Water-Trak Autumn 2021 final test report

AMENDMENT RECORD

ISSUE	DATE	AMENDMENT
Draft	24/01/2022	Issue for proof reading
1	27/01/2022	First issue for circulation
2	31/01/2022	Addition of section 5.2.4 for step 3 braking
3	17/03/2022	Updated section 5.2.2 with increased Control sample size. Figure 19 added to Section 5.2.4
4	30/03/2022	Final report for proof reading
5	04/04/2022	Final report

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WATER=TRAK

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1 INTRODUCTION

1.1 Project Summary

Water-Trak Ltd is advancing a system mounted on rolling stock which applies a small amount of water to the rail head in low adhesion conditions. Research has shown that the amount of water on the rail head plays a critical role in adhesion; while a dry rail gives the best results and a fully wetted rail still provides good braking, a damp, contaminated rail causes very low friction. The Water-Trak system creates "rainy day" conditions on the rail head when low adhesion is detected by adding a controlled quantity of water.

The concept has previously been successfully trialled both on a test track and in mainline testing. The purpose of this autumn 2021 trial is to provide the rail industry with operational evidence for the effectiveness of water addition in mitigating low adhesion.

The pilot was conducted with Water-Trak operating from trains in passenger service. Two Northern Class 319/3 trains, equipped with Water-Trak systems, ran throughout autumn 2021 and continue to operate into 2022. A new Water-Trak system design was also completed and approved for the Northern Class 170 train, but due to operational constraints was not available for trial in time for autumn. Two units will be available for further trials in 2022.

This report contains an analysis of the key results from the trial, documenting the impact of water addition on a range of relevant train performance parameters.

2 OBJECTIVES

The aim of this project was to gather operational evidence for Water-Trak deployed for the first time from trains running in passenger service on the mainline. Specifically, this evidence includes:

- Quantification of the braking and traction improvement delivered through the combination of Water-Trak and sanding (using the existing single, fixed-rate sanders on the test trains)
- Evaluation of the railhead treatment impact for following trains
- Resilience to freezing conditions
- An assessment of the impact of driving style on Water-Trak operation

In order to meet the above objectives, it was necessary to develop, approve and install Water-Trak systems for operation in passenger service on two Northern Trains passenger train types, the Class 319 and Class 170.

3 DESIGN AND APPROVALS

3.1 Class 319

In 2019, the first implementation of the Water-Trak solution was installed in the experimental HydroFLEX train, based on the Class 319. During autumn 2020, this design was updated and fitted to a Northern Class 319 train (319368) for mainline trials under signal protection. The

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Class 319-based solution was again selected for the autumn 2021 trail due to the requirement to have Water-Trak installed and operational from early autumn.

3.1.1 Overview of installation

The Water-Trak systems were installed in each driving car positioned on the train underframe behind the leading bogie – see figure 1. Control units were mounted inside each driving carriage on the luggage rack, with connections to the driver's traction sand button, the WSP rack and the main water delivery unit. The control units each contained a data logger which received GPS input as well as train parameters via the OTMR and water system control. During the trial, data was transmitted for remote analysis via a roof-mounted 3G/GPS antenna.

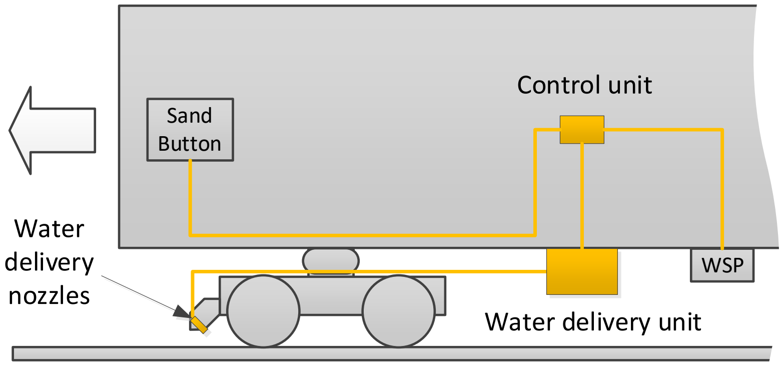

Figure 1: Class 319 Water-Trak system schematic

Water dispensing was triggered by the following inputs:

- Wheel slide indicated by operation of any of the four blow-down valves in the driving carriage.
- Driver operation of the cab-mounted traction sanding button

Figure 2 shows one of the two trains installed with the Water-Trak system – 319368.

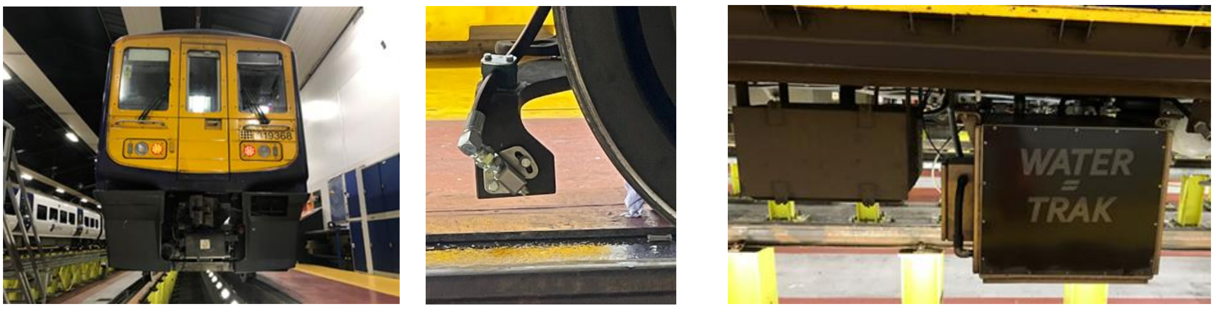

Figure 2: Water-Trak installation on Class 319

3.1.2 Approvals

In order to achieve approval for operation of Water-Trak in passenger service in the Class 319, the following documents were completed and signed off:

- Design Attestation AC-0161-21 prepared by Aegis Certification Services Ltd.

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- Network Rail summary of compatibility NRSC/0319/110/t
- Safety Requirements close-out document WTSRS001.4
- AC-0349-21 Construction Attestation Statement - Class 319 Water-Trak, prepared by Aegis Certification Services Ltd.
- Northern SHE validation
- Northern Engineering Change approval

3.2 Class 170

The Class 319 is nearing the end of its service life, potentially limiting the opportunity to roll-out Water-Trak across the GB rail network. It was therefore necessary to develop a Water-Trak solution for an alternative train class. The likely initial target for Water-Trak is in 2 and 3 car trains, where the benefits of the upcoming Double Variable Rate Sanding solution are less clear. Working with Northern trains, the Class 170 was chosen as the best option to demonstrate the benefits of water addition and support the subsequent roll-out.

3.2.1 Overview of installation

The water delivery unit (comprising the water tank, a pneumatic pump with ancillaries and trace heating) was positioned in the centre of the train underframe ahead of the leading bogie – see figure 3. The Water-Trak control unit was mounted inside the electrical cabinet at the rear of the leading carriage and was connected to the WSP rack, Remote Monitoring Device (RMD) and OTMR mounted in the same cabinet. When actuated, water is delivered through flexible high-pressure hose from the water delivery unit to nozzles attached to the lifesavers ahead of the leading axle.

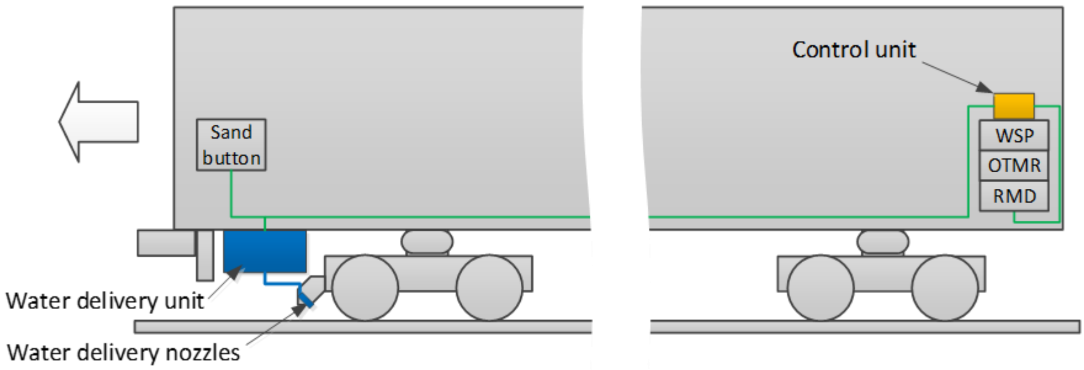

Figure 3: Schematic of the Water-Trak installation in the Class 170 train

Water dispensing can be activated in two ways: when a signal is received from the WSP wheel slide relay or as the result of a manual dispense signal. The manual dispense signal is actuated when the cab sanding button is pressed.

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Figure 4 shows a selection of views of the Water-Trak system installed in a Class 170 train.

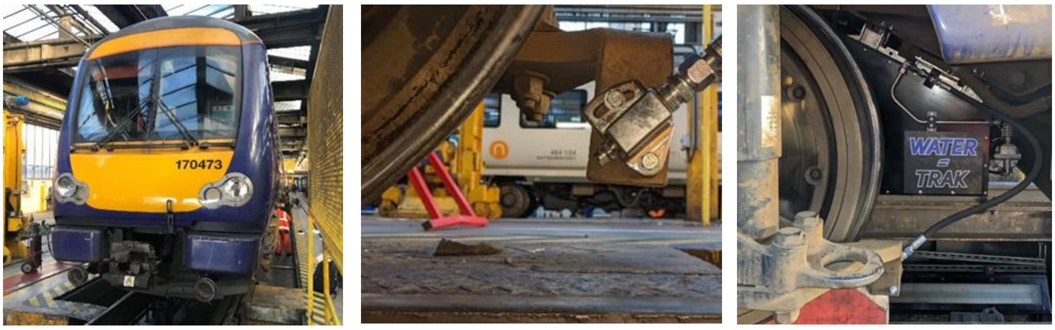

Figure 4: Water-Trak installed in Class 170

3.2.2 Approvals

In order to achieve approval for operation of Water-Trak in passenger service in the Class 170, the following documents were completed and signed off:

- Design Attestation AC-0364-21 prepared by Aegis Certification Services Ltd.
- Network Rail summary of compatibility NRSC/0170/102/i
- Safety Requirements close-out document WTSRS002.2
- AC-0435-21 Class 170 Water-Trak Construction Attestation Statement, prepared by Aegis Certification Services Ltd.
- Northern SHE validation
- Northern Engineering Change approval

4 TEST PLAN

4.1 Evidence required

The aim of the trial was to provide operational evidence to support the subsequent implementation of Water-Trak. Specifically, this evidence is intended to enable the following objectives to be achieved:

- Quantification of the braking and traction improvement delivered through the combination of Water-Trak and sanding
- Evaluation of the railhead treatment impact for following trains
- Resilience to freezing conditions
- An assessment of the impact of driving style on Water-Trak operation
- Evaluation of water consumption during autumn

4.2 Data sources

To support delivery of the evidence detailed above, data was drawn from the following sources:

- Incident data reports from Northern Trains (e.g. Station over-runs, tyre turning)
- Weather data from MetDesk and Rail Weather Monitoring provided for the trial regions
- Rail Head Treatment Train (RHTT) performance and timetabling
- Driver feedback (e.g. depot whiteboards)
- Depot maintenance records and feedback
- Route information, including gradient data (5 Mile Line Diagrams document)
- Journey time and GPS speed data
- OTMR data

The data paths for journey time and OTMR information are shown in figure 5.

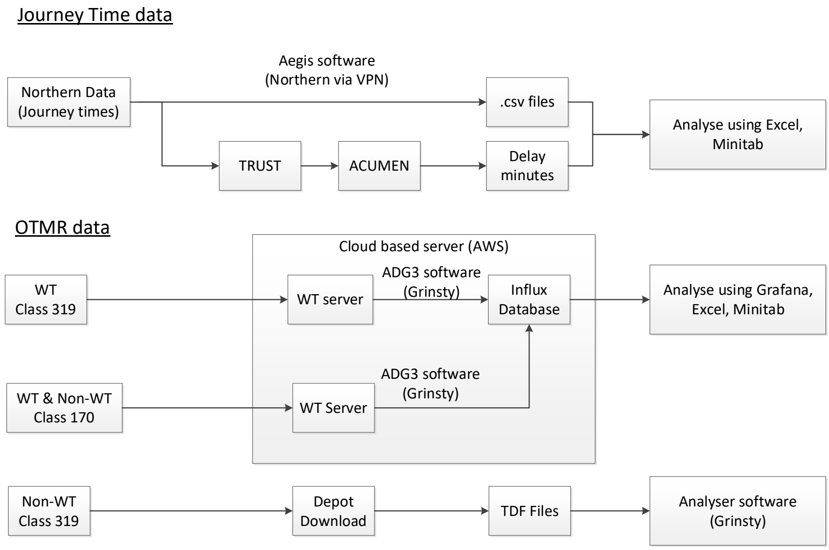

Figure 5: Water-Trak 2021 autumn trial data paths

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4.3 Analysis

4.3.1 Journey time impact

Data from the Northern Trains Aegis database was analysed firstly to quantify the "autumn effect" on journey times and then to evaluate the impact of water addition. The analysis looked at the average and variation in journey times, which have been shown to increase in autumn in previous studies.

