SPEED, FLOW AND CAPACITY RELATIONS ON MULTILANE HIGHWAYS

by

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SPEED, FLOW AND CAPACITY RELATIONS ON MULTILANE HIGHWAYS

To my parents.

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ABSTRACT

Traffic engineers rely heavily upon the fundamental relationships between the variables speed, flow and capacity which characterize the traffic stream. Accurate knowledge of the operational behaviour of roadway traffic inevitably enhances the reliability of planning and design. Because of the importance of basic relationships to traffic engineering, this study was undertaken. The study involves investigating the important relations between speed, flow and capacity currently existent for uninterrupted flow on multilane highways in Ontario. The results are compared with information established by both the Highway Capacity Manual (HCM) and Polytechnic Institute of New York (PINY). Comparisons are made of 5-minute and 15-minute hourly flow rates, and calculated truck equivalents with those currently recommended. In addition, the impact of adverse weather conditions on fundamental speed-flow relationships and how occupancy (density) relates to speed and flow were investigated.

Results of the study indicate that there is a significant difference between relations presently in use and those existing on roadway facilities. In particular, capacity was found to be in excess of 2000 passenger cars per hour and speeds were noted as being higher than established values.

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LIST OF ABBREVIATIONS

FSCS	Freeway Surveillance and Control System
HCM	Highway Capacity Manual
kph	kilometers per hour
MTC	Ministry of Transportation and Communications
OPP	Ontario Provincial Police
pce	passenger car equivalent
pcph	passenger cars per hour
PINY	Polytechnic Institute of New York
QEW	Queen Elizabeth Way
S-D	Steepest Descent
vph	vehicles per hour
vpk	vehicles per kilometer
vpm	vehicles per mile

CHAPTER 1

INTRODUCTION

The foundation of planning and design for multilane highways rests on the ability of the engineer to adequately describe traffic behaviour. In order to characterize the operational behaviour of the traffic stream certain key variables must be defined. Fundamental relationships between these important variables of speed, volume and density have been established by the Highway Capacity Manual (HCM) (1) and are at present frequently used by traffic engineers throughout North America. It is these basic relations which have become a subject of great concern since they were established in 1966. Since then much has changed, especially in the way of driver behaviour and vehicle characteristics, yet little has been done to update the material published in 1966. This research effort was undertaken with the aim of identifying some of the most important fundamental relationships which currently exist on multilane highways in Ontario.

1.1 Traffic Flow Measures.

In order to adequately describe the operation of a roadway section, knowledge of existing speed, flow and density relations are important. The fundamental relations documented by the HCM are as conceptually illustrated in Figure 1.1.

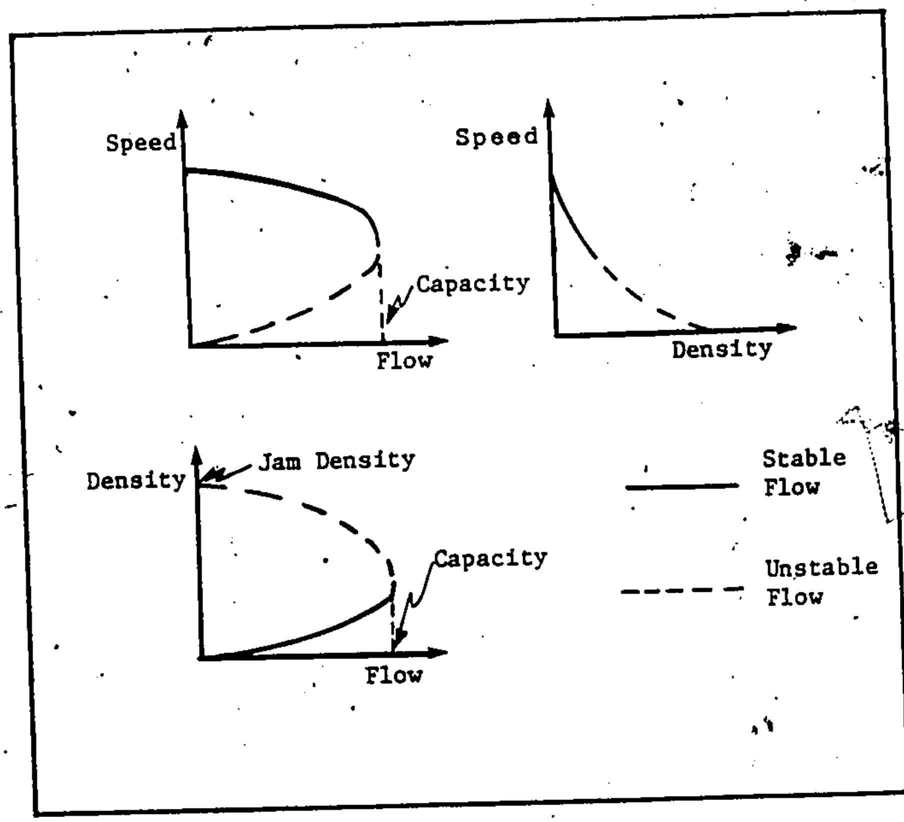


Figure 1.1 Fundamental Relationships Between Speed, Flow and Density, Adapted from Reference (2)

These curves were developed for U.S. conditions prior to 1966. However, more current information is warranted as changes in vehicle and roadway design and environmental conditions may affect these basic relations. Of the three relations shown, the speed-flow relationship is most commonly used by traffic engineers. Such relations may differ according to trip purpose, trip length, driver behaviour and geographic location, as shown by the hypothetical example in Figure 1.2. Revisions to the speed-flow relation made by the Polytechnic Institute of New York (PINY) (2) and Allen (3) are shown in Figure 1.3 where the relations depicted are for ideal geometric and weather conditions. It is evident that a significant difference exists at low flow rates between the more recent Allen (3) and other relations. At high flows there also tends to be a difference in shape, particularly at the maximum flow (capacity) where a range of speed values exist with Allen.

Because the established curves differ significantly, it was thought essential to investigate these relationships using a large data source. Important to the study are definitions of variables employed and as such Sections 1.1.1 to 1.1.6 were included.

1.1.1 Speed

There are different measures of speed which can be defined for the basic relations. Operating speed was employed in the relationships described in the HCM and is often used. This speed is defined as the highest overall speed at which a driver can travel on a given highway

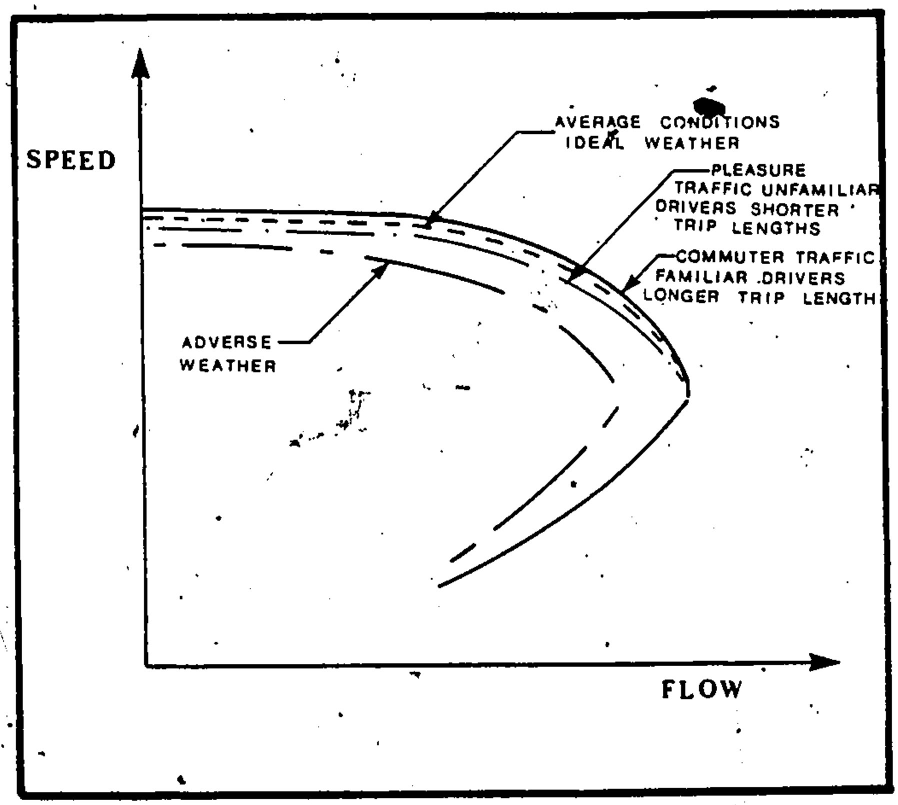


Figure 1.2 Illustration of Probable Effect of Pertinent Factors on Speed-Flow Relations, Adapted from Allen (4), p.20

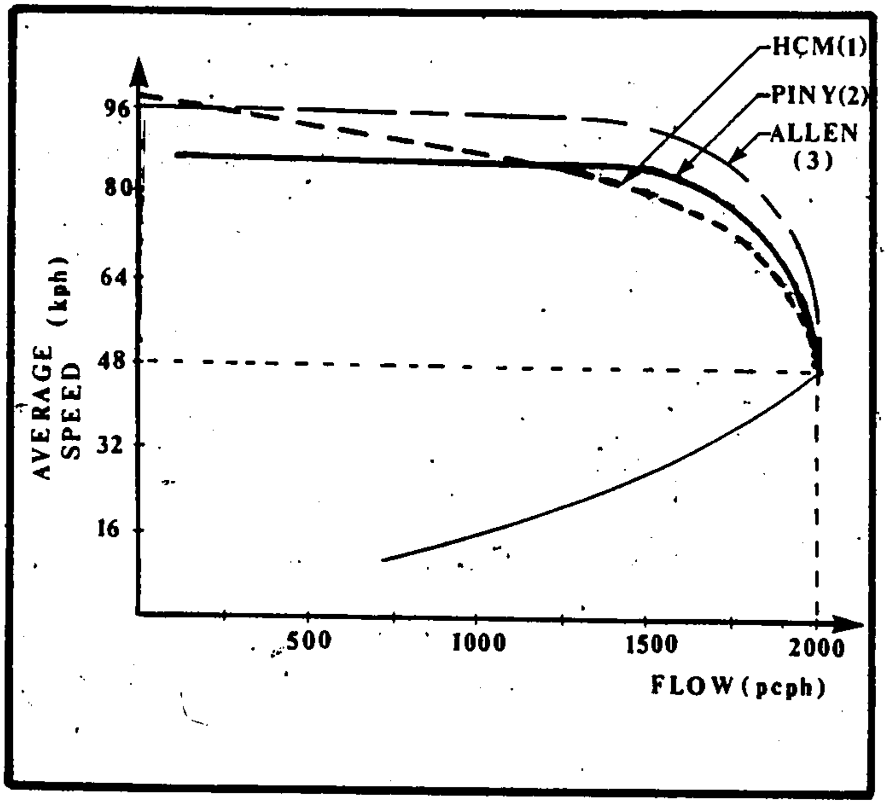


Figure 1.3 Illustration of Speed-Flow Curves

under prevailing traffic conditions without exceeding the safe speed on a section by section basis. Operating speed therefore takes into account factors relevant to the definition of level of service, for example, freedom to manoeuvre. It is however not necessarily representative of average speeds attained in the traffic stream. Nevertheless, designers and planners do often choose to use operating speed for defining quality of service and computing travel times as information on it is available in the HCM.

PINY (2) and Allen (4) recommend the use of average running speed as opposed to operating speed. It is the summation of distances travelled divided by the summation of running times i.e. space mean speed. The difference between operating speeds and average running speeds for low flow conditions is likely to be about 5-7 kph.

For the purposes of this research average spot speeds were employed because of the ease of computation and the fact that spot speeds are true parameters of the traffic stream. Spot speeds are defined as the speed of a vehicle as it passes a specified point on a roadway. From the definition of operating speed it is expected that their values will likely be higher than average spot speeds in free flow conditions. In the region of capacity, the values may be identical. Allen (4) compared spot speeds and space mean speeds and found a small difference.

1.1.2 Flow

In addition to speeds, for planning and design of transportation systems, vehicular volumes are often necessary. These volumes are frequently expressed on an hourly basis. Peak hour volumes represent critical conditions in the transportation system but do not necessarily indicate the duration of peak demand periods. Thus it is sometimes necessary to obtain vehicle counts for periods less than an hour and express them as an equivalent rate in vehicles or passenger car units per hour. This is defined as the flow rate. The magnitude and sequence of short term fluctuations within an hour characterize hourly volumes.

Various flow rates have been used in the past for traffic studies, for example 1-, 3-, 5-, 6- and 15- minute durations. The larger the data collection period, the less the scatter will be and shorter term fluctuations will go unnoticed. Consequently, the criteria for selecting a given interval is based on the purpose for which the study is being conducted. The most common intervals used for speed-flow relations for uninterrupted flow are 5- and 15- minutes. Past research does not provide adequate justification for the preference of one value over the other. As a result it was decided that for the purposes of this research, a comparison of 5- and 15- minute flow rates would be carried out. Maximum flows attained on roadways are referred to as capacity and are treated in the following section.

1.2.3 Capacity

Highway capacity is defined in the HCM as the maximum number of vehicles which has a reasonable expectation of passing over a given section of a lane or roadway in one or both directions during a given time period under prevailing roadway and traffic conditions. It is limited by the physical features of the highway, traffic conditions determined by traffic composition, and ambient conditions which include visibility, road surface conditions, temperature and wind.

The determination of service volumes for uninterrupted flow conditions involves factoring the basic capacity value of 2000 pcph if conditions are not ideal. The standard method employed is based on equation 1.1. See for example HCM [(1), p.265]

$$C = 2000\ NWT_c \qquad 1.1$$

where C = capacity (mixed vehicles per hour, total for one direction).

2000 = capacity per lane under ideal conditions for average multilane facilities (pcph).

N = number of lanes in one direction,

W = adjustment for lane width and lateral clearance,

and T_c = truck factor at capacity.

As a basis for freeway capacity analysis, a set of conditions has been established and described as ideal, see for example HCM [(1), p.14]. These conditions include the following:

(i) 3.7 m (12') lane widths

(ii) at least two lanes for the exclusive use of vehicles in each direction.

(iii) a minimum of 1.8 m (6') between the edge of the travelled lanes and the nearest obstacle or object on the roadside.

(iv) negligible horizontal or vertical roadway curves.

(v) no trucks, buses or recreational vehicles in the traffic stream, i.e. only passenger cars.

The HCM [(1), p. 246] recommends an ideal lane capacity of 2000 passenger cars per hour (pcph) at a speed of 48 kph for average multilane facilities. On freeways this capacity is reached at a speed of 56 kph. It is also stated that optimum values of 2100 pcph have been reported for some freeway lanes. The Polytechnic Institute of New York (PINY) study [(2), p.17] has reiterated that values of 2000 pcph for capacity and 48 kph for the speed at capacity be adopted. The authors also note that capacities in excess of 2000 pcph have been reported. Allen (3) has however gone somewhat further and recommended an ideal lane capacity of 2200 pcph at a speed of 60 kph.

It is seldom that conditions are in fact ideal and the adjustment factors W and T_c of equation 1.1 are often vital. Reference [(5), p.324] has reported that a Texas study noted a 10% reduction in capacity on freeways as a result of adverse weather. Kaufman (6) and Allen (3) have also reported some effects of adverse weather conditions on traffic flow behaviour. In regions where adverse weather conditions are persistent, it may be necessary to account for this in service volume calculations. Consequently, an attempt was made in this study to quantify the effect of adverse weather conditions on speed-flow relationships.

1.2.4 Trucks

Trucks, buses, and recreational vehicles are longer than passenger cars and therefore occupy more roadway space. The operating capabilities of these vehicles are also generally inferior to those of passenger cars. The prominence of this inferiority increases as the grade on which these vehicles travel increases. Their presence in the traffic stream creates gaps which cannot always be filled. Because they often travel slower than cars and require longer headways, they reduce the capacity of a highway in terms of total vehicles accomodated per unit time.

Trucks are defined in the HCM [(1), p.15] as vehicles with dual tires on one or more axles. This reference also defines a passenger car equivalent (pce) as the number of passenger cars displaced in the traffic flow by a truck under the prevailing roadway and traffic conditions. Sites surveyed in this research depict level terrain and for this condition a pce value of 2.0 is recommended by the HCM [(1), p. 287] regardless of the percent trucks. Table 9.4 of the HCM indicates that at grades greater than or equal to 2%, as the percent trucks increase, the pce value decreases. Also noted is that capacity is reduced as the percent trucks increases for any given grade, see for example Table 9.6, HCM [(1), p. 289].

The two methods employed in the evaluation of pce's are briefly described in HCM [(1), p. 101]. In one case detailed information on speeds and headways of vehicles during various rates of flow are collected and analysed. Passenger car equivalents are also calculated from speed distributions of cars and trucks at any given volume level. The criteria considered is the relative number of passings if each vehicle traveled at its normal speed for the conditions under study.

A recent study by Linzer et al (7) has indicated that pce values were evaluated in a simulation study. The authors computed values similar to those shown in the HCM. For level terrain, a value of 2.0 was again developed. The results of that study were recently adopted by the Transportation Research Board for their new interim Highway Capacity Manual material.

There seems to be a great deal of consistency with regards to a pce of 2.0 for level terrain. Since a large data source on truck volumes was readily available a review of this equivalent was considered.

1.2.5 Density/Occupancy.

As previously mentioned, speed, flow and density relations are fundamental to the traffic engineer as they enable him to interpret the behaviour of traffic. Density is often termed as concentration and defined as the number of vehicles occupying a unit length of roadway. It has been suggested that density may be a better predictor of speed than flow, see for example HCM [(1), p.68]. The density of roadway traffic, however, is almost never measured directly as this requires costly elevated or aerial photography.

In review of past work, speed-density relations were generally found to obey linear or exponential characteristics as in References (1) and (8) respectively. Wohl and Martin (9) have summarised earlier relations developed for speed and density and have also noted exponential relations. Flow-density relations were also reviewed. The general belief was that a parabolic form existed, see for example References (1) and (9).

Not only is the amount of past work on speed, flow and density relations limited, but also such research was executed quite a few years ago and thus may be outdated. This may be due to a probable change in driver behaviour in addition to vehicle and roadway characteristics.

Similar to density, is the variable occupancy, which is defined as the percent time a roadway is occupied. This variable is measured by loop detector recordings of vehicle passages. Although it is expensive to set up a system of loop detectors for occupancy measurements it is felt that this data is less costly to compile than density on a long term basis. In addition it has been effectively utilized in the control of roadway traffic, for example, on the Queen Elizabeth Way in Mississauga. Past studies reporting on occupancy relations are even more limited than for density.

Only one recent reference has been cited for occupancy relations. In their article, Koshi et al (10) developed relations for flow and density which are certainly not parabolic. They have also shown a high correlation between density and occupancy data. For the above reasons it was thought appropriate to analyse occupancy data from the Mississauga system.

1.2 Objectives

The objectives of this thesis are formulated for the previously described areas in which research is urgently needed for uninterrupted flow conditions on multilane highways. Objectives are classified as primary and secondary. They are identified as follows:

Primary Objectives:

(1) the determination of basic speed-flow relationships on multilane highways.

(2) the determination of ideal lane capacity on multilane highways.

Secondary Objectives:

(1) the computation of the difference between 5-minute and 15-minute flow rates.

(2) the evaluation of passenger car equivalents for trucks travelling in ideal conditions.

(3) the estimation of the impact of adverse weather conditions on basic speed-flow relationships.

(4) the determination of basic relationships between speed, flow and occupancy.

1.3 Documentation

Functional forms used to fit speed and flow data are reviewed and discussed in Chapter 2. The inadequacies found with the past models are identified and new functions are considered. In order to fit equations to the data Marquardt's method was selected for use in the nonlinear parameter estimation. Marquardt's method is compared to other computer algorithms and is also treated in the second chapter. Chapter 3 includes the descriptions of and reasons for sites selected for study. Also, the methods employed in the collection of data and approach applied to data access and reduction are discussed. Information pertinent to the description of the format of data are contained in Appendix 1. Data analysis is described in Chapter 4 and in every instance, plots are referred to. These data plots are contained in Appendices 2-6. Conclusions and recommendations are treated in Chapter 5.

CHAPTER 2

MODELING TECHNIQUE

2.1 INTRODUCTION

In order to effectively summarize a mass of data, a single functional equation or set of equations is often utilized. Equation formulation enables easy comparison with other data sources and is often thought to provide a more sound basis for interpretation of trends than visual inspection methods. Consistent with this usual approach, equations or models were selected for this study and fitted to speed, flow and occupancy data using available analytical techniques where possible.

The applicability of past models to speed-flow data was reviewed, the strengths and shortfalls of which are identified in section 2.2. Using the data collected for this research project, models were tested to determine the nature of fit to characteristics of that data. The approach adopted for that testing is also documented in the following section. Analytical techniques for fitting chosen equations to data were reviewed and are discussed in section 2.3. Marquardt's method was chosen for regression analysis in the nonlinear parameter estimation. This method is known to be derived from Gauss' method and it incorporates the best features of the method of Steepest Descent. These two approaches are also briefly introduced in section 2.3.

2.2 MODELS

Functional analytic forms throughout this study are denoted as models. They are used primarily to provide useful summaries of given data sets. Models also enable easy comparison with other data as they can be easily plotted. In most traffic flow studies, nonlinear functions have been defined. The linearity or nonlinearity of a statistical model describes the manner in which the parameters enter the expression. In some way or another past relations developed between speed and flow have generally proven to be inadequate. A review of those approaches is contained in section 2.2.1.

2.2.1 Review

In the past, speed-flow curves have often been fitted to data by visual inspection. A recent study by Allen (3) suggested that such relationships for multilane highways could be effectively represented by

$$f(x) = \beta_1 + (\beta_2 - \beta_1)[1 - (\frac{x}{\beta_4})^{\beta_3}] \qquad (2.1)$$

where $f(x)$ = speed function (kph),

β_1 = speed attained at capacity flow rates,

β_2 = speed attained at free flow rates,

β_3 = exponent which controls the rate of slope change on the curve,

β_4 = capacity (vph), and

x = flow (vph).

Reference is made to Figure 2.1 for a conceptual representation of equation 2.1. The equation is dimensionally consistent and fits typical data sets fairly well. One shortfall, however, is that the parameter β_3 often does not provide an adequate rate of change of slope for the curve. At very low flows, although the slope can achieve a relatively small value, it cannot reach zero, which is in fact the trend observed from the typical data shown in Figure 2.2 which is also representative of that collected for this research.

May and Keller (8) studied the use of two-regime models in describing speed-density relationships. This approach also applies for speed -flow relations. They suggest that data characteristics for stable and unstable regions differ and perhaps require different models. See for example Figure 2.3(i) for the definition of stable and unstable. The use of two regimes is not only important when two distinct models were required, but also when speed is regressed against flow. In such regression analyses, the minimum sum of squares is found in vertical sections. Computer algorithms are unable to distinguish the upper from lower arm when one curve is used to describe both regions. This is exemplified in Figure 2.3(i).

When the data is divided into two regimes, the representation shown in Figure 2.3(ii) is obtained. It is then possible to fit separate equations to the individual flow regimes. However, May and Keller (8) note that determination of the limits for both flow regimes is difficult and this problem can affect model and parameter value selection.

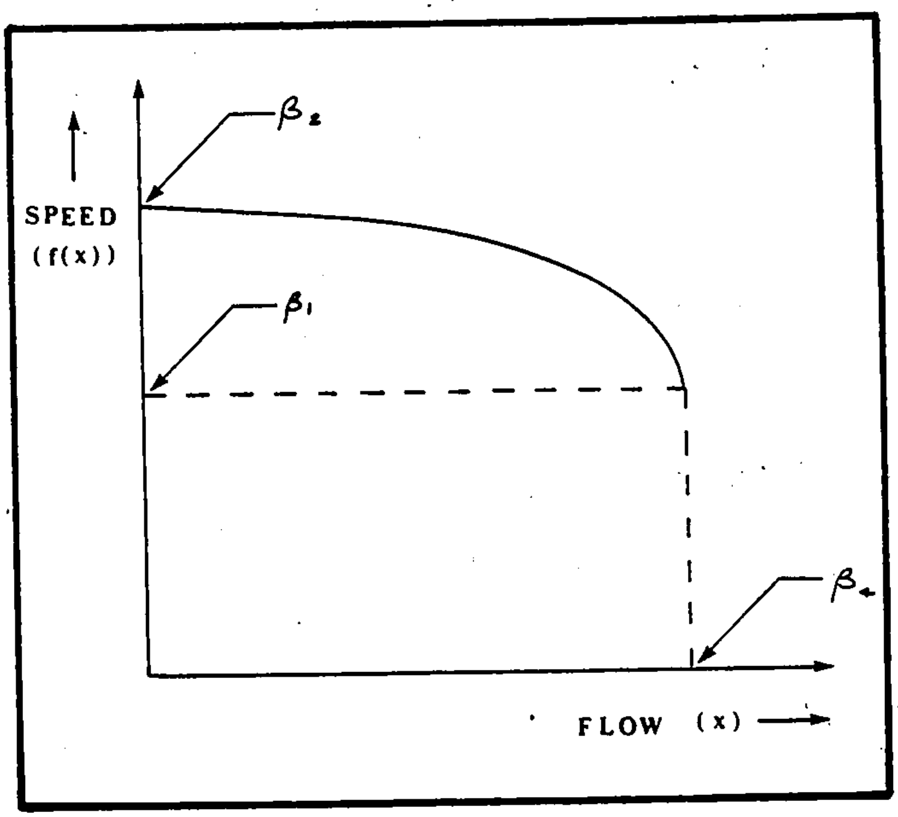


Figure 2.1 Speed-Flow Curve Representing Equation 2.1

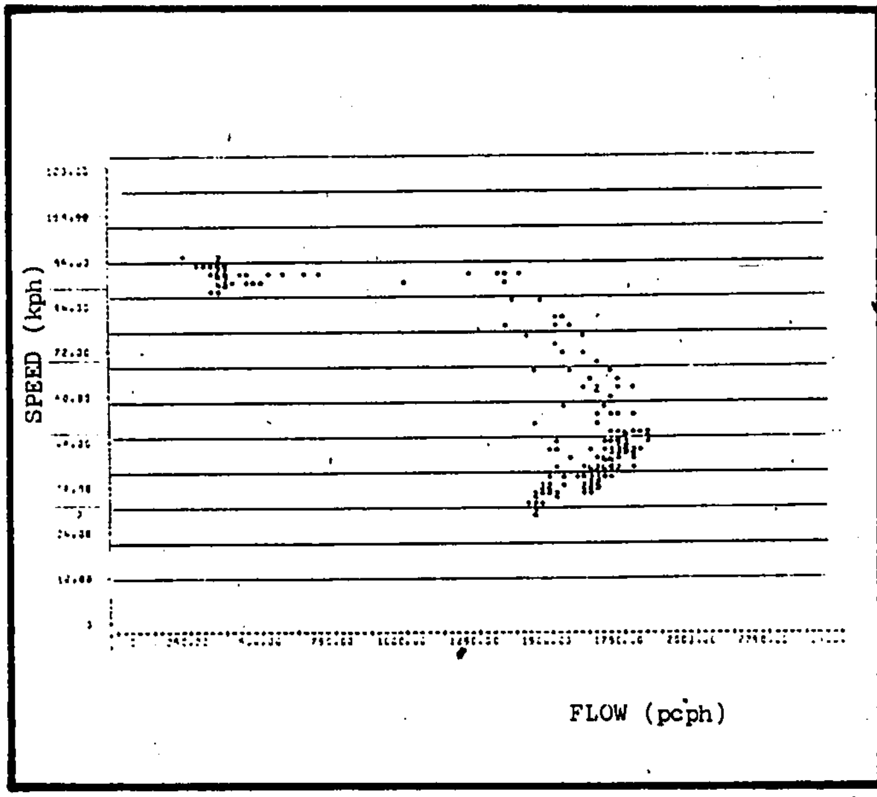


Figure 2.2 Typical Speed-Flow Data, Allen (3)

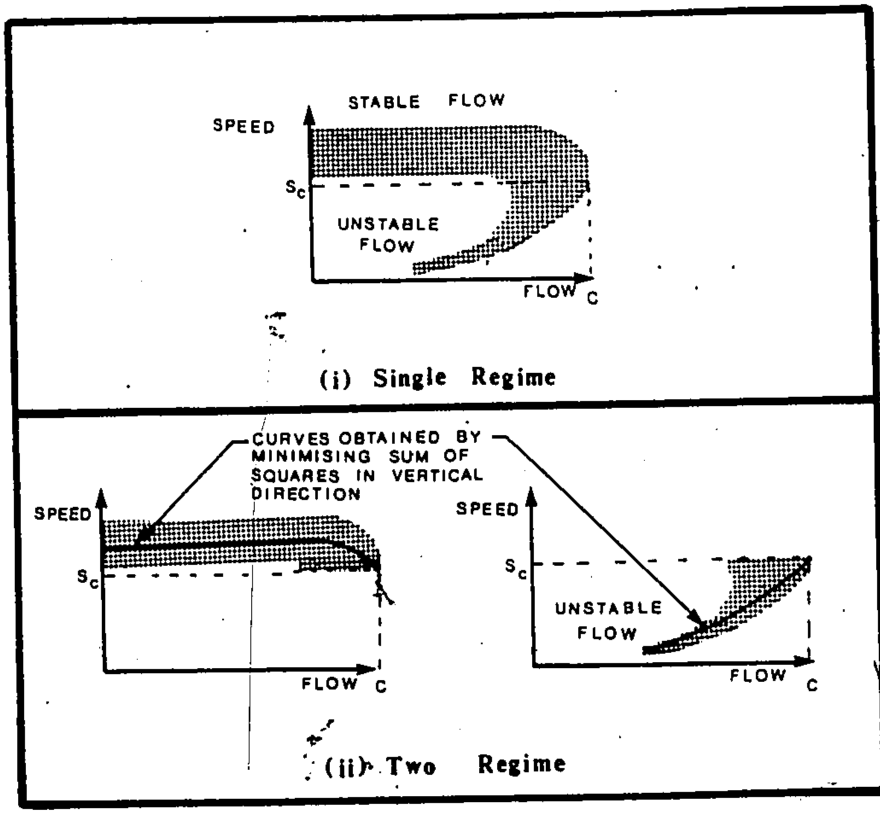


Figure 2.3 Single and Two-Regime Speed-Flow Curves

Wohl and Martin (9) have summarised plots with the variables speed and flow. Figure 2.4 illustrates some of the earliest of these relations. The curves tended to be parabolic in nature. The trend of the data in Figure 2.2 is however not parabolic. The Highway Capacity Manual (HCM) recommends relations of the form shown in Figure 1.3, which tends to be similar to those of Figure 2.4. The Polytechnic Institute of New York (PINY) study (2) was one of the most recently significant works carried out on traffic flow analyses. PINY reports that the speed-flow relations studied are as shown in Figure 1.3. Although neither the HCM nor PINY have documented mathematical expressions for their curves, these relations are included since they represent the present published state-of-the-art.

Since all previous models proved to be not completely adequate, and some curves were not fitted with equations, new models were considered and are treated in Chapter 4.

2.3 REGRESSION ANALYSIS TECHNIQUES

The fitting of equations to data is often carried out by using a least squares approach. In this regression method, the sum of squared deviations of the observed values from those predicted by the model is minimized. The regression analysis involves the estimation of parameters that appear in the regression model. Models considered throughout this study are described as nonlinear.

Many algorithms are currently available for deriving least squares values. The minimization techniques can be effectively executed

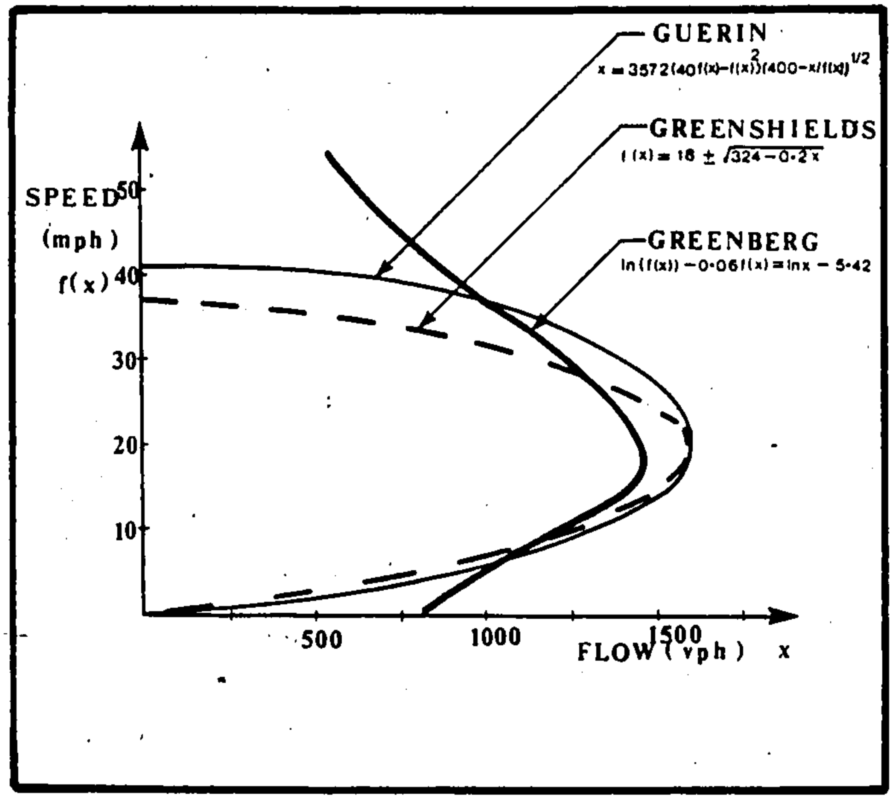


Figure 2.4 Illustration of Speed-Flow Curves, Adapted from Wohl and Martin (9), p.334

on computers. For this study, Marquardt's algorithm (11) was found to be appropriate. A discussion of the technique is documented in section 2.3.3. Marquardt's method is described as a compromise between Gauss' and the method of Steepest Descent (S-D). These methods are introduced in sections 2.3.1 and 2.3.2 respectively. A review of current techniques and comparisons with Marquardt's approach are included in section 2.3.4. Conclusions are presented in section 2.3.5.

2.3.1 Gauss Method

Marquardt's method is very often classified as a modification to Gauss' method (12). Consequently, it was thought appropriate to include a brief introduction to Gauss' approach which is as attractive as it is simple. When initial parameter guesses are good, the minimum sum of squares is easily obtained. Beck and Arnold (12) recommend that for cases in which indistinct minima exist, modifications to Gauss' method are quite appropriate.

To illustrate the basic approach, consider a function represented as follows:

$$y_i = f_i(x,b) + \epsilon_i \qquad i = 1, 2, \ldots, N ,$$

where y_i = dependent variable for case i,

x = independent variable,

b = parameter,

$f(x,b)$ = model function, and

ϵ_i = error term.

From an initial parameter value, say b_o, the following Taylor expansion can be written:

$$f(x,b) = f(x,b_o) + \sum_{k=1}^{N} \left[\frac{\partial f}{\partial b_k}\right]_{b=b_o} (b_k - b_{ko}) \qquad (2.2)$$

Let $z_k^o = \left[\frac{\partial f}{\partial b_k}\right]_{b=b_o}$,

$f^o = f(x,b_o)$,

and $\beta_k^o = b_k - b_{ko}$.

$$\therefore \quad f(x,b) = f^o + \sum_{k=1}^{N} z_k^o \beta_k^o$$

$$y - f^o = \Sigma z_k^o \beta_k^o + \varepsilon \qquad (2.3)$$

$$\therefore \quad \beta_k^o = (z_o^T z_o)^{-1} z_o^T (y - f^o) \qquad (2.4)$$

$$S'(b) = \Sigma \varepsilon_i^2 = \Sigma [y_i - f_i(x,b)]^2 \qquad (2.5)$$

$$S'(b) = \Sigma [y_i - f_i^o - \Sigma z_k^o \beta_k^o]^2 \qquad (2.6)$$

The parameter b_k is then relabeled and a linear regression is performed on equation 2.4 to obtain a new set of parameter estimates. Gauss' method converges very slowly for some nonlinear models. When convergence is slow it is sometimes necessary to reparameterize the model, see Draper and Smith [13, p284]. The method is not sensitive to scaling factors as is Marquardt's. The above discussion was extracted from Reference (14).

2.3.2 Method of Steepest Descent

This method focuses on S(b) as in equation 2.5 The basic idea involves the evaluation of the first set of partial derivatives of S(b) with respect to b at the starting point. This set of numbers, called the gradient, always points away from a minimum in its vicinity. If the initial parameter estimate, b_o, is changed in the direction of the negative gradient a minimum value will be approached. In practice, the solution path formed at each iteration tends to have a zigzag form as the minimum is approached. At each iteration, the sum of squares function is only slightly reduced and little progress is made toward the minimum. This brief introduction was developed from Reference (14).

2.3.3 Marquardt's Method

Marquardt's method is a compromise between Gauss' and the Steepest Descent (S-D) method. The bulk of the ensuing description was also derived from Reference (14). Marquardt combined the best features of both methods. His method almost always converges and does not slow down as the solution is approached. Many problems were studied with both Gauss and S-D methods. It was observed that new parameters were situated 80-90° away from the S-D parameters. Thus, Marquardt developed an approach which produced parameter estimates located at some angle between the two methods.

The method starts the same way as Gauss, i.e. in a Taylor series expansion truncated after the second term. Instead of utilizing equation 2.4, Marquardt solves β_o as follows:

$$\beta_o = (z_o^T Z_o + \lambda I)^{-1} z_o^T(y - f_o) \quad , \qquad (2.7)$$

where I = identity matrix, and

λ = correction factor.

Lambda is set to zero for the first iteration. When λ is zero, equation 2.7 becomes identical to equation 2.4, i.e. Marquardts' is identical to Gauss' method. However, if the sum of squares is increased (instead of decreased) at iteration γ, the zero λ value is replaced by

$$\lambda + \frac{\beta_\gamma^T \beta_\gamma}{\beta_\gamma^T (z_\gamma^T z_\gamma + \lambda I)^{-1} \beta_\gamma}$$

, and the solution is repeated.

As λ increases, the parameters produced tend to turn more and more toward the S-D direction. Thus, the estimates at each iteration depend more and more on the units chosen for the parameters. One drawback to Marquardt's method is its sensitivity to the scaling of the parameters.

2.3.4 Overview

Bard, (15) compared 13 algorithms which included modified versions of Gauss' method, variations to the variable metric methods and different versions of the Davidon-Fletcher-Powell technique, respectively described as categories A, B, and C. The performance of A, which includes Marquardt's method, far surpasses that of B and C. The differences in performance between algorithms within each group are small. The problems defined by Bard include linear and nonlinear types and involve least squares, maximum likelihood, and Bayesian estimation problems. All programs were written in Fortran IV, and executed on an IBM System/360 Model 50.

In the paper by Davies and Whitting (16) a comparison of five methods was made for seven problems defined by Jones (17). The problems are the first seven discussed by Jones and comprised both linear and nonlinear types. For all problems, except the fifth, the results shown in Table 2.1 indicate that the Gauss method is superior to the others including Marquardt's. One drawback to Gauss', however, is its inability to treat problem 5. Beck and Arnold (12) have also analysed the problems using two forms of the Box-Kanemasu method, i.e. the modified and unmodified versions. These two methods compare quite well to Gauss and in the case of problem 5 are superior. They do not require many iterations for linear problems.

Because of near-linear dependence of the sensitivity coefficients and/or poor initial parameter estimates, Gauss' method may tend to be unstable. Improvements to this method have been undertaken to enhance early convergence. The Box-Kanemasu method converges when Gauss does not.

Beck and Arnold have also compared Box-Kanemasu with the Halving-Doubling method and Marquardt's. Marquardt's was found to be the slowest and Box-Kanemasu the best. In his book, Bard, (18) appears to favour a modification of Box-Kanemasu, which is described as the interpolation-extrapolation method.

TABLE 2.1 Number of Iterations Required to Reduce Sum of Squares to Approximately 10^{-14} in Test Problems as Given by Davies and Whitting (16).

Problem No.	Marqu-ardt	Spiral	Leven-berg	Modified Leven-berg	Gauss	Box-Kanema-su	Modified Box-Kanemasu
1	92	17	71	100*	2	99	26
2	72	27	69	100*	2	59	103
3	49	39	58	94	9	11	10
4	98	66	45	100*	13	13	14
5	103	76	46	100*	-	15	15
6	61	9	42	60	1	1	1
7	21	13	54	78	1	1	1

* Convergence was not attained at 100 iterations and computation was stopped.

Jones (17) compared SPIRAL with Marquardt's and Powell's methods using 13 test problems. Of the three algorithms, Spiral appears to give the best results for the test problems. Marquardt's is marginally better than Powell's. The reader is referred to Table 2.2 for a comparison of iterations with the three methods. Computer time required on a UNIVAC 1108 were 1 minute, 4 seconds, and under 1.5 seconds for problems 12, 11 and 1-10 respectively, for each method.

The literature survey shows that Marquardt's method has been both reliable and unreliable. No one algorithm can be considered ideal for every problem. The algorithm was considered for use since it was readily available at McMaster, simple to use and inexpensive.

The speed, flow and occupancy data collected in this research are discussed in Chapter 3. The analysis of this data employing Marquardt's method is treated in Chapter 4.

Table 2.2
Function Evaluations with Different Algorithms, Jones, (17).

Problem	Marquardt	Powell	SPIRAL
1	92	143	17
2	72	103	27
3	49	319	39
4	98	81	66
5	103	112	76
6	61	27	9
7	21	52	13
8	67	97	31
9	27	12	13
10	22	25	13
11	-	23	33
12	-	32	29
13	106	48	21

CHAPTER 3

DATA COLLECTION

3.1 INTRODUCTION

In the determination of ideal lane capacity and speed-flow relationships, data from a variety of multilane roadway types and configurations which include seasonal, weekly and daily variations of traffic flow, different geometric and vehicle characteristics, and varying trip purposes would be desirable. Because of cost and time limits, sites on only three roadway facilities were considered in this research. These include sections of Highways 400 and 401, and the Queen Elizabeth Way (QEW). The reader is referred to Figure 3.1 for the overall highway locations. For both Highway 401 and the QEW, traffic flow on 2-lane and 3-lane sections were analyzed. In the case of Highway 400, a 3-lane section was found to be appropriate for data collection.

Detailed descriptions of each site and the rationale for selection are described in section 3.2 of this chapter. Data collection techniques and the subsequent treatment of the collected data are documented in sections 3.3 and 3.4 respectively.

3.2 SITE DESCRIPTION

The QEW in Mississauga and Hamilton, and Highways 400 and 401 are the facilities on which data were collected. Descriptions of site

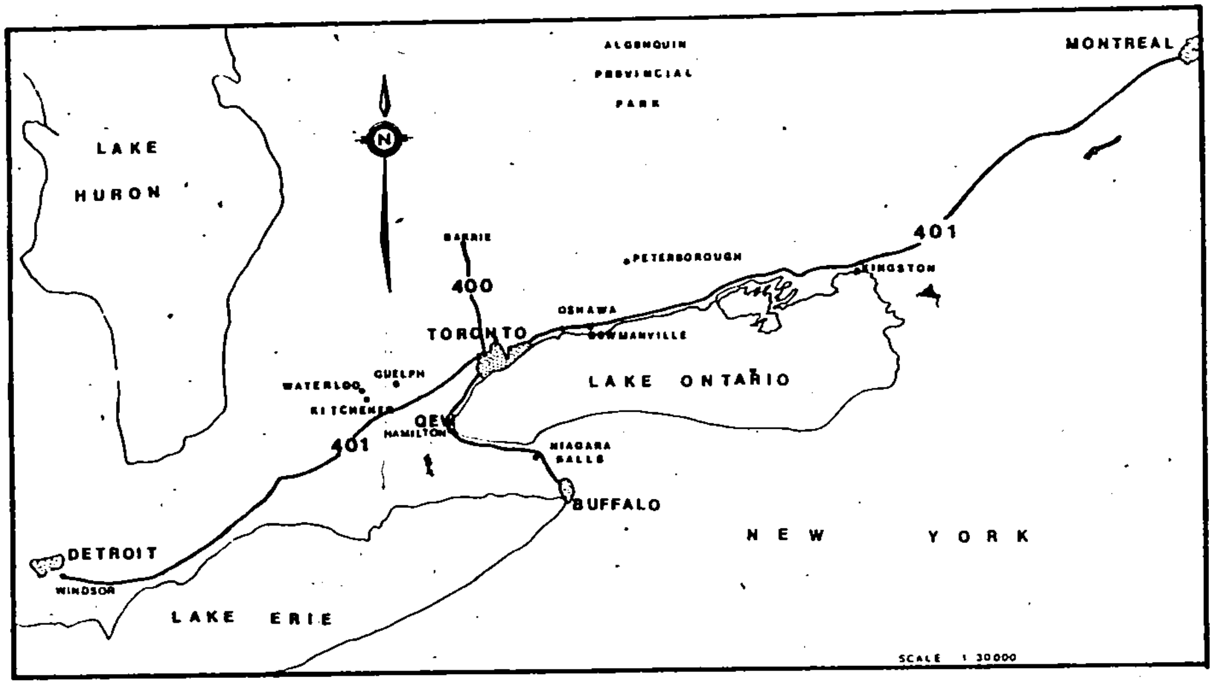


Figure 3.1 Highway Locations

characteristics are presented in this section. To aid in these descriptions, photographs taken at or near to the sites are shown. The reasons for site selection and trip types are also noted.

3.2.1 Queen Elizabeth Way (QEW) in Mississauga

The QEW connects the Niagara Peninsula with Toronto. This freeway serves as a major commuter access route from Burlington, Oakville, and Mississauga to the large metropolitan Toronto area. In addition, the majority of all roadway trips between Hamilton and Toronto use this freeway. Figure 3.2 depicts the major regions which generate trips along the QEW. Since the QEW is such a heavily used facility and is often congested during peak periods, it was selected as the site for a Freeway Surveillance and Control System (FSCS) demonstration project operated by the Ontario Ministry of Transportation and Communications (MTC). The reader is referred to Figure 3.3 for the location of the FSCS.

The FSCS surveillance capability presently comprises nine television cameras spanning from Winston Churchill Boulevard to Cawthra Road, in Mississauga. In addition, there are ten stations at which traffic flow data are recorded. Each data station comprises loop detectors in the three eastbound lanes. It is for these lanes that data are recorded. The stations lie at varying distances apart, as shown in Figure 3.4.

