Quantifying the likelihood of barrier strike maintenance

February 2016

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NZ Transport Agency research report 580
Contracted research organisation – Abley Transportation Consultants Limited, Christchurch

ISBN 978-0-478-44542-8 (electronic)
ISSN 1173-3764 (electronic)

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Smith, D, R Hyde, C O'Neil and B Corben (2016) Quantifying the likelihood of barrier strike maintenance. *NZ Transport Agency research report 580*. 102pp.

Abley Transportation Consultants Limited was contracted by the NZ Transport Agency in 2013 to carry out this research.

Keywords: barrier strike, maintenance costs, nuisance barrier strike, strike rate

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Acknowledgements

The project team would like to thank the New Zealand Transport Agency Research Owner, Fergus Tate, and members of the Steering Group for their time and helpful feedback including David Darwin, Julian Chisnall (the New Zealand Transport Agency), and Ken Stevenson (Waimakariri District Council).

The project team would also like to thank our peer reviewers, Rod Troutbeck, Troutbeck and Associates, and Tim Hughes from the New Zealand Transport Agency, for their guidance and advice.

We would also like to acknowledge the assistance of New Zealand Transport Agency Regional Representatives and their contractors for their input and involvement in the early stages of the research, as well as the technical support and assistance of the wider team at Abley Transportation Consultants.

Abbreviations and acronyms

AADT	average annual daily traffic
AMA	Auckland Motorways Alliance
ATP	audio tactile profiled/profiling
BSD	Barrier Strike Database
GIS	geographical information system
KAT	KiwiRAP Analysis Tool
KiwiRAP	New Zealand Road Assessment Programme
LHS	left-hand side
RAMM	Road Assessment and Maintenance Management (Database)
RCA	road controlling authority
RP	route position
RS	reference station
SCRIM	sideway-force coefficient routine investigation machine
SH	state highway, as in SH1
STA	Swedish Transport Administration
Transport Agency	New Zealand Transport Agency
TLA	territorial local authority
VKT	vehicle kilometres travelled
VRS	vehicle restraint systems
WRB	wire rope barrier

Contents

Executive summary

This research investigated the occurrence and corresponding maintenance costs associated with vehicle strikes on W-beam and wire rope barrier installations. The research considered nuisance strikes in isolation from all-strike events. Nuisance strikes are events whereby the barrier is struck by a vehicle which is then able to drive away and the event is not recorded in the NZ Transport Agency Crash Analysis System (CAS). The likelihood and cost of nuisance strikes have been evaluated in isolation as they result in significant maintenance costs on the state highway network which cannot be recovered through conventional processes.

The purpose of the research project was to identify significant variables influencing barrier strikes and the cost of associated collision maintenance, and subsequently produce a predictive model to assist the NZ Transport Agency in understanding the relationship between collision maintenance costs, barrier installation, barrier type and environmental factors including median width and carriageway width.

The specific objectives of the research were to:

- undertake a literature review to report on best practice in similar safety barrier and collision maintenance research, and ensure it takes into account and complements existing NZ Transport Agency research
- provide a model that predicts the expected barrier strike rate and corresponding maintenance costs as a function of the operational and environmental variables identified
- determine the implications of the decision to install a barrier, select a specific barrier type, and widen a carriageway to reduce maintenance costs.

The scope of the research included wire rope and W-beam barriers but not concrete barriers, wooden barriers or those constructed from other materials. A review of national and international literature was undertaken to identify previous studies into the relevant environmental and operational factors that influence crash risk for roadside safety barriers and the effect these have on asset maintenance and life cycle costs. The extent of research relating specifically to nuisance strikes on wire-rope and W-beam barriers was limited; however, international research relating the frequency of all barrier strike events found there is a direct association with some or all of the operational and environmental factors listed in the table below.

Type of variable	Variable
Operational	Impact angles and impact speeds
	Speed limit
	Vehicle type and mass
	Increased curvature
	Barrier placement
Environmental	Lateral offset of the barrier
	Road type, alignment and cross section
	Median widths
	Number of traffic lanes
	Shy or drive lines
	Regional characteristics
	Seasonal effects

International and New Zealand practitioners were contacted and asked for their experiences and knowledge relating to variables that influence the nuisance barrier strike rate in their areas. The Swedish Transport Administration is undertaking research to reduce the impact of 'run-off road' crashes, which considers road design elements and other factors of interest to this research. Australian authorities expressed concern that increasing maintenance funding restrictions are leading to cost-focused decision making rather than following the Safe System approach when making decisions regarding barrier installations that achieve safety benefits.

The factors considered by the various road controlling authorities (RCAs) throughout New Zealand which affect the rate of nuisance strikes generally correspond with the factors investigated and identified in existing international and New Zealand research. However, certain RCAs found they do have what they consider to be a high level of nuisance strikes, usually located on specific points of their network, while other RCAs do not consider these types of strikes to be a particularly significant issue. The general consensus was that wire rope barriers are preferred, where possible, given the reduced installation and maintenance costs and the ease of repair following crashes.

In order to quantify the barrier strike incident rate and its influence on maintenance costs, data was requested from New Zealand and Australian roading authorities. Nuisance strike data was received from a number of NZ Transport Agency regional offices and required a significant amount of data cleaning in order to produce a database containing 1,213 strike records. These records were then linked to KiwiRAP Analysis Tool and Road Assessment and Maintenance Management Database data to provide a comprehensive set of variables fit for subsequent nuisance strike analysis. By combining this dataset with a CAS query output for non-drive away events involving a guardrail strike between 2005 and 2014, a dataset with the total number of barrier strikes was able to be collected. The data gathering stage revealed both a lack of data record keeping for nuisance strike events as well as an inconsistency in the data collection standard and formatting between regions.

Multivariate linear and non-linear regression analysis was undertaken to determine the operational and environmental variables which are statistically significant factors in determining the rate of barrier strikes and consequent collision maintenance costs. The key (independent) variables that were tested in the regression analysis included traffic volumes, median width, carriageway width, offset from centreline, horizontal alignment, terrain, number of lanes, length of barrier, posted speed, presence of audio tactile profiled (ATP) road markings and percentage of heavy vehicles.

Regression models were developed for wire rope and W-beam barriers, both for left-hand side (LHS) and median installations. Two barrier strike categories were considered, nuisance strikes (where a barrier is struck but the driver carries on driving and avoids liability for the repair cost) and all-strikes (which include nuisance strikes and strikes recorded through CAS).

The models generated a set of significant variables responsible for the variation in barrier strike rates and consequential maintenance costs. The table opposite summarises the significant variables for each nuisance strike model (N) and all-strike model (A) that was developed. The nuisance strike models predict the number of nuisance strikes per million vehicle kilometres travelled so also take into consideration the length of each barrier and the volume of traffic at the corresponding barrier location. The all-strike models evaluated the number of strikes per annum.

Significant variables	Median wire rope	Left-hand side wire rope	Median W-beam (>40m)	Left-hand side W-beam (>40m)	Median W-beam (≤40m)	LHS W-beam (≤40m)
Horizontal alignment	A/N	A/N		A/N	A	A/N
Median width	A/N					
ATP	A/N	A/N				
Posted speed	A/N					
Offset from centreline		A/N				
Terrain			A/N	A/N	N	A/N
Average annual daily traffic	A	A	A	A		A
Length of section	A	A	A	A		
Percentage heavy vehicles						A

The significant variables generally align with those identified in the literature review as being significant for vehicular crashes with roadside barriers, although the literature generally did not isolate nuisance strikes from non-drive away events.

Having identified relationships between the rate of barrier strikes and the operational and environmental variables, these factors can be used to inform planners and road controlling authorities when deciding if a barrier should be installed. The primary motivation for barrier installation is to preserve lives and maximise road user safety. There is the opportunity to also predict and consider the likely maintenance cost implications of barrier strikes as part of a wider business case to install further barrier infrastructure on the New Zealand road network.

The barrier strike spreadsheet tool that accompanies this research calculates the maintenance cost per annum associated with wire rope and W-Beam barriers. This cost prediction can be used in conjunction with other cost components to form part of the wider economic assessment of the relative benefits (or dis-benefits) associated with the installation of WRB in a given location. When deciding what type of barrier should be installed, the cost of crashes should also be taken into consideration.

With regards to the implementation of this research, it is recommended that:

- The predictive spreadsheet tool developed in this research be applied within NZ Transport Agency and shared with other road controlling authorities to support decisions in relation to the installation of barriers, widening of medians and carriageways, and installation of ATP road markings in the vicinity of barriers.
- A standard template be established to collect barrier maintenance data captured throughout New Zealand, supported by regular maintenance schedules across high-risk parts of the roading network.
- Manage barrier maintenance data in a central repository such as a GIS platform providing the opportunity for barrier strike information to be interrogated and mapped spatially, and integrated with other road safety and asset management datasets.

Abstract

Recent research both in New Zealand and Australia has identified the benefits associated with the installation of various barrier types and in particular the significant benefits associated with wire rope barriers (WRBs). A result of that research will be an increase in the use of barriers and in particular WRB.

This research investigated the occurrence and corresponding maintenance costs associated with vehicle strikes on W-beam and WRB installations. The likelihood and cost of nuisance strikes have been evaluated in isolation from all-strikes as they result in significant maintenance costs on the state highway network. Nuisance strikes are events whereby the barrier is struck by a vehicle which is then able to drive away and the event is not recorded in the Crash Analysis System.

The environmental and operational variables that significantly influence the rate at which barrier strikes occur are determined in this research and a predictive spreadsheet tool has been developed to model the likely strike rate and maintenance costs associated with various barrier installation types. This tool is intended to assist practitioners with:

- the decision to install a barrier
- the selection of barrier type
- whether or not a carriageway or median should be widened to reduce future maintenance costs.

1 Introduction

The NZ Transport Agency contracted Abley Transportation Consultants, supported by Corben Consulting to quantify the likelihood of barrier strike maintenance on the New Zealand state highway and local road networks.

The increased use of wire rope barriers (WRBs), in particular on the SH network, puts additional pressure on barrier maintenance funding. This research investigated the occurrence and corresponding maintenance costs associated with strikes on W-beam and WRB installations. The research focused largely on nuisance strikes in isolation, but also developed models to predict the likelihood and costs associated with all barrier strike events. Nuisance strikes are events whereby the barrier is struck by a vehicle which is then able to drive away and the event is not recorded in the NZ Transport Agency Crash Analysis System (CAS). This research is particularly relevant because of the increased use of flexible barriers such as wire rope which increases the proportion of nuisance strikes and un-claimable costs.

The purpose of the research project was to identify significant variables influencing barrier strikes and the cost of associated collision maintenance, and subsequently produce a predictive model to assist the NZ Transport Agency (the Transport Agency) to understand the relationship between collision maintenance costs, barrier installation, barrier type and environmental factors including median width and carriageway width.

The specific objectives of the research were:

- To undertake a literature review to report on best practice in similar safety barrier and collision maintenance research, and ensure it takes into account and complements existing Transport Agency research.
- To produce models which predict the expected barrier strike rate and corresponding maintenance costs as a function of the operational and environmental variables identified.
- To determine the implications of the decision to install a barrier, select a specific barrier type (flexible and semi-rigid), and widen a carriageway to reduce maintenance costs.

Rigid (concrete) barriers were initially considered for inclusion as part of the research; however, following consultation with the Steering Group, it was agreed that these should be removed.

The research underpinning this report was undertaken during 2013–2015 and involved six phases of work, starting from an initial literature review and concluded by refining and finalising the prediction models and corresponding spreadsheet tool[1]. Each phase of the project separately reported to the project Steering Group. This report presents both an overview of the research process as it was developed and the outputs (including recommendations) that were generated.

1.1 Report structure

The report is organised as follows:

- Chapter 2 provides background for the research by summarising the findings of international and New Zealand barrier strike literature and chapter 3 presents the key learnings from discussions with New Zealand, Australian and Swedish practitioners.

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[1] The barrier strike cost prediction model developed as part of this research can be accessed at www.nzta.govt.nz/resources/research/reports/580. See also appendix C.

- Chapter 4 describes the data collection process whereby New Zealand and Australian practitioners and contractors provided nuisance barrier strikes data for inclusion in the research. Data cleaning, aggregation and management are also addressed in this chapter.
- Chapter 5 documents the methodology for the development of the regression models, and the models are presented in chapters 6 and 7 alongside discussion around the application of the models, specifically addressing some key questions from the research brief.
- Chapter 8 describes the spreadsheet tool developed which predicts the expected barrier strike rate and corresponding maintenance costs as a function of the operational and environmental variables identified.
- Chapters 9 and 10 present conclusions and recommendations.

2 Literature review

2.1 Background

A targeted review of the national and international literature was undertaken to identify studies into the relevant factors that influence crash risk for roadside safety barriers, focusing on WRBs and W-beam barriers.

WRBs consist of steel cables mounted on weak steel posts. They have a low initial installation cost, low impact severity, and occupy less road space due to their thin profile. WRBs provide effective vehicle containment and their open design prevents snow accumulation and provides good visibility through the barrier.

Figure 2.1 Wire rope barriers

W-beam barriers consist of a steel beam with a w-shaped guard rail profile, mounted on wooden or steel posts. Due to their rigidity, they have the ability to maintain a degree of efficiency after minor impacts; however, they have a high sensitivity to placement to ensure the risk of vehicles vaulting or under-riding the barrier is minimised.

Figure 2.2 W-beam barriers

The literature review focuses largely on the impact of nuisance barrier strikes, as opposed to all instances in which a barrier may be struck by a vehicle as there is already an extensive body of literature detailing these types of strikes.

A nuisance barrier strike is defined as 'an impact to a barrier that does not cause injury and the vehicle is able to drive away, but inflicts damage to the barrier that requires expensive maintenance'. Nuisance strikes may not feature in crash data or be immediately noticed.

This section reports on the findings of this targeted literature review on best practice in similar international and New Zealand safety barrier and collision maintenance research.

In addition to the published literature, a number of international, New Zealand and Australian experts have been contacted to obtain information and insights into this issue, from an expert practitioner's perspective. The results are reported in chapter 3 of this report.

2.2 International research

A small number of publications have been found that provide directly relevant information on the frequency of barrier collisions as a function of traffic exposure and the physical characteristics of barriers and their surrounds. None of these isolate nuisance barrier strikes specifically; however, the variables that contribute to the occurrence of nuisance strikes are likely to be relevant to those that contribute to the crash risk of roadside barriers. The main findings of relevance are presented below.

Chimba et al (2014) provide an up-to-date review of past studies, as well as reporting the results of a new analysis of barrier crash histories for a sample of barrier installations in Tennessee, USA. The study provides a comprehensive overview of what is known about the factors that influence barrier crash frequency for cable barriers installed in medians.

The factors investigated by Chimba et al (2014) have been limited to findings for crashes that occurred after barrier installation (the study also reports the results of similar analyses for median crashes that occurred before barriers were installed). Table 2.1 shows the factors that were statistically significant at the 95% confidence level, as well as factors that showed a non-statistical association but had a positive or negative correlation with median barrier crash frequency. Except, perhaps, for inside shoulder width, associations were generally found to be in the directions expected. The key findings were that barrier installations on road segments with large differential elevations between the two directions, sharp curves and narrow medians would incur a greater strike rate.

In relation to the results summarised in table 2.1, Miaou et al (2005) also found an association between barrier crash frequency and lateral offset of barrier, number of traffic lanes and median widths. The direction of the associations was the same as for Chimba et al (2014). Research conducted by Donnell and Mason (2006) reported an association between barrier crash frequency and lateral offset of barrier, again supporting the intuitive conclusion that barriers will be struck more often if they are positioned closer to the traffic lane. A high posted speed and high average annual daily traffic (AADT) were also factors likely to increase barrier strike rates; however, these variables were not statistically significant at a 95% confidence interval.

Table 2.1 Summary of factors associated with median barrier crash frequency (after installation)

Statistically significant factors result in an increase in crash frequency	Not significant factors but associated with an increase in crash frequency	Not significant factors but associated with a decrease in crash frequency
Inside shoulder width	Posted speed limit	Higher number of lanes per carriageway
Difference in elevation between opposing carriageways	Increase in traffic volume (AADT)	A wider lateral offset of cable barrier from traffic lane
Horizontal curve radius	Left-turning curves	Wider median width
	Right-turning curves	

Chimba et al (2014) also describe the analysis method used to investigate relationships between the range of factors for which data was collected and median barrier crash frequency. After comparing both the Poisson and negative binomial distributions for the purposes of modelling relationships, it was found that the negative binomial distribution was a better fit for the crash and injury data. The authors report using the maximum likelihood estimation criterion for the negative binomial model estimation. The commercially available software STATA 10 was used to conduct the modelling and the assessment of statistical significance of the variables was carried out using the Z test.

Levett et al (2008) report the findings of the NSW Centre for Road Safety that 'increasing curve radius, within particular ranges, can reduce crash likelihood but may also increase the expected severity of crashes that do occur (presumably because the crashes happen at a higher average speed)'. The tendency for increased curvature to increase crash frequency is consistent with the findings of Chimba et al (2014).

Karim et al (2011) studied road barrier repair costs and the factors that influence cost outcomes. Their study focused on median and mid-barriers, as data on roadside barriers was too limited. They note that the maintenance costs for road barriers differ according to various barrier, road design and situational factors, including:

- barrier type, design and placement
- road type, alignment and cross-section
- speed limit
- impact angles and impact speeds
- vehicle type and mass
- regional characteristics and
- seasonal effects (eg icy or wet road surfaces).

However, there is a general lack of knowledge of how these (and potentially other) factors affect barrier repairs and their costs, and a clear need exists for research into the role of road and traffic factors in determining barrier repair costs. In Sweden, as in New Zealand and Australia, the use of roadside barriers, especially cable/wire rope types, is far more prevalent today, principally because of the demonstrated effectiveness of flexible barriers to eliminate a vast part of the severe road trauma involving lane departures. Many hundreds of kilometres of rural roadway in Sweden have been reconstructed to create 'collision-free roads', also known as 2+1 roads whereby there are two lanes in one direction, one in the other and a median barrier as pictured in figure 2.3

Figure 2.3 Example of 2 + 1 'collision free' roadway in Sweden

Karim et al (2011) refer to evaluation studies (Carlsson and Brüde 2004; 2005; 2006) of the performance of Sweden's collision-free roads, in terms of serious injuries and fatalities. Collision-free roads in Sweden predominantly use cable barriers and tend to be of lower geometric standards than motorways. The damage risk for cable barriers was found to be 20% higher on roads with a speed limit of 110km/h, when compared with roads with a speed limit of 90km/h. The number of repairs per million vehicle kilometres (VKT) travelled was the basis for this comparison. It was also argued that the annual repair costs for cable barrier damages were likely to be higher along roads with a 110km/h speed limit. Fewer barrier repairs were found along collision-free roads 14m wide compared with those 13m wide. This is believed to be due to the greater separation between opposing directions of travel along 14m wide roads. A potential limitation in translating the findings of the studies by Carlson and Brüde is that many barrier collisions involve low severity outcomes, which may exhibit different characteristics from those described above for the higher severity crashes.

Road type, speed limit, barrier type and seasonal effects were investigated by Karim et al (2011), using case studies from four of the Swedish Road Administration regions. A sample of 1,625 barrier repairs carried out during 2005 and 2006 were collected. The number of barrier repairs and the average repair cost per vehicle kilometre were found to be higher along collision-free roads, than along motorways and four-lane roads. It was argued that the more confined nature of collision-free roads compared with motorways is the likely explanation for this finding. In addition, the number of barrier repairs and the average repair cost per vehicle kilometre were found to be higher for cable barrier than other types of barrier. In summary, no conclusions could be drawn regarding the influence of speed limits on barrier repairs and associated costs. This was due largely to the fact that regional results were divergent and not statistically significant.

Linear and generalised linear models were used to analyse the influence of selected factors on the number of barrier repairs and on average repair costs per vehicle kilometre. Barrier types, road types, speed limit and regional effects were the main factors analysed. The statistical analysis methods of Karim et al (2011) are described in greater detail in their paper.

Queensland Government Department of Transport and Main Roads (2005) provides specific guidance on the reduction of barrier maintenance and collision costs. It advises that where nuisance crashes are relatively common, a crash cushion with redirection capability should reduce or eliminate the maintenance effort required for minor repairs or partial replacement of an end barrier treatment system. In relation to choosing the appropriate crashworthy end treatment for a barrier, the department states that a number of matters should be considered including the capacity of the end treatment to absorb nuisance crashes and cost and maintenance factors. The type of end treatments will also be influenced by the space available and physically smaller systems may be selected on the basis that a smaller size will reduce the number of crashes, particularly nuisance crashes, thereby reducing the maintenance that must be completed following an incident.

Tasmania Government Department of Infrastructure Energy and Resources (2007) found that in situations where space is severely restricted, it may be necessary to locate the barrier in an optimal position that may involve narrowing of the shoulder and the barrier type/design will be chosen so that it minimises deflection under impact. It states in its *Road safety barrier design guide part A*' that:

> *In situations where the hazard is located within the clear zone, but a substantial distance from the road, it may be preferable to locate a flexible or semi rigid barrier as far from the edge of the traffic lane as is practicable. This should only be done if the area between the edge of the traffic lane and the barrier is a relatively flat and traversable surface. The advantages of maximising the distance is that many errant vehicles recover within 5m of the edge of the traffic lane and nuisance strikes are minimised.*

In addition to the factors influencing barrier strikes, both Williams (2007) and Karim (2008) discuss using whole-of-life costs associated with median safety barriers to optimise design and choice of barrier type by using a process of life-cycle cost analysis with a particular emphasis on road maintenance. Although neither piece of literature specifically mentions nuisance strikes, their cost would be implicit in the total maintenance costs considered.

> *The cost of a road construction over its service life is a function of its design, quality of construction, maintenance strategies and maintenance operations. An optimal life-cycle cost for a road construction requires estimations of the above mentioned components. Unfortunately, designers often neglect a very important aspect which is the ability to perform future maintenance activities* (Karim 2008).

Karim's investigation identifies that the crucial factor for an accurate calculation of life-cycle costs is the use of accurate data. Due to the large number of factors that affect maintenance costs, collecting data is a difficult task and so a lack of data related to the maintenance costs of barrier repairs and the factors influencing these costs exists. This together with the absence of a calculation model for repair costs which take these factors into consideration means designers are faced with an almost impossible task of considering life-cycle costs.

2.3 New Zealand research

The factors influencing the rate of nuisance strikes and corresponding maintenance costs are not specifically addressed in existing New Zealand research. However, there are two case studies in New Zealand particularly relevant to the use of WRBs and the associated maintenance records: first the Crowther and Swears (2010) study of the median WRB located on SH1 between Longswamp and Rangiriri. Second, an investigation by Marsh and Pilgrim (2010) into the performance of a WRB on a narrow median installation on Centennial Highway.

Crowther and Swears (2010) analysed the number of crashes pre and post installation of a median WRB along a 9km section of SH1 between Longswamp and Rangiriri. Crash data and barrier repair information were analysed and indicated that while the number of crashes increased by 64% post installation of the WRB, the number of fatal and serious crashes had reduced significantly by 63%.

Crash analysis by Crowther and Swears (2010) identified two common characteristics for crash cluster sites within the Longswamp to Rangiriri study area:

1. single lane section, right-hand curve on an uphill gradient
2. single lane section, left-hand curve on a downhill gradient.

Subsequent investigation of the physical features of the crash cluster sites indicated two particular issues with the road environment, mainly:

1. the lack of visibility on right hand curves
2. roadside barriers were located in close proximity to the edge line.

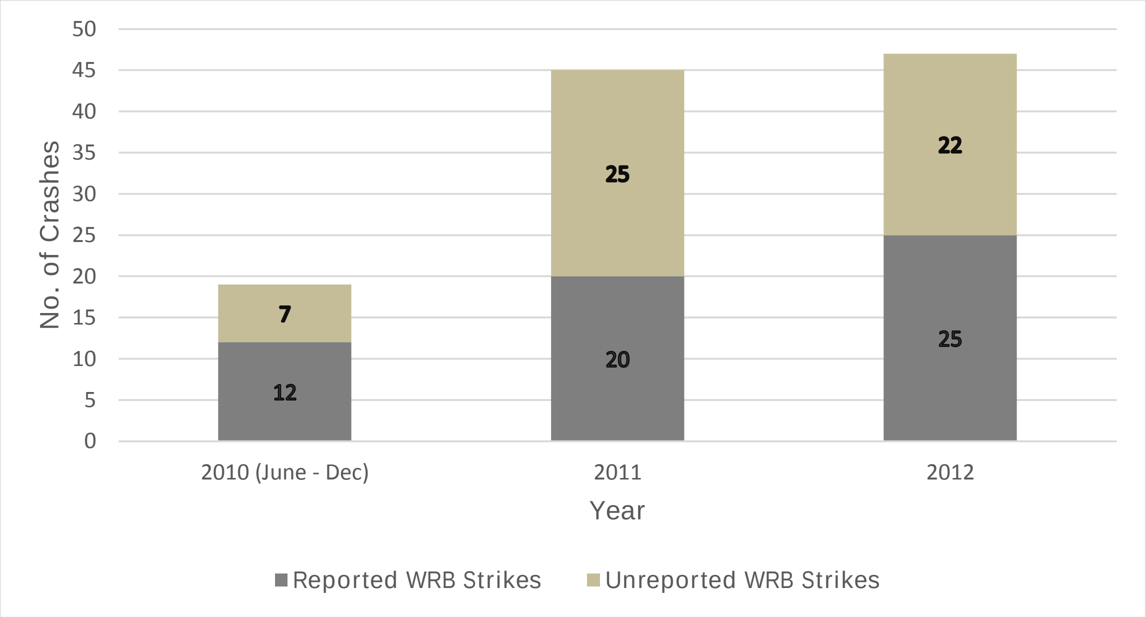
Following the crash analysis, a number of measures were recommended to mitigate the number of crashes occurring, including:

- provide clear zones
- increase median widths to accommodate the WRB design deflection on both sides
- delineation through the use of WRB marker posts in line with edge marker posts or, audio tactile profiled (ATP) centre lines against the WRB or, long-life markings and/or raised reflective pavement markers on the edge and lane lines, or edge marker posts at reduced spacing.

A report by McCarthy and Underwook (2013) carried out further analysis on this same section of State Highway (SH) 1, including examination of the contractors' WRB maintenance records.

The crash reports and the contractors' maintenance records were cross checked for the period from June 2010 to December 2012. This found a significant number of wire rope maintenance records with no corresponding reported crash based on the reported crash date and location. The resulting damage to the barriers was therefore assumed to be due to nuisance strikes. Figure 2.4 shows that the number of unreported barrier strikes for 2011 and 2012 were almost equivalent to the number of reported crashes. A comparison with the data from Crowther and Swears (2010) found that the reporting rates for barrier strikes had reduced from an average of 63% in the period 2006–2009 to an average of 57% for the period 2010–2012.

Figure 2.4 Reported vs unreported wire rope barrier strikes



To assess the effect of the environmental and operational conditions on the number of WRB strikes, the study area was broken into sections. The traffic lane arrangement for the section which had the highest number of unrecorded (nuisance) strikes had one lane in each direction and a strike rate of approximately 12 strikes per km. Similarly, the section with the highest reported strike rates of 42 strikes per km also had one lane in each direction.

Marsh and Pilgrim (2010) reported on the performance of a WRB on a narrow median installation on Centennial Highway. Marsh and Pilgrim analysed camera surveillance of the Centennial Highway median barrier and found that vehicles generally sustained relatively little damage when they struck the barrier and were often observed to drive away after the impact. Examples of such instances included one motorist suffering from fatigue drifting towards the centre of the road and on contact with the barrier awoke and continued the journey without incident. A second incident involved a heavy vehicle drifting into the median barrier. If there had been no barrier in place on both occasions, the drivers would have veered into oncoming traffic.

The barrier strikes recorded by the maintenance contractor indicated over the complete 3.5km length, the crash rate was 5.6 recorded impacts per km per year, or 1 crash per 1.5 million vehicle km. The average impact along Centennial Highway resulted in 12 damaged posts at a repair cost of $1,356 and an average cost of $7,649 per km per year for the total 3.5km section. In 90% of the impacts the damage was limited to 24 posts or less at a cost of $2,394 or less.

The Centennial Highway experience is similar to that of the Longswamp to Rangiriri WRB with regard to the increased maintenance costs associated with impacts on the WRB barrier. Following their research, Marsh and Pilgrim (2010) recommended that wherever possible, wider medians should be adopted to minimise the associated maintenance costs. Ideally, the median should provide at least sufficient space to fully accommodate the design deflection of the selected barrier system.

Marsh and Pilgrim (2010) suggested there may be merit in applying ATP line markings on the centrelines to reduce the likelihood of strikes on the barrier. It recommended further research to determine the likely reduction of median barrier strikes with the installation of ATP centreline markings and that this would enable a benefit–cost evaluation to be carried out to determine whether the installation of ATP markings is likely to offset the maintenance costs associated with barrier impacts on new and existing installations.

While no specific New Zealand research has been found which explicitly relates to the factors influencing the rate of nuisance strikes on WRBs and W-beam barriers and the resulting maintenance costs, there is still valuable and relevant research regarding the variables which influence crash rates and their severity.

Jamieson and Richardson (2013) provided information on the crash severity in relation to barrier height and condition of the barrier and whether it would be cost effective to rectify or replace existing roadside crash barriers that do not conform to the installation specifications or to install new roadside crash barriers at previously untreated locations. The study found there was wide regional and contractor variation in the costs, both to erect new barriers and to fix or raise them; however, WRBs were generally cheaper to erect and fix than W-beam barriers.

The ranges of prices per metre of length for rectifying/maintaining W-beam and WRBs and installing new ones found by Jamieson and Richardson (2013) are shown in table 2.2.

Table 2.2 Costs for new roadside barrier construction and maintenance (including raising height)

Barrier type	New construction cost/range ($/m)	New construction cost median ($/m)	Raising barrier cost range ($/M)	Raising barrier cost median ($/m)
W-beam	85–185	135	~44–85	73
Wire rope	75–128	95	~40–60	NA[(a)]

[(a)] Only one source of pricing

The simulation modelling by Jamieson and Richardson (2013) included both straight and curved road sections and suggested that the effects of barrier height on crash severity along with the various cost factors associated with barrier construction or remediation meant that it is more cost effective to install new barriers in previously untreated locations than to raise the existing ones to the correct height, particularly in the case of WRBs.

A study by Jamieson et al (2013) sought to quantify the effects of barriers and clear zones on the mitigation of crash numbers and crash severity through the statistical analysis of New Zealand crash data. An existing crash risk model which covered road condition, road geometry and crash data was extended to also include the relevant available information on roadside clear zones and barriers.

Crash rates were predicted for different types of barrier and different roadside condition risk categories from the statistical analyses carried out by Jamieson et al (2013) on the existing database. These are shown in table 2.3. The roadside risk categories relate to the physical makeup of the roadside through the KiwiRAP severity outcomes and their descriptions. These descriptors are defined in table 2.4 where Jamieson et al (2013) have taken the KiwiRAP risk descriptors in table 2.5 to derive a measure of roadside risk crash rate by using the number of predicted and actual crashes, and the ratio of the two.

Table 2.3 Crash rates associated with different barrier / rail types and roadside condition

Classification type	Barrier/rail type or roadside condition	Predicted crash rate (per 100 million vehicle.km)
Barrier/rail	Rigid (concrete)	17
	Short-rail[a]	23
	Semi-rigid (w-beam)	13
	Flexible (wire rope)	10
Roadside condition (derived by KiwiRAP)	Tiny	0.4
	Low	6
	Medium	10
	High (moderate hazard)	13
	Extra high (severe hazard, eg large tree)	14

[a] Short rails are those short lengths usually associated with other structures (eg bridges).

