Effect of Adverse Weather Conditions on Speed-Flow-Occupancy Relationships

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The effect of adverse weather conditions on the flow-occupancy and speed-flow relationships is studied. The data used in the analysis were obtained from the Queen Elizabeth Way Mississauga freeway traffic management system. Regression analyses were performed to select proper models representing the flow-occupancy and speed-flow relationship for uncongested operation. Then dummy variable multiple regression analysis techniques were used to test for significant differences in traffic operations between different weather conditions. It is concluded that adverse weather conditions reduce the slope of flow-occupancy function and cause a downward shift in the speed-flow function. Adverse weather conditions also reduce the maximum observed flow rates.

This paper addresses the effect of adverse weather on freeway operations, a topic that is of interest for several reasons. Most of the data and analyses presented in standard reference works such as the *Highway Capacity Manual* (HCM) (*1*) deal solely with "correcting" for other departures from ideal conditions. No corrections are provided for weather effects, in part perhaps because little is known in detail. The introduction of intelligent vehicle-highway systems (IVHS) will require much more detailed knowledge of the operational characteristics of freeways under various conditions. If adaptive control of freeways is to become a reality, one of the factors that must be adapted to is weather. Intuitively, snow or heavy rain decreases speeds and perhaps volumes. The topic of this paper is not simply whether that intuition is correct, but what quantities can be put on those intuitive expectations.

BACKGROUND

Three main issues are addressed in the literature review. The first is the findings of previous studies on the effect of adverse weather conditions on speed-flow-occupancy relationships. The second is the nature of the functions for those relationships, to focus the analysis. The third issue concerns using a dummy variable multiple regression analysis technique that provides a means of testing for significant differences between data sets.

A computerized bibliographic search was conducted through the Transportation Research Information Service records and the Engineering Information Index to find related previous work. The search showed that six items dealt with the effect of weather on roadway traffic operations. One of the six, by Hall and Barrow (*2*), discussed the effect of weather on the relationship between flow and occupancy; the other five (*3–7*) focused on the relationship between adverse weather and road safety. Two results of those studies were helpful for this analysis. Andrey and Yagar found that collision risk returns to normal immediately after rain stops (*7*). Hence, it appears important to confine the analysis to the occurrence of adverse weather in order to indicate clearly the impact of weather on traffic operations. Salonen and Puttonen found that darkness reduces the operating speed by 5 km/hr (*3*). Thus, the weather effect should be studied keeping day- and nighttime traffic data separate.

In addition to those found through the computerized bibliographic search, there are three more references mentioned in Chapter 6 of the HCM. Jones and Goolsby reported a reduction in capacity of 14 percent during rain, but the severity of the rain is not noted (*8,9*). Kleitsch and Cleveland reported an average reduction of 8 percent but emphasized the variation in the reduction that was associated with rainfall intensity (*10*).

The literature can also be helpful on a second topic, the shape of the function to use in the analysis. Several researchers (*11–14*) have reported on the occurrence of gaps or discontinuities in freeway speed-density and flow-density data. They suggested that discontinuous functions are necessary to properly describe the observed traffic behavior. Given the recent changes in understanding of the shape of the speed-flow curve (*15*), rather than use functional forms as specified in the earlier literature, regression analysis will be used to identify forms from the data. To simplify the analysis, only the uncongested operations will be analyzed.

The dummy variable multiple regression analysis technique used by Hall and Barrow (*2*) will be used for the current study. That technique used a dummy variable with values of 1 and 0 to distinguish between two data sets. For instance, if a linear function is used to represent the flow-occupancy relationship (for the uncongested data), the general equation used for the dummy variable regression analysis will be of the form

$$\begin{aligned}\text{Flow} = a + b * \text{occupancy} + c * \text{dummy} \\ + e * \text{dummy} * \text{occupancy}\end{aligned}$$

If the coefficient of the dummy variable is significantly different from 0, there is a significant difference for the value of the intercept between the two data sets by an amount equal to the estimated coefficient c. If the coefficient on the product of the dummy and occupancy is significant, this means there is a difference in the slope with a value equal to the coefficient e. When both coefficients involving the dummy variable are significant, both slope and intercept for the two functions are different. Under those conditions, for the data set that has a dummy value equal to 0,

$$\text{Flow} = a + b * \text{occupancy}$$

For the data set that has a dummy value equal to 1,

$$\text{Flow} = (a + c) + (b + e) * \text{occupancy}$$

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DATA

There are two issues to address with respect to the data for this study: first, where they come from and how the sites and times were selected for analysis; second, how the weather information was obtained, how well it represents actual conditions at the site, and how it affects the sample selection.

