off as the storm progressed. This may not hold true for storms of abnormally long duration.

The safety aspect of snow and ice control becomes a minor economic effect for short highway segments or highways without extremely high traffic volumes. Many vehicle-kilometers must be traveled during and shortly after a storm for the small difference in accident rates for various road surface conditions to have a measurable effect.

User savings as a result of snow- and ice-control activities should be made by means of a comprehensive economic analysis that includes the costs of providing higher levels of service. The most extreme service for snow and ice control will still result in user costs. It is not anticipated that for every dollar saved in user costs, a dollar's expenditure is justified to control snow- and ice-covered highways. An incremental benefit-cost analysis is required to determine the point of diminishing returns. Even in this case, the costs summarized should be used as a tool to tender responsible administrative decisions.

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Impact of Highway Deicing Salts on Rural Stream Water Quality

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This study examines chloride concentrations in small rural streams receiving runoff from highways treated with deicing salts. Sampling points were established near Jamesville, New York, on Butternut Creek and some of its smaller tributaries. Higher mean chloride levels were found downstream of the highway than upstream. Downstream dilution reduced mean chloride levels in approximately inverse proportion to the additional watershed area; the higher variability was still evident. The chloride level in highway runoff was correlated by linear regression with the level in the receiving stream. Other relations were developed by investigating downstream dilution, stream confluence, temperature, and recent salt applications. Precipitation and temperature seem to act as controls on the release of salts from the highway area into natural drainage systems. There are also indications that much salt can be temporarily stored in the roadway vicinity until it rains. Intensive sampling showed that chloride concentrations can vary significantly in a matter of hours. And, when salt infiltrates the soil, stream chloride levels vary long after the season of salt applications.

The purpose of this study is to provide quantitative, preliminary data for assessing the impact of highway deicing salts on rural stream water quality. Published data of this type are currently rather limited.

Samples taken from rural streams both upstream and downstream of a salted highway were checked for differences in chloride levels attributable to highway runoff. Also investigated were chloride levels in the highway runoff. Also investigated were chloride levels in the highway runoff itself, the effects of dilution as watershed area increases downstream of the highway, and environmental factors affecting salt delivery to the streams.

STUDY AREA DESCRIPTION

The study area is in the Butternut Creek watershed, just east of Jamesville, New York. I investigated Butternut Creek, which has a drainage area of 48.2 km^2 (18.6 miles^2) at the sampling sites, and two small tributaries, stream I, which has a watershed of 1.8 km^2 (0.7 mile^2), and stream II, which drains 1.8 km^2 (0.7 mile^2). These tributaries were further subdivided into basins Ia and Ib, and IIa and IIb in Figure 1, where the sampling sites are the lettered circles.

Butternut Creek in this area runs through a glacial valley on the northern fringe of the Allegheny Plateau. Butternut Valley has a local slope of about 1 percent; the tributaries sampled slope from 5 to 10 percent diagonally down the valley side. All the streams studied receive deicing salt from US-20, which traverses the area in an east-west direction.

Land use is primarily agricultural, but there are woods and permanent pastures, where slope or soil or both precludes efficient cultivation. The area is free of high-density land uses, and residential development is confined to scattered one-family dwellings.