The freeway section under surveillance was chosen for this study

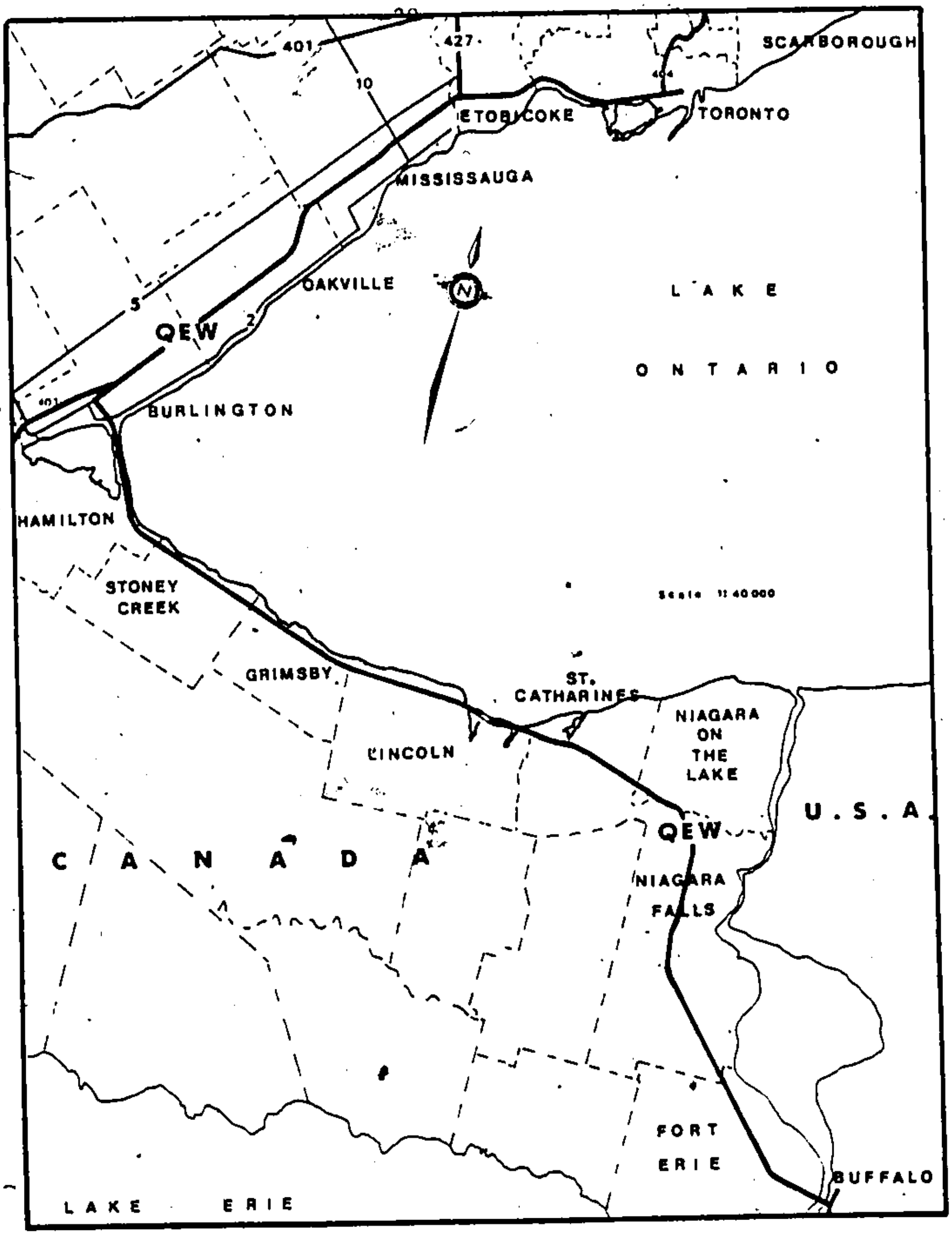


Figure 3.2 Location of Queen Elizabeth Way (QEW)

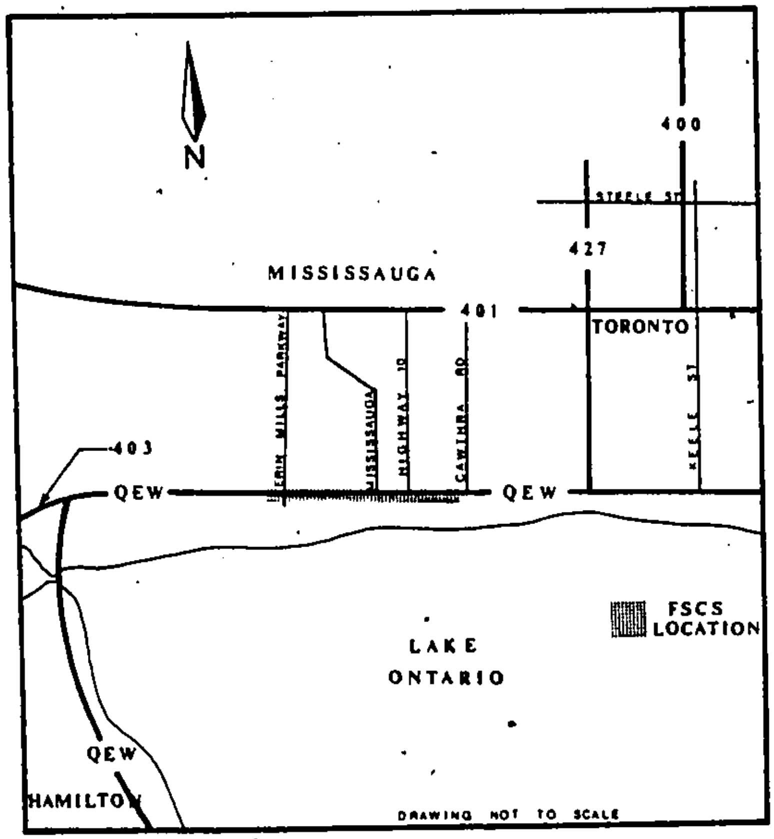


Figure 3.3 Freeway Surveillance and Control System Location

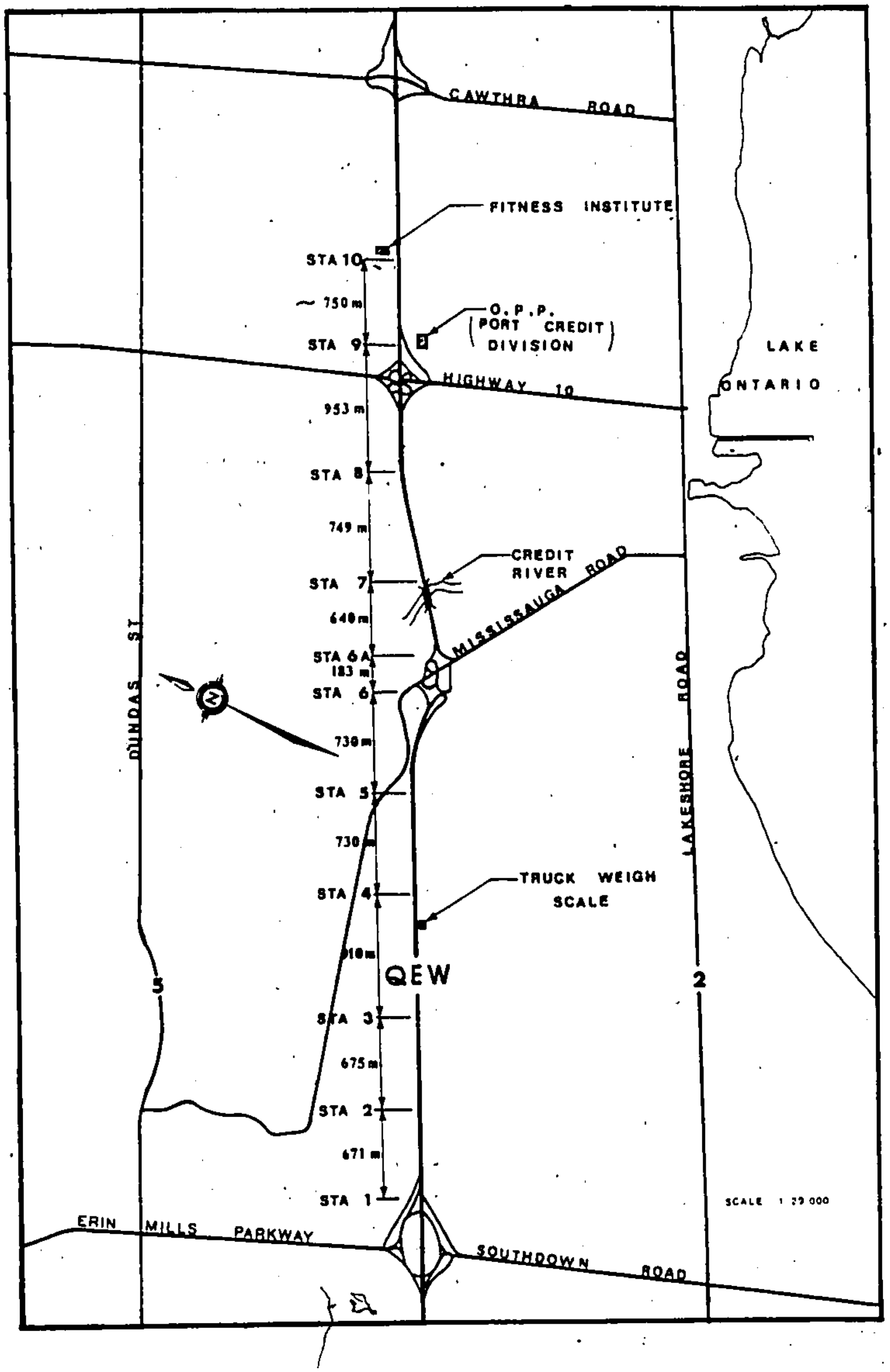


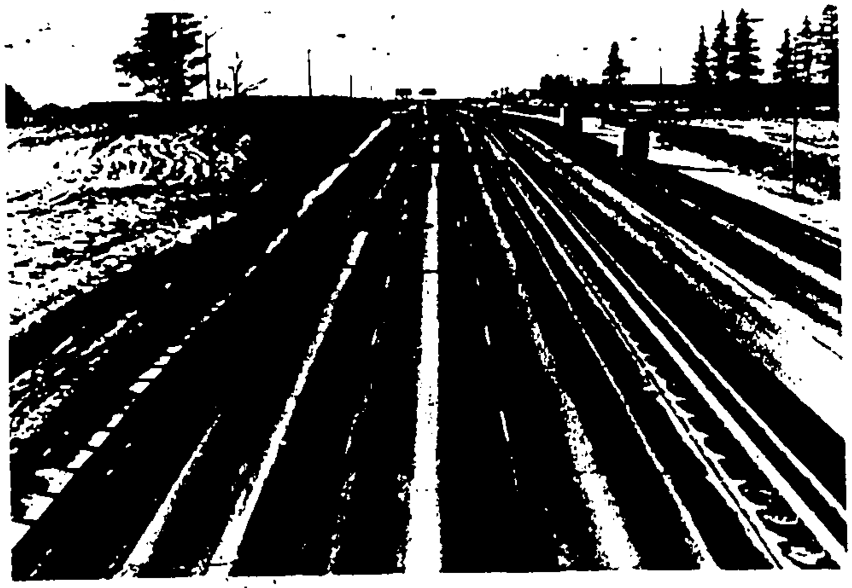
Figure 3.4 Station Locations, QEW (Mississauga)

due to four reasons. First, flow on the freeway section was expected to reach capacity and the determination of lane capacity is a major objective of this research effort. Second, several locations under surveillance present ideal geometric characteristics, which is necessary to define ideal capacity. Third, the costs and time associated with a crew for manual data collection are alleviated, and fourth, large sets of traffic flow data are readily available from the computerized collection system.

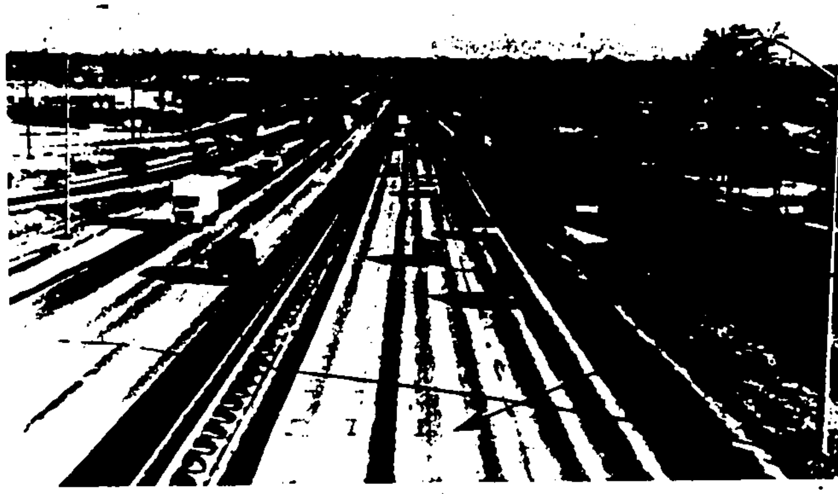
Toronto bound (or eastbound) traffic is monitored under the FSCS. Figure 3.5 shows pictures obtained from the overpass at Southdown Road which lies to the west of Station 1. A downgrade and ramp in close proximity to this station cause it to be considered as non-ideal. The downgrade exists upstream of the overpass and this is expected to influence speeds recorded at the station. Figure 3.5(i) depicts the grade. The entrance ramp from Southdown Road can be seen in Figure 3.5(ii). In addition, the loop detectors at the station can also be observed.

A uniform freeway section (i.e. without entrance or exit ramps) is represented by Station 2. This site conforms to the description of ideal conditions, discussed in section 1.3 of Chapter 1. Figure 3.6 shows two photographs taken from the shoulder at Station 2. The uniformity of the roadway can certainly be observed from the figure.

A truck weigh scale is located between Stations 3 and 4. This is noted in Figures 3.7 and 3.8 which show upstream and downstream views, obtained from the shoulder at both sites. Tangent sections are easily



(i) Upstream



(ii) Downstream

Figure 3.5 Views from Southdown Road Overpass Near Station 1

(i) Upstream

(ii) Downstream

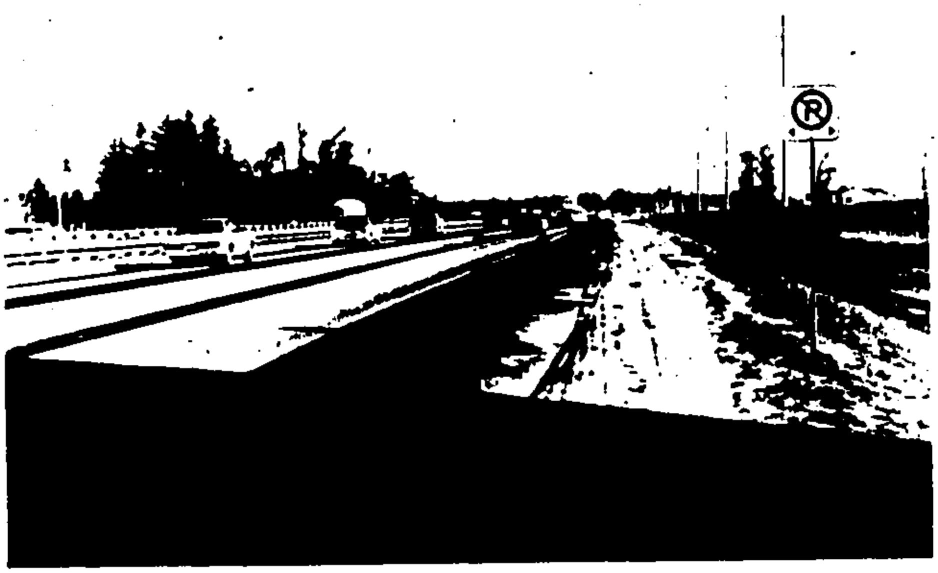
Figure 3.6 Views from Station 8

(i) Upstream

(ii) Downstream

Figure 3.7 Views from Station 3

(i) Upstream



(ii) Downstream

Figure 3.8 Views from Station 4

observed in the four photographs. Traffic flow close to these two stations is expected to be influenced by trucks decelerating (accelerating) toward (from) the weigh scale system. Station 5 lies on a horizontal curve. This is clearly depicted by the pictures shown in Figure 3.9. These photographs were taken from the shoulder, a few meters east of the station. In addition to lying on a horizontal curve, Stations 6 and 6A are in close proximity to the exit and entrance ramps at Mississauga Road. Figure 3.10 includes photographs taken from the shoulder, east of Station 6A. The horizontal curvature and ramp location can certainly be identified.

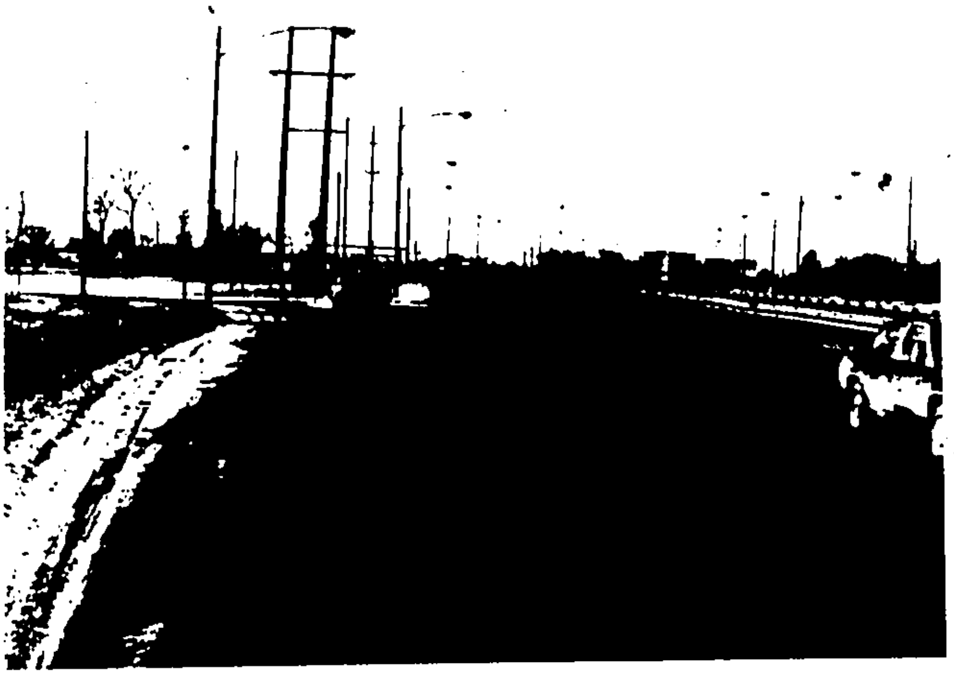
Station 7 is situated on another uniform section of the freeway. It lies east of the Credit River. The shoulder on the bridge is less than 6' wide, a possible constraint, worthy of note. Figure 3.11 shows photographs taken a few meters east of Station 7. Bridge rails can be observed in Figure 3.11(i). Station 8 lies on a mild horizontal curve, west of the exit ramp at Highway 10. This recording station is sufficiently far from the exit ramp to be treated as ideal. Photographs taken on the shoulder, a few meters east of the station are shown in Figure 3.12. The two views show a uniform freeway section.

The final automatic data recording location, Station 9, lies on a vertical curve. Figures 3.13(i) and 3.13(ii) were taken from east of the station location. The photographs were taken from a moving vehicle in the shoulder lane of the traffic stream. Figure 3.13(i) includes a view of the vertical curve and Highway 10 entrance ramp. The uniform freeway section downstream of the station is seen in Figure 3.13(ii).

(i) Upstream

(ii) Downstream

Figure 3.9 Views Near Station 5

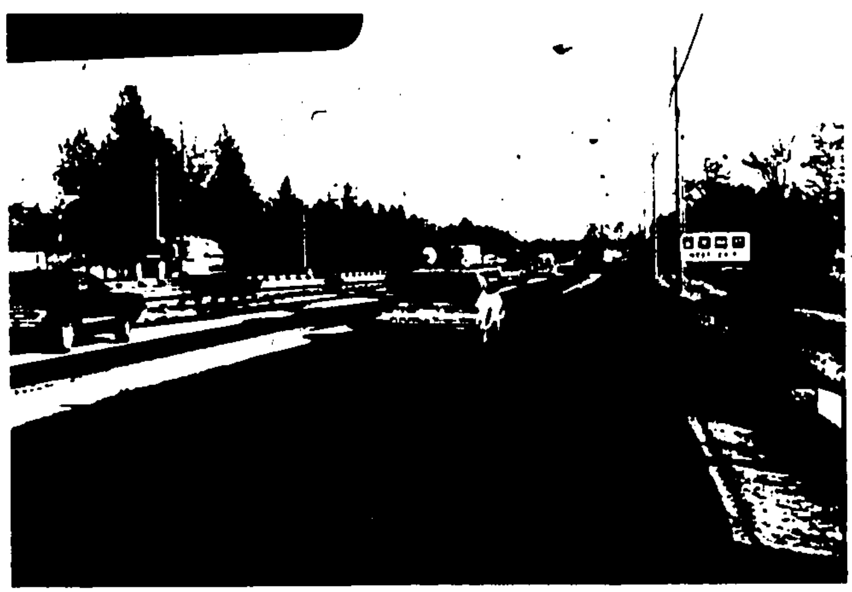


(i) Upstream

(ii) Downstream

Figure 3.10 Views Near Station 6A

(i) Upstream



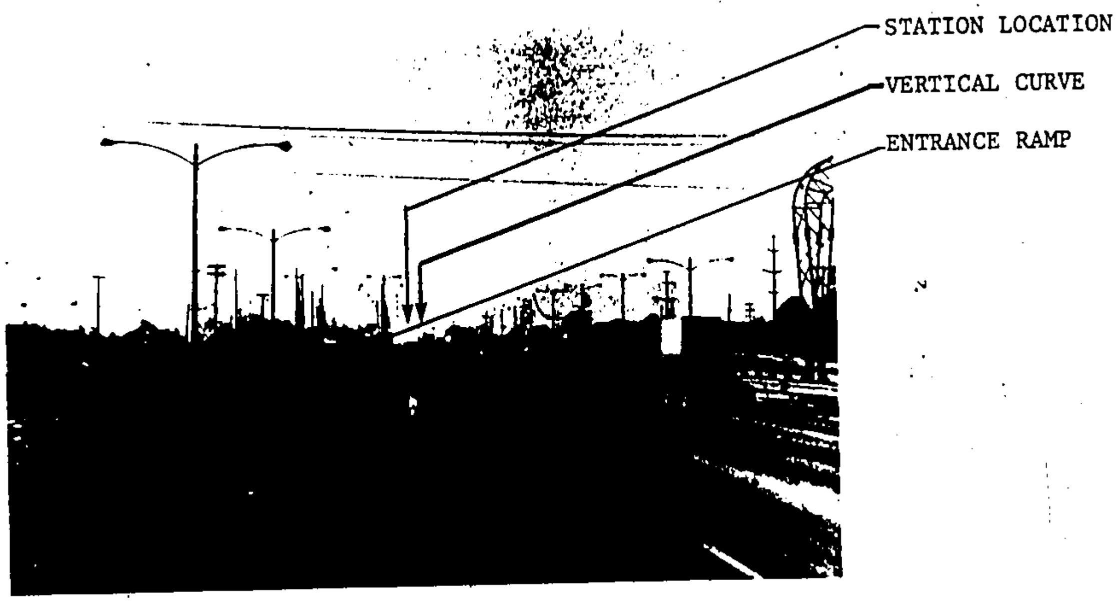
(ii) Downstream

Figure 3.11 Views from a Location East of Station 7

(i) Upstream

(ii) Downstream

Figure 3.12 Views from a Location East of Station 8



(i) Upstream

(ii) Downstream

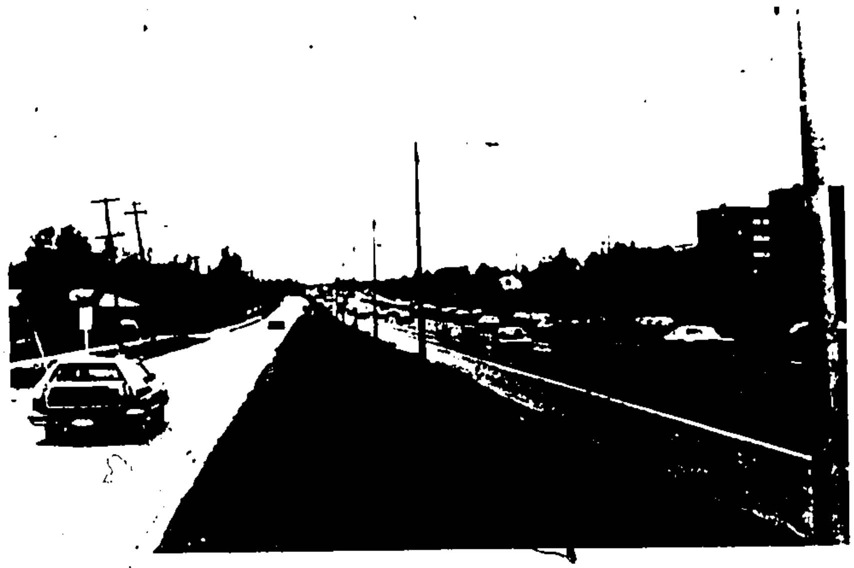
Figure 3.13 Views from a Location East of Station 9

The section of the QEW west of Highway 10 experiences congestion in the morning peak period. A bottleneck is caused as a result of the Mississauga traffic entering the freeway at the Highway 10 entrance ramp. Queues of vehicles often extend upstream Station 1 as a result of this congestion. A data collection site was selected within the bottleneck section so as to determine capacity. The site lies close to the Fitness Institute in Mississauga and was denoted as Station 10. There are no detectors at this location. Figures 3.14(i) and 3.14(ii) include photographs taken from the South Service Road adjacent to Station 10 and illustrate the uniformity of the freeway section, the Fitness Institute and camera used for data collection.

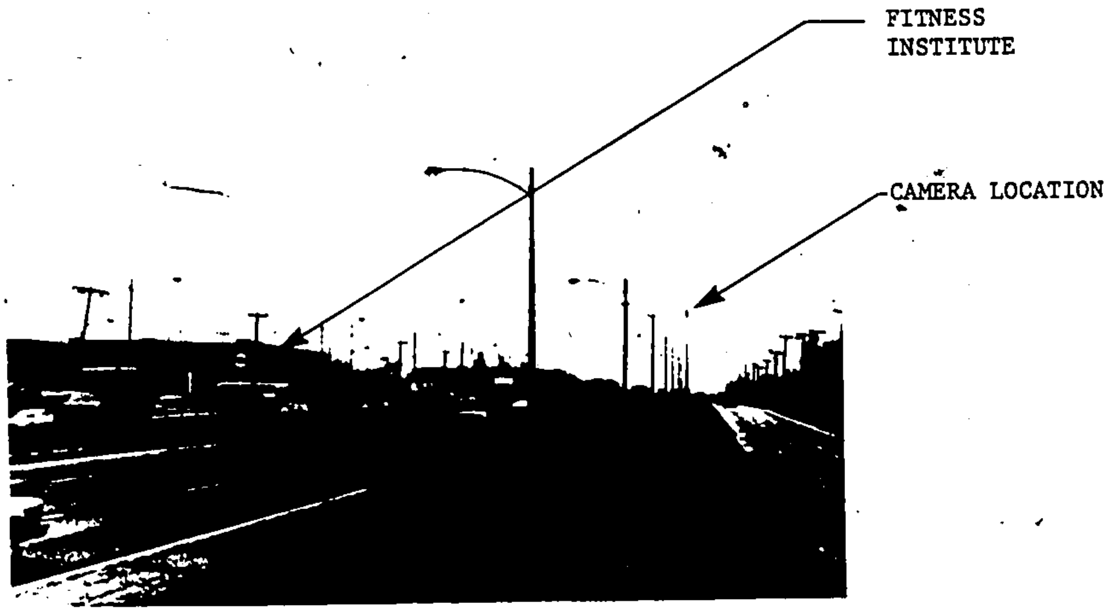
3.2.2 Highway 400

Highway 400 spans from Toronto to Barrie. It passes through the major trip generating regions of Barrie, Bradford and Richmond. The data collection site on Highway 400 was adjacent to Rutherford overpass. Northbound traffic was surveyed and was expected to be primarily recreational traffic. Figure 3.15 shows the location of the overpass. Figure 3.16 shows photographs taken from the overpass. Ideal characteristics can be observed in the pictures. The data collection site enables a survey crew to be conveniently positioned for data collection.

Data were previously compiled from this 3-lane section and plotted in Allen [(3),p.37]. The plots indicate operation in free flow conditions. The site was again surveyed for this project in an attempt



(i) Upstream



(ii) Downstream

Figure 3.14 Views from Station 10, Near the Fitness Institute

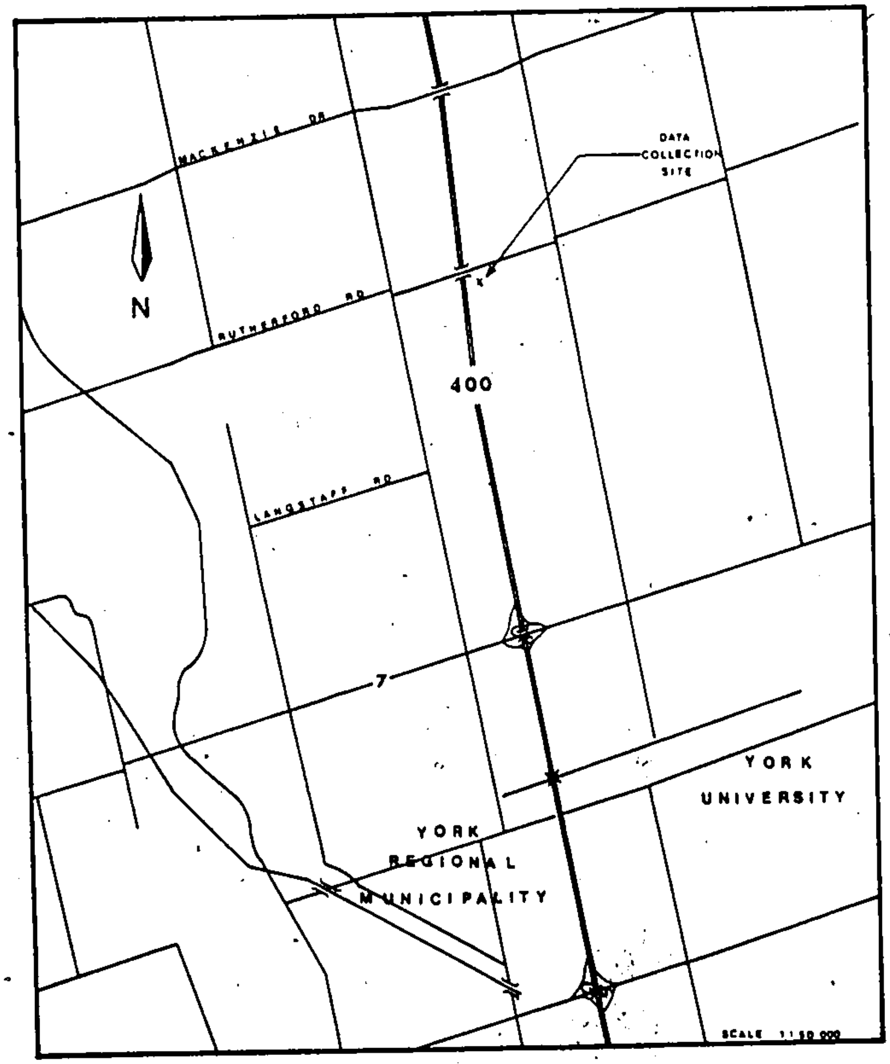
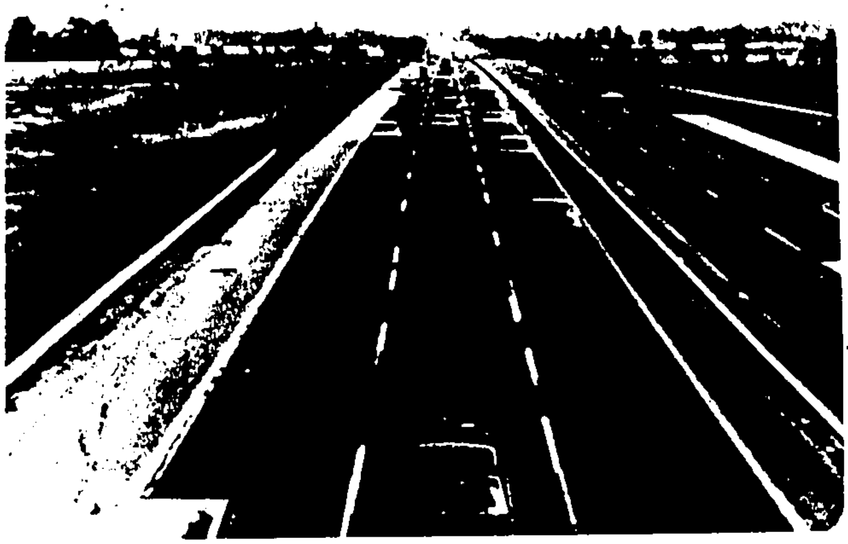


Figure 3.15 Highway 400 Data Collection Site



(i) Upstream

(ii) Downstream

Figure 3.16 Views of Highway 400 from Rutherford Overpass to obtain flow values at or close to capacity.

3.2.3 Highway 401

The MacDonald Cartier freeway, Highway 401, is a high quality facility which extends from Windsor to Quebec, passing through Metropolitan Toronto. Figure 3.1 shows the overall location of the freeway. Between Toronto and Quebec, Highway 401 serves as a major access route to the recreational regions of Algonquin, Peterborough and Hasting. In addition, it services trip generators in New York State and Kingston. The facility is certainly known to be heavily utilized.

On holiday weekends the section of corridor between Toronto and Quebec is heavily used by holiday makers. In particular, a congested 2-lane section between interchanges 73 and 74 in the Toronto bound direction was surveyed. Reference can be made to Figure 3.17, for the location of data collection sites. Although there was no shoulder adjacent to the median lane, the site was surveyed. It enabled the crew to be well concealed during the collection of data. Figure 3.18 shows the uniform freeway section at the site as taken from the shoulder.

Data were also compiled at a 3-lane section in close proximity to the Holiday Inn, which lies approximatly 2.6km west of the 2-lane site. Figures 3.19(i) and 3.19(ii) are upstream and downstream views from the collection site. A concrete safety barrier serves as the median and a shoulder about 2 m wide is adjacent to the shoulder lane. Again, the survey crew was well hidden from the traffic stream.

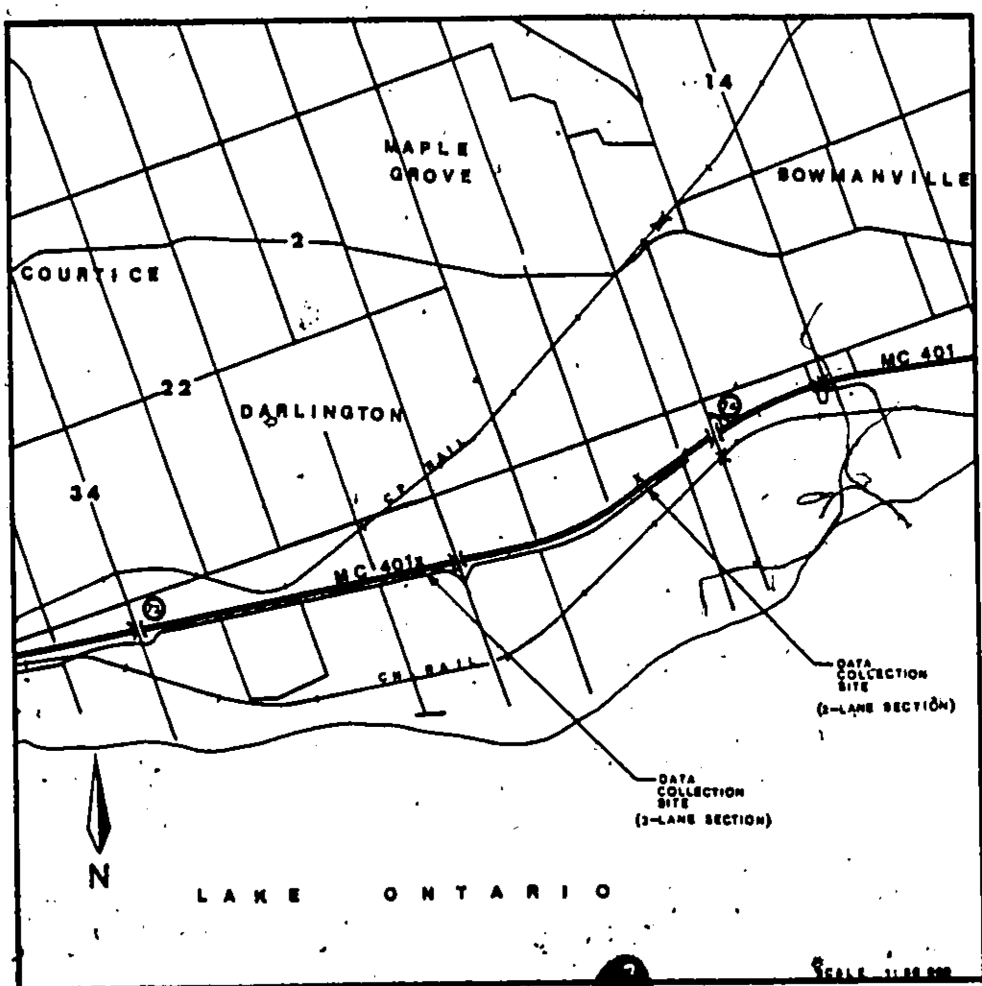


Figure 3.17 Highway 401 Data Collection Sites

Figure 3.18 Two Lane Section of Highway 401 Between Interchanges 73 and 74

(i) Upstream

(ii) Downstream

Figure 3.19 Views of 3-Lane Section of Highway 401

3.2.4 Queen Elizabeth Way (Hamilton)

The traffic operations on a 2-lane section of the QEW in Hamilton are also studied in this report. Figure 3.20 depicts the region. The corridor serves primarily as a connector for peak period trips between Burlington, Hamilton, Stoney Creek and the St. Catherines area. Two locations were studied in the corridor. In both cases Niagara bound traffic was monitored. One location was chosen at the Millen overpass, and the other upstream from the Highway 20 entrance ramp. The former site was selected because of the ideal geometric characteristics and availability of a convenient location for the crew. Also, flows close to capacity were expected during the evening peak period. In the latter case, low flows were expected since the site is located upstream from the entrance ramp at Highway 20.

Figures 3.21(i) and 3.21(ii) are pictures taken from Millen overpass. Ideal conditions are unmistakable in the photographs. At the data collection site upstream of the Highway 20 entrance ramp, pictures taken from the South Service Road are shown in Figure 3.22. A uniform freeway section is also noticeable in these figures.

3.3 DATA COLLECTION

For the sites described in section 3.2, speed and flow data were collected in each case. For the QEW in Mississauga at nine stations data were collected at the nine automatic collection stations by a computer and stored on magnetic tapes. In all other cases, however, manual data collection was required. Five-minute recordings of volume

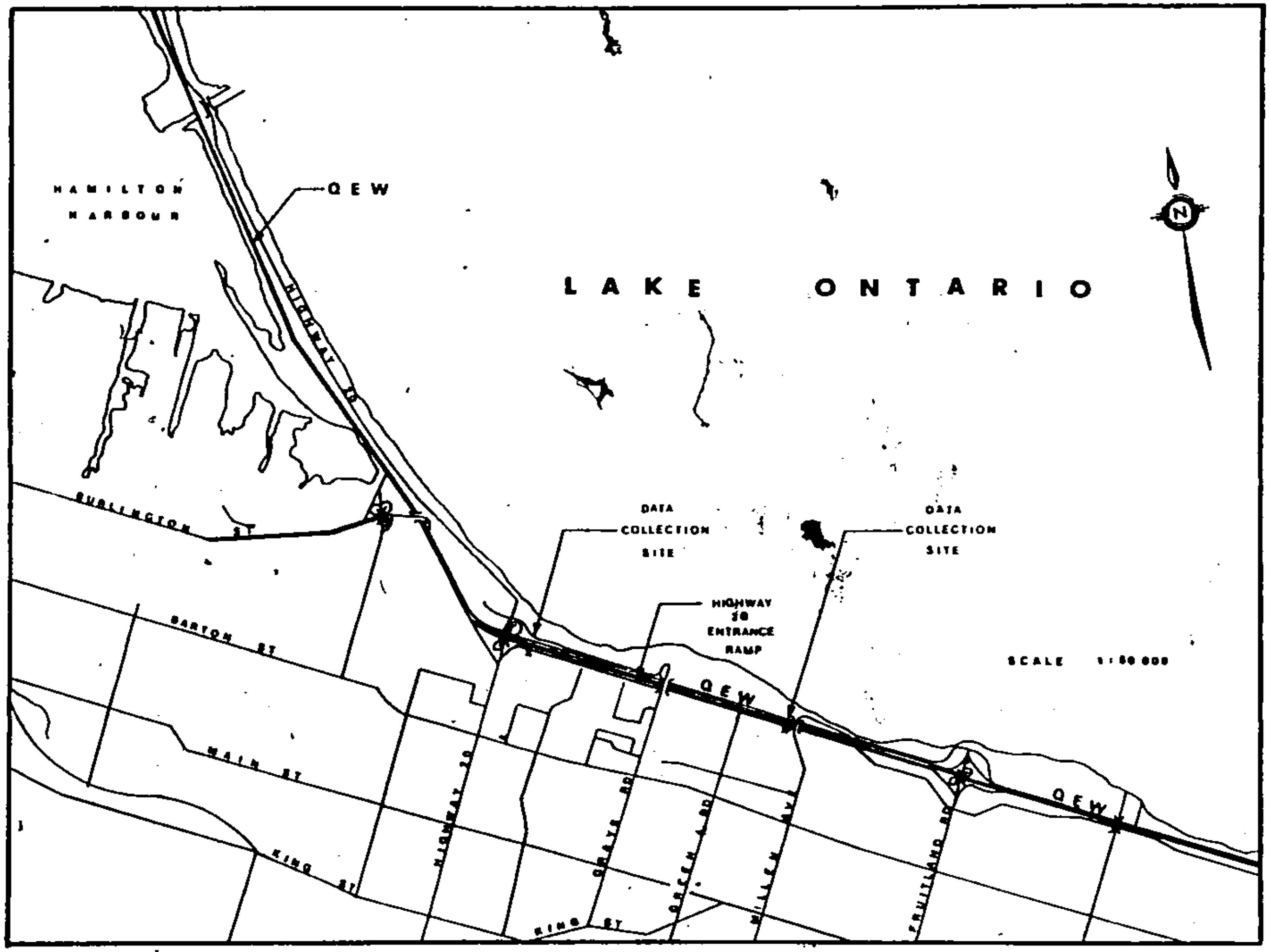
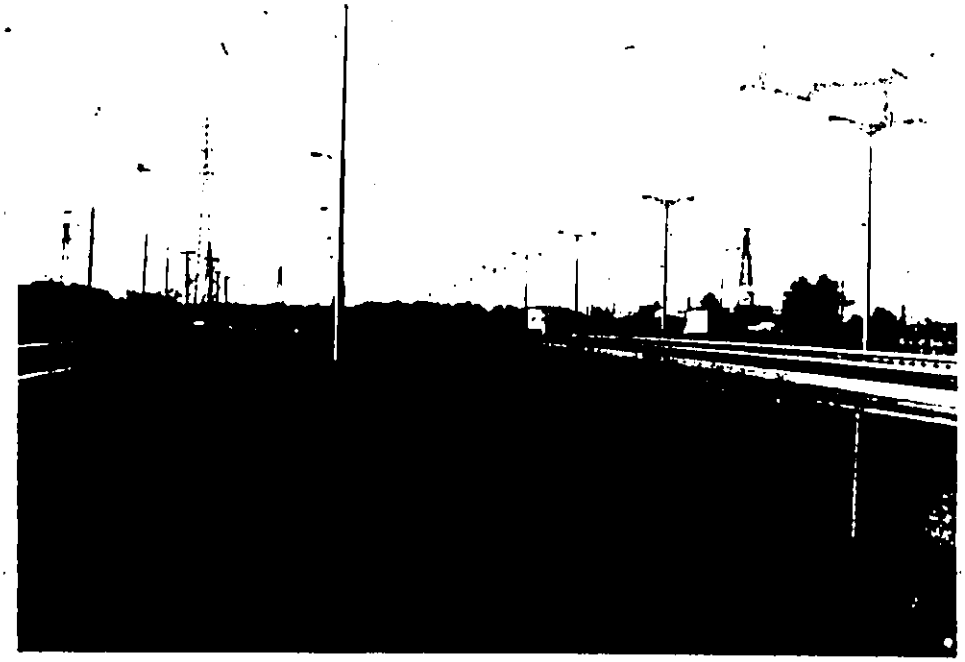


Figure 3.20 QEW (Hamilton) Data Collection Sites

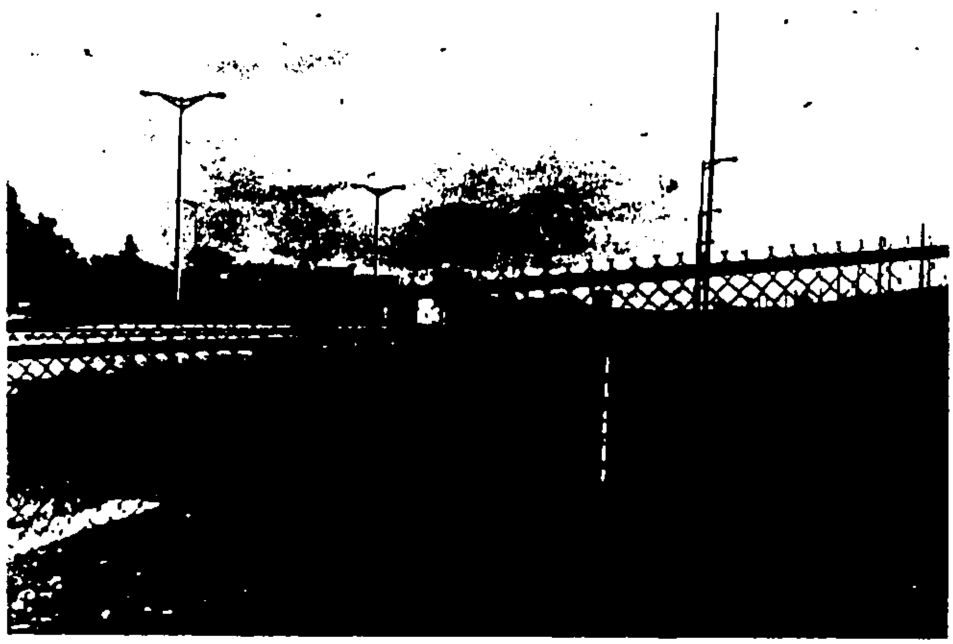
(i) Upstream

(ii) Downstream

Figure 3.21 Views from Millen Overpass



(i) Upstream



(ii) Downstream

Figure 3.22 Views from the Location Upstream of Highway 20 Entrance Ramp and speed were made. Traffic composition was monitored together with random spot speeds recorded on a per-lane basis.

3.3.1 Queen Elizabeth Way (Mississauga)

Subsection 3.2.1 dealt with descriptions of the data collection sites in Mississauga. Herein, the method of data collection at the sites is explained. The Ministry utilizes a traffic data program to compile real time traffic data for Stations 1 to 9. Station 6A is not included. Data collection was carried out for eastbound traffic in the morning peak period, that is, approximately 7:00-9:00 a.m. The data includes lane and station values of volume, speed and occupancy updated at 30 second, 1-minute and 5-minute intervals.

Traffic flow information, compiled on any given day are stored in various files. Since this research was executed based on 5-minute data, the 5-minute data file was extracted for each day. The file contained volume, average spot speed and occupancy data on a lane basis for 5-minute periods.

Twelve 2400-foot, 9 track magnetic tapes are employed in the FSCS. At any given time there are eleven with stored traffic flow data. The remaining tape is kept on the computer at the Ontario Provincial Police (OPP) station (in Mississauga). Usually, one tape can accommodate one month of traffic flow data.

Seven magnetic tapes were made available by the Ministry and contain data from July 1979 to February 1980. Because of the numerous problems associated with the detectors and modems, no data had been compiled beyond July 1980. Tapes from March 1980 to July 1980 were not analyzed.

The magnetic tapes were to be used on the CDC 6400 available at McMaster University. They were compiled in dump format. At the end of a period of time, for example, one month, the compiled data were dumped unto tape. These data tapes not only contain data files but have additional information, e.g., dates and times of file creations and error checks. Since the format of this information was unknown, compatibility with the CDC 6400 proved to be impossible. The only feasible alternative was to extract the necessary data files without specifying the data format. This was possible on a Data General computer, since the magnetic tapes were also created on a Data General machine.

The specific files containing 5-minute volume, speed and occupancy values were copied in ASCII format to new magnetic tapes on a Data General computer. Since the format of these new tapes were completely known it was then possible to read them on the CDC 6400.

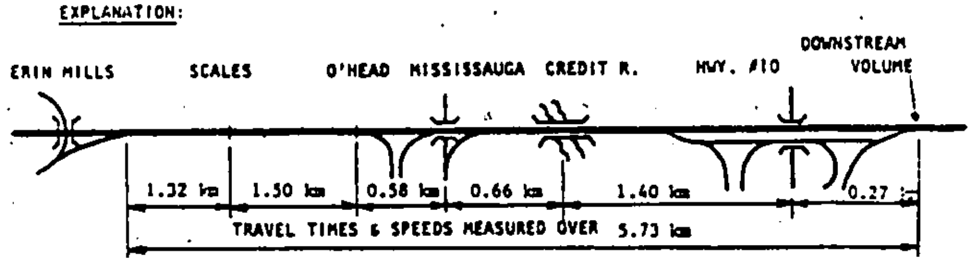
Figure 3.23 is an example of a daily report form used by MTC for the FSCS. These reports enable relevant weather and traffic conditions to be obtained on a daily basis. A summary of these reports from July 1979 to February 1980 is contained in Table A1.1 of Appendix 1. The dates and times for which conditions are considered to be ideal are obtained from Table A1.1. Times beyond which accidents occur are not classified as ideal.

FREEWAY SURVEILLANCE & CONTROL PROJECT

PRESENT CONDITIONS					NON - METERED CONDITIONS	
DATE	DAY	WEATHER			NON-METERED GOOD DAYS	NON-METERED BAD DAYS
Max. T.T./Speed		MINS/	km/h		13.10/26.3	22.60/15.3
Av. T.T./Speed		MINS/	km/h		10.10/34.3	16.10/21.4
CONGESTION PERIOD		(	MINS)		07:15-09:00 (105)	07:15-9:25 (130)
END OF FWY. QUEUE					SCALES	E. MILLS
RAMP QUEUES:						
1) SOUTHDOWN	MAX/AV	VEH/	VEH		0/ 0	30/10
2) MISS. S/B	MAX/AV	VEH/	VEH		60/20	80/40
3) MISS. N/B	MAX/AV	VEH/	VEH		15/ 5	30/10
4) HWY. #10 S/B	MAX/AV	VEH/	VEH		90/40	110/60
5) HWY. #10 N/B	MAX/AV	VEH/	VEH		50/20	60/25
VOLUME 07:00-09:00			VEH		11,050	10,200
PERFORMANCE GRADING						

COMMENTS:

EXPLANATION:



BAD DAYS: DAYS WHEN WEATHER IS BAD OR COLLISIONS OR INCIDENTS OCCUR.
GOOD DAYS: REMAINDER
MAX T.T.: MAXIMUM TRAVEL TIME FROM ERIN MILLS INTERCHANGE TO HWY. #10 INTERCHANGE (5.73 km) DURING CONGESTED PERIOD.
AV. T.T.: AVERAGE TRAVEL TIME AS ABOVE.
CONGESTED PERIOD: TIME PERIOD OVER WHICH DOWNSTREAM DENSITY AT HWY. #10 IS ABOVE USUAL CONDITIONS.
MAX. RAMP QUEUE: MAXIMUM NUMBER OF VEHICLES IN QUEUE MEASURED FROM SIGNALS, DURING THE CONGESTED PERIOD.
TYP. RAMP QUEUE: TYPICAL QUEUE AS ABOVE.
END OF FWY. QUEUE: MEASURED FROM DOWNSTREAM HWY. #10.
DAILY PERFORMANCE GRADING: EFFECT OF WEATHER, INCIDENTS, OR ACCIDENTS ON TRAFFIC FLOW.

1. GOOD TRAFFIC FLOW - NO EFFECT FROM WEATHER, ACCIDENTS OR INCIDENTS.
2. FLOW SLIGHTLY AFFECTED.
3. FLOW MODERATELY AFFECTED.
4. FLOW SEVERELY AFFECTED.
5. COMPLETE BREAKDOWN.

Figure 3.23 Sample Daily Report Form

Data collection at Station 10 was accomplished by means of the camera located in close proximity to the Fitness Institute. Television monitors operating in the Port Credit Division of the Ontario Provincial Police (OPP) enabled videorecordings at Station 10 to be made. Videorecordings were obtained for the period 10/10/80 to 11/5/80 for ideal weather conditions in the peak period. For each day, unusual incidents and weather conditions were noted. The days for which data were collected are shown in Table 3.1. One day was spent collecting data for low flows, i.e. on 12/4/80 from 10:00 a.m. to 2:00 p.m.

