THE N2 COLLAPSE AT BOT RIVER: REGIONAL IMPACT ON TRAFFIC PATTERNS AND LESSONS LEARNT FOR RESILIENCE

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ABSTRACT

Unprecedented rainfall in 2023 in the Western Cape led to numerous severe flooding events. Heritage Day (24 September 2023) saw a cut-off low system hit the southern regions of the Western Cape, with particularly heavy rain over the Overberg District along the southern coast. A section of the N2 between Caledon and Grabouw, 90 km from Cape Town, was washed away by the Bot River causing significant disruption to long weekend traffic and of course longer-term impact on traffic using this important national route. The road re-opened on 31 October 2023, 36 days after the flooding incident. This paper aims to evaluate the traffic impact caused by the worst flooding event seen in recent years in the Western Cape, provide an historical record of the response by SANRAL to get vehicles back on the N2, and consider lessons learnt for emergency response road construction, considering resource procurement. This paper will evaluate the traffic impact of the full closure of the N2, considering the impact of traffic redistribution to alternative routes as far away as the N1. Floating Car Data are used as the primary source of data in a unique application of this widespread data.

1. INTRODUCTION

Two major flooding events occurred in the Western Cape in 2023; one flood early in June, and a second, more widespread flood over the Heritage Day long weekend late in September. Heavy rainfall started on Sunday 24 September and continued through the public holiday of Monday 25 September. The impact of the flood was felt around the Western Cape, with the Overberg District particularly hard hit. Approximately 80 roads were closed and passenger rail services were cancelled. By 27 September, 11 people had lost their lives in the flooding and thousands had to be evacuated from their homes (Maseko & Muia, 2023).

The Bot River burst its banks on the morning of 25 September and washed away a 70 m long section of the N2 between Caledon and Grabouw, 90 km from Cape Town. The photograph presented in Figure 1, taken in early October 2023, shows the significant infrastructure destruction. The road adjacent to the bridge was completely washed away. Damage to the bridge structure itself was minimal. The timing of the flood had severe impacts on long weekend traffic, essentially trapping holiday makers trying to head home after the long weekend. There were accounts of queues 20 km long, and TimesLIVE reported that there were no safely passable routes into or out of Cape Town on Monday 25 September 2023 (TimesLIVE, 2023).

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Figure 1: Damage to the N2 at Bot River (photo courtesy of Independent Media)

Repairs to the section of road destroyed in the flood started with rechannelling the river back to its original contours. Rockfill was already laid in the second week of October 2023 (Paarl Post, 2023) only two weeks after the flood. Repair to the road required the infill of the embankment of the Bot River adjacent to the bridge, reinstatement of pavement layer works, road surfacing, and the reinstatement of guardrails and lane markings.

The N2 was reopened to traffic on Tuesday 31 October 2023 (Greyton Today, 2023), a mere 36 days after the road segment was washed away. The extensive repairs to the road are evident from Figure 2 below, with the left photograph showing the replaced infill adjacent to the bridge and the Bot River returned to its original course, and the right image showing the new pavement surfacing and guardrails.

Figure 2: N2 Repair at Bot River (authors own photographs)

This paper aims to report on the traffic impact of the road closures in the immediate aftermath of the severe September 2023 flooding event, and the impact of the N2 closure in the month after the flood. Floating Car Data (FCD) are used as the primary source of data in a unique application of this widespread data. The following sections present literature on flood impact appraisal, indicating that FCD has not been used for this purpose before. Data, study area and analysis methods are then presented and results of traffic pattern changes described. The paper is concluded with a discussion on lessons that can be learnt for emergency response road construction, particularly regarding resource procurement.

2. APPRAISAL OF FLOOD IMPACT ON TRANSPORT SYSTEMS

Floods cause both direct and indirect effects on transportation systems (Rebally et al., 2021). Direct flooding effects result from contact between infrastructure and flood waters, for example physical damage to infrastructure. Indirect effects are felt beyond the geographical limits of the flood, such as traffic congestion experienced on routes well away from the flooded area because of vehicles that are forced to reroute away from flooded areas (Pyatkova et al., 2019) (Rebally et al., 2021). Indirect effects of flooding may be significant and long lasting and are quantified according to the extent of disruption (both spatially and over time) to transportation (Shahdani et al., 2022).

The effects of floods are further classified temporally according to short-, medium-, and long-term impacts (Rebally et al., 2021). Short-term impacts are felt during a flooding event up to approximately two weeks after the flood. Short-term impacts are associated with emergency response, haphazard redistribution of traffic, and mopping up efforts. The impact of the flood on traffic movement may persist long after flood waters have receded (Pyatkova et al., 2019). Medium-term impacts are defined to last from 2 weeks post-flood to about 6 months after the flooding event (Rebally et al., 2021), and are typically associated with traffic disruptions caused by infrastructure repair. These disruptions often result in the extension of travel time and significantly longer travel distances (Shahdani et al., 2022). Long term effects extend for longer than 6 months and could include changes to transport infrastructure, land-use and long-term planning to mitigate future flooding (Rebally et al., 2021).