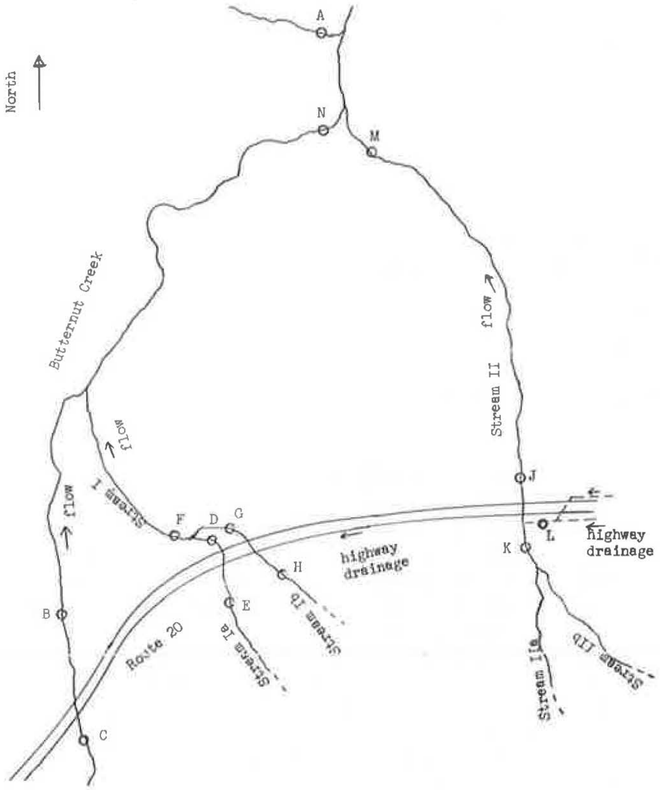
Stream I's watershed includes 0.8 km (0.5 mile) of US-20 and 1.1 km (0.7 mile) of unpaved town road. Stream II's watershed has 1.3 km (0.8 mile) of US-20, 1.7 km (0.8 mile) of paved county road, and 0.8 km (0.5 mile) of unpaved town road. Deicing salt effects from the town and county roads near the upper watershed boundaries are considered minimal.

SAMPLING ANALYSIS AND COLLECTION SITES

Samples were collected on 43 occasions, from January 25 to July 12, 1975, at 14 sites, but not at every site on every occasion. Originally, I intended to concentrate on a stream the size of Butternut Creek, but early results indicated no measurable impact from the US-20 effluent. Thus, most of the conclusions of this study are based on studying the small tributaries.

I chose to test with a chloride field test kit that uses potassium chromate for the indicator reagent and silver nitrate for titration. I was concerned not with minute changes in salt concentrations but with grosser changes that have greater potential impact on stream communities. I took 10 ppm as the lower limits of this testing procedure (1) and as indicative of 10 ppm or less. Samples containing more than about 1000 ppm were diluted to 1 in 4 or 1 in 10 with distilled water for analysis.

Figure 1. Sketch of principal sampling sites.



Climatological data from stations located about 13 km (8 miles) away were used as indicators of general conditions and trends. U.S. Geological Survey flow data from a gauging station on Butternut Creek about 3 km (2 miles) downstream of the study area were obtained as a flow regime indicator.

Highway salt inputs were estimated from records kept by the Onondaga County Highway Department, which maintains US-20 in the study area. These records indicated that about 30 Mg (33 short tons) of sodium chloride were applied to each 1.6 km (1 mile) of US-20 from January 1, 1975, to the end of the season's salting program.

RESULTS OF THE SAMPLING

Basic Analysis and Description of the Data

The range, mean, standard deviation, coefficient of variation, and number of samples taken at each sampling point for chloride levels are given in Table 1. The sampling points are grouped generally by stream or tributary.

Site A was sampled to indicate possible chloride inputs from Onondaga County Route I, which parallels Butternut Creek through the study area. Judging from the levels found at points C, B, and N on Butternut Creek, inputs from all sources in the study area, including Onondaga County Route I, were not sufficient to raise chloride concentrations by a measurable degree. In fact, mean concentrations upstream of suspected inputs are actually higher than downstream means, although by only 1 ppm, which is not considered meaningful with the type of testing I performed. In any event, the inputs certainly have very little impact on Butternut Creek.

Sampling points E and H provide background levels for tributary stream I. One of these locations was usually sampled on any given occasion. The means are in good agreement at 11.8 and 11.2 ppm respectively. On five occasions when stream IIa was tested separately from stream IIb, the mean was 12.4 ppm, which is reasonably close to the levels found in Ia and Ib for a local background concentration. The threshhold value of the testing equipment may have concealed an even lower actual level for these sites.

Point D is downstream of the highway on tributary I. Even though it received drainage from only 137 m (450 ft) of highway, it had an average concentration of 15.3 ppm, or 3.5 ppm higher than point E, which is upstream of the road. Applying the F-test (as outlined by 2, chapter A1) to the 21 occasions when both points were sampled at the same time indicates statistical significance at the 1 percent level. Based on this, it appears that 137 m (450 ft) of salted highway produced a mea-

Table 1. Chloride concentration, variability, and number of samples at principal sites.