Source: Jamieson et al (2013)

Table 2.4 KiwiRAP Run-off road severity codes and risk descriptors

Severity outcome	Offset from sealed carriageway			
	<4m	4–9m	9–15m	15m+
Negligible/wire rope	Negligible	Negligible	Negligible	Negligible
Rigid barriers	Minor	Negligible	Negligible	Negligible
Moderate (including semi-rigid)	Moderate	Minor	Negligible	Negligible
Severe/head-on	Severe	Moderate	Minor	Negligible

Source: Jamieson et al (2013)

Table 2.5 Severity codes and risk descriptors

Severity outcome	Offset from edge of sealed carriageway			
	0–4m	4–9m	9–15m	15+m
Negligible	Medium	Low	Tiny	Tiny
Moderate	High	Medium	Low)	Tiny
Severe, head-on	Extra high	High	Medium	Low
Rigid barriers	Rigid	Rigid	Rigid	Rigid)

Source: Jamieson et al (2013)

The statistical analysis carried out by Jamieson et al (2013) found that the best performing roadside conditions were the tiny and low-risk categories, and flexible WRBs performed better than the other types. This performance of the wire rope seemed more important on right-hand bends. While the lateral offset of the hazard from the road is important, ie the width of the clear zone, it is also the type of hazard that is encountered at the far side of this offset distance that is important in determining the crash rate. It is likely that the crash rate for different barrier types will be influenced by the typical use of each type, by way of example concrete barriers may be installed in quite different environments to WRBs.

No existing predictive tools have been found, either in New Zealand or internationally, which focus on modelling barrier maintenance costs. There are, however, a number of crash prediction models, which have been developed for application in Australasia and New Zealand that identify the variables which influence crash rates, including various environmental and operational factors. Although these tools do not specifically model the variables affecting the rate of nuisance wire rope and W-beam barrier strikes, they are still beneficial to this research in understanding the relationship between various factors and crash rates.

Turner et al (2004) discuss how crash prediction models indicate some of the important variables that can contribute to the number of crashes involving roadside hazards. The study found that crash rates increased as:

- the number of severe hazards increase
- traffic volumes increase
- road width decreases
- road alignment is less straight.

A pilot study carried out by Turner et al (2009), developed preliminary crash prediction models for rural roads to identify relationships between the flow variables (ie mean number of crashes and AADT) and the non-flow variables such as road geometry, roadside hazards, frequency of accesses and skid resistance.

From the initial list of 28 variables for which data was collected, a most representative and best performing set of eight was selected to be incorporated into the multi-variable models alongside traffic volume. Neither of the variables involving barriers was included. The overall preferred model was found to involve volume, distance to non-traversable hazard, absolute gradient, sideway-force coefficient routine investigation machine (SCRIM) coefficient, and percentage reduction in curve speed. The results of the model demonstrated the influence of the roadside environment and road geometry on the predicted crash rate.

Cenek et al (2012b) developed a statistical crash prediction model for application to rural New Zealand state highways by combining detailed road geometry, road surface condition, carriageway characteristics and crash data information. The resulting Poisson regression model was used to identify critical variables and their relationship with crash risk. Horizontal curvature had a strong effect on crash rates. Traffic flow and skid resistance also strongly correlated with crash rates. Lane roughness was also identified as a critical variable but to a lesser extent than horizontal curvature, traffic flow and skid resistance.

2.4 Summary

Overall the extent of the research from both international and New Zealand sources which directly relate to the variables influencing nuisance strikes on wire-rope and W-beam barriers and the associated maintenance costs has been found to be limited. However, there are a number of research papers which although not directly relating to nuisance strikes are still considered to provide valuable background to this research. International research relating to the frequency of barrier strikes as a function of traffic exposure and the physical characteristics of their surrounds has found there is a direct association between barrier crash frequency and some or all of the operational and environmental factors listed in table 2.6.

Table 2.6 Variables affecting barrier crash frequency

Type of variable	Variable
Operational	Impact angles and impact speeds
	Speed limit
	Vehicle type and mass
	Increased curvature
	Barrier placement
Environmental	Lateral offset of the barrier
	Road type, alignment and cross section
	Median widths
	Number of traffic lanes
	Drive lines
	Regional characteristics
	Seasonal effects

The extent to which these, and potentially other, factors influence the rate of barrier repairs and their costs is unclear. However, current guidance on how to reduce the rate of wire rope and W-beam barrier strikes occurring suggests measures such as locating the barrier as far from the edge of the traffic lane as possible, increasing median widths, installing delineation such as ATP road markings and installing crash cushions with redirection capability.

New Zealand research generally accords with international findings regarding the environmental and operational variables affecting crash rates and these may be similarly applicable for nuisance strikes.

3 Consultation with practitioners

A selection of international and New Zealand practitioners were contacted and asked to share their experiences and knowledge specifically relating to nuisance barrier strikes. Responses were received from Sweden, Australia and New Zealand.

3.1 International practitioners

The Swedish Transport Administration (STA) revealed the existence of a relatively new European study, known as Project SAVeRS (Selection of Appropriate Vehicle Restraint Systems). Project SAVeRS seeks to reduce the severity of 'run-off-road' crashes, by creating 'forgiving roadsides'. To be successful, road designers and operators must be able to select vehicle restraint systems (VRS) that best suit the specific traffic conditions and location types. It is intended that the project will produce a user-friendly guide on the selection of VRSs for a range of practical situations.

One of the SAVeRS initiatives determines how road design elements, traffic conditions, vehicle types and other variables can influence the type and severity of collisions that can arise with a VRS. This work was commencing at the time of writing so there are no results available for inclusion in this review. It is recommended that contact be established with STA so that results and other valuable insights can be shared with the transport sector.

Each Australian state and territory was contacted to gather further information, knowledge and insights on the barrier strike issue. A summary of the key responses is set out below.

- The growing use of barriers, especially WRBs, is a concern to maintenance engineers. The cost and need to fix them promptly is problematic for road agencies.
- No additional funds are being provided by governments to meet the growing cost of maintenance and this is affecting the choices of barrier type, barrier use and placement.
- Decisions on whether to install barriers are being made on the basis of benefit–cost analysis values and future maintenance costs, rather than regarding barriers as fundamental safety measures, like centre or edge lining, or guide posts. This philosophy is in conflict with the Safe System vision which holds life and health as paramount and not to be traded for other benefits or costs. That is, the traditional method of comparing the monetary saving from the loss of a statistical life with the cost of making the saving requires critical re-examination.
- Key factors that are believed to influence the risk of barrier strikes are speed limit, traffic volume, road curvature and barrier offset. Road maintenance engineers observed that when barriers were placed in close proximity with the traffic lanes, more frequent repairs were required.
- It would be worth investigating the role of traffic composition and longitudinal vertical geometry as barrier strike risk factors.

3.2 New Zealand practitioners

All Transport Agency regional representatives in New Zealand, along with four territorial local authorities (Auckland, Hamilton, Hutt City and Dunedin) were contacted to provide input. The following New Zealand road controlling authorities (RCAs) and maintenance contractors were able to provide valuable knowledge and data in relation to nuisance barrier strikes in their regions:

- NZ Transport Agency Nelson/Tasman/Marlborough
- NZ Transport Agency Wellington
- NZ Transport Agency Central Otago
- NZ Transport Agency Waikato
- Dunedin City Council
- NZ Transport Agency Dunedin
- NZ Transport Agency Tauranga
- Auckland Motorways Alliance (AMA)
- NZ Transport Agency Hamilton
- NZ Transport Agency North Canterbury

The RCAs revealed differences in the extent of the perceived problem caused by nuisance strike on New Zealand roads. Dunedin City Council and NZ Transport Agency Tauranga for example did not consider there to be a significant issue due to nuisance strikes within their areas. NZ Transport Agency Wellington, NZ Transport Agency Nelson/Tasman/Marlborough and NZ Transport Agency Central Otago found there to be a high incident rate of nuisance strikes causing damage to particular sections of WRB on their networks.

NZ Transport Agency Dunedin has experienced a high number of nuisance strikes along the Northern Motorway. Initially it was thought this was due, at least partially, to seasonal effects given the high altitude of the summit at approximately 360m. Consequently, this section of the Northern Motorway is frequently affected by snow and ice in winter months. However upon further examination of the data, only half of the damage occurs during the winter months with only one occurrence directly attributed to snow and only one or two incidents in the early morning when ice may be around. The road alignment was also considered to be another contributing factor to strike incidents. Elsewhere in Otago, speed was noted as a dominant factor contributing to the rate of nuisance strikes, particularly on high-speed high-volume roads.

The underlying environmental or operational factors considered by each RCA correlating to the rate of nuisance strikes, tended to correspond with the crash variables investigated within previous studies such as Karim et al (2011) and Cenek et al (2012b). The predominant variables noted by a number of RCAs included:

- the road alignment/geometry
- seasonal effects
- traffic volumes
- proximity of the barrier to the edge of the seal
- sight distances
- lighting
- skid resistance.

NZ Transport Agency Wellington, NZ Transport Agency Waikato and AMA all noted driver inattention or fatigue as likely causes. Fatigue was particularly linked to routes such as SH3/4 which are used by ski traffic and where there are long distances between towns or centres for rest stops. Central Otago has found that areas which experience a high nuisance strike rate tend to have narrow sealed shoulders and consider this to be a main contributing factor. Whereas NZ Transport Agency Waikato has found a high proportion of nuisance strikes generally occur in mid-block rural locations.

NZ Transport Agency Nelson/Tasman/Marlborough has found that typically nuisance strikes occur on their network when a truck cuts a tight radius corner and the rear trailer wheels connect with the barrier, thus the curvature of the road is the main factor in the rate of nuisance strikes in this region. They have also been able to identify a particular section of WRB on the Whakatu Drive which requires a repair each time it is hit. Conversely the W-beam barriers within the region have regular nuisance strikes but do not warrant repair after each strike. Typically, when the W-beam barrier is hit hard enough to warrant repair, the vehicle which hit it needs assistance in being removed, consequently repairs to W-beam barriers due to nuisance strikes are minimal.

There are various options available to RCAs when deciding on the type of barrier to install. The majority of RCAs questioned prefer to install a WRB where possible. This is mainly due to the fact it is easy to repair following a strike and in most cases can be repaired while cleaning up from the crash, thus reducing the number of times a contractor must visit the site and reducing traffic management costs. NZ Transport Agency Dunedin has found that the installation and maintenance costs for the WRB are much less in comparison with other barrier options but it is not suitable for all locations particularly where there is limited space within the road reserve. Auckland Motorways have a large proportion of barriers on their network which are concrete. While maintenance is a factor in deciding which type of barrier to install, the prevailing factor is containment levels. Lighting columns can also be incorporated within a concrete median which gives some protection to the column as opposed to columns on the roadside which are more exposed and frequently struck.

When barriers were first being installed in Central Otago in the early 1990s traditional steel guardrails were considered; however, this was considerably more expensive compared with the option of installing the WRB. They also had an issue with narrow shoulder space which was overcome with the WRB. Another aspect which influenced the type of barrier to be used was the views of the lake which would be less obscured through the use of the wire rope rather than solid steel. Through the use of the WRB over steel guardrails they have found:

- there is better chance of vehicle recovery by capturing the vehicle
- a lower chance of glancing off a solid barrier into the opposing lane
- it is cheaper to fix damaged wire rope posts than steel guardrail
- it takes up less horizontal space of the sealed shoulder towards the edge line
- looks environmentally better without blocking views of the lake for tourists.

At the time of writing the NZ Transport Agency Hamilton project services team is undertaking research to determine the appropriate cross sections to be constructed as part of work being carried out to upgrade part of SH2. The information provided is work in development, but to date has found that costs are high where WRBs are installed on narrow medians and this cost reduces, with an exponential relationship, as the median width is increased. The comparison of the strike costs with the indicative capital costs required to provide additional median widening indicated that the whole life cost decreased to a minimum value when a 3.0m wide median is provided (given a barrier is used) and these costs tended to increase as additional width above 3.0m is provided.

3.3 Summary

The STA is undertaking research to reduce the impact of run-off road crashes, which considers road design elements and other factors of interest to this research. Australian authorities expressed concern that increasing maintenance funding restrictions are generating cost-focused decision making rather than the Safe System approach to make safety-focused decisions to support barrier installations that achieve safety benefits.

The factors considered by the various RCAs throughout New Zealand which affect the rate of nuisance strikes generally correspond with the factors investigated and identified in existing international and New Zealand research. However, certain RCAs found they do have what they consider to be a high level of nuisance strikes, usually located on specific points of their network, while other RCAs do not consider these types of strikes as being a particularly significant issue. The general consensus was that WRBs are preferred, where possible, given the reduced installation and maintenance costs and the ease of repair following crashes.

4 Data collection

4.1 Introduction

In order to prepare a predictive model of barrier strike rates and associated maintenance costs, a comprehensive database of nuisance barrier strike information has been prepared. The research team contacted each Transport Agency regional office and four local authorities in New Zealand as well as the seven Australian state roading controlling authorities to source available data. The four local authorities approached were those with the highest number of guard rail hits on local roads following analysis of CAS crash data between 2003 and 2012.

A formal request was made to supply raw data on nuisance barrier strikes in their region over the past five years. The following specifics on each strike were requested:

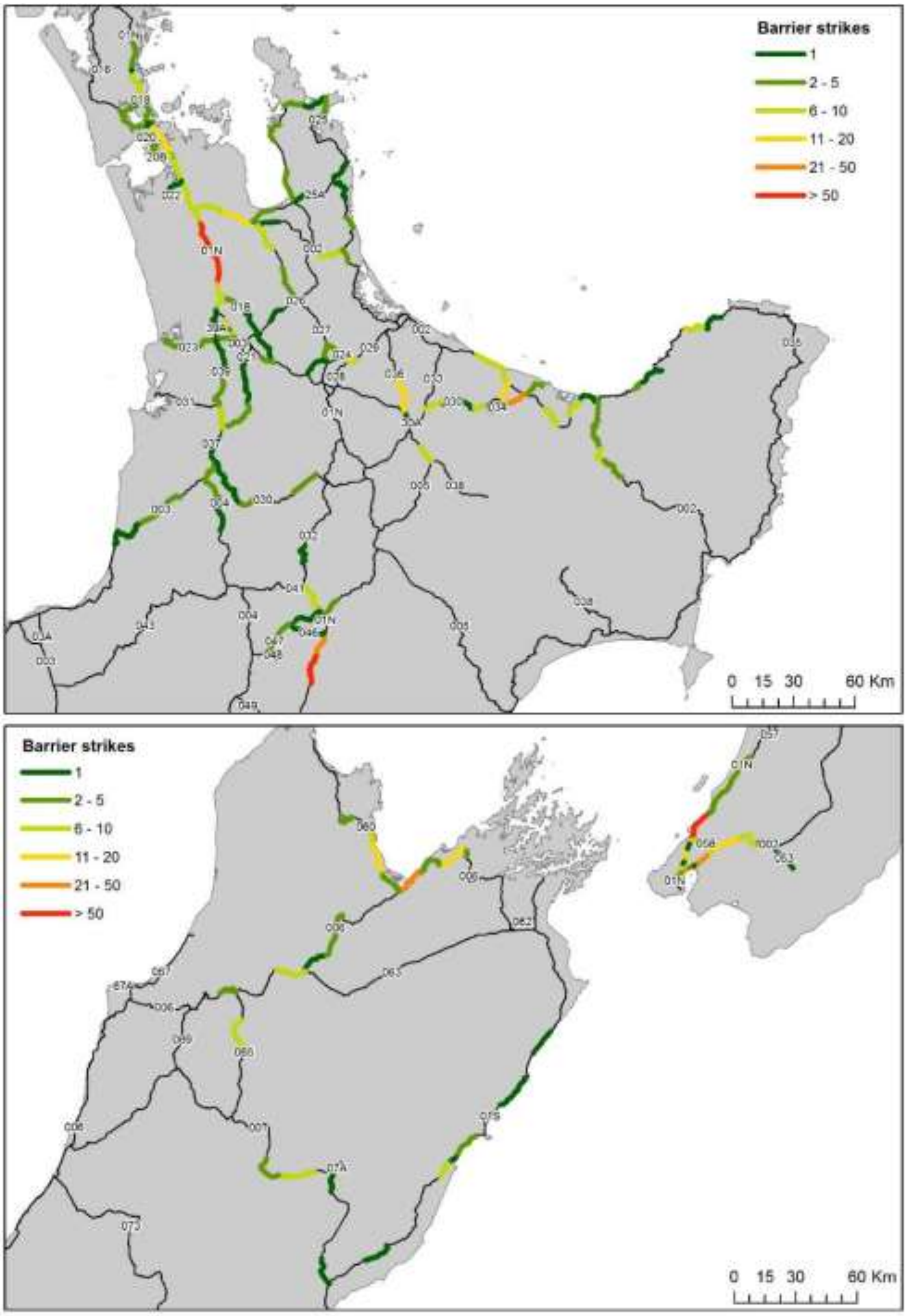
- date and time of barrier strike
- specific barrier location
- barrier type
- extent of repair (including the length of the barrier affected, number of posts etc)
- cost of repair including labour and traffic management.

Comprehensive barrier strike datasets have been received from 10 Transport Agency representatives (or their network maintenance contractors); however, no information was available from the local authorities approached. Subsequently all of the data collected corresponds to the New Zealand state highway network. Eight of the respondents were from the North Island, and the remaining two were from the top of the South Island. Figure 4.1 provides an overview of the location and frequency of the state highway barrier strikes in New Zealand based on the raw data received (prior to any data cleaning).

The data sources are a mix of contractor maintenance repair archives and specific strike records covering a repair period from November 2005 to March 2014. The raw data received contained a total of 2,007 repair records and encompassed strike information for both median and shoulder barriers. It is evident from the responses received, that there is currently no common template or process for the collection of barrier strike maintenance information within the Transport Agency.

Efforts were made to contact Australian road authorities; however, the research team was not successful in obtaining any comprehensive sets of maintenance, repair or strike data.

Figure 4.1 Location of raw barrier strike data received



4.2 Dataset collation – nuisance strikes

Each of the 10 datasets received were formatted differently and included a variety of variables and coding of strike data. A data collation and cleaning process was undertaken to develop one dataset containing all the input variables and strike data to better facilitate the data analysis and model development stage of the research. Nuisance barrier strikes were isolated and classified as corresponding to wire rope median, wire rope left-hand side (LHS), W-beam median or W-beam LHS barriers. All data was filtered to ensure it corresponded with one of these four categories, and any concrete barrier strike data, ramp data and records pertaining to pedestrian refuge island barriers and street signage replacements or repairs were removed.

Each strike record was classified as a nuisance strike, crash or unsure. After speaking with several representatives who provided data, it was determined that a strike or repair record would be classified as a nuisance strike unless the data record specifically made reference to a crash, Police incident number, regular maintenance, or if the repair involved a length of barrier greater than 30 posts (WRB) or 30m (W-beam). These non-drive away events were discarded. In the case of barrier strikes on the Auckland Motorway network, an incident was classified as a nuisance strike based on its priority for repair. Any repair that was booked to occur between three months and one year post identification was classified as a nuisance strike as agreed with the AMA representative who supplied the data.

All records were checked against Transport Agency's state highway video (summer 2013/14 set as supplied by Argonaut Limited) to confirm the exact barrier location, barrier type and road position. The width of the offset, the presence of ATP, and the proximity to any hazards or variables that could be factors influencing the likelihood of barrier strike were also recorded against each incident based on observations made from the state highway video. This video is fully referenced using the reference station (RS) and route position (RP) locations. The video also includes topographical map data so that location descriptions and RS/RP locations could be matched where any inconsistencies or uncertainty around the location of barrier strike data was observed.

Care has been taken to account for the difference between the state highway video and records supplied by Transport Agency staff and contractors where it is obvious there is a discrepancy. Where RS/RP locations on records did not match up with the video or the position description in the received data, the position description was used to determine the correct RS/RP. When a RS/RP location road side sign was visible on the video it was observed there was a difference between the video reference and the sign reference position of up to 200m in some instances.

The data cleaning process also included:

- removal of any duplicate records
- conversion of some RP locations from kilometres to metres
- combining line item costs relating to a single repair to give a total repair cost.

Following the data collation and cleaning of the datasets received, a single robust and representation dataset was prepared containing 1,198 records. This dataset is intended to inform the development of a predictive model for nuisance barrier strikes and is referred to as the Barrier Strike Database (BSD) in the remainder of this report.

4.3 Dataset collation – all strikes

In order to prepare a predictive model that includes all barrier (nuisance and crash) strike rates and associated maintenance costs, a comprehensive database of barrier strike information was compiled. This was done by combining the BSD from the original research with a CAS query output for all crashes involving a guardrail strike between 2005 and 2014 and aggregating this to the nuisance strike dataset. CAS information was only extracted for the regions and lengths of corridor where nuisance barrier strike information was available.

The dataset containing all incidents involving barriers was input into a geographical information system (GIS) by the project team and the strike locations matched to the individual barrier installations from the Transport Agency barrier database.

A comprehensive data cleaning process was undertaken to ensure that crashes involving concrete barriers, temporary barriers, street signs or similar objects that had been coded as guardrail strikes in CAS were removed. A list of incidents where more than one barrier was struck was also generated and each of these incidents was checked against the Police report in CAS to determine which barrier location had been struck. During this analysis some key themes relating to the barrier incidents were evident. These included:

- multiple barrier strikes in one crash event
- motorists falling asleep at the wheel
- epileptic fits while driving
- lane change errors cutting other traffic off
- excessive speed
- intoxication
- losing control of trailers while towing.

The most significant observation from the review of the CAS incident records is the high number of events involving multiple barrier strikes in one crash event. This could consist of a vehicle striking a length of barrier installation more than once or striking multiple installations in close proximity. Care needs to be taken with the recording of an event involving multiple barrier strikes to ensure that the number of individual strikes on one or more barriers is represented as accurately as possible.

4.4 Limitations and risks

Following the data collation and cleaning, a number of limitations and risks were identified which required some additional consideration in the analysis and model development phases of the research. These are presented in this section.

The date of each repair or strike could be used to determine the season in which the barrier strike occurred which was necessary in order to analyse any seasonal effect on barrier damage and the repair cost.

Most regions were not able to provide a date or time of barrier strike, due to the nature of barrier strikes only being recorded post-strike. The repair date has therefore been used as the time variable for each occurrence. Only one region was able to provide an accurate date of the actual barrier strike event due to its high use of surveillance on its network.

The interpretation of the data received involved an element of subjectivity due to the range of data formats, variation in variables supplied and the level of detail in the data. No data sources specifically differentiated between nuisance barrier strikes (drive away) and strikes occurring due to a crash (that is, data that would also be recorded in CAS), therefore assumptions were made following consultation with several data providers and applied as described in section 4.2.

An element of uncertainty also exists about the actual date of a nuisance barrier strike as the damage to the barrier from the impact is often only picked up during inspection. For this reason the repair date has been used as the time variable, as this information was available on all datasets. Most records specified the day and month of the repair; however, there were 15 records that only recorded a year range of up to four years. These records are hard to classify as there is the potential here for a strike to have occurred in one year, but the repair not to have taken place for several months, pushing this into the following year.

Care has been taken to determine the exact location of each barrier strike using the state highway video; however, the RP/RS road signage visible at several locations highlighted the potential for the video RP/RS reference to be approximately 200m different from that displayed on roadside signs. Spot checks using the video were used to check data location and barrier types. Discrepancies discovered during this process were either removed or corrected. The exact location of some barrier strikes was selected carefully while compiling the dataset as highlighted in the data collation process, but may include errors.

An indication of the direction (increasing or decreasing) of travel was often omitted from records. The state highway video was used to determine the correct direction as far as possible, with increasing being the default direction assigned when it was unclear. The data received was from a small number of New Zealand regions, which presents a risk as to whether this is representative of the whole country.

Many of the shorter W-beam installations particularly those located on the median were installed adjacent to concrete barriers as pictured in figure 4.2. While the nuisance strike records clearly specified the material of the barrier struck, following an extensive review of available CAS reports the majority did not state the type of barrier struck where there were multiple types in close proximity. Subsequently it was very difficult to extract reliable crash data for short lengths of W-beam barrier as there was a chance that the strike occurred on adjacent concrete barriers.

Figure 4.2 Example of short W-beam length

The initial W-beam regression analysis in chapter 7 for all-strikes focused on developing equations for all barriers irrespective of length. However, when barriers with a length less than 40m were removed from both the median and LHS W-beam datasets, a much improved model fit was achieved. For this reason, separate models were developed later on in this report for barriers with lengths greater than 40m and less than or equal to 40m.

Care was taken to minimise the risks highlighted to provide a BSD that would be as robust and fit for purpose as possible given the information available.

4.5 Linking dataset to operational and environmental variables

International research relating the frequency of barrier strikes to traffic exposure and the physical characteristics of their surrounds has found there is a direct association between barrier crash frequency and a range of operational and environmental factors as previously documented in the literature review (table 2.6).

The location, barrier type, position and the date of the repair/strike are available for each record within the BSD. RS and RP measures were used to determine the location of the barrier strike and have been necessary for other key information (eg speed limits, road type, and road profile) to be drawn from other data sources. Barrier type and position information was available directly from the maintenance records supplied. For those instances where barrier type was not specifically indicated, it was determined based on a description of the materials damaged (for example Armco, guardrail, railings, z bars) in the raw datasets. This was then checked against the state highway video footage to ensure accuracy.

In order to analyse the relationship between operational and environmental variables identified in the literature review to the data received ready for further analysis, additional variables needed to be added to the BSD. A link between each record in the BSD and the KiwiRAP Analysis Tool (KAT) database was made to link to the full range of variables available in KAT, including the:

- AADT volume
- road type
- average sight distance
- horizontal alignment
- speed limit
- terrain.

Each recorded barrier strike location has been snapped into 100m lengths to link the BSD to the KAT database locations, as accurately as possible.

To complete the link between the BSD and the range of variables identified in table 2.6, the BSD has also been linked to the NZ Transport Agency Railing Database received on and current as at 18 September 2014. This documents each barrier throughout the state highway network with corresponding physical variables including the:

- railing offset from centreline
- carriageway width
- offset
- ground height.

Definitions of these variables are consistent with those stated by Transport Agency sources including the RAMM and KAT databases, which have provided the data.

4.6 Maintenance costs

The majority of maintenance costs for road barriers are due to repairs of barrier damages caused by vehicle impacts and in some instances may require traffic management to enable the repair to be undertaken.

The repair costs to remedy damage to barriers may depend upon a number of environmental and operational variables as identified in table 2.6, including speed limit, traffic volume, road alignment, seasonal effects, barrier strength and the distance between the edge of the traffic lane and the barrier itself. According to road designers, limited data related to the maintenance costs of barrier repairs and the factors influencing these costs is the major obstacle preventing the total cost for barriers over their service life being taken into consideration during the road design phases (Karim 2008).

The raw strike data collated in the BSD provides the general cost of repair information for 716 incidents, representing approximately 59% of the dataset. There is a large variation in cost attributed to each strike with the average cost to repair a strike of approximately $2,700 for a wire rope and $2,000 for a W-beam nuisance strike. The standard deviation of the cost of repair demonstrates the level of variation in the data collected and is approximately $2,900 for wire rope and $1,100 for W-beam installations.

The repair cost data supplied appears to be low and therefore any obvious outliers were not included in these figures. However, following enquiries with data suppliers it was confirmed that all costs were inclusive of labour, materials and any traffic management costs.

The repair costs may also be sensitive to the influence of a range of other factors including the design, construction quality, maintenance strategies or maintenance operations (Karim 2008), and may be subject to regional variations. For this reason it is difficult to make a more detailed analysis of the maintenance cost associated with each barrier strike and a representative average is assumed instead.

5 Model development

5.1 Background

Using the data captured as reported in chapter 4, analysis of the frequency of barrier strikes against a range of input variables was undertaken to directly address the primary objective of the research. That is, to develop a Maintenance Cost Prediction Model that predicts the expected barrier nuisance strike rate and corresponding maintenance costs as a function of the operational and environmental variables identified.

Linear and non-linear multivariate regression analysis has been undertaken to determine the operational and environmental variables which are statistically significant factors in the rate of barrier strikes and consequent maintenance costs. The key (independent) variables tested in the regression analysis were:

- AADT
- median width
- carriageway width
- barrier offset from centreline
- horizontal alignment
- terrain
- number of lanes
- length of barrier
- posted speed
- presence of ATP.

The resultant regression equations by barrier type have formed the basis for a spreadsheet-based barrier strike cost prediction model. This model has been designed to be used interactively to predict the strike rate and maintenance cost implications of barrier installation, changes in barrier types (flexible, semi-rigid and rigid), and change in carriageway width and barrier offset variables.

5.1.1 Key data inputs

The following four data sources provided the key inputs to the predictive model:

1. BSD created from nuisance barrier strikes received from Transport Agency staff and contractors
2. Transport Agency Railing Database
3. KAT data
4. Observations using the Transport Agency’s state highway video (and supplemented by Google Earth where required).

The modelling process then proceeded by converting the number of nuisance strikes to strikes per annum and number of strikes per million VKT by determining the length of the barrier, AADT and the number of years of nuisance strike data available. These are the candidate dependent variables considered in the regression modelling. Correlation coefficients between each of the independent variables were calculated and any redundant variables that exhibited a high degree of co-relation removed.

Microsoft Excel Data Analysis Toolpak was used to undertake multivariate regression analysis and a combination of linear, non-linear, binary and step functions was tested to enable a range of relationships to be explored and where significant, evaluated. A p-statistic of 0.1 was used as a general guideline to ascertain whether an independent variable was considered to be significant (that is the probability of a type one error being no greater than 0.1) although some leeway was given for marginal variables. Where this is the case it has been highlighted in the reporting of results.

5.2 Assumptions

Models were developed for each of the four different barrier types and positions. Each model required a number of assumptions to be made, as documented in this section.

5.2.1 Wire rope assumptions

The dependent variable selected was the number of strikes per million VKT. Tests were carried out to ensure the barrier length and AADT were not highly correlated. The resulting correlation coefficient was 0.14 and -0.26 for LHS and median barriers respectively. This was considered to be acceptable.

The independent variables tested were horizontal alignment, terrain, median width, presence of ATP road-marking, carriageway width, AADT, number of lanes and posted speed. The horizontal alignment and terrain were taken as the mode (most commonly occurring) along the length of the barrier.

During data checking an inconsistency in the offset measurements was observed. Some records appeared to be measured from the median and some from the LHS. Additional data cleaning was undertaken by applying sensibility checks based on the number of lanes and installation location to address this.

In all instances where data was provided the median wire rope was installed in the centre of the median, so in each case the offset to the right-hand side was half of the median width. Special consideration is required to represent an environment where the median wire rope is installed off centre. Strictly speaking the models developed in this research would not directly apply to this; however, the measurement of the offset between the median lane marking and the barrier location could be used as a proxy for half of the median width.

The analysis included all wire rope installations within the catchment areas where nuisance strikes were recorded, including those that had not been struck. This provided a more robust assessment of the likelihood of nuisance strikes.

5.2.2 W-beam assumptions

The model for W-beam barriers tested the appropriateness of a range of dependent variables as follows:

- the number of strikes per million VKT
- strikes per annum
- binary function = 1 if barrier struck otherwise = 0
- step function = 2 if barrier struck more than once, = 1 if barrier struck once, otherwise 0.

Due to the significant size of the railings dataset, the presence of ATP was not tested as an independent variable. To have done this would have required sourcing the data manually using tools such as Google Earth or the Transport Agency's state highway video at thousands of locations. This would have required significant time investment which was not within the scope of the project.