4.3.2 Braking improvement

OTMR data was used to analyse braking deceleration rates during WSP events for both Water-Trak and non-Water-Trak equipped trains. Key OTMR and data logger parameters included brake demand from the driver, brake pressure, WSP activity, water delivery duration and train speed. In some instances, the OTMR train speed was supplemented with GPS train speed data from the Northern Trains Aegis database.

4.3.3 Traction improvement

OTMR data was used to analyse acceleration for both Water-Trak and non-Water-Trak equipped trains. Specific OTMR and data logger parameters of interest included power demand from the driver, sanding button activity, water delivery duration and train speed.

4.3.4 Following trains impact

Downloads from the Northern Trains Aegis database provided journey time data for multiple trains running in sequence on the same section of track. The following train impact was assessed by studying differences in journey time, acceleration and deceleration for Water-Trak and non-Water-Trak trains using Aegis data in conjunction with OTMR data.

4.3.5 Resilience to freezing conditions

Weather data was used to identify periods when temperatures were below 0°C. Data logger parameters, in particular water system pressure, were analysed during and after these periods to assess the impact of freezing on the operation of the system. It was also possible to analyse the frequency of operation in low temperature conditions by recording the number of times the system triggered.

4.3.6 Driving style

The OTMR and data logger were used to analyse the impact of driving style on operation of the Water-Trak system. Key parameters included driver inputs of brake demand, traction demand and sanding button operation together with brake pressure, WSP activity, water delivery duration and train speed.

4.3.7 Water consumption

The number of dispenses and individual delivery durations were used to assess the volume of water dispensed per day of autumn operation.

4.4 Trial operation

4.4.1 Driver requirements

A driver briefing document was prepared which informed the drivers that no additional action is required of the driver when operating trains equipped with the Water-Trak system. The briefing also instructed drivers to operate the trains as normal and avoid adjusting their driving style when operating the trial units. The current driving policy within Northern is to apply a constant level of Step 2 braking, avoiding "fanning" of the brakes (i.e. continually cycling the brakes between Steps 1 and 2).

4.4.2 Routing

The Class 319 and 170 trains continued to operate normally on their usual routes, in accordance with the standard timetable requirements.

4.4.3 Filling and maintenance

A comprehensive set of maintenance procedures were prepared for both train classes. The documents detailed the activities needed to support filling, inspection and servicing. In addition, winterisation procedures were developed to protect the systems in low temperatures and to mitigate the risk of damage due to freezing.

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5 RESULTS

5.1 Water-Trak operation

The rail industry recognised autumn period in 2021 was between 1st October and 15th December. The Water-Trak systems in 319368 and 319379 both went live on 18th October 2021 and the first Water-Trak operational data was captured on 19th October. Initially, both trains ran with traction and braking water delivery enabled. On November 7th, traction water delivery was disabled, with the systems on both trains continuing to operate in braking when the WSP triggered. The first Class 170 (170473) Water-Trak system was installed during week commencing 15th November and returned to operation on November 22nd. Activation of the system was delayed due to the need for driver approval and further work is required to confirm correct operation of the data logging system. A second Class 170 (170454) has been partially fitted with Water-Trak and full fitment is expected to be complete by May 2022.

5.1.1 Overall summary

The total dispensing history for the two Class 319 trains is shown in table 1. Overall, the two trains covered over 37,000 miles during the trial and dispensed water 767 times of which 456 occurred while braking.

		Period 8				Period 9				Period 10	
		Week 1	Week 2	Week 3	Week 4	Week 1	Week 2	Week 3	Week 4	Week 1	**Totals**
319368	77472 dispenses	23	12	49	27	17	38	8	0	1	**175**
	77473 dispenses	35	19	47	23	5	25	4	6	0	**164**
	Total	**58**	**31**	**96**	**50**	**22**	**63**	**12**	**6**	**1**	**339**
	Mileage	2098	340	2952	3017	1950	2133	2316	1938	242	**16986**
319379	77494 dispenses	22	49	68	13	37	15	34	1	0	**239**
	77495 dispenses	23	48	43	21	24	12	17	0	1	**189**
	Total	**45**	**97**	**111**	**34**	**61**	**27**	**51**	**1**	**1**	**428**
	Mileage	1641	1833	3000	1836	2504	2497	1594	3219	2271	**20395**
Disp. type	Stationary	6	7	12	0	0	2	2	0	0	**29**
	Accel	66	84	128	1	0	0	0	0	0	**279**
	Decel	30	37	66	83	83	88	61	6	2	**456**
Overall	Total mileage	3739	2173	5952	4853	4454	4630	3910	5157	2513	**37381**
	Total dispenses	103	128	207	84	83	90	63	7	2	**767**
	Disp. duration (s)	4310	7207	9982	3205	3146	2961	2248	213	90	**33362**
	Total water (litres)	575	961	1331	427	419	395	300	28.4	12	**4448**

Table 1: Summary of Water-Trak operation during autumn 2021

During the first three weeks of the trial, traction water delivery accounted for approximately two thirds of all dispenses and there were several days when the trains dispensed over 400 litres of water (for reference, one Class 319 train carries two Water-Trak systems, each containing 200 litres). There was only one occasion when a system ran out of water: the 29th of October. The total volume of water delivered throughout the entire trial was approximately 4,500 litres. This is equivalent to less than one hour of water output for a single Railhead Treatment Train.

5.1.2 Location and density of water dispenses

Figure 6 shows the location and density of water dispenses in the form of a heat map; red indicates a larger number of dispenses over the autumn trial period. The trace shows the primary areas where the largest volume of water was dispensed, including Liverpool to Wigan, Liverpool to Newton-Le-Willows and the area around Manchester Airport.

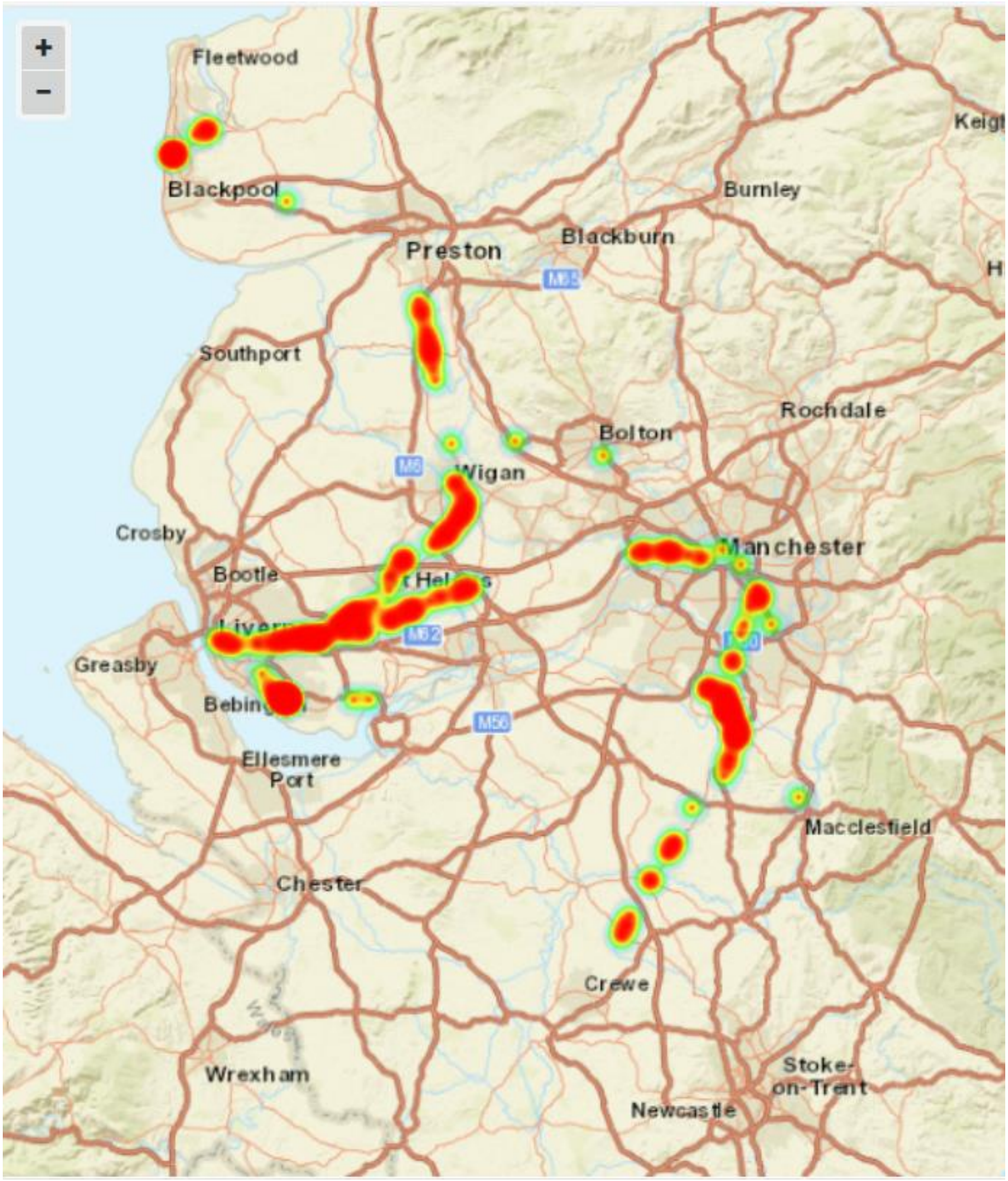

Figure 6: Heat map of water dispense locations

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5.1.3 Autumn timeline

Figure 7 shows a graph of the water dispensing frequency ordered by day. The colour bar at the top of the chart indicates the adhesion predicted for each day. The graph shows the relatively large amount of traction water delivered and indicates the point where it was disabled on the 7th November. The results appear to show poor correlation between the adhesion index forecasted and the level of low adhesion experienced by the trial trains. The level of adhesion problems varies significantly day-to-day; it is difficult to predict tomorrow's performance based on todays.

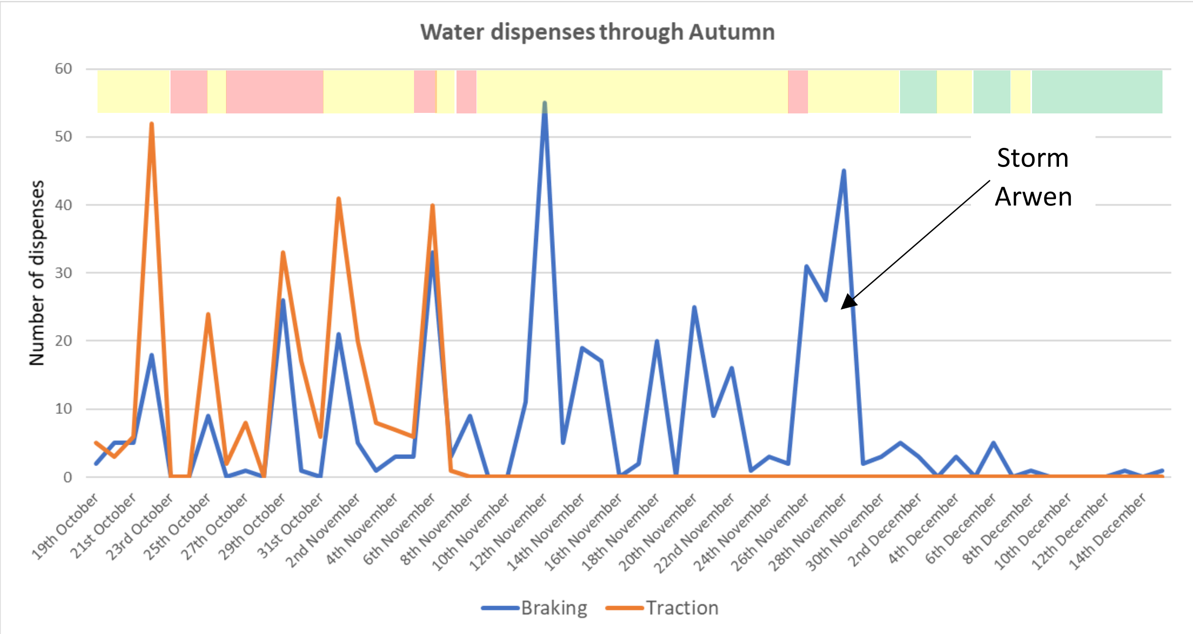

Figure 7: Dispensing frequency through autumn 2021

Figure 8, analysing purely water delivery during braking, shows that a few days in autumn account for a large part of the total number of water dispenses.