Previous research to evaluate the effect of flooding on transport networks have extensively used complex modelling approaches. Probabilistic empirical modelling using observed data, such as satellite imagery during flooding, has been used to create flood maps and predict traffic redistribution (Rebally et al., 2021). Pyatkova et al. (2019) integrated dynamic flood models with traffic models to map the movement and depth of flood waters and observe traffic pattern changes as a result. Shahdani et al. (2022) applied a dynamic mesoscopic model which allowed investigation of changing flood water movements over time, improving on static models where the advancing flood could not be modelled.

Traffic models describing traffic during flooding events need to take into account how driver behaviour is impacted during flooding. Pyatkova et al. (2019) and Shahdani et al. (2022) applied a method to reduce the speed of vehicles on roads according to the flood water depth. Lu et al. (2020) considered how traffic movement is impacted by inclement weather such as slower driving speeds, increased propensity for traffic crashes, and the reduction of roadway capacity during heavy rainfall. These investigations, however, account for behaviour changes during flooding on a relatively basic level, and do not consider the social response of humans during a disaster (Yang et al., 2020). Shahdani et al. (2022) indicated that their model was calibrated using traffic data of a typical day, as no traffic data was available during the flooding event. They assumed that people would not change their travel behaviour or mode of travel during a flooding event. This is, of course, unlikely to be true. Panic, changes in mode choice during evacuation, and difficulties faced during emergency situations, are often overlooked (Rebally et al., 2021).

Lu et al. (2020) stated that it is impossible to properly evaluate the behaviour of drivers during a flood without observation of actual human response because of the complex emotional reaction of people when faced with an unexpected disaster. In order to investigate the actual response during a flood event, Yang et al. (2020) made use of georeferenced social media data to track flood water movement and impact. The data was able to evaluate "public emotional information" (Yang et al., 2020) because assessed the level of emotive response from public postings through social media. The degree of a disaster can be evaluated from this emotional information by assessing the level of panic and number of posts (Yang et al., 2020) and can also be related to the physical location of the people making the posts. This data would shed light on the behaviour of people during an emergency event, which if linked to traffic models, would indicate the geographic and transportation impact of a flood.

This paper considers the use of a different source of socially provided data: floating car data (FCD). FCD are an alternative traffic data source reporting on vehicular movement from sensors carried in vehicles within the traffic stream. The sensors (or probes), including smartphones, built-in navigation devices and logistics tracking devices (Verendel & Yeh, 2019), report GPS-based vehicular position over time, providing speed, number of probes, and route selection data. This data can be considered to be socially provided because it is generated by the general population when using navigation apps or tracking devices.

It is anticipated that FCD observed during a significant event such as a flood will highlight variations in travel patterns when compared to typical traffic movements. This paper represents the first time that traffic patterns disrupted by flooding have been investigated using FCD in South Africa, and possibly other countries as well. No evidence of previous studies have been encountered by the authors that specifically used FCD to track flood impacted traffic movements.

3. DATA COLLECTION

3.1 Traffic Data

Investigation of changes to traffic movement patterns during flood events requires analysis of traffic patterns before the flood (to gain a baseline indication of traffic movement), during the flooding event, and on days following the flood to evaluate longer term impact (Shahdani et al., 2022). Traffic information was evaluated for the period before the flood, the two days of actual flooding (25 and 26 September 2023), two weeks after the flood (to evaluate traffic during disruption caused by roadworks) and the period after the N2 was reopened in November 2023. Because the flooding event occurred on a Monday and Tuesday, the Average Daily Traffic (ADT)for Monday and Tuesday were evaluated for each period. The analysis periods are described in Table 1 below. ADT was evaluated over four days (except during the flood event).

Table 1: Analysis periods

Period	Pre-flood	Flood Event	Repair	Post-repair
Date Range	11-12 Sept 18-19 Sept	25-26 Sept	9-10 Oct 16-17 Oct	6-7 Nov 13-14 Nov

Two sources of traffic data were evaluated to assess the impact of the September 2023 flood on traffic movement: 1) FCD providing number of probes and routing information, and 2) traffic volume information obtained from permanent count stations on primary Western Cape roads.

The FCD were obtained from TomTom, a global provider of commercial FCD and maps. Commercial FCD are a source of FCD that are collected and processed to structured, readily accessible formats by numerous third-party traffic data providers (Verendel & Yeh, 2019), including, for example, TomTom, INRIX, HERE, and Google, making this FCD widely available for use by transport engineers and roads planning authorities. FCD were collected using the TomTom Move portal (move.tomtom.com) through a partnership between the Stellenbosch Smart Mobility Lab at Stellenbosch University and TomTom. The portal provides users with the option to select the area of analysis, the date range, and times of the day for data collection. FCD are aggregated according to these times and dates to ensure that personal information of the probes logging the data are removed, providing typical travel patterns.