The traffic data available for this study were from the freeway traffic management system (FTMS) for the Queen Elizabeth Way (QEW) in Mississauga, Ontario. The data are recorded 24 hr/day at 30-sec intervals. Three variables are available: volume, occupancy, and speed.

Three criteria were chosen for site selection. The first was the existence of double loop detectors, which provided measured speeds. The second was that the study site should not be influenced by ramp or weaving sections. The third was the data quality. Only Stations 14 and 21 met all criteria; both are used for the analysis.

The study was performed for the median lane and for the average data across three lanes. The median lane has the highest flow rates of the three lanes and includes passenger cars only. Any differences between that and the three-lane average data could indicate the effect of adverse weather on the behavior of trucks and slow vehicles.

The comparison between weather conditions was limited to the same time of day under each condition for three reasons. First, driver behavior differed from daytime to dark for the same weather condition, as found by Salonen and Puttonen (*3*). Second, regression equations representing the flow-occupancy relationship for different periods proved to be significantly different. Third, data sets from various times of day included a different range of occupancy and flow, which itself made any cross-period comparison difficult.

Detailed weather records for Pearson International Airport were obtained from the Atmospheric Environment Service in Downsview, Ontario, and were compared with the operators' log book at the FTMS center in Mississauga to ensure that the records for the airport accurately reflected weather conditions at the QEW freeway in Mississauga. The information available in the operators' log book agreed with the airport weather records.

Three factors were considered in selecting days to use in the study. The first was to include days with different types and intensities of weather conditions: light rain, heavy rain, light snow, snow storms, and clear. The visibility criterion was used to identify the intensity of snow, and the rate of fall was used to identify the intensity of rain. To increase the likelihood of adverse weather conditions, the months of October, November, and December 1990 and January and February 1991 were considered. Clear days were taken from the same months.

The second factor considered in choosing the days was day of the week. It was hoped to exclude Saturdays, Sundays, and holidays because of possible changes in travel patterns, but Saturday, December 29, 1990, was used for rainy weather conditions because it had 6 hr of rainfall during the relevant time of day, and there was a lack of good data for rainy conditions during other days.

As stated, the comparison was limited to the same period in all days. To enable a focus on uncongested data, the period from 10:00 a.m. to 4:00 p.m. was chosen. If adverse weather did not last for the whole 6 hr, observations before or after adverse weather were deleted from the data file. The result is that the days used for the analysis constitute not a probability-based sample but all of the days with consistent adverse weather in the period investigated, together with an arbitrarily chosen representative set of days with clear weather (Table 1).

TABLE 1 Selected Days for Different Weather Conditions

Date (yymmdd)	Weather cond.	Duration of weather condition	Number of Good Data Points			
			Station 14		Station 21	
			median lane	Avg over 3 lane	median lane	Avg over 3 lane
901002	clear	10:00 - 16:00	297	634	706	720
901015	clear	10:00 - 16:00	720	604	702	720
901115	clear	10:00 - 16:00	601	567	593	601
901116	clear	10:00 - 16:00	697	695	694	690
901205	clear	10:00 - 16:00	697	720	719	720
901210	clear	10:00 - 16:00	694	720	720	720
901105	rain	10:00 - 16:00	677	695	658	663
901122	rain	10:00 - 16:00	674	588	710	712
901221	rain	10:00 - 16:00	720	713	707	711
901229	rain	10:00 - 16:00	720	688	720	722
901012	rain	11:49 - 16:00	495	388	465	494
910214	snow	10:00 - 16:00	713	720	719	720
910215	snow	10:00 - 15:13	556	553	521	528
910108	snow	10:00 - 14:00	333	332	308	403
910111	snow	10:00 - 16:00	661	571	647	618
901204	snow	10:00 - 16:00	720	720	693	696
901203	snow	10:00 - 14:30	414	390	423	400