Location	Sample	No. of Samples	Range (ppm)	Mean (ppm)	Standard Deviation (ppm)	Coefficient of Variation (%)
County Road	A	15	12.5 to 25	18.5	4.5	24
Butternut Creek	B	15	15 to 25	19.0	3.6	18
	N	24	12 to 25	19.1	4.1	21
	C	23	15 to 27.5	20.0	4.2	20
Stream I	E	21	10 to 20	11.8	2.5	20
	H	11	10 to 20	11.2	3.5	30
	D	33	10 to 20	15.3	3.4	27
	G	29	35 to 235	93.4	52.0	55
	F	22	15 to 70	29.8	14.7	48
Ditch	L	43	20 to 5500	448.0	900.0	198
Stream II	K	29	18 to 30	24.2	3.6	15
	J	40	22.5 to 165	40.4	23.7	58
	M	30	15 to 55	27.6	7.5	27

surable effect on this stream of about 1.2 km^2 (0.5 $mile^2$) of watershed.

The effect of highway salting on the small stream Ib [about 0.5-km^2 (0.2-$mile^2$) watershed] is more obvious from the sample means. The background level is 11 to 12 ppm (based on sites E and H), but the downstream sample average (site G) is 93.4 ppm, with a high of 235 ppm. I also noted that the variability was greater here than at the upstream sites. Even after stream Ib has joined stream Ia, which is about 2.5 times larger, the variability of the receiving stream (I at point F) remains high, although the mean drops considerably. The impact of this greater variability might be as important an ecological consideration as the actual means. Stream Ib receives runoff from approximately 671 m (2200 ft) of highway.

A similar procedure for testing upstream and downstream of the highway was used on tributary stream II, which drains about 1.8 km^2 (0.7 $mile^2$) before reaching the road. It is estimated that 1250 m (4100 ft) of highway drains into this stream. Stream II differs somewhat from stream I in that it receives highway effluent at one localized discharge point via a concrete-lined ditch. (Some seepage into the soil is possible before the effluent reaches stream I's channel.) Sampling point L, at this discharge point, provides a measure of chloride concentrations in the highway runoff just before it enters the stream. The samples show this runoff to have highly variable chloride levels and a standard deviation almost double the mean. A comparison of points K (upstream) and J (downstream) reflects the effects of this discharge. The mean levels increase from 24.2 to 40.4 ppm, and the variability is notably greater, as was true of stream I.

Point M on stream II was tested for the effects of dilution on chloride levels. This point, about 1829 m (6000 ft) downstream of point J, has approximately double the watershed area. Mean chloride levels here have dropped considerably. The variability has also dropped, but not to as great an extent as the mean.

Interrelations Among Sampling Points

I speculated at the beginning of the study that runoff from salted highways would raise chloride levels in receiving streams in some predictable fashion. Examination of the statistics in the previous section indicates the magnitude of some impacts, but further analyses using correlation coefficients and regression equations are valuable in considering the predictability of some of the variables. The results of these analyses are presented in Table 2, where x is the independent variable, y is the dependent variable, n is the number of paired samples, r is the correlation coefficient, and y = a + b(x) is the regression equation [1°F = 1°C(1.8) + 32].

Of the variables with sufficient numbers of paired data sets, those that I tested were chosen to demonstrate the effects on chloride levels of (a) stream confluence, going from point G to point F, (b) downstream dilution, going from point J to point M, and (c) highway runoff entering receiving streams, considering points L and J as well as points L and G.

Table 2. Correlations and regressions among sample points for chloride values.

x	y	n	r	a	b	t-Test Significance Level (%)
Point J	Point M	29	0.79	17.1	0.232(x)	0.1
Point L	Point J	32	0.90	29.97	0.0232(x)	0.1
Point G	Point F	22	0.95	7.69	0.26(x)	0.1
Temperature (°F)	Point L	27	0.37	58.9(x)	-585	10
Salt applied (3 d before sample)	Point L	27	0.15	—relationship not indicated—		
Point L	Point G	18	0.56	0.104(x)	84.3	2

The effects of temperature and salt applications were also considered by testing those factors relative to chloride levels at point L, the highway runoff. Point L was chosen because a strong relation was found between this runoff and the receiving stream. Predicting the chloride levels at point L is therefore an important step in predicting stream levels.