Independent variables tested included horizontal alignment, terrain, carriageway width, median width, AADT, installation height and number of lanes. The horizontal alignment and terrain were taken as the mode (most commonly occurring) along the length of the barrier. Where a barrier was less than 100m in length the corresponding values were snapped from the nearest KAT data point. The variable posted speed was not tested as it was clear from the wire rope technical analysis already conducted that the horizontal alignment had a more significant bearing on outcomes.

As was the case with WRBs, all W-beam guard installations were included in the analysis, not just those with nuisance strikes.

Two locations were identified as potential outliers from the LHS wire rope model where multiple strikes had been recorded on corridors with low AADT, as this created very high values of strikes per million VKT. In later analysis which focused on creating models to fit the number of strikes per annum, these two observations were not considered to be outliers as they were not disproportionately higher than the rest of the data assuming this variable. Subsequently they were reintroduced into the analysis. These two high incidence sites are shown in figures 6.9 and 6.10 and accompanied by commentary in section 6.5 to consider why they may have been struck so frequently.

5.3 Summary of data

A total of 2007 raw repair records were received from state highway contractors to prepare a nuisance strike database, and this was cleaned to a set of 1,198 strike records. In table 5.1, a summary of key statistics from the resultant BSD provides an overview of the information which has been cleaned and collated from the datasets supplied by Transport Agency representatives. This does not represent all crashes, instead it specifically relates to the nuisance and crash strikes that occurred at the locations of the data supplied for the research, and the actual number of non-drive away crash events is significantly greater. All of this data was linked to Transport Agency KAT data and Railing Database sources to provide a comprehensive set of variables for subsequent analysis.

Nearly 90% of the data was confirmed as nuisance strikes and most of these were for wire rope installations. A relatively small number of crash strikes were removed from this analysis and carried forward for subsequent analysis. A very small number of concrete barrier strikes were also discounted from further analysis. A total of 702 wire rope and 344 W-beam nuisance strike records were carried forward into the analysis to prepare the nuisance strike rate predictive model.

Table 5.1 Summary of BSD by barrier type

Barrier type	Nuisance strikes	Crash strikes	Total strikes	Percentage
Wire rope	702	63	765	64%
W-beam	344	76	420	35%
Other (concrete)	13	0	13	1%
Total strikes	1059	139	1198	100%
Percentage	88%	12%	100%	

The strike records in the BSD cover up to a 10-year repair period, from November 2005 to March 2014 with 60% of the data recording barrier strike repairs in the years from 2011 to 2013. This provided a mix of old and new maintenance data to consider for analysis. With more wire rope installations in recent years, this could explain the greater proportion of recent data, or it could also be due to the improved recording of strike information over time. The specific data ranges of the strike data repair date distribution are shown in table 5.2.

Table 5.2 Summary of barrier strike data date ranges

Year	Number of strikes	Year	Number of strikes
2005	10	2010	99
2006	51	2011	196
2007	47	2012	221
2008	51	2013	301
2009	90	2014	132

The nuisance strikes from the BSD were combined with data extracted from CAS for a total of 2,449 barrier installations along the state highway with the majority (61%) of these being LHS W-beam installations. Table 5.3 provides a summary of available data for each barrier type.

Table 5.3 Summary of data in final analysis

Barrier type	Nuisance strikes	CAS crash strikes	Total strikes	Total installations	Installations with nuisance or CAS strikes	Unstruck installations	% of barrier installations struck
Median wire rope	658	263	921	67	52	15	78%
LHS wire rope	42	42	84	37	32	5	86%
Median W-beam	3	47	50	60	18	42	30%
LHS W-beam	299	371	670	1,497	330	1,167	28%
Total	1,044	829	1,873	2,449	519	1,930	21%

For nuisance strikes, the locations of the barrier locations are included in the figures in appendix D. Overview plots are included to show the locations of the inset plots for:

- LHS W-beam barriers in figure D.1
- LHS WRBs in figure D.2
- median W-beam barriers in figure D.3
- median WRBs in figure D.4.

Each barrier and number of strikes per million VKT are shown in the inset plots in figures D.5 to D.10.

For all-strikes, the locations of the barrier locations are included in the figures in appendix E. Overview plots are included to show the locations of the inset plots for:

- LHS W-beam barriers in figure E.1
- LHS WRBs in figure E.2
- median W-beam barriers in figure E.3

- median WRBs in figure E.4.

The location of each barrier and the number of strikes (per million VKT for wire rope and per annum for W-beam barriers) are shown in the inset plots in figures E.5 to E.11.

A number of limitations/risks relating to the barrier strike location and the regional representation of the dataset have been highlighted. The greatest risk is in the consistency and interpretation of the data received in the absence of any common method of recording nuisance barrier strikes and their associated costs across regions.

Overall the research team is confident that the dataset created provides a robust, representative dataset to inform the development of a predictive model for nuisance barrier strikes in isolation and for all barrier strike events.

6 Nuisance barrier strike prediction models

Four regression models were developed to determine which variables had a significant effect on the rate of nuisance barrier strikes for each of the barrier types and to generate predictive models to calculate strike rates and corresponding costs. The models are presented in this section and the full regression output is included in appendix A.

6.1 Median wire rope nuisance strike model

Multivariate regression modelling was undertaken to establish the relationship between the barrier strike rate per million VKT and each of the key independent variables. Equation 6.1 presents the median wire rope equation for predicting nuisance strikes per million VKT.

$$\textit{Strikes per million VKT} = 0.0792\,H + 0.8056\,M - 0.1432\,A - 0.2694\,P \qquad \text{(Equation 6.1)}$$

where:

- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation)
- M = 1 if median width <2m otherwise M = 0
- The nuisance barrier strike dataset contained no data with median widths around 2m so the model was calibrated on median widths of 1.5m or greater than 2.5m. Caution should be taken if using the model equations or spreadsheet tool when median width is between 1.5m and 2m. It is suggested that the user interpolates results when working in this range, or uses the model to determine upper and lower bounds around the likely strike rate.
- A = 1 if ATP road markings are present, otherwise A = 0
- P = 1 if posted speed is less than 100km/h otherwise P = 0.

The model has an adjusted R-squared statistic of 0.706 indicating that approximately 70% of the variance is explained by the model. This indicates that the data fits well to the statistical model developed. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.000
- M – p = 0.000
- A – p = 0.108 (indicates variable is not statistically significant if the test statistic of P = 0.1 is applied; however, it has been included as delineation such as ATP is known to influence crash rates with barriers from the literature review and the p statistic is marginal)
- P – p = 0.028.

The scatterplot in figure 6.1 shows the distribution of the observed versus predicted number of barrier strikes per million VKT at each median wire rope site. This demonstrates a reasonable fit. The median wire rope model residuals approximate a normal distribution as shown in figure 6.2, demonstrating that the linear model is an appropriate model form.

Figure 6.1 Observed versus predicted number of median wire rope nuisance barrier strikes

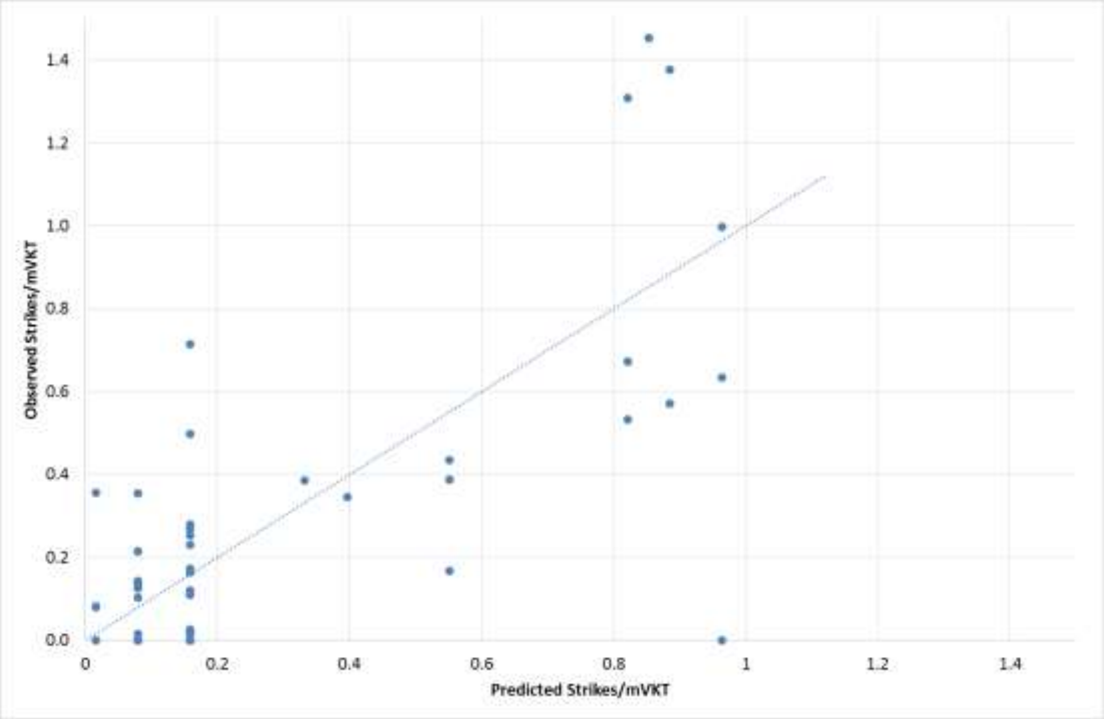
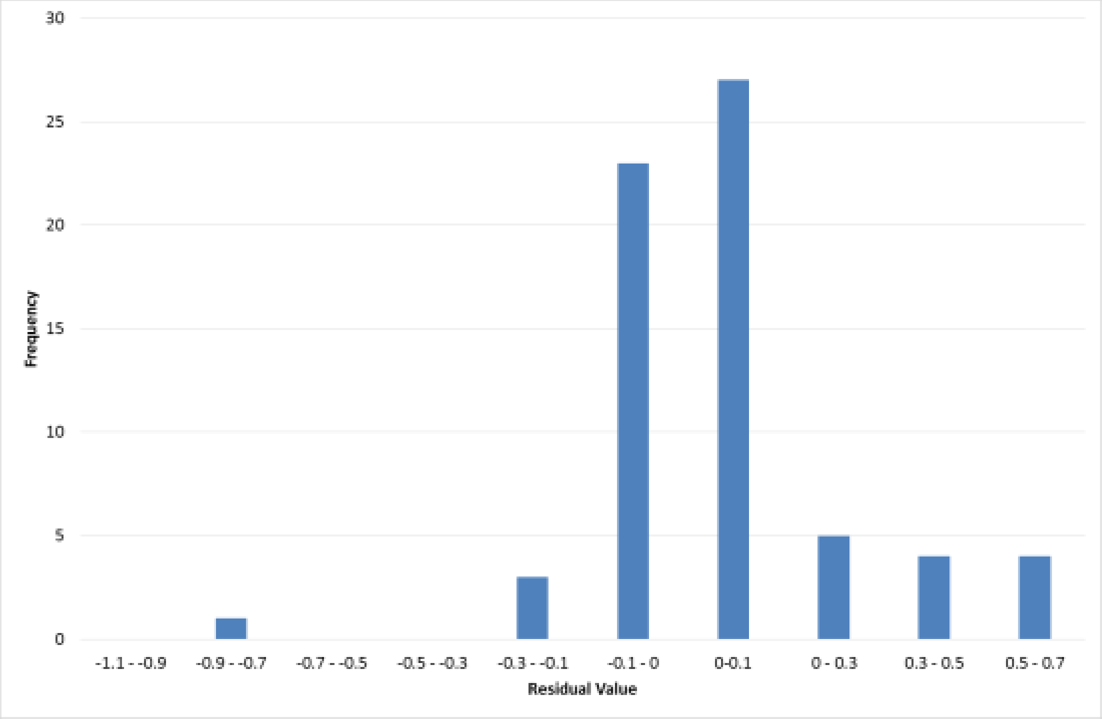


Figure 6.2 Residual values of median wire rope nuisance strike model



6.2 Left-hand side wire rope nuisance strike model

Equation 6.2 presents the LHS wire rope equation for predicting nuisance strikes per million VKT.

$$\text{Strikes per million VKT} = 0.1556\ H - 0.5906\ A + 2.074\ F \qquad \text{(Equation 6.2)}$$

where:

- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation)
- A = 1 if ATP road markings are present otherwise A = 0
- F is a function to represent offset to the LHS barrier where F = 0 if the offset is greater than or equal to 5m, otherwise F = (5- offset to LHS barrier) if the offset <5m. The offset should be measured as the distance between the centreline and the LHS barrier in metres for single-lane roads, or measured as the distance between the right-hand edge of the lane furthest to the left for multilane corridors.

The adjusted R-squared statistic for the model is 0.632 indicating that 63% of the variance of nuisance strikes occurring at LHS wire rope installations are explained by the model. This shows that the data fits reasonably well to the statistical model developed. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.004
- A – p = 0.117 (indicates variable is not statistically significant if the test statistic of P = 0.1 is applied; however, it has been included as delineation such as ATP is known to influence crash rates with barriers from the literature review and the p statistic is marginal)
- F – p = 0.000.

A scatterplot of the observed versus predicted number of barrier strikes per million VKT at each LHS wire rope site is displayed in figure 6.3. This assesses the goodness of fit and demonstrates reasonable fit. The LHS wire rope model residuals approximate a normal distribution as shown in figure 6.4, demonstrating that the linear model is an appropriate model form.

Figure 6.3 Observed versus predicted number of left-hand side wire rope nuisance barrier strikes

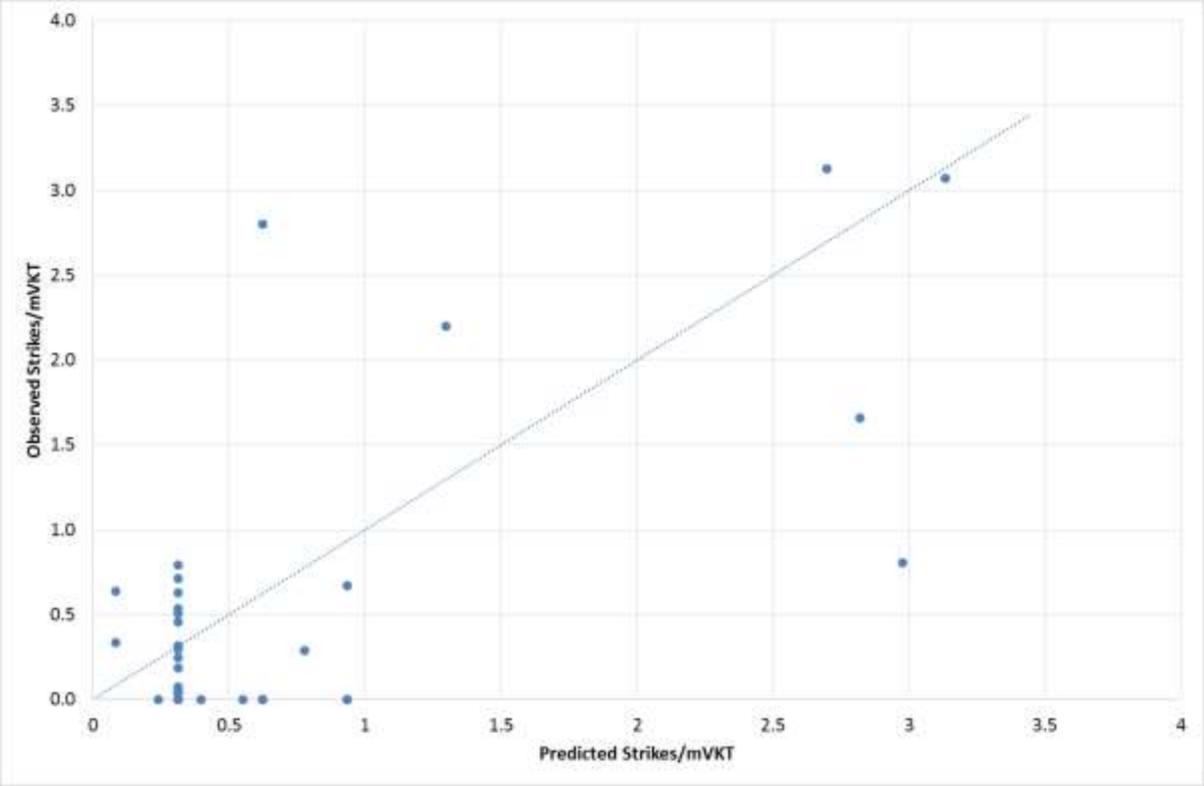
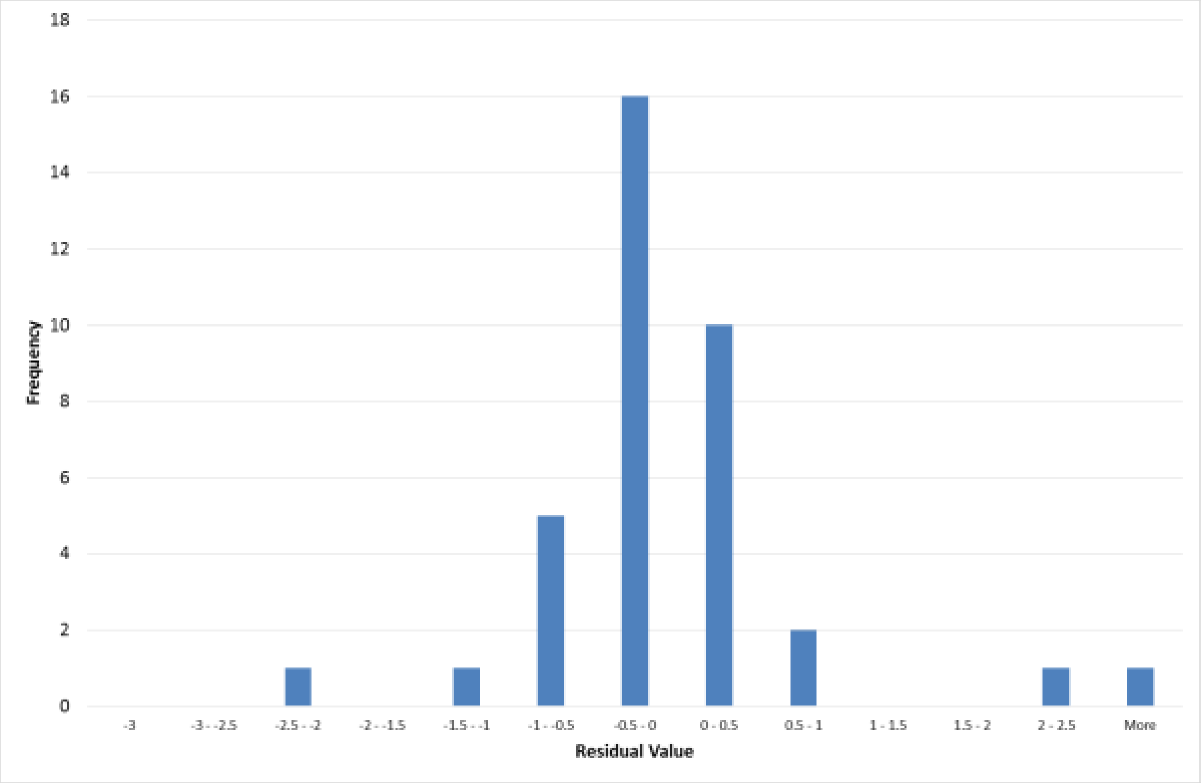


Figure 6.4 Residual values of left-hand side wire rope nuisance strike model



6.3 Median W-beam nuisance strike model

The W-Beam regression models were initially tested with the number of strikes per million VKT as the dependent variable. None of the independent variables emerged as being significant, therefore the number of strikes per annum was assessed as the dependent variable. Equation 6.3 presents the median W-beam equation for predicting the number of nuisance strikes per annum.

$$\text{Strikes per annum} = 0.0125T \qquad \text{(Equation 6.3)}$$

where:

- T is the terrain variable directly from KAT data (mode across length of installation).

Only a small number of installations of median W-beam barrier had nuisance strikes recorded, wherein four barriers were struck. Of the barriers that were struck, they all corresponded to terrain type 2 (rolling) and there were no median installations in the dataset located on mountainous terrain. Subsequently non-linear functions of the variable, T, were not able to be tested. There were other W-beam barriers located on terrain type 1 that were not struck.

Further regression analysis was carried out testing binary or step functions of the number of strikes. This failed to produce any additional significant variables.

The adjusted R-squared statistic for the final model is 0.026 indicating that very little of the variance of nuisance strikes occurring at median W-beam installations are explained by the model. The p-value, indicating the statistical significance, is 0.024, indicating the terrain variable is significant.

A scatterplot of the observed versus predicted number of barrier strikes per annum at each median W-beam site is displayed in figure 6.5 and demonstrates very poor fit. This poor fit is due to both the high proportion (98%, as shown in table 6.1) of barriers with no observed nuisance strikes dominating the analysis and the lack of significant variables identified in the assessment.

The model residual values are plotted in the histogram shown in figure 6.6. The sites with no observed nuisance strikes include residual values of near zero, while those very few barriers which have been struck at least once are included in the 0.2 to 0.4 range, with one outlier of just over 1. The residuals are not normally distributed as there are not enough strikes to produce a range of non-zero observed values across the barrier sites. The very high frequency of zero values in figure 6.6 represents those barriers not struck in the observed dataset.

Figure 6.5 Observed versus predicted number of median W-beam nuisance barrier strikes

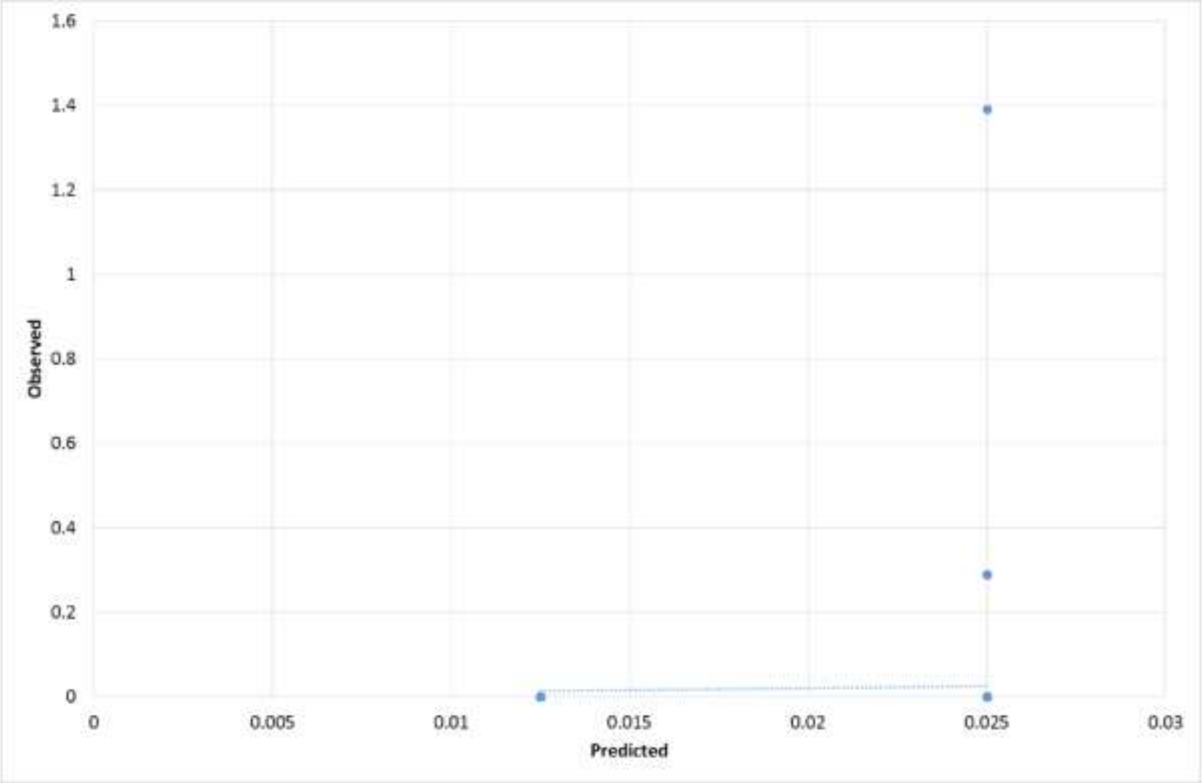
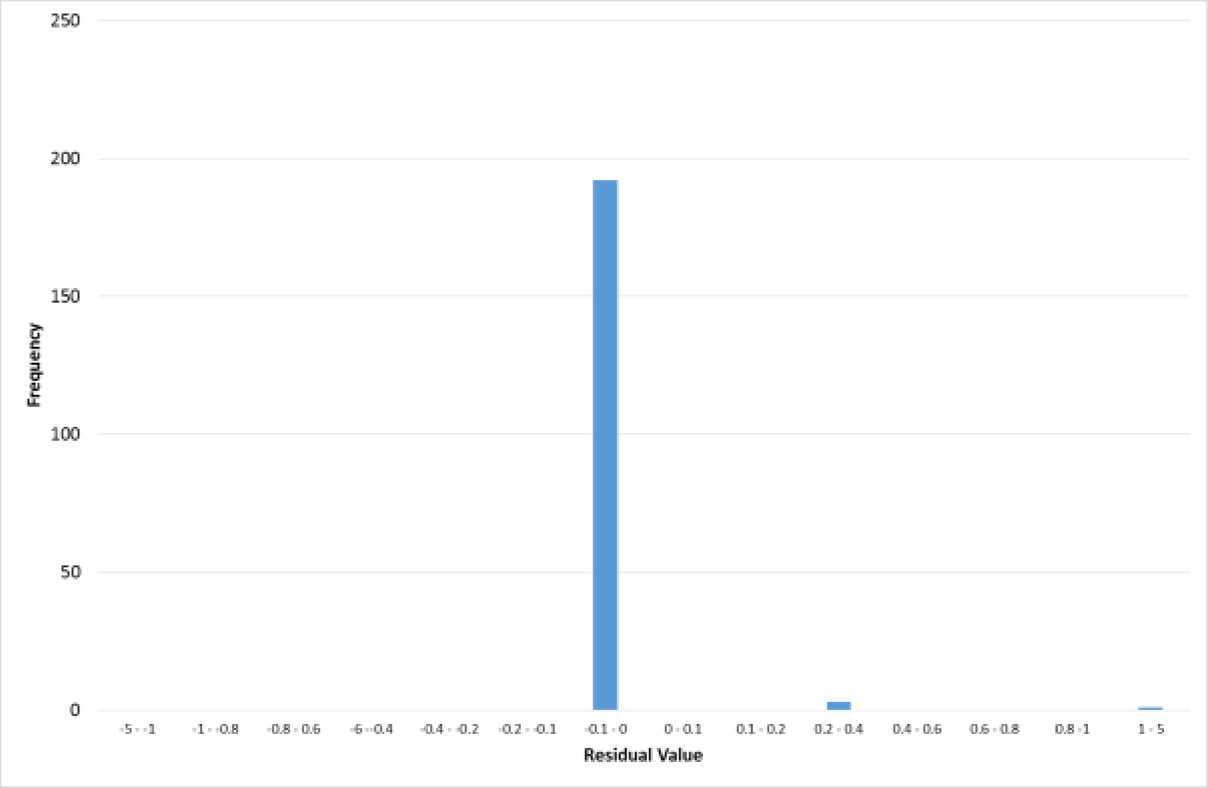


Figure 6.6 Residual values of median W-beam nuisance strike model



6.4 Left-hand side W-beam nuisance strike model

Two regression models were developed to represent nuisance barrier strikes occurring at LHS W-beam barriers. Model 1 represents the number of strikes per annum as the dependent variable and model 2 presents a binary assessment whereby the dependent variable is the probability that at least one strike will occur.

As in the median W-beam analysis, no independent variables were found to be significant in predicting the number of strikes per million VKT.

6.4.1.1 Model 1

The LHS W-beam model predicts strikes per annum (irrespective of the length of the barrier) in equation 6.4 as follows:

$$\text{Number of strikes per annum} = 0.00825e^{T} \qquad \text{(Equation 6.4)}$$

where:

- T is the terrain variable directly from KAT data (mode across length of installation). The non-linear function has a slightly improved fit compared with a linear function.

The adjusted R-squared statistic for the final model is 0.064 indicating that very little of the variance of nuisance strikes occurring at LHS W-beam installations are explained by the model. The p-value, indicating the statistical significance, is 0.000, indicating the terrain variable is significant.

A scatterplot of model 1 for the observed versus predicted number of barrier strikes per annum at each LHS W-beam site is pictured in figure 6.7. This demonstrates very poor fit with an R-squared statistic of 0.01. This lack of fit is due to the high proportion of barriers with no observed nuisance strikes (91%, as shown in table 5.3) which dominate the analysis as well as the lack of significant variables identified in the assessment.

The residuals for model 1 are plotted in figure 6.8. The high frequency of zero residual values denotes barrier installation sites with no observed nuisance strikes, while those barriers which have been struck at least once are generally included in the 0.2 to 1 range. The residuals show a non-normal distribution indicating that the large number of barriers which have not been struck significantly outnumber the non-zero observed values across the barrier sites.