Data were recorded on 30-minute and 1-hour duration videotapes. When recordings were executed, the time of commencement and termination were noted. The times at which unusual occurrences on the television monitor occurred were also recorded.

3.3.2 Highway 400

On Friday, 8/29/80, was chosen as the date for data collection at the Highway 400 location. This particular day was selected as it preceded a holiday weekend. Thus, it was expected that many people would be travelling to the recreational regions on Friday afternoon. Traffic flow between 1:00 and 6:00 p.m. in the northbound direction was therefore monitored.

An 8-mm time lapse camera was employed for collecting volume and speed data. A continuous manual check was maintained to detect increases in flow. The camera was activated when flow rates began increasing. This was done since only information at or close to

Table 3.1 Dates on which Data were Collected from Station 10

DATE	DAY
10.10.80	Fri.
10.20.80	Mon.
10.22.80	Wed.
10.27.80	Mon.
10.30.80	Thurs.
11.3.80	Mon.
11.4.80	Tues.
11.5.80	Wed.
12.4.80	Mon.

capacity were needed. The positioning of crew and instruments was as shown in Figure 3.24. Both markers were present in the filming which was operated at 2 frames per second. Timings of vehicle passage over a given distance enabled average space mean speeds to be calculated. Typical data collection sheets used throughout the surveys are shown in Figure 3.25.

On Highway 400, the demand at the study site did not reach capacity. Maximum flows attained were of the order of 1700 pcph. One possible reason for the unexpected low flow is the forecast of poor weather for that weekend. Data from Allen et al, [3], are also included in this research. However, Allen collected 1-minute data and summed five consecutive values to derive 5-minute data. This data collection procedure involved manual flow recordings and the timing of vehicles over a given distance for the determination of speeds.

3.3.3 Highway 401

Data were collected at two locations simultaneously from Highway 401. Crews were hidden from the view of drivers in the traffic stream being filmed. The afternoon peak for a holiday weekend was selected for the time of study. Recordings were made on 9/1/80, a Monday, which was a holiday. It was expected that Toronto bound traffic would be heavy because of the returning recreationists.

At the 2-lane section, 5-minute volume counts of cars, trucks, and recreational vehicles were manually recorded for each lane. Speeds were compiled randomly within each 5-minute volume using a portable Muni

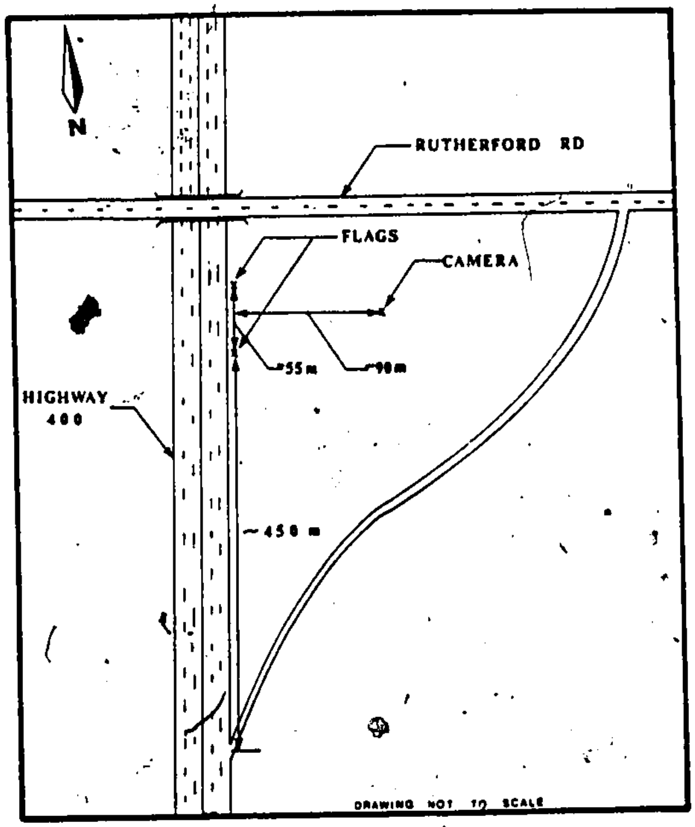


Figure 3.24 Highway 400 Data Collection Site Details

DATE:
CREW:
WEATHER:

SITE:
COMMENTS:

LANE	TIME	5-MIN VOLUMES			SPEEDS (mph)
		CARS	TRUCKS	REC VEHS.	

Figure 3.25 Format of Typical Data Collection Sheet

Quip radar gun connected to a 12V battery i.e.. spot speeds. Prior to recording speeds, the gun was calibrated with a 50 Hz tuning fork.

Data collection commenced at 1:30 p.m. and ceased when the peak was observed to have passed. This time period was chosen so as to incorporate both low and peak traffic volumes in the speed-flow curves. There were 50 data points collected for the 2-lane section of the Highway 401 site.

The crew consisted of five (5) members. One person each checking the two lane volumes. The volumes were recorded on counters attached to clipboards. A sketch of a typical clipboard configuration is shown in Figure 3.26. At the end of each 5-minute count, the recorder moved to the other counter. One person was assigned the task of tabulating the 5 minute volumes and zeroing the counters. In addition, he was responsible for noting the start and end of 5-minute periods and tabulating radar speeds. One person operated the radar gun and called out random speeds and lanes for which the measurement was made. The remaining crew member was used to relieve those doing the 5-minute volume counts.

For the 3-lane section time lapse photography was used. The advantage of filming is that it enabled the data to be rechecked, if necessary. The cost, however, is inevitably more than having a crew manually collect the field information because of the time needed to extract data from the film. Filming was carried out at a speed of two frames per second. Within two successive frames, the distance covered by a vehicle could be measured. The distance between two hydroelectric

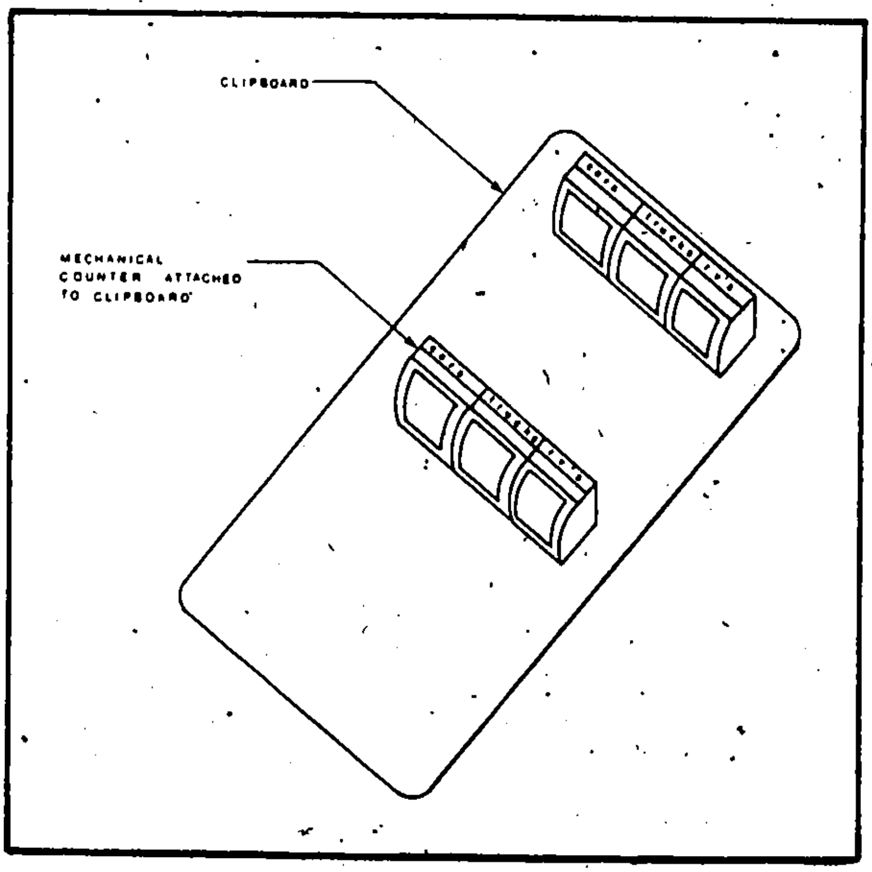


Figure 3.26 Schematic of Counter Board

with distance on the film enabled distances covered by vehicles in each one second interval to be obtained. Thus, vehicle speeds could be easily deduced subsequently.

3.3.4 Queen Elizabeth Way (Hamilton)

At both 2-lane sections of the QEW, counts were obtained between 1:00 and 5:00 p.m. The survey was carried out in December 1980 for the days listed in Table 3.2. Manual counts of cars and trucks for 5-minute flows were made at both sites. Spot speeds were randomly measured using a radar gun.

The crew consisted of four members at the downstream site. One person checked traffic volume in each [illegible] the two lanes. Recordings were made on a counter attached to a clipboard. At the end of each 5-minute period, the board was replaced by another. This change of boards was made by the recorder. The recorder noted the volumes and zeroed the counters. He was also responsible for noting speeds called by the radar gun operator. The crew was stationed in a van parked on the South Service Road.

At the upstream section, three crew members were utilized. Because the flows were low, e.g., 500 passenger cars per hour, one person was allowed to check cars and trucks for both lanes. The two remaining crew members filled the jobs of recorder and radar gun operator. Again, the vehicle was parked on the Service Road.

TABLE 3.2 Days on which data were collected on the QEW (Hamilton)

Date	Data collection period	Location
12.16.80	2:15 - 4:35 pm	Niagara bound, downstream of Highway 20
12.17.80	1:00 - 4:30 pm	"
12.19.80	1:45 - 4:25 pm	Niagara bound, upstream of Highway 20

3.4 DATA REDUCTION

Data collection procedures were described previously. The method of treatment of each data set collected is described in this section. For the QEW in Mississauga the rearrangement of the raw data file, DATA5M and Station 10 data are discussed. Except for the 3-lane section on Highway 401, all that was required for other sites was a summary of raw field data. In all cases plots were made by utilizing the Statistical Package for Social Sciences (SPSS) available at McMaster. Flows were converted to passenger car units per hour (pcph). Reference [1] suggests a value of 2.0 for both trucks and recreational vehicles travelling under ideal conditions and this standard value was used unless otherwise stated.

3.4.1 Queen Elizabeth Way (Mississauga)

The traffic flow data obtained on the QEW in Mississauga were divided on a lane and station basis. The format of the file DATA5M, collected from the FSCS is shown in Table A1.2. The first 23 numbers give ramp occupancy which is not needed for the study. The last 31 numbers are not useful information. Thus, in each array, the first 23 and last 31 numbers were deleted. The remaining numbers are lane and station values of occupancy, speed and vehicle volume. Truck volumes were measured in the system by calculating the vehicle length according to equation 3.1.

$$V = S \times T - L \qquad (3.1)$$

where V = Vehicle length in feet,

S = Spot speed in feet per second,

T = Time obtained from occupancy recordings, and

L = Loop length, i.e. 6'.

Vehicles with lengths in excess of 25 feet were classified as trucks.

The numbers in the file DATA5M were rearranged from one number per line to 5 numbers per line. This not only reduced on the space needed on the computer, but also enabled the data to be more easily read and understood. The new format of the file is as shown in Table A1.3.

For the seven data tapes available, seven data files were created. From the information available in Table A1.1 in Appendix 1, data affected by incidents are deleted from each file. Further file editing was carried out in order to class the data into clear, rain and snow conditions. The seven files were then merged and subsequently subdivided according to stations. With this process, final data files on a lane and station basis were obtained.

In the case of Station 10 video records were made, as described in section 3.3.1. From the videorecordings, 5-minute volumes of cars and trucks for the three lanes were obtained. Random samples of time measurements over a fixed distance were taken in each period to enable computation of speeds. The fixed distance was four delineation lines on the freeway. Figure 3.27 shows the variation of the lane markings for the eastbound direction on the QEW in the region of the filming. The average values shown in Table 3.3 were used for speed computations. The

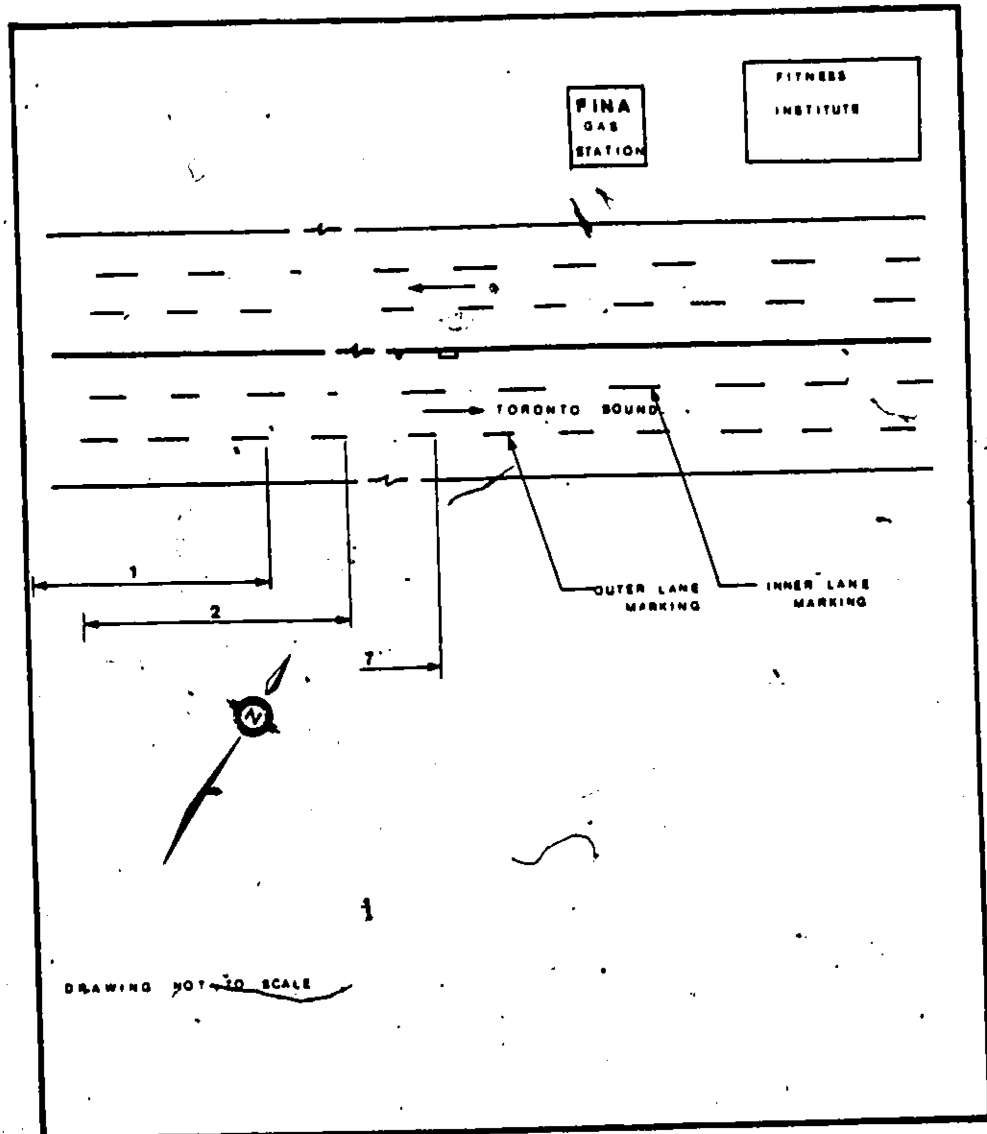


Figure 3.27 Lane Markings on QEW at Station 10

TABLE 3.3 Outer and inner lane marking distances at Station 10

Distance No.	Outer lane marking Length (ft).	Inner lane marking Length (ft).	Remarks
1	98.3	96.2	
2	97.3	102.0	
3	100.6	100.3	
4	101.0	98.6	
5	101.6	101.0	
6	96.0	95.3	
7	101.0	98.2	
8	102.0	92.8	
9	101.0	96.3	
10	101.0	96.5	1st line east of manhole
11	98.0	98.0	
12	97.9	95.0	
Average	99.6	97.5	

distance numbers in the first column of the table coincide with the numbers drawn in Figure 3.27.

A two member crew was employed for analyzing the videotapes. The tapes were first viewed for car counts and random speeds on a per lane basis. They were again reviewed for the measurement of trucks and a second check of random speeds.

3.4.2 Highway 400

Highway 400 data collected represented only free flow conditins. Since Allen (3) had already compiled and plotted speed-flow data for the same site in free flow, this data are included instead of data recorded in 1980. A total of 200 data points are shown.

3.4.3 Highway 401

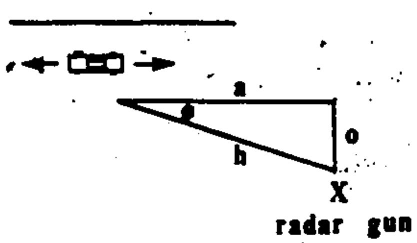
Speed and 5-minute flow data for the 3-lane section were extracted from the time lapse film record. All information obtained were average values for the three lanes. This was because traffic in different lanes could not be distinguished on the film. Speeds were determined by measuring distances traversed in one second.

For the 2-lane section on Highway 401, spot speeds were obtained by averaging values recorded in each 5-minute period. In some intervals speeds were not recorded. Values for these occasions were obtained by interpolation. Radar speeds were corrected for the angle of incidence according to Table 3.4. A factor of 0.966 was employed.

TABLE 3.4 Tables Relating to Angle Error Determinations.

B		A	
Angle	Correction Factor	Tangent	Tables
1°	.999	1°	.017
5°	.996	2°	.035
10°	.985	3°	.052
15°	.966	4°	.070
20°	.940	5°	.087
25°	.906	10°	.176
30°	.866	15°	.268
35°	.819	20°	.364
40°	.766	25°	.466
45°	.707	30°	.577
		35°	.700
		40°	.839
		45°	1.000

$$\text{True Vehicle Speed} = \frac{\text{Indicated Speed}}{\text{Correction Factor}}$$



$\theta = \tan^{-1}(o/a)$

obtain θ from part A of table
then see part B for correction

3.4.4 Queen Elizabeth Way (Hamilton)

For both sections on the QEW in Hamilton, the data are treated in the same manner. A mean value of the spot speeds recorded in each 5-minute interval was computed. An average of eight values were recorded for each interval per lane. Radar speeds were corrected for the angle of incidence according to Table 3.4. In this case a value of 0.986 is utilised.

CHAPTER 4
DATA ANALYSIS

4.1 INTRODUCTION

The basic operational characteristics of a particular section of highway can be effectively defined by the speed and flow values attainable at that part of the facility. In effect, capacity can be measured provided sufficient demand exists at the particular study location. As indicated in Chapter 1, capacity is one focal point of this research and its importance in transportation planning and design cannot be overemphasized.

As described in the previous chapter, speed and flow data were collected and analysed on a lane basis for selected 2-lane and 3-lane highway sites. Plots of these data were made using the Statistical Package for Social Sciences (SPSS) available at McMaster University. Marquardt's method was used for fitting curves to data whenever possible. Curves were also fitted to data by visual inspection.

Results of the study suggest that ideal lane capacity is significantly in excess of 2000 pcph. This result is documented in section 4.2. A variation of approximately 4% is noted between 5-minute and 15-minute hourly flow rate computations. Discussion of this observation is contained in section 4.3. The determination of passenger car equivalents for trucks operating in ideal geometric roadway conditions was made from the QEW Mississauga data. Computed values seem to be lower than the recommended value of 2.0 passenger cars per truck. The approach employed and results obtained are noted in section 4.4. The impact of adverse weather conditions is quantified in section 4.5. There appears to be a reduction in average lane capacity of about 7% due to adverse weather conditions. Section 4.6 deals with the relationship between occupancy, speed and flow which suggests a parallel with the density concept. In addition, well defined relations are noted which do not completely agree with established concepts.

4.2 SPEED-FLOW RELATIONSHIPS

Observed operational relationships between speed and flow are presented herein for the selected sections of the QEW in Mississagua and Hamilton, and those sections of Highways 400 and 401 described in Chapter 3. These relations are discussed in sections 4.2.1 to 4.2.4. In all cases, scattergrams were plotted using the Statistical Package for Social Sciences (SPSS) and are shown in Appendix 2.

With the exception of Stations 1-9 on the QEW in Mississauga, all data used are tabulated in Appendix 2. The very large data sets associated with the nine QEW stations are contained on magnetic tape and available from the Traffic Research Group at McMaster University. All values of speed shown are in kilometers per hour (kph). Flows are in units of passenger cars per hour (pcph) and were all computed as 5-minute hourly flow rates unless otherwise stated. Passenger car equivalents (pce's) of 2.0 were used to convert both trucks and recreational vehicles to passenger car units. The justification for the use of 5-minute flow rates and a pce value of 2.0 for trucks are discussed later in the chapter in sections 4.3 and 4.4 respectively.

Plots of typical speed-flow data are shown in Figure 4.1. Due to the different curve characteristics observed between lanes it seemed appropriate to deal with lanes individually and not average lane values as in Reference (1). Attention was given to four aspects of each data plot. First, the speeds observed under free flow and/or low flow conditions were noted. Second, the maximum flows on the facility at the specific location were identified. Third, the range of speeds at capacity were observed and the fourth noteworthy aspect identified from the plots was the general pattern portrayed by the data.

4.2.1 QEW in Mississauga

Data from the morning peak periods for eastbound traffic at Stations 1-10 were compiled. Resultant speed-flow relationships for ideal weather conditions at the ten stations are shown on a lane basis in Figures A2.1 to A2.10 in Appendix 2. A typical set of data has been reproduced in Figure 4.1 for easy reference in the following discussion.

Speeds greatly in excess or below the mean value in low flow conditions were considered to be outliers as shown in Figure 4.1. From each of the plots, capacity was identified with specific selection criteria. First, the observed flow must be in close proximity to the majority of data points and must seem to fit the general characteristics of the data. Second, since many sites were known to have operated at

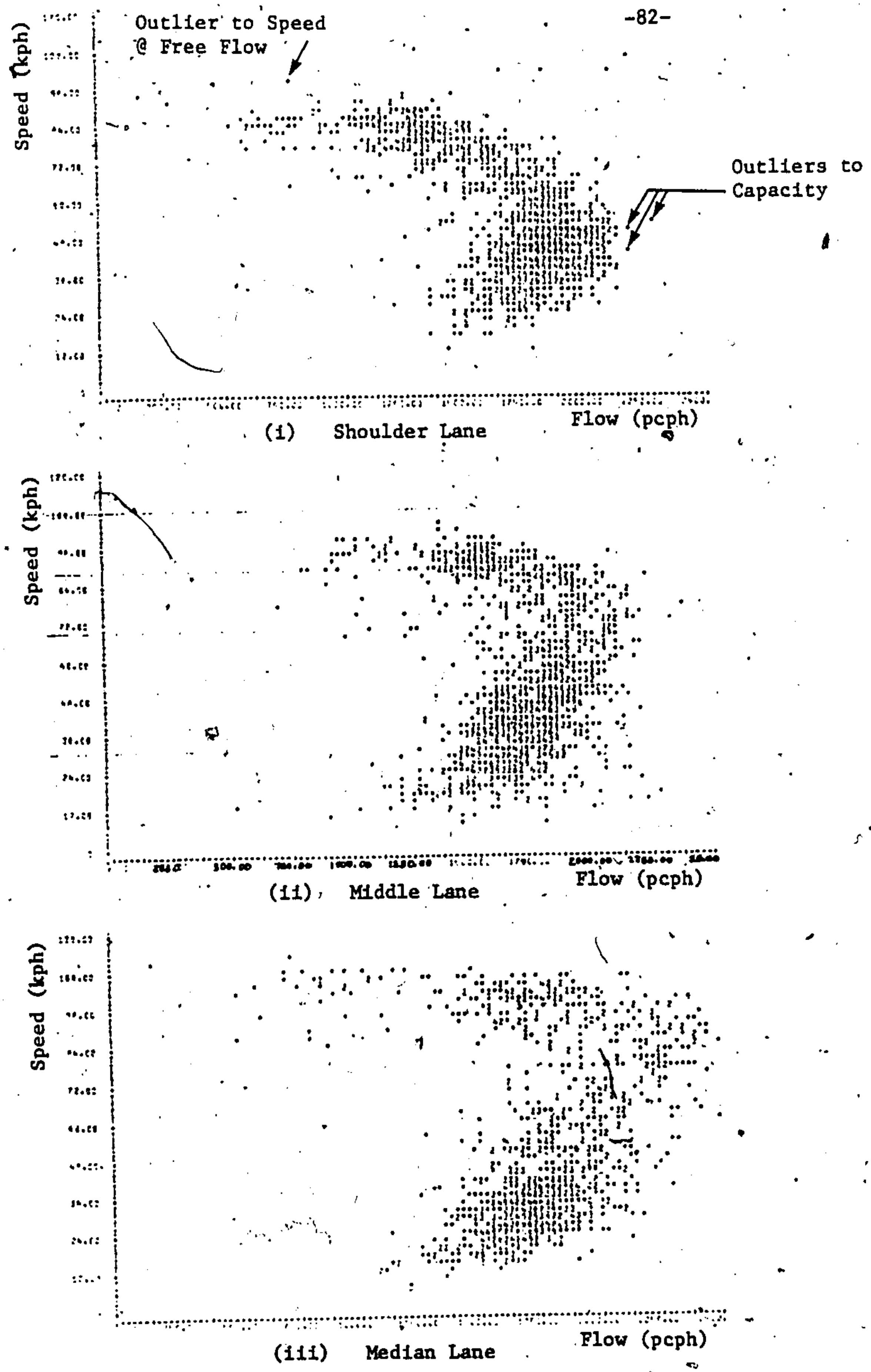


Figure 4.1 Typical Speed-Flow Data (QEW, Mississauga, Station 8)

capacity on more than one occasion, the maximum flow observed in the data plots did not necessarily define capacity. The behaviour of the data indicates that at capacity, the slope of the curve approaches infinity. At this flow, speeds were defined provided the values are realistic and they conformed to the general trend of the data.

The reader should also note the marked difference in the shape of curves for the three lanes. This difference in shape is considered to be a result of the presence of varying percentage trucks, side friction and driver behaviour which may affect basic speed-flow relations. A high percentage of trucks, i.e. 15%, was often recorded in the shoulder lane. In this lane there is friction on the left hand side and drivers may tend to be more timid than those in the faster lanes. For the middle lane, the truck proportion was on average only about 8%. Side friction exists on both sides of the lane in this case but the drivers may tend to be less timid. The truck percentage was about 2% in the median lane and side friction occurs only on the right hand side of the lane. (Although the Ontario Highway Traffic Act prohibits trucks from using the median lane, it was apparent that some truck drivers continue to use this lane.) Despite these differences, one common trait of the relationships in the three lanes is that for low flows, the speed-flow relation has a slope of zero i.e., as flow increases, the speed remains unchanged over relatively large flow ranges.

Since determination of the outliers to the data plotted for Stations 1-10 was a very important aspect, Table 4.1 was prepared indicating the percentage of outliers to the free flow conditions in the

TABLE 4.1 Outliers in Speed-flow curves for QEW Stations 1 to 10

Station	Lane	No of Data Points	Outliers to Upper free flow speed.		Outliers to Lower free flow speed.		Outliers to capacity		Outliers to speed at capacity.	
			No.	%	No.	%	No.	%	No.	%
1	shl	1451	8	0.6	37	2.5	–	–	–	–
	mid	1498	14	0.9	29	1.9	3	0.2	1	0.1
	med	1477	5	0.3	21	1.4	9	0.6	3	0.2
2	shl	863	21	2.4	40	4.6	–	–	–	–
	mid	863	1	0.1	23	2.7	3	0.3	1	0.1
	med	835	0	0	34	4.1	0	0	0	0
3	shl	893	13	1.5	21	2.4	–	–	–	–
	mid	–	–	–	–	–	–	–	–	–
	med	836	8	1.0	10	2.4	6	0.7	3	0.4
4	shl	1087	6	0.6	57	5.2	–	–	–	–
	mid	1027	–	–	17	1.7	7	0.7	5	0.5
	med	1095	12	1.1	11	1.0	5	0.5	0	0
5	shl	1460	13	0.9	42	2.9	2	0.1	0	0
	mid	1212	2	0.2	29	2.4	8	0.7	5	0.4
	med	1266	6	0.5	16	1.3	9	0.7	2	0.2
6	shl	1343	7	0.5	23	1.7	7	0.5	4	0.3
	mid	881	6	0.7	18	2.0	–	–	–	–
	med	1435	0	0	22	1.5	3	0.2	0	0
7	shl	1397	3	0.2	17	1.2	8	0.6	1	0.1
	mid	662	0	0	5	0.7	–	–	–	–
	med	1319	3	0.2	27	2.0	7	0.5	4	0.3
8	shl	1453	13	0.9	31	2.1	10	0.7	5	0.3
	mid	1419	3	0.2	50	3.5	5	0.4	4	0.3
	med	1202	2	0.2	15	1.2	8	0.7	4	0.3
9	shl	1360	15	1.1	38	2.8	11	0.8	9	0.7
	mid	1514	13	0.9	18	1.2	8	0.5	8	0.5
	med	1532	1	0.1	11	0.7	6	0.4	2	0.1

curves, to capacity, and to speeds at capacity. For the upper limits of speed in free flow conditions, there is an average of less than 1% outliers. The lower speed limits were more difficult to define and were computed with about 5% of the points excluded. For determination of capacity, there was an average of 0.5% outliers. Negligible outliers existed for speeds at capacity. The average percentage was about 0.3%. Consequently, the values chosen are felt to be adequately representative of average operational conditions.

Having identified the outliers, the speed-flow data characteristics will now be discussed. In some cases it was impossible to define capacity because the demand did not reach capacity during the data collection period. In other cases detector malfunctions prevented the compilation of sufficient data points for confident capacity definition.

The following paragraphs deal with the models considered for speed-flow data exemplified in Figure 4.1. A review of the models discussed in Chapter 2 indicated that inadequacies do exist. These were identified in two basic areas. First, the models do not always conform to the characteristics of the data. Second, there tends to be high correlations between parameters in a given model which render the model inadequate. Consequently, it was decided that new forms should be developed. Investigations of characteristics of various plots, for example the one shown in Figure 4.1, indicated that a logarithmic model might be appropriate. Thus, equation 4.1 was considered.

$$f(x) = \alpha_1 - \alpha_2(\ln x)^{\alpha_3} , \qquad (4.1)$$

where $f(x)$ = speed function (kph) ,

x = flow ,

α_1 = speed attained at free flow rates, and

α_2, α_3 = parameters which determine the degree and rate of change of curvature.

Because of the difficulty in estimating α_2, (a parameter value of about 1×10^{-22}), the equation was reformulated as follows

Let $\alpha_4 = \alpha_2 (\ln x)^{\alpha_3}$

Then $\ln \alpha_4 = \ln \alpha_2 + \alpha_3 \ln(\ln x)$

Therefore $\alpha_4 = e^{[\ln \alpha_2 + \alpha_3 \ln(\ln x)]}$

Equation 4.1 now becomes,

$$f(x) = \alpha_1 - e^{[\alpha_2' + \alpha_3 \ln(\ln x)]} , \qquad (4.2)$$

where $\alpha_2' = \ln \alpha_2$.

Although the equation can now be analysed, shortfalls remain. The variable x is not normalised and the equation therefore has no dimensional significance. Despite this, program runs were made with equation 4.2.

May and Keller (8) had previously developed speed-density relations analogous to equation 2.1. However, the models incorporated an additional parameter β_5, where

$$f(x) = \beta_1 + (\beta_2 - \beta_1)\left[1 - \left(\frac{x}{\beta_4}\right)^{\beta_3}\right]^{\beta_5} , \text{ and} \qquad (4.3)$$

where β_5 = additional parameter which affects the degree of slope change on the curve.

Equation 4.3 fits the available data quite well. This is primarily due to the fact that the equation allows for negligible slope in the free flow region of the curve. However, β_1 to β_5 cannot all be used as parameters since they are highly correlated with each other. High parameter correlations imply that a small change in one parameter causes a large change in the other. This means that very large and unrealistic confidence regions for the parameters exist.

The speed at free flow, β_2, can be easily obtained and can be substituted as a constant in the equation. However, high correlations were still obtained with the four remaining parameters. Neither parameters which control the degree of curvature could be treated as constants nor integrated into one value. Also, the speed at capacity, β_3, could not be easily deduced. The remaining parameter, β_4, was therefore considered for use as a constant in the equation. When x/β_4 is greater than unity, the term in the square brackets in equation 4.3 is negative. Unless β_5 is a whole number, the negative term cannot be evaluated. This provides a constraint for the regression analysis. This however can be alleviated if values of x greater than the β_4 value selected are eliminated from the data set. Different β_4 values can then be used until an optimum one is obtained.

This particular model was investigated using the above approach. The results proved to be unsatisfactory and were thus not further employed.

Stations 2, 3, 4, 7 and 8 were previously described as ideal, (See Section 3.2.1). Figures A2.2, A2.3, A2.4, A2.7 and A2.8 in Appendix 2 represent speed-flow relationships at stations 2, 3, 4, 7 and 8 respectively. Large sets of data are plotted at each station on a per lane basis, e.g. 1200 data points. However, because of the absence of data in some regions of the plots, the models often did not fit the data in a realistic manner. In such cases curves were fitted to the data by visual inspection. However, data from the five ideal stations were combined and curves described by 4.2 were fitted to the larger data set using Marquardt's method for the nonlinear parameter estimation. Two-regime analysis was considered in the data analysis when regressing speed against flow in order to change from a bimodal to unimodal function. The results of fitting equation 4.2 to the data are contained in Table 4.3. Curves drawn to the data are depicted in Figure 4.2.

Although the statistical results of the regressions are favourable, from Figure 4.2 it can be observed that in the region of capacity, the curves are higher than they should be. This effect can be attributed to two factors. First, data points below the 'cut-off' speed at capacity which represent variations to data points above the cut-off speed are not included in the analysis. Inclusion of these would have caused the curve to be lower in the region of maximum flows. The variation of density of data points throughout the plot is the second aspect worthy of note. Because there are more data points flows between 500-1500 pcph as compared to the region of capacity, the former has a greater control over the shape of the curve, thus resulting in the

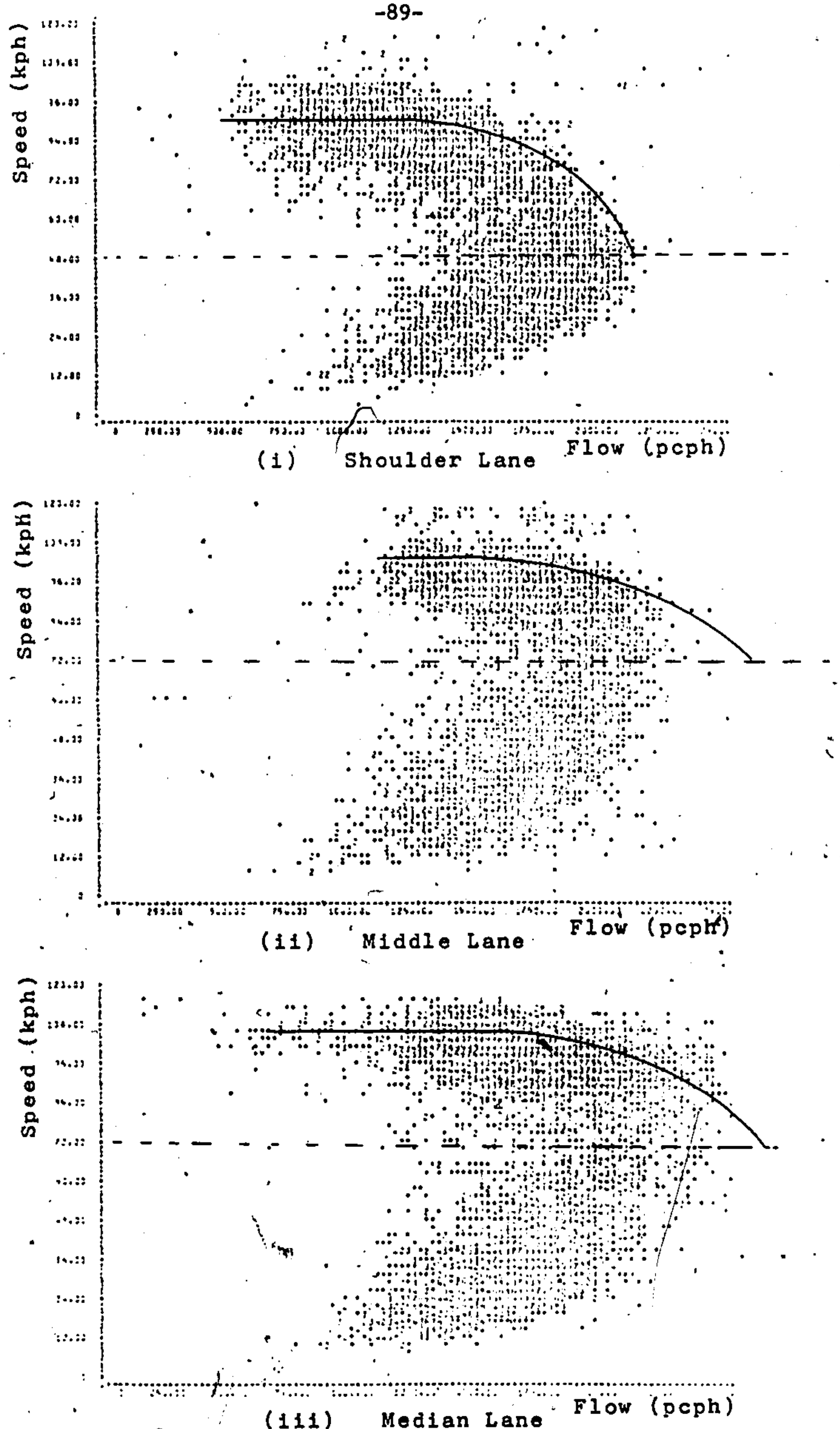


Figure 4.2 Speed-Flow Curves Developed from Two-Regime Analysis Employing

TABLE 4.2 Results of Regression Analysis

Lane	Parameter	Parameter Value	Confidence Region	Correlation with Parameter
Shoulder	α_1	89.61	88.03-91.20	α_2: -0.79
Shoulder	α_2	24.90	23.83-25.96	α_3: 0.99
Shoulder	α_3	46.81	43.24-50.38	α_1: -0.80
Middle	α_1	99.77	97.84-101.70	α_2: -0.86
Middle	α_2	24.98	22.70-27.26	α_3: 0.99
Middle	α_3	48.02	40.28-55.77	α_1: -0.87
Median	α_1	107.10	103.00-111.20	α_2: -0.89
Median	α_2	24.88	31.52-81.23	α_3: 1.00
Median	α_3	48.21	25.54-70.87	α_1: -0.89

higher curve.

Consideration was therefore given to treating the speed-flow data above the cut-off speed in two parts, while remaining with the two regime analysis. One regression could be executed at low flow conditions and the other at higher flows. However, determination of data division would considerably affect any estimated parameter values. Consequently, this approach was not adopted.

Another functional form developed from hydraulics analyses obeys the following equation,

$$f(x) = \beta_1 x (\beta_2 - x)^{1/2} \tag{4.4}$$

where $f(x)$ = flow in pcph ,

x = Speed in kph , and

β_1 and β_2 = parameters.

This function was considered in regressing flow against speed. However since there are some values of x which are greater than β_2 (β_2, being the free flow speed), the term in the bracket is sometimes negative. Marquardt's method is unable to evaluate this function because negative numbers cannot be raised to a power which is other than an integer.

In view of the above shortcomings in attempting to fit models to the collected speed-flow data, it was decided that the characteristics of the study data would be evaluated only by visual inspection methods. A summary of the data characteristics employing such methods is contained in Table 4.3 on a lane and station basis.

TABLE 4.3 - Speed-Flow Data for 10 Stations on the QEW in Mississauga

Station	Lane	Mean Speed in Free Flow (kph)	Capacity (pcph)	Speeds at Cap. (kph)
1	shl	106	-	-
	mid	106	1990	75-96
	med	108	2120	82-100
2	shl	90	-	-
	mid	100	2190	78-92
	med	102	2320	74-92
3	shl	92	-	-
	mid	-	-	-
	med	102	2250	78-92
4	shl	90	-	-
	mid	100	2180	76-88
	med	104	2300	82-98
5	shl	94	-	-
	mid	96	-	-
	med	104	2300	80-96
6	shl	90	1000	36-56
	mid	96	-	-
	med	104	2400	82-98
7	shl	90	2050	52-60
	mid	98	-	-
	med	104	2420	80-100
8	shl	88	2100	40-56
	mid	96	2200	66-74
	med	102	2400	78-88
9	shl	84	1620	24-52
	mid	90	2125	50-70
	med	100	2320	78-90
10	shl	84	2025	55
	mid	92	2250	60
	med	98	2310	60

For the ideal stations, mean speeds for the shoulder, middle and median lanes are 90 kph, 100 kph and 105 kph respectively in free flow conditions. Average capacities recorded for the shoulder, middle and median lanes at Stations 2, 3 4, 7 and 8 are 2170, 2190 and 2340 pcph respectively for an average lane capacity of approximately 2200 pcph. In addition to showing these capacities, Table 4.4 also indicates that speeds at capacity are 55 kph, 75 kph and 85 kph. An average lane speed of 70 kph is noted.

The following paragraphs deal with stations 1, 5, 6 and 9 which did not depict ideal geometrics. Reference can be made to Section 3.2.1 for a detailed description of roadway geometrics at these locations.

Figure A2.1 for Station 1 reflects the impact of the downgrade upstream of the data collection site. Speeds compiled at this station are higher than for cases with ideal geometrics. The speeds are 16%, 6% and 4% higher for the shoulder, middle and median lanes respectively, i.e. the upper speed bounds. The median lane experiences the smallest increase since the observed speed is already high in ideal conditions. Since demand at the data collection site seldom approached capacity, lane capacity could not be accurately defined at Station 1.

Station 5 lies on a horizontal curve. Nevertheless, detected speeds were quite high, for example 114 kph in the median lane as shown in Figure A2.5. Flows in excess of 2200 pcph for the middle and median lanes are also noted. Despite the horizontal curve, road traffic operation appears to be similar to that experienced under ideal conditions. This is likely due to the extremely mild roadway curvature.

TABLE 4.4 Average Speed-Flow Information at Stations 2, 3, 4, and 7

Lane	Free Flow Speed (kph)	Capacity (pcph)	Speed at Capacity (kph)
Shoulder	90	2070	55
Middle	100	2190	75
Median	102	2340	85
Average of 3 Lanes	98	2200	72

Station 6 was studied so that the effect of the exit ramp on capacity could be observed. The results in Figure A2.6 indicate that the maximum flow in the shoulder lane capacity is relatively low, i.e. 1600 pcph. This is 23% less than the average shoulder lane capacity value of 2070 pcph. At Station 9, the Highway 10 entrance ramp contributes to the shoulder lane capacity also being reduced by approximately the same amount. Speed-flow curves at this station are shown in Figure A2.9. Despite the difference in roadway characteristics at Stations 6 and 9, the shoulder lane capacity of both are quite similar. The common feature at both locations is a ramp and this is thought to be the most significant contributor to the capacity reduction.

Data compiled at Station 10 are shown in Table A2.1 in Appendix 2. Plots for the three lanes are shown in Figure A2.10 of Appendix 2. Capacities of 2025 pcph, 2250 pcph and 2310 pcph were recorded for the shoulder, middle and median lanes respectively. Speeds of 55 kph, 60 kph, and 60 kph are noted for the respective lanes. These values are notably lower than those at Stations 1-9.

4.2.2 Highway 400

Data for this 3-lane Highway 400 roadway section were obtained from the study by Allen et al (3). The data collection site was described in section 3.2.2. Reference can be made to Figure 3.15 for the site location. Table A2.2 in Appendix 2 shows the values used. Worthy of note is the fact that the 5-minute data were derived from

1-minute computations.

Speed-flow curves for the data collection site are shown in Figure A2.11. Percent trucks vary from 0-5% in the traffic stream. The traffic surveyed at this site were expected to be primarily recreationists. The reader should recall to the contrary that the Mississauga trips were work trips. Recorded speeds in free flow conditions are 90 kph, 98 kph and 108 kph for the shoulder, middle and median lanes respectively. Since the demand of the study location on Highway 400 did not reach capacity it could not be defined. The reader should note the consistency of the characteristics of this data with the QEW Mississauga information.

4.2.3 Highway 401

Speed-flow curves for two sections on this facility were studied. Reference can be made to section 3.2.3 and Figure 3.17 for site locations. The results of data analyses for the 2-lane and 3-lane roadway sections are respectively discussed in sections 4.2.3.1 and 4.2.3.2.

4.2.3.1 2-lane Section

Table A2.3 in Appendix 2 contains the 50 data points plotted for the study location. Flow in the median lane was corrected for the absence of a shoulder. Reference [(1), p.256] recommends that traffic flow should be factored by 1.11 to account for no shoulder adjacent to the median lane. Plots of data at this site are shown in Figure A2.12.

Recorded speeds in free flow conditions are 85 kph and 90 kph for the shoulder and median lanes respectively. Maximum flows of 2050 pcph and 2250 pcph are recorded for the two lanes, i.e. an average lane value of 2150 pcph.

4.2.3.2 <u>3-Lane Section</u>

Only one speed-flow curve is shown for this section of Highway 401. Average data plotted in Figure A2.13 are recorded in Table A2.4. Average values were computed since the traffic variables could not be extracted on a lane basis from the time lapse film. Speeds in free flow conditions are noted as being 92 kph on average. Roadway traffic demand at the site did not reach capacity and thus capacity is not defined.

4.2.4 <u>QEW in Hamilton</u>

Two sites were surveyed for this 2-lane section of the QEW. Figure 3.20 shows the location of the data collection sites and a description is contained in section 3.2.4. Trips are predominantly of the home to work type. Speed and flow data collected both downstream and upstream of the Highway 20 entrance ramp are listed in Table A2.5. Both data sets are plotted in Figure A2.14. Recorded speeds are 94 kph and 104 kph for the shoulder and median speeds respectively. Demand at the collection site did not reach capacity and therefore could not be defined.

4.2.5 Summary

A summary of the characteristics of previously described speed-flow relations observed for 2-lane and 3-lane highways are contained in Table 4.5. Typical curves for the QEW in Mississagua and Hamilton and Highways 400 and 401 are depicted in Figure 4.3. Lane capacity values are certainly in excess of 2000 pcph and for the Mississauga data, average lane capacity is 2200 pcph. Not only are the flows on the QEW (Mississauga) in excess of 2,000 passenger cars per hour, but they well exceed 2,000 vehicles per hour. This is clearly shown in Figures A2.15 to A2.23 in Appendix 2 for Stations 1 to 9.

The shapes of the curves are noteworthy, together with speeds at free flow. A similarity is also noted for both 2-lane and 3-lane facilities.

4.3 COMPARISON OF 5-MINUTE AND 15-MINUTE PLOTS

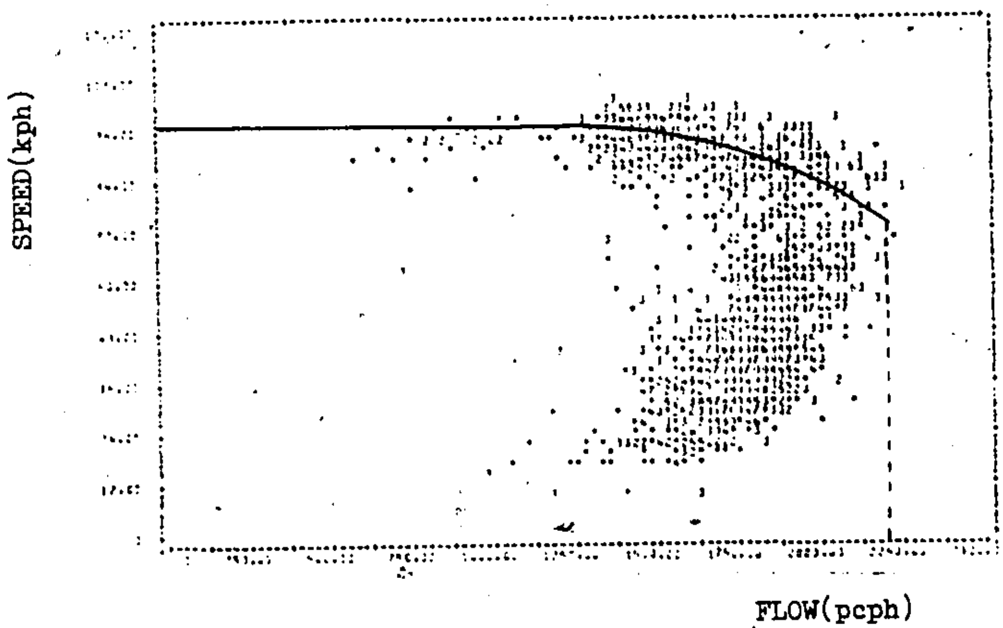
The justification for use of 5-minute volume data expanded to hourly flow rates is contained in this section. 1-minute flows were not considered as a result of the potential for high error as compared to 5-minute flows. A comparison is made herein between 5-minute and 15-minute flows. Speed-flow curves were plotted for Stations 2, 3, 4, and 8 using two representative months of data for comparison purposes. These ideal stations were arbitrarily selected. All values were recorded for 5-minute periods.