Traffic volume data was collected from ten SANRAL operated permanent traffic count stations around the Cape area for the months of August to November 2023, from which ADT was extracted for each analysis period. The count stations cover a number of major routes in the study area, including the N1 and N2, as well as a few lower order regional distributor roads. The location of count stations is described in the following section detailing the study area.

3.2 Study Area

The study area comprised an area of just over 18 000 km^2 indicated as the shaded zone in Figure 3. The study area included the N1 from Touwsrivier and N2 from Swellendam to the urban edge of the City of Cape Town. The N2 road closure at Bot River is indicated on the map with the road closure sign. The permanent count station locations are indicated with numbered black pins. Care was taken to ensure that the study area encompassed routes that would have served as alternative routes to the N2 when impassable at Bot River. Not all road classes were evaluated in the collected TomTom FCD. Only higher order arterial roads, including national and regional distributer roads were included in the data.

3.3 Data Analysis

FCD was used to assess road closures and movement patterns during the four analysis periods. FCD provides detail of where vehicles are travelling FCD because it details the trajectory of a sample of vehicles. FCD therefore allows traffic practitioners to monitor the routes that the vehicle population are using at any one time. Because FCD indicate *where* vehicles are moving, FCD are an excellent data source to determine where vehicles are *unable* to move, for example at road closures. The structure of FCD also makes it possible to evaluate the proportion of trips making use of different routes through an origin – destination analysis. This OD data allows investigation of the route decision making of the driver population between specific origins and destinations. FCD analysis was conducted geographically using the GIS-type interface available through the TomTom Move portal (move.tomtom.co.za).

Traffic volume information from the permanent count stations was analysed in MS Excel. Traffic data, in the form of hourly volumes for the months August to November 2023, were provided by SANRAL through their data partner Mikros. ADT was calculated for the four analysis periods described in Table 1. The change in ADT as a percentage of ADT reported during the *Pre-flood* time interval was calculated for each of the other three periods and described in graphs.

Figure 3: Study area (Map data from OpenStreetMap through TomTom Move)

4. REGIONAL TRAFFIC IMPACT

4.1 Road Closures

Average speeds reported by TomTom FCD for the midday period on 25 and 26 September 2023 are presented for the Cape region in Figure 4, indicating widespread road segments with no traffic (grey segments), mostly due to road closures as a result of flooding. Significant road closures occurred on the N2 at Bot River (1), R44 Clarence Drive (2), the R321 north of Grabouw (3), the R45 Franschhoek Pass (4), the N1 at De Doorns (5), the R406 (6) and Helderstroom Road (7) to Greyton, and numerous roads south of the N2 around Bredasdorp. Zones of slow traffic (orange and red) are visible on the approaches to these road closure zones indicating the formation of queues caused by flooding.

4.2 Routing Patterns

Figure 5 describes the distribution of vehicles along different routes between the City of Cape Town and the section of the N2 east of Swellendam. Figure 5a presents traffic heading out of Cape Town (origin: Cape Town, destination: N2 east of Swellendam). The figure on the left indication traffic in the *Pre-flood* period, and on the right is during the *Repair* period. *Pre-flood* 20% of vehicles were using the N1 and R60 through Robertson to reach the N2 at Swellendam, and 81% the N2. In contrast, when the N2 was closed at Bot River, 90% of traffic was using the N1 and R60 route, while 10% headed along the N2, turning off just before Bot River onto the R43 towards Hermanus. From there, a third of these vehicles took the R320 (Hemel en Aarde Road), linking back with the N2 at Caledon, while 2/3 drove through Hermanus, turning onto the R326 at Standford to get back to the N2.