The analyses were prepared following methods outlined by Riggs (2) and Freese (3). However, some errors of measurement are probable, and the data may not be normally distributed. Therefore some of the underlying assumptions of correlation and regression analysis are probably imperfectly satisfied. Riggs (2), in his discussion of the use of statistics for hydrological analyses, notes that the non-normality effects commonly found are not sufficient to prohibit meaningful use of such analyses.

Some of the relations found were expected. For instance, sample G is from stream Ib, a relatively salt-laden, small tributary. Sample F is on stream I, just downstream of the input from Ib, and would be expected to be influenced by levels at G, as the analysis indicates. It was also considered likely that downstream dilution does reduce concentrations and would be indicated by a relation between point J and point M farther downstream. The regression of the data examined (29 sets of samples at each point) showed t-test significance at the 0.1 percent level. The stream at point M has about double the watershed area found at point J.

A strong relation was found between the input of point L, the highway drainage ditch, and point J, just downstream. The t-test of the regression indicated significance at the 0.1 percent level, which was not necessarily expected, because the runoff characteristics of the highway effluent compared with the natural flow in the receiving stream were an unknown factor. The possibility of point L's having value as a general index of highway salt delivery was also considered by comparing the L values with those found at point G on stream Ib. The relation was weaker than that between the road runoff and the actual receiving stream but was still adequate for the t-test on the regression to indicate significance at the 2 percent level.

If we assume, then, that the chloride concentration of receiving streams is closely related to the concentration of chloride in highway runoff, we should next consider factors influencing those runoff concentrations. Factors of potential importance include (a) time and quantity of salt applications, (b) temperature, (c) snow, ice, and water availability for formation of chloride solutions, (d) effects of plowing and traffic on movements of salty material to highway drainage facilities, and (e) rainfall flushing action. Athough the present study results were not as concrete as I would have liked, they do permit some speculations for some factors.

Salt Applications

The first few years of salting will establish an equilibrium in the roadside soil, and it is likely that salt applied during a given year will leave the sub-basin during that time in approximately the same quantities. Previous studies have noted a good correlation between long-term salt use and long-term average chloride concentrations in the receiving streams (4).

In the short run, however, this study does not indicate an immediate relation. For instance, no statistical relation was found in the amount of salt applied during a 3-d period before a sample of highway runoff was collected, at least not by using simple analysis (Table 2). At some time interval salt application must become significant, but it appears that for particular occasions during the salting season, the salting operates as much as a prerequisite as an immediate cause of fluxuating chloride levels.

Nevertheless, inspection of the data does show occasions when heavy applications occurred for a period of several days preceding the sample, and the effluent seemingly responded. For instance, about 2 Mg/km (3.5 tons/mile) were applied during the 10 d before the February 5 reading of 1875 ppm at point L, and about 4.5 Mg/km (8 tons/mile) for a similar period before the February 7 reading of 1750 ppm (point L). The highest reading of 5500 ppm (also point L) on February 16 likewise followed a period of heavy salting and marked a rise in temperature after a relatively cold period. It may be that climatic or other natural conditions and trends generally control the release of chlorides from the roadway vicinity, while the amount depends on salt applications of the near past.

Temperature

The test of temperature and runoff chloride level showed t-test significance at a 10 percent level (Table 2). This test employed rather imperfect temperature data [mean daily temperatures at Tully, New York, over 12 km (8 miles) away, and about 150 m (500 ft) higher], so the level of significance is weighted as a potentially positive indicator.

A rise in temperature facilitates melting of snow and ice and the movement downslope of the water and salt solution. The highest sample concentration during this study was 5500 ppm or 0.55 percent, which has very little effect on the melting point of ice. It seems unlikely, then, that salt lowered the melting point or had much effect on the stream. A little salt will enhance mechanical movement of snow and ice from the roadway to the ditch and shoulder area by traffic and plows, but temperatures near or above the freezing point are probably more important in initiating runoff from the system.