Figure 6.7 Model 1 observed versus predicted number of left-hand side W-beam nuisance barrier strikes

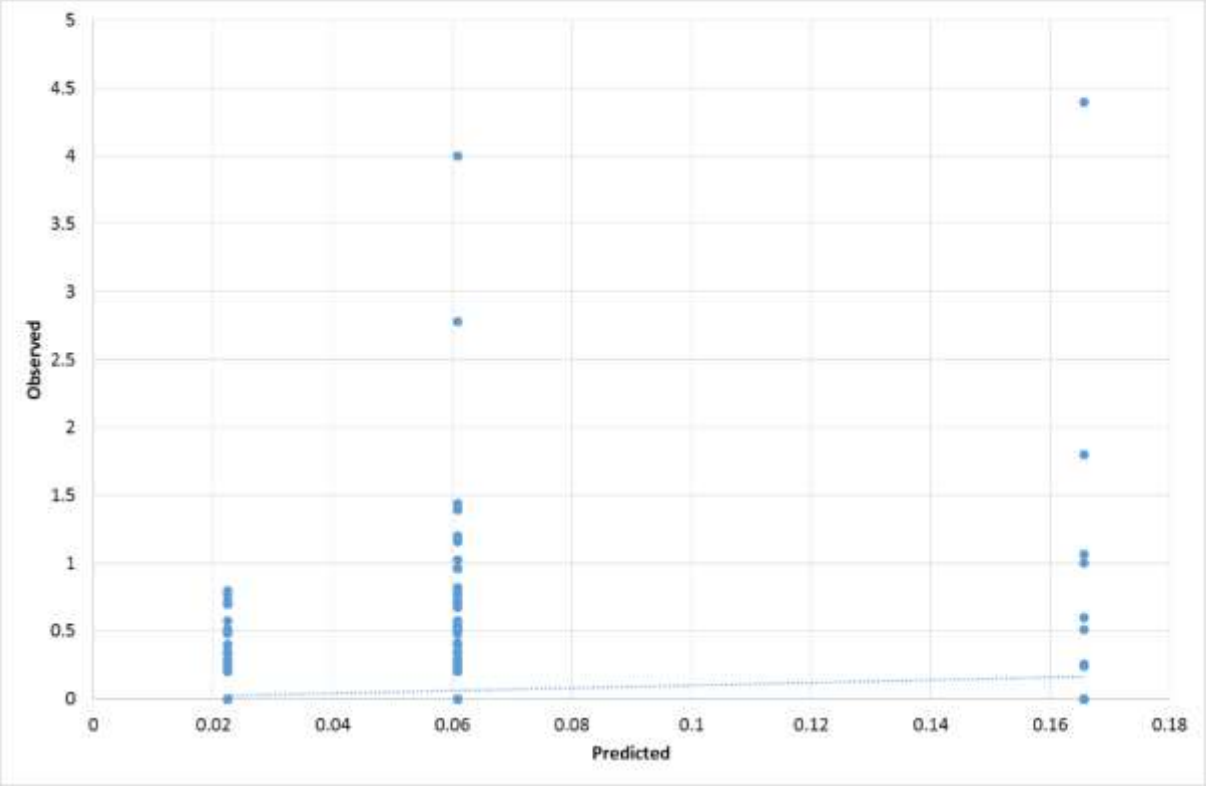
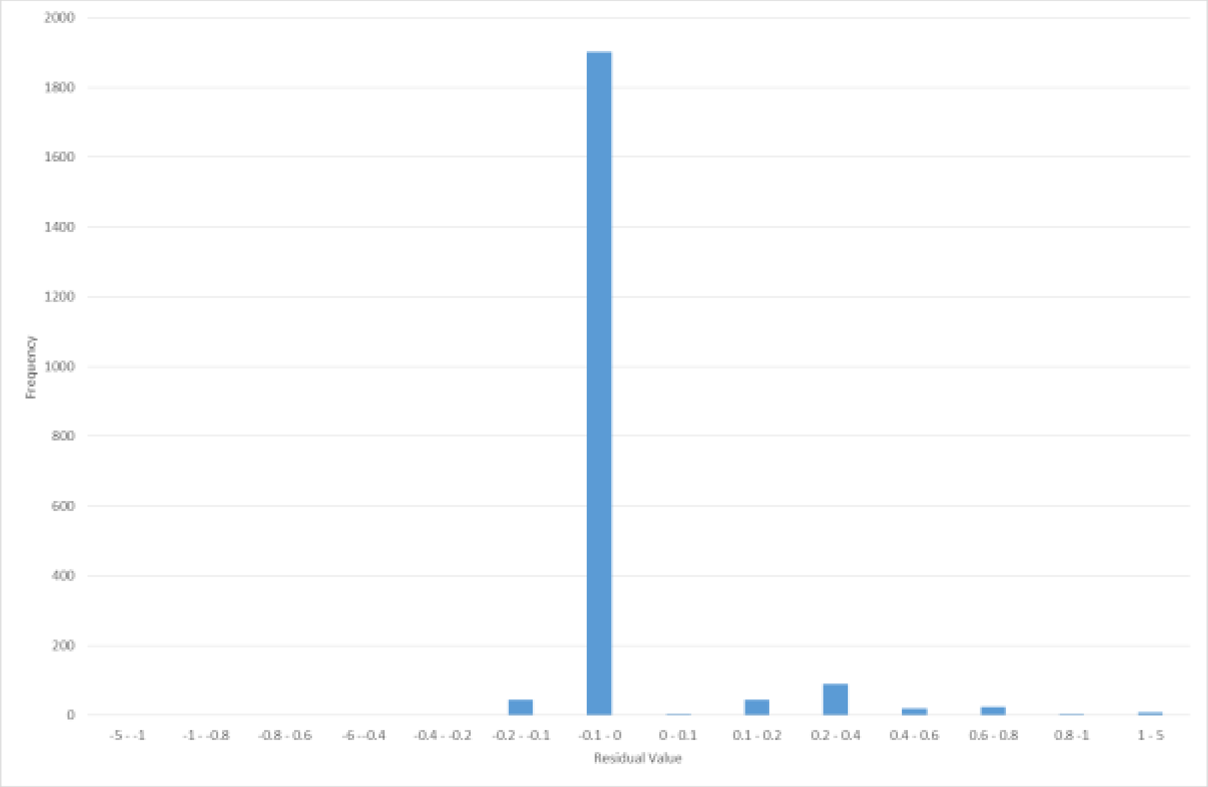


Figure 6.8 Model 1 residual values of left-hand side W-beam nuisance strike model



6.4.1.2 Model 2

A second model was developed to test whether more variables were introduced when treating the dependent variable either as a:

- binary function = 1 if barrier struck, otherwise = 0, or
- step function if barrier struck more than once = 2, if barrier struck once = 1, otherwise = 0.

The best fit was achieved using the binary function. It is acknowledged that the underlying data represents on average 3.5 years of nuisance strike records. Subsequently the coefficients established in the regression model are somewhat arbitrary, and this is offered as an indicative assessment only. Ideally the coefficients should be normalised to a per annum rate.

The LHS W-beam binary model using equation 6.5 predicts that at least one strike will occur within the dataset as follows:

$$\textit{Probability that at least one strike will occur} = 0.01564\,H + 0.00858e^{T} \qquad \text{(Equation 6.5)}$$

where:

- H is the horizontal alignment variable (column U) directly from KAT data (mode across length of installation).
- T is the terrain variable directly from KAT data (mode across length of installation). The non-linear function has a slightly improved fit compared to a linear function.

The adjusted R-squared statistic for the final model is 0.105 indicating that very little of the dataset variance is explained by the model. The p-value, indicating the statistical significance, is 0.000 for both variables, indicating both are significant.

The scatterplots and histogram for model 2 are very similar to those from model 1 exhibiting poor fit and non-normal residuals and have not been included in this report. Regardless, the assessment provides evidence that terrain is also a significant variable, in addition to horizontal alignment.

Acknowledging that the W-beam data and the linear regression model residuals are not normally distributed, additional testing was conducted to attempt to fit multiplicative regression models (which has been successfully applied to non-normal data in other Transport Agency research including Turner et al 2012). This was unsuccessful, predominantly due to the lack of independent variables identified as having a significant bearing on the incidence of nuisance strikes.

Specific analytical tests undertaken included:

- Analysis of results under multiplication of predictor variables, with predictor variable removal and combinations of variable. No new models were identified.
- Assessment of any trends for barriers with a non-zero strike rate. No new models were identified.

Additional quantitative assessment to further understand the influence of independent variables was undertaken by placing strike rates and factors in bins, with findings as follows:

- At sites with higher strike rates a greater proportion of sites corresponded to terrain codes 2 (rolling) and 3 (mountainous).
- No relationship to median width, carriageway offset or AADT was established.
- At sites with higher strike rates a greater proportion of sites corresponded to greater numbers of lanes although this was not a significant result.

- At sites with higher strike rates a smaller proportion of sites corresponded to horizontal alignment 1 and 2, but a greater proportion corresponded to alignment 3 through 6 although this was not a significant result.

These observations confirm the findings of the linear regression analysis in identifying that horizontal alignment and terrain are the key predictive variables.

6.5 W-beam nuisance strike discussion

Detailed analysis as to where the nuisance strikes were occurring at barriers was undertaken by examining high frequency sites. Three sites on SH1 were identified as exhibiting high incident rates. Figures 6.9 to 6.11 provide pictures of these locations taken from Transport Agency state highway video footage. These short lengths of barriers were recorded to have received 22, 20 and 9 nuisance strikes respectively in an approximate five-year period. The first two of these sites occur on roads with low traffic volumes and were identified as potential outliers in the technical analysis when the number of strikes per million VKT was isolated as the dependent variable. They were, however, reintroduced into the analysis when strikes per annum were assessed.

Figure 6.9 W-beam high incident site #1 SH01N RS 777 RP14110–14316

Figure 6.10 W-beam high incident site #2 SH01N RS 777 RP5900–5910

Figure 6.11 W-beam high incident site #3 SH01N RS 763 RP10000–11200

Each of these worst performing sites is classified as being in rolling terrain, with no ATP marking and with W-beam barriers set within no more than 1–2m of the edge marking. Site one and three cover areas with moderate to tight corners and site two is on an approach to a narrow bridge.

Viewing state highway video footage indicates that the sites with high incidence rates of nuisance strikes are on either on a sharp horizontal curve or narrow undulating (uneven vertical alignment) sections of New Zealand roads where the terrain and horizontal alignment variables identified in the linear regression analysis correspond to higher values.

Following consultation with contractors supplying the data it is understood that nuisance barrier strikes at these locations generally occur due to handling errors where vehicles have under-estimated the degree of road curvature and/or the undulating nature of the road. Vehicles are not travelling at high speeds due to the terrain; however, errors in driver judgement result in vehicles striking the barriers at very shallow angles and then being able to drive away.

Crash analysis literature by Crowther and Swears (2010) identifies two common characteristics for crash cluster sites: single-lane section, right-hand curve on an uphill gradient and single-lane section, left-hand curve on a downhill gradient. The investigation of the physical features of the crash cluster sites indicated two particular issues with the road environment, mainly the lack of visibility on right-hand curves and roadside barriers were located in close proximity to the edge line.

This is supported by feedback from local roading authorities in the Nelson/Tasman/Marlborough region, who shared their experience that nuisance strikes typically occur on their network when a truck cuts a tight radius corner and the rear trailer wheels connect with the barrier. Thus, the curvature of the road is the main factor in the rate of nuisance strikes in this region. The W-beam barriers within the region have regular nuisance strikes but do not warrant repair after each strike.

6.6 Wire rope nuisance strike discussion

High frequency strike locations for median WRBs were also identified and analysed. Table 6.1 outlines the 10 locations exhibiting the highest nuisance strike incident rates from the data collected in this research. The Rangiriri stretch of SH1 in northern Waikato was highlighted in the research brief as having an unusually high rate of nuisance strikes compared with other wire rope installations throughout New Zealand. The dataset confirms this, with eight out of the 10 most frequently struck WRBs (including the top five locations) located along this stretch of SH1.

All of the Rangiriri barriers recorded in table 6.1 are installed on a narrow median less than 2m in width and the horizontal alignment is generally regarded as easy curves. Three locations on this stretch of SH1 have ATP installed. Each barrier length on this busy Rangiriri section of SH1 has been struck between 26 and 90 times in an approximate five-year period.

Table 6.1 Ten most frequently struck WRB locations

Ranking	Location SH/RP	Location start RS	Location end RS	Strikes per million VKT	Horizontal alignment	Median width	ATP present
1	01N 502	434	900	1.67	Moderate curves	< 2m	No
2	01N 486	12,528	13,101	1.51	Easy curves	< 2m	No
3	01N 502	65	398	1.38	Straight	< 2m	No
4	01N 486	11,412	12,345	1.31	Easy curves	< 2m	Yes
5	01N 486	15,888	17,059	1.00	Easy curves	< 2m	No
6	02 962	5,875	6,110	0.71	Easy curves	>2m	No
7	01N 486	9,017	11,383	0.67	Easy curves	< 2m	Yes
8	01N 486	14,875	15,853	0.63	Easy curves	< 2m	No
9	058 0	1,534	2,269	0.57	Straight	< 2m	No
10	01N 486	13,141	14,835	0.53	Easy curves	< 2m	Yes

Transport Agency state highway video footage has been examined to determine the relative characteristics or variables that may contribute to the high strike rates occurring at these locations. Figures 6.12 to 6.14 illustrate the three locations with the highest strike incidence rate.

Figure 6.12 Median wire rope high incident site #1 SH01N RS 502 RP 434–900

Figure 6.13 Median wire rope high incident site #2 SH01N RS 486 RP 12528–13101

Figure 6.14 Median wire rope high incident site #3 SH01N RS 502 RP 65–398

All of these sections of highway are confirmed by the video to have a narrow median width (less than 2m) and the horizontal alignment is mostly easy curves with the worst section being on moderate curves. The posted speed environment for all three median wire rope sections exhibiting the highest strike rates is 100km/h. Two of the three sites include a break in the median to allow for right-turning vehicles.

The two non-SH1 locations identified in the top 10 sites in table 6.1 are on lower volume roads and each section of WRB is relatively short. These installation sites have a much lower nuisance strike incidence rate with records showing they have only been struck between three and seven times. One of these locations has a narrow median less than 2m, and the horizontal alignment is generally on easy curves with no ATP markings.

7 All barrier strike prediction models

The development of regression models was undertaken to determine which variables had a significant effect on the rate of all barrier strike events for each of the barrier types and to generate predictive models to calculate strike rates and corresponding costs. Different trends were observed for LHS and median W-beam sections less than 40m in length so models for each length category were created for both LHS and median W-beam barriers. The six regression models developed are presented in this section and the full regression output is included in appendix B.

7.1 Median wire rope all barrier strike model

Multivariate regression modelling was undertaken to establish the relationship between the barrier strike rate per million VKT and each of the key independent variables. Equation 7.1 presents the median wire rope equation for predicting all barrier strikes per million VKT.

$$\text{Strikes per million VKT} = 0.122\,H + 0.00401e^{M} - 0.423\,P - 0.132\,A \qquad \text{(Equation 7.1)}$$

where:

- H is the horizontal alignment variable (column U) directly from KAT data (mode across length of installation)
- M = 7 less median width (in metres) or zero, whichever value is larger
- P = 1 if posted speed is less than 100km/h otherwise P = 0
- A = 1 if ATP road markings are present otherwise A = 0.

The model has an adjusted R-squared statistic of 0.712 indicating that approximately 71% of the variance is explained by the model. This indicates that the data fits well to the statistical model developed. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.000
- M – p = 0.000
- P – p = 0.009
- A – p = 0.264 (indicates variable is not statistically significant; however, it has been included as delineation such as ATP is known from the literature review to influence crash rates with barriers).

The scatterplot in figure 7.1 shows the distribution of the observed versus predicted number of barrier strikes per million VKT at each median wire rope site; this demonstrates a reasonable fit. The median wire rope model residuals approximate a normal distribution as shown in figure 7.2, demonstrating that the linear model is an appropriate model form.

Equation 7.2 presents a modified version of the median wire rope equation for predicting all barrier strikes per annum.

$$\text{Strikes per annum} = (0.122\,H + 0.00401e^{M} - 0.423\,P - 0.132\,A)*365*AADT*Length/10^{9} \qquad \text{(Equation 7.2)}$$

where:

- length = length of the section in m
- AADT = annual average daily traffic (vehicles/day).

Figure 7.1 Observed versus predicted number of median wire rope all barrier strikes

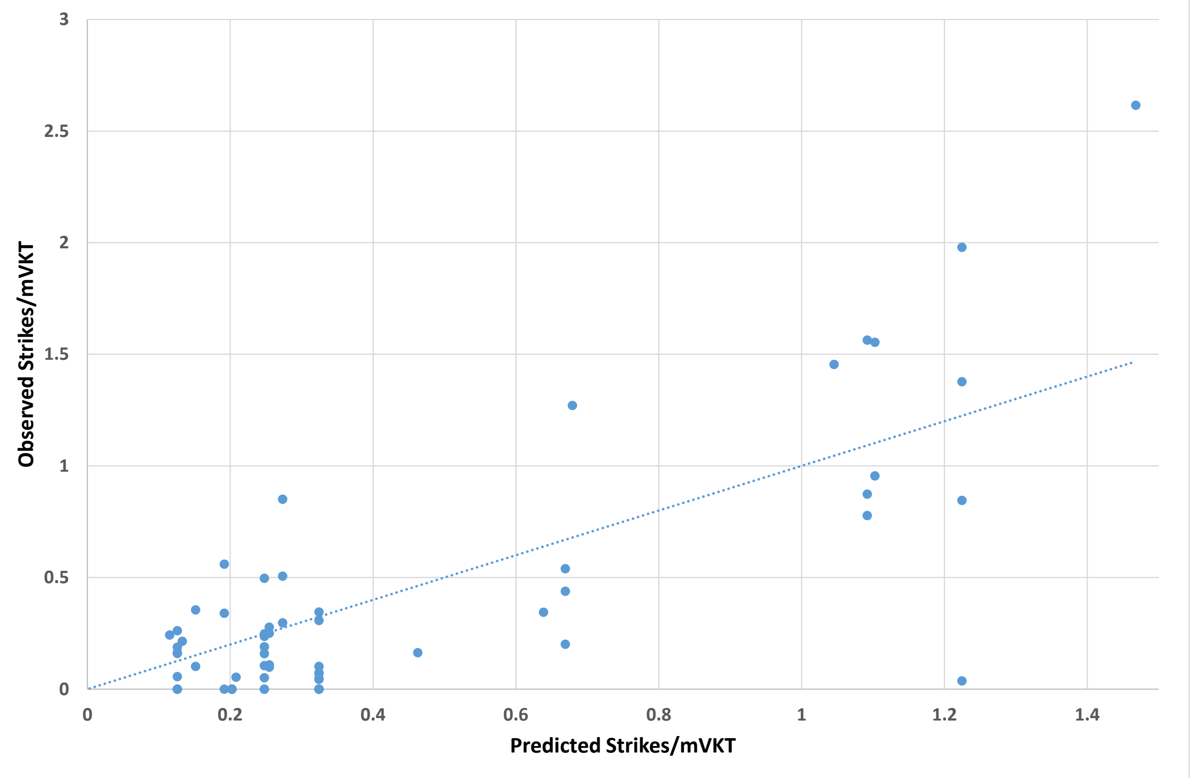
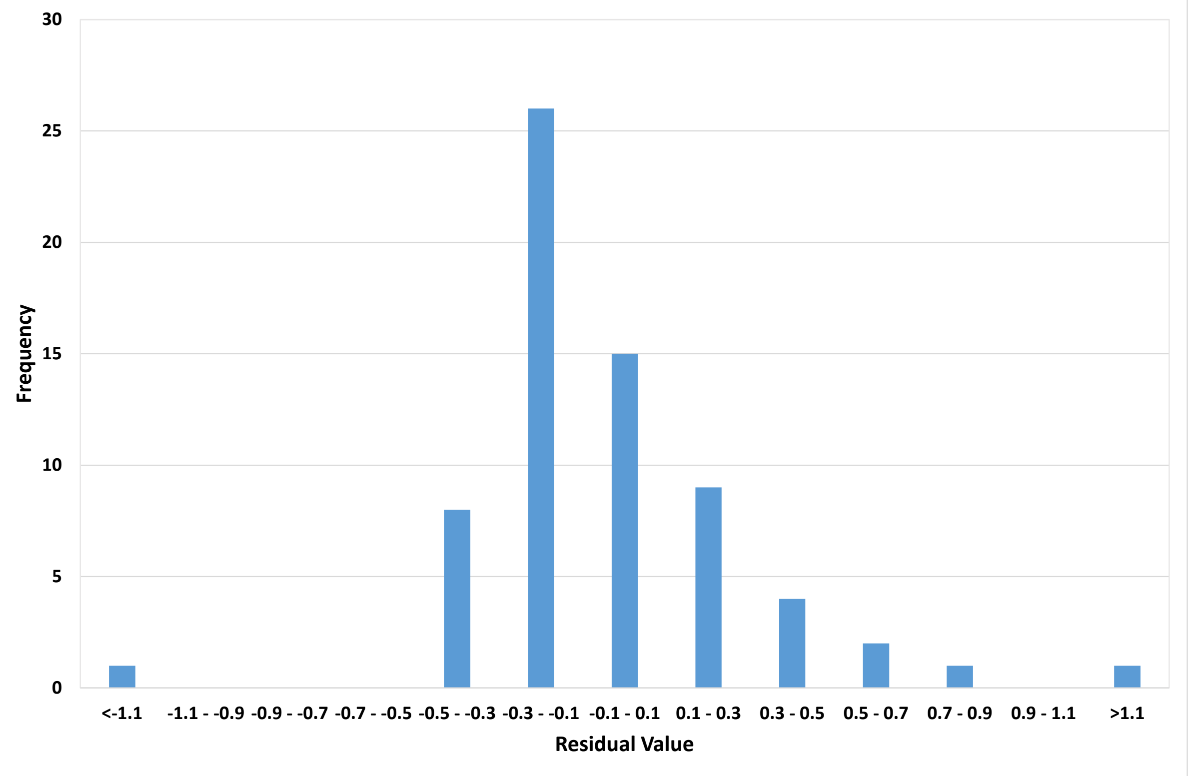


Figure 7.2 Residual values of median wire rope all barrier strike model



7.2 Left-hand side wire rope all barrier strike model

Equation 7.3 presents the LHS wire rope equation for predicting barrier strikes per million VKT.

$$\text{Strikes per million VKT} = 0.177\,H - 0.413\,A + 2.00\,F \qquad \text{(Equation 7.3)}$$

where:

- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation)
- A = 1 if ATP road markings are present otherwise A = 0
- F is a function to represent offset to the LHS barrier where F = 0 if the offset is greater than or equal to 5m, otherwise F = (5- offset to LHS barrier) if the offset <5m. The offset should be measured as the distance between the centreline and the LHS barrier in metres for single lane roads, or measured as the distance between the right-hand edge of the lane furthest to the left, for multilane corridors.

The adjusted R-squared statistic for the model is 0.646 indicating that 65% of the variance of strikes occurring at LHS wire rope installations is explained by the model. This shows the data fits reasonably well to the statistical model developed. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.001
- A – p = 0.266 (indicates variable is not statistically significant if the test statistic of P = 0.27 is applied; however, it has been included as delineation such as ATP is known to influence crash rates with barriers from the literature review)
- F – p = 0.000.

A scatterplot of the observed versus predicted number of barrier strikes per million VKT at each LHS wire rope site is displayed in figure 7.3 and demonstrates reasonable fit. The LHS wire rope model residuals approximate a normal distribution as shown in figure 7.4, demonstrating that the linear model is an appropriate model form.

Equation 7.4 presents a modified version of the LHS wire rope equation for predicting all barrier strikes per annum.

$$\text{Strikes per annum} = (0.177\,H - 0.413\,A + 2.00\,F) * 365 * AADT * Length/10^{9} \qquad \text{(Equation 7.4)}$$

where:

- length = length of the section in m
- AADT = annual average daily traffic (vehicles/day).

Figure 7.3 Observed versus predicted number of left-hand side wire rope all barrier strikes

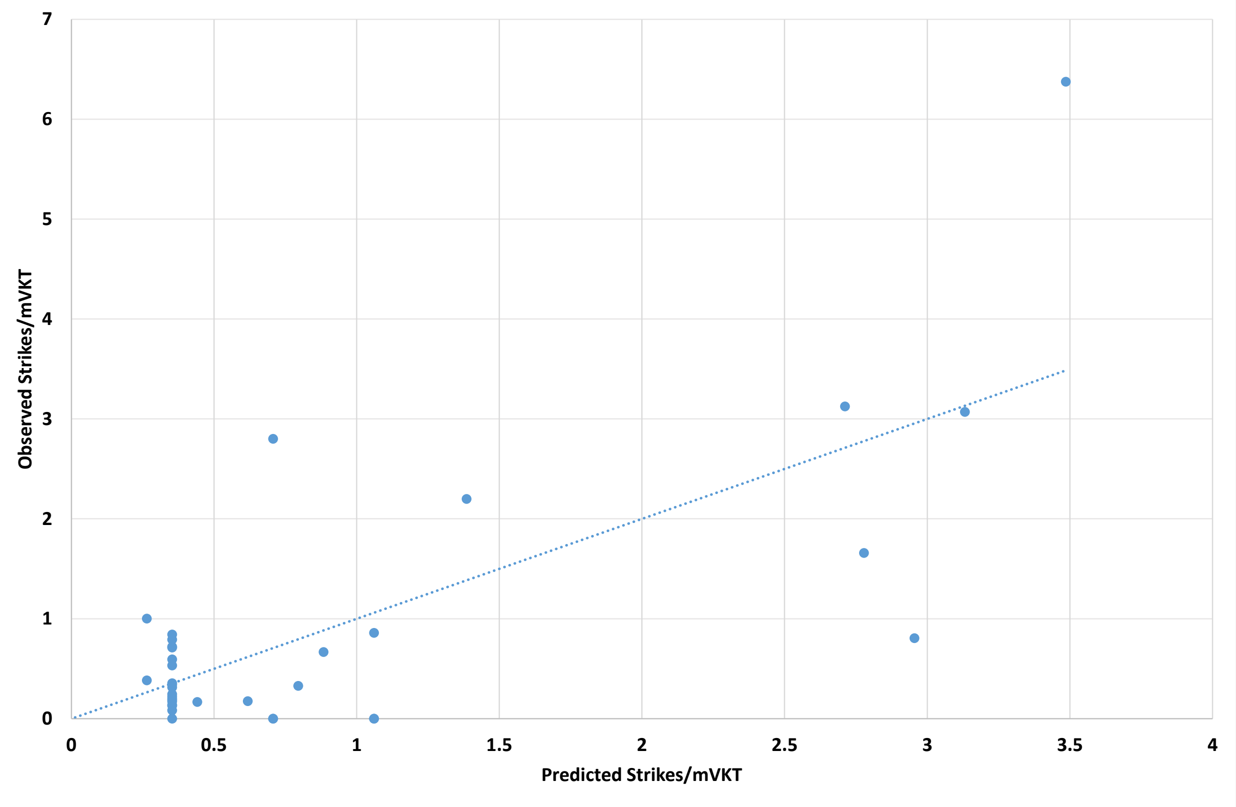
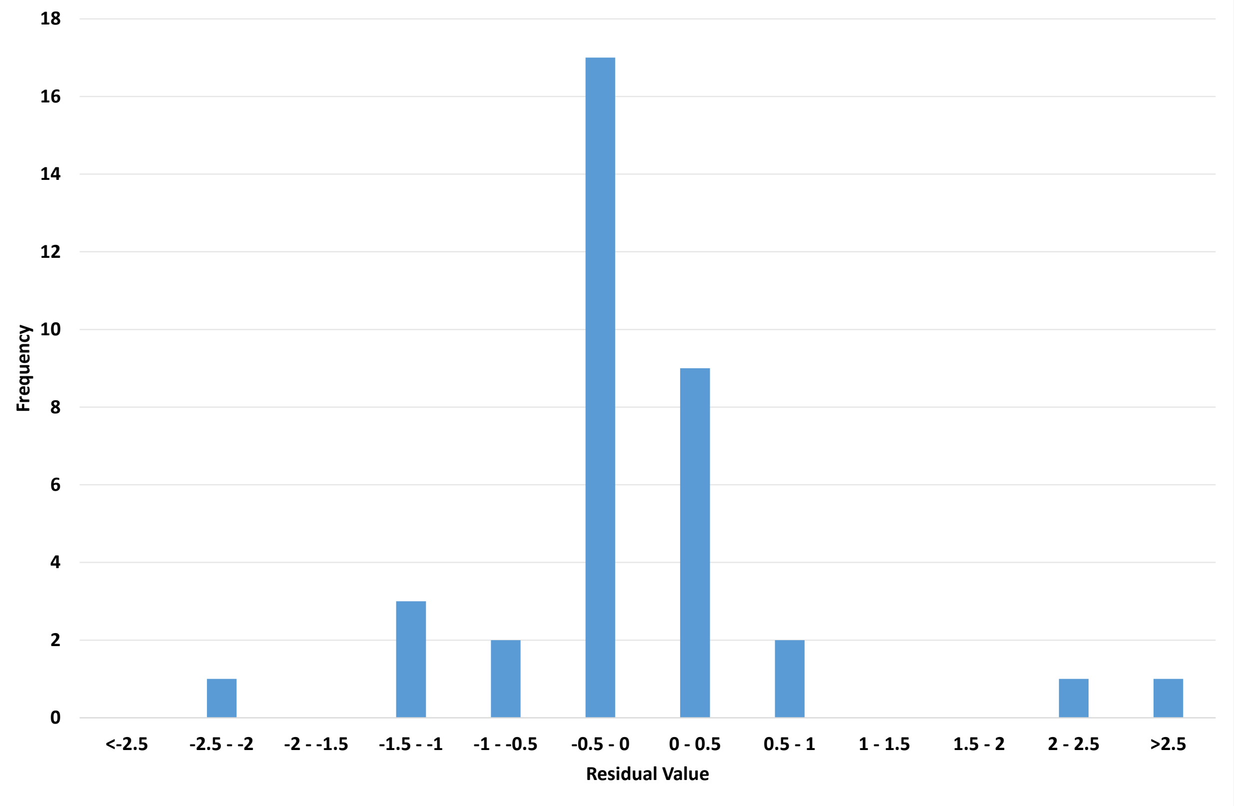


Figure 7.4 Residual values of left-hand side wire rope all barrier strike model



7.3 Median W-beam all barrier strike model

The W-beam regression models were initially tested with the number of strikes per million VKT as the dependent variable. None of the independent variables emerged as being significant, therefore the number of strikes per annum was assessed as the dependent variable. Different trends were found for barriers with a length less than or equal to 40m, and those greater than 40m. Therefore models were created for each length category.

Equation 7.5 presents the median W-beam equation for predicting the number of barrier strikes per annum for lengths of barrier greater than 40m.

$$\text{Strikes per annum} = 0.236T - 0.324L + 0.00000529AADT \qquad \text{(Equation 7.5)}$$

where:

- T is the terrain variable directly from KAT data (mode across length of installation)
- L = 1 if the length of the section is less than 400m otherwise L = 0
- AADT is the annual average daily traffic count for both sides of the road if the section is undivided. If the road section is divided then it is the AADT for the side of the road where the barrier is located.

The adjusted R-squared statistic for the model is 0.328 indicating that 33% of the variance of strikes occurring at median W-beam installations is explained by the model. This shows that the model provides a poor fit with the underlying observed data. P-statistics indicating the statistical significance for the model variables are as follows:

- T – $p = 0.002$
- L – $p = 0.001$
- AADT – $p = 0.051$.

The p-values for all variables are low indicating that all variables are significant.

A scatterplot of the observed versus predicted number of barrier strikes per annum at each median W-beam site is displayed in figure 7.5 and demonstrates reasonably poor fit as is consistent with the adjusted R-squared statistic. This lack of fit is largely due to the high proportion of barriers with no observed barrier strikes (70%, as shown in table 2.1) which dominate the analysis. The median W-beam installations model residuals roughly approximate a normal distribution as shown in figure 7.6.