SELECTION OF MODELS AND PRELIMINARY ANALYSIS

Regression analyses were conducted on the clear weather data to select models for the uncongested part of the flow-occupancy and speed-flow relationships. From a visual inspection of a plot of 30-sec flow-occupancy data, two functional forms appeared plausible: a linear function or a quadratic function. For the linear model, flow = $a + b *$ occupancy, the results are as follows:

St. 14 (median): flow = 1.4 + 1.14 * occ $R^2 = .9592$
St. 14 (average): flow = 2.2 + 0.85 * occ $R^2 = .8434$
St. 21 (median): flow = 4.8 + 0.75 * occ $R^2 = .6165$
St. 21 (average): flow = 2.5 + 1.06 * occ $R^2 = .8581$

The regression analysis showed significant values for the intercept and slope at the 5 percent level and respectable values of R^2, indicating a good fit of the model to the data. However, three of the intercept values are large, which is meaningless in practical terms. It is possible to have a value of 1 or 2 veh/30 sec at zero occupancy since the occupancies are truncated, but it is not possible to have a value of 4.8, and even 2.5 is unlikely.

For the second model, flow = $a + b *$ occupancy $+ c *$ occupancy^2, the results are as follows:

St. 14 (median): flow = 0.8 + 1.29 * occ − 0.009 * occ^2 $R^2 = .9607$
St. 14 (average): flow = 1.3 + 1.08 * occ − 0.013 * occ^2 $R^2 = .8461$
St. 21 (median): flow = 1.2 + 1.42 * occ − 0.034 * occ^2 $R^2 = .6367$
St. 21 (average): flow = 1.2 + 1.39 * occ − 0.020 * occ^2 $R^2 = .8612$

All the estimated parameters were again significant at the 5 percent level, and the value of R^2 is in all four cases slightly higher than for the linear model. The fact that the quadratic term is significant led to the choice of the quadratic model over the linear model. As well, with the quadratic term, the value of the intercept dropped to 1 veh/30 sec.

For speed-flow data, the 30-sec observations showed high scatter, which made it difficult to predict a good model for this relationship. Nevertheless, three functions were tested to fit the data. The linear model showed significant values (at the 5 percent level) for the intercept and coefficient but a very low R^2, as follows:

St. 14 (median): speed = 114 − 0.36 * flow $R^2 = .0679$
St. 14 (average): speed = 104 − 0.42 * flow $R^2 = .0308$
St. 21 (median): speed = 100 − 0.48 * flow $R^2 = .0623$
St. 21 (average): speed = 100 − 0.47 * flow $R^2 = .0549$

The low values of R^2 can be attributed to the high scatter in the data. The fact that the R^2 is so low suggests that caution should be used when interpreting the coefficient on flow, even given that it is statistically significant. The flow used in the regressions is the actual 30-sec volume, which ranges from 0 to 25 vehicles. Hence, a coefficient of 0.4 would imply a speed drop of 10 km/hr over the full range. Because 25 veh/30 sec would translate to a flow rate of 3,000 veh/hr, it can be seen that there is very little speed drop over the range of flows. (Of course, the flow of 25 veh/30 sec is not sustained even for two consecutive 30-sec intervals, much less for a full 1 hr.)

A quadratic function was also estimated. It did not improve the R^2; it reduced the significance of the linear coefficient for the median lane data; and it did not result in significant coefficients for the three-lane average data. Therefore, the linear model was chosen over the quadratic model.

In addition, analysis was conducted to test the goodness of fit of a piecewise linear model. The break-point between the two segments of the model was identified by using the multiple regression technique with one dummy variable. The equation used was of the form

$$\text{Speed} = A + B * \text{flow} + C * \text{dummy} + E * \text{dummy} * \text{flow}$$

Five values of the breakpoint, from 12 to 18 veh/30 sec (1,440 to 2,160 vph), were tested. The R^2 values were all small (from .0680 to .0691). Compared with the value of R^2 for the linear model (.0679), there was not much gained by using a piecewise model. Therefore, in order to simplify the comparison between weather conditions, the simple linear model was used for the speed-flow relationship.