Rain

Rain that fell during some of the sampling occasions appeared to raise chloride levels. For instance, on January 25 no heavy salting had occurred for several days, but the chloride level was 1000 ppm (concentrations in this discussion refer to point L), more than double the mean observed at this point. It was raining lightly at the time. A more convincing example of this rain effect occurred on March 29. On this occasion, a sample taken at 9:30 a.m. contained 950 ppm of chloride, whereas one taken at 3:00 p.m. the previous day contained 92 ppm; a sample concentration at 6:00 p.m. on March 29, just hours after the 950 ppm sample, contained 125 ppm. It had started raining about half an hour before the 950 ppm sample and quit about noon the same day.

No salt had been applied for three days, so the rain appears to have triggered this higher sample, sandwiched between two lower ones. On April 20, 12 d after the last salting, a sample registering 82 ppm was taken. Before this, on March 16 and 18, levels were down to 20 and 25 ppm respectively, but the rain apparently influenced the sample on March 20. Temperatures had previously risen well above 0°C (32°F), and no obvious factor except the rain could explain the upsurge in chloride level.

Roadside Samples

Some samples of snow and slush in the roadway vicinity were tested, and these results reflect, at least partially, the above hypothesis concerning temperature or other natural factors.

Six snow or slush samples ranging from 25 to 8500 ppm of chloride were taken near the roadway or in the ditch. On most occasions these levels were above that of the runoff at point L, and, if the concentration of the liquid portion is considered when the snow or ice is only partially melted, the chloride levels are even higher. For instance, the slush sample, which measured 8500 ppm when totally melted, was tested (the liquid portion) when it was about 30 percent liquid and 70 percent ice; the concentration then was 22 000 ppm.

The concentration of the initial brine formed as the salt first dissolves can be expected to be very high, but such levels were not found at point L.

This indicates relatively salt-free snow and ice in the catchment area, probably transport and dilute runoff from the highway drainage system. Even in the salted areas enough melting probably also precedes runoff conditions to dilute the effluent considerably from the initial chloride levels on the road surface. The roadway area draining to point L includes some high shoulders, and melt from snow samples 1.5 to 3 m (5 to 10 ft) up the bank measured 60 ppm and 12 ppm of chloride on the two occasions when such samples were taken. These samples indicate a source of relatively uncontaminated runoff material to dilute the saltier discharge from the road.

Intensive Sampling

Six samples were taken between 9:00 a.m. on March 26 and 3:00 p.m. on March 28. Conditions included 3.3 cm (1.3 in) of snow on March 25 and 469 kg (1042 lb) of salt applied on March 26, all before 3:00 p.m. according to the records. There was no further precipitation or salting during this sampling. Results at point L, together with temperatures, are presented below [1°C = (1°F - 32)/1.8].

Date	Time	Chloride Concentration (ppm)	Temperature (°C)
3/26	9:00 a.m.	250	-9.1
3/26	3:30 p.m.	340	+0.6
3/26	11:00 p.m.	82	-12.2
3/27	4:00 a.m.	70	-7.8
3/27	10:00 a.m.	65	-7.7
3/28	3:00 p.m.	92	-0.6

The rise of 90 ppm from 9:00 a.m. to 3:30 p.m. on March 26 was probably caused by the daytime temperature increase and by the freshly applied salt. By 11:00 p.m. that night the concentration had dropped considerably and continued to drop, apparently in response to colder temperatures.

This drop was caused not merely by depletion of salt present, as evidenced by the rise to 92 ppm the next day (March 28), when temperatures rose even though no new salt had been spread. Then, as mentioned previously, it rained on March 29, and concentrations rose to 950 ppm at the 9:30 a.m. sampling and fell again after the rain stopped. Chloride levels in the receiving stream (stream II), measured at point J, followed the trend established at point L.

Residual Effects of Salting

The last salting for the winter of 1974 to 1975 occurred, according to county records, on April 8, the end of a major snowfall of 58 cm (23 in). Fourteen samples were collected after this date, mostly in April, but extending to July 12.