Fifteen minute data were obtained by adding three successive 5-minute values on any given day. It was therefore necessary to

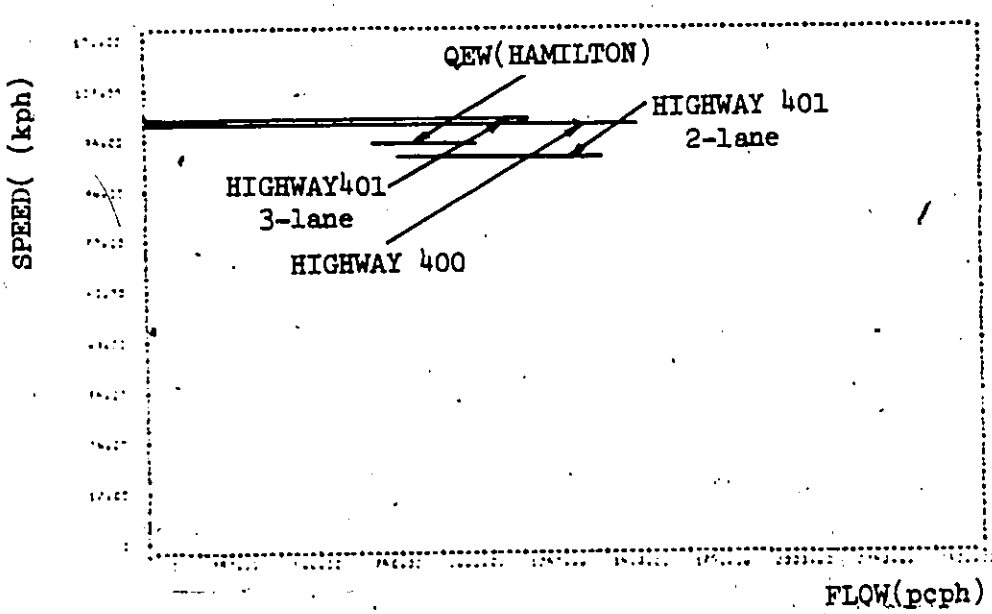
Table 4.5 Summary of Speed-flow curve characteristics

Lane	Location	Free Flow Speeds (kph)	Capacity (pcph)	Speed @ Capacity (kph)
Shoulder	QEW (Miss)	90	2070	55
Middle	"	100	2190	75
Median	"	102	2340	80
Average	"	98	2200	70
Shoulder	Highway 400	90	-	-
Middle	"	98	-	-
Median	"	108	-	-
Average	"	98	-	-
Shoulder	Highway 401 (2-lane)	88	2050*	-
Median	"	94	2250*	-
Average	"	90	2150*	-
Average	Highway 401 (3-lane)	94	-	-
Shoulder	QEW (Hamilton)	96	-	-
Median	"	104	-	-
Average	"	100	-	-

*These values are maximum flows recorded for the facility during the data collection period and do not necessarily represent capacity.

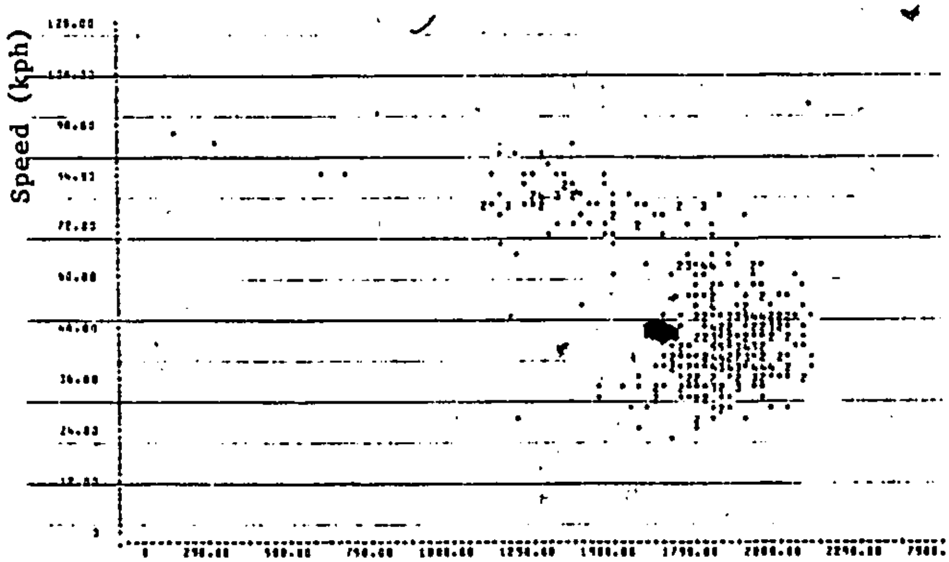


(i) QUEEN ELIZABETH WAY (MISSISSAUGA)

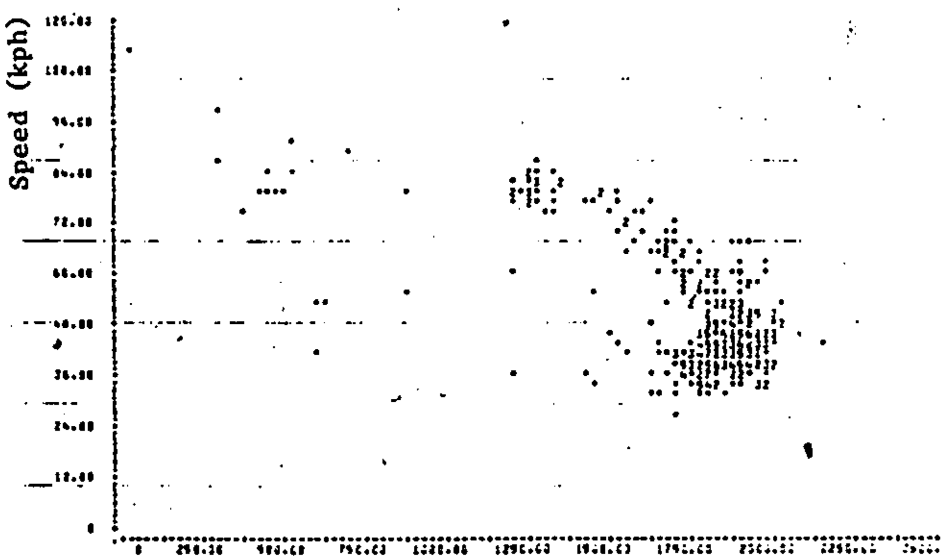


(ii) HIGHWAYS 400,401 and QEW(HAMILTON)

Figure 4.3 Summary of Speed-Flow Data on an Average Lane Basis



(i) 5-Minute Flow Rates



(ii) 15-Minute Flow Rates

Figure 4.4 Typical Data Showing 5-Minute and 15-Minute Flow Rates

Table 4.6 Comparison of 5-minute and 15-minute data

Station	Lane	5-min Speed @ free flow	15-min Speed @ free flow	% Diff	5-min Cap	15-min Cap	% Diff	5-min Speed @ Cap	15-min Speed @ Cap	% Diff
3	shl	90	90	0	-	-	-	-	-	-
4	shl	90	90	0	-	-	-	-	-	-
8	shl	80	80	0	2100	2040	2.9	48	48	0
2	mid	100	100	0	2180	2100	3.7	-	-	-
8	mid	90	88	2.2	2100	2050	2.4	66	64	3.0
2	med	100	100	0	2330	2180	6.4	76	74	2.6
3	med	102	102	0	2250	2150	4.4	84	84	0
4	med	-	-	-	2300	2200	4.3	84	84	0
8	med	100	98	2.0	2350	2220	5.5	-	-	-

TABLE 4.7 Average Differences Between 5-minute and 15-minute data

Lane	Stations	% Diff. in Speeds at Free Flow	% Diff. in Capacity	% Diff. in Speed at Capacity
Shoulder	3, 4, 8	0	2.9	0
Middle	2, 8	1.0	3.0	3.0
Median	2, 3, 4, 8	0.7	5.1	1.0
Average	—	0.5	3.7	1.3

subdivide the data on a daily basis. Speeds used are average weighted values for 15-minute periods. The same method was employed for plotting both 5-minute and 15-minute data. A typical set of data are shown in Figure 4.4. All scattergrams are shown in Figures A3.1 to A3.11 in Appendix 3. For these curves, speeds in free flow conditions, capacity and speeds at capacity are compared, in Table 4.6. Fifteen minute plots show less scatter as expected. For speeds in free flow conditions, the percent differences range from 0-2.2%. Average reductions shown in Table 4.7 are 0%, 1.0% and 0.7% for shoulder, middle and median lanes respectively. An average value for the three lanes is 2.5%. Average differences in lane capacities are respectively 2.9%, 3.0% and 5.1% for the shoulder, middle and median lanes. The average difference for the three lanes is 3.7%. Differences of 2.5% and 3.7% for speed and capacity are respectively equivalent to reductions of 2.5 kph and 80 pcph. The average difference noted for speed at capacity is 1.3%.

The difference between 5-minute and 15-minute data was found to be small especially in free flow conditions where it was quite negligible. It is also noted that in many instances there were few points at low flows since data collection was during the peak period. It is therefore felt that when compared to 15-minute flow rates for the purposes of this study, 5-minute hourly flow rates are quite adequate. Also, 5-minute data were readily available in some cases and are used throughout.

4.4 PASSENGER CAR EQUIVALENTS

The computation of representative passenger car equivalents (pce's) for trucks is considered important since it reflects the impact of trucks on the traffic stream. For ideal conditions, the HCM [(1), p.288] recommends a pce of 2.0. An estimate of actual passenger car equivalents was obtained using the QEW (Mississauga) data. For individual stations and lanes, speed-flow curves were plotted for varying truck percentages. A typical example is shown in Figure 4.6. Five minute data were used as in subsection 4.2.1. In this case however, flows are recorded in vehicles per hour (vph) as opposed to passenger cars per hour (pcph). Varying 5% intervals of truck percentages were used, that is, 0-5%, 5-10%, 10-15% and 15-20% for the shoulder and middle lanes. In the case of the median lane 2.5% ranges were used.

The percent trucks recorded were as high as 20%, 10%, and 5% for shoulder, middle and median lanes respectively. Capacities at varying percent trucks were estimated by visual inspection for stations 2, 4, 7 and 8 on a lane basis. Characteristics of the curves shown in Appendix 4 are summarised in Table 4.8. From information in the table, curves of percent trucks versus capacity in vph were drawn on a lane basis and are shown in Figure 4.6. Also shown in the table are pce's which were derived from

$$P = \frac{(C_o - C_t)}{t\ C_t} + 1 \quad , \qquad (4.5)$$

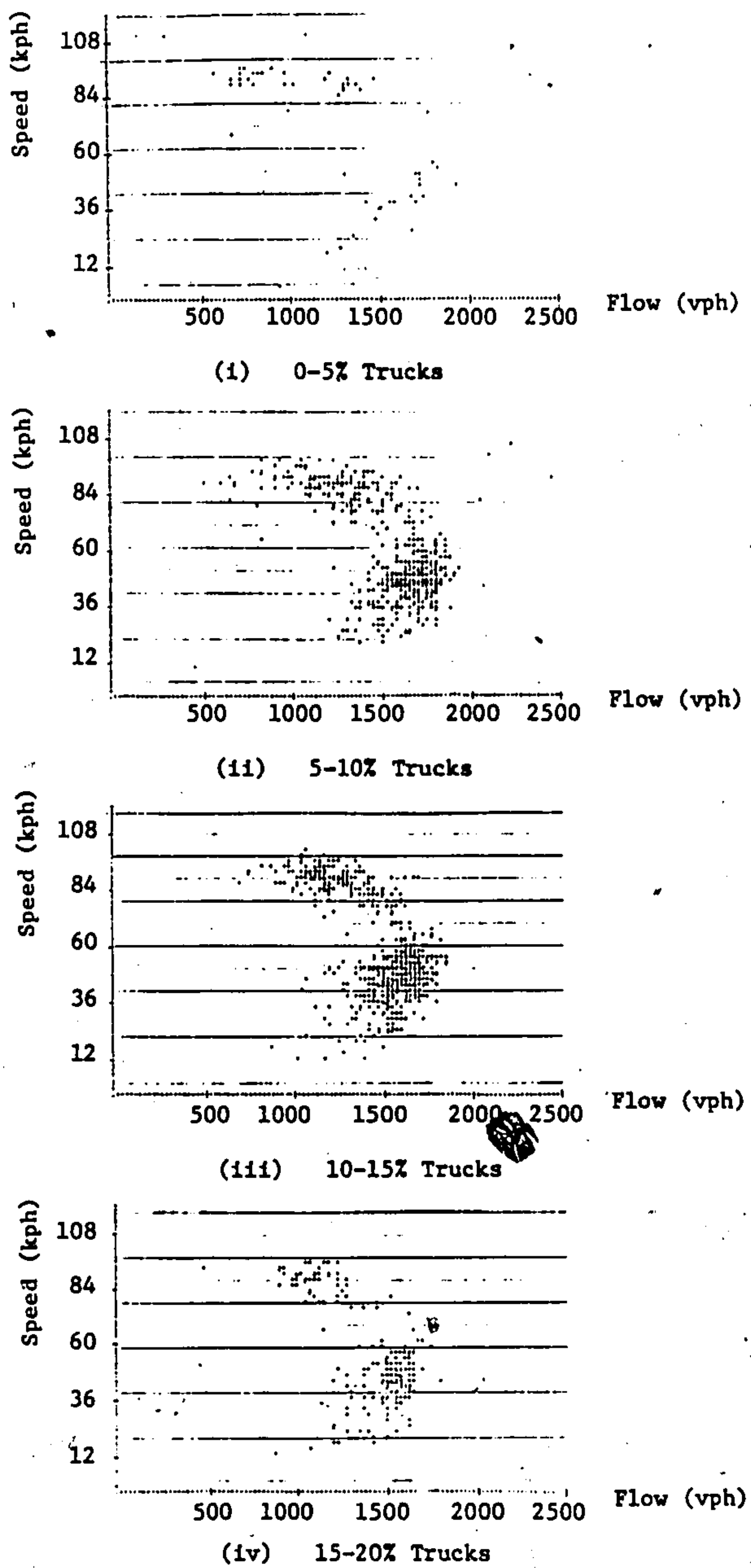
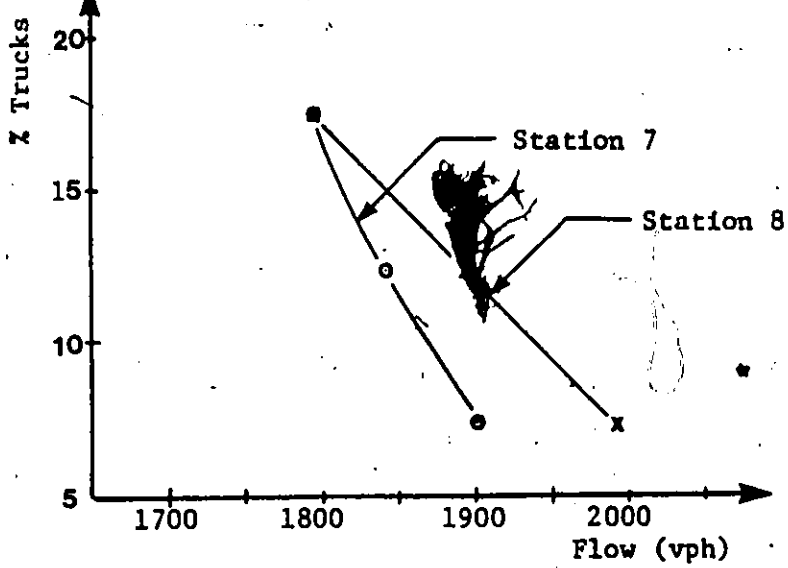
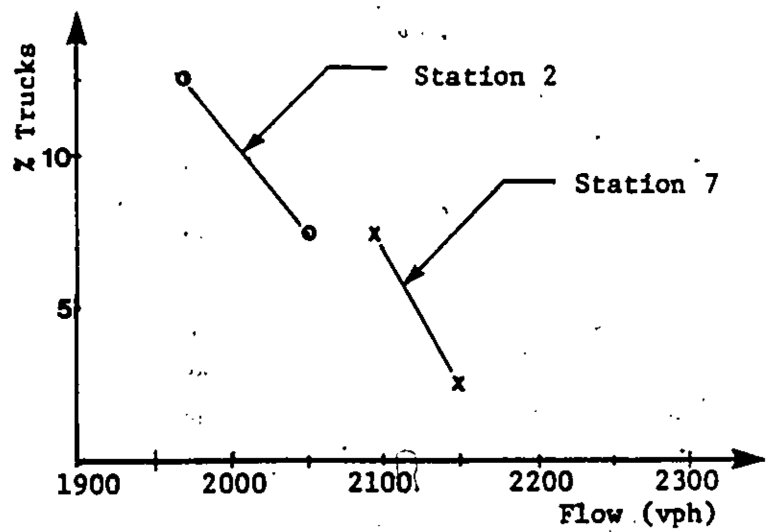


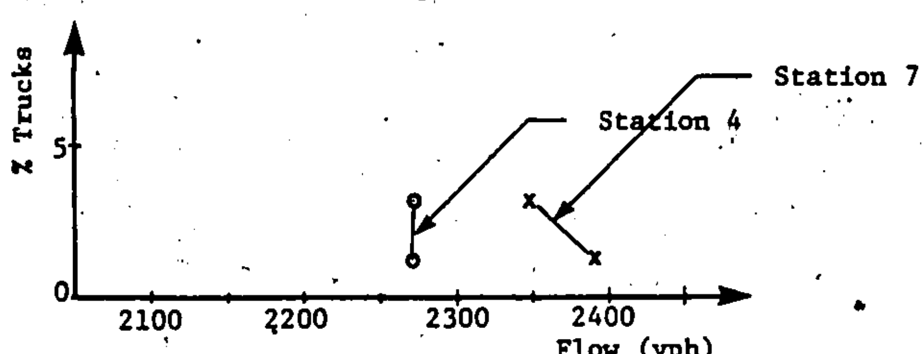
Figure 4.5 Speed-Flow (vph) Data at Varying



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure 4.6 Variation of Capacity with Percent Trucks where P = passenger car equivalent for trucks,

C_o = lane capacity with no trucks in the lane (vph),

t = proportion of trucks in a given lane, and

C_t = lane capacity with proportion t trucks in the lane (vph).

The results indicate that lane capacity C_t decreases as the percent trucks present in the lane increases. For the shoulder and middle lanes, pce values are all less than those recommended in the HCM, (1), i.e. 2.0. Average pce's are shown in Table 4.9. These figures were calculated by averaging the values recorded in Table 4.8. As percent trucks increase, pce values also increase. Values range from 1.0 to 1.7.

For an average of three lanes, pce's for different percent trucks are illustrated in Table 4.10. Thus, from the results it appears that an average pce for the three lanes should be 1.3. This suggests that Reference (1) overestimates capacity by about 4.8%. This figure was calculated according to equation 4.6

$$\Delta C = t \frac{(P_0 - P_1)}{(1 + tP_0)} \times 100 \quad , \qquad (4.6)$$

where ΔC = percent change in capacity,

t = average proportion of trucks for 3 lanes, i.e. 8%,

P_0 = pce of 2.0, HCM, (1), and

P_1 = pce value of 1.3

For an average lane capacity value of 2200 pcph, 4.8% reduction represents a decrease of 106 pcph. The results contained herein are pce

TABLE 4.8 Lane capacity at varying percentage trucks.

Station	Lane	% Truck range	Capacity (vph)	Pce	Data points
7	shoulder	0-5	-	-	51
"	"	5-10	1920	-	471
"	"	10-15	1850	1.5	644
"	"	15-20	1800	1.4	193
8	shoulder	0-5	-	-	102
"	"	5-10	2000	-	684
"	"	10-15	1900	1.7	561
"	"	15-20	1800	1.6	100
2	middle	0-5	-	-	223
"	"	5-10	2050	-	482
"	"	10-15	1970	1.3	150
4	middle	0-5	-	-	601
"	"	5-10	-	-	364
"	"	10-15	-	-	-
7	middle	0-5	2150	-	317
"	"	5-10	2100	1.3	256
"	"	10-15	-	-	80
4	median	0-2.5	2270	-	860
"	"	2.5-5.0	2270	1.0	226
"	"	5.0-7.5	-	-	-
7	median	0-2.5	-	-	288
"	"	2.5-5.0	2390	-	569
"	"	5.0-7.5	2350	1.3	295
8	median	0-2.5	-	-	625
"	"	2.5-5.0	2290	-	454
"	"	5.0-7.5	-	-	89

TABLE 4.9 Average Passenger Car Equivalents (pce's) on a Lane Basis

Lane	Stations	% Trucks	Average pce
shoulder	7, 8	10-15	1.6
shoulder	7, 8	15-20	1.5
middle	2, 4, 7	5-10	1.3
middle	2, 7	10-15	1.3
median	2, 4, 7	2.5-5.0 5.0-7.5	1.0 1.3

TABLE 4.10 Passenger Car Equivalents (pce's) for Average of 3 Lanes

% Trucks	Average pce for 3 lanes
0–5	1.0
5–10	1.3
10–15	1.5
15–20	1.5

values at capacity. The reader should note the distinction between this value and that computed in the HCM, (1). In the case of the HCM, the pce is for varying levels of service, not only at capacity. Although it was stated that C_o in equation 4.1 was the lane capacity with no trucks present, this condition was seldom obtained from the data. Thus the estimation of C_o was from a lane with some trucks present. Thus, the true pce value is likely to be higher than the one calculated. It is felt that a larger data source could enhance the confidence of the results shown.

4.5 INFLUENCE OF ADVERSE WEATHER

In most instances in transport planning which involve capacity when considering traffic flow, ideal weather conditions are used. However, in some cases it is advisable to account for the effect of adverse weather conditions. There is very little past work directed toward evaluating the effect of adverse weather on traffic flow. This section deals with the observed impact of rain and snow on traffic flow at the QEW Mississauga location. A listing of the 10 days for which the weather in the a.m. peak period was described as rainy and 8 days as snowy is shown in Table A2.6 in Appendix 2.

Speed-flow curves at Stations 8 and 9 for rain and 1-9 for snow are respectively shown in Figures A5.1-A5.2 and A5.3-A5.11 in Appendix 5. Some plots were not included because of the small number of data points available which arise as a result of detector malfunctions. A summary of characteristics of the curves in Appendix 5 is documented in

TABLE 4.11 Summary of Speed-Flow Data for Adverse Weather Conditions

Station	Lane	Free Flow Speed			Capacity (pcph)			Speed (kph)			Data Points	
		Ideal	Rain	Snow	Ideal	Rain	Snow	Ideal	Rain	Snow	Rain	Snow
1	shl	106	-	100	-	-	-	-	-	-	-	179
	mid	106	-	102	1990	-	1800	75-96	-	90-92	-	171
	med	108	-	102	2120	-	1920	82-100	-	90-96	-	177
2	shl	90	-	84	-	-	-	-	-	-	-	121
	mid	100	-	96	2190	-	2100	78-92	-	84-92	-	117
	med	102	-	96	2320	-	2100	74-92	-	90-92	-	114
3	shl	92	-	90	-	-	-	-	-	-	-	157
	mid	-	-	-	-	-	-	-	-	-	-	-
	med	102	-	96	2250	-	2100	78-92	-	68-92	-	155
4	shl	90	-	80	-	-	-	-	-	-	-	92
	mid	100	-	-	2180	-	-	76-88	-	-	-	170
	med	104	-	-	2300	-	-	82-98	-	-	-	155
5	shl	94	-	92	-	-	-	-	-	-	-	157
	mid	96	-	-	-	-	-	-	-	-	-	83
	med	104	-	-	2300	-	-	80-96	-	-	-	83
6	shl	90	-	84	1600	-	1400	36-56	-	24-46	-	130
	mid	96	-	-	-	-	-	-	-	-	-	-
	med	104	-	104	2400	-	2120	82-98	-	84-96	-	170
7	shl	90	-	86	2050	-	2050	52-60	-	42	172	172
	mid	98	-	-	-	-	-	-	-	-	-	40
	med	104	-	102	2420	-	2080	80-100	-	52-76	111	203
8	shl	88	80	82	2100	2000	2000	40-56	42-52	46	222	172
	mid	96	88	88	2200	2170	2090	66-74	64-68	54-60	220	156
	med	102	96	96	2400	2200	-	78-88	58-78	44-72	221	177
9	shl	84	-	82	1620	1580	1580	24-52	24-36	36-40	187	221
	mid	90	-	86	2125	1950	1950	50-70	40-56	52	175	221
	med	100	-	96	2320	1980	2000	78-90	52-66	60	190	221

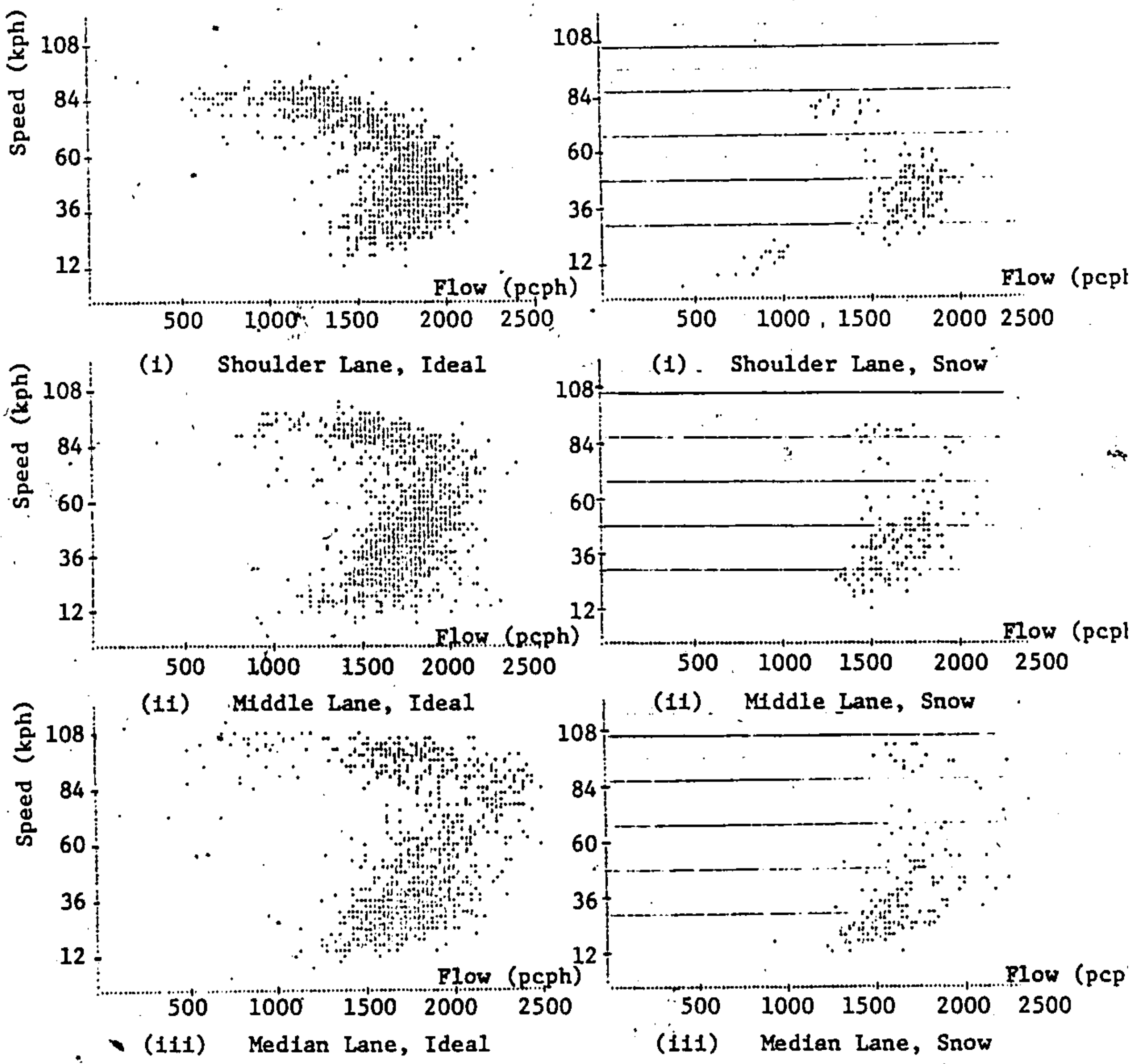


Figure 4.7 Typical Speed-Flow Data for Ideal and Adverse Weather Conditions, Station 8

TABLE 4.12 Difference Between Speed-flow Curve Characteristics For Ideal, Rainy and Snowy Weather Conditions

Station	Lane	Ideal-Rain Free Flow		Ideal-Snow Free Flow		Ideal - Rain Capacity		Ideal - Snow Capacity		Ideal-Rain Speed @ Capacity		Ideal-Snow Speed @ Capacity	
		Diff	%	Diff	%	Diff	%	Diff	%	Diff	%	Diff	%
1	shl	-	-	6	5.6	-	-	-	-	-	-	-	-
	mid	-	-	4	3.8	-	-	190	9.5	-	-	-	-
	med	-	-	6	5.6	-	-	200	9.4	-	-	-	-
2	shl	-	-	6	6.7	-	-	-	-	-	-	-	-
	mid	-	-	4	4.0	-	-	90	4.1	-	-	-	-
	med	-	-	6	5.9	-	-	220	9.5	-	-	-	-
3	shl	-	-	2	2.2	-	-	-	-	-	-	-	-
	mid	-	-	-	-	-	-	-	-	-	-	-	-
	med	-	-	6	1.9	-	-	150	6.7	-	-	5.0	5.9
4	shl	-	-	10	11.1	-	-	-	-	-	-	-	-
	mid	-	-	-	-	-	-	-	-	-	-	-	-
	med	-	-	-	-	-	-	-	-	-	-	-	-
5	shl	-	-	2	2.0	-	-	-	-	-	-	-	-
	mid	-	-	-	-	-	-	-	-	-	-	-	-
	med	-	-	-	-	-	-	-	-	-	-	-	-
6	shl	-	-	6	6.7	-	-	120	7.5	-	-	11	24.0
	mid	-	-	-	-	-	-	-	-	-	-	-	-
	med	-	-	0	0	-	-	280	11.7	-	-	0	0
7	shl	-	-	4	4.4	-	-	0	0	-	-	-	-
	mid	-	-	-	-	-	-	-	-	-	-	-	-
	med	-	-	2	2.0	-	-	340	14.0	-	-	26.0	28.9
8	shl	8	9.1	6	6.7	100	4.8	100	4.8	1.0	2.1	2.0	4.2
	mid	8	8.3	8	3.3	30	1.4	110	5.0	9.0	13.6	13.0	18.6
	med	6	5.9	6	5.9	200	8.3	-	-	15.0	18.0	25.0	30.0
9	shl	-	-	2	2.4	40	2.5	40	2.5	8.0	21.0	0	0
	mid	-	-	4	4.4	175	8.2	175	8.2	12.0	20.0	8.0	13.3
	med	-	-	4	4.0	340	14.7	320	13.8	25.0	29.0	24.0	28.6

TABLE 4.13 Average Reduction in Speed-Flow Curve characteristics Due to Rain and Snow For Stations With Ideal Geometrics

Lane	Reduction in Free Flow Speed		Reduction in Capacity		Reduction in Speed @ Capacity	
	Rain	Snow	Rain	Snow	Rain	Snow
Shoulder	9.1	6.2	4.8	2.4	2.1	4.2
Middle	8.3	6.2	1.4	4.6	13.6	18.6
Median	5.9	3.9	8.3	10.1	18.0	30.0
Average of 3 Lanes	7.8	5.4	4.8	5.7	11.0	17.6

Table 4.11. Figure 4.7 shows typical data for ideal and adverse conditions. It enables the reader to observe the difference in data characteristics. Recorded in Table 4.11 are speed in free flow conditions, lane capacity, speed at capacity and the number of data points in each plot. To allow an easier comparison, information from Table 4.2 for ideal conditions was also included in the table.

The percentage difference between speed-flow curve characteristics at Stations 1-9 are shown in Table 4.12. For stations 1, 5, 6 and 9 reductions range from 4-15%. Average values for ideal stations (i.e. 2, 3, 4, 7 and 8) are shown in Table 4.13. Reduction in speed in adverse weather conditions is often as a result of impaired vision. The results indicate that in the region of capacity speeds are reduced by as much as 30% for the median lane. These values were obtained by comparing the average of upper and lower speed limits. An average value of reduction in lane speed for both rain and snow is about 14%. Average reductions in free flow speeds and capacity range from about 3.9-9.1%. From the above data it appears that adverse weather does reduce both speed and capacity, the effect on the former at high flow rates being quite pronounced. Also, on average, the effect of snow is greater than that of rain.

4.6 RELATIONSHIPS BETWEEN DENSITY, OCCUPANCY, SPEED AND FLOW

Occupancy is a variable of the traffic stream measured by loop detectors and is defined as the percent of time the roadway is occupied by vehicles. Limited work is in fact available in the literature on this subject. It is new in that only in the past decade has it been gaining widespread acceptance and its importance in defining the characteristics of the traffic stream is being gradually realized. For these reasons it was felt that the relation of occupancy with speed, flow and density should be considered in this research undertaking. Typical speed-density relations developed earlier are as shown in Figures 4.8 and 4.9. There tends to be a linear or exponential form.

For the QEW in Mississauga occupancy data were compiled under the FSCS. A typical data set is shown in Figure 4.10. Speed-occupancy plots at all nine station locations are shown in Figures A6.1 to A6.9 in Appendix 6 and are for the same period as the speed-flow data of Figures A2.1-A2.9 in Appendix 2. Plots are shown on a lane basis for Stations 1-9. The data appear to characterize a linear form in free flow conditions and curvilinear trend in unstable flow. Data from the ideal stations, i.e. 2, 3, 4, 7 and 8 were combined in one data plot. The result of a model fitted to the data using Marquardt's method is noted in Figure 4.10(iv) for the average of three lanes. As expected, as occupancy increases, speeds decrease, i.e. the presence of a larger number of vehicles in the lanes restrict the ability of drivers to manoeuvre and consequently cause drivers to reduce their speed. At all station locations, the rate of change of speed with occupancy appears to be lowest in the shoulder and highest in the median lane. However, at some stations, it appears that speeds in the middle lane decrease at a faster rate than in the median see for example Stations 6 and 7. This

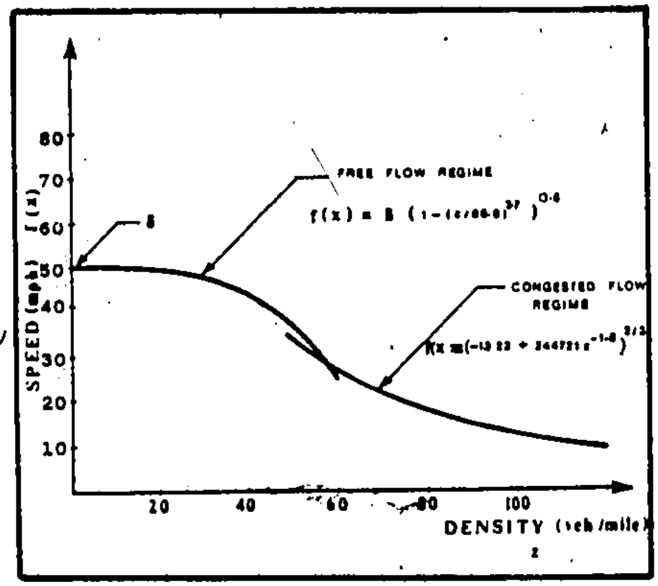


Figure 4.8 Illustration of Speed-Density Relation for a Freeway, Adapted from May and Keller (8)

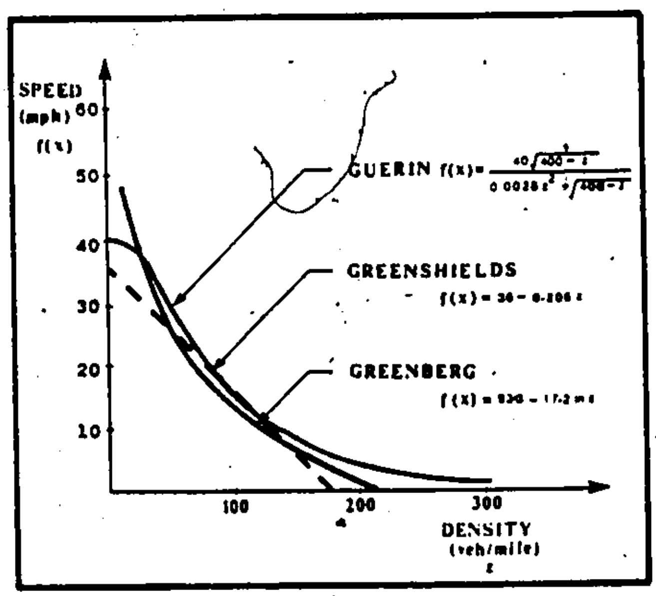
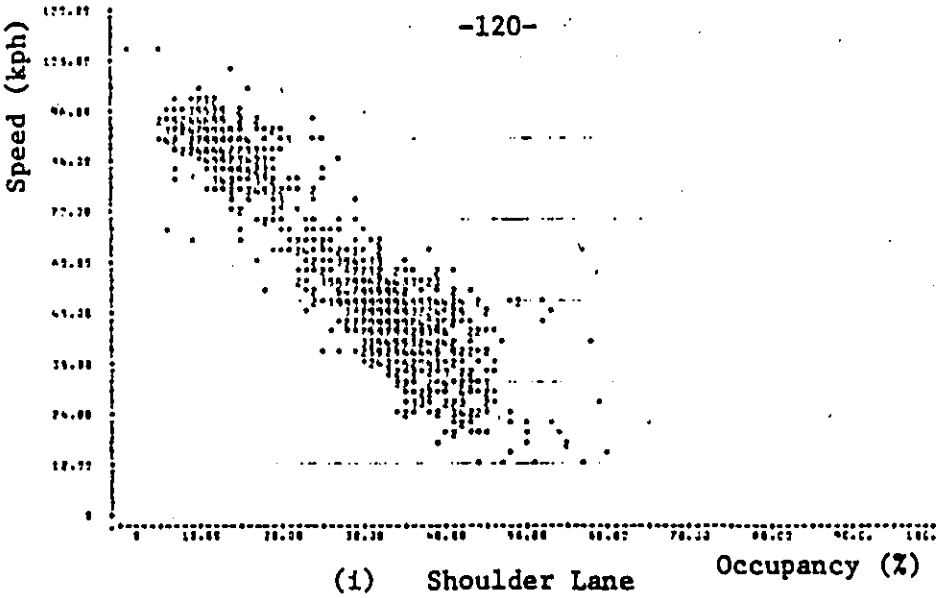
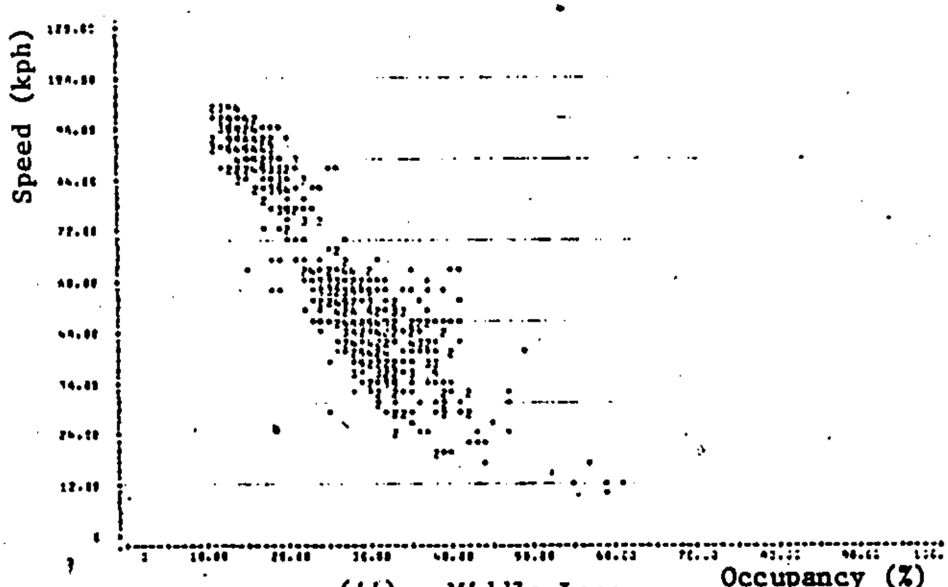


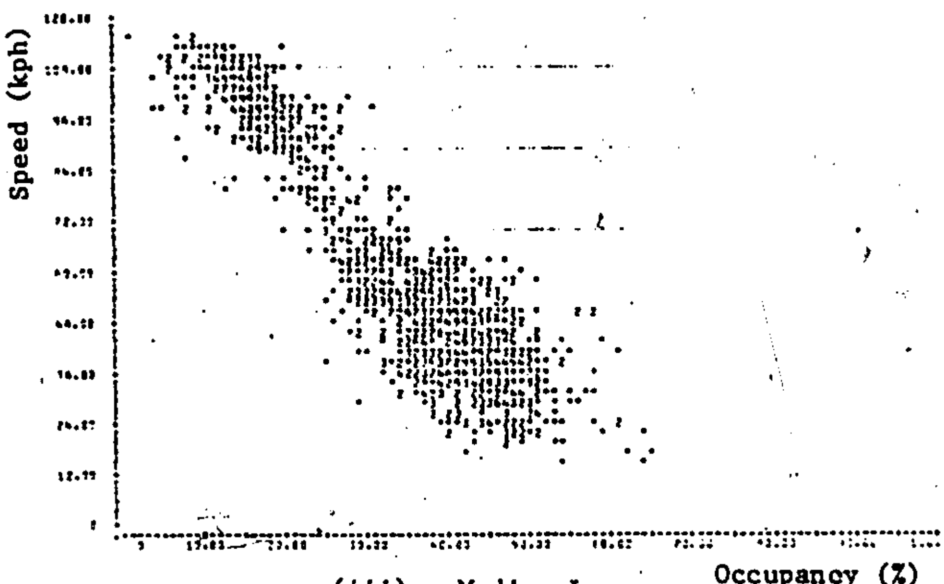
Figure 4.9 Illustration of Speed-Density Curves, Adapted From Wohl and Martin (9), p.333



(i) Shoulder Lane

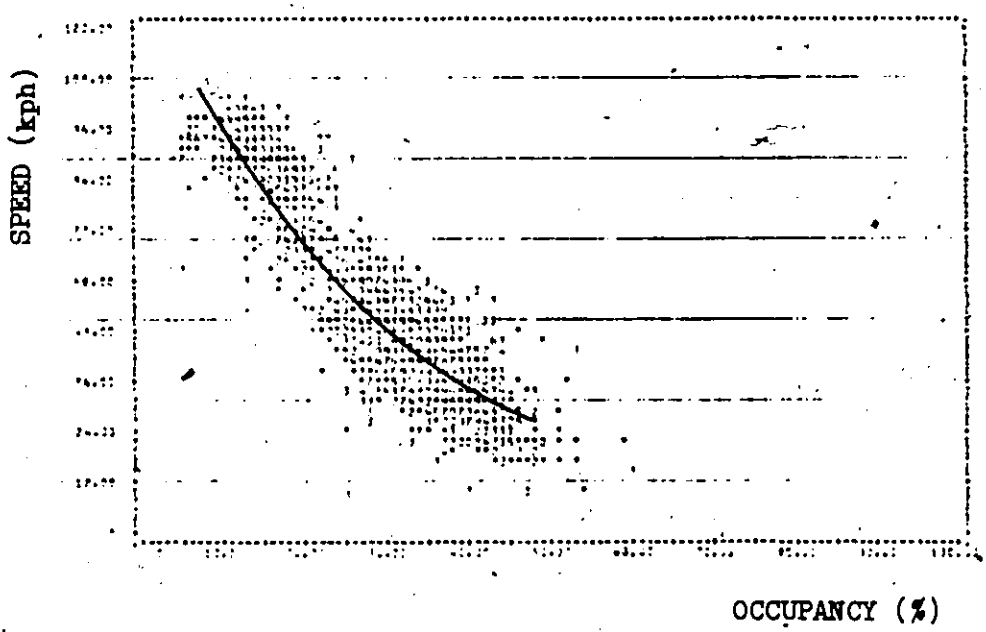


(ii) Middle Lane



(iii) Median Lane

Figure 4.10 Typical Speed-Occupancy Data



$u = 217.3 - 48.68 \ln(O_c)$

where u = speed (kph)
O_c = occupancy (%)

Correlation Coefficient = 0.99
Residual Sum of Squares = 318204
Data Points = 2858

Confidence Limits on
Linear Hypothesis 214.5-220.2
47.77-49.51

Figure 4.10 (iv) Speed-Occupancy Relation on an Average Lane Basis could be attributed to the high degree of manoeuvering which occurs close to these stations. The noticeable absence of data points in some areas of the plots is likely due to a sudden change from stable flow to unstable flow with large reductions in speed resulting.

The fundamental relation between speed, flow and density is as follows,

$$q = k\,u \qquad 4.7$$

where q = flow rate

u = space mean speed

k = mean density

If any two of these three variables are known, the third can be determined. Reference (5) indicates that density is often considered the dependent variable because speed and flow are easier to measure and, therefore serve as the independent variables.

For this research average spot speeds or time mean speeds were employed. There is little difference between time mean speeds and space mean speeds at low flow conditions and this difference diminishes at higher flow rates. Equation 4.7 was therefore employed, with time mean speeds being utilized. Thus, density values were derived by dividing flow rates by time mean speeds. Figure 4.11 shows the relation between speed and density for the shoulder, middle and median lanes at an ideal station. The observed forms are extremely similar to that developed by Guerin. See for example Figure 4.9 for Guerin's relation. Thus it was decided that a model similar to that developed by Guerin would be fitted to the speed-density data using Marquardt's method. The results of the

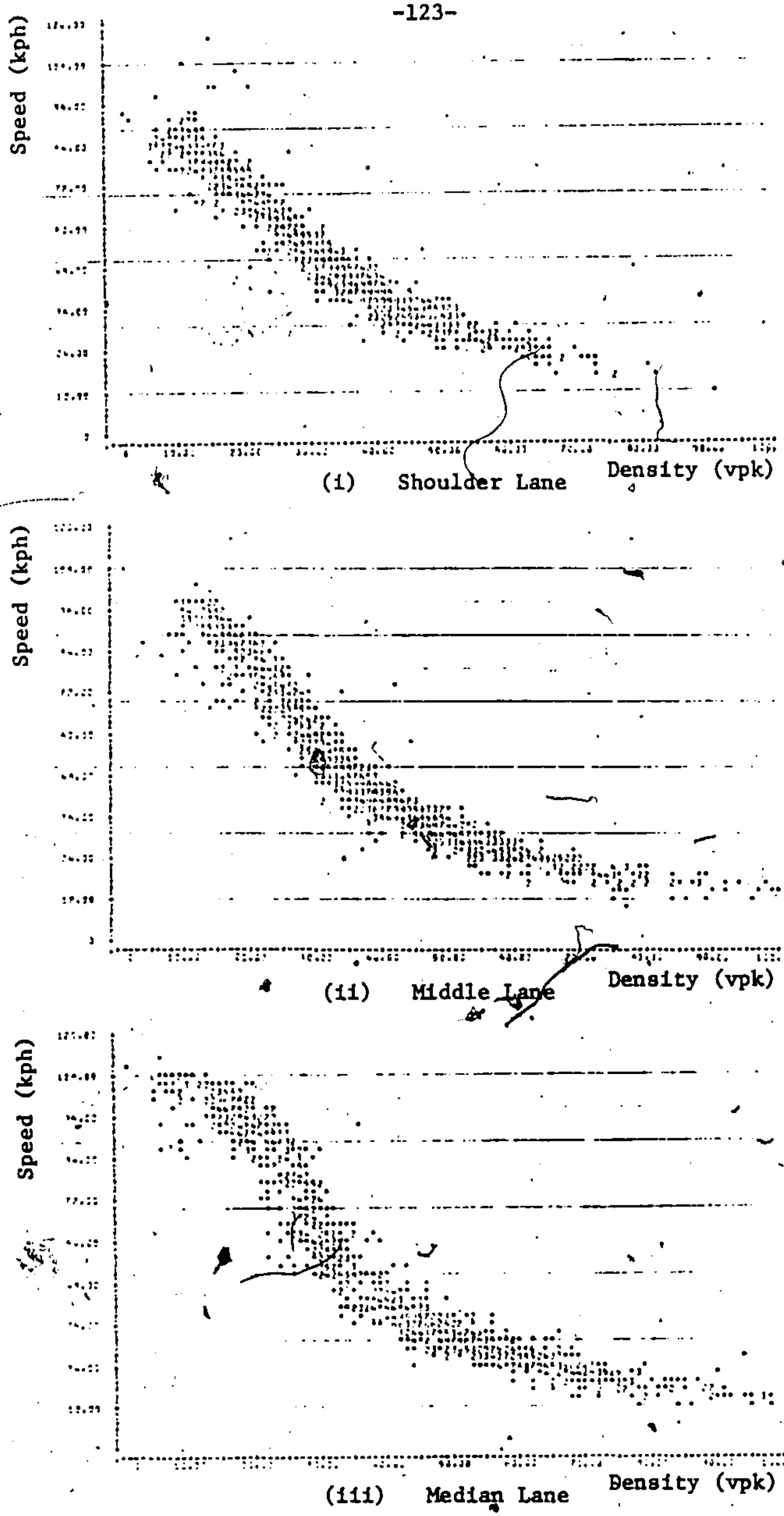
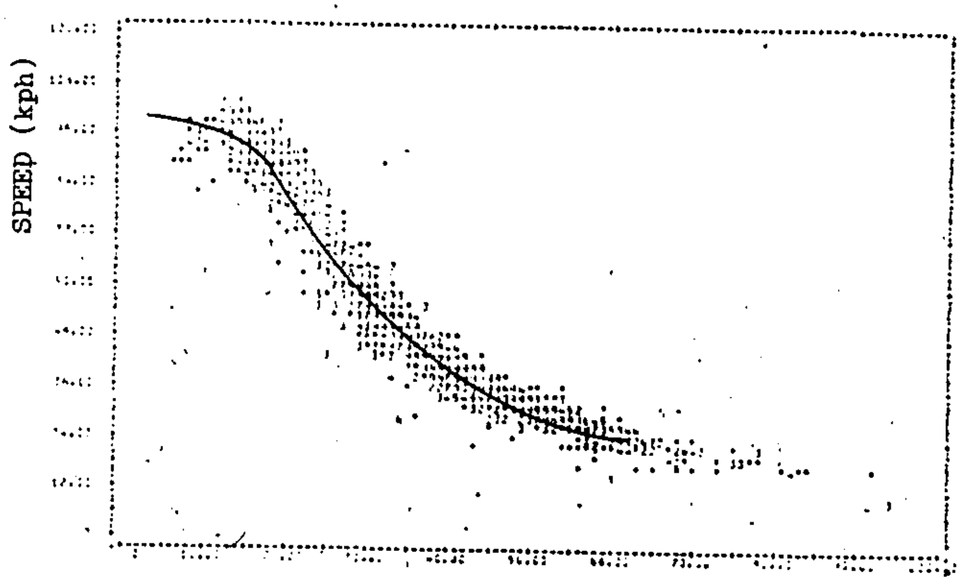


Figure 4.11 Speed-Density Relations, Station 8



$$u=\frac{100(300+k)^{0.417}}{0.00783+(300+k)^{0.417}}$$

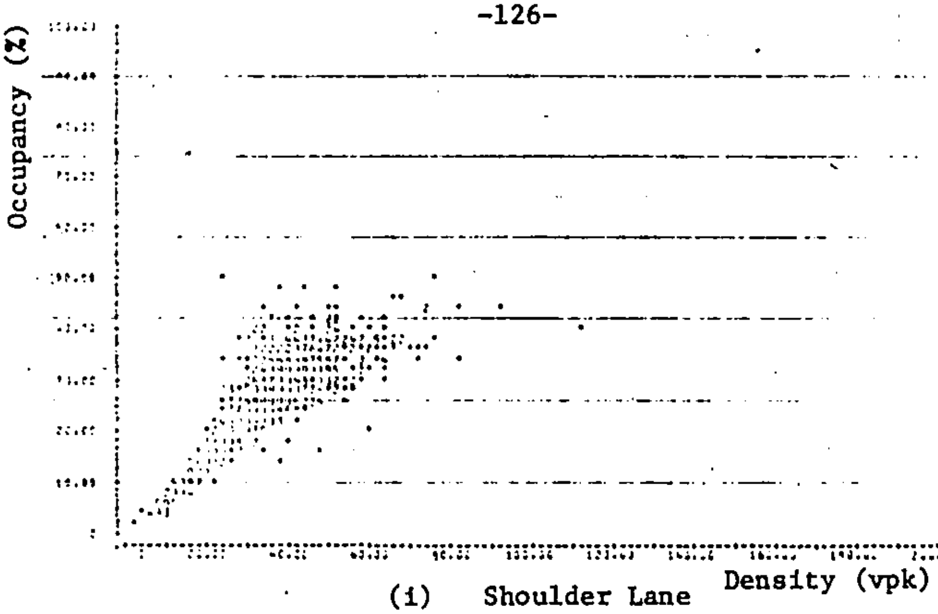
where u=speed(kph)
k=density(vpk)

Residual Sum of Squares=165881
Correlation Coefficient =0.99
Confidence Region :0.2146-0.6197
0.0203- -0.0046

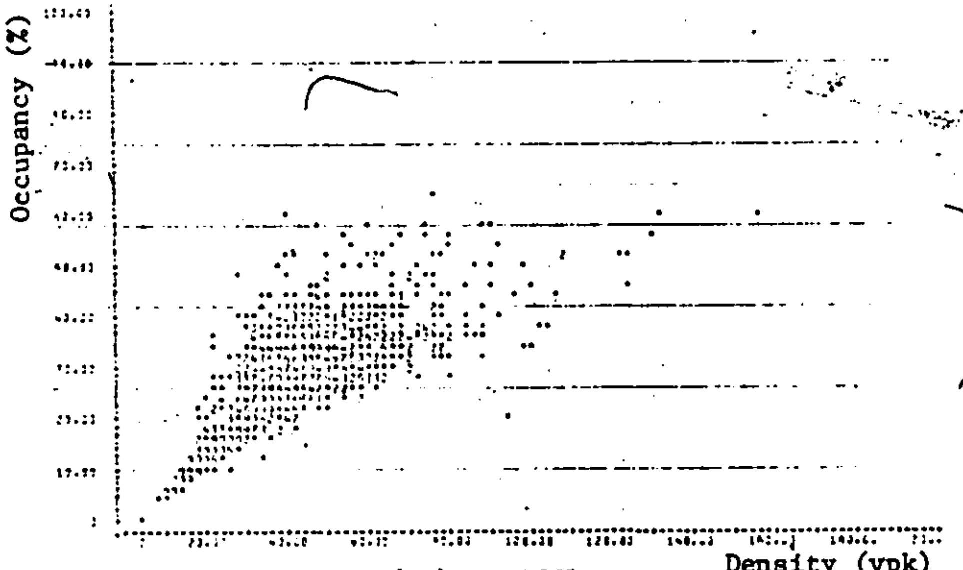
Figure 4.11 (iv) Speed-Density Relation on an Average Lane Basis regression analysis for the average of three lanes are included in Figure 4.11(iv). Speed-occupancy and speed-density relation appear to be quite similar.