COMPARISON STUDY OF DIFFERENT WEATHER CONDITIONS

Three comparison tests were performed to study the effects of rainy and snowy weather on the underlying relationships: first, clear and rainy weather were compared to test the effect of rainy weather and investigate whether differences within the rainy weather were more important than differences between the clear and rainy weather; then clear and snowy weather conditions were compared in a similar manner, as were rainy and snowy conditions. All three analyses were conducted using the 30-sec data, which incorporates the greatest amount of variation. To test whether the results depended on the level of temporal aggregation, tests were also conducted with 5-min aggregated data. Finally, the effect of adverse weather on maximum observed flows is observed.

Variation Within Each Weather Condition

An important issue was whether to treat all days of the same weather condition as one data set. This issue was decided with a two-step analysis. First, a regression analysis was done for each day separately, and then the underlying functions for all days of each weather condition were plotted on the same graph to identify the upper and lower functions for each condition. Second, multiple regression analyses were conducted to test the differences between the highest and lowest functions for each weather condition.

The highest and lowest functions for clear days at both stations were found to be statistically different. For the flow-occupancy function, over the four data sets the dummy variable itself never entered, the dummy on slope was significant (at the 5 percent level) in two of the four analyses, and the dummy on curvature was significant three times. For the speed-flow relationship, the dummy entered three of four times (with the largest magnitude being 3 km/hr), as did the dummy on the slope. Hence there are differences between the upper and lower functions for clear days, but the nature of the differences is not the same across the four data sets.

Nevertheless, these results may reflect normal variation within a range of behavior that can be represented by an average equation for all clear days. Hence, a test was conducted for the upper day, December 10, 1990, against the data of the other five clear days. There was a statistically significant difference in the curvature of the flow-occupancy function for the four data sets, but it was small in practical terms. For instance, the largest value of the difference in the quadratic term was found to be –0.005 (for median lane data at Station 14). For occupancy equal to 20 (the highest observed value), the difference in the flow would be 2 veh/30 sec.

For the speed-flow relationship, differences were absent in two data sets and minimal in the third. A noticeable difference was found for the slope and intercept only for median lane data at Station 14.

Although these analyses showed that there are some differences within the clear days, the differences are not consistent across the four data sets, nor are the differences for the most part of practical significance. Therefore, it was decided to consider the data for the 6 days as one data file representing the clear weather, which would have the benefit of retaining considerable variation within this part of the data.

Testing the differences within the rainy and snowy weather showed that there were significant differences in the intercept, slope, and curvature of the flow-occupancy relationship and in the intercept for the speed-flow relationship. The magnitude of these differences between the upper and lower functions for snowy days was much bigger than for the rainy days, especially for the slope of the flow-occupancy relationship and the intercept of the speed-flow function. Thus, it was decided not to treat the rainy or snowy days as one data file but to consider the highest and lowest functions in the comparison of weather conditions. The highest function was termed the "light" condition (rain or snow) and the lowest was termed the "heavy" condition. This means that although 5 and 6 days of data were selected for these two conditions, only December 21 and November 5, 1990, for the rainy days and December 4 and December 3, 1990, for the snowy days will be used in the ensuing analysis.

Comparison Between Clear and Rainy Weather

The comparison analysis used two dummy variables. The first tested the difference between clear and light rain (dummy1 = 0 for clear, 1 otherwise), and the second tested the difference between light and heavy rain (dummy2 = 1 for heavy rain, 0 otherwise). The results (Table 2) showed that the difference in slope of the flow-occupancy function within the rainy condition (ranging from –0.12 to –0.16) was more important than the difference between slopes for the clear and light rain (which vary from 0.07 to –0.04). The difference in the intercept of the speed-flow function within the rainy weather (ranging from –3 to –9 km/hr) was more important than the difference between the clear and rainy weather (which was only –1 or –2 km/hr).

Heavy rain caused a decrease in the slope of the flow-occupancy function (with a maximum value of –0.16 for the three-lane average data at Station 14). For the speed-flow function, there was a drop in the free-flow speed (with a maximum value of 10 km/hr for the median lane data at Station 14) and a change in the slope (with a maximum value of –0.56 for the three-lane average data at Station 14). Interestingly, the slope does not vary between light and heavy rain; only the intercept (free-flow speed) does.