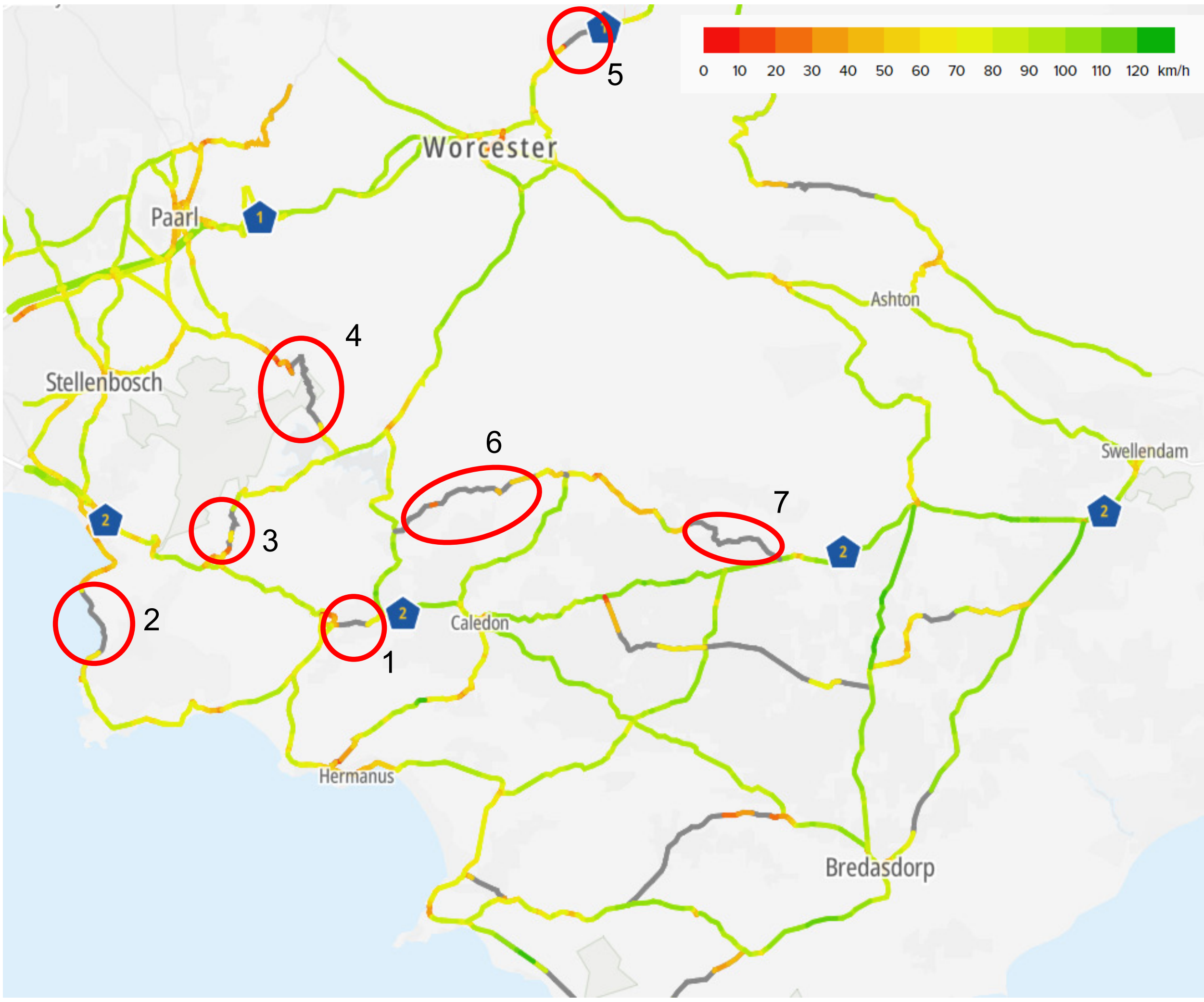

Figure 4: Road closures (TomTom FCD, Map data from OpenStreetMap)