Stream Ib strongly suggests residual effects of winter salting. On April 9, the chloride level was 115 ppm and dropped fairly steadily to 35 ppm, which was recorded on the last four sampling dates. The chloride level upstream of the highway during this time ranged from 10 ppm to 15 ppm but did not exceed 12 ppm after April 11.

As previously noted, the highway runoff to this stream is not guttered all the way to the channel; apparently chloride has ample opportunity to infiltrate the soil and to percolate out at some later date. It should be noted in connection with the lower summer flow levels that the same chloride concentration does not imply that the same amount of salt was delivered to the stream but merely that it is in the same proportion relative to stream flow.

Thus data indicated that progressively less salt reaches the stream as summer lengthens. Road salting influencing groundwater and effluent streams beyond the salting season has been previously reported.

PROJECTION OF MEAN AND PEAK CHLORIDE LEVELS

If chloride levels in roadside soils can be assumed to be in equilibrium, then in most cases estimating mean chloride outputs, such as an annual mean concentration, on a long-term basis, is fairly straightforward. This can be calculated on the basis of the amount of salt applied in a basin and the amount of flow that will be dissolving and transporting that salt.

Although such average figures can be calculated fairly simply, the variation of chloride levels around their means has not been reported. Comments on this topic have been generally limited to observations of seasonal variations, such as concentrations during spring high flows compared with summer low flows.

VARIABILITY ESTIMATES

In this study the coefficient of variation was calculated for each sampling site. At site G, this coefficient was 55 percent, and at site J it was 58 percent. This is in contrast to 20 and 15 percent for the respective upstream sampling stations. Thus, highway salting is apparently responsible for approximately tripling or quadrupling the variability of chloride concentrations in the subject streams.

Halbritter (5) showed that the coefficient of variation increased from 24 percent at the control site to 54 percent after two salted highways intersect. This approximate doubling of the variability occurred in conjunction with a rise in mean levels from 9.6 to 17.9 ppm.

Another variability index is the ratio of the maximum observed value to the mean. For site G these values are 235 and 93 ppm, showing the high value to be 2.5 times the mean. At site J, a similar procedure, dividing 165 ppm by the mean of 40 ppm, shows the high value to be 4.1 times the mean.

In the absence of sampling, such an index could be useful in estimating probable peak concentrations. For instance, a mean chloride level could be estimated according to projected salt use and stream flow volumes. Then a factor of four or five, applied to the estimated mean, would represent the probable peak. The actual factor, of course, may require modifications as more data become available.

CONCLUSIONS

When salt is applied to highways as part of a deicing program, most of it can be expected to be dissolved in the runoff water and to leave the drainage area. If a chloride equilibrium has been reached in the nearby soil, salt output of the system essentially equals the salt applied—at least at the magnitudes of current deicing programs. This salt can be detected by comparing concentrations upstream with those downstream of the highway; the result, taken as a long-term mean (minimum of several months, say), depends primarily on the amount of salt applied in the basin and on the flow volume of the stream.

In addition to raised mean chloride level, I found that the variability in chloride levels was three to four times as great downstream of the highway as upstream. Also, peak values were two to four times the mean.

The chloride levels downstream of highway inputs were decreased by dilution. Chloride concentration decreased in roughly inverse proportion to increased area contributing to flow.

The runoff from the salted highway was such that the effect on chloride levels in the receiving stream could be predicted fairly confidently by a linear regression equation. Initial brine levels on the roadway were very high, but such solutions were diluted considerably before reaching the stream.

The timing of the highway runoff relates to natural environmental factors such as temperature and precipitation. Until runoff occurs, the salt is probably stored in the immediate vicinity of the roadway. I observed that rainfall seemed to initiate peaks or upsurges of chloride concentrations in the highway effluent and receiving streams.

The few samples gathered in the late spring and summer from stream Ib indicate that deicing salts were stored within the drainage basin well beyond the salting season. Levels downstream of the highway were approximately 25 ppm higher than those upstream in this small waterway. This increase was last observed on July 12, 1975.