Comparison Between Clear and Snowy Weather

A similar analysis was performed for snowy weather. The difference within the snowy weather was again greater than that between clear weather and light precipitation, as indicated in Table 3. Heavy

TABLE 2 Testing Difference Between Clear and Rainy Weather

The Flow-Occupancy Relationship

Variable	Station 14		Station 21	
	Median lane	Average over 3 lanes	Median lane	Average over 3 lanes
Intercept	0.8	1.1	1.9	1.5
Occupancy	1.29	1.13	1.39	1.40
Occupancy^2	- 0.009	- 0.015	- 0.032	- 0.021
Dummy1				
Dummy2				- 0.7
Dummy1*Occupancy	-0.04	0.02		0.07
Dummy2*Occupancy	-0.12	- 0.14	- 0.16	
Dummy1*Occupancy^2				- 0.006
Dummy2*Occupancy^2				- 0.1

The Speed-Flow Relationship

Intercept	114	105	101	102
Flow	- 0.36	- 0.49	- 0.53	- 0.64
Dummy1	- 1	- 2	- 2	
Dummy2	- 9	- 3	- 5	- 7
Dummy1*Flow	- 0.20	- 0.56	- 0.22	- 0.33
Dummy2*Flow				

Dummy1=0 for Clear
Dummy2=0 for Clear and Light Rain

Dummy1=1 for Light and heavy Rain
Dummy2=1 for Heavy Rain

TABLE 3 Testing Difference Between Clear and Snowy Weather

The Flow-Occupancy Relationship

Variable	Station 14		Station 21	
	Median lane	Average over 3 lanes	Median lane	Average over 3 lanes
Intercept	0.8	1.3	1.8	1.3
Occupancy	1.29	1.08	1.42	1.39
Occupancy^2	- 0.009	- 0.012	- 0.034	- 0.020
Dummy1			- 0.3	
Dummy2	- 0.6	- 1.0	- 0.8	0.8
Dummy1*Occupancy				0.06
Dummy1*Occupancy^2	- 0.003	- 0.003	- 0.004	
Dummy2*Occupancy	- 0.46	- 0.36	- 0.51	- 0.47
Dummy2*Occupancy^2	- 0.007		0.017	
The Speed-Flow Relationship				
Intercept	114	105	101	102
Flow	- 0.37	- 0.43	- 0.54	- 0.64
Dummy1			- 3	- 1
Dummy2	- 50	- 41	-35	- 37
Dummy1*Flow	- 0.23	- 0.19		- 0.20
Dummy2*Flow		- 0.42		

Dummy1=0 for Clear Dummy1=1 for Light and heavy Snow
Dummy2=0 for Clear and Light Snow Dummy2=1 for Heavy Snow

snow affected traffic operation dramatically; it reduced the slope of the flow-occupancy function by a maximum value of 0.53 (three-lane average data at Station 21). It also caused a drop in free-flow speed between 35 and 50 km/hr and changed the slope of the speed-flow function three times out of four with a maximum value of –0.61 (three-lane average data at Station 14).

Comparison Between Snowy and Rainy Conditions

The differences between snowy and rainy weather were tested by using three dummy variables. The first distinguished between the snowy and rainy weather (dummy1 = 0 for light and heavy snow, 1 otherwise). The second involved differences within the snowy weather (Dummy2 = 1 for heavy snow, 0 otherwise), and the third tested differences within the rainy weather (dummy3 = 1 for heavy rain, 0 otherwise).

There was no significant difference between light rain and light snow, but there were great differences between heavy rain and heavy snow (Table 4). For the flow-occupancy function, the magnitude of difference in slope between the light snow and heavy snow (–0.42) was greater than the difference between the light rain and heavy rain (–0.12). For the speed-flow relationship there was a drop in the intercept values between and within each of the two adverse weather conditions. The greatest drop was within the snowy weather (–50 km/hr for median lane data at Station 14); next was that within the rainy weather (–9 km/hr); and the smallest drop was between the light snow and light rain (–1 km/hr).