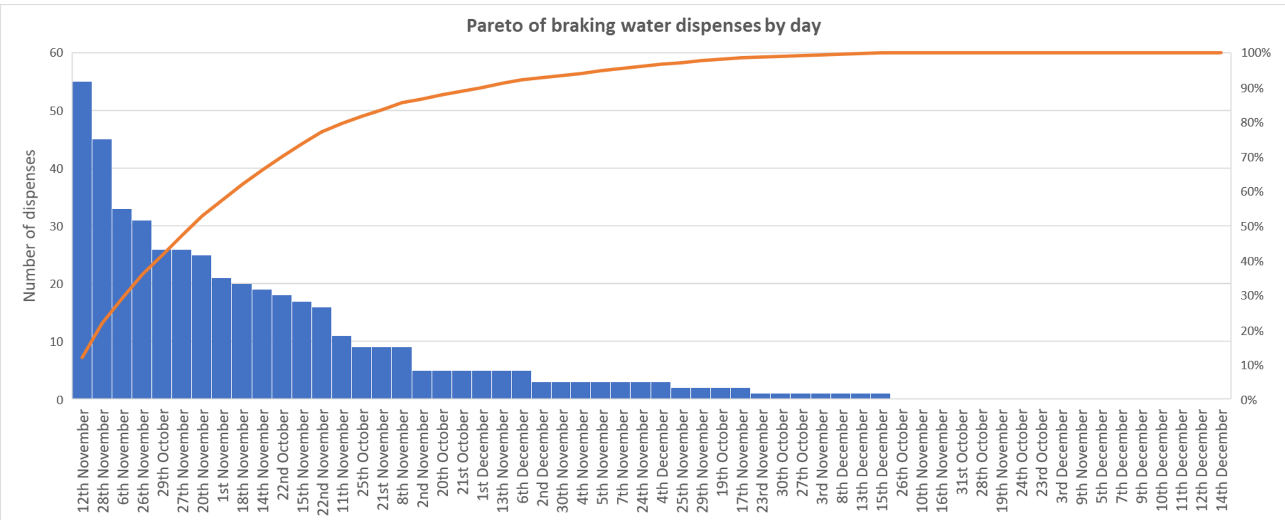

Figure 8: Pareto of water dispenses

5.1.4 Operation in freezing conditions

Figure 9 shows air temperature readings recorded hourly at Manchester Airport (MetDesk data) between 19th October and December 15th, 2021. During the trial period, freezing conditions were encountered on five days. Storm Arwen landed on 26th of November and continued to have an adverse effect through the 27th, 28th and 29th November. The lowest autumn temperatures were recorded during this period.

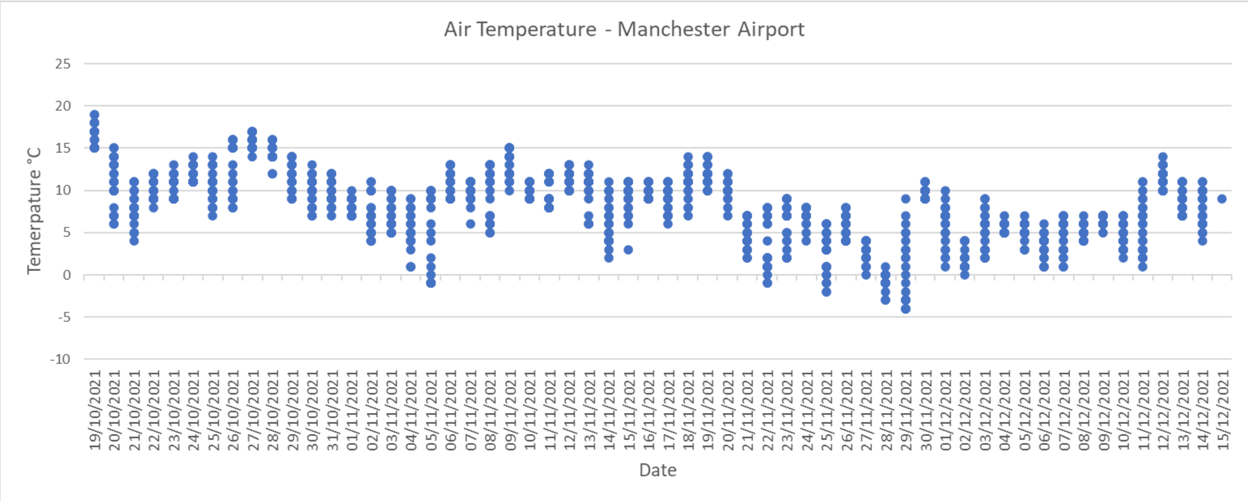

Figure 9: Air temperature readings at Manchester Airport, autumn 2021

Figure 10 shows the temperature readings for the period when the effects of storm Arwen were most severe. The lowest temperature recorded was -4.8°C on the night of the 28th/29th November. The prolonged period of sub-zero temperatures led to water delivery elements of the Water-Trak systems on both Class 319 trains freezing (indicated by very high-pressure transducer readings and shown on the chart by the light blue shading). It is important to note that the main Water-Trak tanks on the trains did not freeze due to operation of their trace heating systems. As the ambient temperature increased, the water systems thawed (indicated by lower pressure transducer readings) and continued to operate correctly for the rest of the trial.

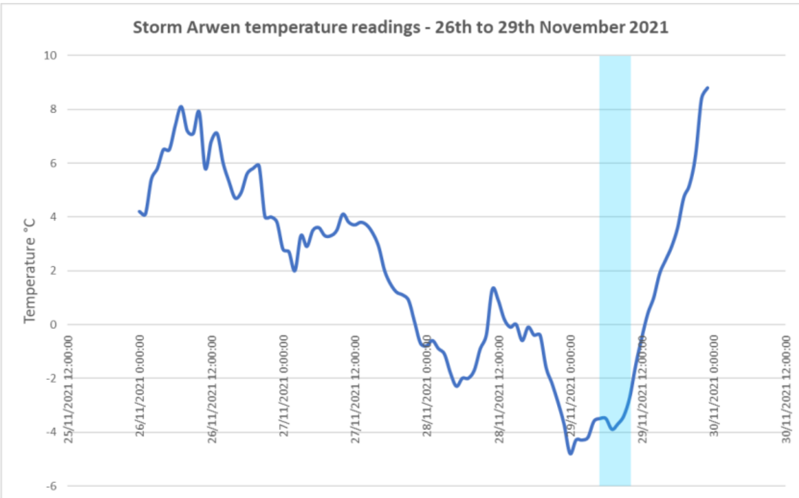

Figure 10: Air temperature readings 26th to 29th November 2021

5.2 Impact on braking

5.2.1 Analysis method

The braking deceleration rates achieved during WSP events were analysed for both Water-Trak and non-Water-Trak equipped trains. Deceleration rates (in units of %g) were quantified for all step 2 braking manoeuvres which lasted for 5 seconds or more. GPS data for the train was used to help quantify decelerations in manoeuvres where the OTMR speed trace was not suitable (e.g. during wheel-slide). Local track gradient data was used, when available, to correct any deceleration results which took place on upgrades or downgrades.

Figure 11 provides more detail of how data from the Grafana analysis dashboard was used to calculate train deceleration. Firstly, timings for WSP triggered water deployment were identified. Valid braking manoeuvres were those where at least 5 seconds of step 2 braking occurred (where brake pressure is over 2). The time period from the start of water addition to the end of step 2 braking was recorded and the speed reduction noted. Deceleration values were calculated by dividing the speed reduction by the braking time period.

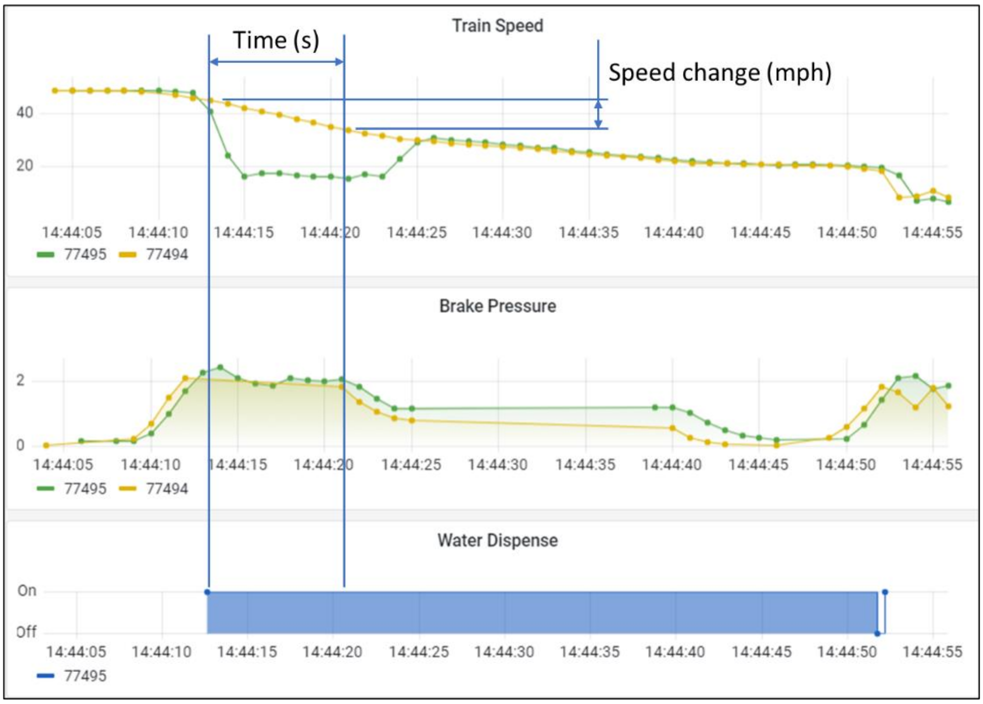

Figure 11: Annotated Grafana speed, brake pressure and water dispense trace

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5.2.2 Overall effect of water addition

Figure 12 shows the individual value deceleration results for all step 2 WSP braking manoeuvres recorded during autumn 2021. The control data was derived from OTMR downloads from Class 319 trains together with data for the two Water-Trak trains running prior to their systems being switched on. 250 samples have been recorded for Water-Trak while the number of Control samples is 117.

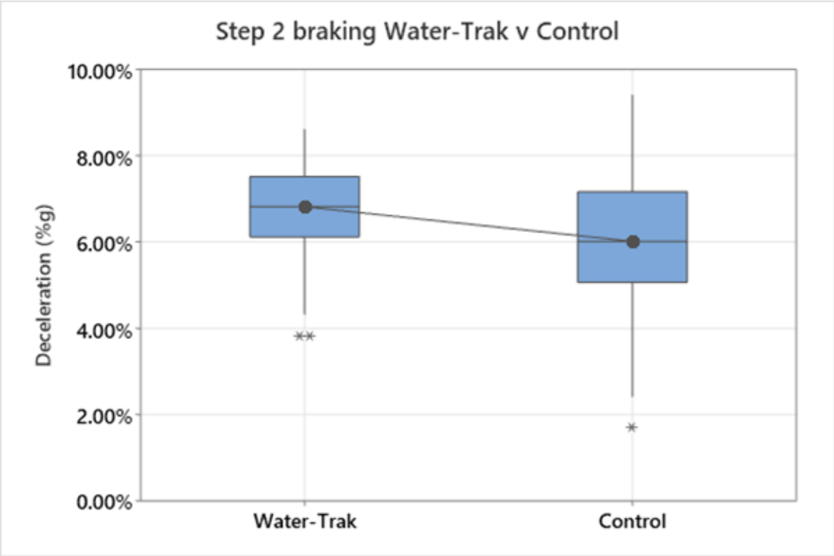

Figure 12: Deceleration rates for Water-Trak trains compared with Control trains

The graph shows that the median deceleration for the Water-Trak trains increases by 0.8%g (from 6.0%g to 6.8%g), equating to a reduction in stopping distance of more than 12%. More importantly, the variation in deceleration appears to be smaller for Water-Trak than the Control. The lowest deceleration values for Water-Trak were 3.8%g, whereas decelerations as low as 1.7%g were recorded for the Control.