Figure 4.12 shows the relationship between density and occupancy. In low flow conditions there appears to be a linear relationship. However, beyond the region of capacity there are large variations in density for given occupancy values and vice versa. The results shown in Figure 4.12(iv) for an average of three lanes, indicates a high correlation between the variables density and occupancy.

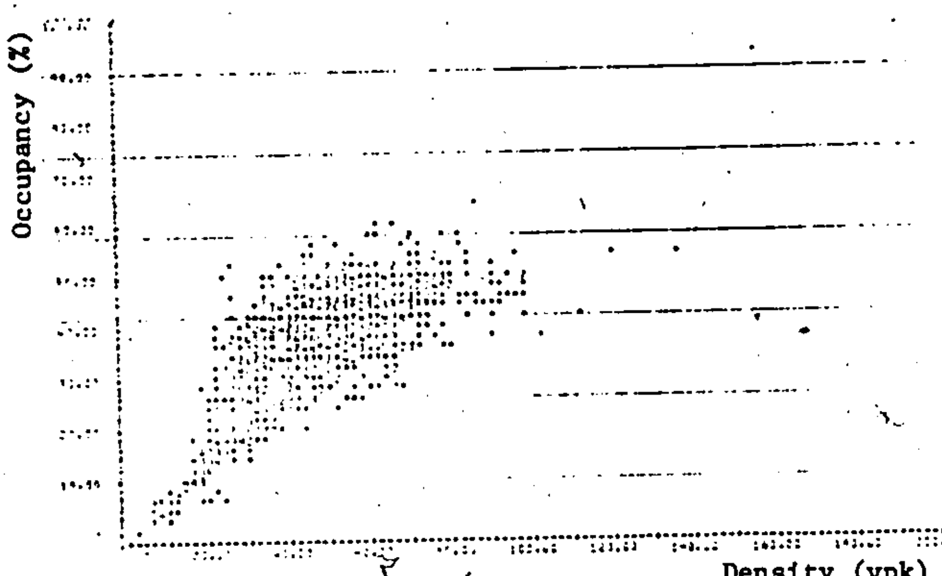
Occupancy-flow relations were in the past described as being parabolic, see for example References (1) and (9) and Figure 4.13. However, data obtained from Mississauga indicated a trend which cannot be described as parabolic, see for example Figure 4.14 and Figures A6.10 - A6.18 in Appendix 6. Curves are fitted to this data by visual inspection methods. There is a definite linear relation in stable flow conditions. This is represented by the lower arm of the data shown. As capacity is approached in the shoulder lane the shape of the data become convex. In unstable flow conditions the shape is however curved. For the middle and median lanes as capacity is approached the relation still appears to be linear. In unstable flow conditions, at high flow rates the data appears to be concave in nature i.e. for the middle and median lanes. However, for the shoulder lane the unstable region tends to be convex in nature. This is the same type of relation observed by Koshi et al (10), see for example Figure 4.15. The reader should however note that there may be a difference in roadway conditions in Japan for which



(i) Shoulder Lane

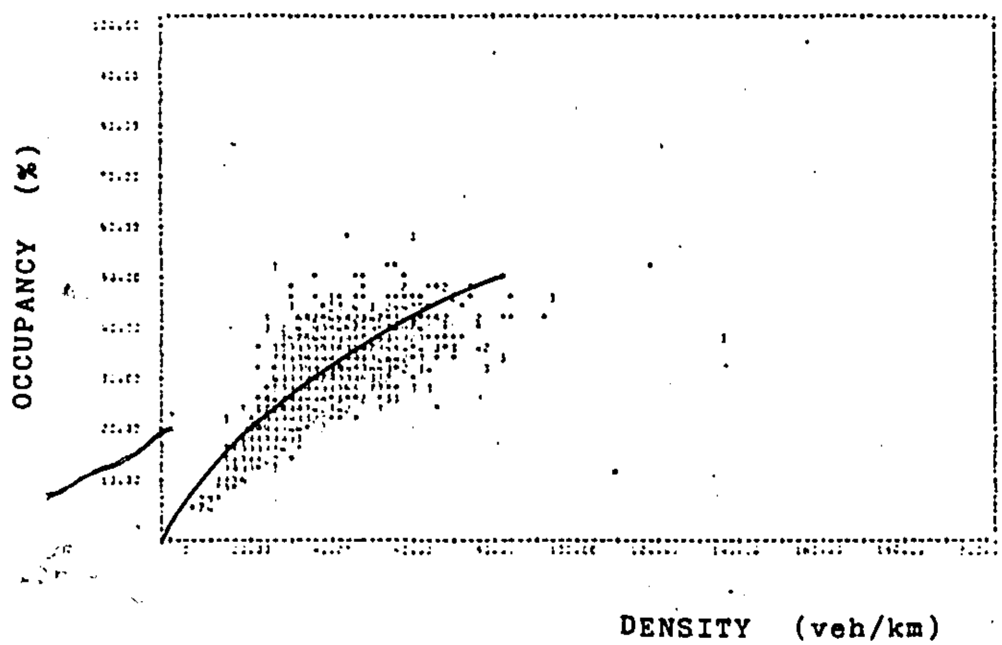


(ii) Middle Lane



(iii) Median Lane

Figure 4. 12 Occupancy-Density Relations, Station 8



$O_c = 2.68\ (k)^{0.675}$

where O_c =occupancy(%)
k =density (veh/km)

Correlation Coefficient =-0.99
Residual Sum of Squares =89565
Data Points =2858
Confidence Limits on
Linear Hypothesis : 2.51 - 2.85
; 6.57 -6.92

Figure 4.12(iv) Occupancy-Density Relation on an Average Lane Basis

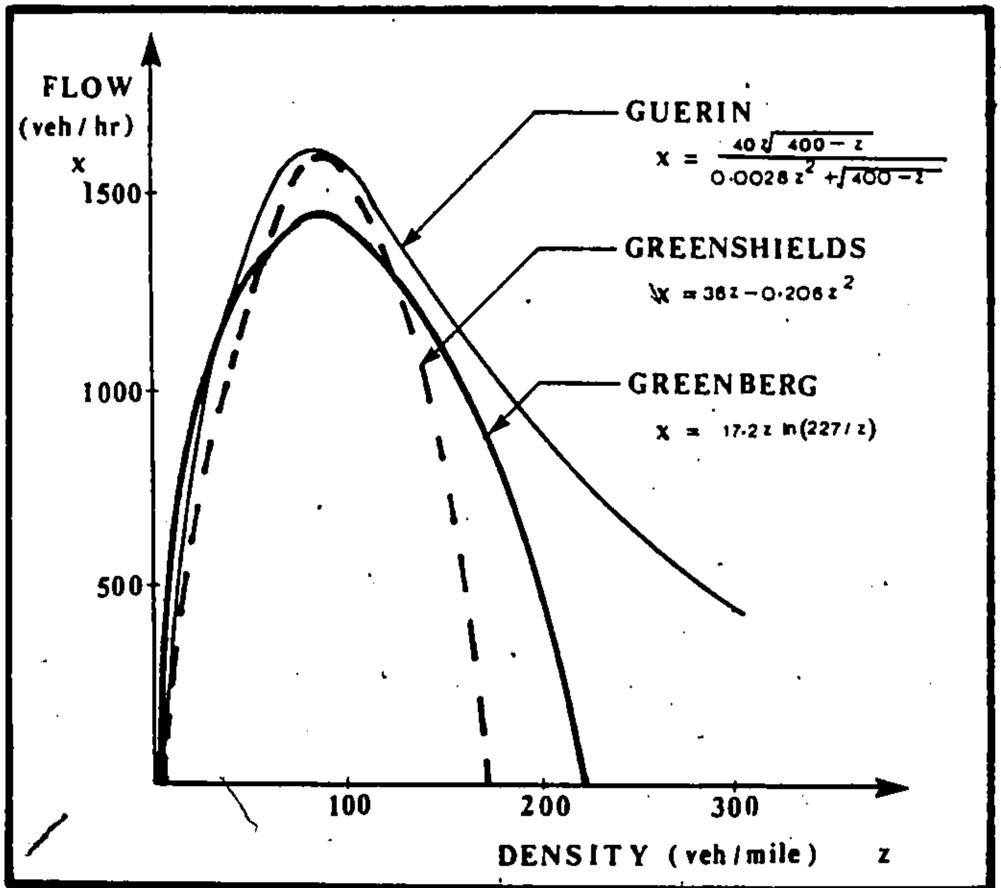


Figure 4.13 Illustration of Flow-Density Curves, Adapted from Wohl and Martin (9), p.335

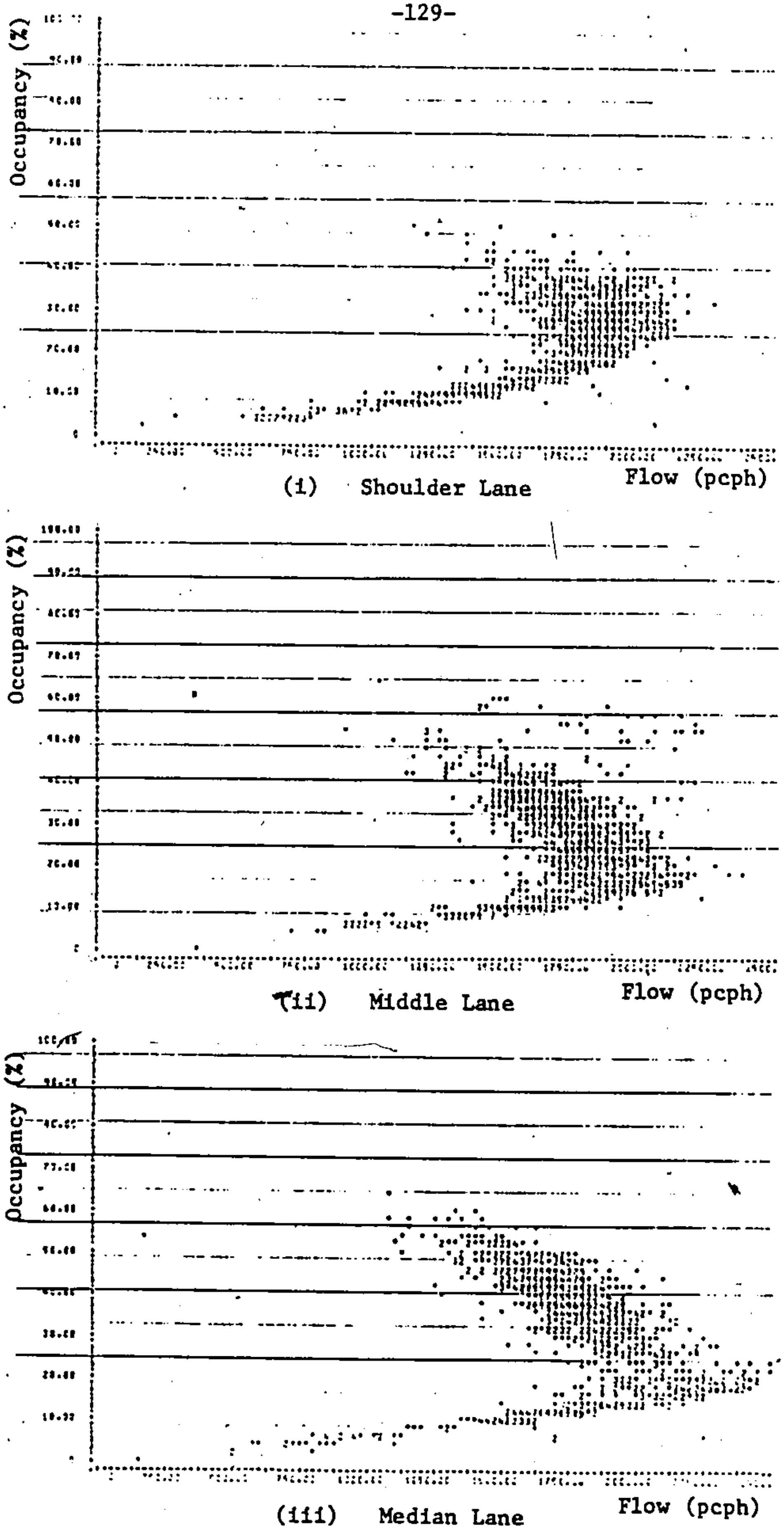
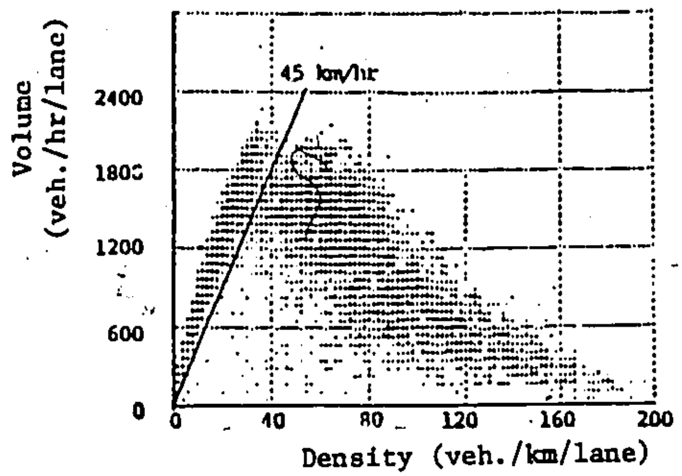
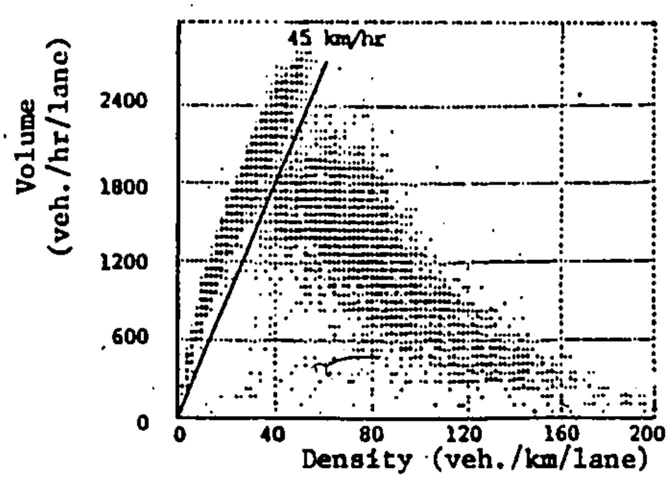


Figure 4.14 Typical Occupancy-Flow Data



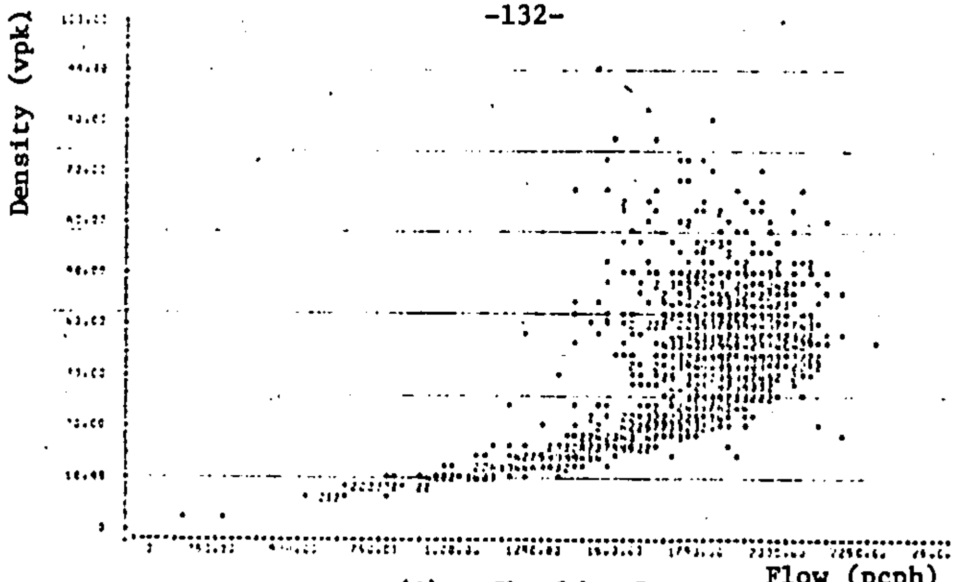
(i) Shoulder Lane



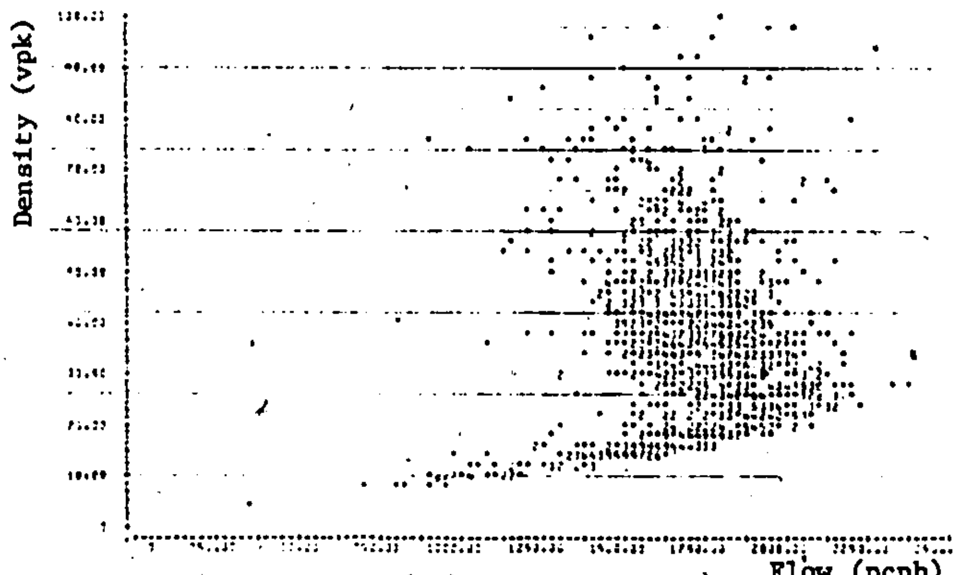
(ii) Median Lane

Figure 4.15 1 Minute Volume-Density at 5.7 km Upstream from Merging Point, Koshi et al (10) the authors conducted their study. In addition there is likely to be a definite difference between North American vehicle characteristics and those of Japan. The high volumes can be attributed to smaller cars in that country.

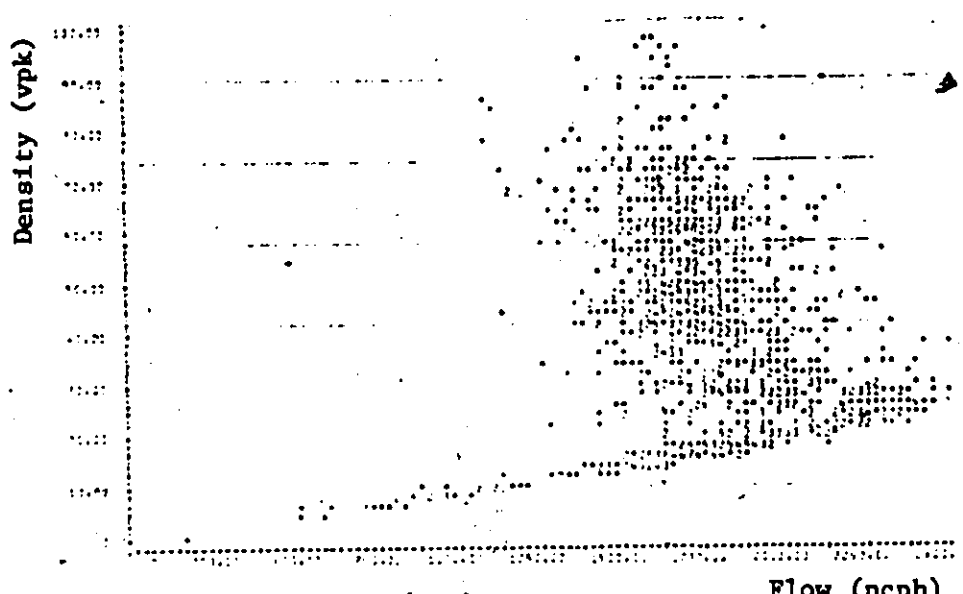
Density-flow curves were also developed for comparison with occupancy-flow relations. The results again appeared to be similar to the curve developed by Guerin shown in Figure 4.13. See for example Figure 4.16 for a typical data set. Although a marked similarity is noted with Guerin's it appears that in unstable flow conditions, the data obtained in this research portrays a linear form unlike Guerin's.



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure 4.16 Density-Flow Relations, Station 8

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The following conclusions have been developed from the results previously presented .

(i) Speed-flow data characteristics are different for the shoulder, middle and median lanes.

From Figure 4.1, speed-flow curves for the three lanes are different in three basic aspects. First, in free flow conditions, the range of speeds at given flow rates is highest in the median and lowest in the shoulder lane. As discussed in subsection 4.2.1, the difference in average free flow speeds between adjacent lanes is about 5-10%. Second, the individual lanes have different capacities. Capacity differences between adjacent lanes is 8-10%. Third, speeds in the region of capacity are lower for the shoulder lane as compared to the other two lanes. One marked similarity between the three relations worthy of note is that at low flows, there is little or no change in speed as flow increases.

A single speed-flow curve, which is an average curve for all lanes, is presently employed in planning and design. Additional computations would be required if studies were to be executed with relations for individual lanes. Once the engineer recognises and takes into account the differences which exist between traffic behaviour in each lane, a single relation is appropriate. Also it is believed that little is gained by additional lane analyses. An average speed-flow relation previously developed in section 4.2.1 for the QEW in Mississauga is as shown in Figure 5.1.

(ii) The shape of speed-flow data characteristics, as shown in Figure 5.2, differs significantly from previously accepted relationships.

In the free flow region of the plots there appears to be no change in slope as flow rates increase. As capacity is approached the slope of the curve increases until in the region of capacity it appears to change rapidly.

In free flow conditions, speeds are higher than those established by HCM and PINY. PINY recommends speeds of about 86 kph at very low flow rates. The results of this research indicate that speeds well over 100 kph were recorded. An average weighted speed for three lanes on the QEW in Mississauga was observed as being 98 kph, i.e. 14% higher than PINY value, a difference certainly worthy of note. As flow rates increase this difference increases, i.e. in free flow conditions. The curve established by the HCM shows a decreasing speed at low flows. thus the difference between the HCM curve and the results obtained herein is quite pronounced. For low flow conidtions the QEW

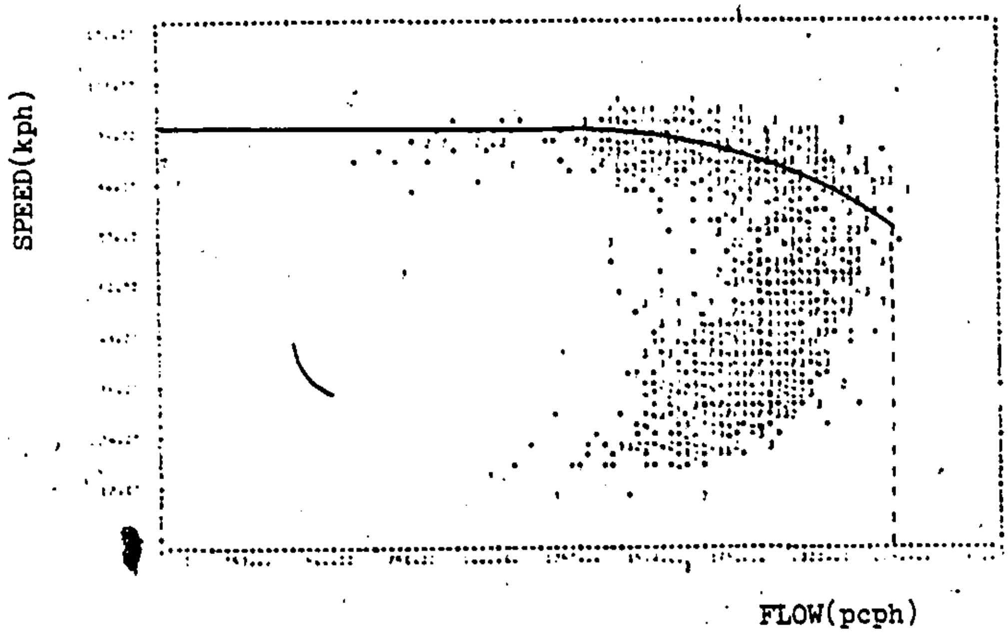


Figure 5.1 Summary of Speed-Flow Data on an Average Lane Basis

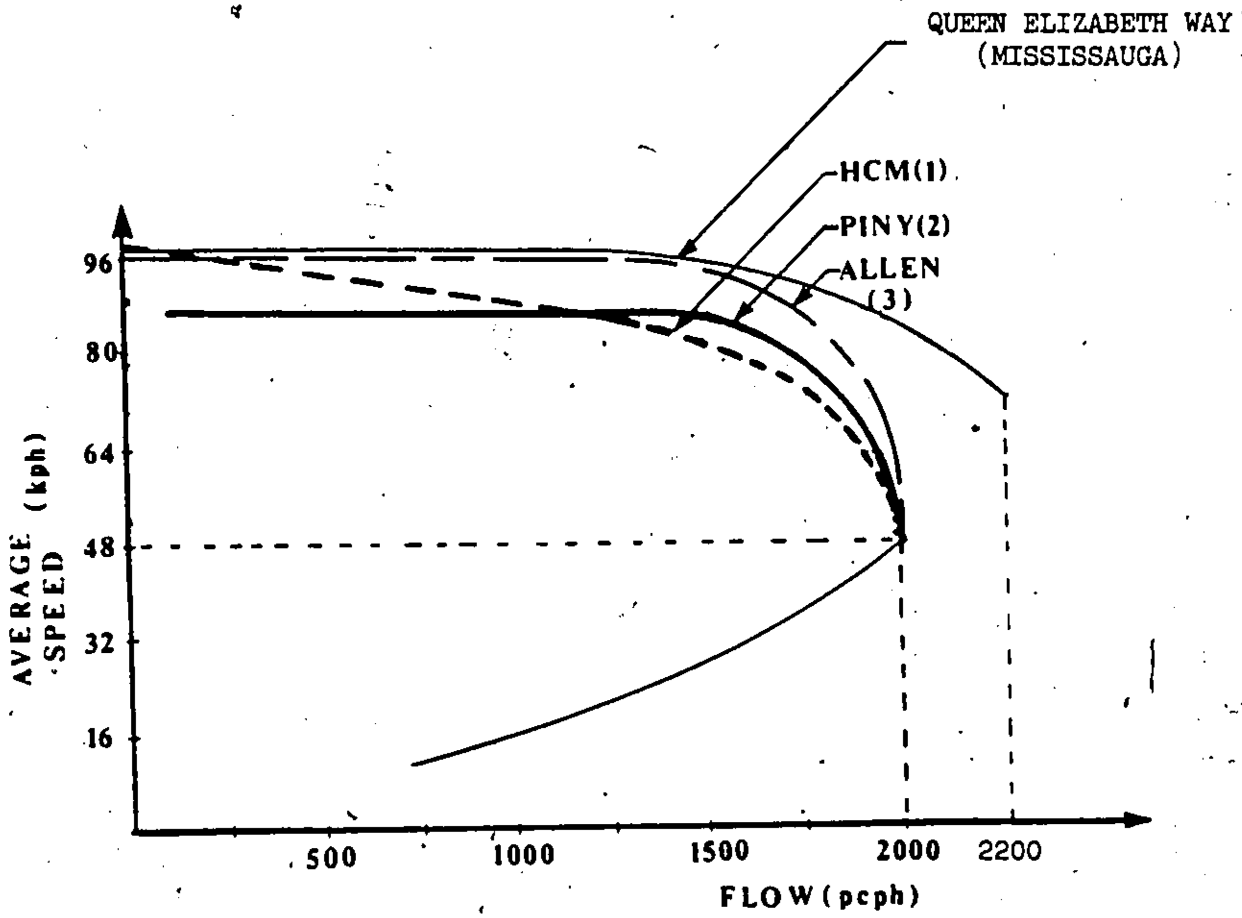


Figure 5.2. Summary of Speed-Flow Relations on an Average Lane Basis

(Mississauga) results agreed with data collected on the QEW in Hamilton, Highway 400 and Highway 401, which included both 2-lane and 3-lane roadway sections.

(iii) Ideal lane capacity is approximately 2340 pcph and the average lane capacity about 2200 pcph for the multilane highways observed in this study.

Both HCM and PINY recommend values of 2000 pcph for ideal and average lane capacities. However, QEW plots indicated flow rates well over 2000 passenger cars per hour. Furthermore, flows were noted as being well above 2000 vehicles per hour, see for example Figures A2.15-A2.23 in Appendix 2. For the QEW in Mississauga, ideal and average lane capacities were respectively computed as 2340 pcph and 2200 pcph. These values represent increases of 17% and 10% above current values.

The impact of incorrect values of average lane capacity can best be observed from equation 5.1 previously discussed in Chapter 1.

$$C = 2000\ N\ W\ T_c \qquad 5.1$$

When the value of 2000 is changed to 2200 a 10% increase in capacity calculations is imminent.

(iv) Shoulder lane capacity can be reduced by as much as 20% in the vicinity of entrance and exit ramps

The reductions in capacity at stations 6 and 9 were respectively found to be 22% and 23%. 5-minute hourly flows were found for the Highway 10 entrance ramp to be about 1080 rph, see for example [Allen (3), p.80]. From PINY [(2), p.165] a shoulder lane volume in the vicinity of an exit ramp is calculated as being 1300 rph or a reduction of about 13%, i.e. at Station 9. Ramp volume at Station 6 were not available and so the effects of the exit ramp on the shoulder lane capacity could not be executed using established methods. More accurate information on guidelines to the capacity of shoulder lanes in the vicinity of ramps may be necessary.

(v) There is very little difference between 5- and 15-minute hourly flow rate computations for uninterrupted flow on multilane highways.

The difference between 5- and 15- minute flow rate capacities appears to be in the region of 3 — 5%. Also, the same difference was noted for speeds in free flow and at capacity. There was no basic difference noted in the general characteristics of the data.

(vi) Based on data available, pce values appear to be lower than those suggested by HCM and PINY.

The evaluation of a passenger car equivalent for ideal conditions indicated that a pce of 1-5 may be appropriate. Although it cannot be concluded that a new value should be adopted it appears that further work to confirm the value of 2.0 may be necessary. The reader should note that if the pce is in fact as low as 1.3, then this means that facilities are presently being over designed.

(vii) Ideal and average lane capacities are reduced by about 7% in adverse weather conditions.

Speed-flow relations observed for adverse weather conditions indicated reductions in capacity from 4-10%. An average reduction was about 6-7%. Speeds in free flow conditions were reduced by similar amounts. At capacity speeds were reduced by as much as 17% i.e. an average value for three lanes. In addition the effect of snow on basic speed-flow relations appears to be greater than for rain.

(viii) There are definite relationships between the variables speed and occupancy and flow and occupancy. Also, there is a high correlation between occupancy and density.

A typical speed-occupancy relation is as shown in Figure 4.11. It differs significantly from speed-density relations shown in Figures 4.9 and 4.10. The plots shown in Appendix 6 indicate substantial evidence of definite relations between speed, flow and occupancy.

Occupancy-flow relations are also quite definite, the most marked feature of this relation, being the linear form in stable conditions, see for example Figure 4.13. The relationships between density-speed and density-flow appear to be as described by Guerin.

5.2 Recommendations

(i) The fundamental speed-flow relations shown in Figure 5.2 are recommended for use.

Engineers are generally accustomed to using a single speed-flow relation when computing travel times and/or service quality. Such a curve is illustrated by the solid line in Figure 5.2. It is obtained by visual inspection of the data taking into account that flow is the dependent and speed the independent variable. It is believed that the curve is representative of multilane highways in Ontario and the large data source from which they were developed enhances their reliability.

(ii) Average and ideal lane capacities are 2200 pcph and 2340 pcph respectively.

In this era of limited road improvement funds more accurate planning and design are necessary if funds are to be used to derive maximum benefits. The use of 2200 pcph as opposed to 2000 will definitely affect service volume calculations. Thus it is essential that these new values be adopted as they are considered to be a closer representation of current traffic behaviour.

(iii) Further studies should be conducted on the pce value of 2.0 established by both HCM and PINY.

In view of the present findings, it is recommended that more consideration should be given to the suggested passenger equivalent value of 2.0 for trucks. Because trucks are almost always present in the traffic stream the impact of their presence is a key issue to the traffic engineer. Especially when the percentage trucks reached as high as 15-20% (e.g. QEW (Mississauga)) an accurate pce value becomes vital.

(iv) The effect of adverse weather conditions on basic speed-flow relations should be taken into account in areas frequently affected.

The results of the data on adverse weather conditions are recommended for consideration. However, it must be noted that effects on capacity and speeds would likely vary with both intensity and duration of adverse weather. Since information on these variables were not obtained in this study it is also recommended that further work be executed to monitor the influence of these.

(v) Speed flow and occupancy relations previously defined are recommended for use in the operation of roadway traffic.

Traffic behaviour is often characterized by speed-flow relations. However for any given flow there are two conditions which exist i.e. stable and unstable. Since there is a near-linear relation between speed and occupancy, for a given value of occupancy, there will be only one condition i.e. either stable or unstable. Consequently the use of occupancy data in the control and operation of roadway traffic is more appropriate than the variable flow.

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APPENDIX 1

Information from Freeway Surveillance

and Control System (FSCS)

Information pertaining to data compiled by the Freeway Surveillance and Control System (FSCS) operated by the Ontario Ministry of Transportation and Communications are included in this Appendix. A summary of daily reports obtained from the Ministry is shown in Table A1.1. Tables A1.2 and A1.3 relate to the data file, DATA5M which contains 5-minute speed, volume and occupancy data at Stations 1-9 on the QEW (Mississauga).

TABLE A1.1

SUMMARY OF DAILY REPORTS COMPILED

BY MTC UNDER THE FSCS

DAY	DATE	WEATHER	COMMENTS
MON	7.9.79	Clear	Construction on Cawthra Rd. - No Detour.
TUES	7.10.79	Overcast	""
WED	7.11.79	Clear	Construction on Cawthra Rd. 8:19 - Vehicle in passing lane at Credit River - blocking for 5 mins.
THURS	7.12.79	Clear	Cawthra Rd. construction
FRI	7.13.79	Clear	Delay due to Cawthra Rd. construction
MON	7.16.79	Clear	Slight delay due to Cawthra construction
WED	7.18.79	Clear	Good flow
THURS	7.19.79	Clear	Van knocked over EP, EB, West of Mississauga Rd. off of roadway, cleared 8:17 - Nominal metering at Highway 10 and Mississauga Rd.
FRI	7.20.79	Clear	Good flow, flat tire being changed EB east of the Credit River, slowed traffic at that location, 7:33 - 8:03.
MON	7.23.79	Clear	Truck stopped on shoulder, EB, E of Highway 10, slowing traffic from 8:00 AM to end of congestion period.
TUES	7.24.79	Clear	Construction @ Cawthra Rd. - Left lane closed until 6:42 7:25 - 7:37, Left lane blocked due to accident.
WED	7.25.79	Clear	Good flow

DAY	DATE	WEATHER	COMMENTS
THURS	7.26.79	Overcast	Light summer volumes
FRI	7.27.79	Clear	Good flow
MON	7.30.79	Clear	Good flow
TUES	7.31.79	Rain	Rain caused congestion
THURS	8.2.79	Overcast	Good flow
FRI	8.3.79	Clear	Good flow
TUES	8.7.79	Clear	Good flow
WED	8.8.79	Clear	Good flow
MON	8.13.79	Clear	7:25 - car disabled east of CRB on shoulder - 7:55 cleared
TUES	8.14.79	Clear	Good flow
WED	8.15.79	Overcast	Good flow
THURS	8.16.79	Clear	Good flow
FRI	8.17.79	Clear	Good flow
TUES	8.21.79	Clear	Good flow
THURS	8.23.79	Clear	6:00 - collision EB @ Dixie Rd. - 6:30 backup @ Highway 10 - 7:15 cleared
FRI	8.24.79	Clear	Severe congestion. 7:15 car stalled in DL @ Cawthra - 7:35 clear. 7:30 car rollover WB @ Highway 10 - 8:20 clear. 8:35 collision @ Dixie. 8:50 car rollover @ CMS. 8:55 collision @ CRB
MON	8.27.79	Rain	8:51 collision west of Highway 10 in PL - 9:34 cleared to shoulder. 8:51 stall E of Highway 10 in PL.

DAY	DATE	WEATHER	COMMENTS
TUES	9.4.79	-	-
WED	9.5.79	Clear	7:35 - 2 car collision DW of Southdown Rd. blocking PL - 7:48 on shoulder
THURS	9.6.79	Clear	Very slow
MON	9.10.79	Clear	8:40 - collision W/B, E of Highway 10 caused slowdown on QEW, EB.
TUES	9.11.79	Clear	7:40 - stall PL. E of Highway 10 - 7:43 closed
WED	9.12.79	Clear	Good Flow
THURS	9.13.79	Overcast	6:40 car stalled in CL, shoulder @ CRB - 7:00 cleared
FRI	9.14.79	Heavy Rain	6:35 collision QEW W/B @ Cawthra. Severe congestion to west of WCB
MON	9.17.79	Clear	6:40 collision E of Highway 10 off road. Slight congestion caused by collision
TUES	9.18.79	Clear	7:02 car stalled E of Highway 10, in PL. 7:25 car on should partly blocking DL. 7:48 car stalled @ Highway 427 Ramp to QEW E-B, blocking DL
WED	9.19.79	Clear	Good flow
THURS	9.20.79	Clear	Good flow
FRI	9.21.79	Clear	Good flow
TUES	10.16.79	Clear	7:30 collision on QEW EB, West of Highway 10, 427
WED	10.17.79	Rain	7:00 stalled car E/B PL @ CRB - 7:10 cleared. Rain and stalled vehicle caused severe congestion.
THURS	10.18.79	Clear	Good flow

DAY	DATE	WEATHER	COMMENTS
TUES	10.23.79	Rain	No metering @ Mississauga Rd, SB due to signal malfunction. Accident west of Miss. Rd. involving truck and several vehicles @ 7:47 accident. Approximately 8:45 W of Southdown
WED	10.24.79	Rain	Poor flow due to drizzle and rain for most of congested period
THURS	10.25.79	Overcast	New detour @ Cawthra Rd. for new interchange construction
FRI	10.26.79	Overcast	Good flow - even with Cawthra detour in effect
MON	10.29.79	Overcast	Stalled car in PL at Highway 10
WED	10.31.79	Clear	Good flow
THURS	11.1.79	Overcast	Good flow
FRI	11.2.79	Clear	Good flow
MON	11.5.79	Clear	[illegible]:21 stall E/B, DL E of scales - 7:27 [illegible]ar; 8:43 stall on CRB - 8:55 cleared
TUES	11.6.79	Overcast	[illegible]d flow
WED	11.7.79	Clear	Good flow
THURS	11.8.79	Clear	Good flow
FRI	11.9.79	Clear	8:40 stall in PL W of Highway 10 - 8:42 cleared
MON	11.19.79	Fog	Foggy
TUES	11.20.79	Overcast	Good flow
WED	11.21.79	Overcast	Good flow

DAY	DATE	WEATHER	COMMENTS
THURS	11.22.79	Rain	7:56 stalled car in PL @ Mississauga Rd - 8:17 cleared Rain and stalled car caused severe congestion
FRI	11.23.79	Rain	6:46 collision @ Dixie Rd. cleared at 7:10 - severe congestion
MON	11.26.79	Rain	Rain caused moderate congestion
TUES	11.27.79	Overcast	Good flow
WED	11.28.79	Rain	Rain caused moderate congestion. 7:30 collision E of Erin Mills
THURS	11.29.79	Clear	7:00 tractor trailer on shoulder E of CRB 7:10 stall at Cawthra detour - cleared at 7:20 7:40 stall Gray Coach near scales partially blocking PL - 8:45 cleared
FRI	11.30.79	Clear	7:20 stall PL Mississauga Rd - 7:26 cleared 7:40 stalled truck on Mississauga Rd on ramp Southdown - 7:45 cleared 8:45 stall in PL West of Highway 10 - cleared at 9:00

MON	12.3.79		8:45 stalled car in PL West of Highway 10 - cleared at 9:00
TUES	12.4.79	Clear	8:15 stall east of Highway 10 on shoulder - 8:40 cleared
WED	12.5.79	Clear	7:45 stall at CRB CL - cleared at 7:57
THURS	12.6.79	Clear	7:42 - 3 car collision east of Highway 10, on shoulder, slight congestion dowstream of Highway 10
FRI	12.7.79	Clear	Good flow

DAY	DATE	WEATHER	COMMENTS
MON	12.10.79	Overcast	8:40 Clear - stalled CL at scales - cleared @ 8:50. 8:45 car stalled west of Mississauga Rd - 9:00 cleared
TUES	12.11.79	Overcast	Good flow
WED	12.12.79	Rain	7:13 collision on Southdown 7:20 collision east of Cawthra, QEW, westbound, 3 cars sideways in PL 7:38 collision westbound at Etobicoke Cr.
THURS	12.13.79	Light Snow	Good flow
FRI	12.14.79	Light Snow	Good flow
MON	12.17.79	Clear	Flow moderately affected
TUES	12.18.79	Snow	Snow and wet pavement
WED	12.19.79	Snow	Snow
THURS	12.20.79	Overcast	Wet pavement
FRI	12.21.79	Overcast	Damp pavement
MON	12.24.79	Rain	Metering unnecessary
FRI	12.28.79	Clear	Metering unnecessary
MON	12.31.79	Clear	Good flow
WED	1.2.80	Rain	Good flow
THURS	1.3.80	Overcast	7:02 tractor trailer on shoulder at Highway 10 - 7:05 cleared, slight congestion
FRI	1.4.80	Light Snow	
MON	1.7.80	Rain	6:30 disabled truck PL, east of Erin Mills - cleared @ 6:55

DAY	DATE	WEATHER	COMMENTS
TUES	1.8.80	Light Snow	Good flow
WED	1.9.80	Snow	Slight congestion
THURS	1.10.80	Clear	8:00 stall east of Mississagua Rd., on north shoulder - cleared @ 8:15
FRI	1.11.80	Rain	-
MON	1.14.80	Clear	Good flow
TUES	1.15.80	Clear	Good flow
WED	1.16.80	Rain	Rain caused moderate congestion
THURS	1.17.80	Clear	Good flow
MON	1.21.80	Overcast	Good flow
TUES	1.22.80	Flurries, Overcast	-
WED	1.23.80	Overcast	Good flow
THURS	1.24.80	Flurries	Slippery pavement - caused moderate congestion
FRI	1.25.80	-	Stalled car in PL @ Mississauga Rd.
MON	1.28.80	Clear	Damp pavement following snow - caused moderate congestion
TUES	1.29.80	Clear	Good flow
WED	1.30.80	Clear	7:00 - tractor trailer on shoulder EB, east of Highway 10, 8:40 stalled car west of Highway 10, eastbound - 8:45 pushed to shoulder
THURS	1.31.80	Clear	Good flow

DAY	DATE	WEATHER	COMMENTS
FRI	2.1.80	Clear	Flow is slightly affected
MON	2.4.80	Clear	Damp pavement - slight congestion
TUES	2.5.80	Clear	Good flow
WED	2.6.80	Snow	Snow caused slight congestion
MON	2.11.80	Overcast	7:00 collision east of Highway 10 - cleared at 7:05 7:20 collision southbound on Highway 10 north of SSR (South Service Rd.) 7:30 stalled car EB, east of Scales - cleared at 7:34 Damp pavement and collision caused severe congestion to west of WCB
TUES	2.12.80	Overcast	8:00 collision @ Highway 427, to QEW E/B. Wet pavement caused moderate congestion
WED	2.13.80	Clear	7:13 stalled car CL, west of Mississauga Rd - slight congestion west of Mississagua Rd.
THURS	2.14.80	Overcast	8:00 PL collision W/B at Highway 427 - Good flow
FRI	2.15.80	Snow	8:15 snow started 8:15 car stalled in PL @ Highway 10 - cleared at 8:30
MON	2.18.80	Snow	6:55 - 4 car collision east of CRB, blocking PL and part of CL - 7:17 pushed to shoulder
TUES	2.19.80	Clear	Good flow
WED	2.20.80	Clear	Good flow
THURS	2.21.80	Overcast	Good flow
FRI	2.22.80	Freezing Rain	Moderate congestion
MON	2.25.80	Overcast	Good flow

DAY	DATE	WEATHER	COMMENTS
TUES	2.26.80	Clear	Good flow
WED	2.27.80	Snow	Wet pavement and light snow caused moderate congestion
FRI	2.29.80	Clear	Good flow

TABLE A1.2 FORMAT OF FILE DATA 5M FROM FSCS

1	PASS	Highway 10 NB on	OCCUPANCY (pulses)
2	DEM	"	
3		Service Road	
4	Q	Highway 10 NB on	
5	PASS	Highway 10 SB on	
6	DEM	"	
7		Highway 10 NB off	
8	Q	Highway 10 SB on	
9		Highway 10 SB off	
10	PASS	Mississauga Rd. NB on	
11	DEM	"	
12	Q	"	
13		Station 6A	
14		"	
15	PASS	Mississauga Rd. SB on	
16	DEM	"	
17	Q	"	
18	Q	"	
19		Mississauga Rd. off	
20	PASS	Southdown Rd. on	
21	DEM	"	
22	Q	"	
23	Q	"	