In conclusion, heavy snow had a greater effect on traffic operations than heavy rain, whereas light rain and light snow have nearly the same effect on traffic operations. There are significant differences in the effects of the two adverse weather conditions depending on the degree of severity of each. Rainfall may affect traffic more than snow and vice versa, depending on the rate of fall, pavement wetness, and visibility.

Five-Minute Data Analysis

After the comparison study based on 30-sec data, median lane data at Station 14 were aggregated to 5-min intervals and similar analyses were repeated to test whether the findings depended on the level of temporal aggregation. Differences that were not significant when using 30-sec data may become significant when using 5-min data because of the lesser variability, since aggregation reduces the scatter of the data.

For the flow-occupancy function the quadratic term was not significant at the 5 percent level. Hence, the linear model appears to be appropriate for the 5-min uncongested data. For the speed-flow relationship, the linear model is still appropriate.

Testing differences within the same weather condition matched to a great extent the previous results based on the 30-sec data files except that there was a significant difference in the intercept of the flow-occupancy function within clear weather; it was practically minimal, however. Within the rainy condition the significant difference in the slope of the flow-occupancy function at the 30-sec data was not found for the 5-min data.

The results of the comparison study between different weather conditions using 5-min data matched the results of the analyses using the 30-sec data two-thirds of the time. For instance, differences between clear and rainy weather and between rainy and snowy weather matched the results for the 30-sec data.

Some results of the comparison between clear and snowy weather were different from those obtained for the 30-sec data. There was a

TABLE 4 Testing Difference Between Snowy and Rainy Weather

The Flow-Occupancy Relationship

Variable	Station 14		Station 21	
	Median lane	Average over 3 lane	Median lane	Average over 3 lane
Intercept	0.9	0.4	2.0	0.6
Occupancy	1.25	1.25	1.29	1.51
Occupancy^2	- 0.009	- 0.023	- 0.031	- 0.033
Dummy1				
Dummy2	- 0.6		- 1.3	
Dummy3				
Dummy1*Occupancy			0.08	0.08
Dummy2*Occupancy	- 0.42	- 0.47	- 0.39	- 0.72
Dummy3*Occupancy	- 0.12	- 0.08	- 0.16	- 0.17
Dummy1*Occupancy^2		0.004		
Dummy2*Occupancy^2	- 0.010		0.010	0.018
Dummy3*Occupancy^2		- 0.005		

The Speed-Flow Relationship

Variable	Station 14 Median lane	Station 14 Average over 3 lane	Station 21 Median lane	Station 21 Average over 3 lane
Intercept	114	106	98	102
Flow	- 0.58	- 0.76	- 0.56	- 0.93
Dummy1	- 1		- 2	
Dummy2	- 50	- 42	- 35	- 37
Dummy3	- 9	- 6		
Dummy1*Flow				
Dummy2*Flow				
Dummy3*Flow		- 0.28	- 0.44	- 6.76

Dummy1=0 for Light and Heavy Snow — Dummy1=1 for Light and Heavy Rain
Dummy2=0 for Light Snow, Light and Heavy Rain — Dummy2=1 for Heavy Snow
Dummy3=0 for light and Heavy Snow and Light Rain — Dummy3=1 for Heavy Rain

significant difference in the intercept between the clear and light snow for the flow-occupancy relationship, and there was a significant difference in the intercept between the clear and light snow for the speed-flow relationship.

The magnitude of the effect of adverse weather using the aggregated 5-min data was almost the same as that for the 30-sec data. For instance, heavy rain caused a reduction in the free-flow speed of 10 km/hr compared with 11 km/hr for the 30-sec data; heavy snow caused a reduction in free-flow speed of 60 km/hr compared with 50 km/hr for the 30-sec data.

Effect of Adverse Weather on Maximum Flows

The effect of adverse weather on capacity is also important. However, the data selected for the previous comparisons did not include operations at capacity: Station 14 lies upstream of three major bottleneck sections on the QEW freeway, and Station 21 lies just upstream of the major bottleneck section and thus is operating most of the time within a queue. Consequently, data on capacity operations were not available at those locations, and the effect of adverse weather on capacity cannot be investigated from the data for these two stations. However, some indication of the effect of adverse weather on flows can perhaps be obtained at these stations, simply by looking at the highest flow rates observed for clear days and for the worst days of rain and snow conditions.