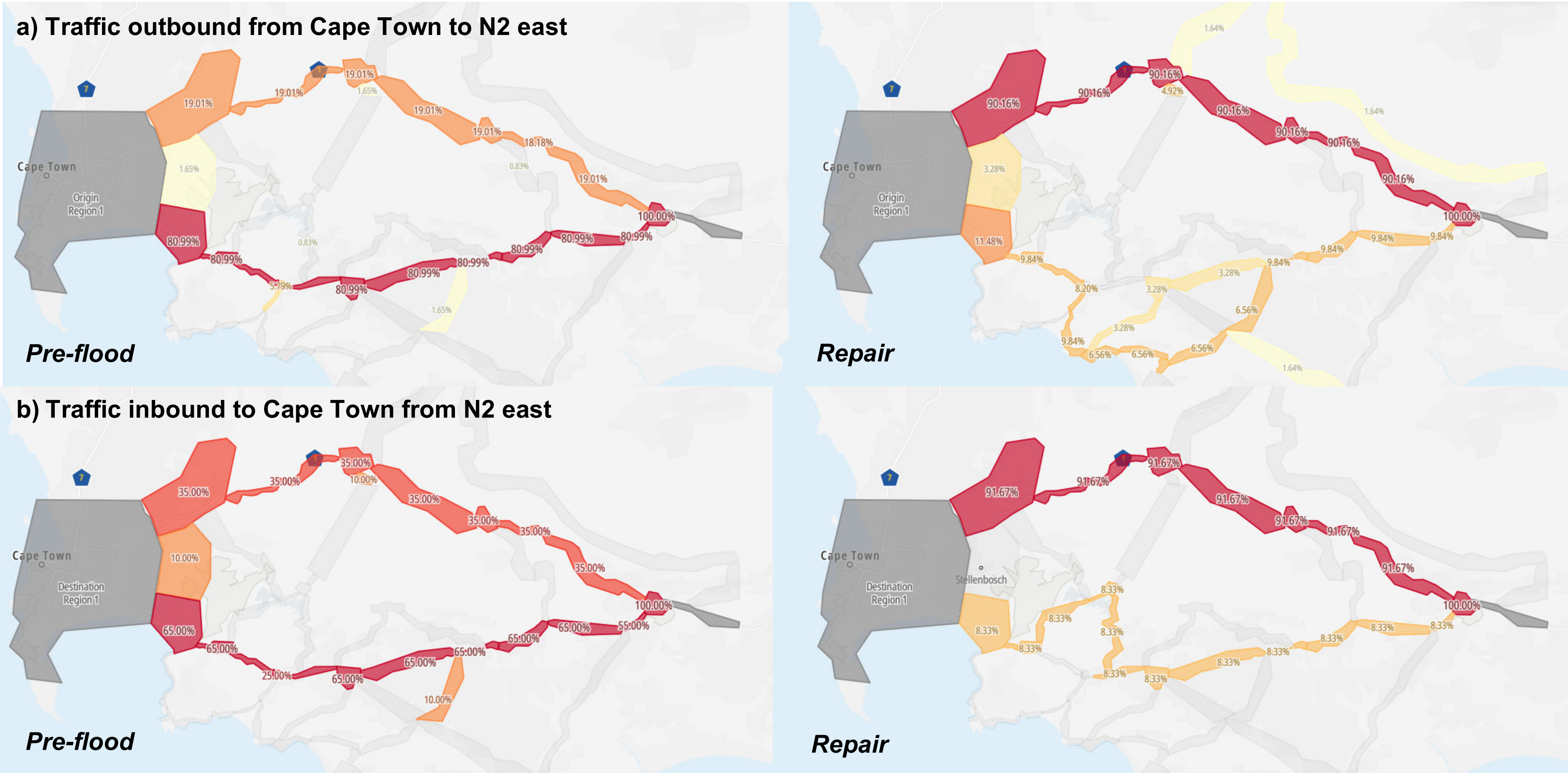

Figure 5: Distribution of inbound (a) and outbound (b) trips between Cape Town and N2 east of Swellendam[1]

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[1] Note that the numerical values on the figure do not necessarily add up to 100%. The values indicate the percentage of trips that pass through each analysis zone between the selected origin and destination. For example, in Figure 5b, 35% of trips used the N1 (northern route) and 65% the N2 (southern route). 10% of these trips also happened to pass through Stellenbosch on their way to Cape Town from the N2 east of Swellendam and 10% of trips made a stop south of the N2 just before Caledon.

Figure 5b considers traffic in the opposite direction (origin: N2 east of Swellendam, destination: Cape Town). *Pre-flood* distribution was 35% R60 and N1, 65% N2. During the *Repair* period, 92% of vehicles used the R60 and N1, while the remaining traffic used the N2, bypassing the closed section of the N2 by travelling northwards to Villiersdorp on the R43, and then the R321 through Grabouw to link up with the N2. It is interesting that the east- and westbound traffic made use of two completely different alternative routes.