24	SHL	Station 9
25	MID	"
26	MED	"
27	SHL	Station 8
28	MID	"
29	MED	"
30	SHL	Station 7
31	MID	"
32	MED	"
33	SHL	Station 6
34	MID	"
35	MED	"
36	SHL	Station 5
37	MID	"
38	MED	"
39	SHL	Station 4
40	MID	"
41	MED	"
42	SHL	Station 3
43	MID	"
44	MED	"
45	SHL	Station 2
46	MID	"
47	MED	"
48	SHL	Station 1
49	MID	"
50	MED	"
51	SHM	Station 9
52	MID	"
53	MED	"

DOWNSTREAM
OCCUPANCY
(pulses)

54	SHL	Station 8
55	MID	"
56	MED	"
57	SHL	Station 7
58	MID	"
59	MED	"
60	SHL	Station 6
61	MID	"
62	MED	"
63	SHL	Station 5
64	MID	"
65	MED	"
66	SHL	Station 4
67	MID	"
68	MED	"
69	SHL	Station 3
70	MID	"
71	MED	"
72	SHL	Station 2
73	MID	"
74	MED	"
75	SHL	Station 1
76	MID	"
77	MED	"
78	SHL	Station 9
79	MID	"
80	MED	"
81	SHL	Station 8
82	MID	"
83	MED	"

SPEED
(ft/sec)

84	SHL	Station 7
85	MID	"
86	MED	"
87	SHL	Station 6
88	MID	"
89	MED	"
90	SHL	Station 5
91	MID	"
92	MED	"
93	SHL	Station 4
94	MID	"
95	MED	"
96	SHL	Station 3
97	MID	"
98	MED	"
99	SHL	Station 2
100	MID	"
101	MED	"
102	SHL	Station 1
103	MID	"
104	MED	"
105	SHL	Station 9
106	MID	"
107	MED	"
108	SHL	Station 8
109	MID	"
110	MED	"
111	SHL	Station 7
112	MID	"
113	MED	"

LONG VEHICLES

114	SHL	Station 6
115	MID	"
116	MED	"
117	SHL	Station 5
118	MID	"
119	MED	"
120	SHL	Station 4
121	MID	"
122	MED	"
123	SHL	Station 3
124	MID	"
125	MED	"
126	SHL	Station 2
127	MID	"
128	MED	"
129	SHL	Station 1
130	MID	"
131	MED	"
132	SHL	Station 9
133	MID	"
134	MED	"
135	SHL	Station 8
136	MID	"
137	MED	"
138	SHL	Station 7
139	MID	"
140	MED	"
141	SHL	Station 6
142	MID	"
143	MED	"

UPSTREAM VOLUME

144	SHL	Station 5	UPSTREAM OCCUPANCY (pulses)
145	MID	"	
146	MED	"	
147	SHL	Station 4	
148	MID	"	
149	MED	"	
150	SHL	Station 3	
151	MID	"	
152	MED	"	
153	SHL	Station 2	
154	MID	"	
155	MED	"	
156	SHL	Station 1	
157	MID	"	
158	MED	"	
159	HRS	Time	
160	MIN	"	
161	SEC	"	
162			INFORMATION NOT USEFUL
163			
164			
165			
166			
167			
168			
169			
170			
186			
187			
188			
189			
190			
191			
192			

LEGEND

PASS	-	PASSAGE Detector
DEM	-	DEMAND Detector
Q	-	QUEUE
SHL	-	Shoulder Lane
MID	-	Middle Lane
MED	-	Median Lane
NB	-	North Bound
SB	-	South Bound
ON	-	On Ramp
OFF	-	Off Ramp

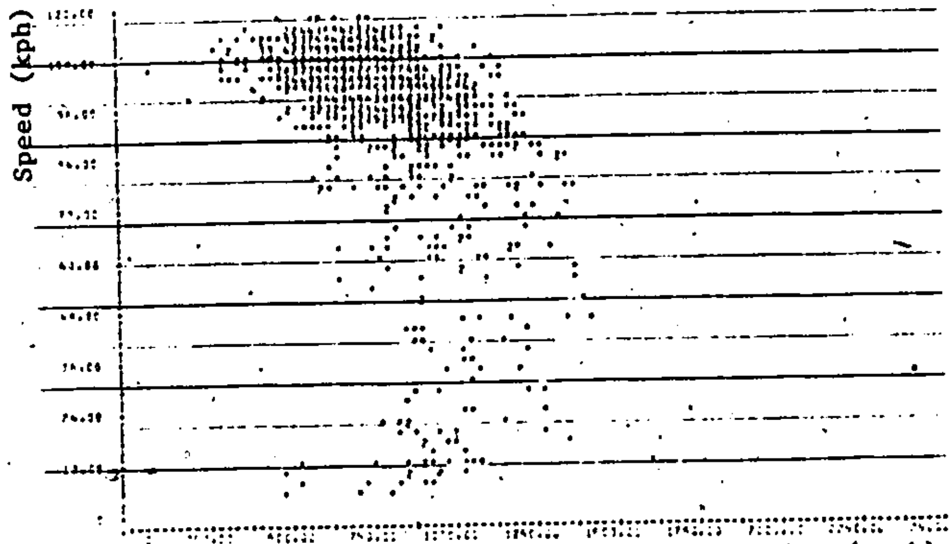
Table A1.3 Rearranged format of DATA 5m file

Downstream Occupancy	Speeds	Long Vehicles	Total Volumes	Upstream Occupancy	
SHL	SHL	SHL	SHL	SHL	Station 9
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 8
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 7
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 6
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 5
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 4
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 3
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 2
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
SHL	SHL	SHL	SHL	SHL	Station 1
MID	MID	MID	MID	MID	"
MED	MED	MED	MED	MED	"
HR	MIN	MIN	SEC	SEC	Time

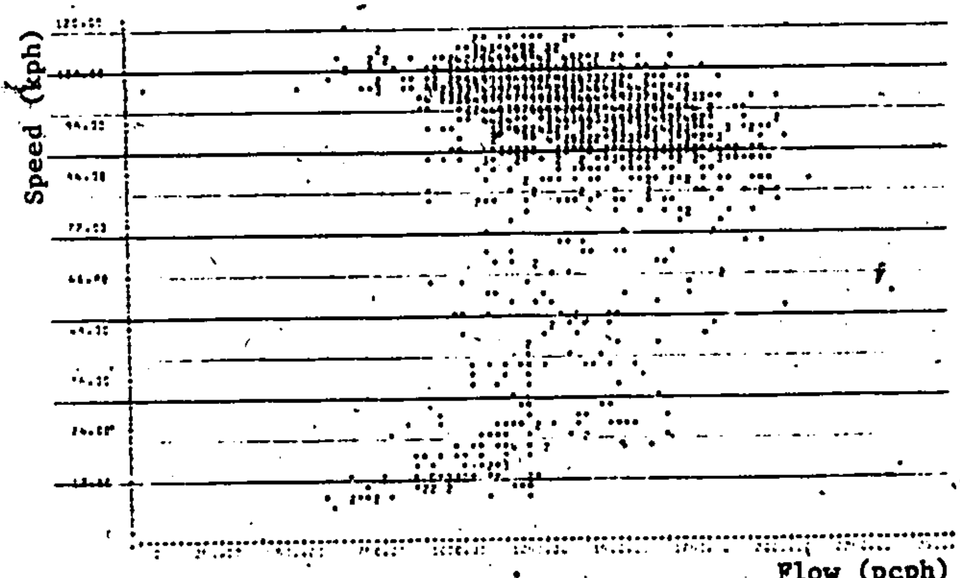
APPENDIX 2

Speed-flow data plots for ideal conditions.

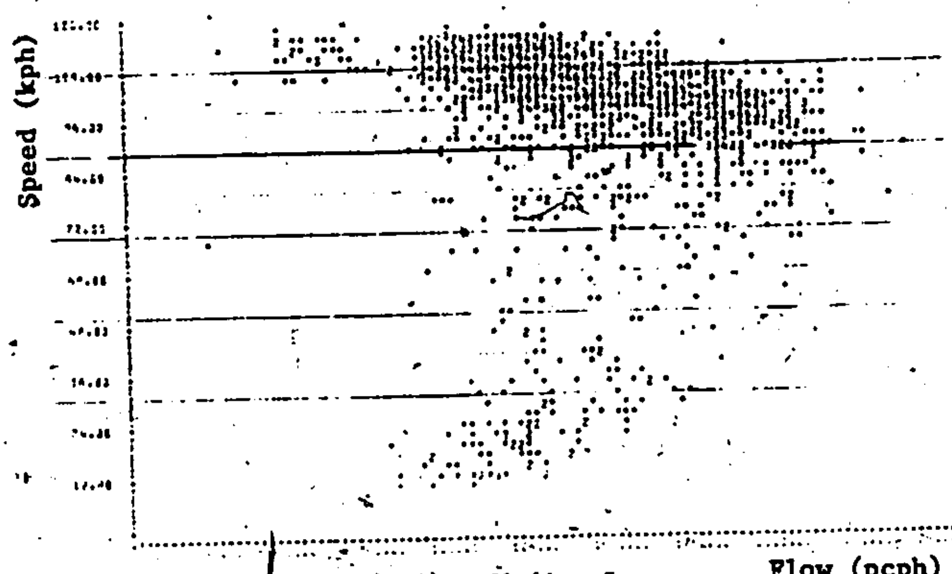
Speed and flow data are shown for the QEW in Mississauga and Hamilton and Highways 400 and 401. Speeds are all noted in kilometers per hour and unless otherwise indicated, 5-minute hourly flow rates are recorded in passenger car units. The numbers in each plot represent the number of data points plotted at the same spot, e.g. 2 represents that two points occur at the same spot. The number 9 however, means that nine or more points are located there.



(i) Shoulder Lane

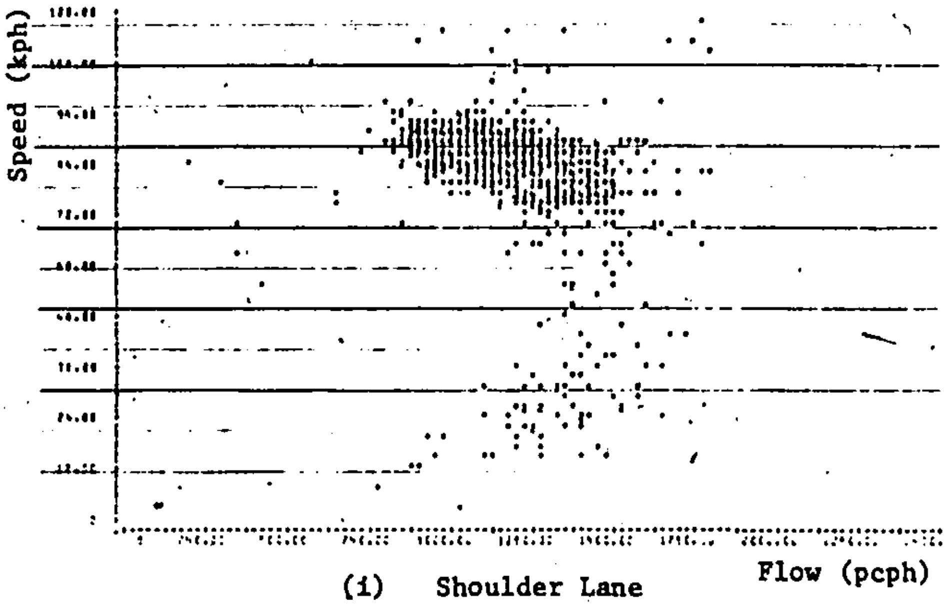


(ii) Middle Lane

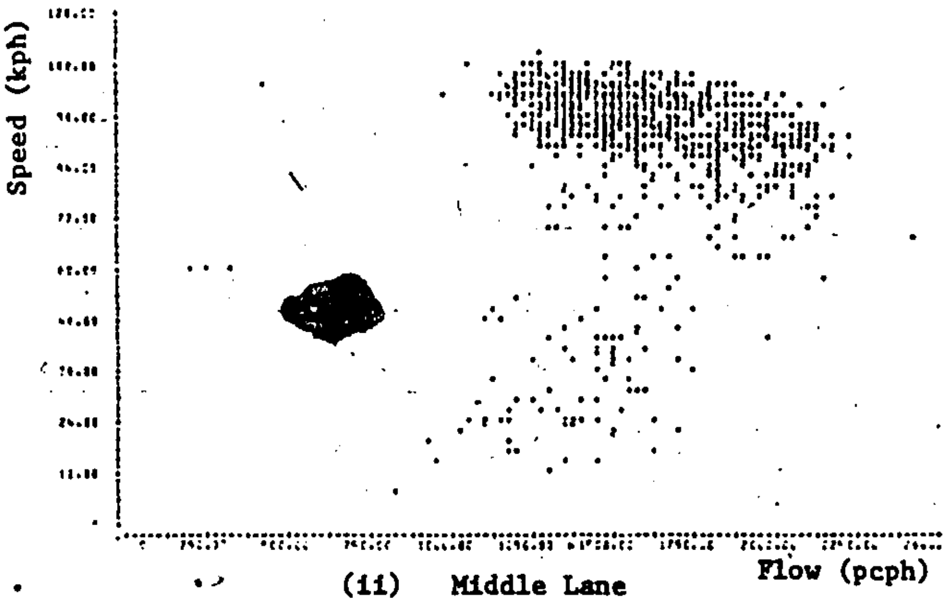


(iii) Median Lane

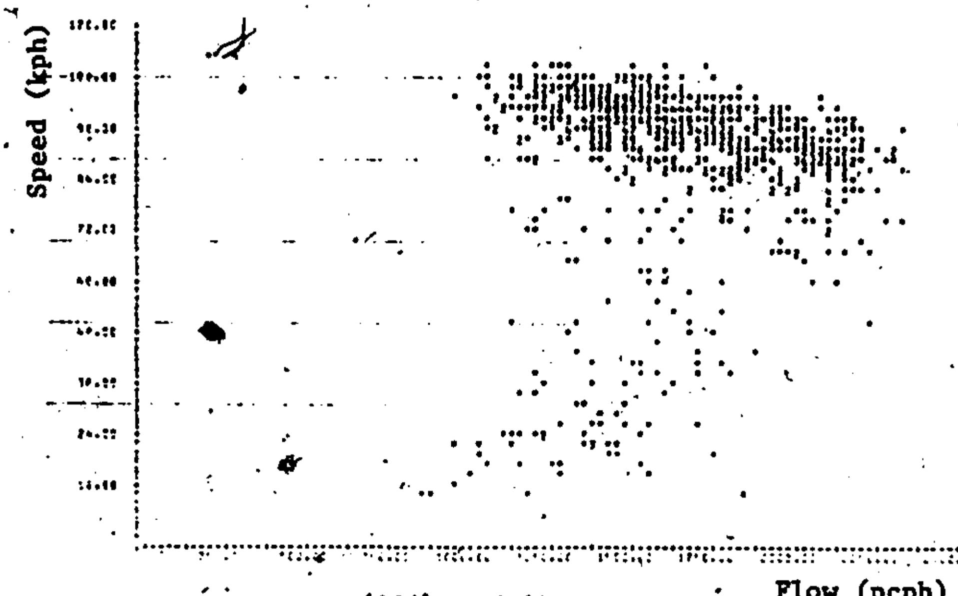
Figure A2.1 Speed-Flow Data, Station 1, QEW (Mississauga)



(i) Shoulder Lane

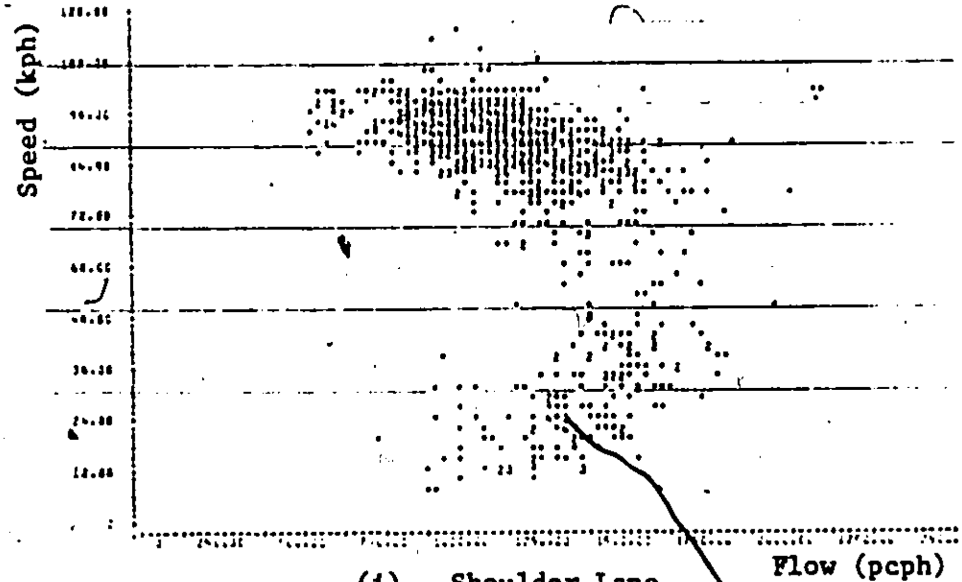


(ii) Middle Lane

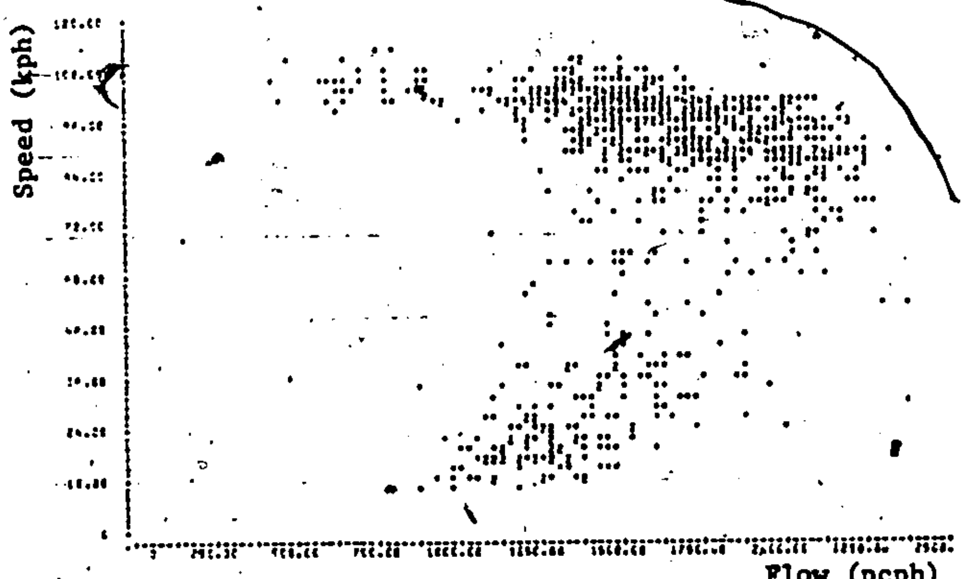


(iii) Median Lane

Figure A2.2 Speed-Flow Data, Station 2, QEW (Mississauga)

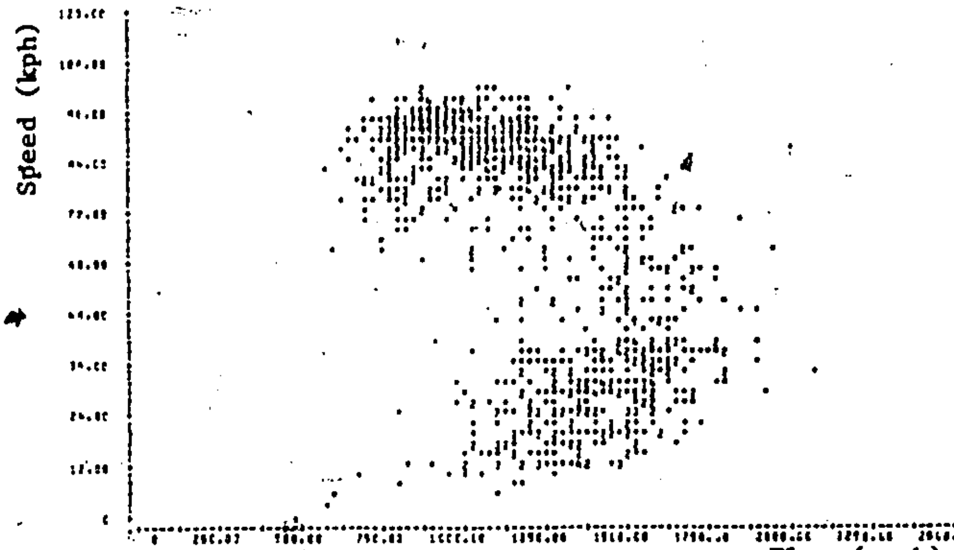


(i) Shoulder Lane

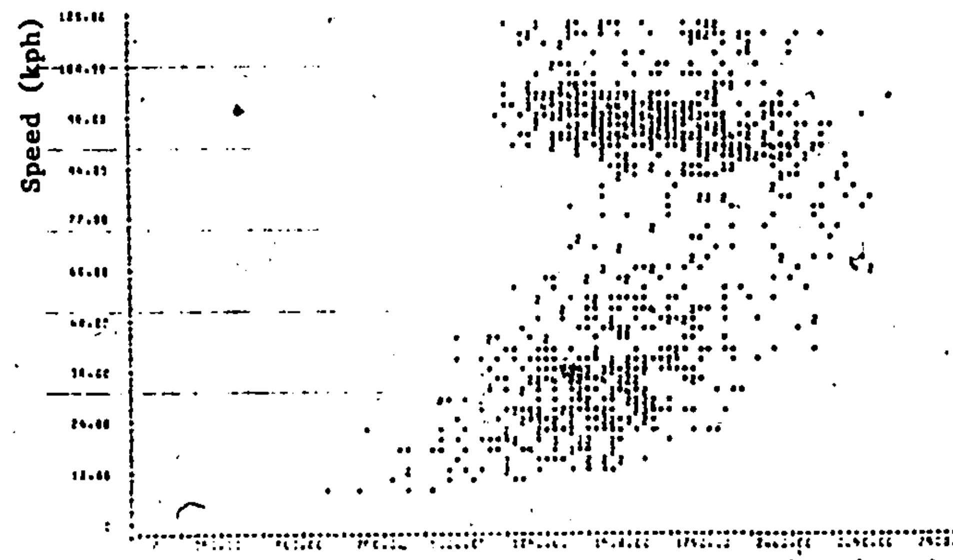


(ii) Median Lane

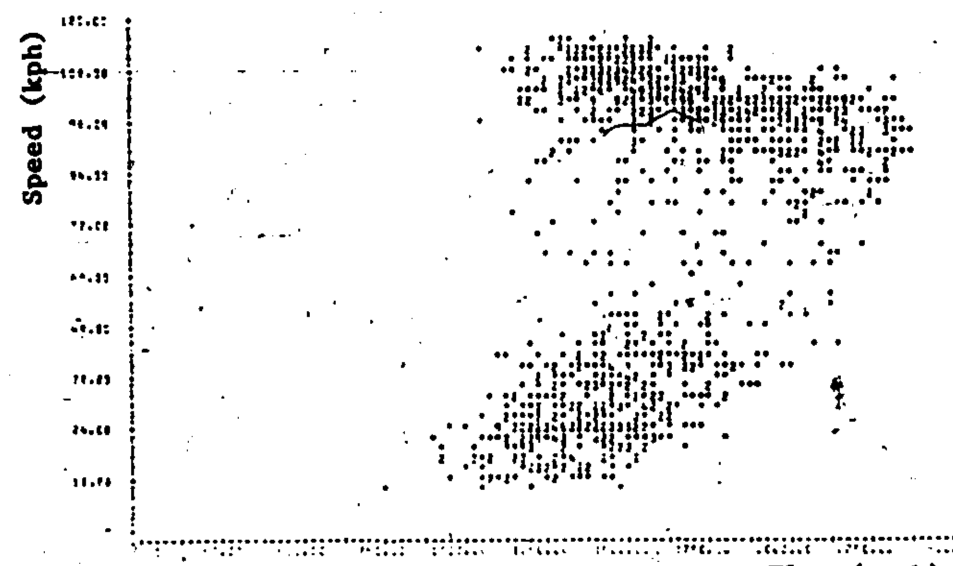
Figure A2.3 Speed-Flow Data, Station 3, QEW (Mississauga)



(i) Shoulder Lane

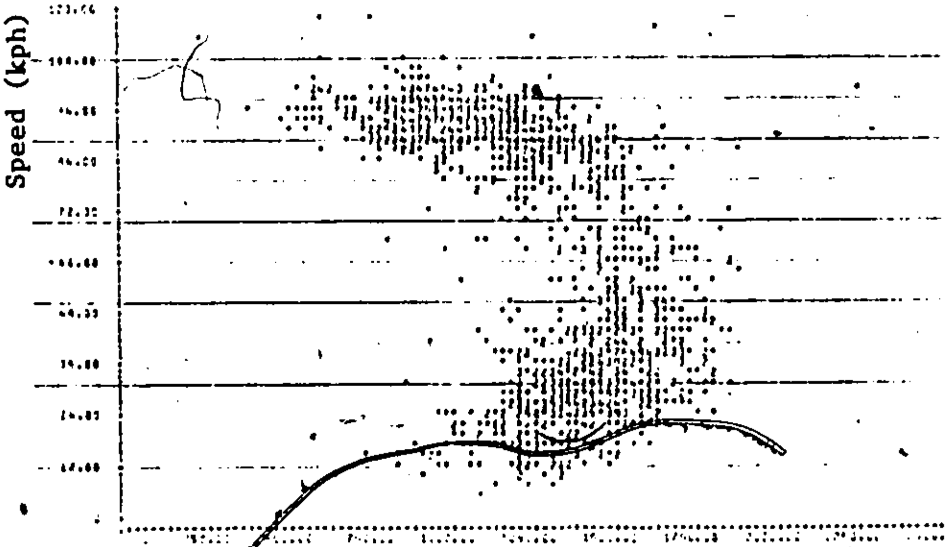


(ii) Middle Lane

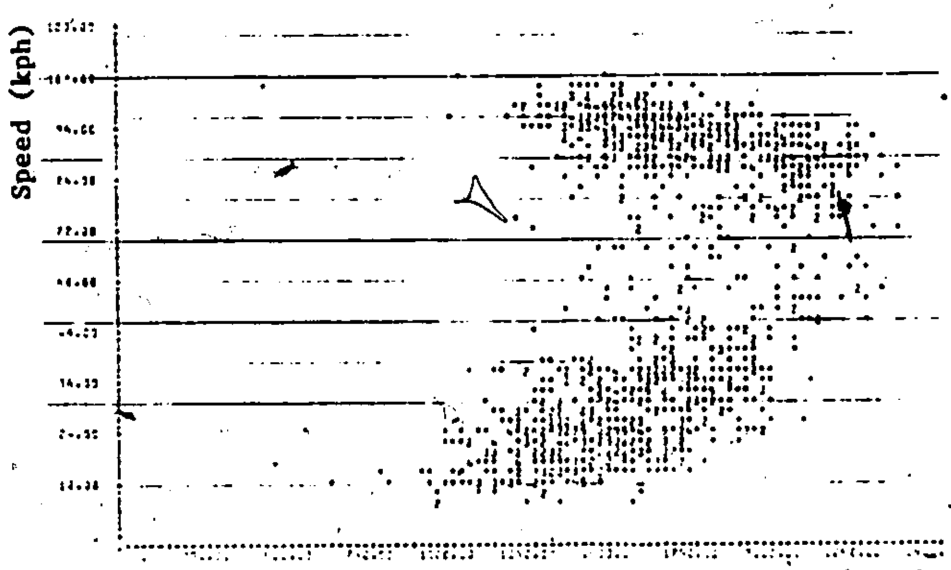


(iii) Median Lane

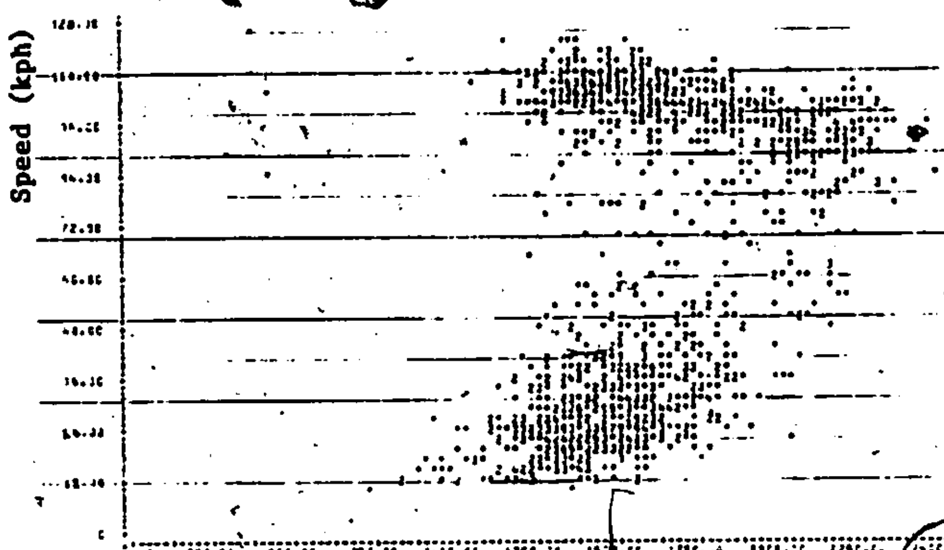
Figure A2.4 Speed-Flow Data, Station 4, QEW (Mississauga)



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A2.5 Speed-Flow Data, Station 5, QEW (Mississauga)

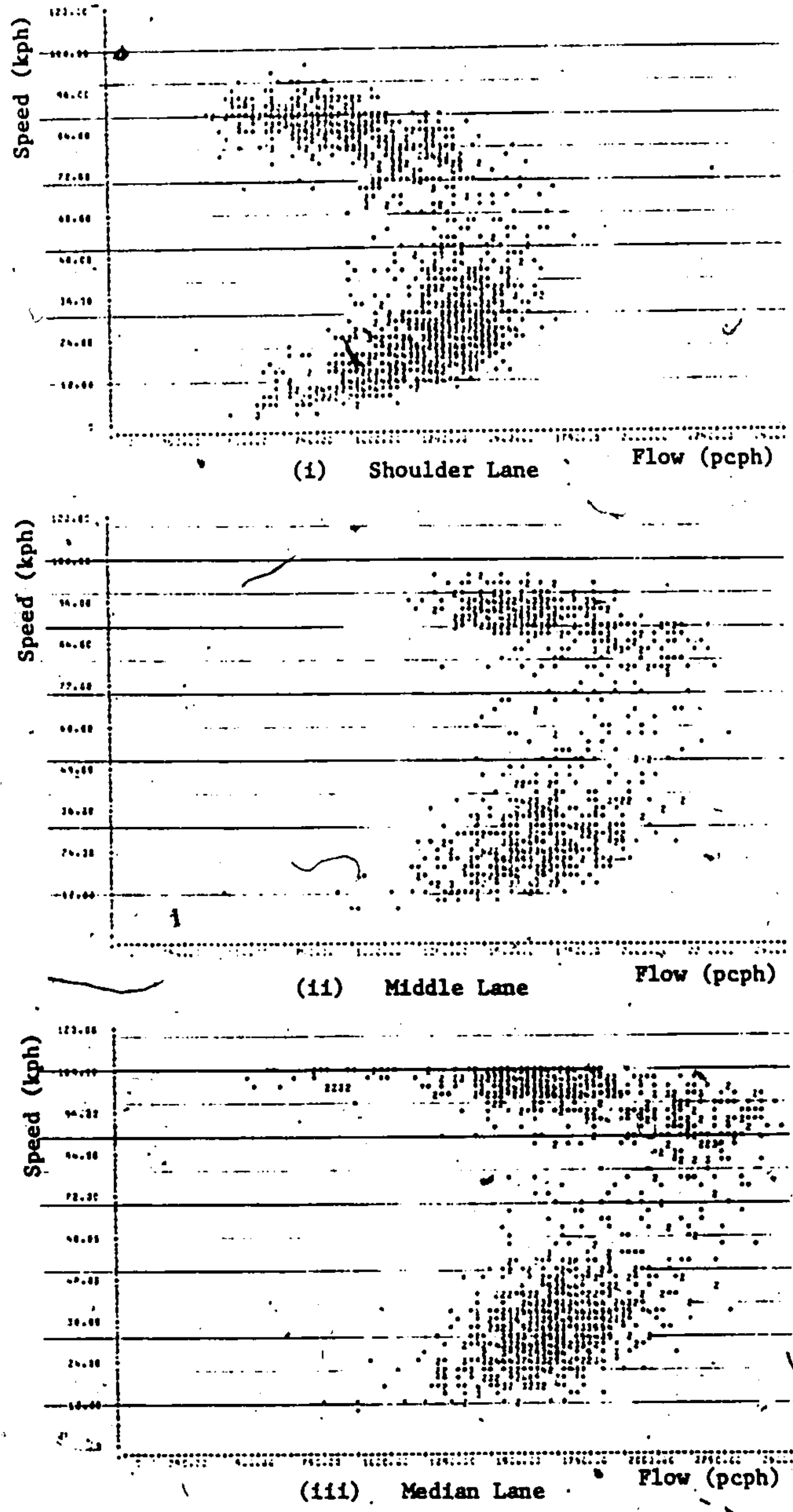
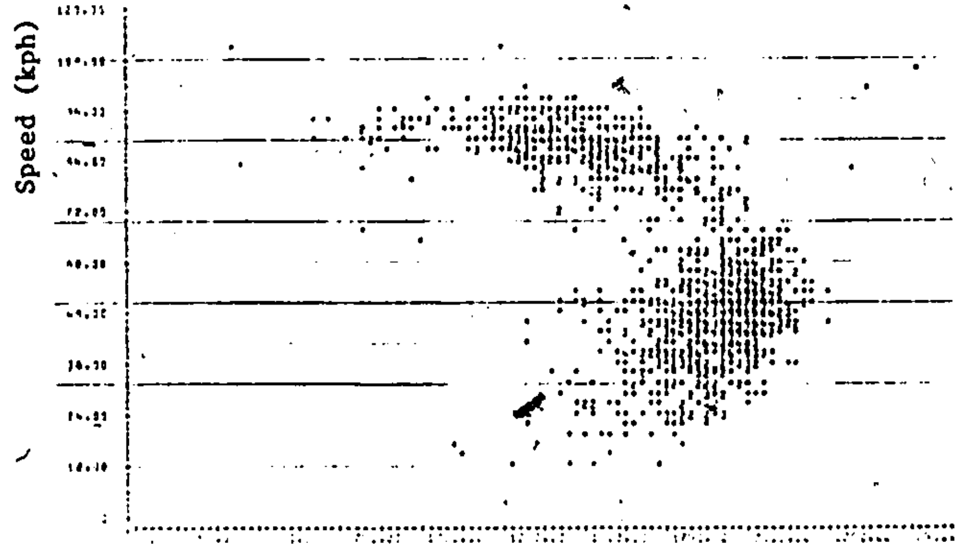
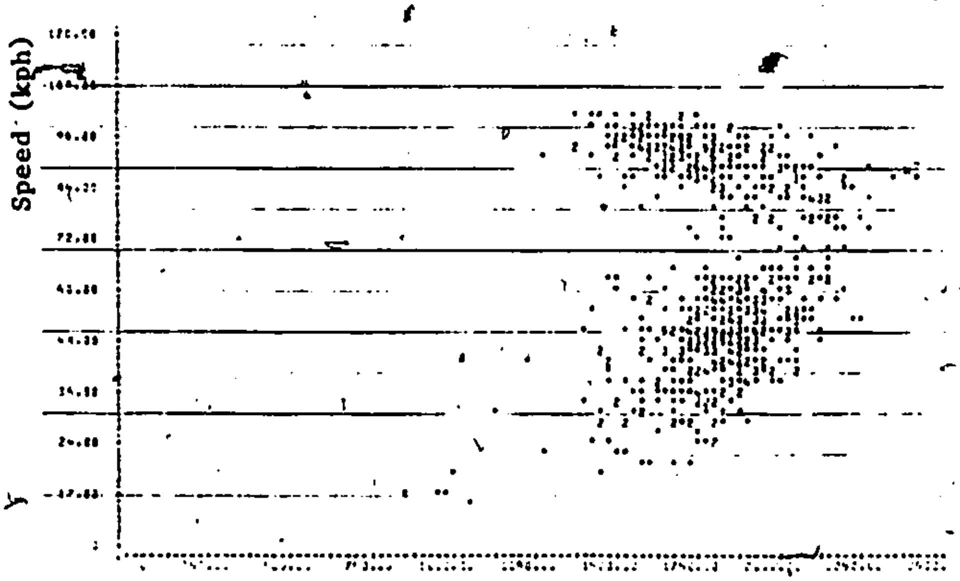


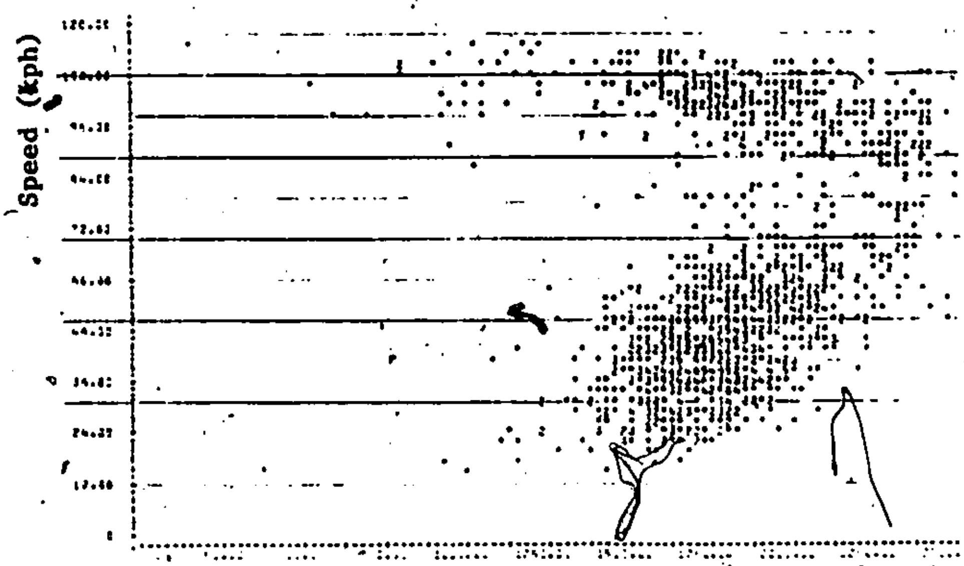
Figure A2.6 Speed-Flow Data, Station 6, QEW (Mississauga)



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A2.7 Speed-Flow Data, Station 7, QEW (Mississauga)

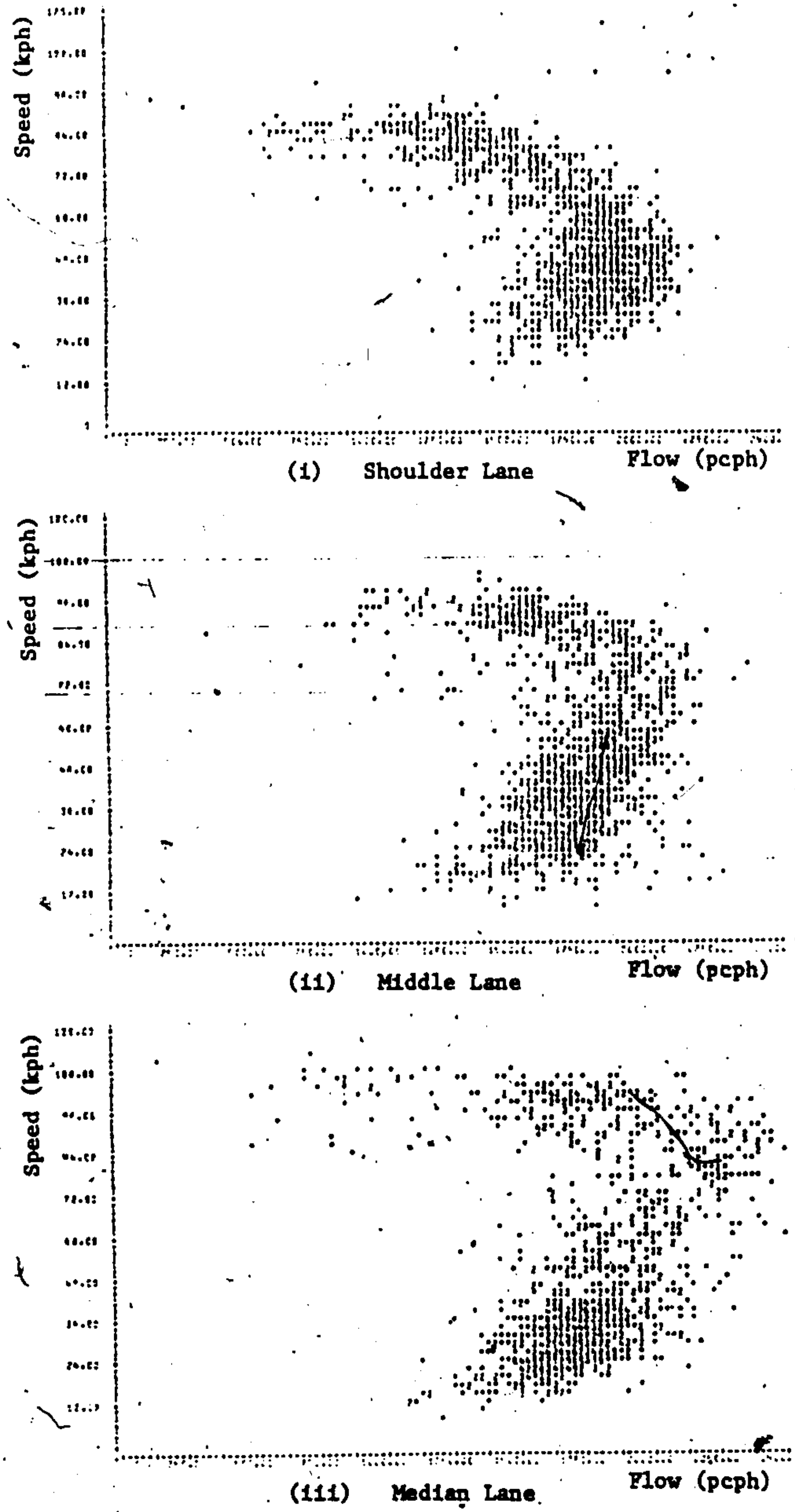
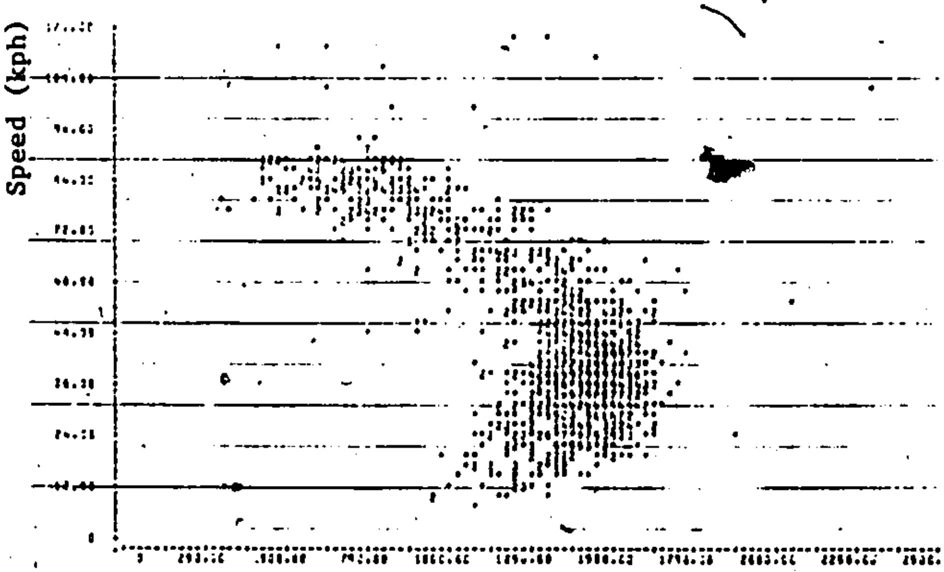
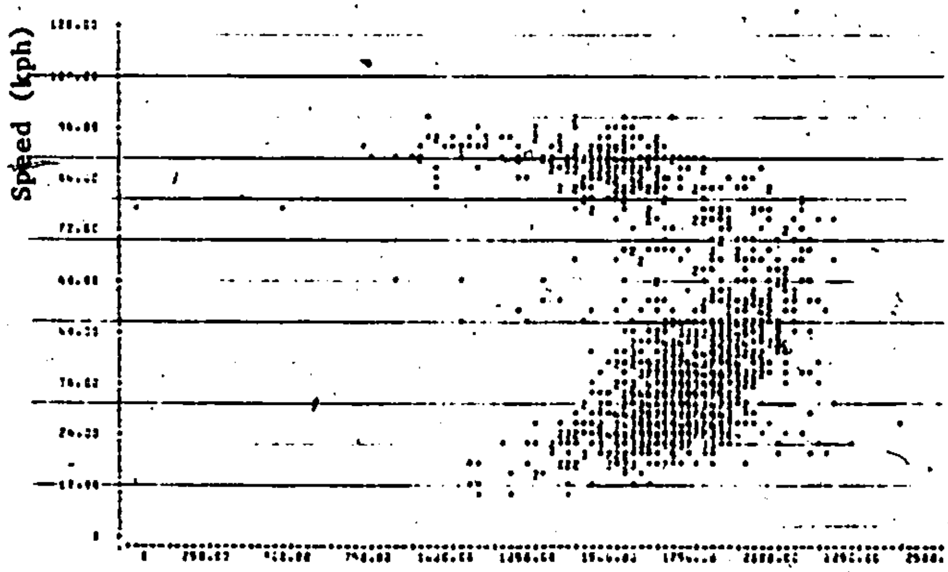


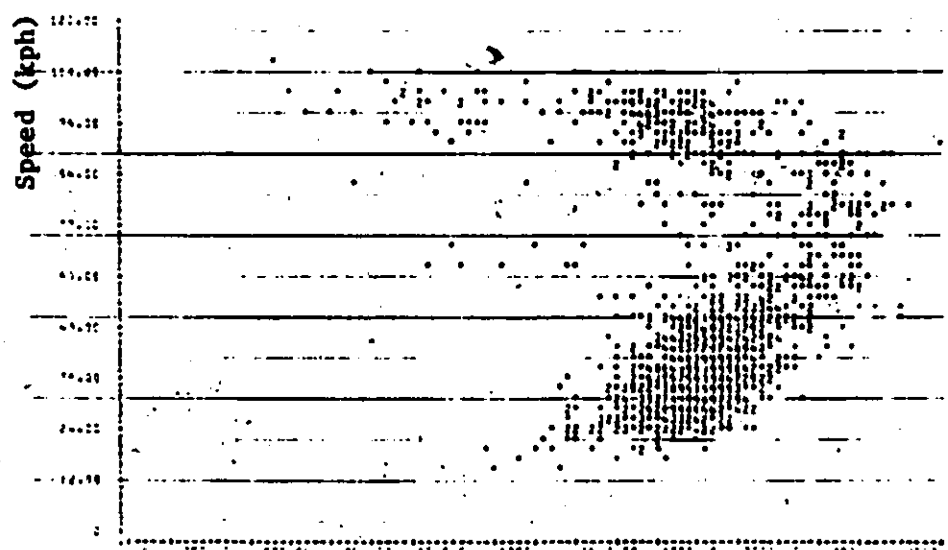
Figure A2.8 Speed-Flow Data, Station 8, QEW (Mississauga)