Additional data, for the period from 6:00 to 10:00 a.m. to include data for the morning peak period (usually between 6:30 and 9:30 a.m.), were collected for these days to cover the highest flow rates at each site. The weather records were reviewed to ensure that only data during adverse weather were included.

The speed-flow median lane data at Station 14 during clear, heavy snow, and heavy rain conditions are shown in Figure 1. There is a

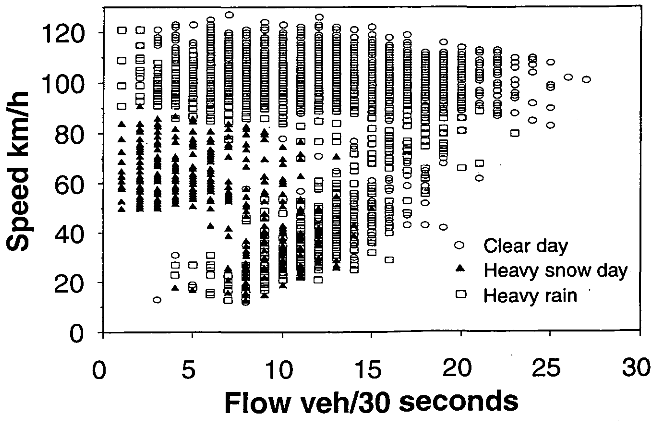

FIGURE 1 Speed-flow data for clear, heavy snow, and heavy rain at Station 14, median lane.

TABLE 5 Maximum Observed Flows for Clear, Heavy Rain, and Heavy Snow Conditions

	Station 14		Station 21	
	Median lane	Avg. over 3 lanes	Median lane	Avg. over 3 lanes
Clear Day				
Flow (vph)	3000	2160	2400	2400
Speed (km/h)	100	90	80	85
Occupancy (%)	25	19	20	18
Heavy Rain				
Flow (vph)	2400	1920	2160	2040
Speed (km/h)	90	75	70	70
Occupancy (%)	20	20	20	20
Heavy Snow				
Flow (vph)	1560	1200	1560	1680
Speed (km/h)	55	40	40	80
Occupancy (%)	30	30	27	13

Speed and occupancy are the averages at maximum flows.
The flows are hourly rates based on 30-second data.

drop in the maximum observed flows, with the drop increasing as the weather worsens. Table 5 presents a summary of the maximum attained values of flow (observed at least five times) and the average of observed occupancies and speeds at those maximum flows at Stations 14 and 21 for both median and three-lane average data.

At Station 14, heavy snow caused a reduction in the maximum flow rate of about 48 percent below the value for clear weather. Heavy rain caused a reduction in the maximum flow rate of about 20 percent. These reductions are slightly lower at Station 21 and for three-lane average data. It should be noted that these results are based on only a few hours of data on a few days at two locations on the freeway.

CONCLUSIONS

The comparison study, based on 68 data files of three weather conditions, confirmed that adverse weather conditions affect both the flow-occupancy and speed-flow relationships: the more severe the weather condition, the greater the effect on traffic operations.

Light rain and light snow caused minimal effects on both relationships. For instance, for the speed-flow function (Figure 2), light rain caused a drop in the free-flow speed of a maximum of only 2 km/hr (Table 2, Dummy 1) and an increase in slope varying from –0.20 to –0.56 km/hr/veh/30 sec. At a flow of 20 veh/30 sec (2,400 veh/hr), the combined effect of these two terms would be a drop in speed of about 13 km/hr relative to speeds during clear, dry weather. Light snow caused a drop in the free-flow speed of a maximum of 3 km/hr and a change in slope varying from –0.19 to –0.23. At 20 veh/30 sec, these coefficients imply a drop in speed of about 8 km/hr relative to dry weather. These changes due to light precipitation are statistically significant, but because of the high scatter of data, they may not be of practical importance.