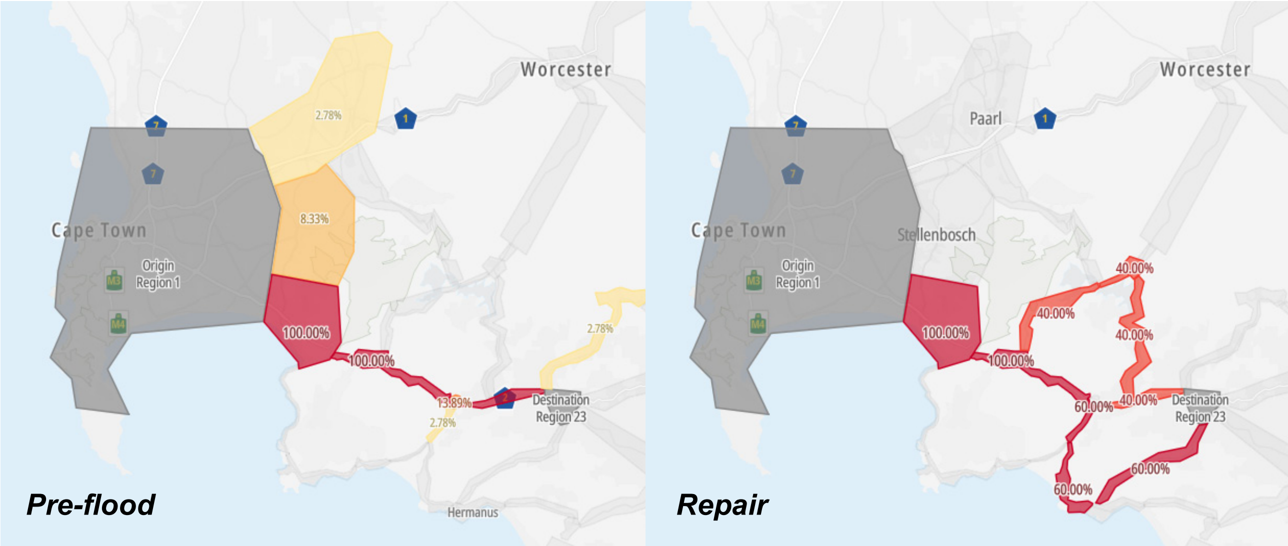

Figure 6: Distribution of outbound trips between Cape Town and Caledon

Figure 6 considers the route taken for shorter trips, where the N1 would not be an alternative (origin: Cape Town, destination: Caledon, just east of the road closure at Bot River). In this case, all vehicles started their journey on the N2, with 40% diverting north through Grabouw and Villiersdorp, and 60% using the southern Route through Hermanus along the R320 Hemel en Aarde Road. The R320 was only recently surfaced in 2016 and proved to be an important link for vehicles after the flood.

4.3 Change in Traffic Volumes

Traffic volumes were evaluated at ten permanent count stations over four time periods: *Pre-flood*, *Flood*, *Repair* and *Post-repair*. The change in traffic volumes from the *Pre-flood* interval at each count station are compared in Figure 7 for trips heading towards Cape Town (*inbound*), and Figure 8 for trips leaving Cape Town (*outbound*). Figure 9 summarises *inbound* and *outbound* traffic changes according to geographic location. In all figures, y-axis variables are the percentage change in ADT of different analysis periods (flood, repair, and post-repair) compared to pre-flood ADT.

Traffic along the R60 (count stations 2 and 3) cannot strictly be classified by an *inbound* / *outbound* designation, therefore, traffic directions were allocated according to how vehicles would have used the R60 during the road closure period. As detailed in Chapter 4.2, vehicles travelling along the N2 heading towards Cape Town turned north along the R60, linking with the N1, and continuing their journey to Cape Town through Worcester and Paarl. Northbound traffic at count stations 2 and 3 were therefore included with *inbound* traffic to Cape Town (Figure 7), and southbound traffic with *outbound* traffic (Figure 8).