Butternut Creek, which drains about 51.8 km^2 (20 miles^2) upstream from the study site, was not affected to a detectable degree by the deicing salts applied to US-20 and to other highways in the study area. Measurable increases in chloride concentrations were detectable in the smaller tributaries tested, which ranged from 0.5 km^2 (0.2 mile^2) of drainage area to 3.4 km^2 (1.3 mile^2).

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Advance Traffic-Control Warning Systems for Maintenance Operations

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This paper discusses the effects of sign size, height of sign installation, and sign legend on driver responses measured by speed, conflict, and queuing parameters. Effects of flashing chevrons were also evaluated in terms of these responses. The experiment was conducted on two-lane highways and the Interstate system at four locations. The conclusions, based on the analysis and evaluation of the various responses using standard statistical procedures, are that (a) speed decrease at two-lane locations was greater for the 0.76-m (30-in) signs than either the 0.91-m (36-in) or the 1.22-m (48-in) signs; (b) at Interstate locations, the 0.91-m (36-in) sign yielded better overall response than the corresponding 0.76-m (30-in) signs; (c) installation height of 0.31 m (1 ft) and 1.52 m (5 ft) and sign legend did not indicate any statistical difference in the measured response; (d) two-way flashing chevrons greatly enhanced the obedience of the driver to warning signs; and (e) differences in responses by location can be discussed in terms of traffic volume and the motorists' attitudes toward signing in general.

The types of advance traffic-control warning systems used during maintenance operations generally include signs and such supplements as flags and flashing lights. Basically, these warn, control, protect, and expedite the flow of traffic and provide safe work areas.

An effective warning system should, among other things, command attention and convey a simple, clear message. Guidelines for the design and placement of various signs have been drawn up (1). Design is specified in terms of size, shape, color, and so forth; placement must be within the driver's core of vision to allow adequate time to respond.

Kentucky (2) has reported on effects of sign color on traffic response at construction sites. However, information on driver response to sign size and placement height is lacking. In recent years, the tendency has been toward larger signs and higher mounting. Although there may be some innate justification for this tendency, the effects of sign design parameters on driver response should be quantitatively evaluated.

This study is an attempt to measure, quantitatively, the effect of sign size and sign height on driver response during maintenance operations involving lane closures in rural areas.

PURPOSE AND SCOPE OF THE STUDY

In this study we attempted to evaluate the effects of advance traffic-control warning systems on traffic flow and driver alertness by varying sign size, sign height, and sign legend, by using signs with and without flashing (attention-getting) devices, and by altering traffic situations in rural areas.

All maintenance operations lasted long enough to require single-lane closure. On the Interstate system, closure was limited to the outside lane only, and the number of vehicles required to merge was larger than for any other lane closure. In rural areas, higher volumes are generally encountered in this lane. All maintenance work zones were limited to less than 91.4 m (300 ft).

The scope of the study did not include observations of variables such as roadway alignment, weather, or terrain. Likewise, situations arising from detours and sight obstructions were also eliminated from the study design. In order to reduce maintenance scheduling problems, use of simulation or "dummy" maintenance operations was allowed, but care was taken to ensure that such simulations duplicated actual closures.

PROCEDURE

Experimental Design

The factors generally considered to affect driver alertness (message comprehension) for Interstates are (a) sign size, which varies 0.76 m (30 in), 0.91 m (36 in), and 1.22 m (48 in); (b) sign height, which varies 0.31 m (1 ft) and 1.52 m (5 ft) from ground elevation to the bottom of the sign; (c) specific, general, or diagrammatic sign legend; and (d) trailer-mounted flashing chevrons. For two-lane roads, only (a) and (b) affect alertness. These are our independent variables.

Our dependent or response variables for Interstates included (a) average speed in critical zone, (b) traffic conflicts, and (c) number of vehicles properly queued in the travel lane between the last sign and the first cone taper. For two-lane highways, only (a) and (b) were dependent variables.

Experiments were conducted at four different locations for each type of facility. All test sites were in rural areas having traffic volumes greater than 1000 vehicles/d. Not all combinations of independent variables were compared across all test sites because of scheduling constraints. For example, diagrammatic signs were tested at one site only. Likewise, for another location, data for flashing chevrons could not be obtained because of an electrical malfunction. Figure 1 is a flow chart of the experimental design for the Interstate system.