Figure 7.5 Observed versus predicted number of median W-beam all barrier strikes

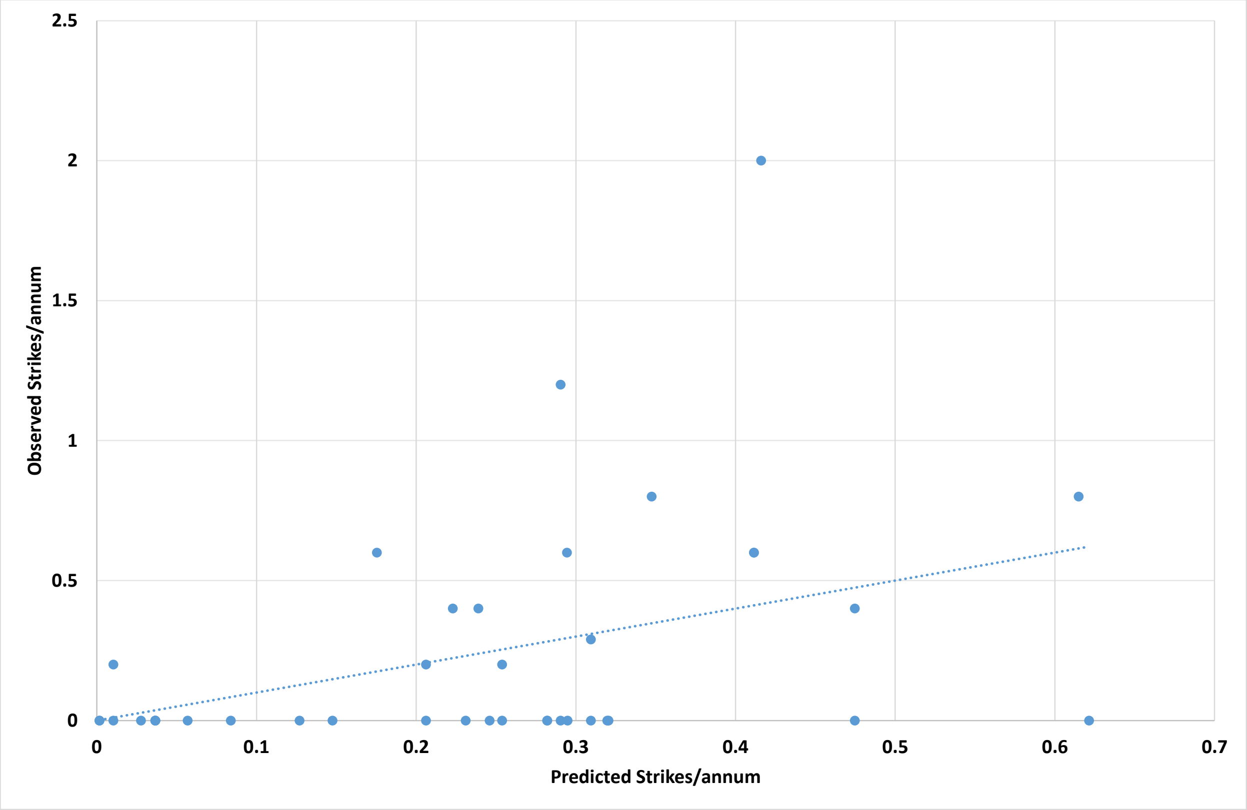
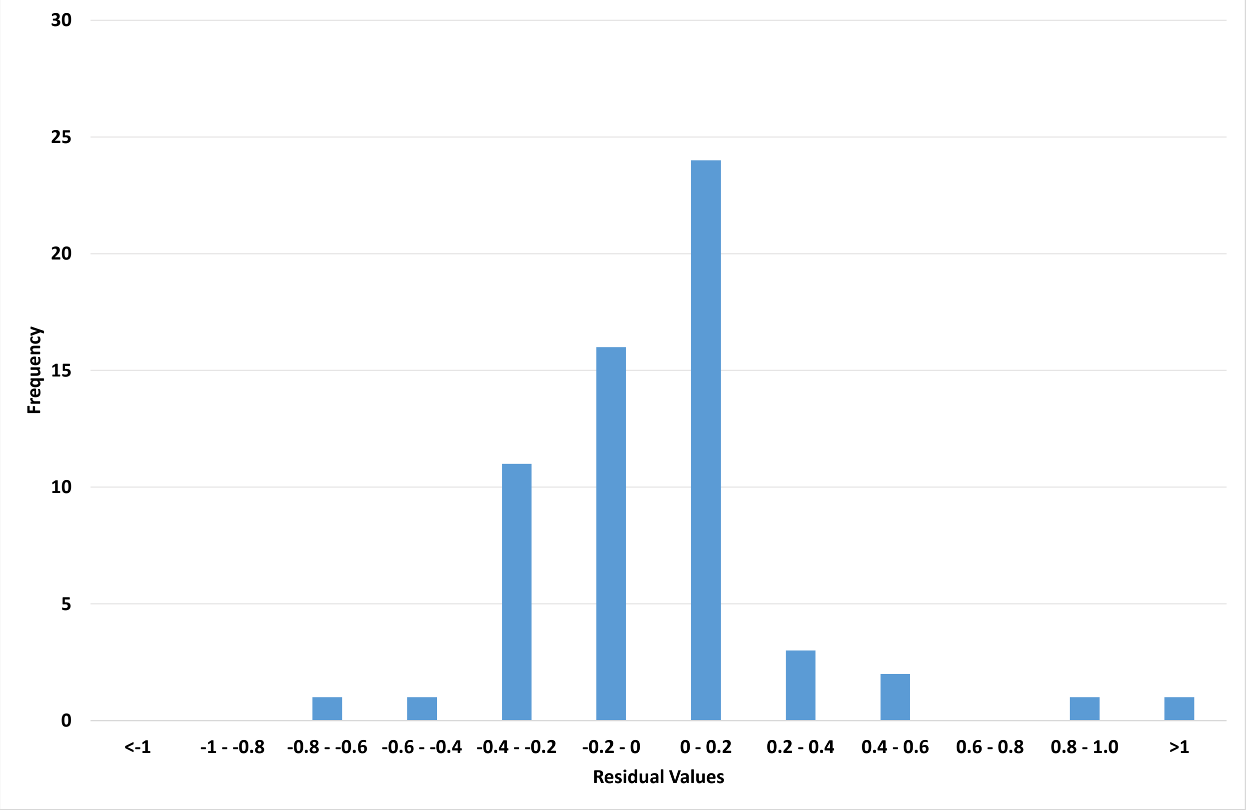


Figure 7.6 Residual values of median W-beam all barrier strike model



Equation 7.6 presents the median W-beam equation for predicting the number of barrier strikes per annum (for lengths less than or equal to 40m).

$$\text{Strikes per annum} = 0.0257H \qquad \text{(Equation 7.6)}$$

where:

- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation).

The adjusted R-squared statistic for the model is 0.081 indicating that 8% of the variance of strikes occurring at median W-beam installations is explained by the model. This shows that the data fits reasonably poorly to the statistical model developed. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.008.

The p-value is low indicating that the variable is significant.

A scatterplot of the observed versus predicted number of barrier strikes per annum at each median W-beam site is displayed in figure 7.7 and demonstrates poor fit. This poor fit is due to the lack of trends identified between the independent variables and the number of strikes with a very small underlying dataset of 70 barriers and only 15 strikes recorded on eight of these 70 barriers. The median W-beam installations model residuals do not approximate a normal distribution as shown in figure 7.8.

This model does not include a variable to relate strikes to AADT or other key variables making it a very coarse model not suitable for use as a prediction model. Subsequently, it has not been included in the predictive spreadsheet tool accompanying this report.

Figure 7.7 Observed versus predicted number of median W-**Beam all barrier strikes (≤40m)**

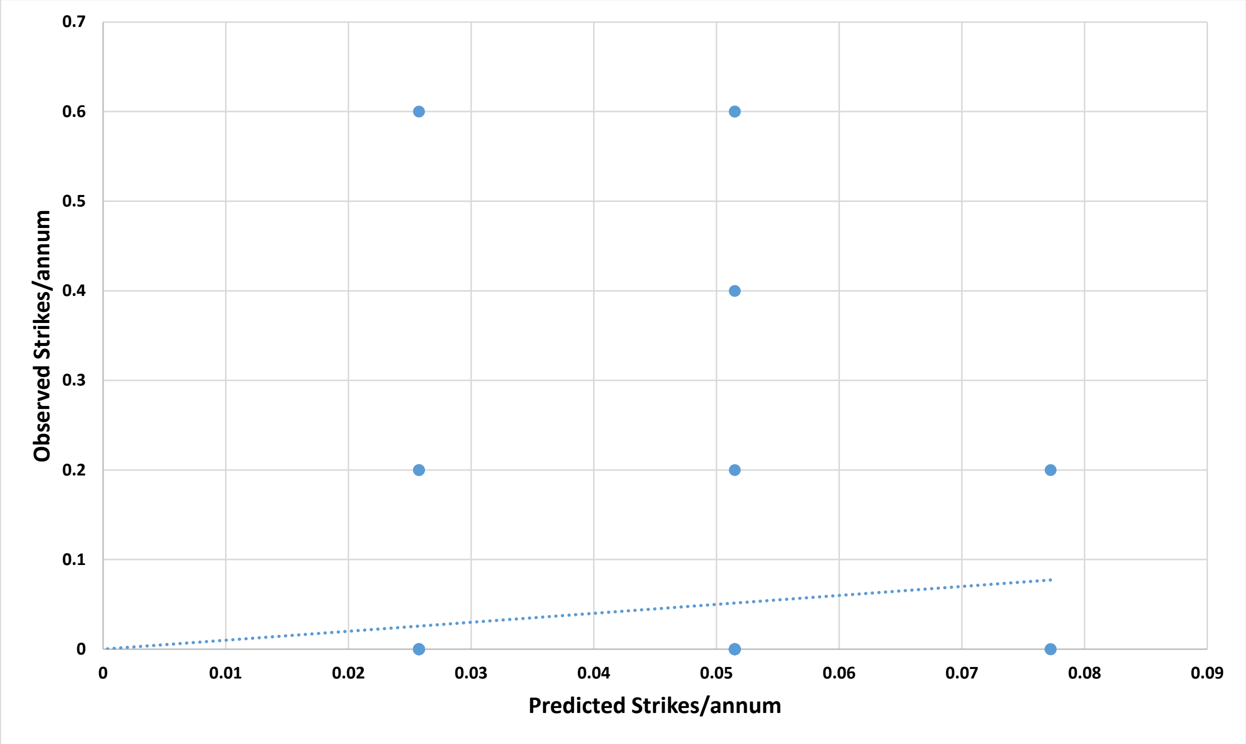
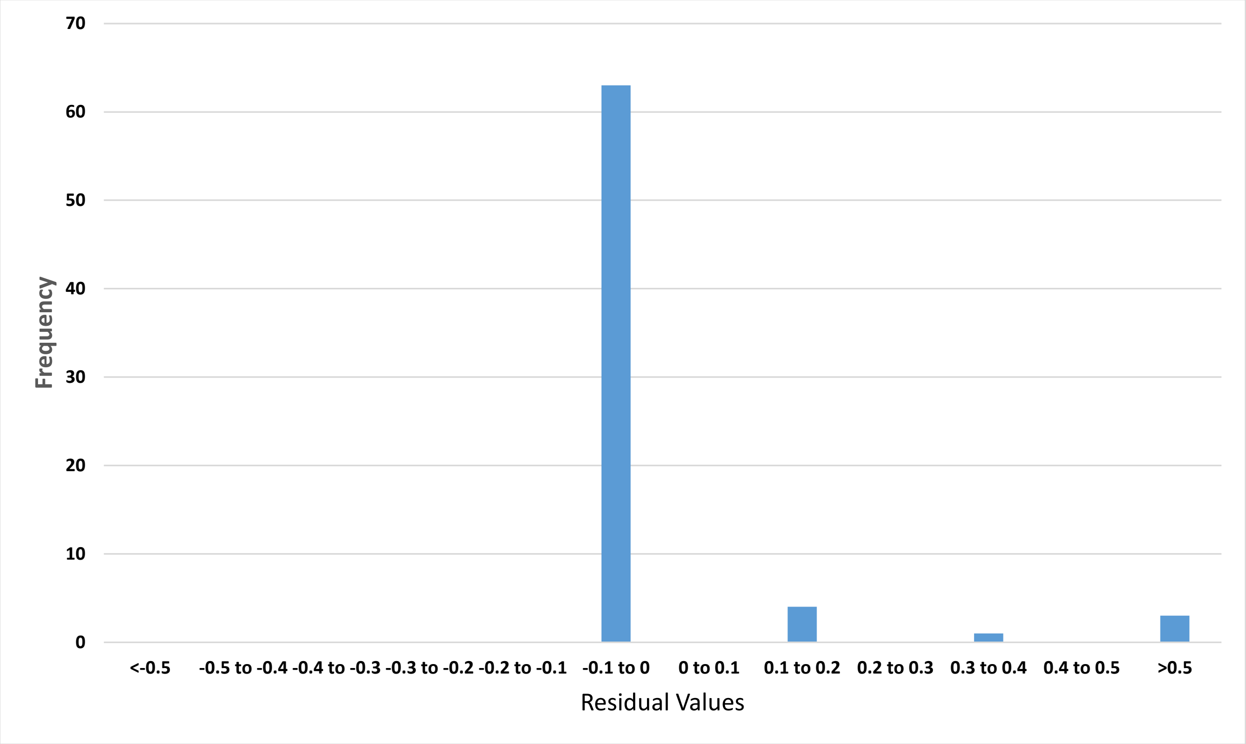


Figure 7.8 Residual values of median W-beam all barrier strike model (≤40m)



7.4 Left-hand side W-beam all barrier strike model

The LHS W-beam regression models were initially tested with the number of strikes per million VKT as the dependent variable. None of the independent variables emerged as being significant, therefore the number of strikes per annum was assessed as the dependent variable. Different trends were found for barriers with a length less than or equal to 40m, and those greater than 40m. Therefore models have been created for each length category.

The LHS W-beam model predicts strikes per annum (for lengths greater than 40m) in equation 7.7 as follows:

$$\text{Number of strikes per annum} = 0.0842T - 0.118L + 0.00000683AADT + 0.0104H \qquad \text{(Equation 3.7)}$$

where:

- T is the terrain variable directly from KAT data (mode across length of installation)
- L = 1 if the length of the section is less than 400m otherwise L = 0
- AADT is the annual average daily traffic count for both sides of the road if the section is undivided. If the road section is divided then it is the AADT for the side of the road where the barrier is located
- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation).

The adjusted R-squared statistic for the final model is 0.156 indicating that little of the variance of barrier strikes occurring at LHS W-beam installations is explained by the model. P-statistics indicating the statistical significance for the model variables are as follows:

- T – p = 0.000
- L – p = 0.000
- AADT – p = 0.000
- H – p = 0.045.

The p-values for all variables are very low indicating that all variables are significant.

A scatterplot of the observed versus predicted number of barrier strikes per annum at each LHS W-beam site is pictured in figure 7.9 and demonstrates poor fit. This lack of fit is largely due to the high proportion of barriers with no observed barrier strikes (72%, as shown in table 2.1) which dominate the analysis.

The residuals for the model are plotted in figure 7.10. The high frequency of zero residual values corresponds to barrier installations with no observed strikes. Barriers which have been struck at least once are generally included in the 0.2 to 1 range. The residuals roughly approximate a normal distribution with some positive skew demonstrating that the linear model is a reasonable fit to the data.

Figure 7.9 Observed versus predicted number of left-hand side W-beam all barrier strikes

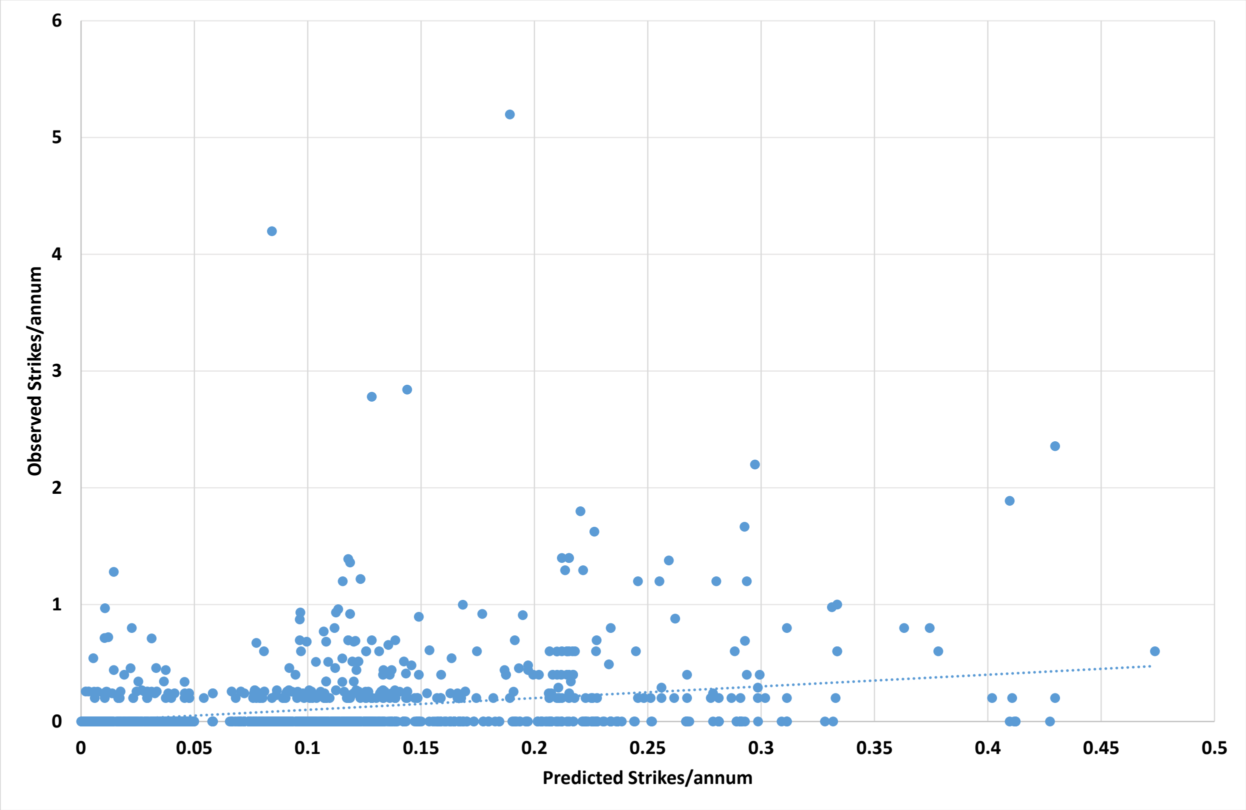
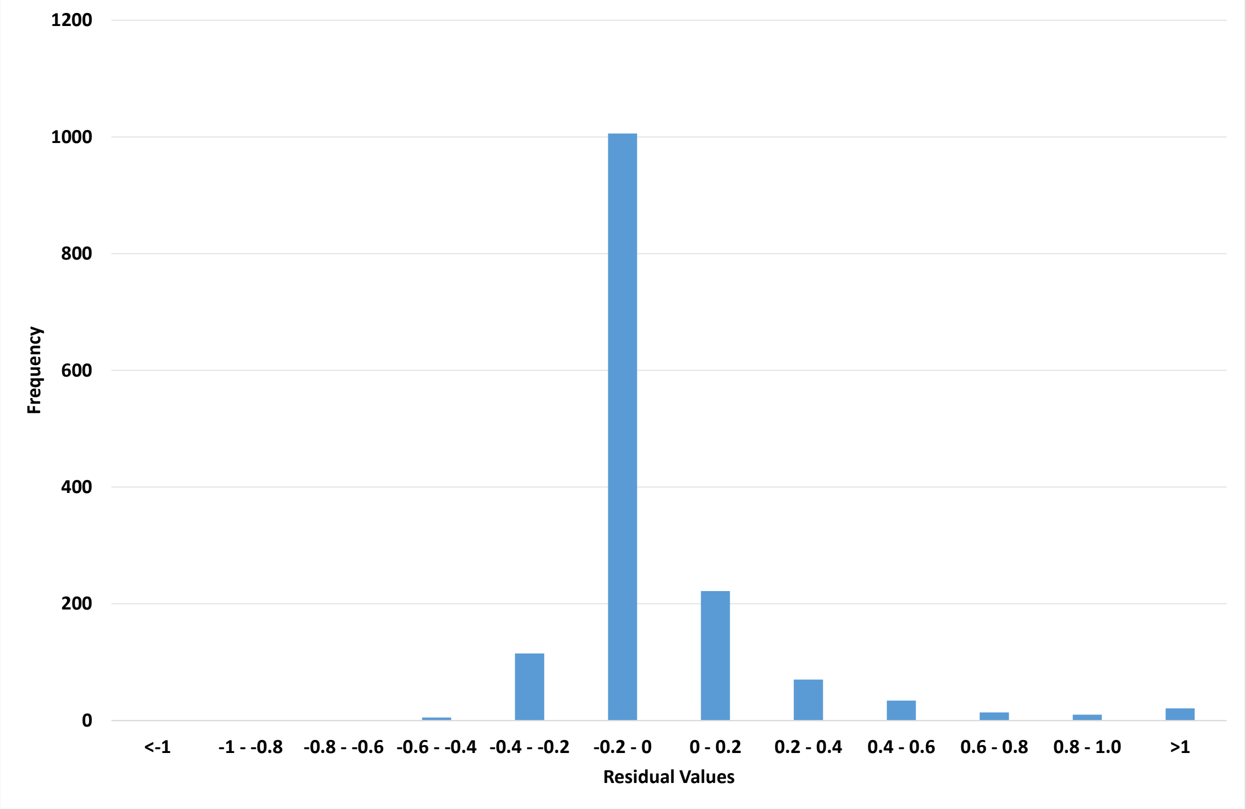


Figure 7.10 Residual values of left-hand side W-beam all barrier strike model



The LHS W-beam model predicts strikes per annum (for lengths less than or equal to 40m) in equation 3.8 as follows:

$$\text{Number of strikes per annum} = 0.00963H + 0.0205T - 0.188/PC + 0.000000672AADT \quad \text{(Equation 3.8)}$$

where:

- H is horizontal alignment variable (column U) directly from KAT data (mode across length of installation)
- T is the terrain variable directly from KAT data (mode across length of installation)
- PC = the percentage of vehicles traversing the section classified as heavy vehicles
- AADT is the annual average daily traffic count for both sides of the road if the section is undivided. If the road section is divided then it is the AADT for the side of the road where the barrier is located.

The adjusted R-squared statistic for the final model is 0.084 indicating that little of the variance of barrier strikes occurring at LHS W-beam installations is explained by the model. P-statistics indicating the statistical significance for the model variables are as follows:

- H – p = 0.012
- T – p = 0.023
- PC – p = 0.017
- AADT – p = 0.22 (indicates variable is not statistically significant if the test statistic of P = 0.22 is applied; however, it has been included as AADT is known to influence crash rates with barriers from the literature review).

The p-values for all variables other than AADT are low indicating those variables are significant.

A scatterplot of the observed versus predicted number of barrier strikes per annum at each LHS W-beam site is pictured in figure 7.11 and demonstrates poor fit. This lack of fit is due to the high proportion of barriers with no observed barrier strikes (72%, as shown in table 2.1) which dominate the analysis as well as the lack of significant variables identified in the assessment.

The residuals for the model are plotted in figure 7.12. The high frequency of zero residual values corresponds to barrier installation sites with no observed strikes. This equation is useful as a high-level predictive model since it contains key variables which relate to barrier strike rates. Subsequently, it has been included in the predictive spreadsheet tool accompanying this research, but should be used with caution given the poor fit of the underlying regression model.

Figure 7.11 Observed versus predicted number of left-hand side W-beam all barrier strikes model (≤40m)

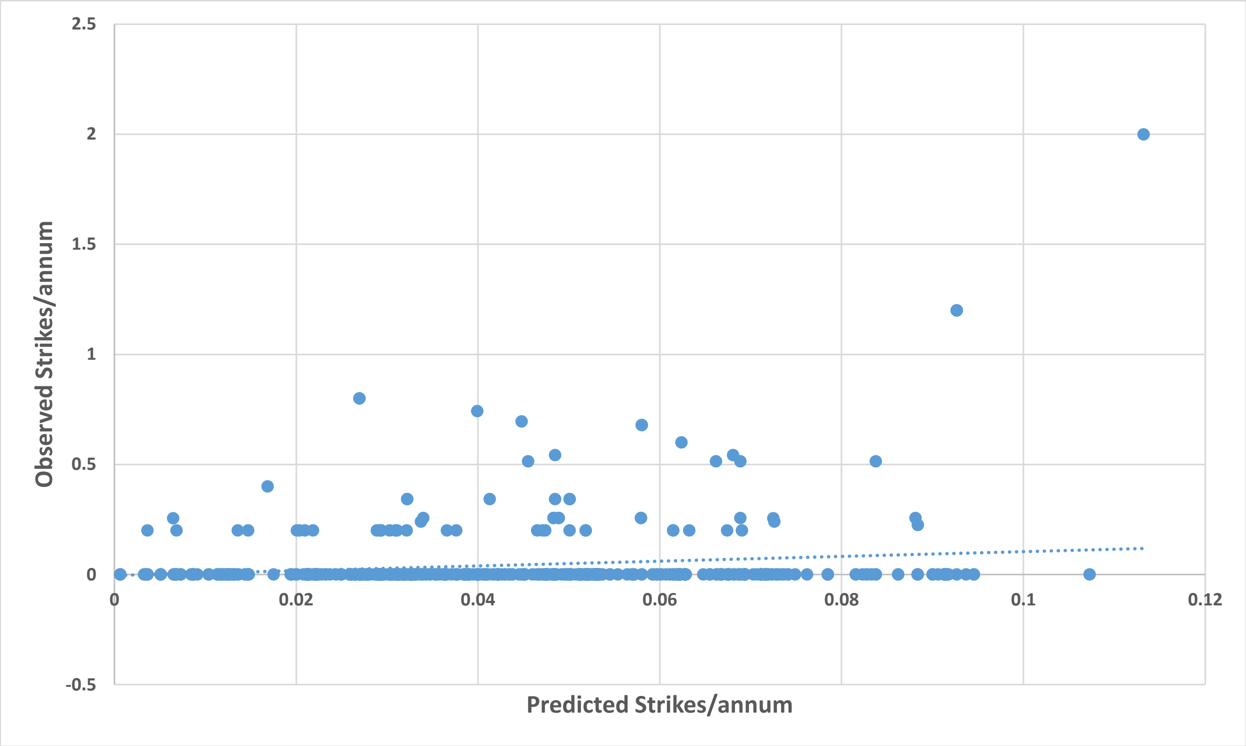
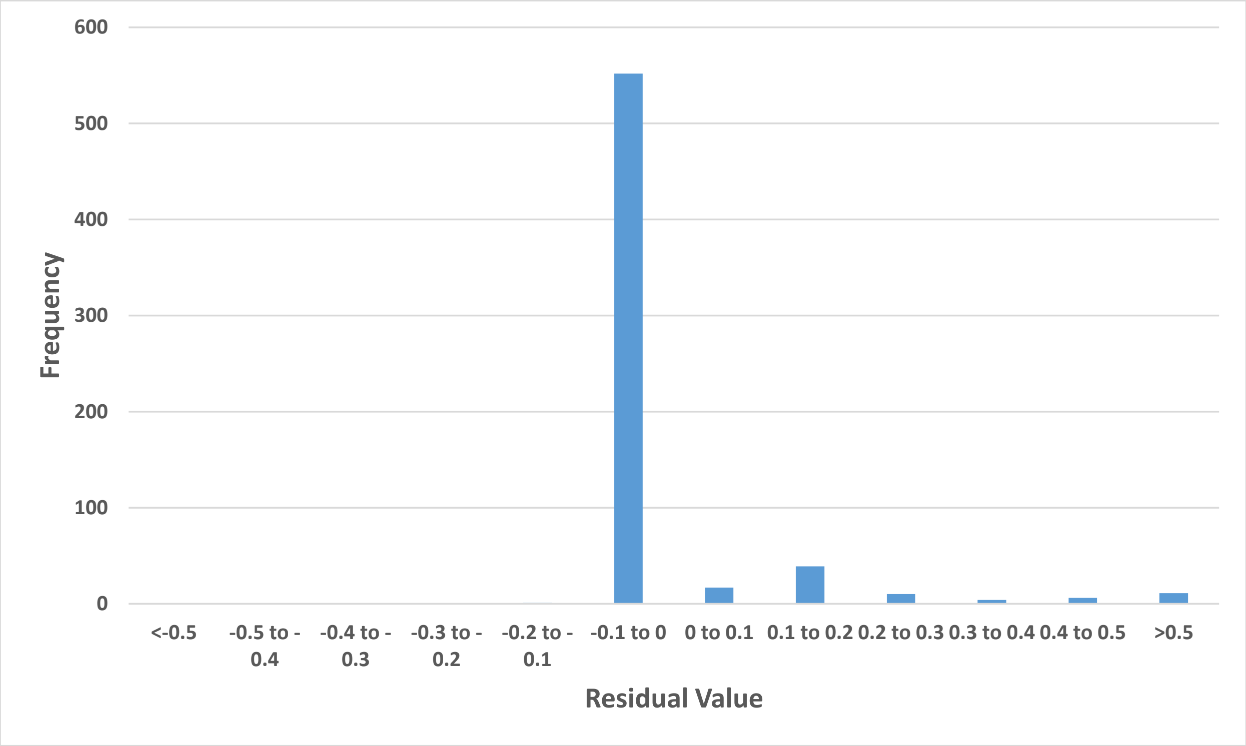


Figure 7.12 Residual values of left-hand side W-beam all barrier strikes model (≤40m)



7.5 W-beam strike model discussion

Sections of W-beam with short lengths exhibited different trends in terms of strikes per annum than those with longer lengths. This can be observed in figure 7.13 below for LHS W-beam sections and figure 7.14 for median W-beam sections.

Figure 7.13 Strikes/annum by length of left-hand side W-beam

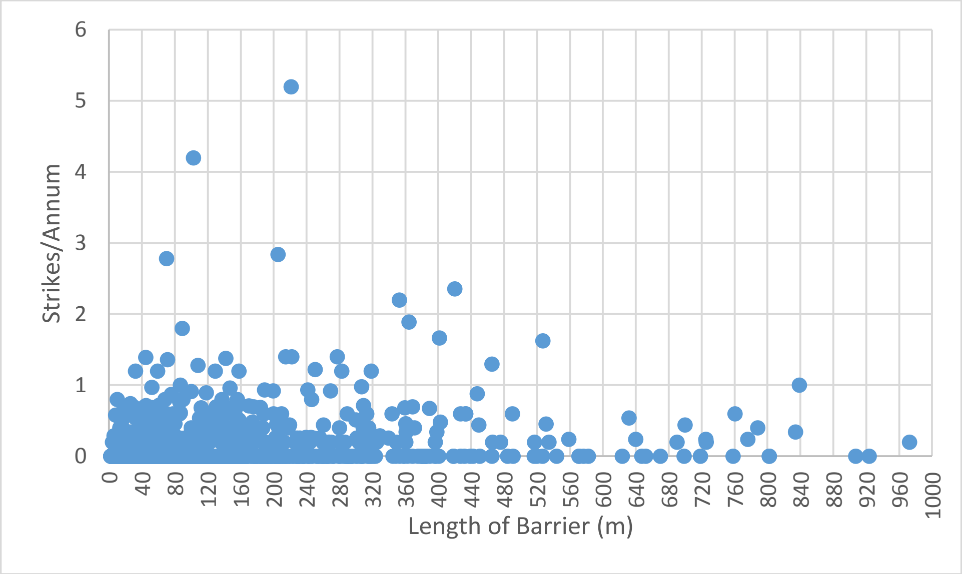
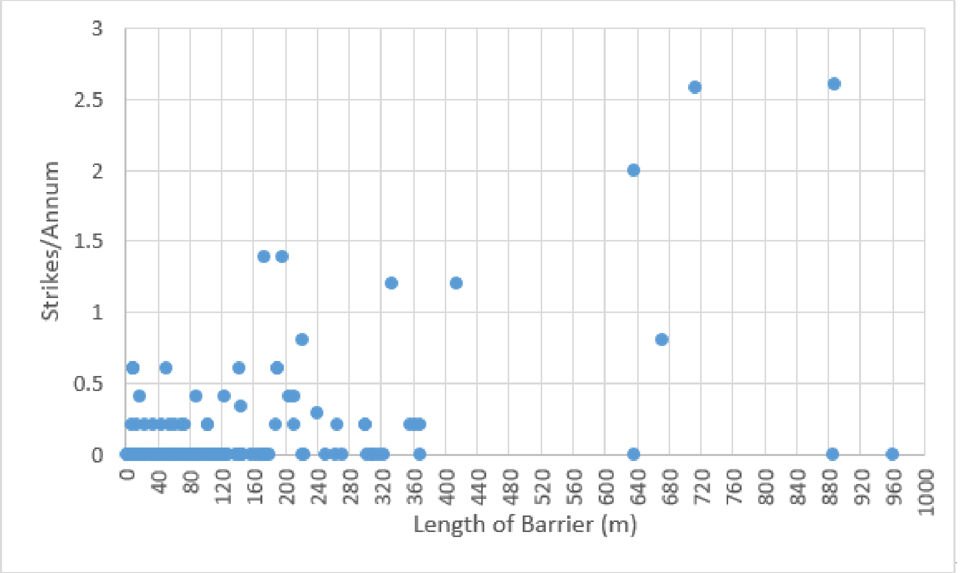


Figure 7.14 Strikes/annum by length of median W-beam



The observed difference in trends is likely due to the different usages of W-beam. W-beam is normally used for a delineation function when longer sections are installed, whereas shorter sections generally perform a capping function for some other roadside feature. Examples of these features include a bridge or concrete barrier (shown in the first two pictures from the left in figure 7.15). In some cases W-beam also protects road users from an isolated roadside hazard (for example an electrical distribution box).