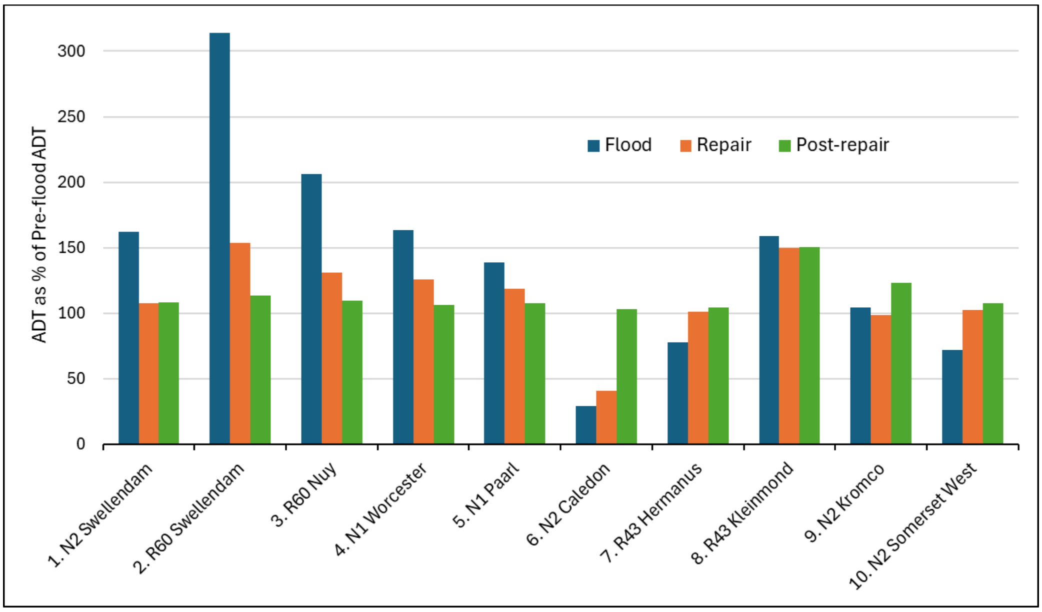

Figure 7: Traffic volume variation at count stations: INBOUND to Cape Town

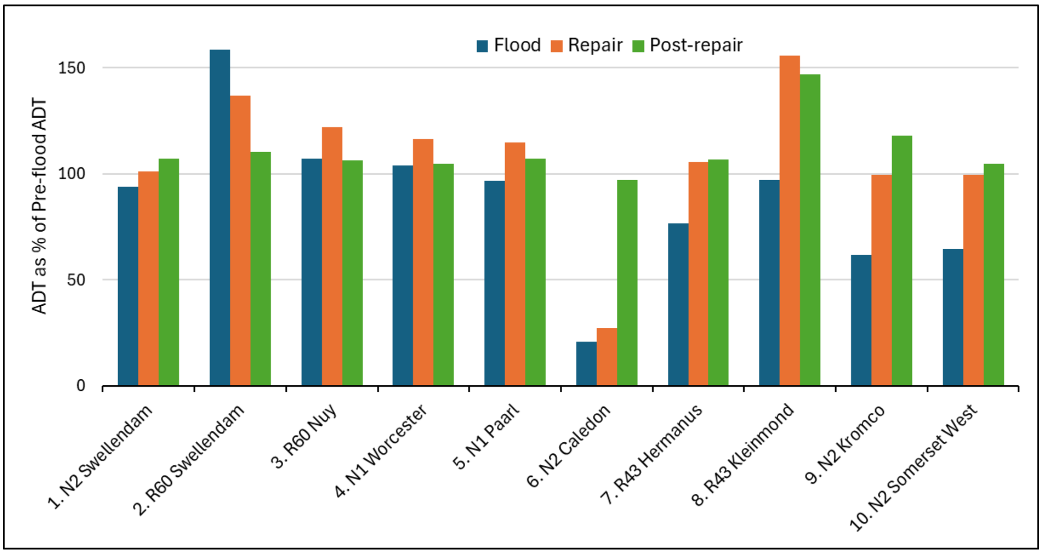

Figure 8: Traffic volume variation at count stations: OUTBOUND from Cape Town

Inbound traffic during the *Flood* period was significantly higher than typical along the N2 at Swellendam and along the R60 – N1 route to Cape Town (Figure 7). This higher traffic is in part due to the long-weekend (holiday makers heading back home to Cape Town) and partly due to the redistribution of traffic away from the N2. Southern routes (the N2 and the R43 at Hermanus) show lower traffic during the *Flood* period.

During the *Repair* period, the redistribution of traffic along the R60 and N1 towards Cape Town can clearly be seen in Figure 9, with traffic being 50% higher on the R60 at Swellendam, and 25% percent higher on the N1 at Worcester and Paarl than before the flood. Traffic on the N2 at Caledon was 41% of *Pre-flood* traffic. After the N1 was opened (*Post-repair*), traffic returned to *Pre-flood* levels at all sites, except at “8”.

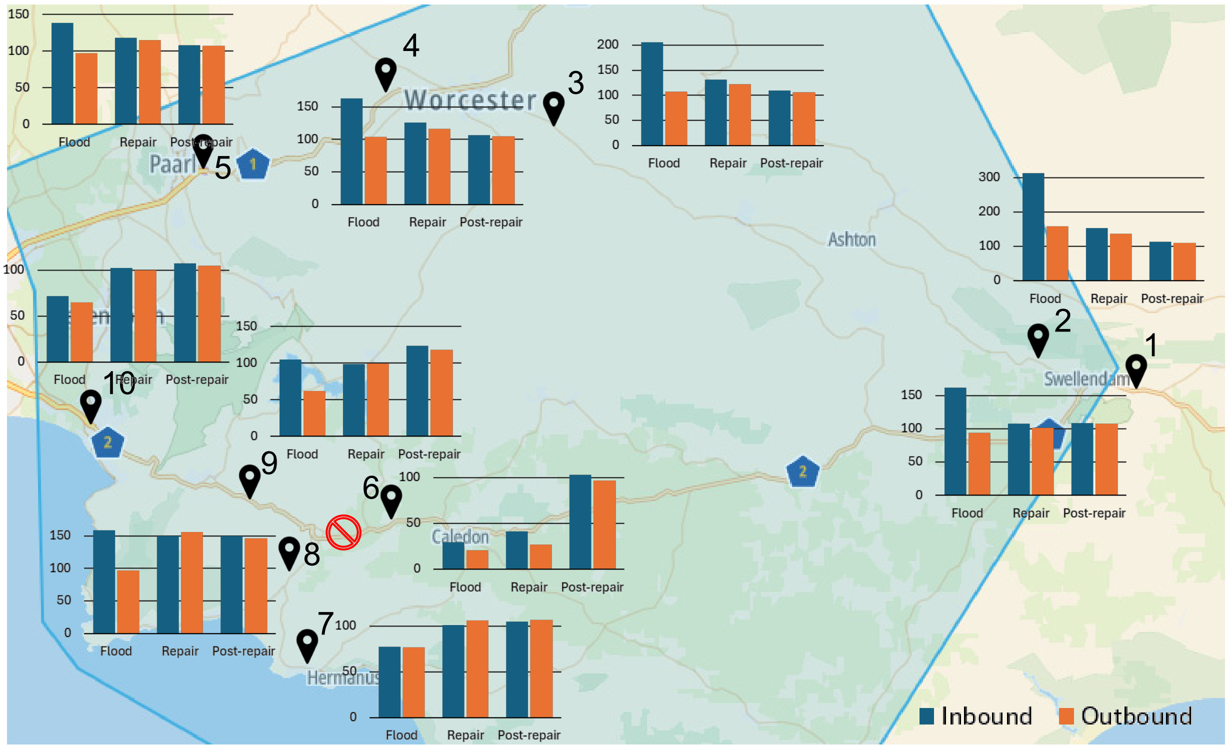

Figure 9: Geographical evaluation of percentage change in traffic volume from the Pre-Flood period at count stations