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Figure 13 shows a two-sample t-test comparing mean decelerations for Water-Trak trains and the Control. The analysis indicates that there is a statistically significant increase in mean deceleration.

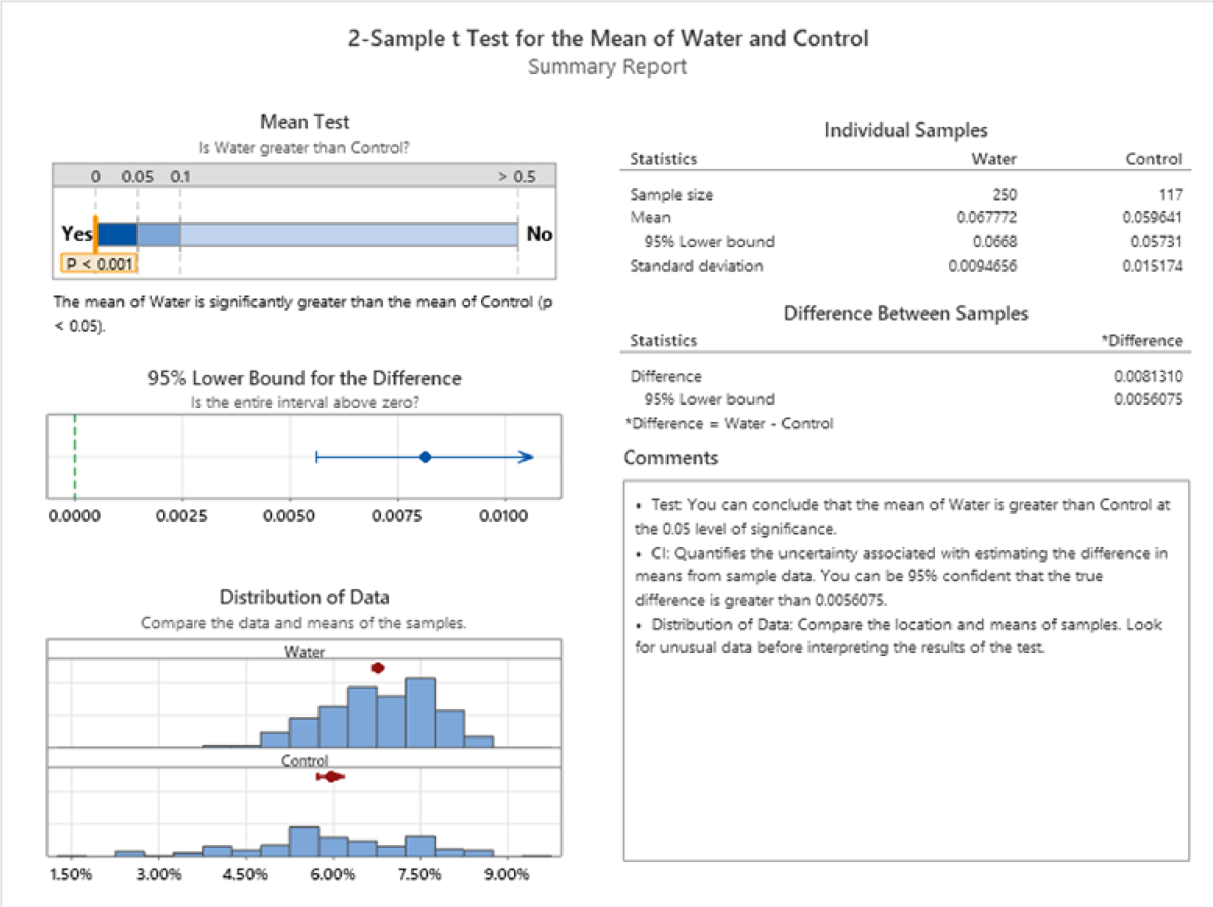

Figure 13: Two-sample t-test comparing means for Water-Trak v Control

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Figure 14 shows the results of a two-sample standard deviation test comparing the variation in the Water-Trak decelerations with the control. The conclusion from this analysis is that the variation in Water-Trak deceleration is significantly lower than that of the control.

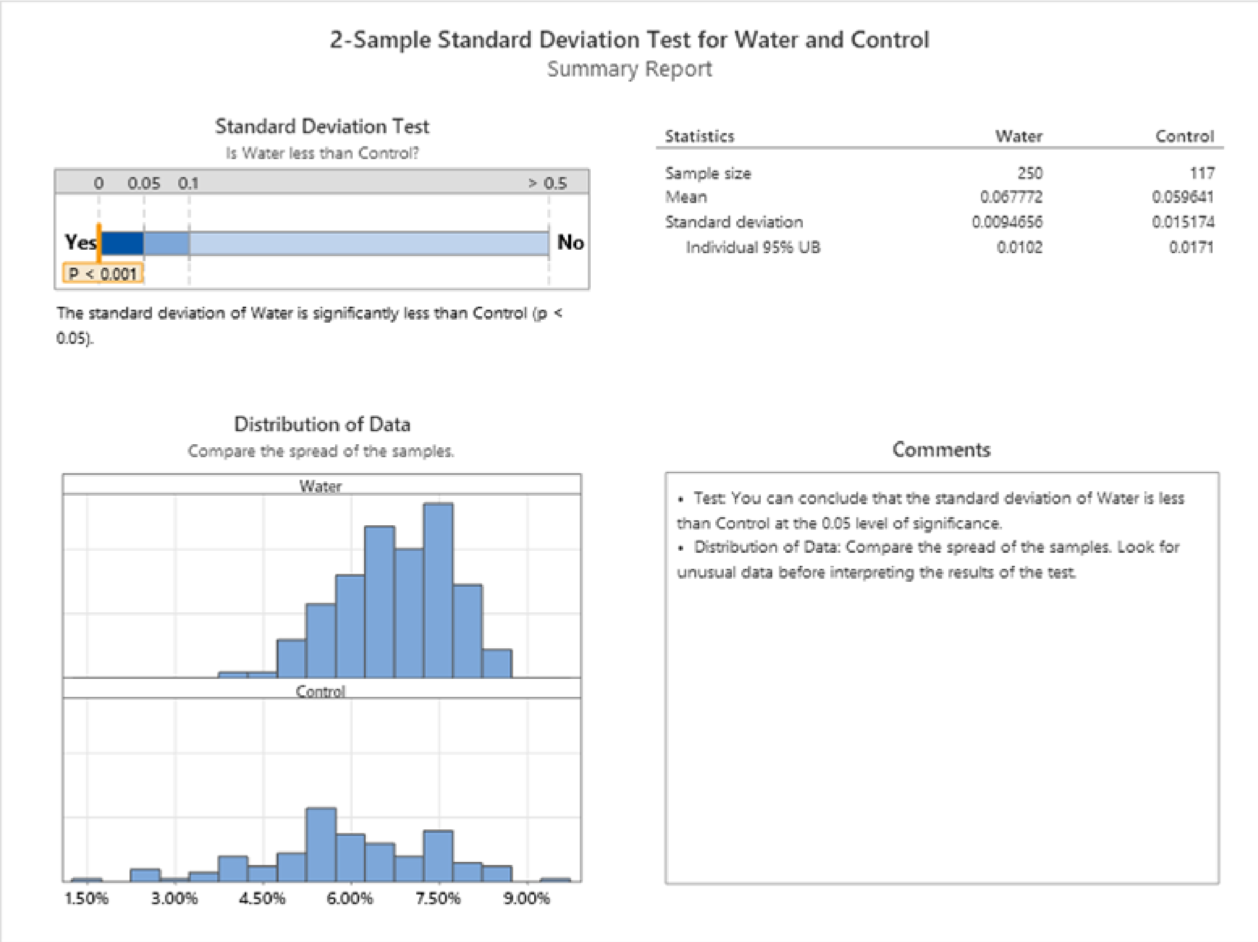

Figure 14: Two-sample standard deviation test comparing Water-Trak and Control decelerations

Overall, this analysis shows that Water-Trak equipped trains have significantly better braking (higher step 2 deceleration with reduced variation) when compared with the control. These results, recorded during passenger service operation through autumn, support the findings from previous Water-Trak lab-based, test track and SPZ trials.

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5.2.3 Braking performance through autumn

Figure 15 shows a timeline by day for Water-Trak train Step 2 WSP decelerations. Generally, the Water-Trak assisted braking performance appears to have been fairly consistent through autumn with the average deceleration remaining, in the most part, above 6%g. There was one day when the average for multiple manoeuvres dropped below 6%g; Sunday, the 28th November during the aftermath of storm Arwen. One of the two lowest deceleration results of 3.8%g was recorded on this day as 319379 approached Newton-Le-Willows from Patricroft. The other result occurred as 319379 approached St Helens Central, heading West on the 21st November, the previous Sunday. This braking manoeuvre took place before the Rail Head Treatment Train (RHTT) pass had occurred for that day.

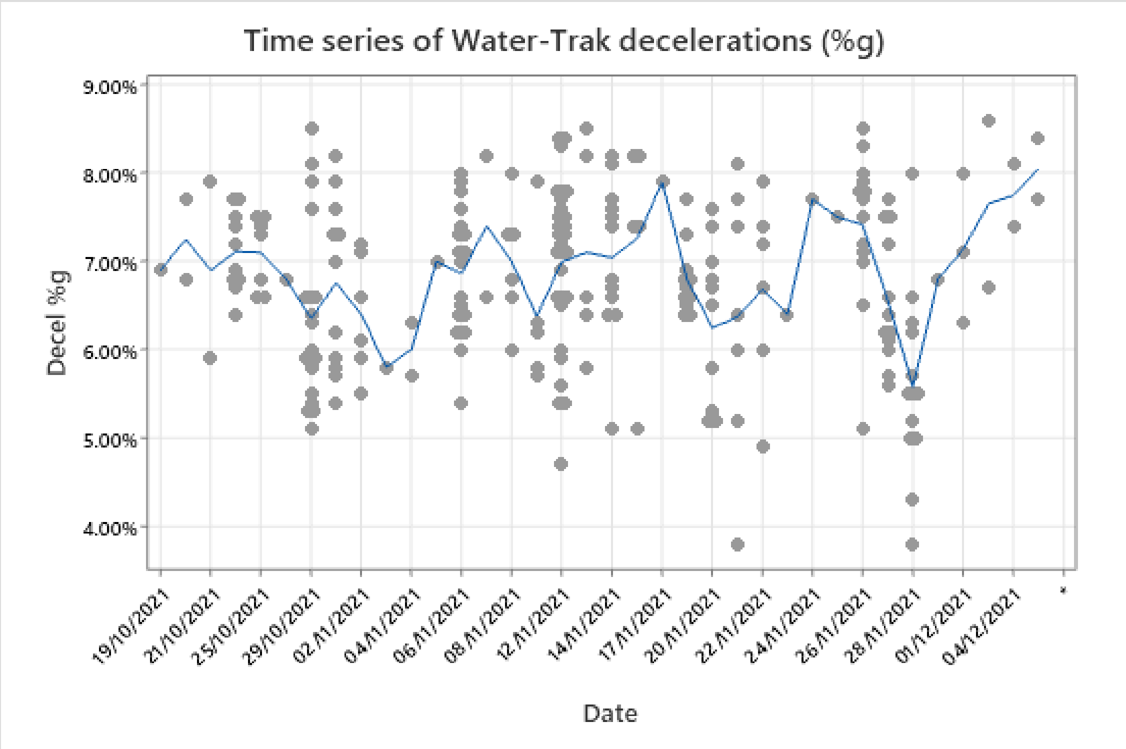

Figure 15: Times series graph of Water-Trak train decelerations from 19th October to 5th December.

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Figure 16 displays how many dispenses occurred for each hour of the day. There is a notable "early morning" low adhesion effect visible as well as an increase in water dispenses towards the end of the day.