Figure 7.1 Examples of W-beam performing a capping function

A value of 40m was chosen as the separation point for different model equations as it fitted well for both median and LHS W-beam data. As a result of the separation, the model fit improved for barriers over 40m in length and reduced slightly for barriers less than or equal to 40m in length.

Because the equations represent different uses of W-beam, appropriate care is required when either of the following situations arise:

- The barrier has a delineation function and ≤40m models are used.
- The barrier has a capping function and >40m models are used.

This distinction is important, particularly when barrier lengths near 40m are being considered. The predicted strikes will change dramatically in this range if a user inadvertently changes from one equation to another. The user should never change between equations in this manner since the function of the W-beam will determine one of the two equations invalid for prediction. This point has been documented in the user guide (appendix C) for the spreadsheet prediction tool accompanying this research.

As already discussed in section 7.3, the model for median W-beam does not include a variable to relate strikes to AADT or other key variables making it a coarse model not suitable for use as a prediction model. Subsequently, it has not been included in the predictive spreadsheet tool accompanying the research.

8 Barrier maintenance cost prediction tool

This research is accompanied by a spreadsheet tool that implements the barrier model equations discussed in chapters 6 and 7, within an Excel tool to simplify the calculations process. This provides a platform for roading authorities to enter the values of the independent variables for WRB on a section of highway and derive the strikes per million VKT, strikes per annum or likelihood of a nuisance strike occurring in an easy to use application. The tool also undertakes simple maintenance cost modelling by multiplying the predicted strikes by the average cost to repair damage to WRBs ($2,700 per repair) and W-beam barriers ($2,000 per repair) as presented in section 4.6. These values have been assumed as the default average strike cost values in the barrier strike spreadsheet tool.

Combining the strike rate and maintenance cost estimates into one platform, the tool allows valuable information to be drawn to inform planners and local roading authorities. A user guide for the tool is included with this report as appendix C.

The outputs of the spreadsheet tool should be used with caution. The LHS and median W-beam regression equations had low adjusted R^2 values so the outputs of the spreadsheet tool associated with these regression equations should be assumed to include a high degree of uncertainty. The LHS and median wire rope regression equations had moderate adjusted R^2 values so the outputs of the spreadsheet tool associated with these regression equations can be assumed to be more reliable than those associated with the LHS and median W-beam regression equations.

9 Conclusions

The barrier strike models have tested variables identified by the research and generated a set of significant variables that are responsible for the variation in barrier strike rates and consequential maintenance costs. Tables 9.1 and 9.2 summarise the significant variables for each model and barrier installation type.

Table 9.1 Summary of significant independent variables – nuisance strikes

Significant variables	Median wire rope	LHS wire rope	Median W-beam	LHS W-beam model 1	LHS W-beam model 2
Horizontal alignment	✓	✓			✓
Median width	✓				
ATP	✓	✓			
Posted speed	✓				
Offset from centreline		✓			
Terrain			✓	✓	✓

Table 9.2 Summary of significant independent variables – all strikes

Significant variables	Median wire rope	LHS wire rope	Median W-beam (>40m)	LHS W-beam (>40m)	Median W-beam (≤40m)	LHS W-beam (≤40m)
Horizontal alignment	✓	✓		✓	✓	✓
Median width	✓					
ATP	✓	✓				
Posted speed	✓					
Offset from centreline		✓				
Terrain			✓	✓		✓
AADT	✓	✓	✓	✓		✓
Length of section	✓	✓	✓	✓		
Percentage heavy vehicles						✓

The nuisance barrier strike rate on WRBs was highly correlated with horizontal alignment, and the presence of ATP for both median and LHS installations. Median width and posted speed were also significant factors for median wire rope installations, while the offset from the centreline was a significant factor in explaining LHS WRB strike rates.

For W-beam installations, a relationship between terrain and nuisance barrier strike rates was identified. Horizontal alignment was also significant for LHS W-beam installations when developing a model with a binary dependent variable. There were no other significant independent variables.

These findings generally align with those identified in the literature review as being significant variables for vehicular crashes with roadside barriers, although the literature generally did not isolate nuisance strikes from non-drive away events.

The all strike models indicate that horizontal alignment and the presence of ATP significantly influence the rate of barrier strikes on WRBs for both median and LHS installations. Median width and posted speed were also significant factors for median wire rope installations, while the offset from the centreline was a significant factor in explaining LHS WRB strike rates. These are consistent with the variables that significantly influence the rate of WRB nuisance strikes.

The development of the barrier strike model for W-beam installations identified additional significant variables compared with the nuisance strike models. AADT and terrain were found to be significant in three out of the four models developed. The length of the barrier was also found to be significant for median and LHS W-beams greater than 40m in length. Horizontal alignment was found to be significant in three out of the four models developed for median and LHS W-beam sections. These findings generally align with those identified in the literature as variables having a bearing on the rate of vehicular crashes with roadside barriers. The model equations developed for W-beam barriers less than or equal to 40m in length should be used with caution due to the poor model fit and relatively sparse underlying datasets.

Having identified relationships between the rate of barrier strikes and the operational and environmental variables, these factors can be used to inform planners and RCAs when deciding if a barrier should be installed. The primary motivation for barrier installation is to preserve lives and maximise road user safety. There is the opportunity to also predict and consider the likely maintenance cost implications of barrier strikes as part of a wider business case to install further barrier infrastructure on the New Zealand road network.

The barrier strike spreadsheet tool that accompanies this research calculates the number of crashes per annum and corresponding maintenance cost for all strikes on WRB and W-beam installations. This cost prediction tool can be used in conjunction with other cost components to form part of the wider economic assessment of the relative benefits (or dis-benefits) associated with the installation of a specific barrier type in a given location.

This research specifically assessed strike rates to barrier maintenance costs; however, when deciding what type of barrier should be installed, the cost of crashes should also be taken into consideration. It is anticipated that the safety benefits in most instances will far outweigh the likely maintenance costs from a purely economic perspective; however, this evaluation lies outside of the scope of the research.

Median width produced a significant relationship with median WRB installations while barrier offset from centreline was significant with LHS wire rope installations. This research and the spreadsheet tool developed will enable the strike rate and cost implications of widening a carriageway or median strip to be assessed. This allows practitioners to evaluate all possibilities and determine the optimal width and cost implications as part of a wider business case. Similarly, the strike rate and cost implications of shifting an existing WRB can be assessed.

The presence of ATP road marking as a form of delineation has been found to have a significant bearing on the nuisance strike rate at WRB installations. This research and the accompanying spreadsheet tool enable practitioners to consider the maintenance cost savings of installing ATP road marking in conjunction with existing or new WRB installations.

The modelling assessment of all barrier strikes revealed relationships with terrain, AADT, horizontal alignment and length of barrier section for W-beam installations. Each of these variables affects the barrier strike rate and through the spreadsheet tool is able to inform decision making for barrier installation.

In the technical assessment in this research, no relationships were established between W-beam barrier strikes and these variables, therefore similar inferences for these installations cannot be made. It is, however, evident that the high frequency W-beam barrier strike locations are generally those with undulating terrain, poor horizontal alignment and where the barriers are installed close to the edge marking. By moving the barriers further away from the edge marking where practicable in these areas with challenging terrain, maintenance costs are likely to be reduced.

10 Recommendations

The recommendations arising from this research project relate first to future work to build upon the findings of the research, and second to highlighting the importance of keeping accurate data and maintenance records for barrier strikes. The data used in the assessment of barrier strikes has been sourced from the Transport Agency state highway network; however, the findings of and recommendations arising from this research are equally applicable to other RCA networks.

It is recommended that the predictive spreadsheet tool developed in this research be applied within the transport sector to support decisions in relation to the installation of barriers, type of barrier installed and widening of medians and carriageways to manage costs. It is further recommended that the spreadsheet tool could be integrated into business case applications to consider the installation of ATP placement adjacent to WRBs.

During the data gathering stage of the project it became apparent there were large inconsistencies in both the volume and content of the data being gathered by regional roading authorities. In order for accurate research and ongoing measurement of incident rates and maintenance costs to occur there needs to be improved consistency of data captured by regions throughout New Zealand. It is recommended the transport sector uses a standard template that records:

- barrier type
- barrier RS/RP location
- barrier position (median/LHS)
- date of strike
- type of strike (crash/nuisance)
- date of repair
- extent of repair
- total cost of repair.

The consistent and accurate collection of maintenance records could be supported by regular maintenance schedules across high-risk parts of the roading network, with outcomes collated in the standard template and managed in a central data repository. The barrier maintenance data repository could be maintained in a GIS platform which is a common environment in which much of NZ Transport Agency's road safety, asset management and network efficiency information is stored. This then provides the opportunity for the barrier strike information to be interrogated spatially, and provides for integration with other datasets. It also provides the ability to visually display information to gain a greater depth of understanding and identify geographical trends.

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Appendix A: Nuisance final regression outputs

Median wire rope regression summary

Regression Statistics	
Multiple R	0.857
R Square	0.734
Adjusted R Square	0.706
Standard Error	0.255
Observations	67

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	11.299	2.825	43.536	0.000
Residual	63	4.088	0.065		
Total	67	15.387			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Horiz Align	0.079	0.018	4.496	0.000	0.044	0.114	0.050	0.109
Median < 2	0.806	0.084	9.570	0.000	0.637	0.974	0.665	0.946
ATP	-0.143	0.088	-1.632	0.108	-0.319	0.032	-0.290	0.003
Posted Speed < 100	-0.269	0.120	-2.254	0.028	-0.508	-0.031	-0.469	-0.070

LHS wire rope regression summary

Regression Statistics	
Multiple R	0.825
R Square	0.680
Adjusted R Square	0.632
Standard Error	0.866
Observations	37

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	54.169	18.056	24.099	0.000
Residual	34	25.475	0.749		
Total	37	79.645			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
Horizontal	0.156	0.051	3.046	0.004	0.052	0.259	0.069	0.242
ATP	-0.591	0.368	-1.606	0.117	-1.338	0.157	-1.212	0.031
Offset Test	2.074	0.370	5.603	0.000	1.322	2.826	1.448	2.700

Median W-beam regression summary

Regression Statistics	
Multiple R	0.161
R Square	0.026
Adjusted R Square	0.021
Standard Error	0.104
Observations	196

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.057	0.057	5.178	0.024
Residual	195	2.128	0.011		
Total	196	2.184			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0.000	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
TerrainCode_1000m	0.013	0.005	2.275	0.024	0.002	0.023	0.003	0.022

LHS W-beam regression summary: model 1

Regression Statistics	
Multiple R	0.254
R Square	0.064
Adjusted R Square	0.064
Standard Error	0.197
Observations	2149

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	5.704	5.704	147.518	0.000
Residual	2148	83.054	0.039		
Total	2149	88.758			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
exp ter	0.00825	0.001	12.146	0.000	0.007	0.010	0.007	0.009

LHS W-beam regression summary: model 2

Regression Statistics	
Multiple R	0.323
R Square	0.105
Adjusted R Square	0.104
Standard Error	0.290
Observations	2149

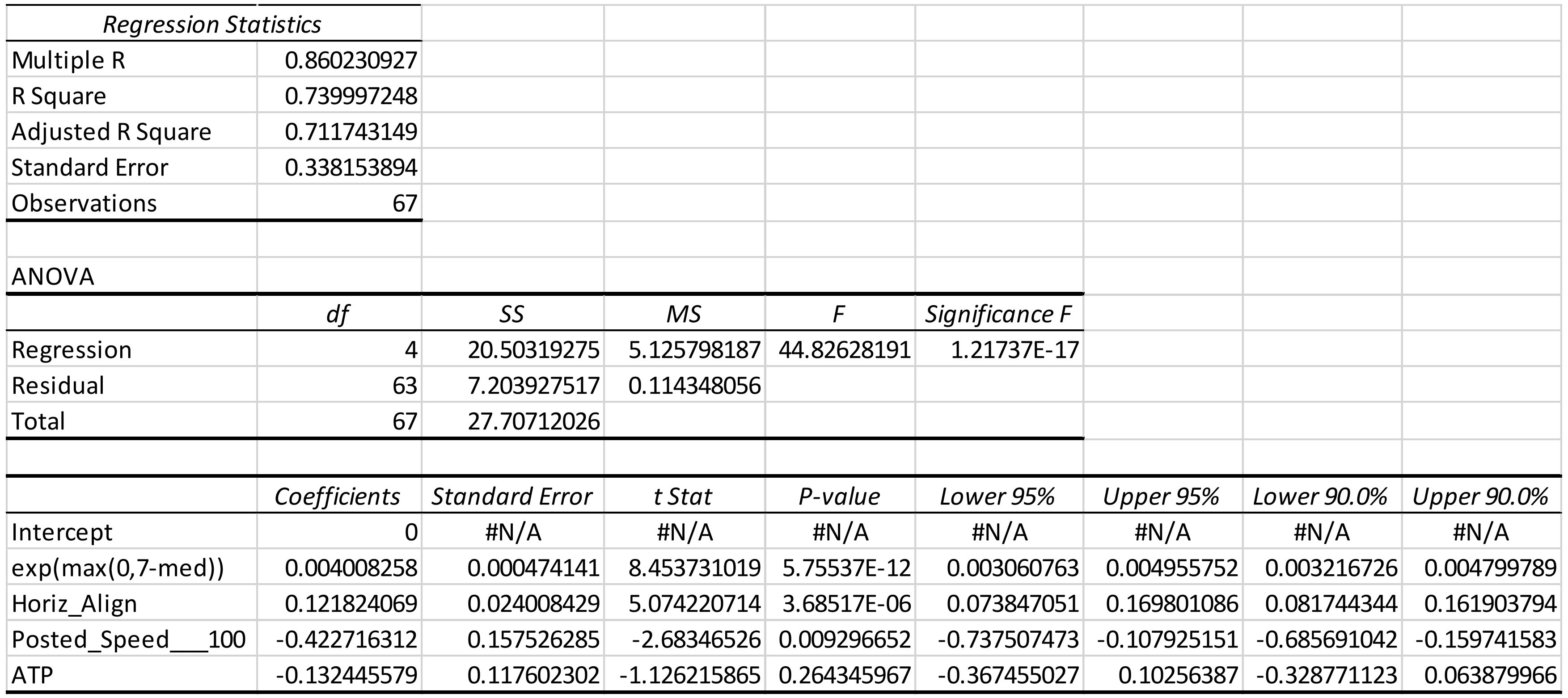
ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	2	21.031	10.516	125.450	0.000
Residual	2147	179.969	0.084		
Total	2149	201			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
HorizontalAlignment	0.01564	0.003	4.975	0.000	0.009	0.022	0.010	0.021
exp ter	0.00858	0.002	5.241	0.000	0.005	0.012	0.006	0.011

Appendix B: All strikes final regression outputs

Median wire rope regression summary



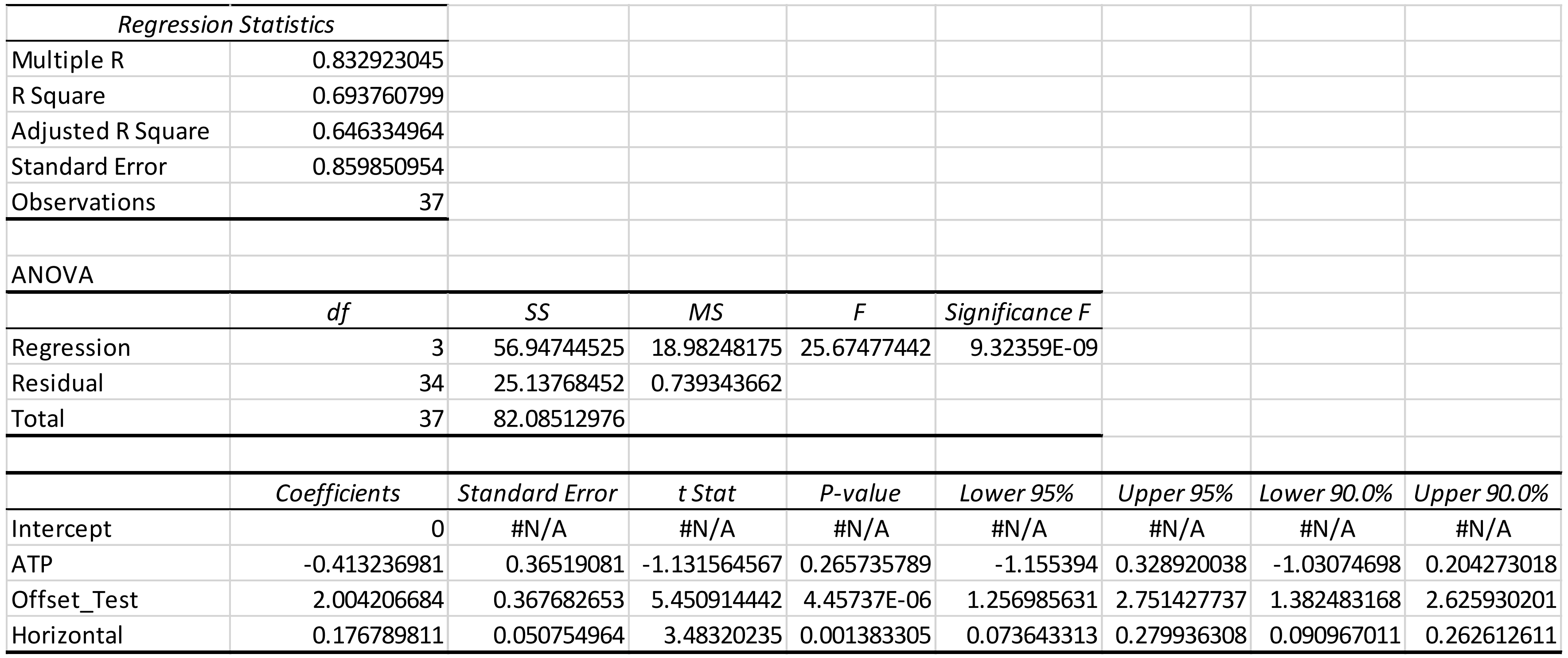
Regression Statistics	
Multiple R	0.860230927
R Square	0.739997248
Adjusted R Square	0.711743149
Standard Error	0.338153894
Observations	67

ANOVA

	df	SS	MS	F	Significance F
Regression	4	20.50319275	5.125798187	44.82628191	1.21737E-17
Residual	63	7.203927517	0.114348056		
Total	67	27.70712026			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 90.0%	Upper 90.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
exp(max(0,7-med))	0.004008258	0.000474141	8.453731019	5.75537E-12	0.003060763	0.004955752	0.003216726	0.004799789
Horiz_Align	0.121824069	0.024008429	5.074220714	3.68517E-06	0.073847051	0.169801086	0.081744344	0.161903794
Posted_Speed___100	-0.422716312	0.157526285	-2.68346526	0.009296652	-0.737507473	-0.107925151	-0.685691042	-0.159741583
ATP	-0.132445579	0.117602302	-1.126215865	0.264345967	-0.367455027	0.10256387	-0.328771123	0.063879966

LHS wire rope regression summary



Regression Statistics	
Multiple R	0.832923045
R Square	0.693760799
Adjusted R Square	0.646334964
Standard Error	0.859850954
Observations	37

ANOVA

	df	SS	MS	F	Significance F
Regression	3	56.94744525	18.98248175	25.67477442	9.32359E-09
Residual	34	25.13768452	0.739343662		
Total	37	82.08512976			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 90.0%	Upper 90.0%
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
ATP	-0.413236981	0.36519081	-1.131564567	0.265735789	-1.155394	0.328920038	-1.03074698	0.204273018
Offset_Test	2.004206684	0.367682653	5.450914442	4.45737E-06	1.256985631	2.751427737	1.382483168	2.625930201
Horizontal	0.176789811	0.050754964	3.48320235	0.001383305	0.073643313	0.279936308	0.090967011	0.262612611

Median W-beam regression summary (>40m)

Regression Statistics	
Multiple R	0.606606586
R Square	0.36797155
Adjusted R Square	0.328251253
Standard Error	0.314559029
Observations	60

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	3.283649398	1.094549799	11.06193787	8.32201E-06
Residual	57	5.640000809	0.098947383		
Total	60	8.923650207			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
length<400	-0.324391234	0.09695487	-3.345796169	0.001456558	-0.518540013	-0.130242455	-0.486502578	-0.16227989
AADT_1	5.29257E-06	2.66034E-06	1.989436787	0.051459119	-3.46607E-08	1.06198E-05	8.44412E-07	9.74073E-06
TerrainCode_1000m	0.235682071	0.070987867	3.320033152	0.001573693	0.09353132	0.377832822	0.116988307	0.354375835

Median W-beam regression summary **(≤40m)**

Regression Statistics	
Multiple R	0.309217198
R Square	0.095615276
Adjusted R Square	0.081329562
Standard Error	0.1344905
Observations	71

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	0.133861386	0.133861386	7.400688145	0.008243692
Residual	70	1.266138614	0.018087694		
Total	71	1.4			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
HorizontalAlignment	0.025742574	0.009462719	2.720420582	0.008217814	0.006869777	0.044615371	0.006869777	0.044615371

LHS W-beam regression summary (>40m)

Regression Statistics	
Multiple R	0.299844322
R Square	0.089906617
Adjusted R Square	0.084041397
Standard Error	0.153636078
Observations	640

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	1.48302762	0.370756905	15.70734652	2.89307E-12
Residual	636	15.01217225	0.023604044		
Total	640	16.49519987			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
HorizontalAlignment	0.009634797	0.003819705	2.522392698	0.011898843	0.002134038	0.017135556	0.002134038	0.017135556
TerrainCode_1000m	0.020541529	0.009039071	2.272526554	0.023387614	0.002791496	0.038291561	0.002791496	0.038291561
AADT	6.7226E-07	5.48413E-07	1.225827947	0.220717132	-4.04659E-07	1.74918E-06	-4.04659E-07	1.74918E-06
1/(PC Heavy)	-0.188381675	0.078735305	-2.392594722	0.017018885	-0.342994268	-0.033769081	-0.342994268	-0.033769081

LHS W-beam regression summary **(≤40m)**

Regression Statistics	
Multiple R	0.398190553
R Square	0.158555716
Adjusted R Square	0.156195145
Standard Error	0.300538878
Observations	1497

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	25.41076084	6.35269021	70.33254867	1.29215E-54
Residual	1493	134.8531606	0.090323617		
Total	1497	160.2639215			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 90.0%*	*Upper 90.0%*
Intercept	0	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A	#N/A
AADT	6.83189E-06	7.4888E-07	9.122812299	2.30123E-19	5.36292E-06	8.30086E-06	5.59933E-06	8.06445E-06
Length<400	-0.118285735	0.022802187	-5.187473268	2.42426E-07	-0.16301346	-0.07355801	-0.155815281	-0.080756188
TerrainCode_1000m	0.084156902	0.012745332	6.602958596	5.58638E-11	0.059156242	0.109157562	0.06317968	0.105134124
Horizont_1	0.010384913	0.005175779	2.006444528	0.044988895	0.000232343	0.020537484	0.001866229	0.018903598

Appendix C: Barrier strike cost prediction model user guide

C1 Introduction

This user guide describes the inputs, operation and outputs of the barrier strikes models. The model was developed by Abley Transportation Consultants as part of the research for this project.

The model allows users to assess the predicted number of nuisance strikes and total strikes, and resultant annual maintenance costs, for both left-hand side (LHS) and median wire rope barriers (WRBs).

The model is implemented within a macro-enabled Microsoft Excel Spreadsheet and accompanies the research report published online (www.nzta.govt.nz/resources/research/reports/580).

C2 Quick start guide

The spreadsheet is, by default, populated with some example values. To perform an assessment:

1 Enter relevant site/location information.

2 Select the barrier type for assessment by clicking on the cell and using the drop-down menu.

3 Enter the relevant inputs for the site by clicking on each cell in turn and selecting an option using the drop-down menu or typing. Inputs not required for the assessment will be blanked out.

4 Review the relevant outputs.

C3 Inputs

The barrier strike models were developed from barrier strike data, and are only valid for certain ranges of inputs, as described in the following sections. Each input is explained below.

2-way AADT

Average annual daily traffic (AADT) volume in both directions, vehicles per day.

Valid range: 1– 100,000 vehicles per day

Barrier length

Length of barrier in metres.

Valid range: 41 – 1,000 metres for LHS wire rope, median wire rope, LHS W-beam >40m and median W-beam > 40m models.

Valid range: 1 – 40 metres for LHS W-beam ≤40m model.

Average strike cost

Average cost of barrier strikes.

Valid range: 1 – 100,000 $/strike

Default value $2,700/strike for wire rope barriers, $2,000/strike for W-beam barriers

Horizontal alignment variable

Mode of horizontal alignment variable over the length of the barrier using the same classification as that used in KiwiRAP Analysis Tool. Possible values are as follows:

Value	Description
1	Straight
2	Easy curves
3	Easy-moderate curves
4	Moderate curves
5	Tight curves
6	Very tight curves

ATP road markings

Indicate if ATP road markings are present at the site adjacent to the barrier.

LHS barrier offset

Offset from centreline to LHS barrier in metres if a single lane road. If multilane then the appropriate measurement is from the right edge of the lane nearest to the LHS barrier in metres.

Valid range: 3.5 – 11 metres

Median width

Width of the median in metres.

Valid range: 1.5 – 10 metres

Posted speed <100km/h?

Indication if posted speed is less than 100km/h.

Terrain code

The terrain variable accessible directly from KAT data (mode across length of installation). possible values:

Value	Description
1	Level
2	Rolling
3	Mountainous

% Heavy vehicles traversing section

The percentage of traffic traversing the section where the barrier is installed classified as heavy vehicles.

Valid range: 1% – 30%

C4 Outputs

The following outputs are generated by the spreadsheet tool for all sites.

Annual VKT

Effective annual vehicle kilometres of travel (VKT) along the length of the barrier.

Strike rate per million VKT

Predicted strike rate per million VKT at the site.

Strike rate per annum

Predicted strike rate per annum at the site.

Maintenance cost per annum

Predicted maintenance cost per annum, product of annual strike rate and average strike cost.

C5 Extra notes

Note that nuisance strikes are only calculable for WRBs. The tool will not display any outputs under estimated nuisance strikes once a W-beam barrier type has been selected.

Users should take note that the two W-beam equations represent two different usage categories for W-beam. Those longer than 40m generally had a delineation function where as those smaller than 40m generally had a capping function for some other roadside feature (for example a bridge or concrete barrier) or in some cases protected road users from an isolated roadside hazard (for example a concrete pillar). For this reason, caution is advised when either of the following situations is true:

- The barrier has a delineation function and <= 40m models are used.
- The barrier has a capping function and >40m models are used.

W-beam sections exhibited different equation fits for small lengths of barrier. A value of 40m was chosen as the separation point for different equations as it fitted well for both median and LHS W-beam data.