(i) Shoulder Lane

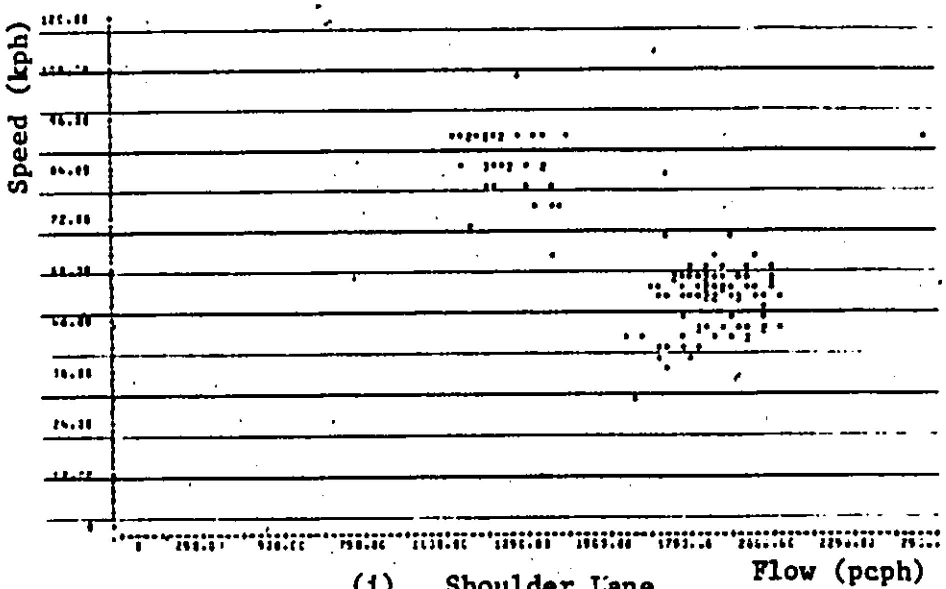


(ii) Middle Lane

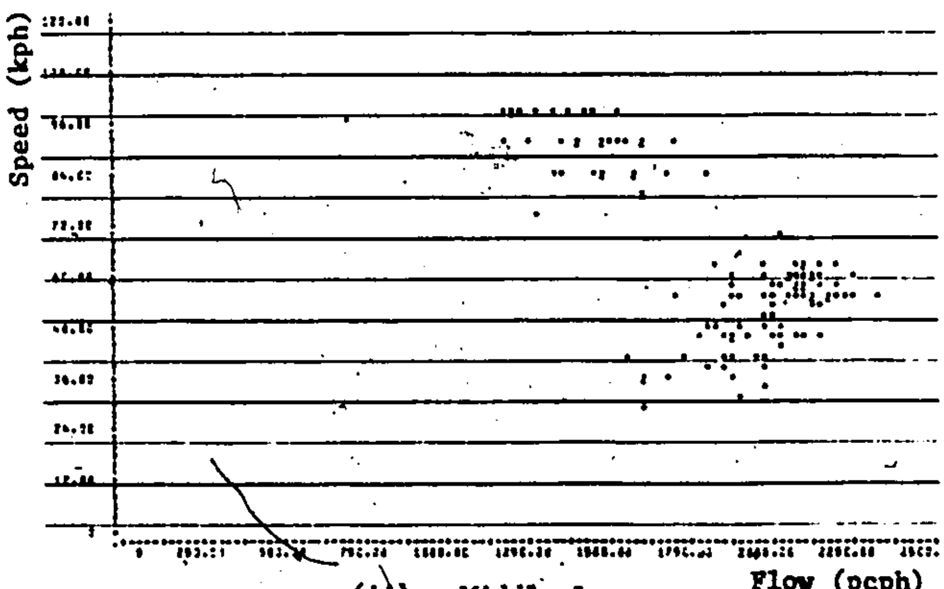


(iii) Median Lane

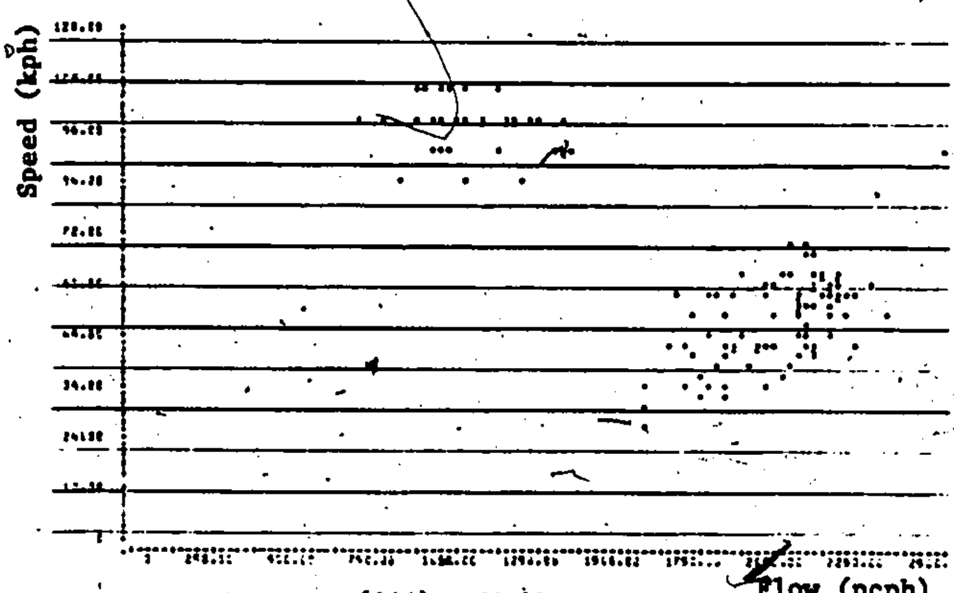
Figure A2.9 Speed-Flow Data, Station 9, QEW (Mississauga)



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A2.10 Speed-Flow Data, Station 10, QEW (Mississauga)

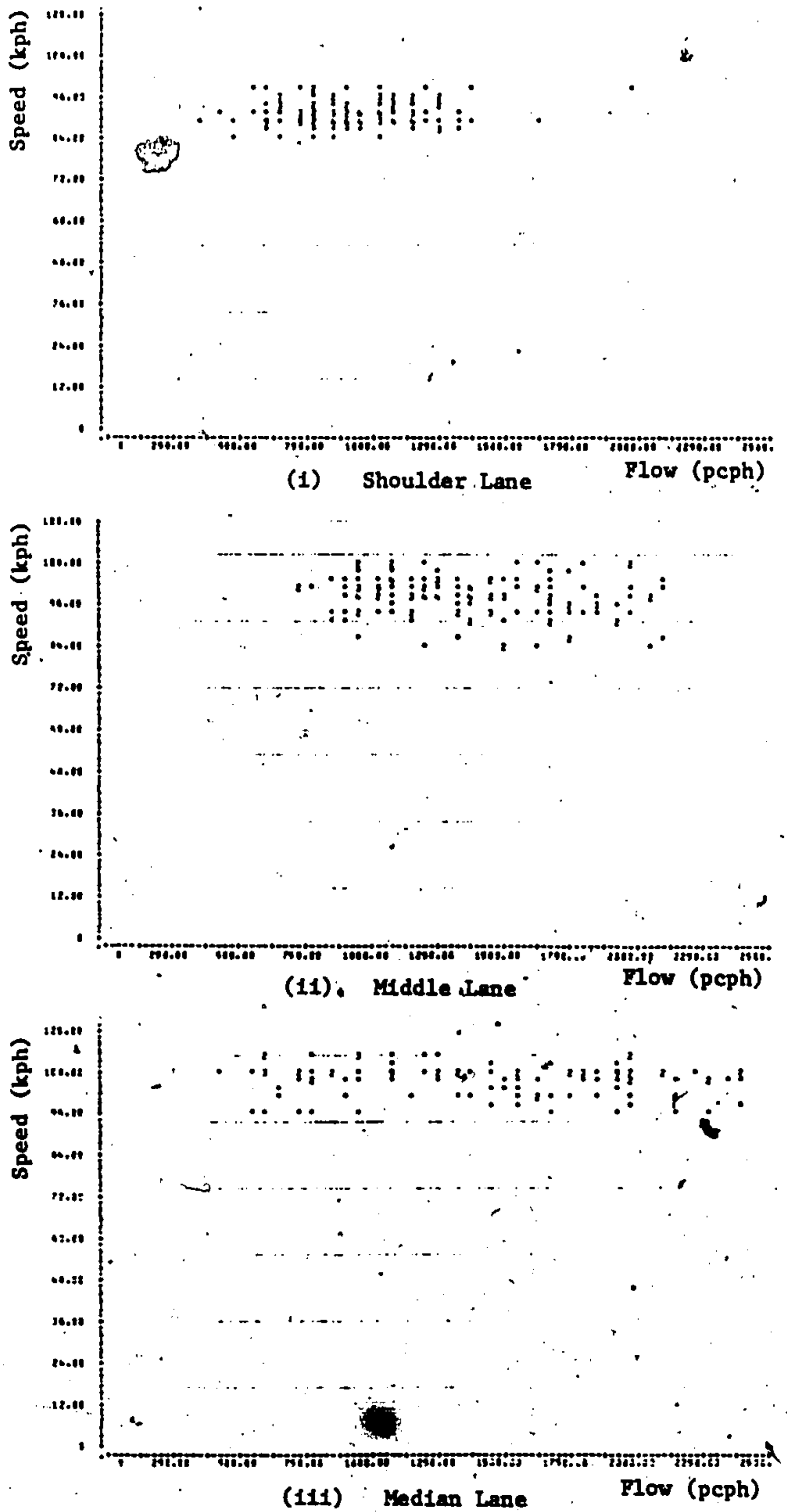
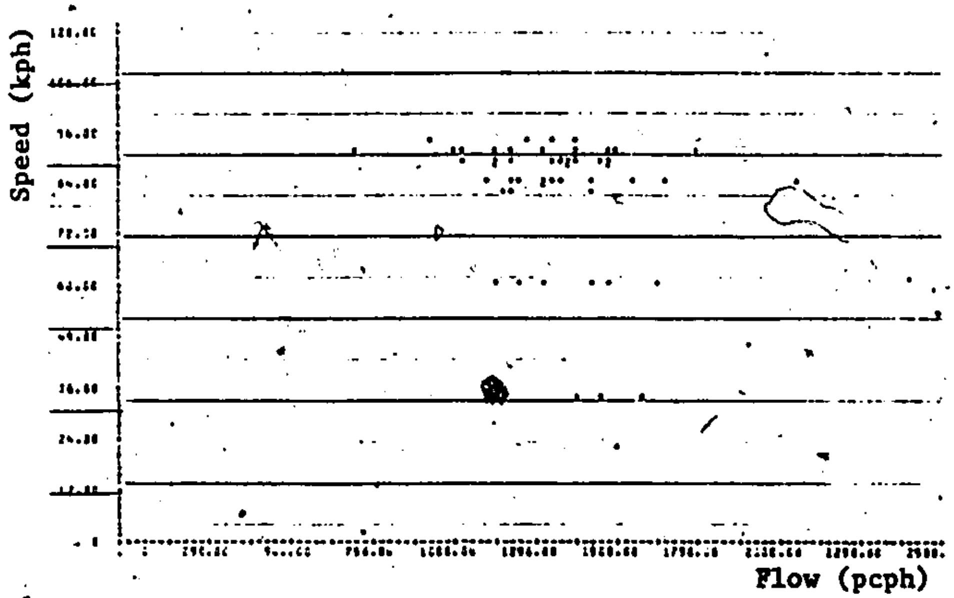
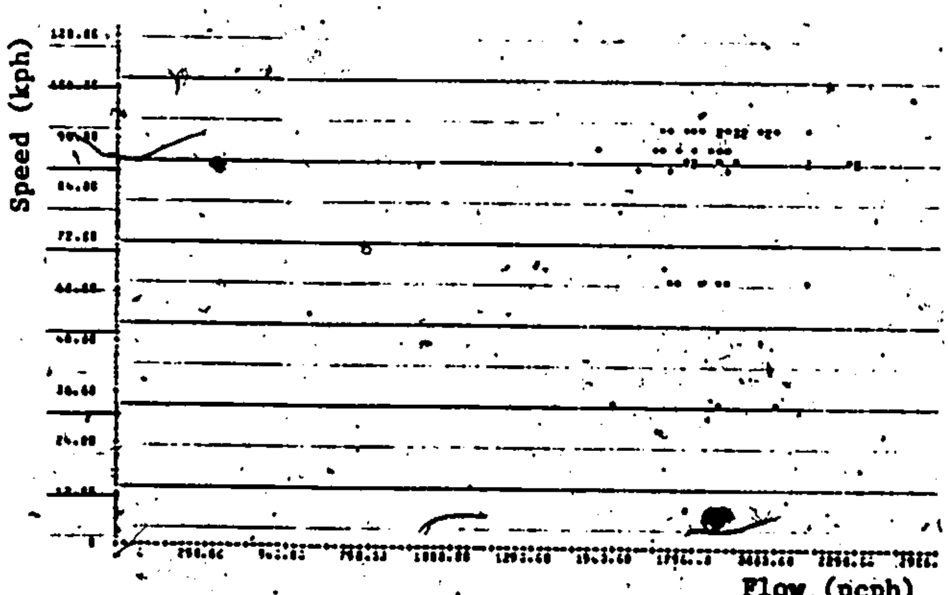


Figure A2.11 Speed- Flow Data, Highway 400



(i) Shoulder Lane



(ii) Median Lane

Figure A2.12 Speed-Flow Data, Highway 401 (2-Lane Section)

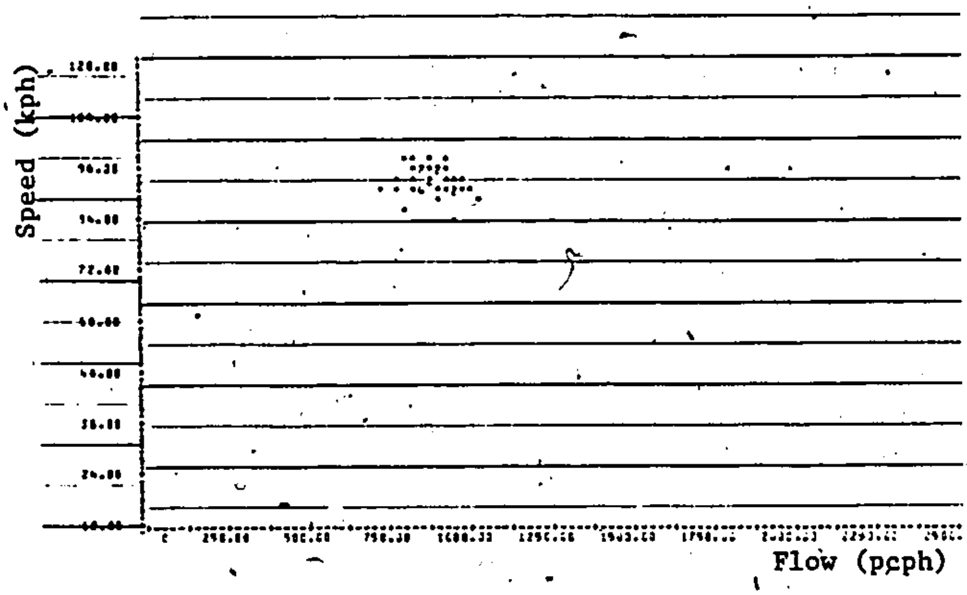
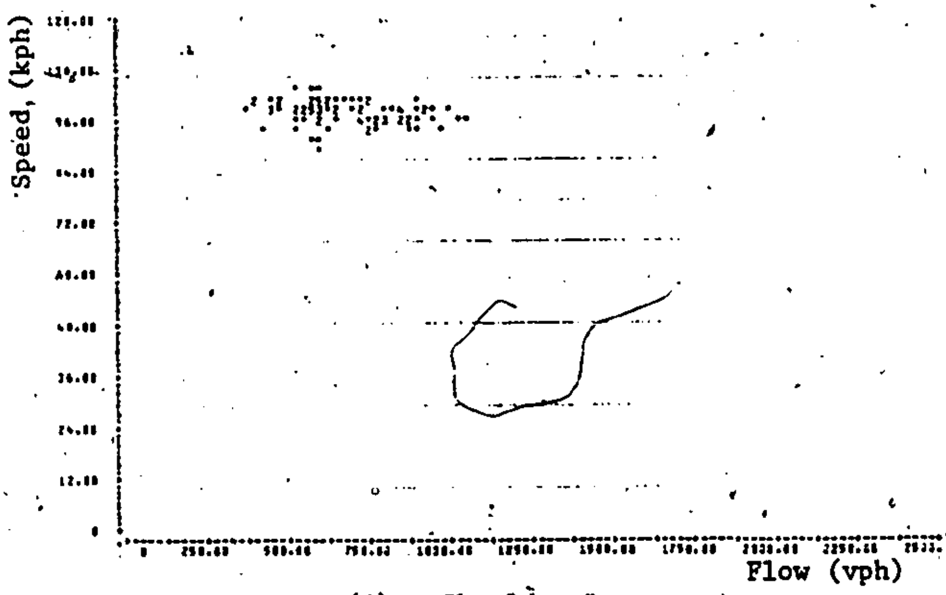
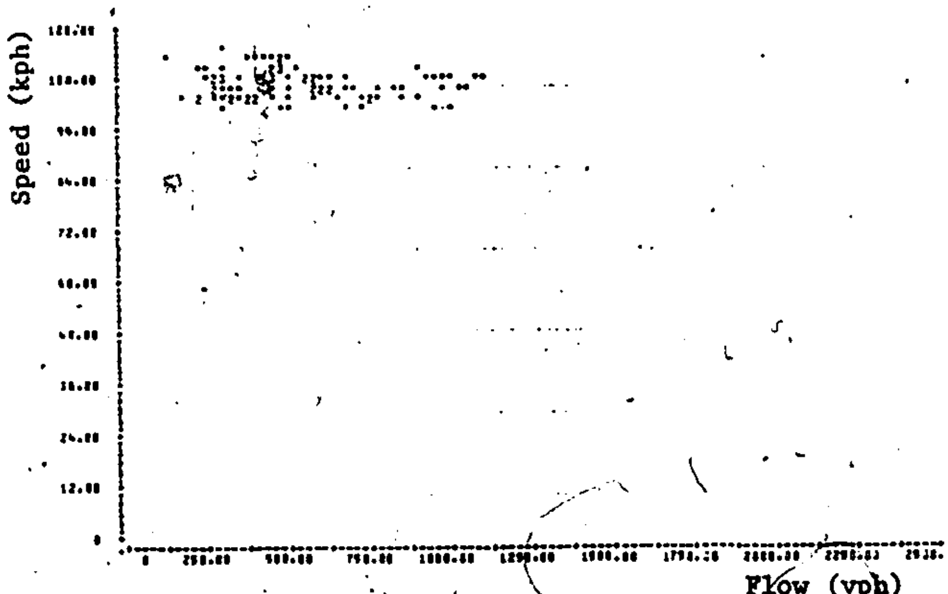


Figure A2.13 Speed-Flow Data, Highway 401
(3-Lane Section)

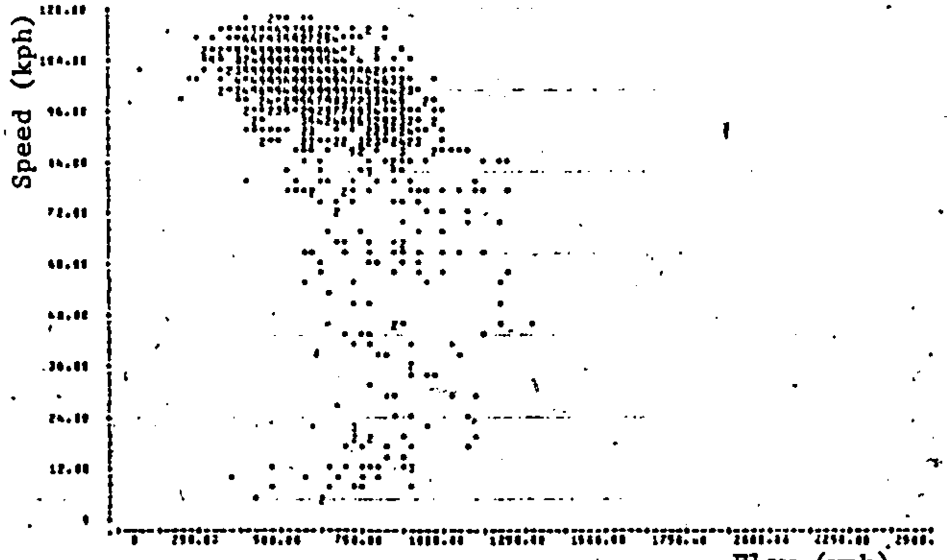


(i) Shoulder Lane

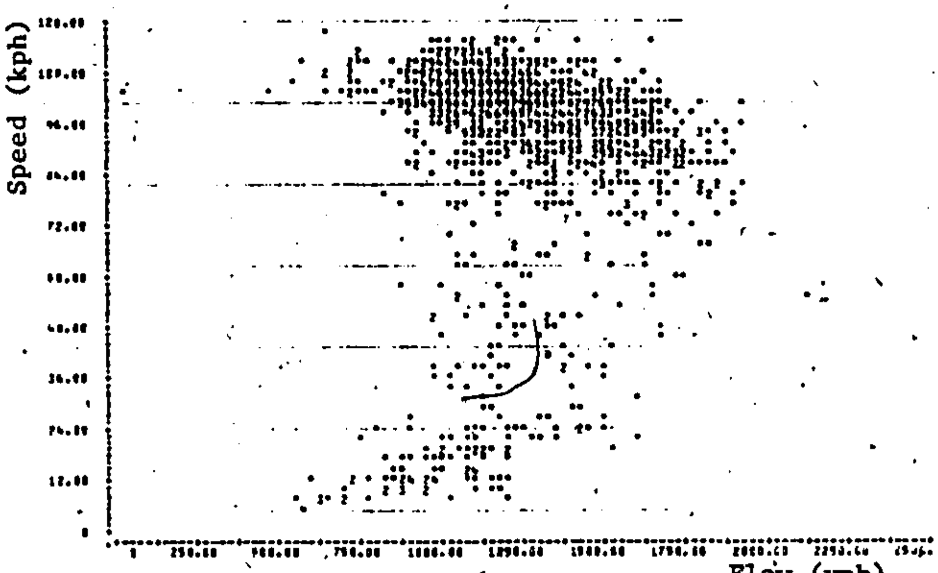


(ii) Median Lane

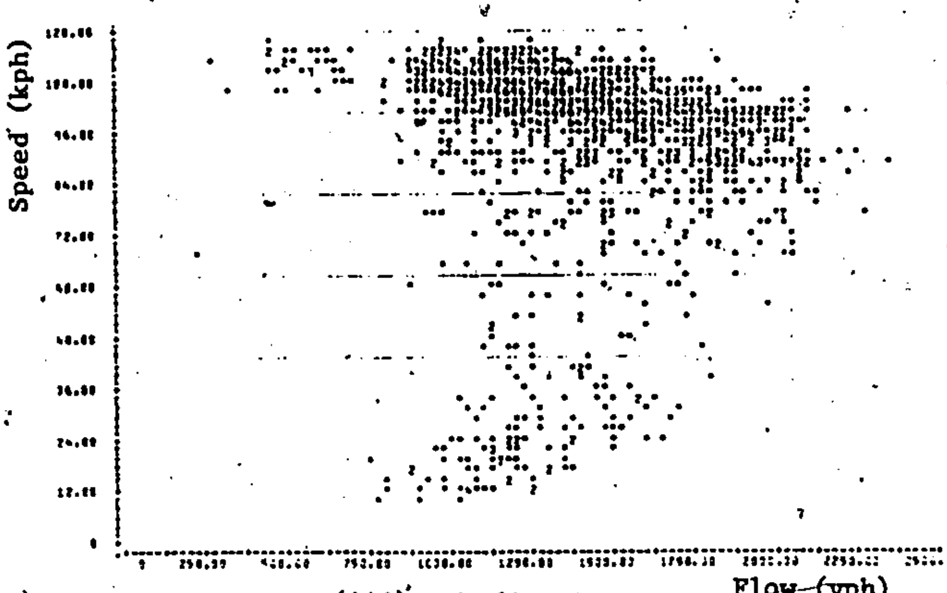
Figure A2.14 Speed-Flow (vph) Data, QEW (Hamilton)



(i) Shoulder Lane

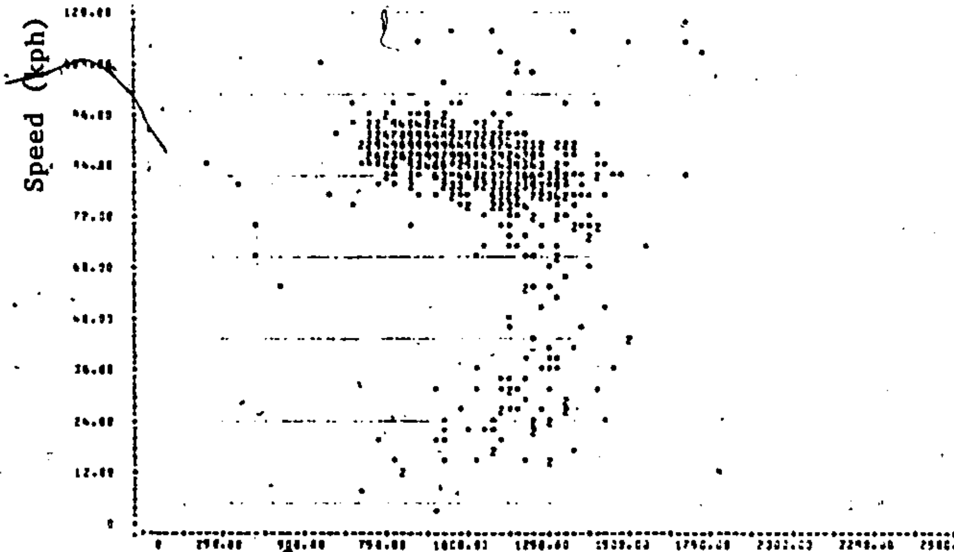


(ii) Middle Lane

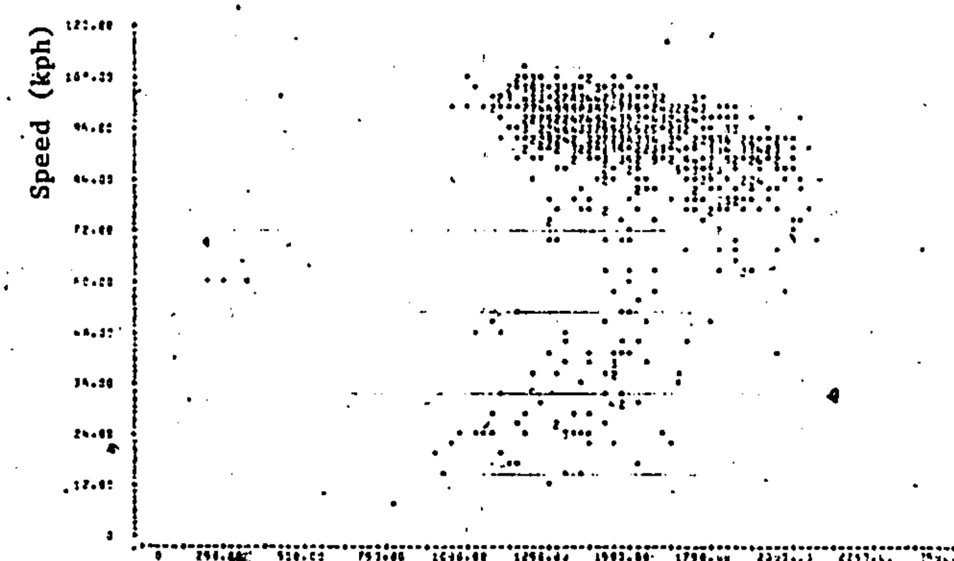


(iii) Median Lane

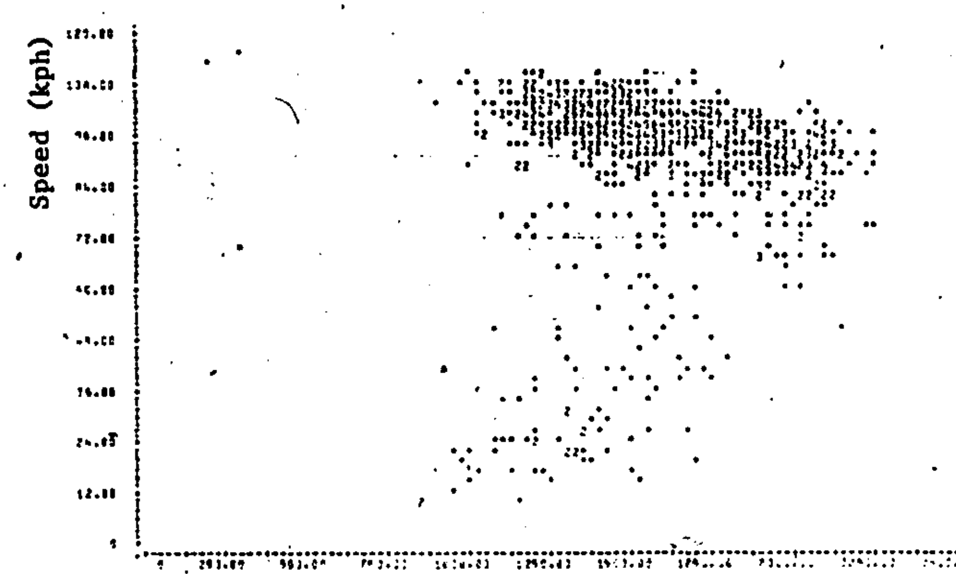
Figure A2.15 Speed-Flow (vph) Data, Station 1, QEW (Mississauga)



(i) Shoulder Lane

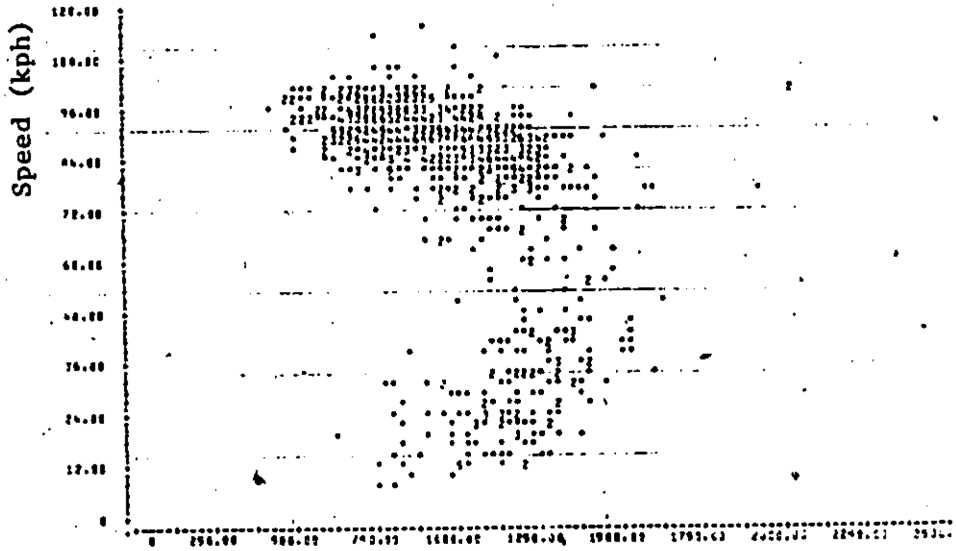


(i) Middle Lane

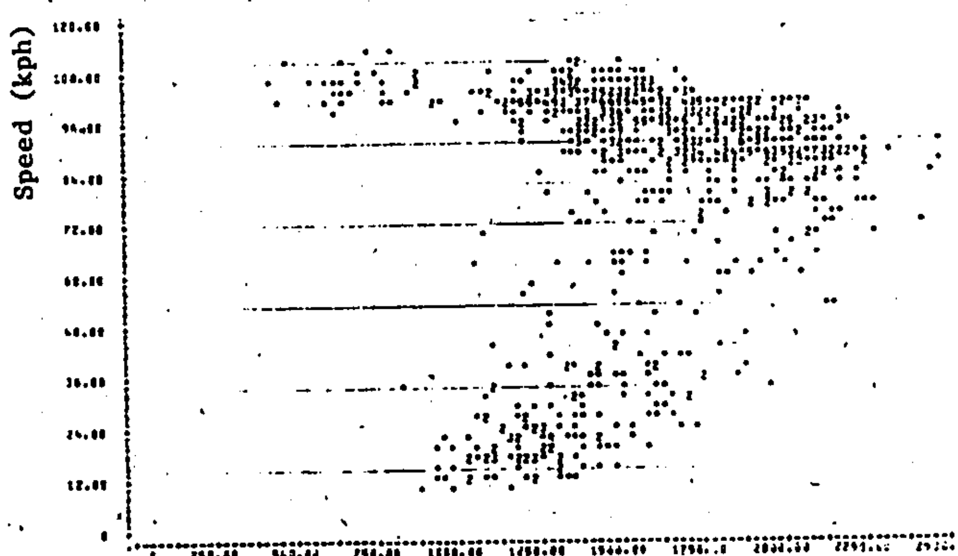


(iii) Median Lane

Figure A2.16 Speed-Flow (vph) Data, Station 2, QEW (Mississauga)

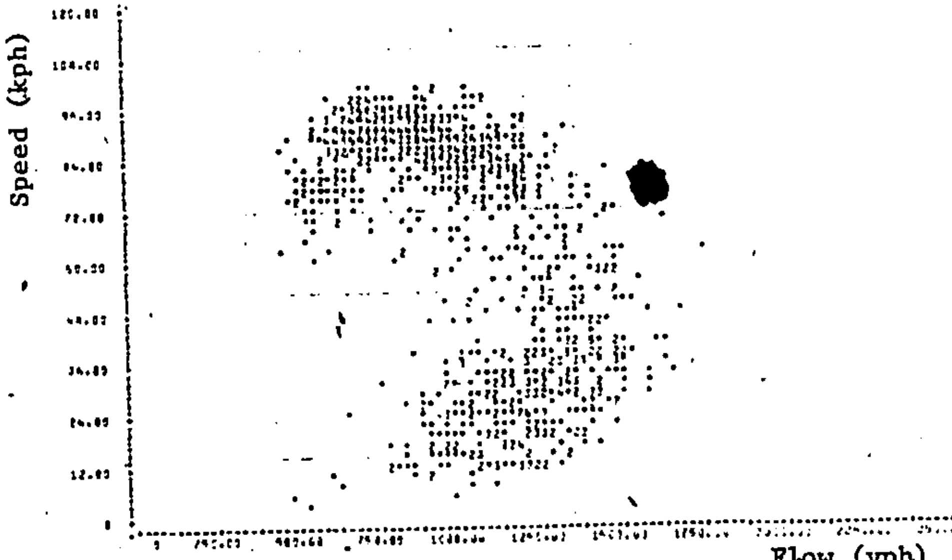


(i) Shoulder Lane

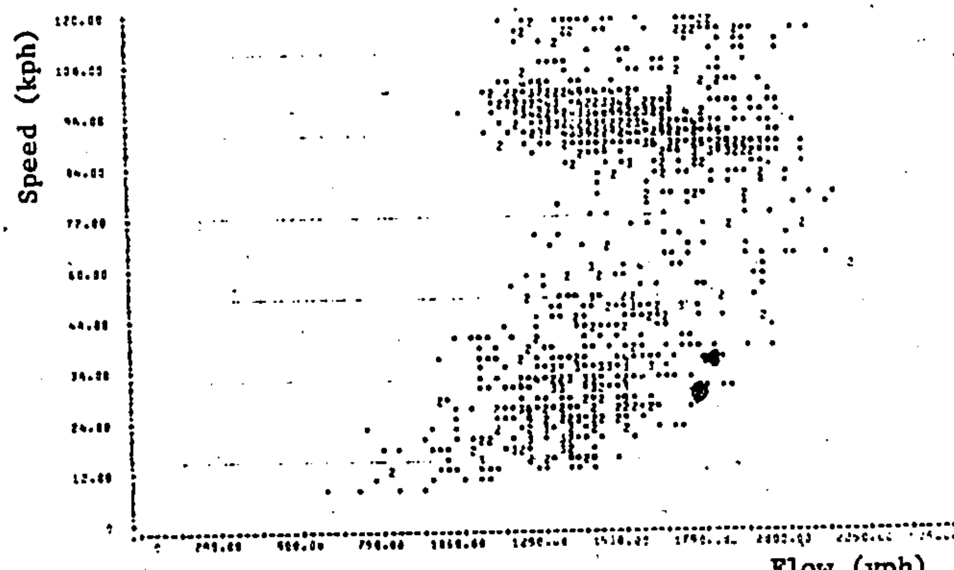


(ii) Median Lane

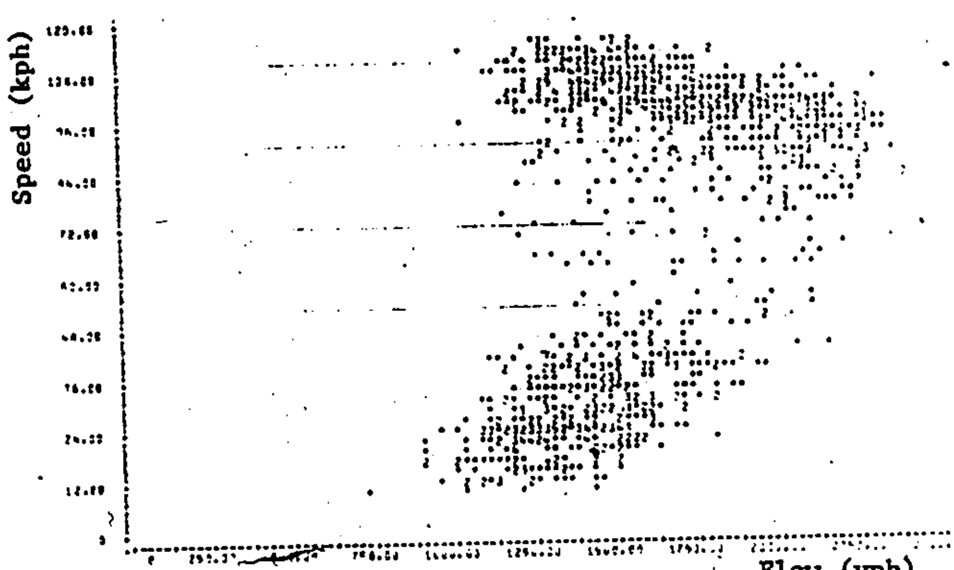
Figure A2.17 Speed-Flow (vph) Data, Station 3, QEW (Mississauga)



(i) Shoulder Lane

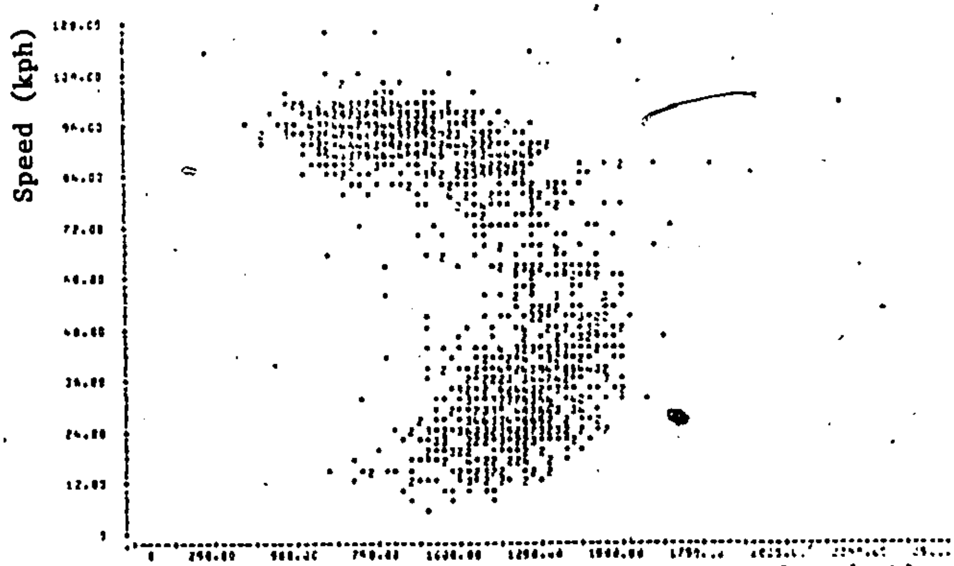


(ii) Middle Lane

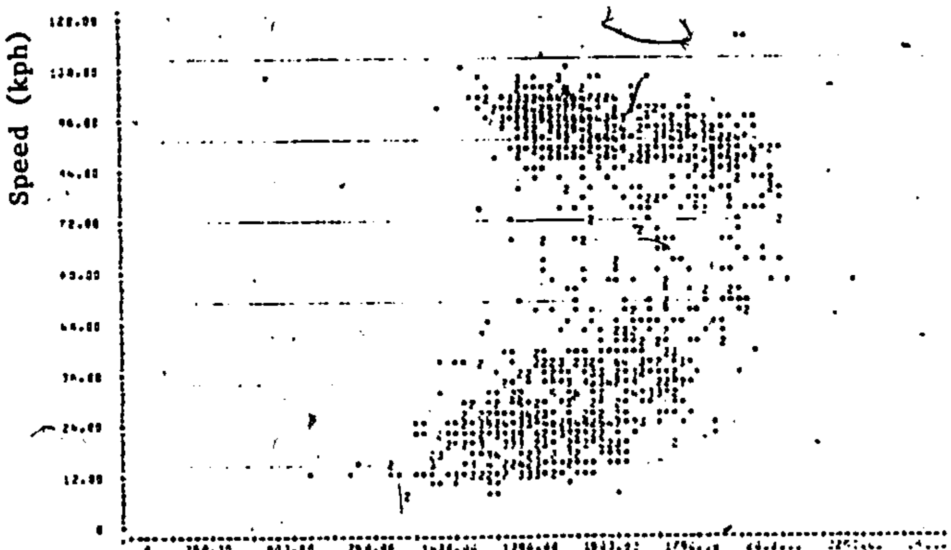


(iii) Median Lane

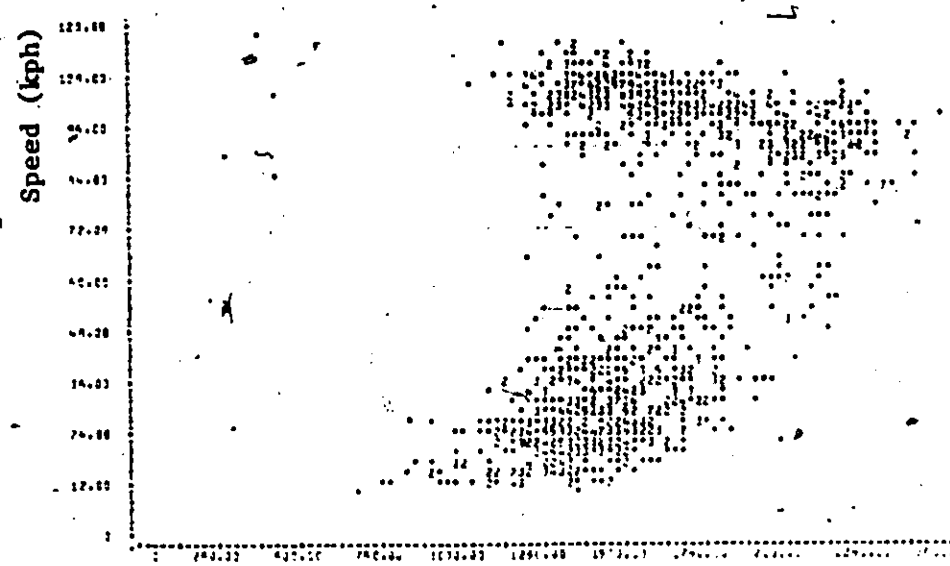
Figure A2.18 Speed-Flow (vph) Data, Station 4, QEW (Mississauga)



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A2.19 Speed-Flow (vph) Data, Station 5, QEW (Mississauga)

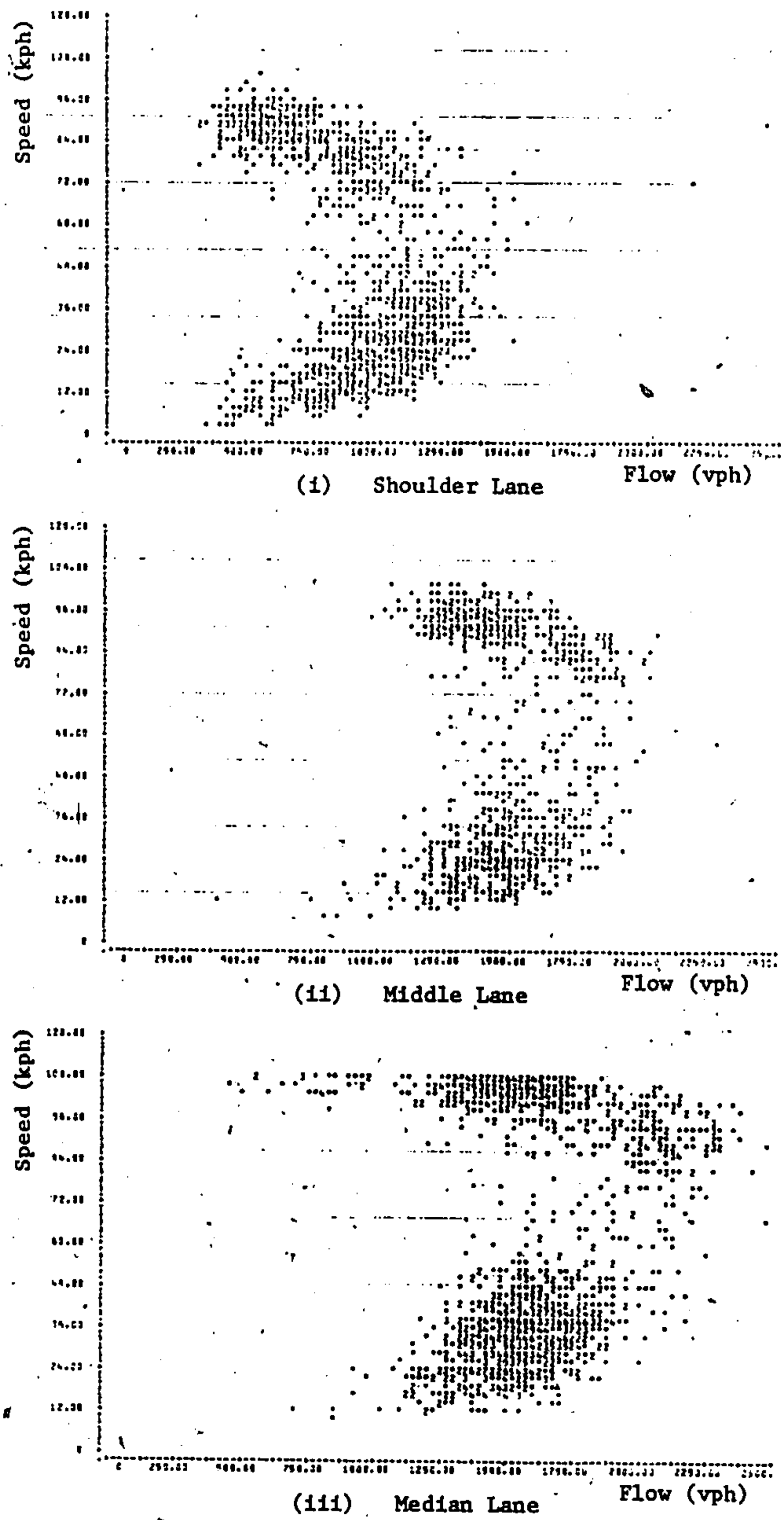


Figure A2.20 Speed-Flow (vph) Data, Station 6, QEW (Mississauga)

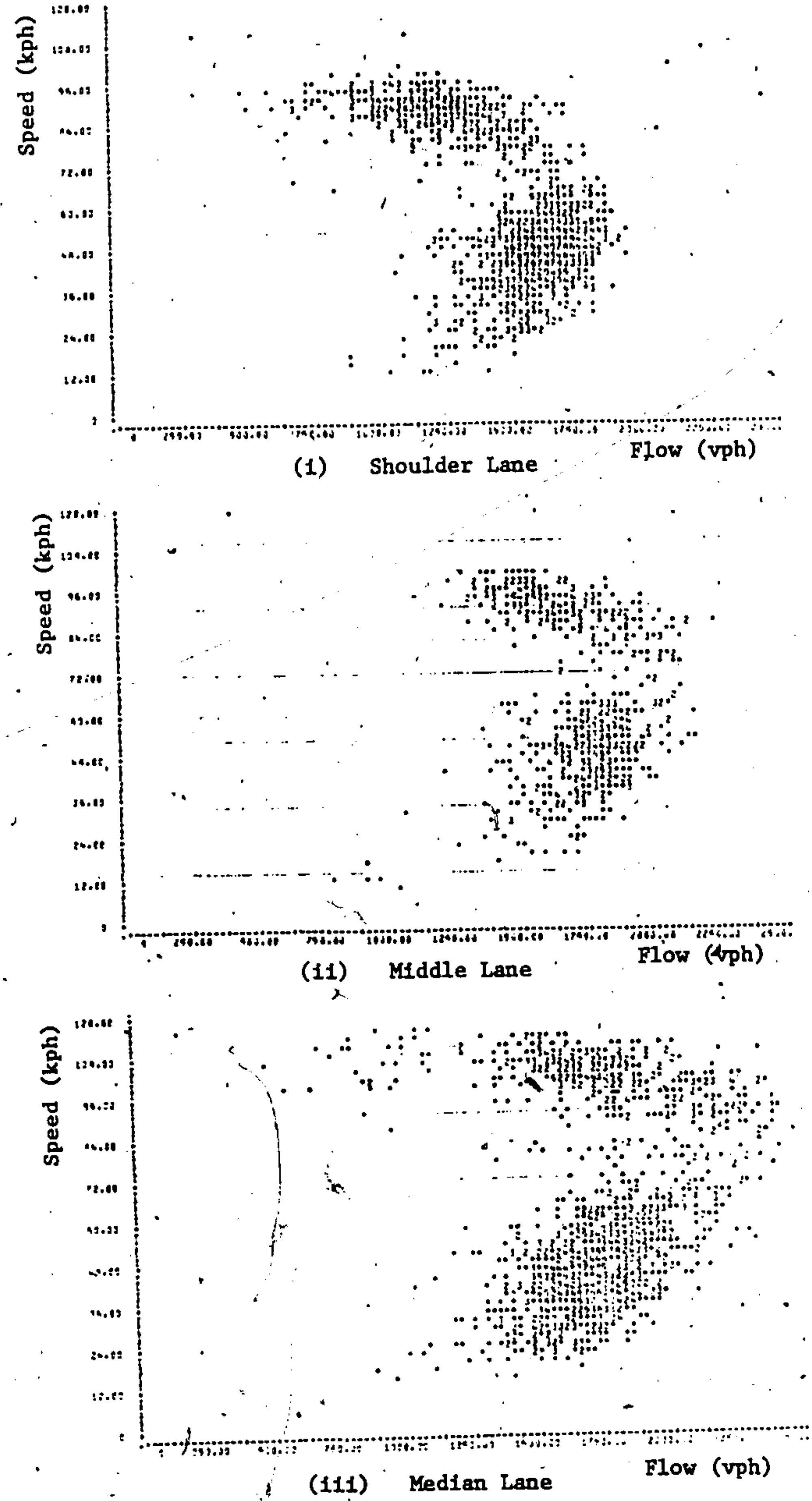
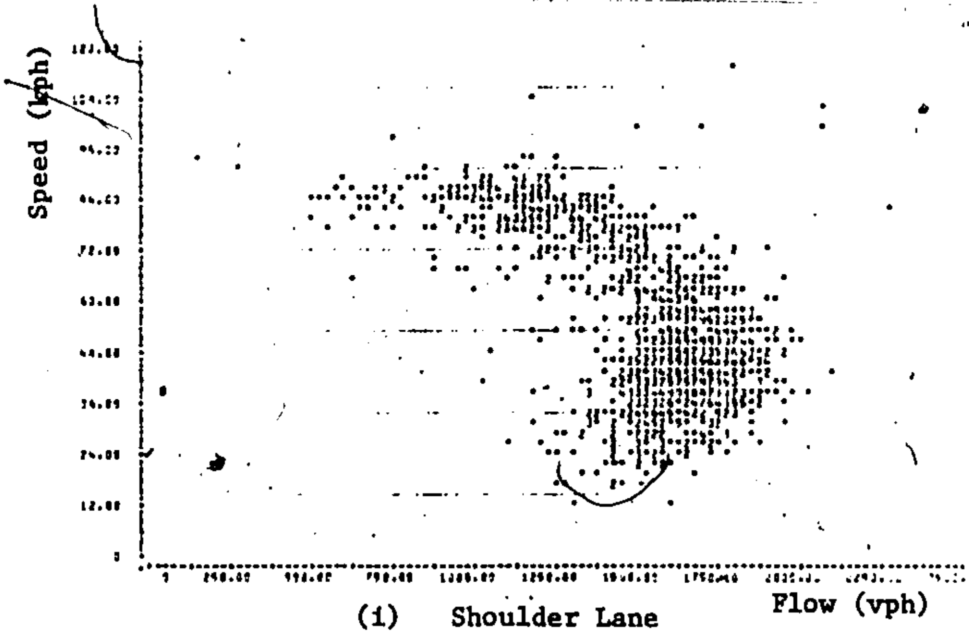
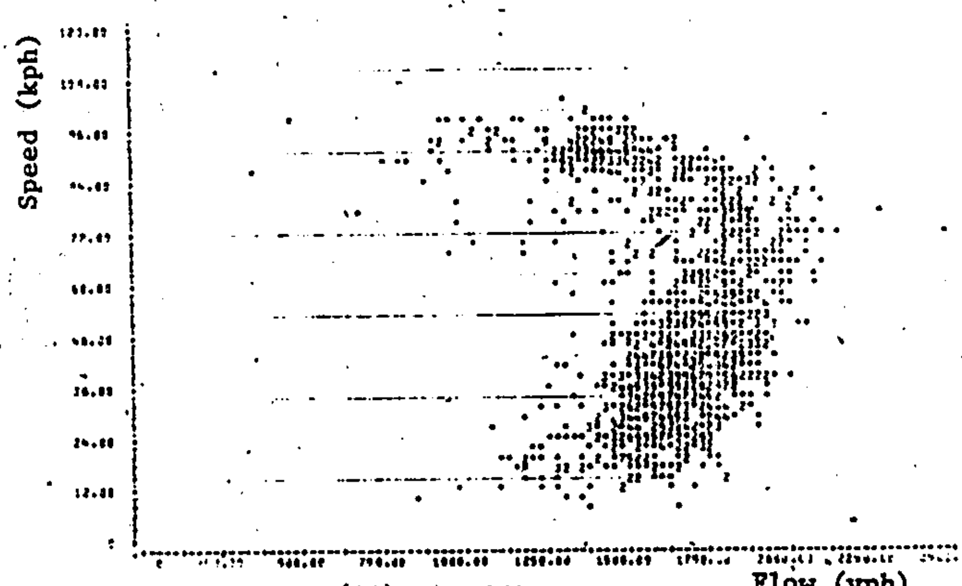