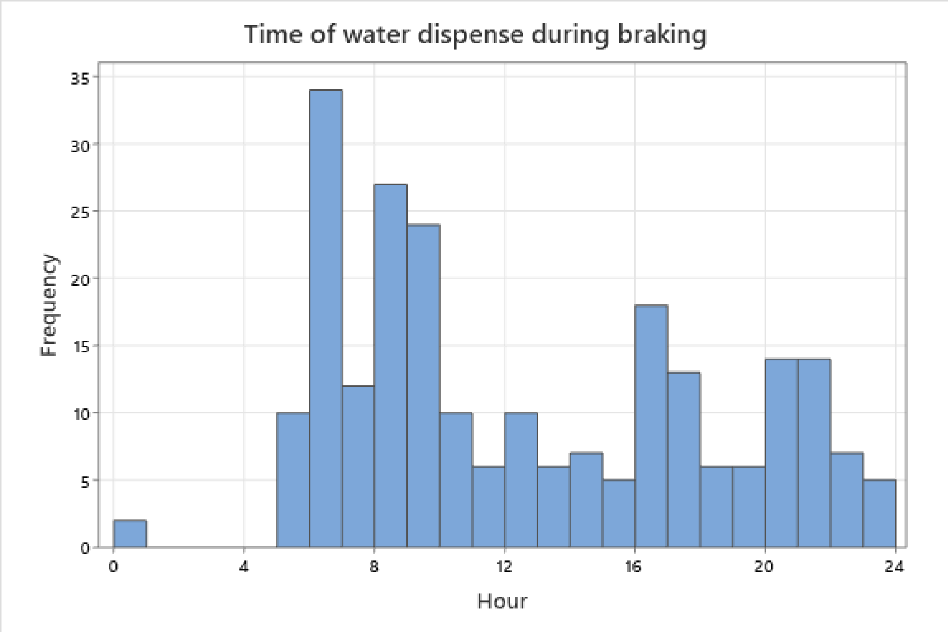

Figure 16: frequency of water dispenses by time of day.

5.2.4 Full-service braking

In extreme conditions, it was noted that drivers would occasionally apply step 3 braking. Out of the 456 water-assisted braking manoeuvres where the train was sliding, only 18 required applications of full-service braking for 5 seconds or more. Figure 17 shows a comparison of Water-Trak deceleration against 14 results for a control group of trains running on the same network.

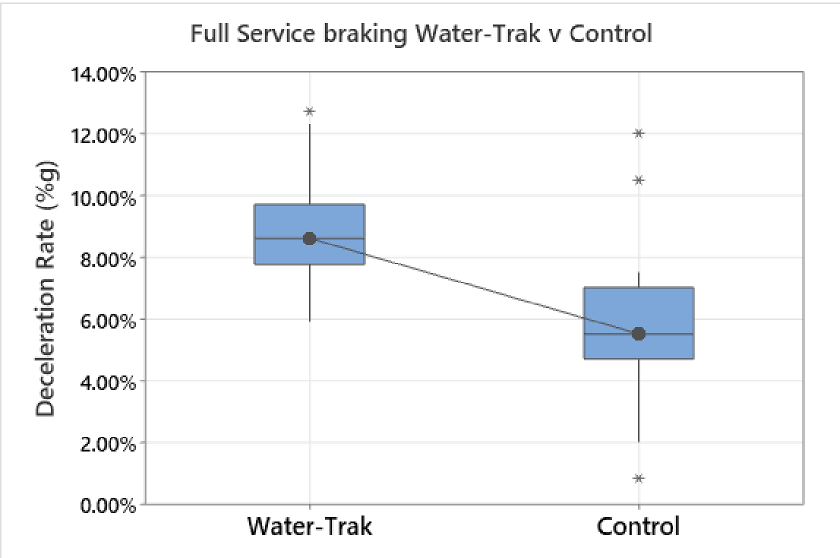

Figure 17: Comparison of full-service Water-Trak braking against OTMR-based control data

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The level of deceleration achieved for the Water-Trak trains with full-service braking increases from an average for step 2 of 6.8% to 8.6%, as shown in figure 18, whereas the deceleration for the Control trains at full-service braking shows no increase in the average above step 2 – see figure 19. This demonstrates that Water-assisted braking provides an additional deceleration margin when full-service braking is selected compared with the Control.

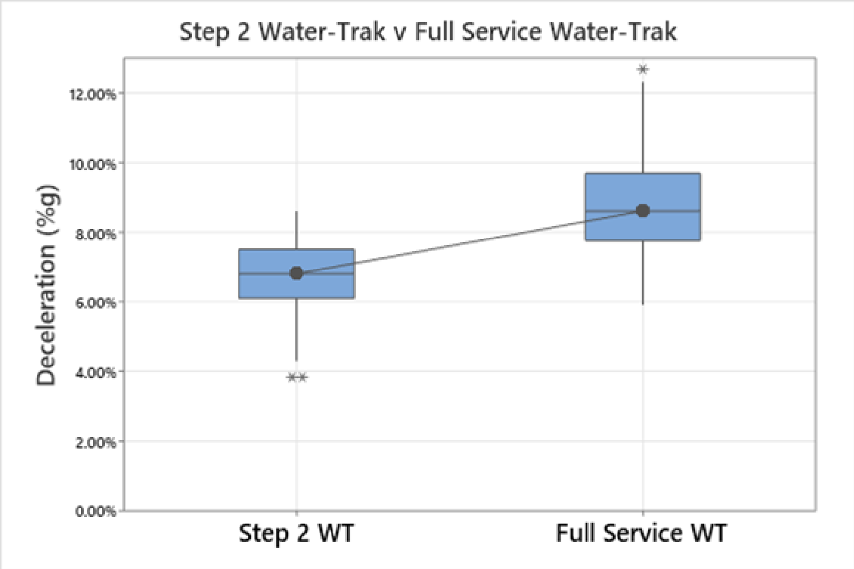

Figure 18: Comparison of step 2 and full-service Water-Trak braking

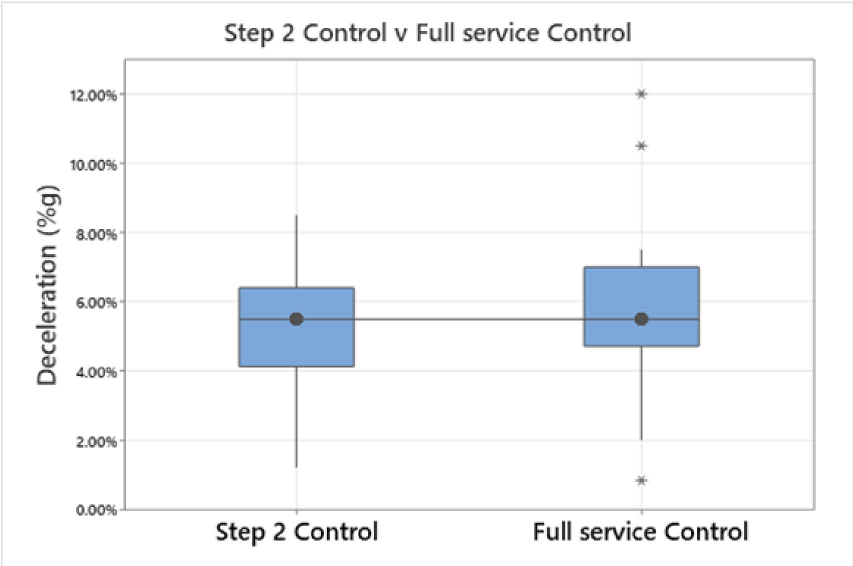

Figure 19: Comparison of step 2 and full-service Control braking

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5.2.5 Comparison of step 2 braking for the two test trains

When the braking performance of the two Water-Trak equipped Class 319 trains was compared it became clear that they behaved differently in braking. Figure 20 shows a box plot comparison of the deceleration results recorded for both trains. While 319379 still performed better than the Control (median = 6.6%g vs 6.0%g), 319368 delivered significantly better deceleration (median = 7.0%g). The graph also shows that the variation in deceleration for 319368 is significantly less than 319379, with no step 2 decelerations for 319368 recorded below 5%g.

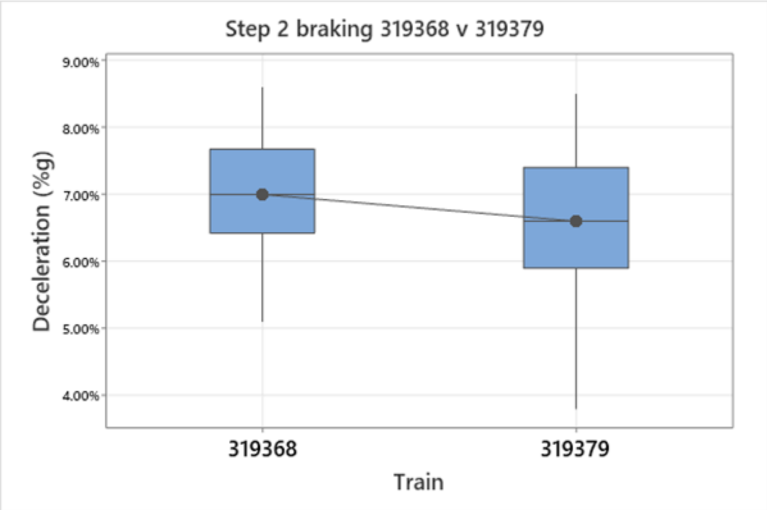

Figure 20: Step 2 braking comparison for the two Water-Trak trial trains

The cause of this difference in braking performance is currently not known although 319379 was reported to have sanding problems on October 29th and a reduced number of sanding signals were received by the telemetry for one end of 319379 (carriage number 77495) on a number of occasions. Further work will be undertaken with Northern trains to investigate the difference in braking performance between the two trains before autumn 2022.

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5.3 Use of water for traction

5.3.1 Overview of water addition for traction

During the testing, some surprising results were observed. Firstly, the drivers pressed the traction sanding button far more frequently than expected. Secondly, the trial results showed that the largest amount of traction water was demanded at high speeds – see figure 21. It had been expected that water would mainly be used to help traction at low speeds.

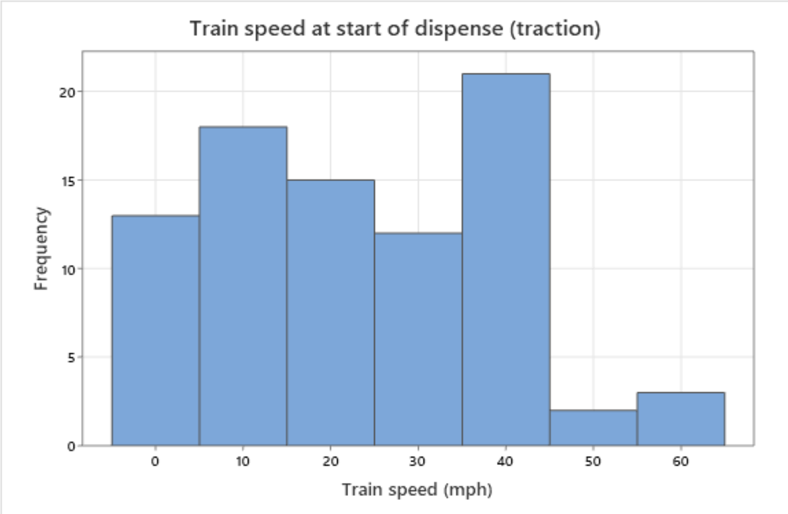

Figure 21: Frequency of traction water dispenses at various train speeds

Thirdly, many dispenses lasted longer than expected. Figure 22 shows that some dispenses continued for almost three minutes. These three issues combined to cause a far greater water usage than expected.

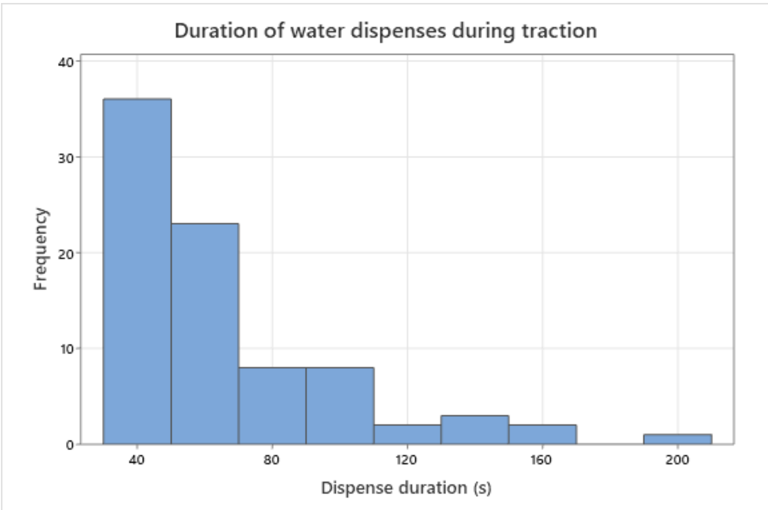

Figure 22: Histogram of water dispense durations

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In addition to the excessive water consumption described above, initially, water addition for traction did not appear to be beneficial in some situations. For these reasons it was decided that the sanding button triggered water should be switched off. The Water-Trak systems continued to operate in WSP triggered mode (water for braking only) from November 7th. Further analysis of the autumn results has now been completed to establish the effect of water addition for traction.