Inbound traffic during the *Flood*, *Repair* and *Post-repair* period along the R43 at Kleinmond (station 8) remained about 50% higher than *Pre-flood* traffic. This is due to the closure of the R44 coastal road between Kleinmond and Strand which was also severely damaged during the September 2023 flood. This road remained closed until 11 December 2023, when it opened with numerous zones of one-way traffic, requiring stop-and-go traffic management (Overstrand News, 2023).

Outbound traffic, described in Figure 8, did not increase to the same levels as the *inbound* traffic during the *Flood* period. Only the R60 at Swellendam really indicated any significant increase in traffic movement during the *Flood* event, caused by the redistribution of traffic along this route. Once the R60 traffic joined with the reduced N2 traffic at Swellendam, traffic on the N2 at this location reached typical levels. The impact of the long weekend is, however, not evaluated in this statement and further research would be required to evaluate how holiday-related traffic was impacted by the flood. Certainly, many reports have surfaced of people abandoning attempts to get home after the flood on Monday 25 September 2023.

ADT was higher along the N1 and R60 in the *Repair* period (between 15 and 35% higher than *Pre-flood*), indicating the use of the N1 and R60 as an alternative route, as highlighted in Figure 9 and discussed in Chapter 4.2. No difference in traffic along the N2 is visible at Kromco or Swellendam, but at Caledon, traffic was significantly lower (27% of *Pre-flood*). This shows that many motorists (particularly making shorter trips, as presented in Figure 6) used the N2 as far as possible, mostly diverting towards Hermanus and then along the R320. Higher than typical traffic on the R43 close to Kleinmond would support this theory. Also, most vehicles were not driving through Hermanus as can be seen in Figure 8.

The slightly higher ADT in November compared to early September in both inbound and outbound directions at all sites is due to seasonal changes in traffic, which is usually higher in summer in the Cape region (De Jongh & Bruwer, 2017).

5. LESSONS LEARNT FOR EMERGENCY RESPONSE ROAD PROJECTS

The reconstruction of the N2 at Bot River was completed over only 5 weeks; an impressive repair period considering the extensive damage to infrastructure, difficult and muddy terrain following unprecedented rainfall, and the effort needed to address the redirected flow of the river. Speculation would imply that this short repair period was only achievable by using road maintenance contractors that had existing appointments with SANRAL, and by redirecting resources (both funds and materials) to repair the N2. Using exiting maintenance contractors would have ensured that the contractors would apply a set of established competitive road maintenance and construction rates which would have been obtained through conventional and compliant procurement processes. A repair of such a nature and in such short time frames would not have been able to go through full procurement tender process, as is the typical requirement for public expenditure projects.

This effort by SANRAL to get the N2 reopened in as short a time as possible should be used in future research as a case study for response to infrastructure damage during natural disasters. The disruption to traffic caused by the N2 closure described in this paper, highlights the need to establish emergency/urgency procurement processes that remain fair, transparent, competitive, and offering value for money in the most efficient manner, or to enable roads authorities to maintain standby road repair contractors in the event of a disaster.

6. CONCLUSIONS

This paper considered both the short-term (immediate) and medium-term (up to 6 months after the flooding event) impacts of the September 2023 flooding event in the Western Cape, during which a large section of the N2 was completely washed away at Bot River. Floating Car Data (FCD) was extensively used in this study, proving the benefit of this publicly sourced and widely available data to evaluate both road closures due to unforeseen circumstances and changes in routing patterns of traffic. This paper is the first time that FCD has been used for appraisal of traffic patterns after a flood in South Africa. Redistribution of traffic on alternative routes could be clearly discerned from both FCD and traffic volume information obtained from static traffic count stations. This showed that the majority of long-distance trips re-routed to the N1 from Swellendam along the R60 through Robertson. Short-distance trips used a variety of routes both north and south of the N2.

Long term effects of flooding (extending for longer than 6 months) were not considered in this paper. These impacts include long-term planning changes and methods to mitigate future flooding. It is proposed that further research should be conducted that consider changes to construction procurement (for example the tendering process), planning for the impact of natural disasters on our national and regional routes, and policy for planning and construction of national infrastructure.

7. ACKNOWLEDGEMENTS

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