 10%logs, 15% bare. 5% litter	5mm	Nil	Nil
6	Steep; gentle on central bar	10.0%	60% veg; 10%litter, 15%log debris, 15% bare	5mm	Nil	Nil
7	Steep; central island = gentle slope	50%	60% veg, 20% flood debris, 10% bare ground, 10% litter	5mm	Nil	Nil
8	Gentle to mod slope	10.0%	40% veg 30% rock 30%bare	Nil	Nil	Nil
9	Gentle slope	10.0%	50% veg; 20% rock 30% bare	Nil	Nil	Nil
10	Steep & short on Sth; sloping (mod) & tall on nth	50.0%	30% veg; 50% litter; 20% bare	10mm	Nil	Nil
11	Steep east, benched west	30.0%	55% vegt; 15% litter; 30% bare	10mm	Nil	Nil
12	Vertical on west, steep slope on east	30.0%	55% vegt; 15% litter; 30% bare	10mm	Nil	Nil
13	Verticals & steep slope	75%	40% vegt; 30% litter; 30% bare	20mm	Nil	Nil
14	Vertical on west, steep slope on east	90.0%	30% vegt; 50% litter; 20% bare	50mm	Nil	Nil
15	Steep; cleared bank benched	35%	60% vegt; 25% litter; 15% bare	20mm	Nil	Nil
16	Steep; cleared bank benched	30.0%	60% vegt; 25% litter; 15% bare	20mm	Nil	Nil
17	Steep; cleared bank benched	40.0%	60% vegt; 20% litter; 20% bare	20mm	Nil	Nil
18	Steep; cleared bank benched	40.0%	60% vegt; 20% litter; 20% bare	20mm	Nil	Nil
19	Steep; cleared bank benched	35%	50% vegt; 20% litter; 30% bare	<10mm	Nil	Nil
20	Steep; cleared bank benched	35%	50% vegt; 20% litter; 30% bare	<10mm	Nil	Nil
21	Steep; cleared bank benched	25%	55% vegt; 20% litter; 25% bare	<10mm	Nil	Nil