5.3.2 Traction analysis method

Acceleration rates were analysed for both Water-Trak and non-Water-Trak equipped trains. In the case of Water-Trak data, the acceleration achieved (in units of m/s^2) was quantified for all power notch 4 applications of over 5 seconds when water was dispensed. Control data was derived from the same OTMR files as were used in the deceleration analysis, applying the same rules for notch 4 application as for Water-Trak. Local track gradient data was used, when available, to correct any acceleration results which took place on upgrades or downgrades.

5.3.3 Effect of water addition on traction

Figure 23 shows a comparison of acceleration results for Water-Trak and Control trains. The Control data clearly illustrates the very poor inherent traction of the Class 319 with a median value of $0.18 m/s^2$ compared with a median value for the Water-Trak trains of $0.3 m/s^2$. A 2 sample T-test gives a confidence level greater than 99.9% that the Water-Trak mean acceleration is greater than that for the Control.

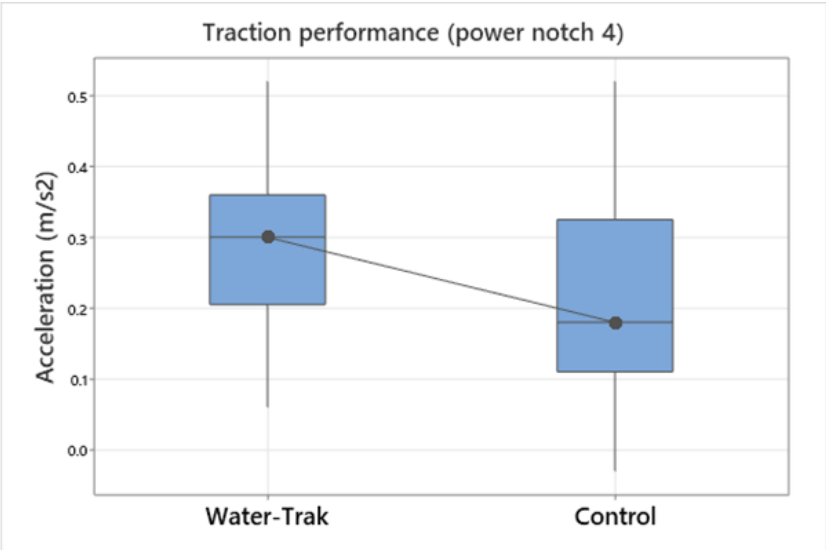

Figure 23: comparison of power notch 4 acceleration values for Water-Trak vs Control

The poor Class 319 Control data has radically changed the initial perception that water did not help train acceleration and puts the traction performance of Water-Trak in context. These results point towards a major improvement in traction performance with water addition; they highlight the potential of Water-Trak to improve the operational performance of trains which suffer from traction issues.

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It is harder to analyse variation of traction than braking as a result of the varying impact of a set power application (e.g. notch 4) at different train speeds i.e. at higher train speeds the same power input results in less acceleration. Figure 24 illustrates the impact of train speed on acceleration for both the Water-Trak and Control trains. The graph shows that the improvement in acceleration with water occurs across the entire operating speed range while also showing more consistent acceleration values.

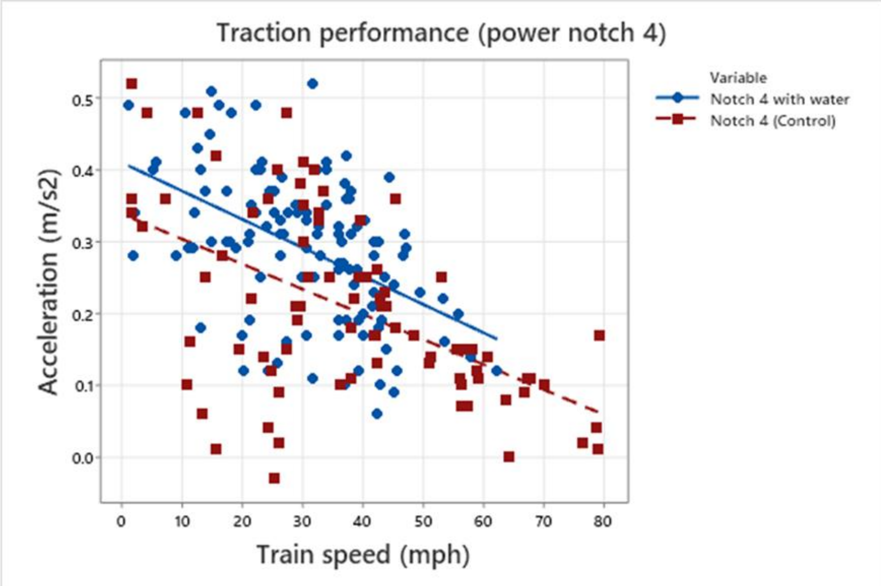

Figure 24: Impact of train speed on acceleration for Water-Trak and Control

5.3.4 Comparison of traction for two trial trains

In addition to the differences noted in traction performance for the Water-Trak and Control trains, it was also noted that the two Water-Trak trains behaved differently. Figure 25 shows a box plot comparison of the acceleration results recorded for 319368 and 319379. These results show that while 319379 still performs better than the Control (median = 0.26m/s^2 vs 0.18m/s^2), 319368 delivered significantly better traction (median = 0.36m/s^2).

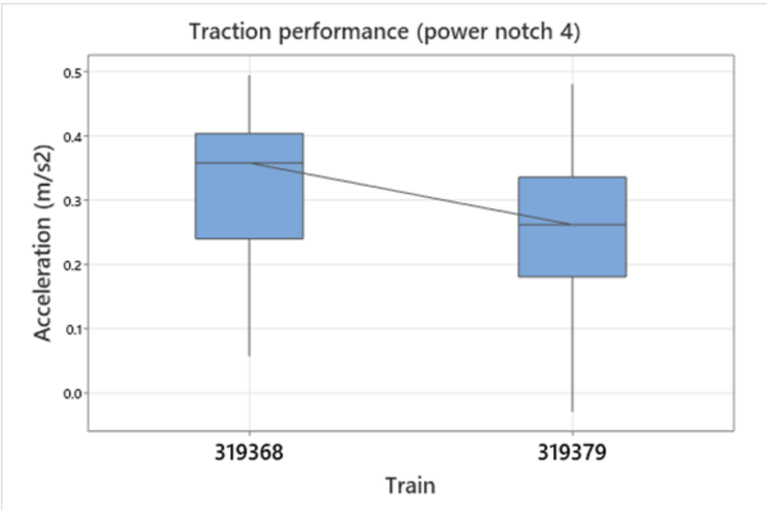

Figure 25: comparison of acceleration values for 319368 and 319379

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It is notable that the under-performing train for traction is the same as for braking (319379). The reason for the different traction performance cannot currently be confirmed but may be caused by the sanding issues described in section 5.2.5.

5.4 Impact on journey times

Journey time data is available on the Northern Aegis database and has been used to analyse comparative train performance for Water-Trak trains, Water-Trak following trains and other trains operating on the same sections.

5.4.1 Autumn effect on journey times

Analysis has been conducted on journey time for individual legs on the line of route running from Huyton to Bryn. A comparison was made between Class 319 journey times in Summer and Autumn. Table 2 shows the outputs of this analysis.

	Huyton-Prescott	Prescott-Eccleston Park	Eccleston Park – Thatto Heath	Thatto Heath-St Helens Central	St Helens Central-Garswood	Garswood-Bryn
Summer Median	202 secs	130 secs	131 secs	173 secs	369 secs	148 secs
Autumn Median	205 secs	137 secs	141 secs	177 secs	373 secs	153 secs
% change	**+1.7%**	**+5.4%**	**+7.6%**	**+2.3%**	**+1.1%**	**+3.4%**
Summer variation (IQR)	12 secs	11 secs	11 secs	10 secs	21 secs	10 secs
Autumn variation (IQR)	13 secs	13 secs	18 secs	14 secs	24 secs	14 secs
% change	**+8.3%**	**+18.2%**	**+63.6%**	**+40%**	**+14.3%**	**+40%**

Table 2: Summary of journey times between Huyton and Bryn, summer vs autumn 2021

The results in table 2 demonstrate that the impact of autumn conditions is not uniform. For example, the autumn shift in median (1.7%) and variation (8.3%) for the leg between Huyton to Prescott, although statistically significant, is relatively small when compared with the median (7.6%) and variation (63.6%) change for Eccleston Park to Thatto Heath. A large part of this difference is likely to be accounted for by the gradients present on the legs, with downgrades potentially responsible for increased variation. Other factors may include the level of trackside vegetation and presence of local infrastructure (e.g. tunnels and viaducts).

5.4.2 Overall comparison of Water-Trak vs non-Water-Trak trains

An overall comparison was made between Water-Trak trains and other units running on the same line of route during autumn 2021. It was hoped that this analysis might reveal a reduction in journey time and variation for Water-Trak trains. Unfortunately, no statistically significant difference was found. Figure 26 shows an example of average journey times for individual Class 319 trains, in this case running between Eccleston Park and Thatto Heath. The dots show the mean values calculated for each train and the bars around the dots indicate the 95% confidence interval for the means. The overlapping of the bars indicates no significant difference in mean journey times for any Class 319s (for reference, the Water-Trak equipped trains were 319368 and 319379).

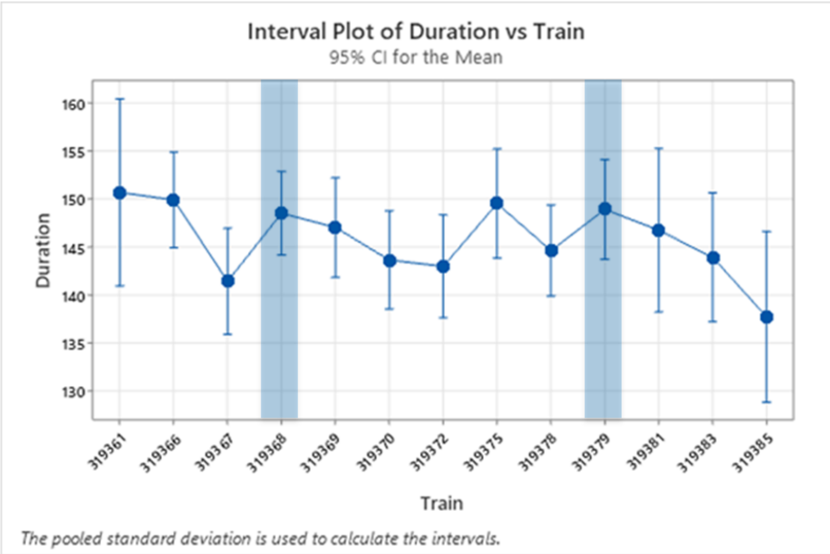

Figure 26: Mean journey times for Class 319s running between Eccleston Park and Thatto Heath during autumn 2021.

5.4.3 Consecutive journey times of trains running on the same section

On reflection, it might seem optimistic to expect to see a reduction in journey time resulting from relatively few water dispenses (for example, for the Eccleston Park to Thatto Heath leg, there were only 13 journeys where water was dispensed over a total of 377 journeys made by 319s during autumn 2021). In order to better understand the impact of water deployment on overall journey times, an analysis was made on individual train movements by studying their speed-time traces for a route running between Newton-Le-Willows and Huyton. Figure 27 shows speed-time traces for three trains running on this section on the 8th November when the adhesion forecast was red. The timetabled journey time for this route is 21 to 22 minutes. Weather conditions were dry with a light dew formation on the rail.