Heavy precipitation, on the other hand, made a noticeable difference in both functions, with heavy snow having a much greater effect than that of heavy rain. The effect can be understood more easily with the speed-flow function results (Figure 3): heavy rain caused a drop in free-flow speeds varying from 5 to 10 km/hr (Table 2, Dummy 1 + Dummy 2) with a change in slope varying from –0.2 to –0.56; heavy snow caused a drop in free-flow speeds varying from 38 to 50 km/hr (Table 3, Dummy 1 + Dummy 2) with a change in the slope varying from –0.20 to –0.61. If flows of 20 veh/30 sec were still observed under heavy snow conditions, these coefficients suggest that the speeds would be reduced by more than 60 km/hr relative to dry weather. This effect stands out despite the variation in the data.

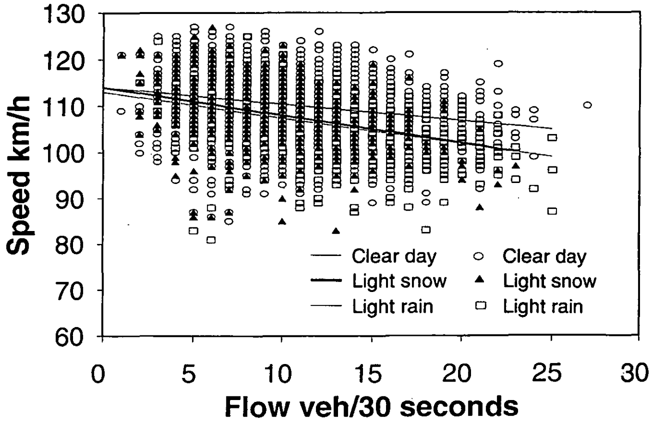

FIGURE 2 Speed-flow data (uncongested) and functions for clear, light snow, and light rain at Station 14, median lane.

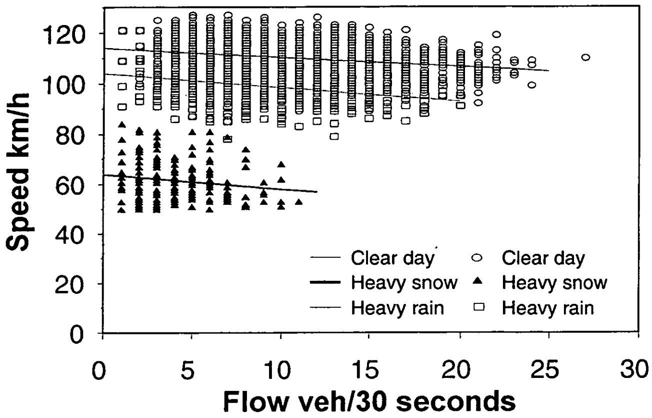

FIGURE 3 Speed-flow data (uncongested) and functions for clear, heavy snow, and heavy rain at Station 14, median lane.

Maximum observed flows were reduced during adverse weather. Heavy rain caused a reduction in the maximum flows of 10 to 20 percent, and heavy snow caused a reduction varying from 30 to 48 percent. Because of the nature of the sites selected, these flows are not capacity flows, but Figure 1 suggests that the flows are good approximations of capacity. These numbers come from only a small sample: two sites, a few hours of data, over a few days. Nevertheless, the changes in maximum observed flows may indicate the magnitude of changes in capacity flows under adverse conditions. Certainly the range of 10 to 20 percent reduction in maximum flows for rain is consistent with the average 14 percent reduction reported by Jones and Goolsby (*8,9*) and with the emphasis on the variability reported by Kleitsch and Cleveland (*10*).

In conclusion, adverse weather clearly affects both the flow-occupancy and speed-flow relationships. Other factors that may affect these relationships are a driver's familiarity with driving in rain and snow. One may expect a greater drop in speeds, for example, during snow in Washington, D.C., than in Ontario. The quality of drainage on the highway—whether it drains well or pools of water remain—can also affect the magnitude of the drop in speeds and flows due to adverse weather.

This paper has documented the range of effects quantitatively for both rainy and snowy conditions on the QEW highway in Ontario. Light precipitation, of either form, does not have a very large effect on any of free-flow speeds, maximum flows, or speed at maximum flows. Both heavy rain and snow can have great effects, such as a 50-km/hr reduction in free-flow speeds, and nearly a 50 percent reduction in maximum observed flows.

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