Appendix D: Nuisance barrier strike locations and strike frequency

Figure D.1 Median wire rope data locations

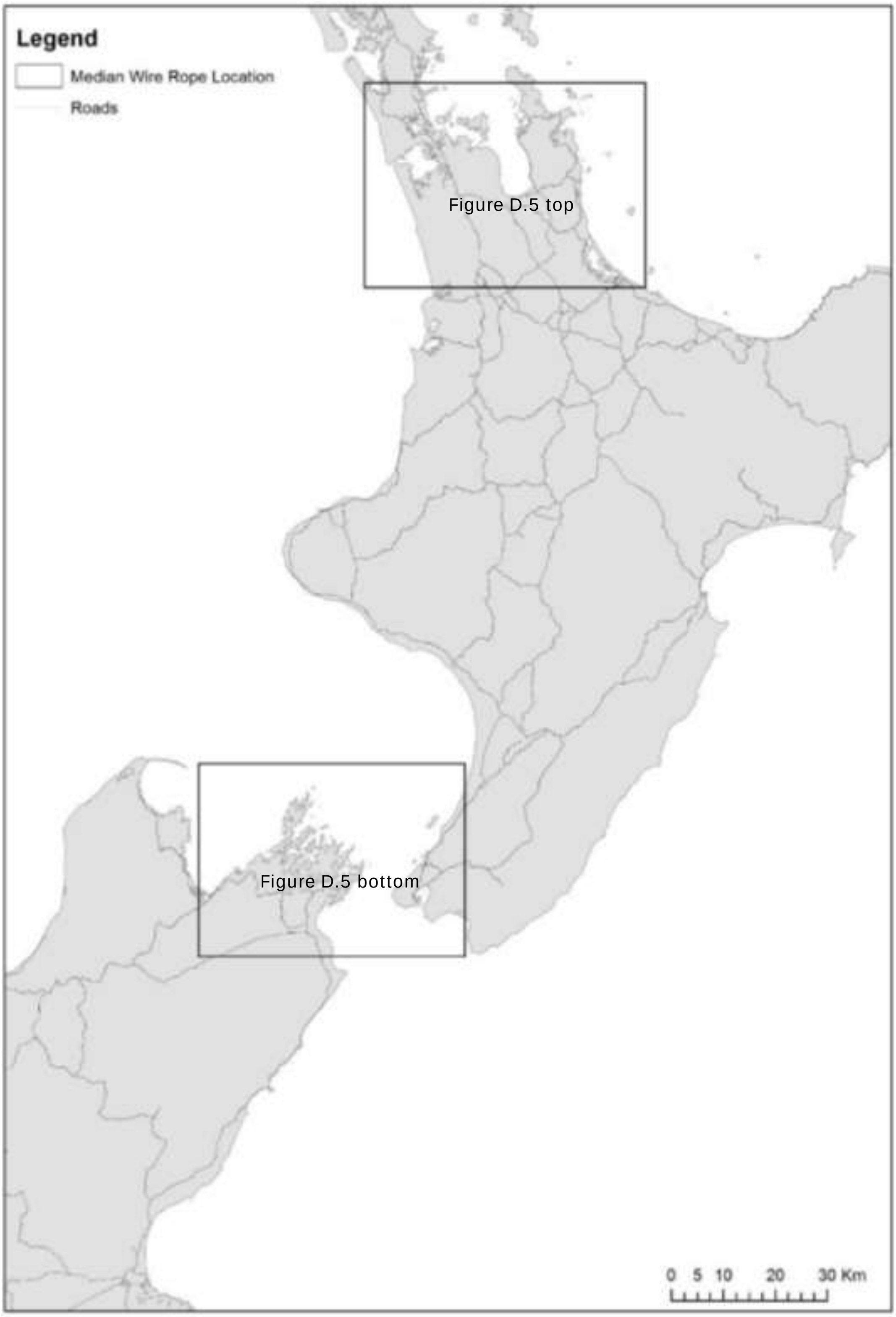


Figure D.2 Left-hand side wire rope data locations

Figure D.3 Median W-beam data locations

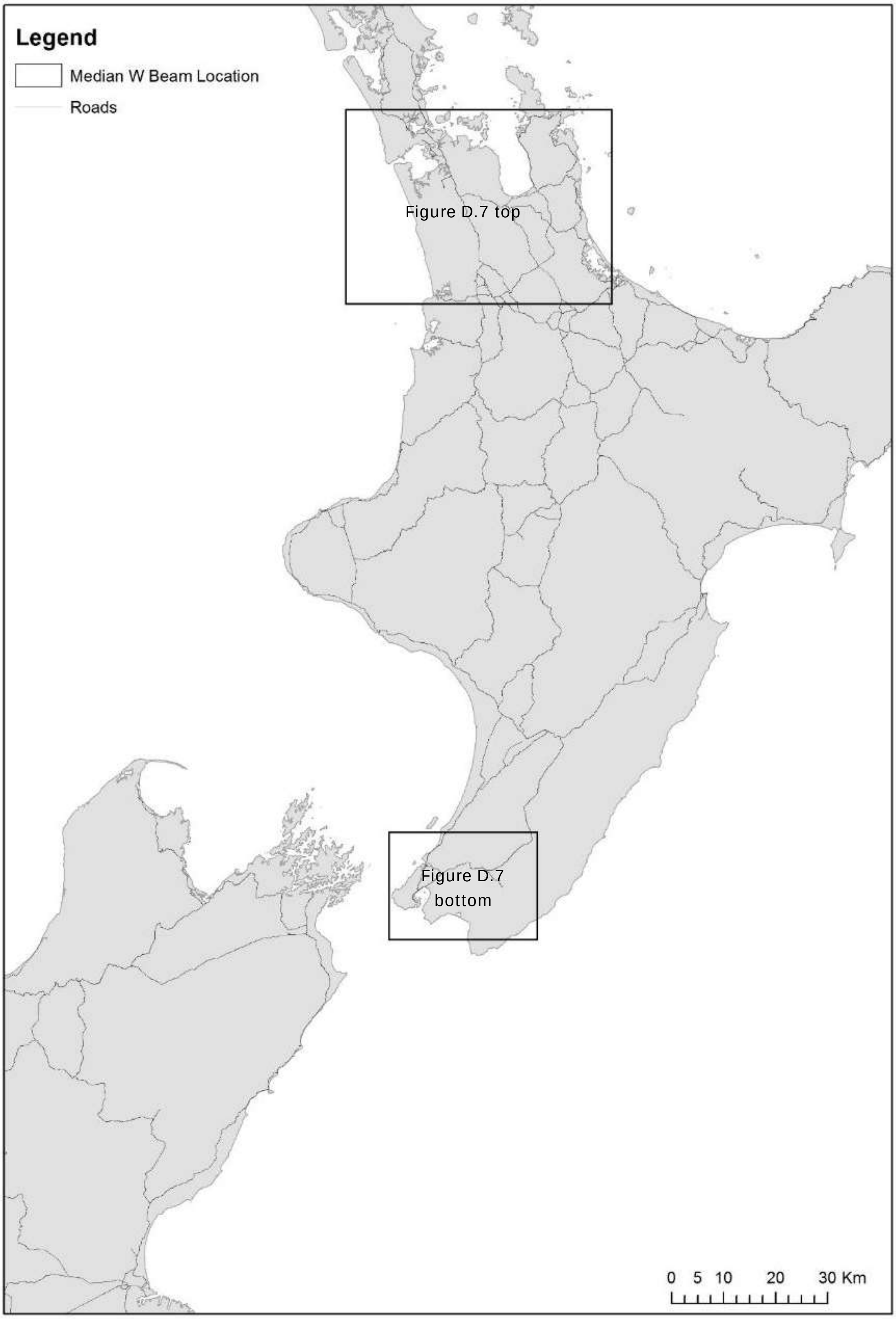


Figure D.4 Left-hand side W-beam data locations

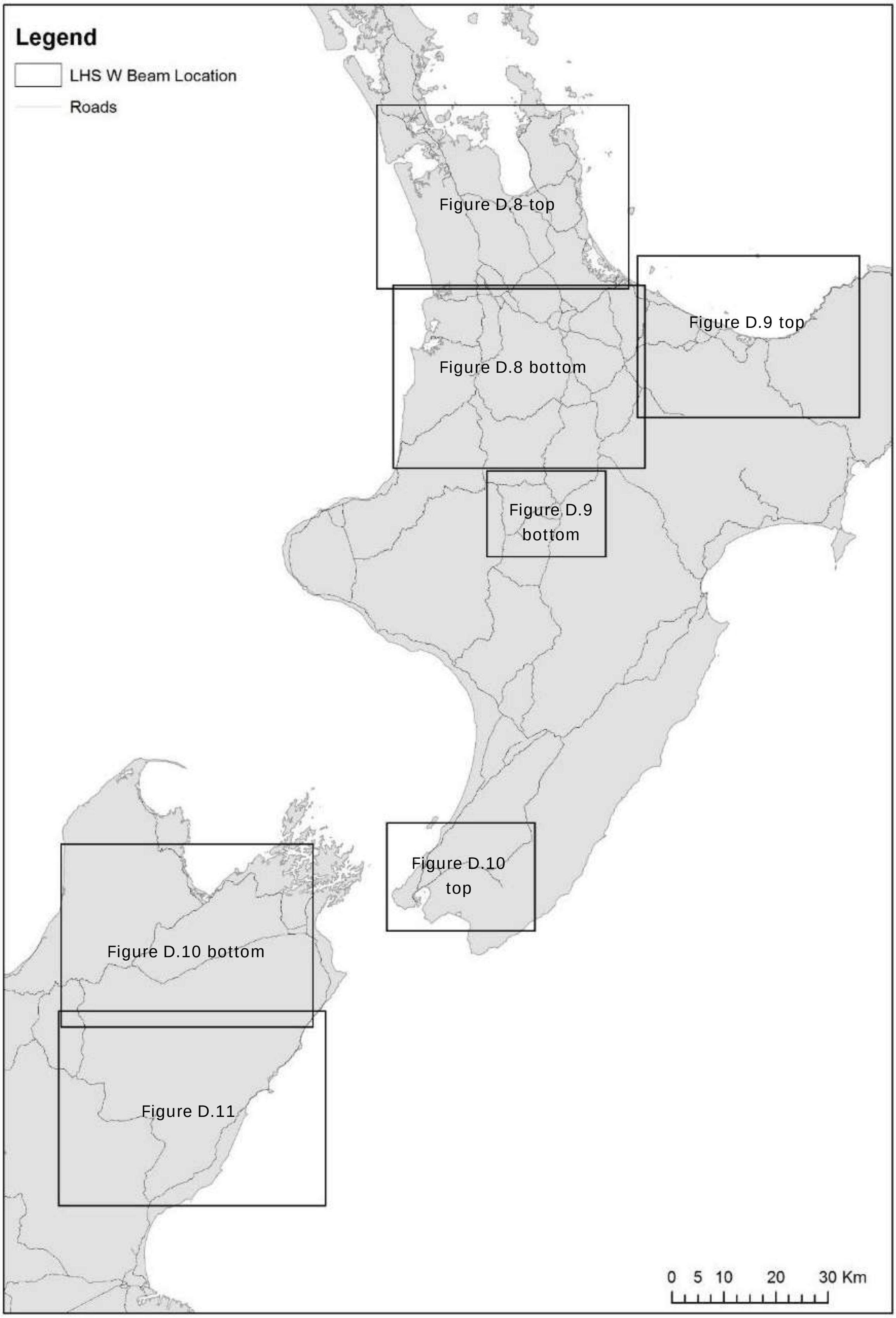


Figure D.5 Median wire rope barrier installations and nuisance strike locations

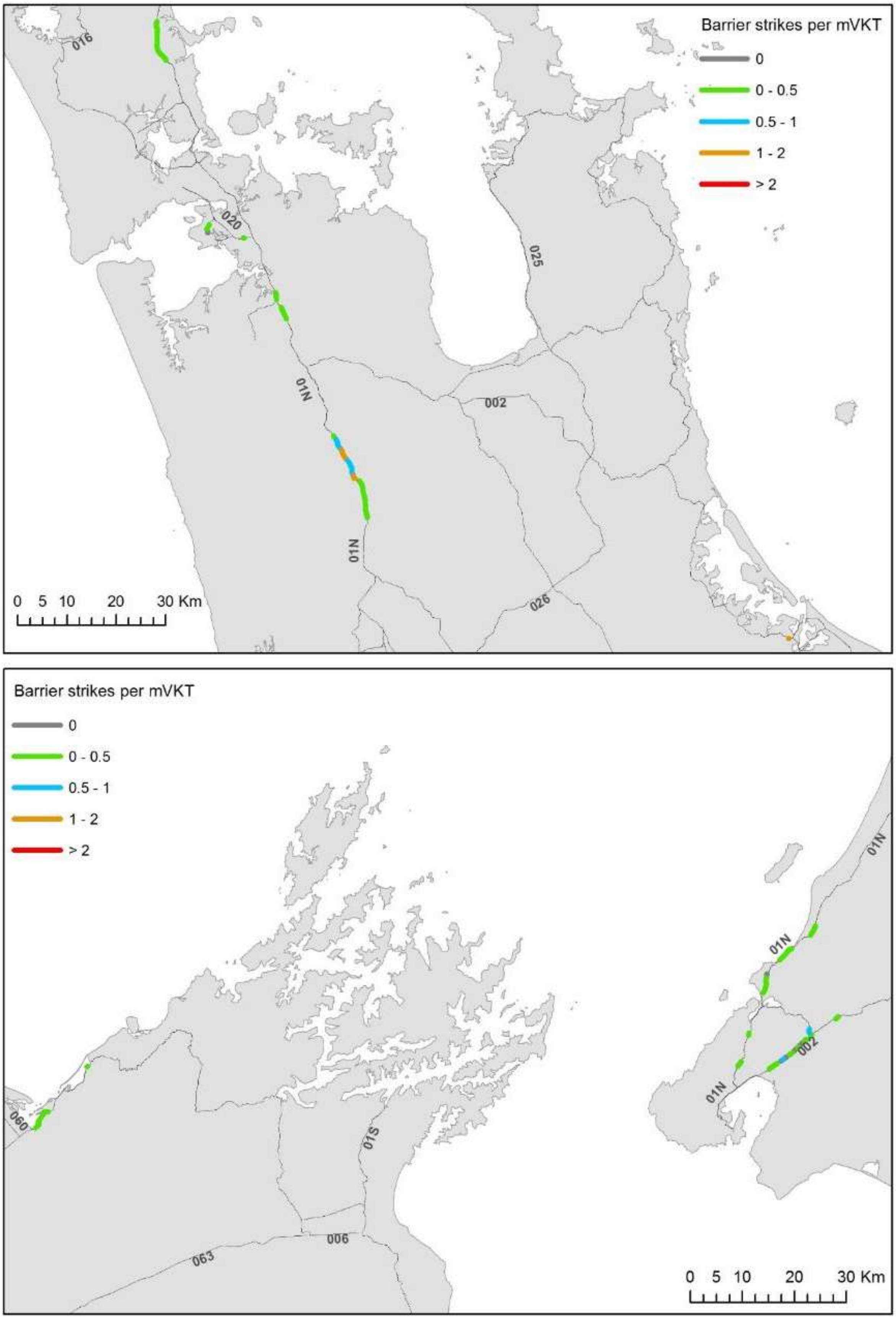


Figure D.6 Left-hand side wire rope barrier installations and nuisance strike locations

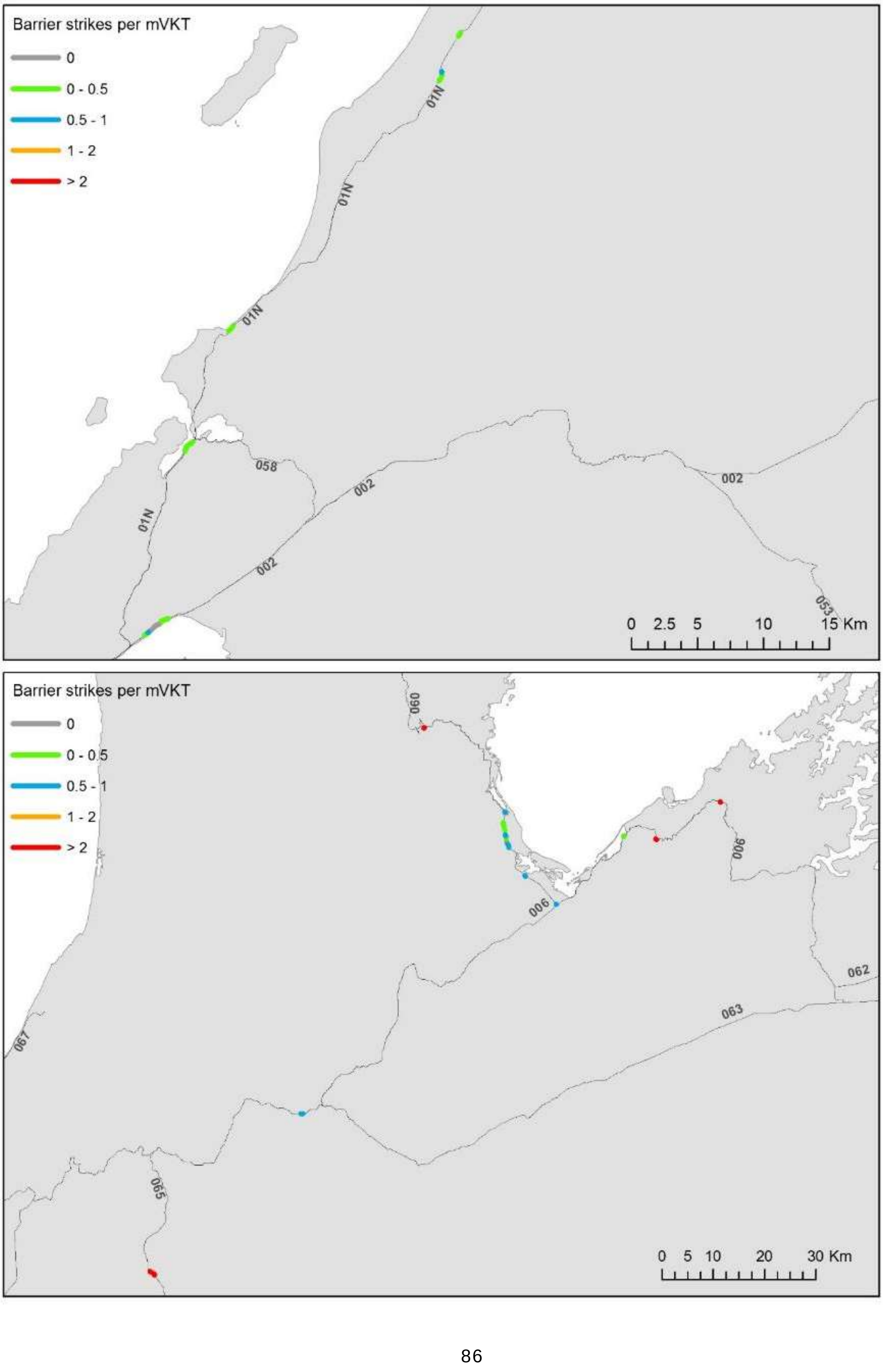


Figure D.7 Median W-beam barrier installations and nuisance strike locations

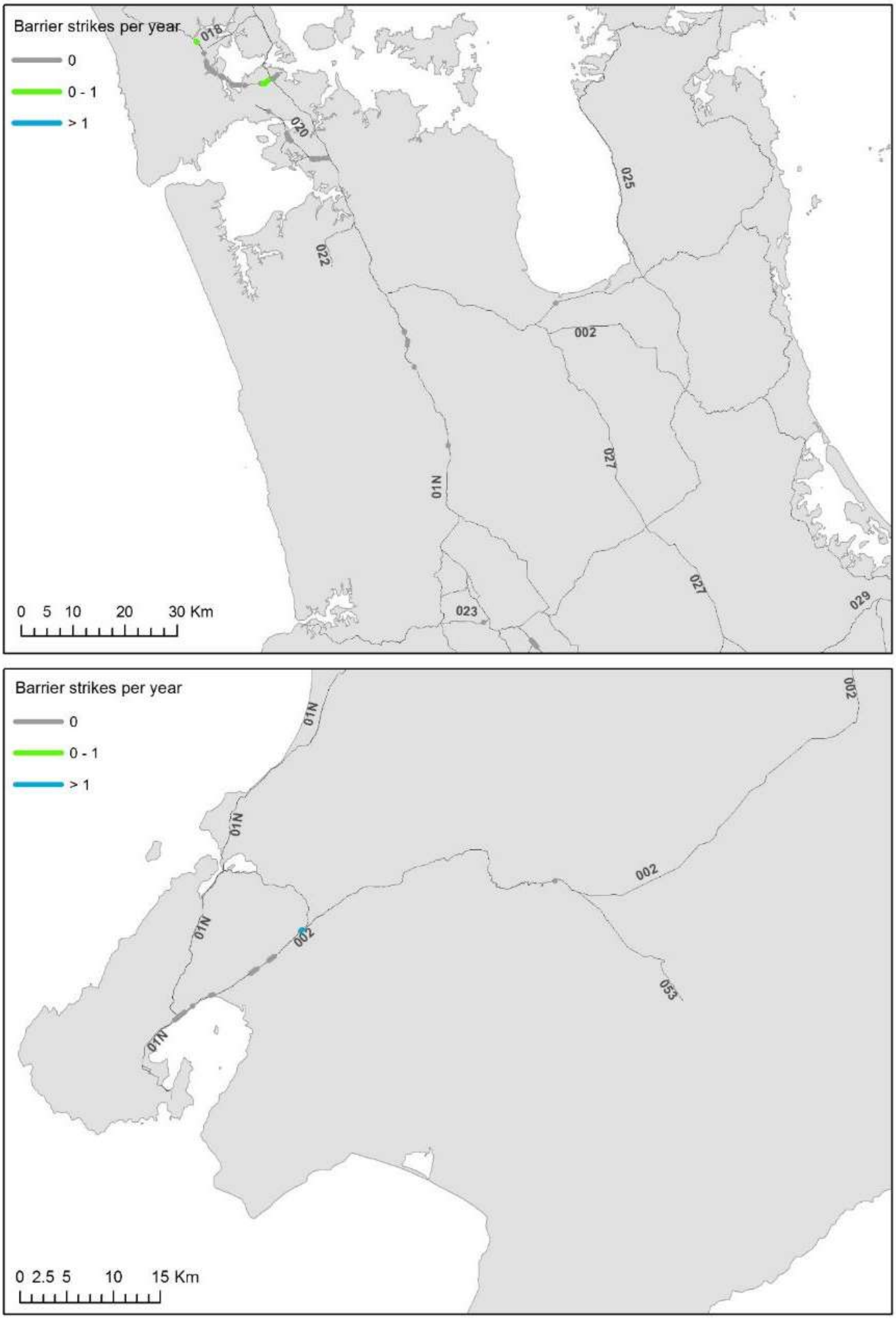


Figure D.8 Left-hand side W-beam barrier installations and nuisance strike locations – Upper North Island

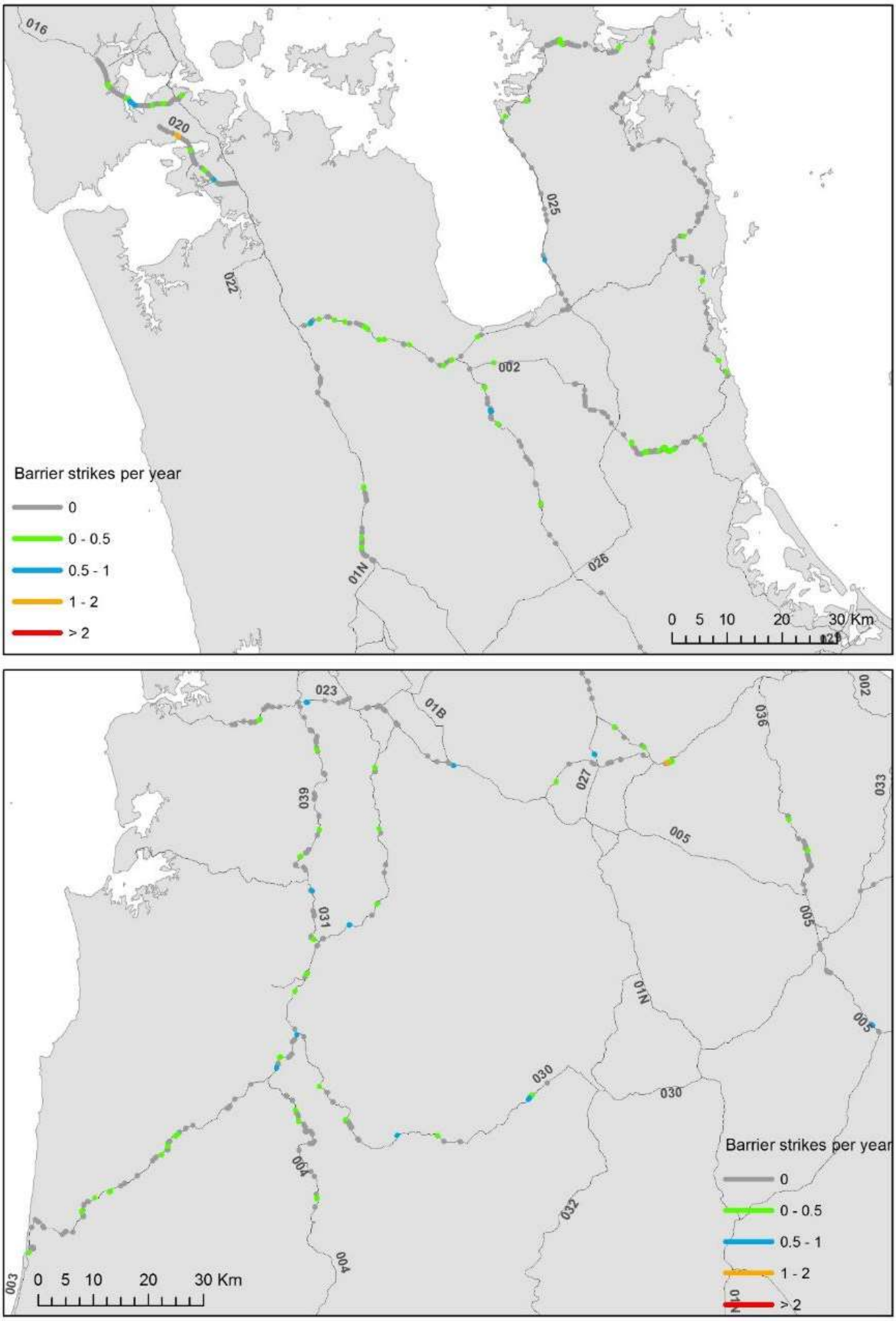


Figure D.9 Left-hand side W-beam barrier installations and nuisance strike locations – central North Island

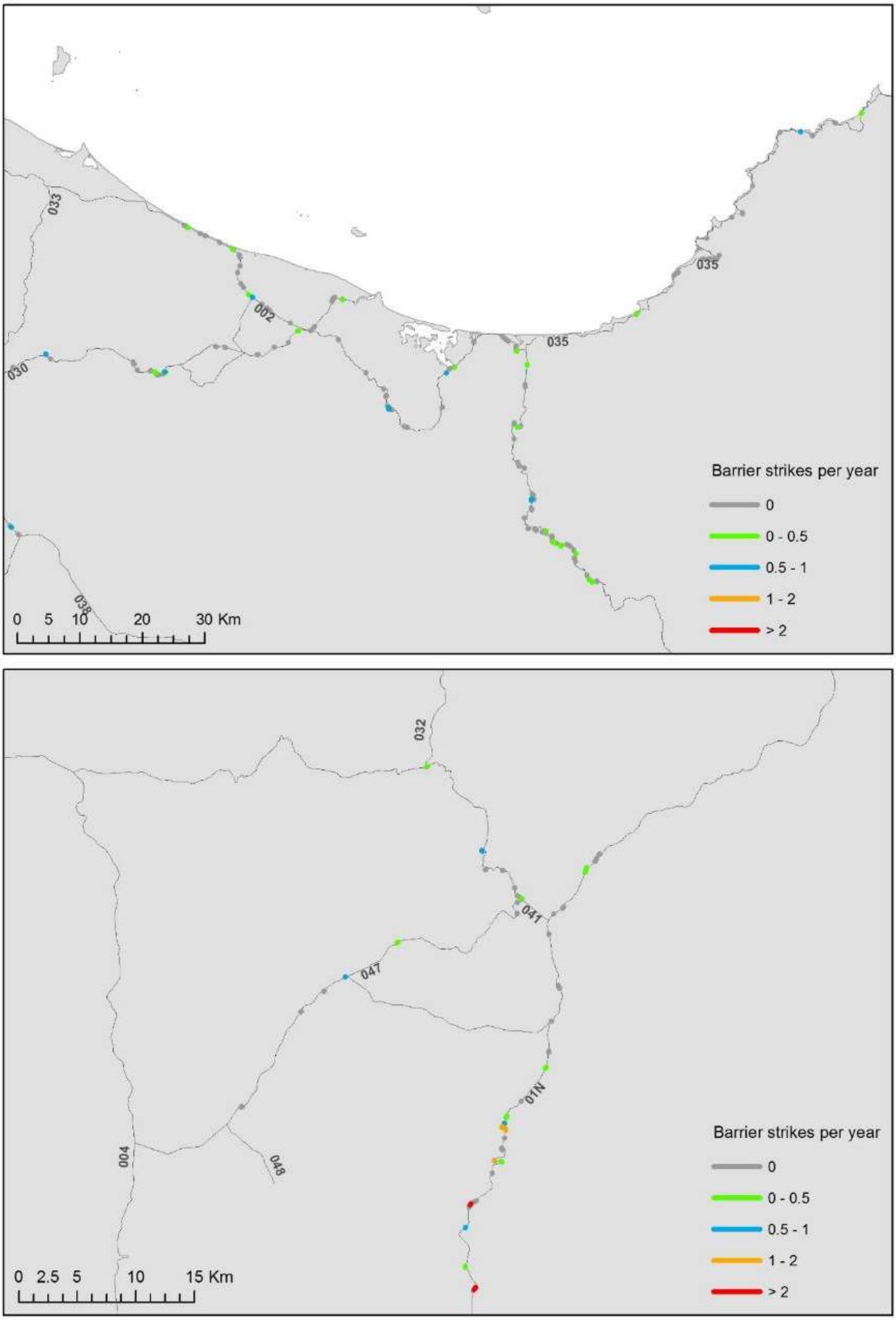
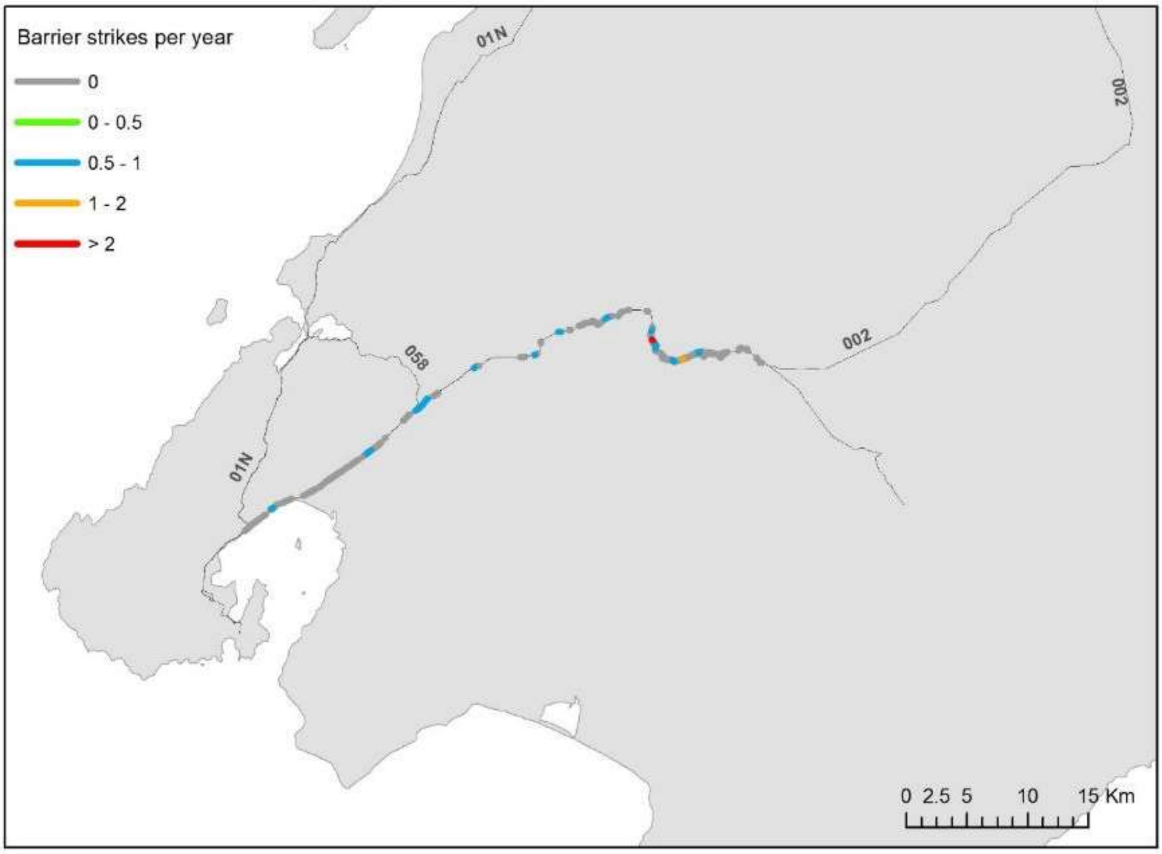


Figure D.10 Left-hand side W-beam barrier installations and nuisance strike locations – lower North Is/upper South Is