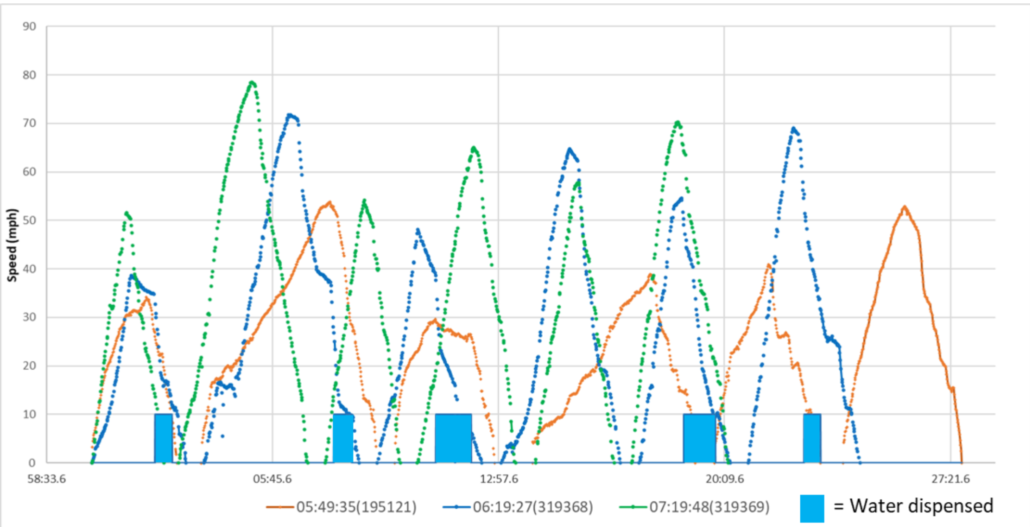

Figure 27: speed-time traces for trains running between Newton-Le-Willows and Huyton on the morning of the 8th November.

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The first train of the day (orange trace) was a Class 195 which started the route at approximately 05:50. The Class 195 completed the journey in 27:43. 30 minutes later, the second train, Water-Trak equipped 319368 (blue trace), completed the same journey in 24:29, while dispensing water six times to assist braking. The third train 319369 (green trace) arrived at the section 60 minutes later and covered the journey in 20:17 – a result which is within the timetable. This analysis indicates a possible benefit from deploying water for the Water-Trak equipped train itself and hints at potential benefits for following trains.

During autumn there is a complex interplay between the previous braking and traction performance of the train, the perceived weather conditions and the current location of the train. Together these factors greatly influence the driving style adopted for subsequent manoeuvres. The analysis in the next part of this section differs from the comparison of times for journey legs described in section 5.4.2 as it aims to quantify any "journey effect" which might result from driving style being influenced by the factors described above.

The "journey effect" analysis studied differences in journey times between the trains that preceded Water-Trak trains (on journeys where water was delivered) and the corresponding following trains. Figure 28 shows the journey time difference between the Water-Trak train and the previous train travelling on the Newton-Le-Willows to Huyton section. These reading were recorded for each journey when the Water-Trak system operated. The red and green bars on the chart show the journey time differences. If the Water-Trak train covered the section in less time than the previous train, the difference is shown by a green bar, while a slower journey time is shown by a red bar. Overall, the chart shows a positive performance for Water-Trak and an average journey time reduction for the complete section of around 70 seconds (equating to 5% of the total journey).

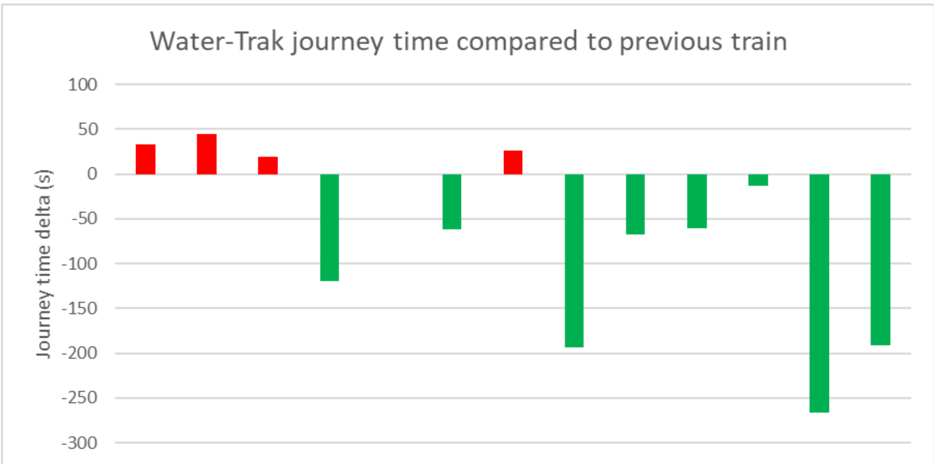

Figure 28: Journey time impact of Water-Trak vs the preceding train

The impact of Water-Trak on the following train was also studied. Figure 29 shows the journey time difference between the Water-Trak train and the following train. The graph shows that the overall journey time for the following train improved by a further 30 seconds compared with the Water-Trak train.

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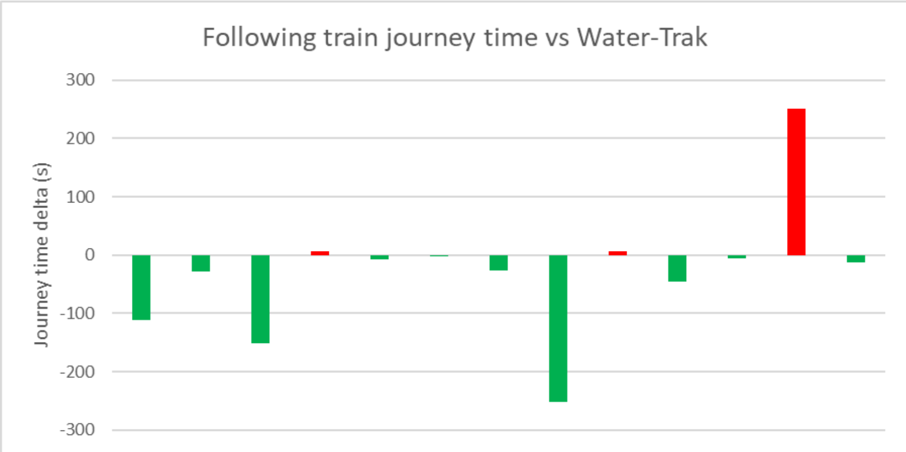

Figure 29: Journey time impact of Water-Trak on the following train

The analysis conducted in this section highlights the importance of driver confidence in delivering improved operations in autumn, especially in relation to journey time. Future analysis of the operational impact of Water-Trak should include an evaluation of the "journey effect" in addition to studying journey leg durations.

5.5 Driving style in autumn

The previous analysis has highlighted that driving style is influenced by the conditions experienced during autumn, with the driver becoming more cautious when low adhesion is present. To understand in more detail how driving styles vary in different adhesion conditions, a number of train operational parameters were analysed. The metrics studied relate to brake operation (brake step and brake pressure) and train speed (maximum speed and average speed) for each journey segment (stop to stop). Three contrasting days were analysed: an autumn day when adhesion conditions were poor – 28th November 2021, an autumn day with normal adhesion – 3rd November 2021, and a spring day with excellent adhesion conditions – 22nd March 2022.

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5.5.1 Brake operation

Figure 30 compares the percentage of brake step applications for journey segments on each of the three days. On the poor adhesion day, there is a larger proportion of full-service brake applications and smaller percentage of step 2 braking. As the conditions improve, the amount of step 3 braking applications reduces and step 2 correspondingly increases. Across all three days, the proportion of step 1 applications remains broadly similar.

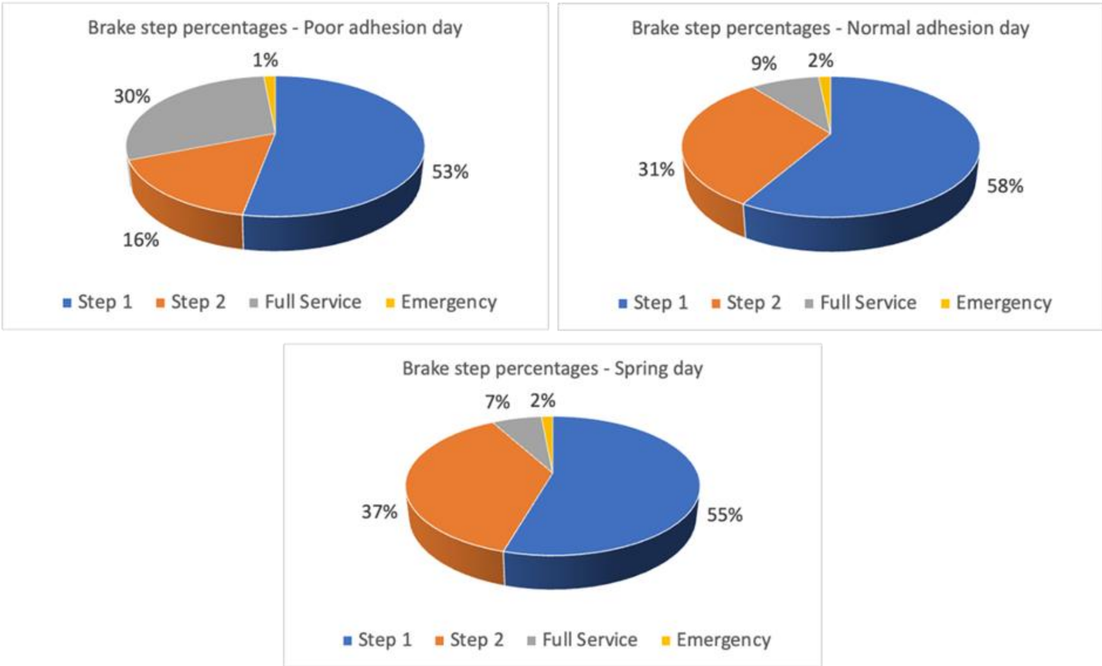

Figure 30: Comparison of brake step applications in different adhesion conditions

Another measure of braking input is the average brake pressure applied for each journey segment. Figure 31 shows a comparison of average brake pressure over the three days.

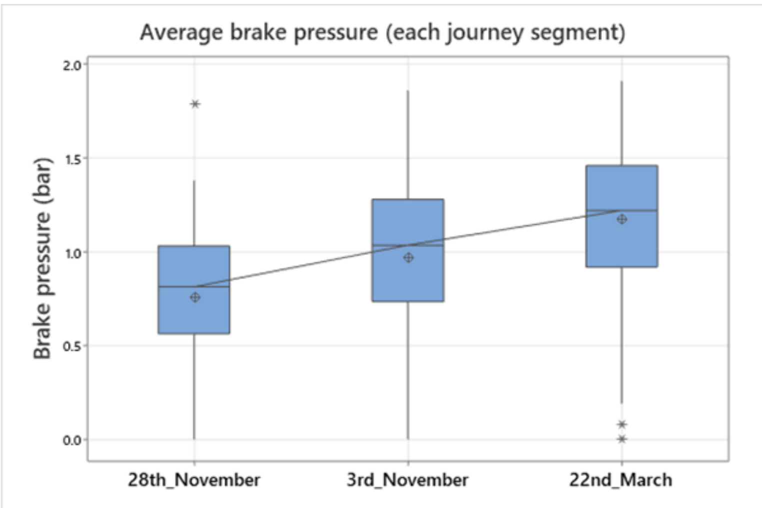

Figure 31: Comparison of average brake pressure in different adhesion conditions

The graph shows the average brake pressure increasing substantially between the low adhesion day and the normal adhesion day. Perhaps, more surprisingly the average brake pressure increases further on the spring day, possibly indicating that drivers are more confident in these conditions and are braking harder and later.

5.5.2 Train speed

Figure 32 shows the maximum train speeds achieved for each of the three days. Train speeds for the poor adhesion day are significantly lower than in the other two days. There is no significant difference between the speeds recorded on the normal autumn day and the spring day.

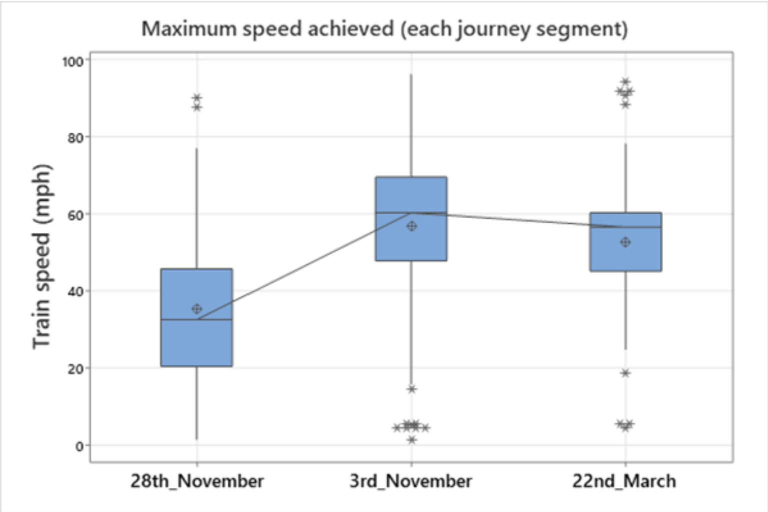

Figure 32: Comparison of maximum speeds in different adhesion conditions

Figure 33 shows a very similar picture for average train speeds, with a significant reduction on the poor adhesion day and no significant difference for the other two days.