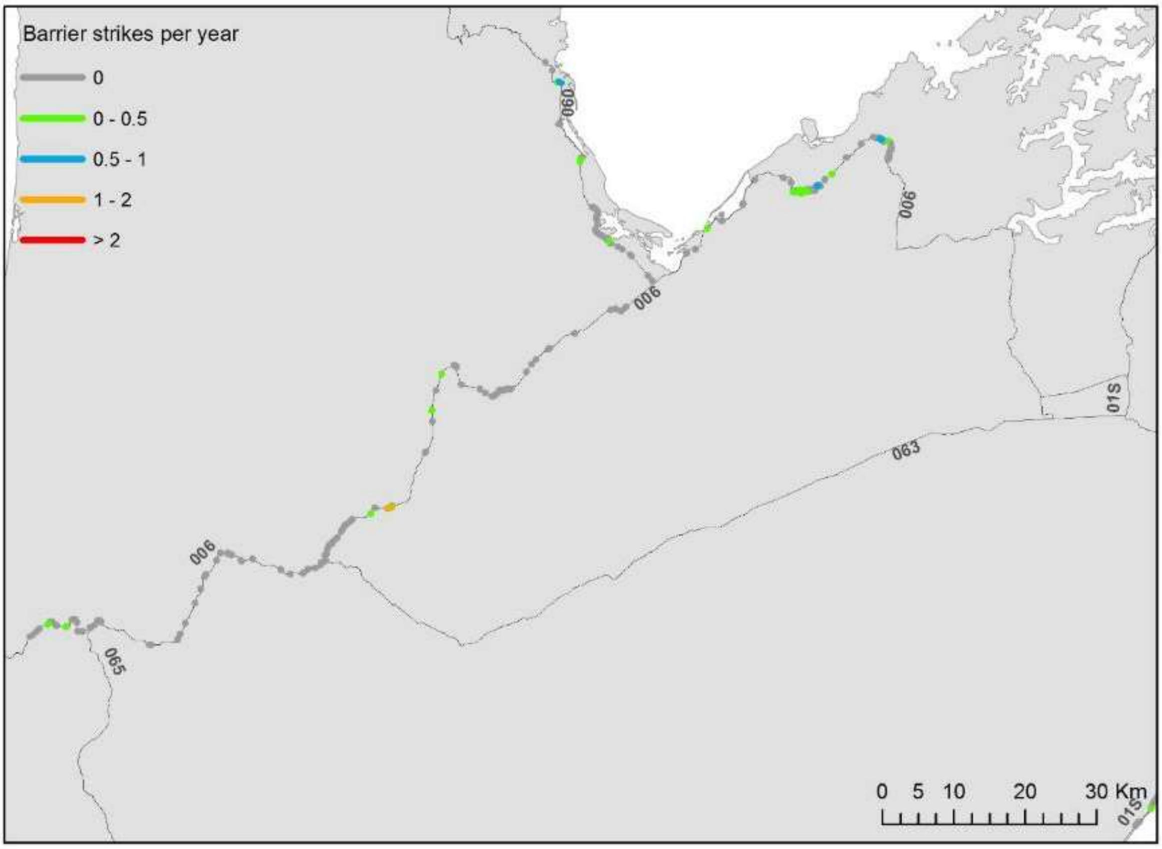
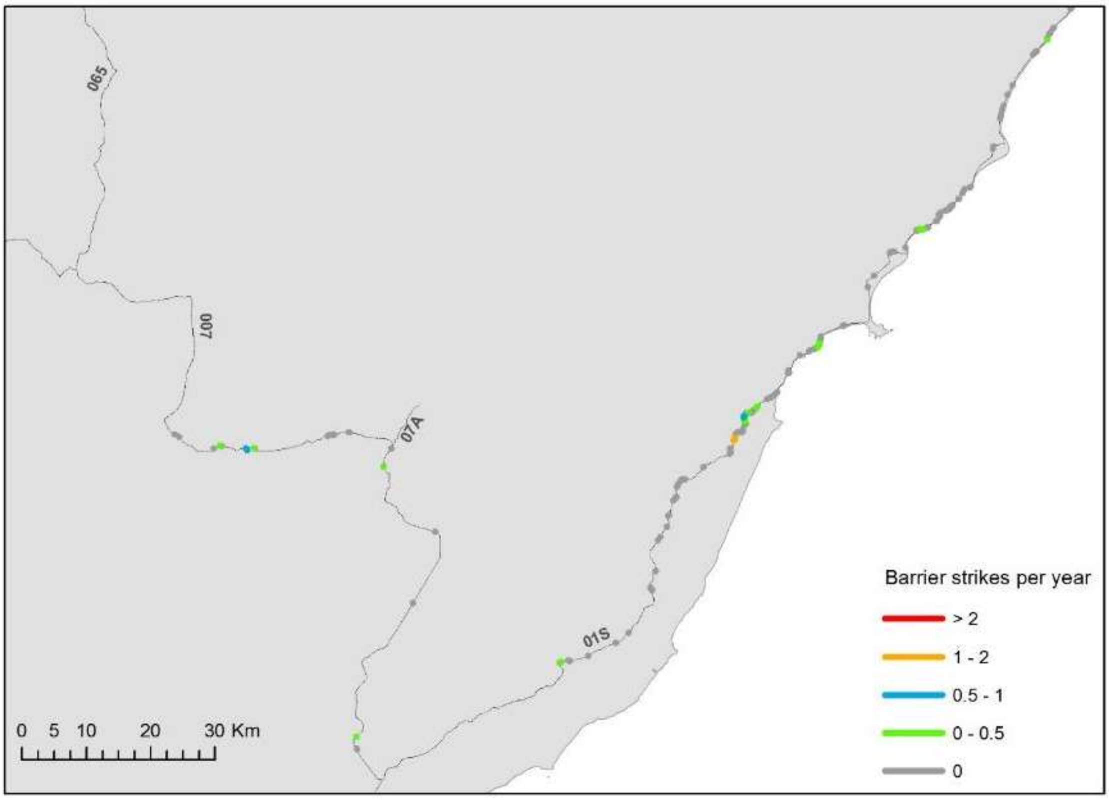


Figure D 11 Left-hand side W-beam barrier installations and nuisance strike locations – South Is – Kaikoura



Appendix E: All barrier strike locations and strike frequency

Figure E.1 Median wire rope data locations

Figure E.2 Left-hand side wire rope data locations

Figure E.3 Median W-beam data locations

Figure E.4 Left-hand side W-beam data locations

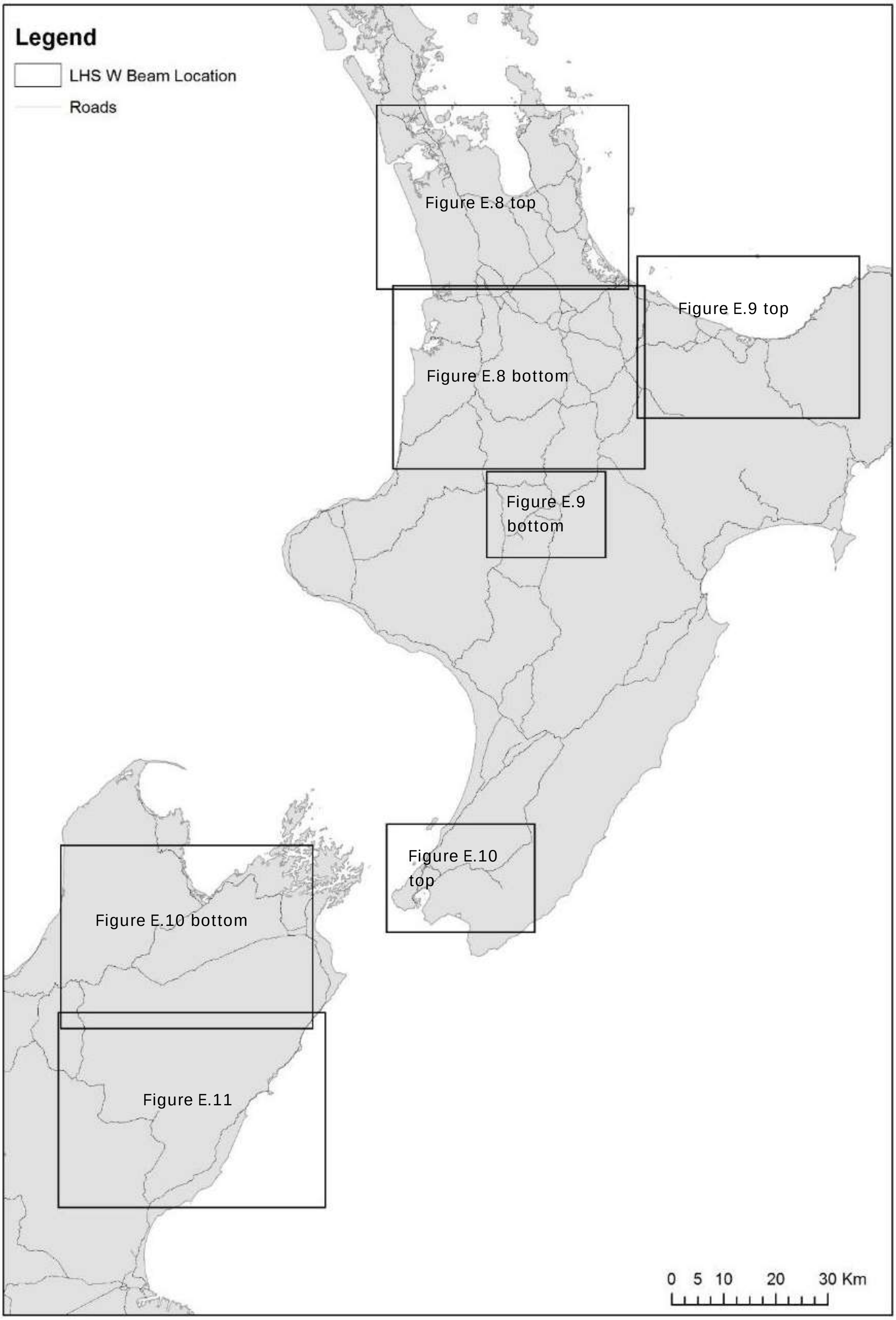


Figure E.5 Median wire rope barrier installations and all strike locations

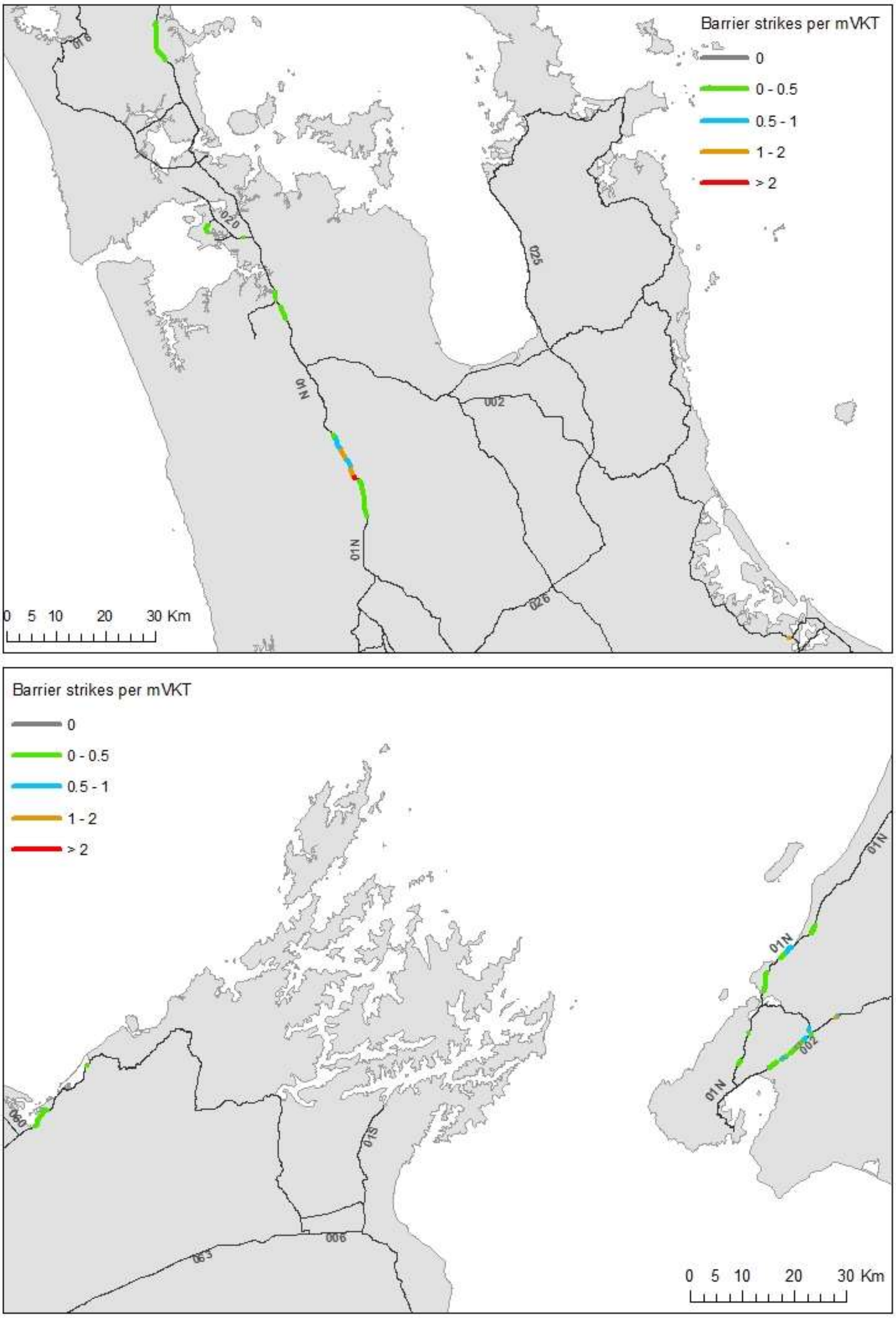


Figure E.6 Left-hand side wire rope barrier installations and all strike locations

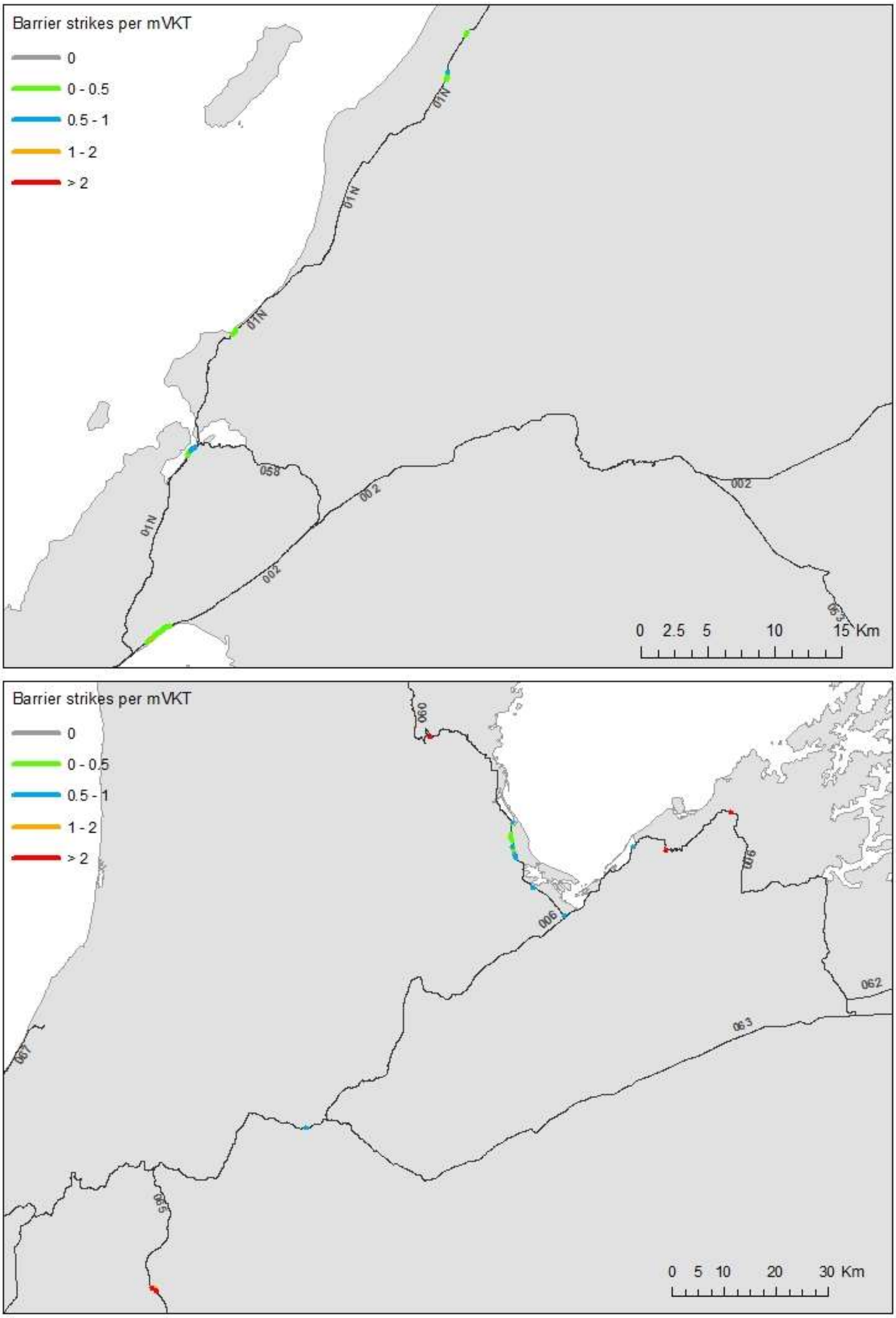


Figure E.7 Median W-beam barrier installations and all strike locations

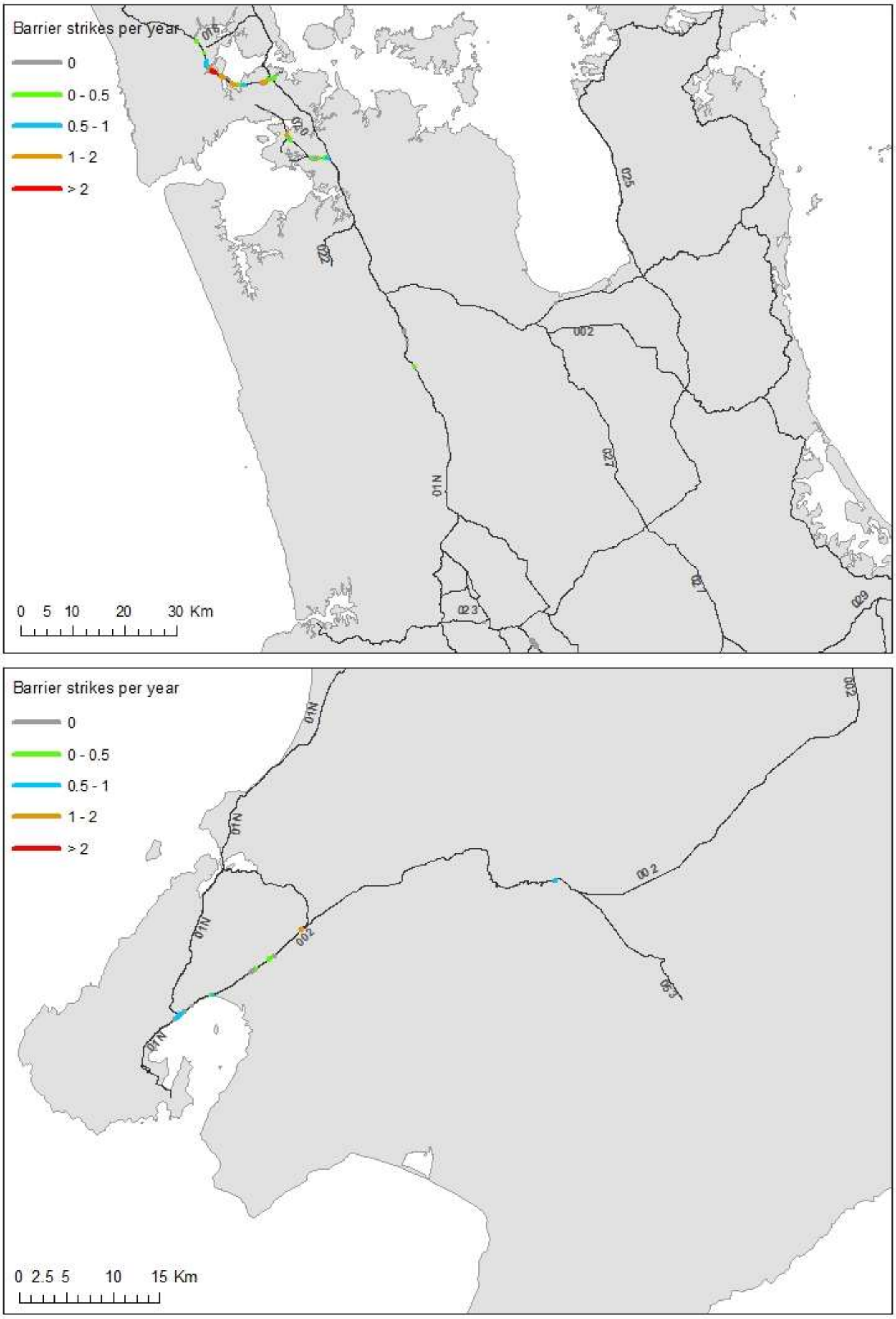


Figure E.8 Left-hand side W-beam barrier installations and all strike locations – upper North Island

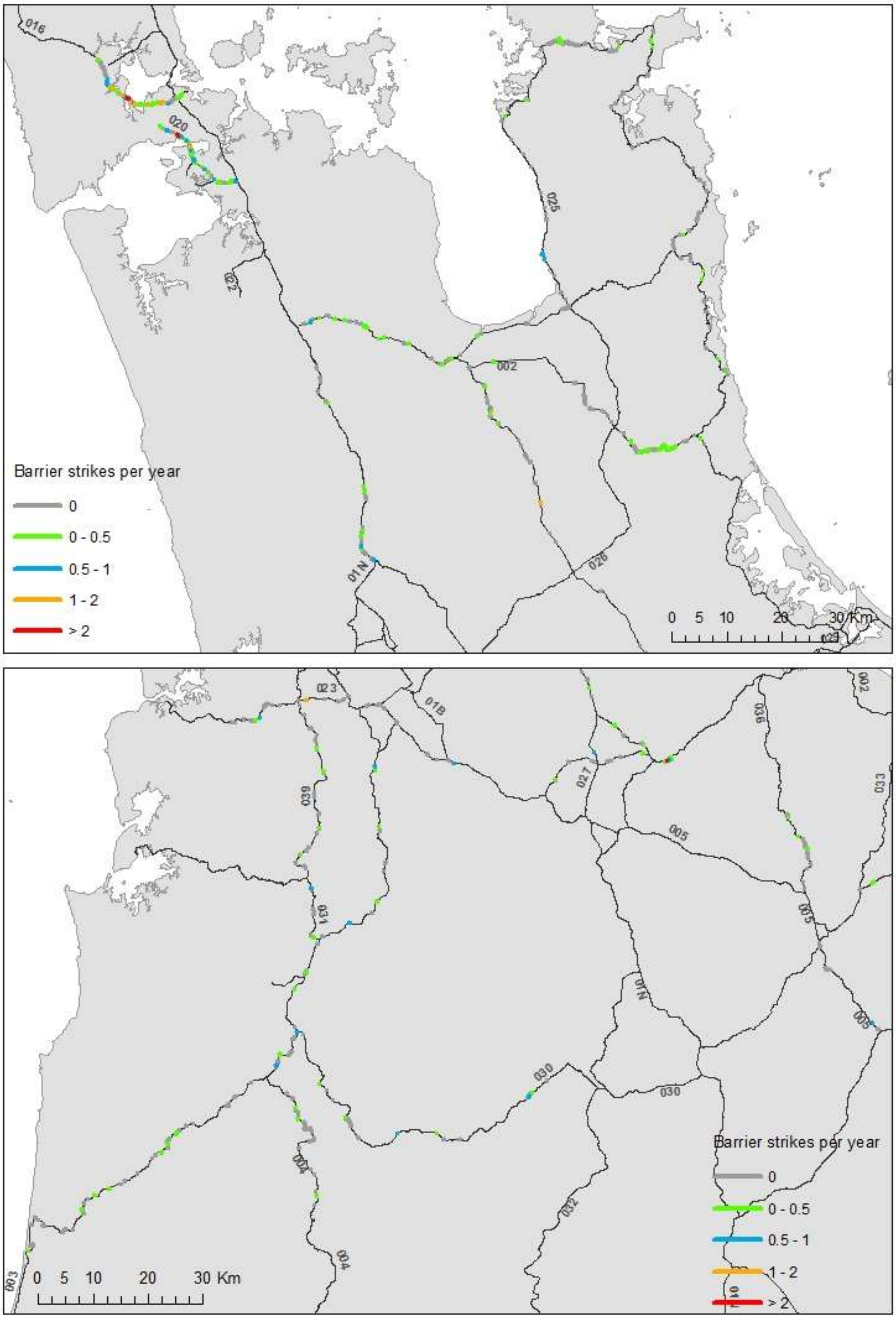


Figure E.9 Left-hand side W-beam barrier installations and all strike locations – central North Island

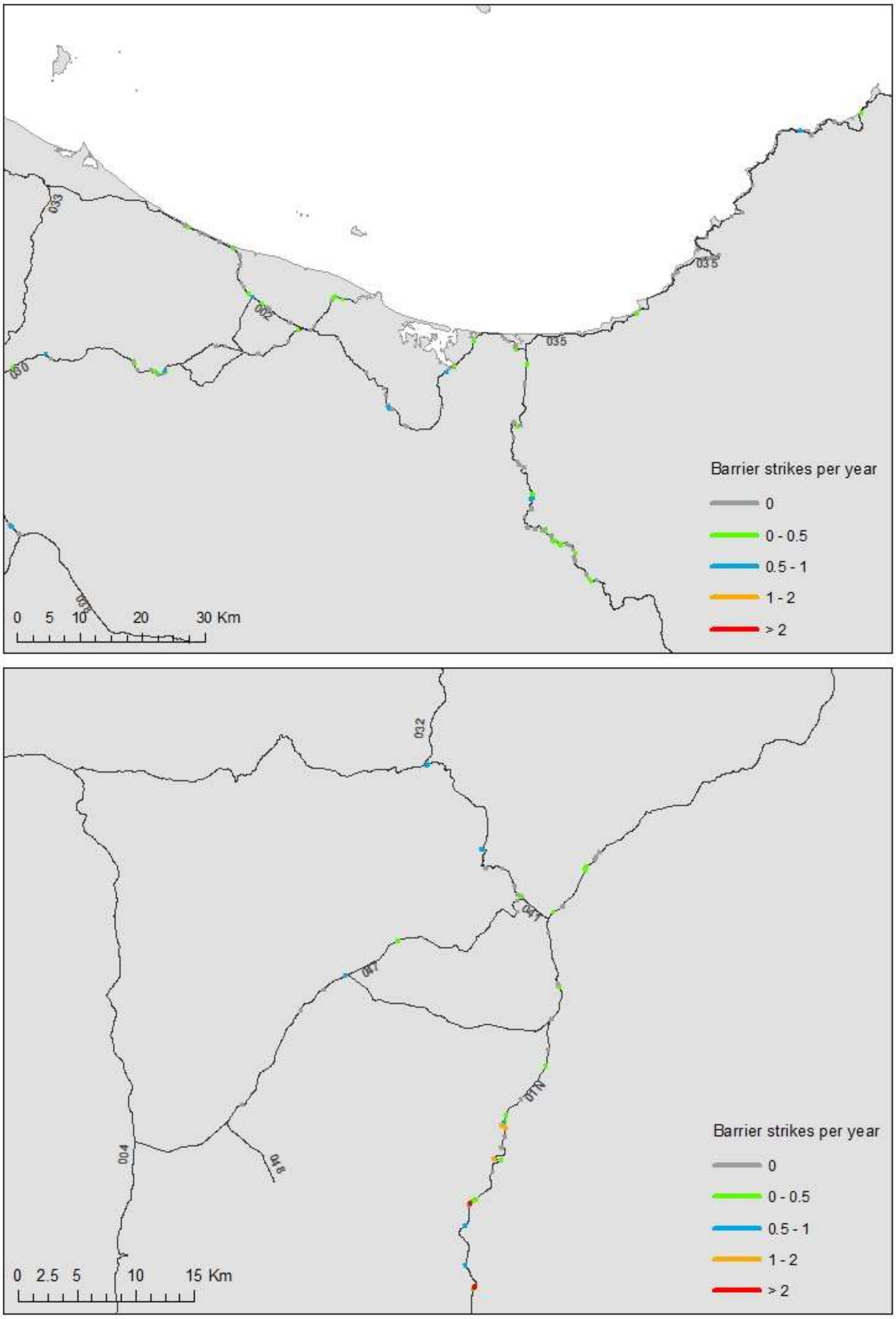
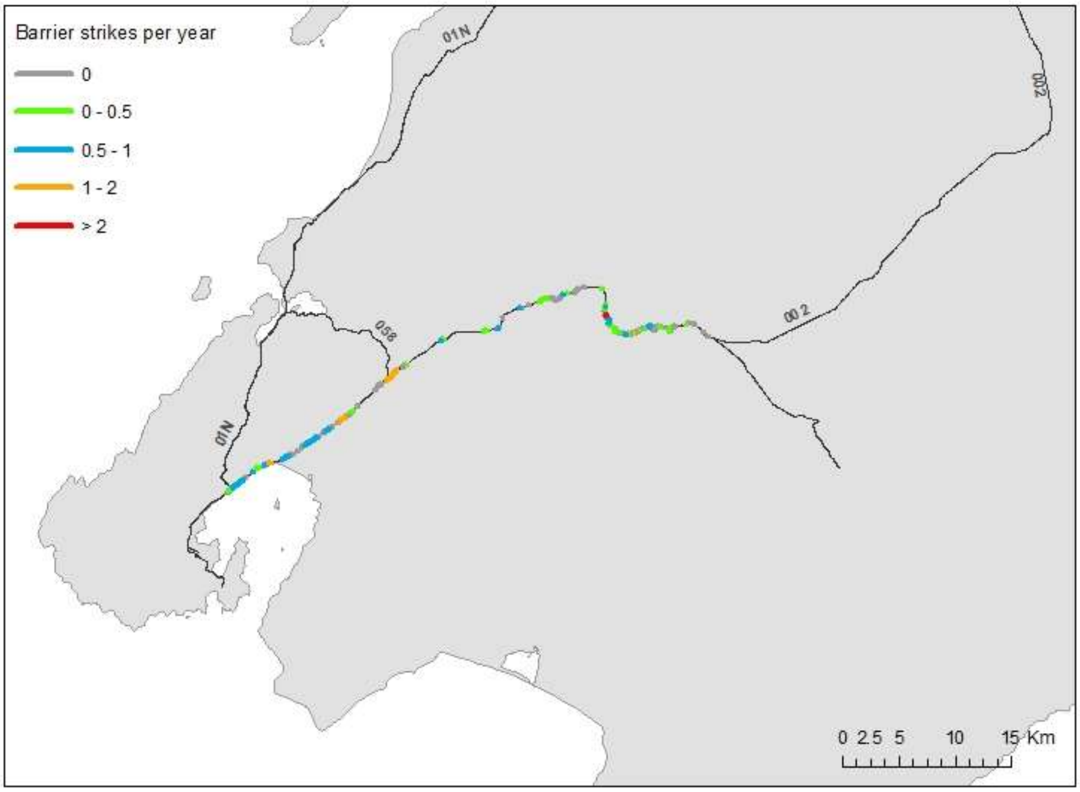


Figure E.10 Left-hand side W-beam barrier installations and all strike locations – lower North Is/upper South Is



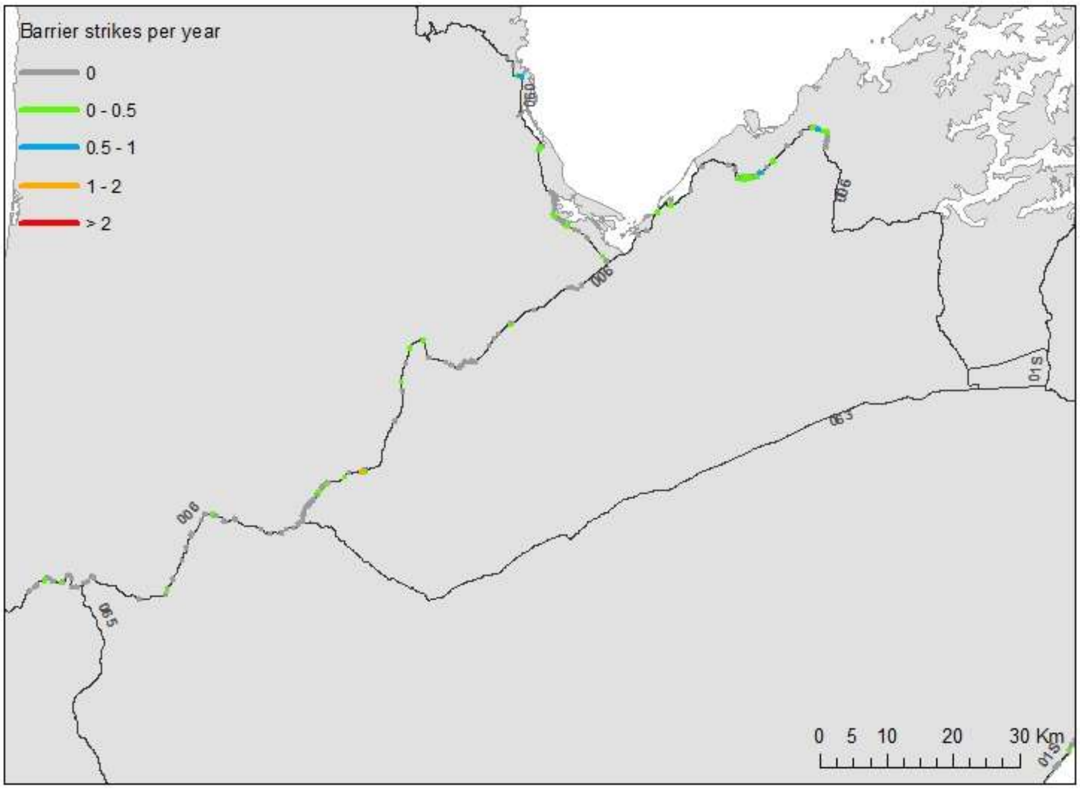


Figure E.11 Left-hand side W-beam barrier installations and all strike locations – South Is-– Kaikoura