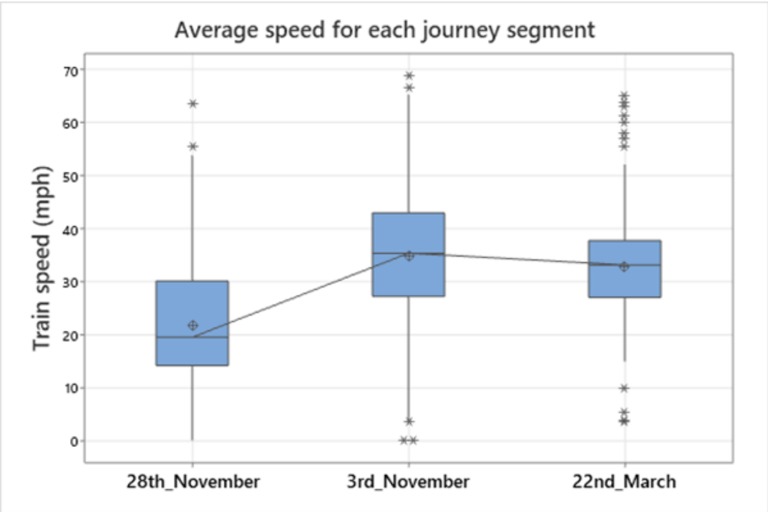

Figure 33: Comparison of average speeds in different adhesion conditions

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5.6 Effect of weather on train performance

Network Rail provided access to their trackside weather stations through the Rail Weather Monitoring website. Although there are many monitoring stations, it was not possible to access data from the exact locations of the test trains. The weather station selected for the overall weather analysis was Glazebury as it is relatively close to the sections where the test trains operated. Figure 34 shows a map of the weather stations available in the North-Western region.

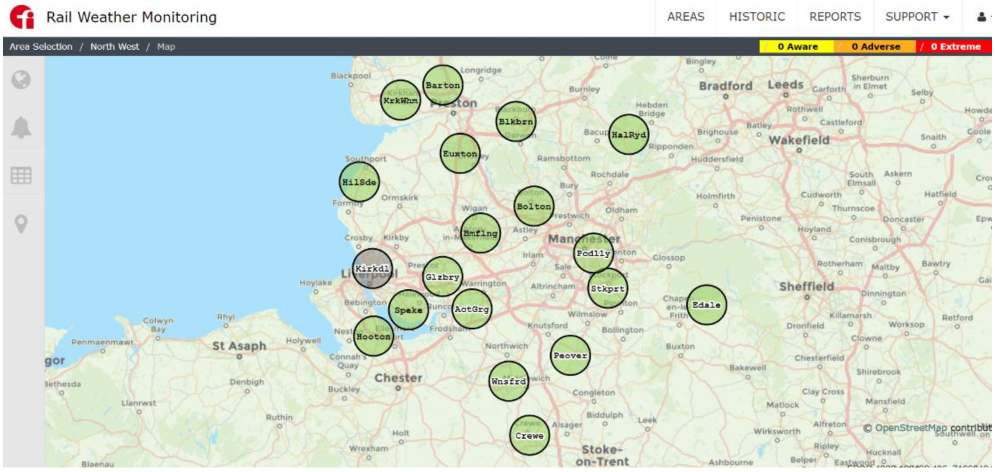

Figure 34: Map of North-Western region weather stations

While the Glazebury station provided a range of weather parameters, the analysis focused on three main measurements: Air temperature (°C), precipitation intensity (mm/hr) and a calculated value related to dew formation on the rail head (based on the relationship of dew point to railhead temperature).

5.6.1 Weather impact on braking

Figure 35 shows how braking performance relates to precipitation and railhead dew formation for a selected period in autumn. The green trace shows precipitation intensity in mm/hr, the blue trace shows the difference between dew point and railhead temperature and the red bars show the resultant deceleration values achieved in step 2 at times when water is deployed.

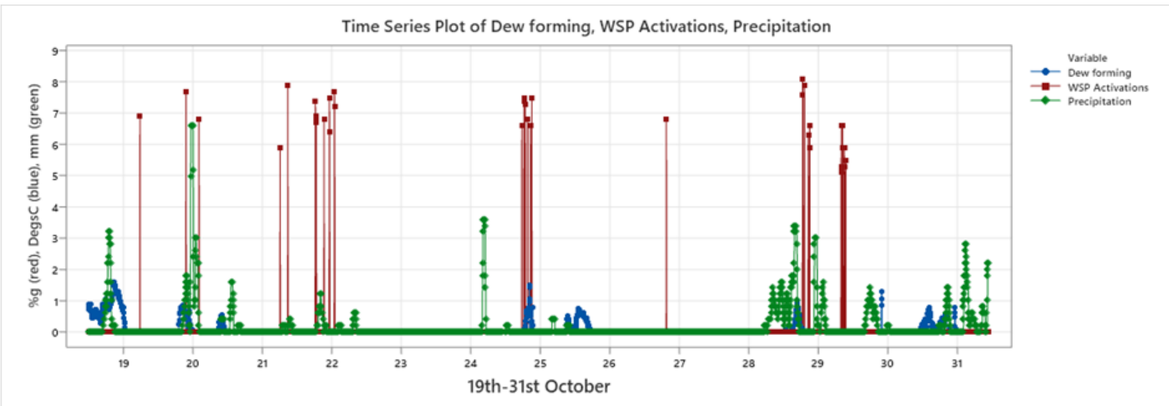

Figure 35: Relationship between deceleration, precipitation and dew formation

The graph illustrates that most wheel slide events occur around periods of light rain or dew formation, reinforcing the understood relationship between low adhesion and railhead moisture.

Figure 36 shows a scatter plot relating deceleration to air temperature for both Water-Trak (shown in blue) and the Control group (shown in red). There is a significant quadratic relationship between air temperature and deceleration for both groups indicated by the regression lines. A drop in air temperature from 10°C to zero reduces deceleration by approximately 1%g for both groups.

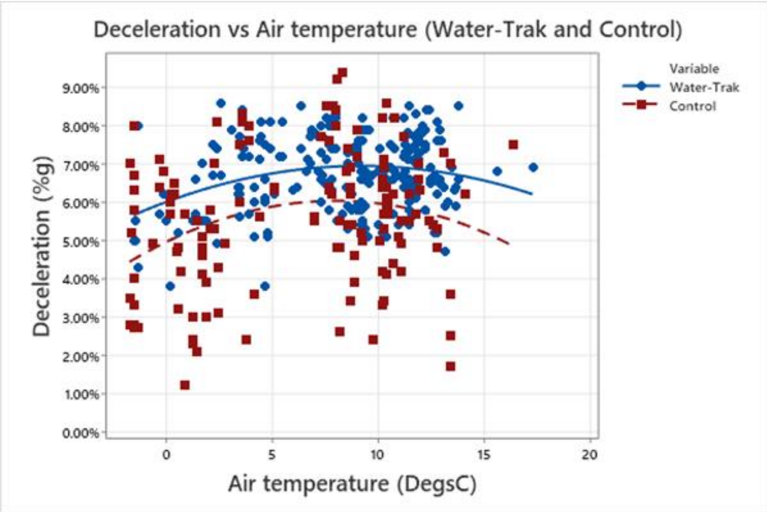

Figure 36: Relationship between air temperature and deceleration

Figure 37 graphs the relationship between precipitation intensity (mm/hr) and deceleration in %g. The vast majority of wheel slide events are occurring at low precipitation levels and there is some indication of improving deceleration as precipitation increases.

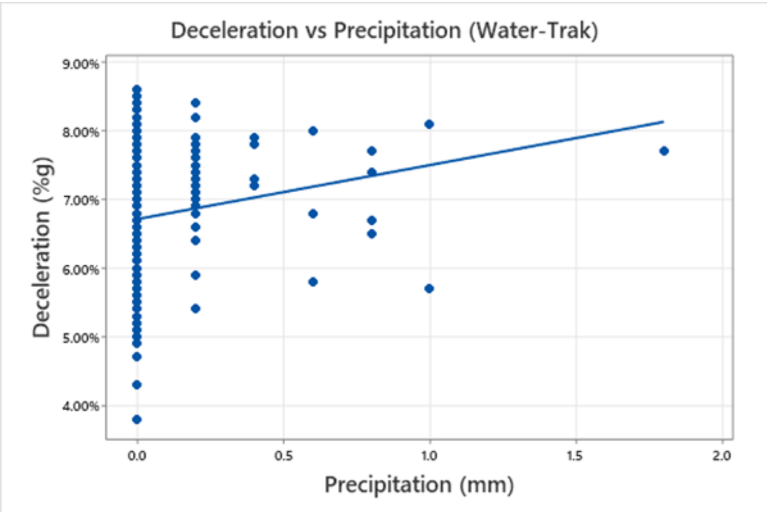

Figure 37: Relationship between precipitation intensity (mm/hr) and deceleration

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6 SUMMARY

6.1 Conclusions

Water-Trak has been proven in service. The systems, fitted to two Class 319 passenger service trains, have functioned without problems through an entire autumn, covering over 37,000 miles and dispensing water 767 times. The trials demonstrated that water addition can improve train performance in low adhesion conditions, yielding the following operational evidence:

- Water-Trak provides improved braking performance in low adhesion conditions increasing median step 2 deceleration by 0.8%g. This is equivalent to a reduction in stopping distances of more than 12%. It is also important to note that the variation in deceleration is significantly reduced, in particular eliminating some of the lowest braking values.
- When step 3 braking is applied, Water-Trak provides an additional 2%g deceleration, giving an overall reduction in stopping distance of more than 30% compared with single fixed-rate sanding alone. It is notable that the control group of trains (also equipped with single fixed-rate sanders) did not show similar improvements in braking performance.
- Water-Trak has been shown to provide a major improvement in traction, increasing median acceleration from $0.18 m/s^2$ to $0.3 m/s^2$ in power notch 4. The trial results also highlighted difficulties in applying water appropriately for the conditions when simply triggered from the cab-mounted sanding button.
- Analysis of journey times for individual legs did not reveal any significant difference between the Water-Trak trains and other Class 319s operating in the same regions. A study of linked-leg journeys when Water-Trak was deployed has shown a journey time improvement for both Water-Trak and following trains.

In addition, the trial has produced the following findings:

- Although results from both trains were significantly better than the Control, a significant difference in braking and traction performance was found between 319368 and 319379, with the latter train performing less well.
- There was a measurable difference in driving style on poor adhesion and good adhesion days, based on the analysis of braking and speed data.
- The analysis of the effect of precipitation and dew formation on wheel slide and deceleration confirms that water plays a key role in creating low adhesion conditions.
- Air temperature has been found to impact braking performance with temperatures approaching zero giving the lowest deceleration values.

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6.2 Recommendations

- For train operating companies, the key operational metrics relate to journey times and delays. The small number of trains running in this trial has limited the opportunity to demonstrate the impact of Water-Trak on these higher-level measures. The next step towards quantifying the benefits of water addition should be to operate Water-Trak across a fleet of trains. Fleet fitment will build driver confidence and enable the effect of multiple deployments of water on the same lines of route to be assessed.
- Driving style is likely to be a key enabler for improved journey times and reduced delays so it is important to engage with drivers ahead of any further autumn trials. This will help to maximise the operational benefits of Water-Trak.
- The significant difference discovered between the two Class 319 trains highlights an opportunity to improve the performance of Water-Trak equipped trains. The reasons behind the differing results for the two units should be investigated and any resulting knowledge used to improve the performance of future Water-Trak trains.
- While Water-Trak has been shown to deploy relatively small amounts of water, consider further limiting water usage by reducing the water dispense time.
- The trial results have shown the potential for water to improve traction as well as braking. To realise any possible improvement, it will be necessary to develop a new traction dispensing strategy to minimise water usage and avoid dispensing inappropriately.
- The report shows that temperature is likely to have a significant effect of braking performance. These findings are in line with previous work which has shown that higher water temperatures result in better deceleration. Further research should be conducted to investigate how braking performance can be impacted by dispensing pre-heated water.

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