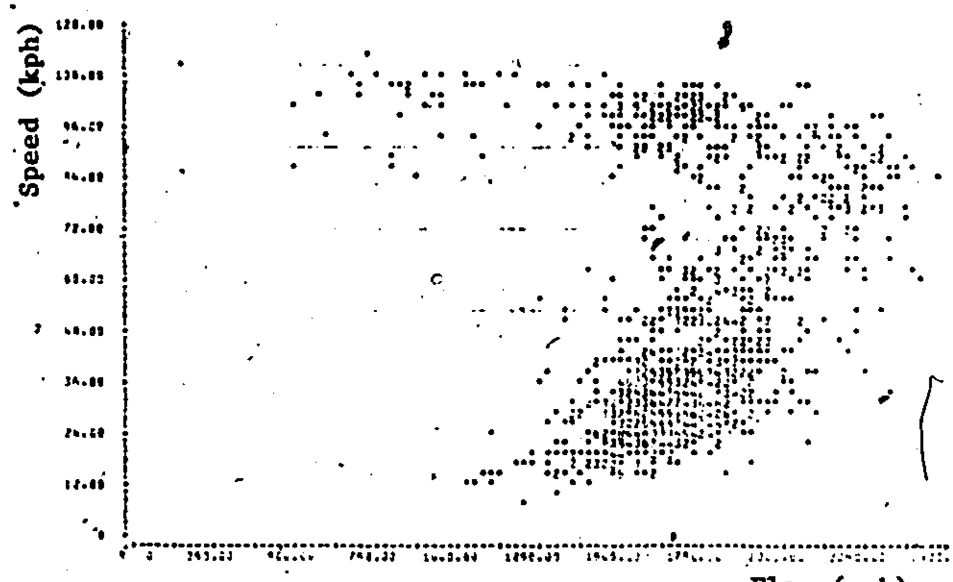
Figure A2.21 Speed-Flow (vph) Data, Station 7, QEW (Mississauga)



(i) Shoulder Lane

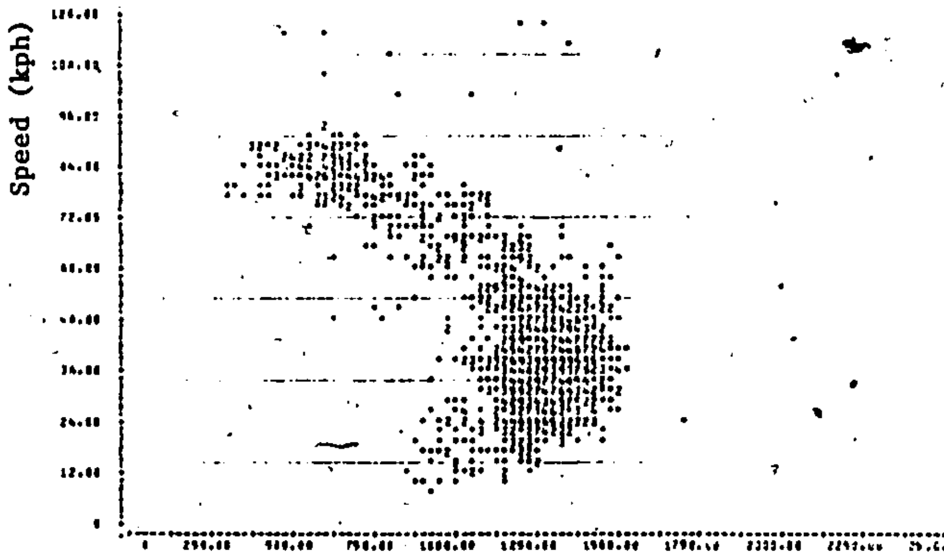


(ii) Middle Lane

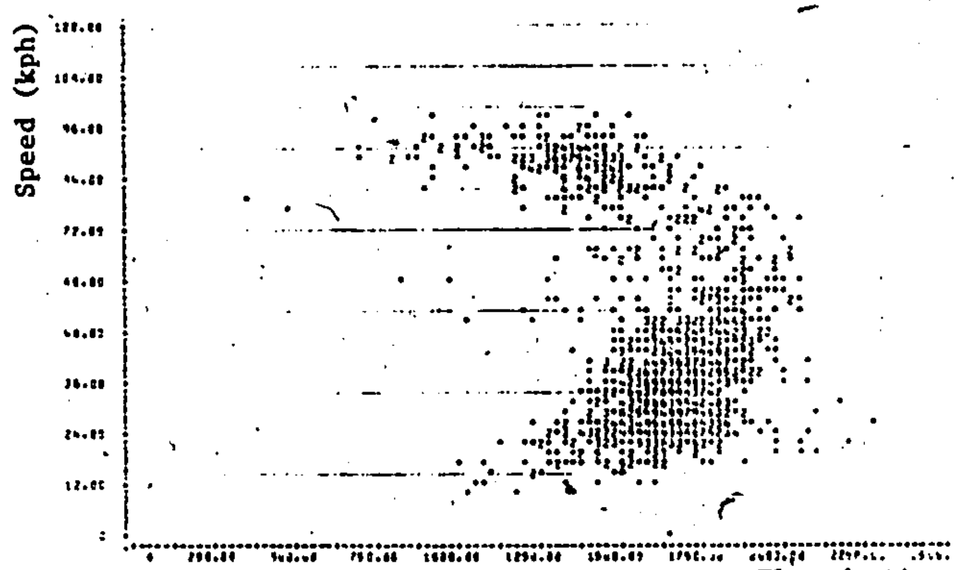


(iii) Median Lane

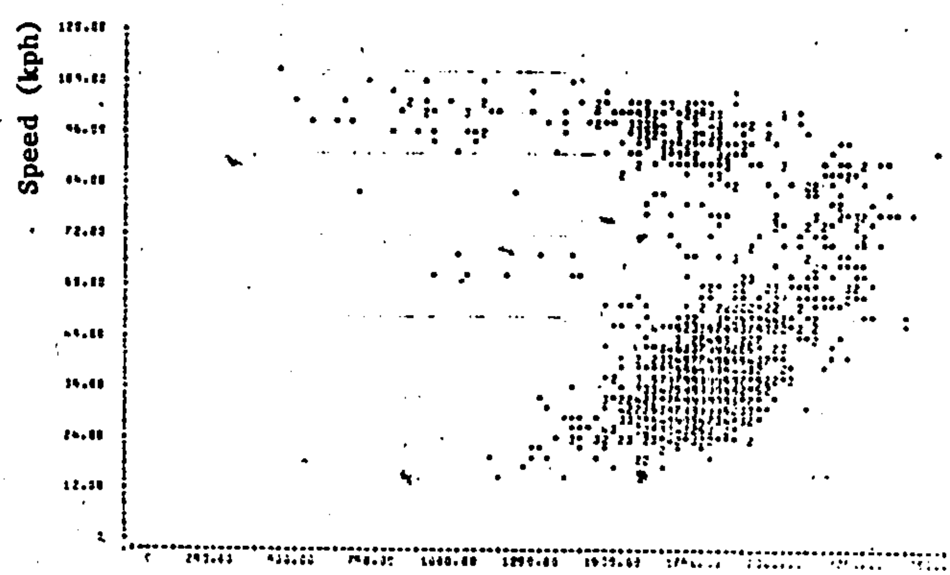
Figure A2.22 Speed-Flow (vph) Data, Station 8, QEW (Mississauga)



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A2.23 Speed-Flow (vph) Data, Station 9, QEW (Mississauga)

Table A2.1 Speed-Flow Data for the QEW in Mississauga at Station 10

SHOULDER LANE		MIDDLE LANE		MEDIAN LANE	
Flow (pcph)	Speed (kph)	Flow (pcph)	Speed (kph)	Flow (pcph)	Speed (kph)
1968	46.24	2160	47.95	2148	58.85
1932	44.65	1920	46.24	1920	46.24
1692	58.85	2184	56.29	2184	58.85
1800	56.29	2148	61.66	2052	58.85
1776	56.29	2136	61.66	2196	58.85
1848	61.66	2184	56.29	2280	61.66
1788	61.66	2208	58.85	2220	58.85
1752	61.66	2136	61.66	2148	61.66
1920	61.66	2316	56.29	2184	61.66
1860	56.29	2124	61.66	2172	64.74
1920	58.85	2196	64.74	2100	68.15
1764	46.24	2016	44.65	2076	46.24
1716	53.95	2016	49.80	2220	47.95
1656	56.29	2088	64.74	2088	64.74
1740	61.66	2124	56.29	2148	61.66
1812	53.95	2244	61.66	2124	64.74
1812	56.29	2076	61.66	2172	64.74
1740	58.85	1980	64.74	2004	64.74
1836	53.95	1968	49.80	2016	43.16
1824	44.65	1908	33.20	1824	34.07
1920	44.65	1968	43.16	1848	46.24
1680	43.16	1776	46.24	1716	53.95
1608	44.65	1860	39.24	1836	44.65
1572	30.83	1596	30.83	1572	28.77
1644	41.77	1884	43.16	1704	47.95
1752	39.24	1860	41.77	1740	40.46
1656	40.46	1668	38.08	1740	34.99
1728	49.80	1860	46.24	1836	46.24
1764	47.95	1560	43.16	1584	38.08
1788	46.24	1836	49.80	1908	43.16
1668	38.08	1608	36.99	1572	31.58
1988	53.95	1872	47.95	1920	47.95
1932	44.65	1872	38.08	1824	38.08
1896	58.85	1884	61.66	1956	61.66
1860	56.29	2232	56.29	2328	53.95
1872	53.95	2136	56.29	2076	56.29
1752	53.95	2064	58.85	2088	61.66
1872	56.29	2028	58.85	2148	56.29
1956	56.29	2196	56.29	2208	53.95
1800	58.85	2244	56.29	2184	58.85
1848	46.24	2100	47.95	2100	46.24
1656	53.95	1884	58.85	1860	47.95
1908	53.95	2064	58.85	1848	58.85
1824	53.95	2148	53.95	2100	56.29
1812	58.85	1872	56.29	1812	58.85
1776	43.16	1800	40.46	1776	38.08
1968	49.80	2076	47.95	2160	49.80
2028	46.24	1980	40.46	1944	36.99
1848	58.85	1992	56.29	1764	58.85
1896	53.95	2100	56.29	2088	44.65
1764	58.85	2100	58.85	2052	56.29
1908	53.95	1848	53.95	1884	49.80
1560	44.65	1800	49.80	1800	43.16
1788	53.95	1980	51.79	1656	47.95
2028	53.95	2148	58.85	2136	58.85
1968	47.95	2028	46.24	2052	44.65
1920	46.24	1944	41.77	1944	46.24
2004	58.85	2136	53.95	2052	58.85
2004	56.29	1992	51.79	2100	47.95
1728	56.29	2040	56.29	1836	53.95
1908	47.95	2004	46.24	1848	46.24
1716	44.65	1716	41.77	1716	44.65
1968	51.79	1884	47.95	1968	46.24
1836	56.29	2052	61.66	2040	53.95

Table A2.1 Continued...

2040	49.80	2076	56.29	1776	53.95
1980	53.95	1992	53.95	1680	53.95
1944	58.85	2040	61.66	1956	53.95
1764	49.80	1908	49.80	1776	46.24
1680	58.85	1692	56.29	1632	56.29
1704	38.08	1596	36.99	1716	41.77
2088	61.66	1968	61.66	1956	64.74
1872	64.74	1824	64.74	1872	68.15
2136	64.74	2112	61.66	1704	58.85
2064	71.93	2016	71.93	1668	68.15
2040	56.29	1992	58.85	1788	61.66
1980	61.66	2112	64.74	1836	64.74
2028	71.93	2076	64.74	1824	58.85
2148	53.95	1980	56.29	2004	58.85
2016	64.74	2052	61.66	1992	61.66
2064	68.15	2160	64.74	1716	58.85
2064	49.80	1896	56.29	1872	49.80
1992	39.24	1968	35.97	1884	44.65
1080	99.60	1452	86.32	1320	80.92
1080	99.60	1572	86.32	1212	86.32
1080	99.60	1464	92.48	1092	92.48
1164	99.60	1464	86.32	1116	80.92
1128	92.48	1476	92.48	1200	86.32
1128	107.90	1704	92.48	1260	86.32
1224	99.60	1272	76.16	1032	92.48
876	107.90	1200	99.60	1236	92.48
768	99.60	1164	92.48	1068	71.93
936	99.60	1164	99.60	1056	86.32
708	99.60	1320	86.32	1296	92.48
972	107.90	1536	92.48	1224	107.90
912	107.90	1236	99.60	1080	92.48
864	99.60	1392	92.48	1056	92.48
960	99.60	1188	99.60	1308	86.32
960	107.90	1248	92.48	1068	92.48
1020	107.90	1452	99.60	1116	92.48
1152	99.60	1404	92.48	1116	86.32
1020	99.60	1344	92.48	1320	76.16
924	92.48	1380	99.60	1308	86.32
1176	99.60	1596	92.48	1164	86.32
1248	99.60	1416	99.60	1344	76.16
1320	92.48	1596	92.48	1368	92.48
1008	99.60	1272	99.60	1116	92.48
1152	99.60	1548	92.48	1176	92.48
960	92.48	1536	99.60	1116	86.32
816	86.32	1344	86.32	1272	76.16
984	92.48	1332	99.60	1116	86.32
1152	99.60	1500	92.48	1176	92.48
2496	92.48	2844	80.92	2484	92.48
1320	99.60	1464	86.32	1140	86.32
1332	92.48	1584	86.32	1332	64.74
1296	92.48	1596	80.92	1260	80.92
1200	86.32	1800	86.32	1284	92.48
1344	92.48	1680	86.32	1152	80.92
1020	86.32	1608	80.92	1140	92.48
2076	51.79	2100	58.85	1920	56.29

Table A2.2 Highway 400 Speed-Flow Data, Allen (3)

SHOULDER		MIDDLE		MEDIAN	
FLOW (pcph)	SPEED (kph)	FLOW (pcph)	SPEED (kph)	FLOW (pcph)	SPEED (kph)
660.00	90.32	1380.00	92.46	720.00	97.86
600.00	90.32	840.00	92.46	600.00	97.86
600.00	90.32	1140.00	92.46	540.00	97.86
600.00	90.32	1500.00	92.46	780.00	97.86
1020.00	90.32	900.00	92.46	960.00	97.86
1260.00	89.06	1440.00	94.56	900.00	102.32
720.00	89.06	1080.00	94.56	1140.00	102.32
900.00	89.06	840.00	94.56	1380.00	102.32
960.00	89.06	960.00	94.56	660.00	102.32
720.00	89.06	1320.00	94.56	1320.00	102.32
720.00	90.42	1020.00	94.53	1440.00	108.06
900.00	90.42	960.00	94.53	1080.00	108.06
960.00	90.42	1140.00	94.53	1080.00	108.06
360.00	90.42	1440.00	94.53	960.00	108.06
1140.00	90.42	900.00	94.53	1320.00	108.06
1020.00	84.21	1260.00	99.36	540.00	108.14
780.00	84.21	1140.00	99.36	1260.00	108.14
840.00	84.21	1260.00	99.36	1200.00	108.14
660.00	84.21	1080.00	99.36	420.00	108.14
480.00	84.21	1380.00	99.36	1080.00	108.14
960.00	92.16	1380.00	100.64	1260.00	107.98
960.00	92.16	1020.00	100.64	780.00	107.98
660.00	92.16	1260.00	100.64	960.00	107.98
720.00	92.16	960.00	100.64	1080.00	107.98
960.00	92.16	1140.00	100.64	780.00	107.98
720.00	89.06	960.00	98.50	960.00	113.90
960.00	89.06	1200.00	98.50	780.00	113.90
840.00	89.06	1200.00	98.50	600.00	113.90
1200.00	88.96	960.00	98.50	1080.00	113.90
840.00	89.06	900.00	98.50	600.00	113.92
1080.00	92.59	1140.00	101.41	780.00	109.76
900.00	92.59	1020.00	101.41	720.00	109.76
720.00	92.59	1020.00	101.41	600.00	109.76
780.00	92.59	1020.00	101.41	600.00	109.76
1020.00	92.59	1380.00	101.41	600.00	109.76
780.00	91.57	1260.00	105.10	720.00	109.73
600.00	91.57	1080.00	105.10	1320.00	109.73
420.00	91.57	1080.00	105.10	840.00	109.73
840.00	91.57	1020.00	105.10	840.00	109.73
540.00	91.57	960.00	105.10	1080.00	109.73
540.00	99.54	780.00	101.25	1800.00	107.76
900.00	99.54	720.00	101.25	1560.00	107.76
780.00	99.54	960.00	101.25	1920.00	107.76
600.00	99.54	960.00	101.25	720.00	107.76
1200.00	99.54	900.00	101.25	900.00	107.76
660.00	95.02	1500.00	84.83	1980.00	110.19
660.00	95.02	1620.00	84.83	1560.00	110.19
600.00	95.02	1200.00	84.83	1920.00	110.19
660.00	95.02	2040.00	84.83	1920.00	110.19
840.00	95.02	1500.00	84.83	2220.00	110.19
840.00	96.45	1860.00	99.12	2520.00	99.76
1080.00	96.45	1980.00	99.12	1980.00	99.76
1260.00	96.45	1200.00	99.12	1560.00	99.76
780.00	96.45	1500.00	99.12	2400.00	99.76
660.00	96.45	2040.00	99.12	1440.00	99.79
1080.00	91.01	1740.00	88.54	2160.00	101.49
1140.00	91.01	960.00	88.54	2880.00	101.49
1080.00	91.01	1740.00	88.54	1620.00	101.49
780.00	91.01	2100.00	88.54	1980.00	101.49
1140.00	91.01	1320.00	88.54	1740.00	101.49
600.00	90.56	1980.00	100.98	2280.00	106.24
720.00	90.56	1560.00	100.98	2340.00	106.24
1080.00	90.56	1380.00	100.98	1980.00	106.24
480.00	90.56	1620.00	100.98	1620.00	106.24
1080.00	90.56	1200.00	100.98	1860.00	106.24
900.00	88.90	1860.00	96.37	1980.00	108.34
840.00	88.90	1080.00	96.37	1860.00	108.34
1320.00	88.90	1680.00	96.37	1740.00	108.34
960.00	88.90	1740.00	96.37	1800.00	108.34
780.00	88.90	1320.00	96.37	2400.00	108.34
840.00	91.36	1320.00	101.31	2160.00	102.00
840.00	91.36	2100.00	101.31	1560.00	102.00
1200.00	91.36	1380.00	101.31	1860.00	102.00
960.00	91.36	1200.00	101.31	1680.00	102.00
1140.00	91.36	1680.00	101.31	1620.00	102.00
840.00	87.54	1920.00	91.98	2280.00	105.71
900.00	87.54	1920.00	91.98	2160.00	105.71
960.00	87.54	1680.00	91.98	2400.00	105.71
1260.00	87.54	1680.00	91.98	1590.00	105.71
780.00	87.54	1380.00	91.98	1980.00	105.71
960.00	92.21	1860.00	94.27	2160.00	97.79
1320.00	92.21	1980.00	94.27	1920.00	97.79
720.00	92.21	1140.00	94.27	1680.00	97.79
1020.00	92.21	1560.00	94.27	2280.00	97.79
1140.00	92.21	1800.00	94.27	2580.00	97.79

Table A2.2 Continued...

1320.00	88.32	1740.00	94.64	1800.00	108.27
1260.00	88.32	1320.00	94.64	2100.00	108.27
1260.00	88.32	1440.00	94.64	2580.00	108.27
1140.00	88.32	1620.00	94.64	1920.00	108.27
600.00	88.32	1680.00	94.64	1980.00	108.27
900.00	90.91	1500.00	99.49	1980.00	110.16
1380.00	90.91	1380.00	99.49	1980.00	110.16
1020.00	90.91	2040.00	99.49	1560.00	110.16
1140.00	90.91	1680.00	99.49	1740.00	110.16
840.00	90.91	1380.00	99.49	1980.00	110.16
600.00	90.19	1140.00	99.66	1920.00	108.14
1020.00	90.19	1440.00	99.66	2100.00	108.14
900.00	89.71	1440.00	99.66	1800.00	108.14
900.00	90.19	1680.00	99.66	2400.00	108.14
1620.00	90.19	1500.00	99.66	2580.00	108.14
1140.00	92.51	1920.00	96.88	960.00	113.58
1020.00	92.51	1860.00	96.88	1200.00	113.17
960.00	92.51	1860.00	96.88	1260.00	113.17
900.00	92.51	1380.00	96.88	1980.00	113.17
1020.00	92.51	1740.00	96.88	1980.00	113.17
1080.00	94.96	1200.00	98.58	960.00	113.17
1080.00	94.96	1020.00	98.58	1440.00	112.50
900.00	94.96	1320.00	98.58	1920.00	112.50
1260.00	94.96	1260.00	98.58	1680.00	112.50
1020.00	94.96	960.00	98.58	1080.00	112.50
660.00	98.37	1260.00	101.49	1920.00	108.90
1080.00	98.37	720.00	101.49	1980.00	108.90
1140.00	98.37	1080.00	101.49	1080.00	108.90
660.00	98.37	1380.00	101.49	1380.00	108.90
840.00	98.37	960.00	101.49	1260.00	108.90
780.00	94.19	1440.00	104.75	1560.00	104.46
780.00	94.19	1080.00	104.75	1920.00	104.46
1140.00	94.19	1080.00	104.75	660.00	104.46
960.00	94.19	1140.00	104.75	1500.00	104.46
1260.00	94.19	1320.00	104.75	1440.00	104.46
720.00	99.38	1020.00	103.10	0.00	0.00
1020.00	99.38	1620.00	103.10	0.00	0.00
1980.00	99.38	1020.00	103.10	0.00	0.00
1380.00	99.38	1800.00	103.10	0.00	0.00
780.00	99.38	1380.00	103.10	0.00	0.00
1020.00	97.68	1200.00	105.23	0.00	0.00
1020.00	97.68	900.00	105.23	0.00	0.00
1260.00	97.68	840.00	105.23	0.00	0.00
1020.00	97.68	1260.00	105.23	0.00	0.00
1140.00	97.68	1500.00	105.23	0.00	0.00
0.00	0.00	2100.00	104.21	0.00	0.00
0.00	0.00	1680.00	104.21	0.00	0.00
0.00	0.00	1260.00	104.21	0.00	0.00
0.00	0.00	1440.00	104.21	0.00	0.00
0.00	0.00	1560.00	104.21	0.00	0.00
0.00	0.00	1620.00	109.68	0.00	0.00
0.00	0.00	1080.00	109.68	0.00	0.00
0.00	0.00	1980.00	109.68	0.00	0.00
0.00	0.00	960.00	109.68	0.00	0.00
0.00	0.00	1560.00	109.68	0.00	0.00
0.00	0.00	1200.00	109.63	0.00	0.00
0.00	0.00	1080.00	109.63	0.00	0.00
0.00	0.00	960.00	109.63	0.00	0.00
0.00	0.00	1980.00	109.63	0.00	0.00
0.00	0.00	1800.00	109.63	0.00	0.00
0.00	0.00	1740.00	106.45	0.00	0.00
0.00	0.00	1260.00	106.45	0.00	0.00
0.00	0.00	960.00	106.45	0.00	0.00
0.00	0.00	1080.00	106.45	0.00	0.00
0.00	0.00	1680.00	106.45	0.00	0.00

Table A2.3 Speed-Flow Data for 2-Lane Section on Highway 401

SHOULDER LANE		MEDIAN LANE	
Flow (pcph)	Speed (kph)	Flow (pcph)	Speed (kph)
1152	86.4	1464	94.5
1285	86.4	1620	94.5
1152	86.4	1524	94.5
1080	86.4	1632	94.5
996	86.4	1656	94.5
1176	86.4	1572	94.5
1188	86.4	1488	94.5
1056	86.4	1308	94.5
1272	83.1	1668	89.8
1044	83.1	1416	89.8
1068	83.1	1512	89.8
1248	95.9	1548	99.5
828	95.9	1572	99.5
1104	95.9	1512	99.5
1176	95.9	1680	99.5
1008	90.0	1896	93.1
1164	90.0	2028	93.1
1212	90.0	1584	93.1
1020	90.0	1644	93.1
1056	90.0	1548	93.1
924	90.0	2532	93.1
1320	90.0	1584	93.1
1200	90.0	1680	93.1
1320	90.0	1884	93.1
924	92.2	1752	100.2
1332	92.2	1896	100.2
1056	92.2	1596	100.2
636	92.2	1776	100.2
900	92.2	1488	100.2
1020	92.2	1716	100.2
1356	92.2	1632	100.2
1572	92.2	1668	100.2
1236	92.2	1680	100.2
1140	92.2	1704	100.2
1236	92.2	1692	100.2
1836	84.8	2364	92.1
1392	84.8	2004	92.1
1476	84.8	2016	92.1
1308	91.4	1800	101.6
1236	91.4	1788	101.6
1212	91.4	1644	101.6
1296	34.2	1800	34.2
1236	34.2	1356	34.2
1428	34.2	1644	34.2
1452	60.6	1500	63.5
1272	60.6	1884	63.5
1320	60.6	1656	63.5
1080	60.6	1644	63.5
1140	60.6	1596	63.5
1020	60.6	1536	63.5

Table A2.4 Speed-Flow Data for the Average of 3 Lanes on the 3-Lane Section of Highway 401

Flow (pcph)	Speed (kph)
860	91.5
900	89.1
968	90.1
932	95.6
844	91.3
720	91.0
780	92.9
924	98.8
880	100.0
908	96.8
852	96.8
868	94.2
832	98.3
828	97.8
888	96.0
856	95.7
884	93.5
916	93.6
840	92.4
956	95.2
960	91.7
1008	92.4
1036	89.0
884	95.4
916	89.8
800	98.8
772	90.7
792	86.6
952	91.1
984	92.8
888	90.4
956	83.0
856	90.3
832	90.5
816	92.7

Table A2.5 QEW (Hamilton)
Speed-Flow Data

MEDIAN		SHOULDER	
FLOW (pcph)	SPEED (kph)	FLOW (pcph)	SPEED (kph)
276.	106.2	744.	95.8
372.	104.2	576.	93.2
264.	104.8	612.	90.3
360.	109.4	756.	97.2
384.	105.1	636.	94.6
852.	103.5	876.	97.4
408.	103.4	758.	97.0
456.	104.6	650.	98.0
708.	106.8	768.	94.8
576.	103.9	612.	93.4
744.	104.7	1056.	96.2
492.	105.8	792.	98.3
816.	106.6	834.	96.7
720.	103.6	840.	96.1
720.	102.6	864.	96.8
612.	106.6	780.	97.3
996.	103.0	960.	97.9
948.	102.6	1020.	96.5
912.	103.7	984.	95.7
840.	107.0	920.	97.6
1104.	109.9	900.	95.2
252.	108.4	432.	95.4
324.	103.[illegible]	732.	98.2
324.	104.9	564.	99.4
312.	102.0	515.	99.0
348.	107.0	630.	98.4
228.	105.1	516.	95.5
180.	105.1	552.	99.3
312.	108.8	564.	98.5
300.	103.3	540.	94.2
252.	110.8	624.	101.3
276.	109.0	564.	99.5
300.	105.6	468.	100.7
276.	108.0	624.	99.9
276.	107.8	600.	100.8
228.	104.7	576.	98.5
504.	104.9	600.	97.4
300.	109.5	528.	96.1
492.	102.5	528.	100.1
324.	106.4	588.	99.0
456.	107.2	720.	96.3
468.	111.4	660.	99.0
480.	100.8	720.	96.4
396.	104.7	756.	95.5
360.	105.2	612.	98.3
564.	106.5	852.	98.1
540.	108.3	732.	97.3
456.	110.0	696.	100.5
588.	105.8	804.	97.7
672.	102.2	840.	99.6
684.	105.9	816.	98.8
624.	106.6	924.	99.6
768.	104.2	912.	101.1
756.	104.9	924.	100.5
660.	105.4	732.	99.7
780.	107.4	888.	99.5
972.	107.2	864.	95.8
1044.	107.8	1078.	99.5
972.	110.0	960.	99.9
1032.	106.0	840.	99.8
936.	108.5	804.	99.4
288.	110.5	444.	99.7
300.	116.6	396.	100.8
132.	115.1	408.	102.7
420.	112.9	456.	100.2
504.	113.0	500.	100.6
456.	111.4	588.	101.7
468.	113.2	480.	102.7
408.	113.4	456.	101.4
384.	112.9	516.	103.4
444.	110.8	564.	102.4
444.	113.5	696.	102.4
228.	110.5	372.	100.1
288.	108.8	468.	102.1
444.	109.5	456.	100.6
624.	107.1	648.	102.5
588.	109.7	648.	100.0
480.	113.6	524.	101.9
468.	112.2	756.	102.4
516.	112.3	630.	103.3
624.	110.3	588.	101.9
480.	113.9	612.	102.1
564.	107.7	540.	100.7
564.	109.6	744.	102.1
552.	110.1	576.	103.6
576.	109.6	576.	98.9
492.	109.4	554.	101.8
456.	110.2	588.	102.3
684.	109.2	732.	101.3
948.	109.6	732.	100.7
1008.	109.3	852.	99.0
1068.	108.7	843.	100.2
912.	110.6	672.	101.6

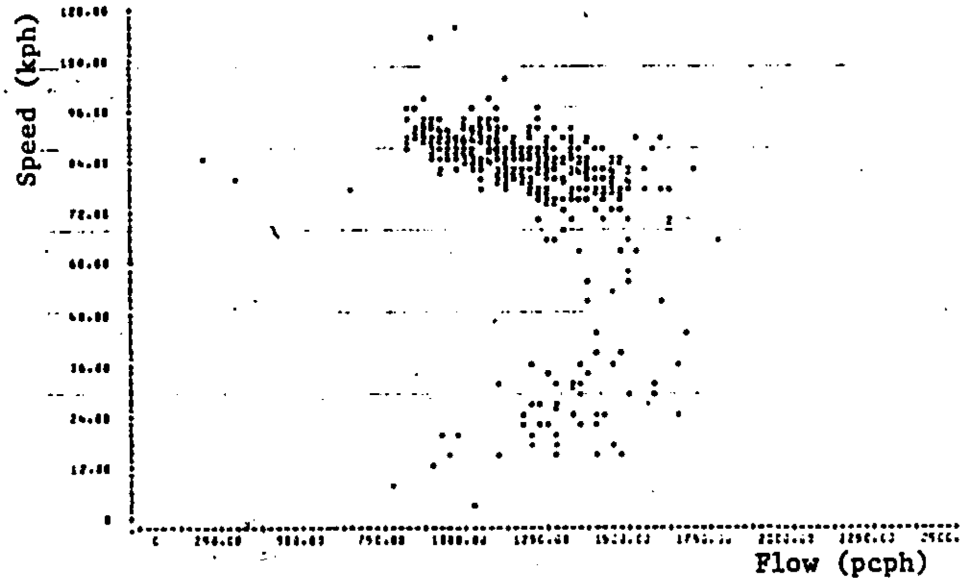
Table A2.6 Days on which the weather conditions were reported as rain and snow.

DATES FOR ADVERSE WEATHER CONDITIONS	
RAIN	SNOW
7.31.79	12.13.79
8.27.79	12.14.79
10.24.79	12.18.79
11.22.79	12.19.79
11.26.79	1. 9.80
11.28.79	2. 6.80
12.24.79	2.15.80
1. 2.80	2.27.80
1.11.80	
1.17.80	

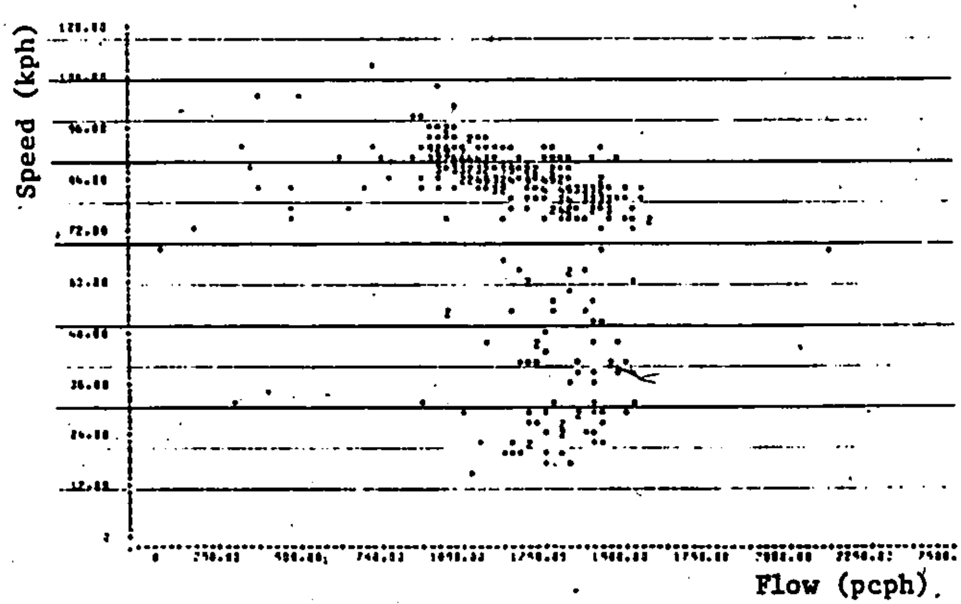
APPENDIX 3

Speed-flow data plots for 5 - and 15 - minute flow rates

Speed-flow curves are shown for both 5 - and 15 - minute hourly flow rates in this Appendix. Plots were made for Stations 2, 3, 4 and 8 on a lane basis. The numbers in each plot represent the number of data points plotted at the same spot, e.g. 2 represents that two points occur at the same spot. The number 9 however, means that nine or more points are located there.

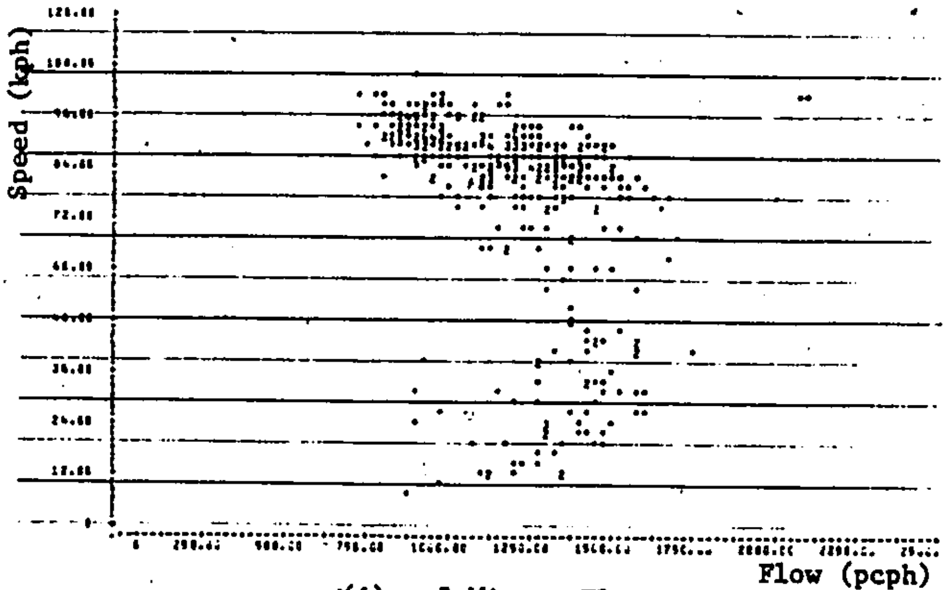


(i) 5-Minute Flow Rates

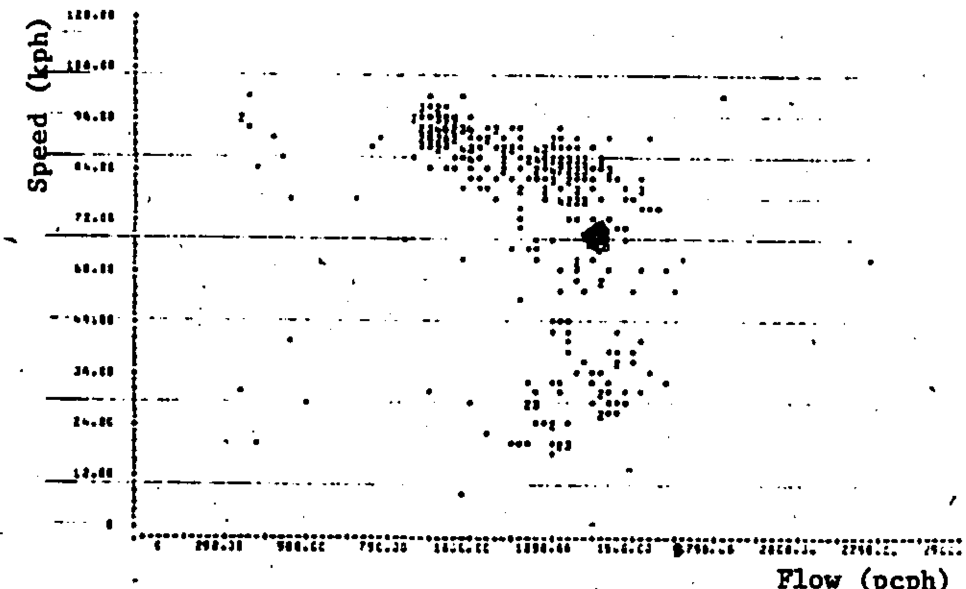


(ii) 15-Minute Flow Rates

Figure A3.1 Speed-Flow Data, Station 2, Shoulder Lane

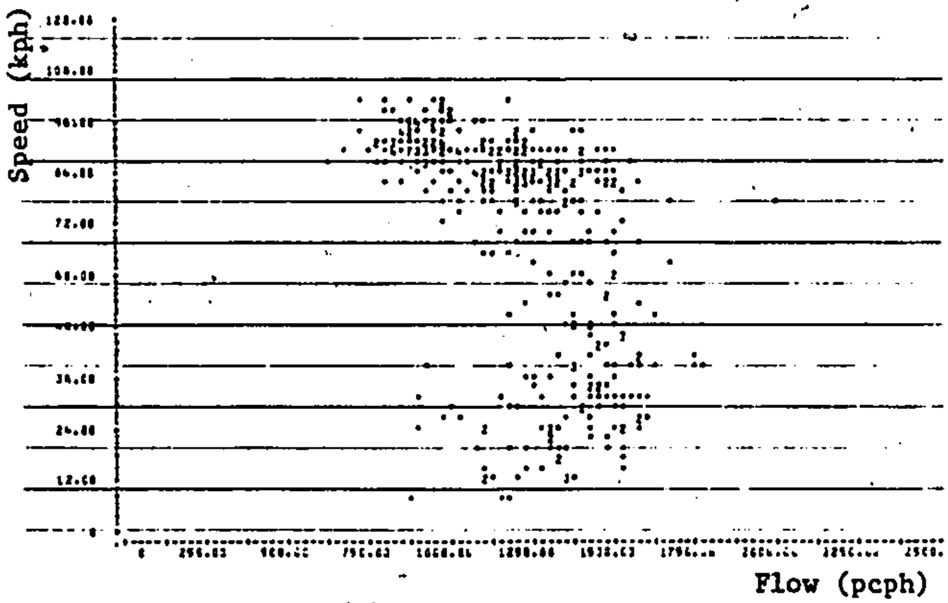


(i) 5-Minute Flow Rates

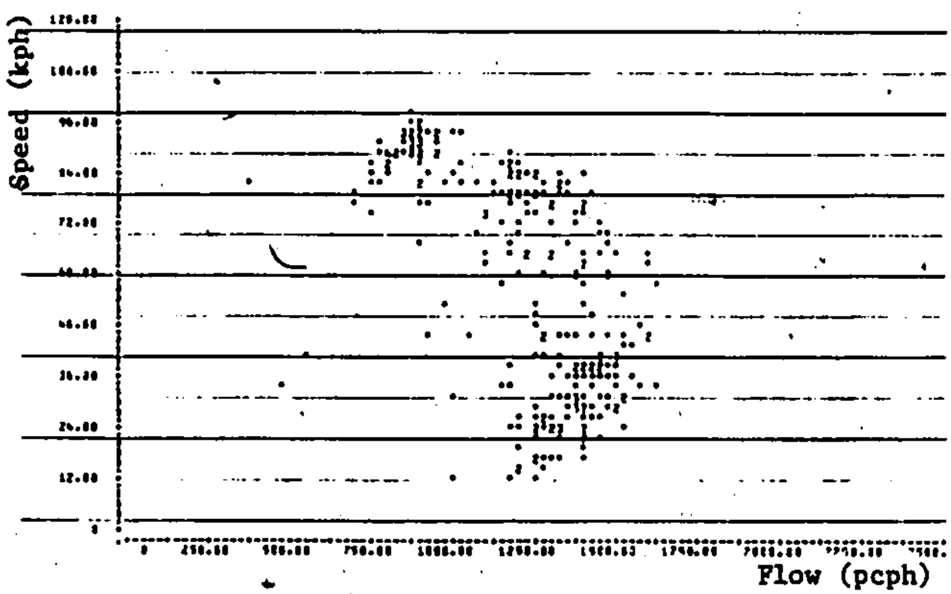


(ii) 15-Minute Flow Rates

Figure A3.2 Speed-Flow Data, Station 3, Shoulder Lane

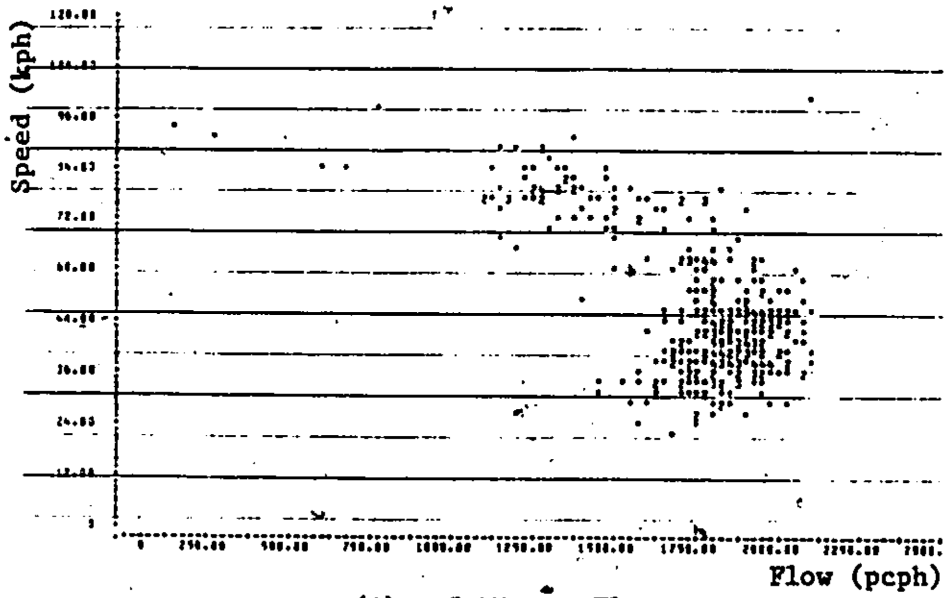


(i) 5-Minute Flow Rates

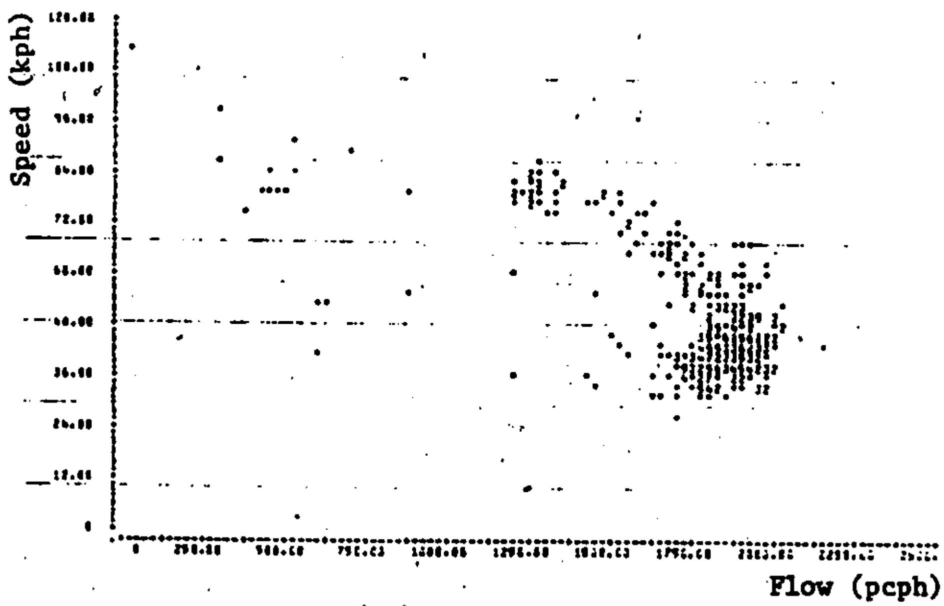


(ii) 15-Minute Flow Rates

Figure A3.3 Speed-Flow Data, Station 4, Shoulder Lane

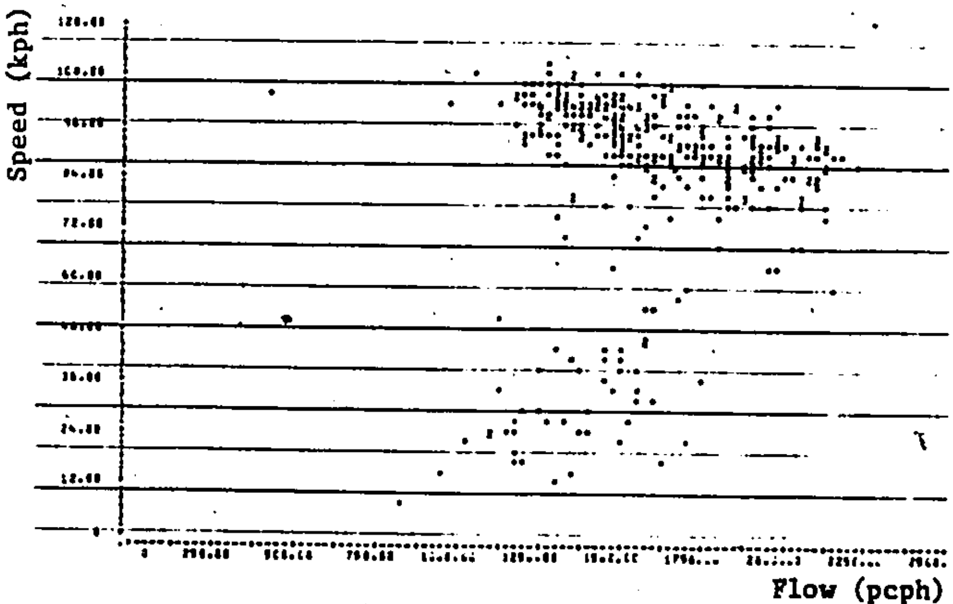


(i) 5-Minute Flow Rates

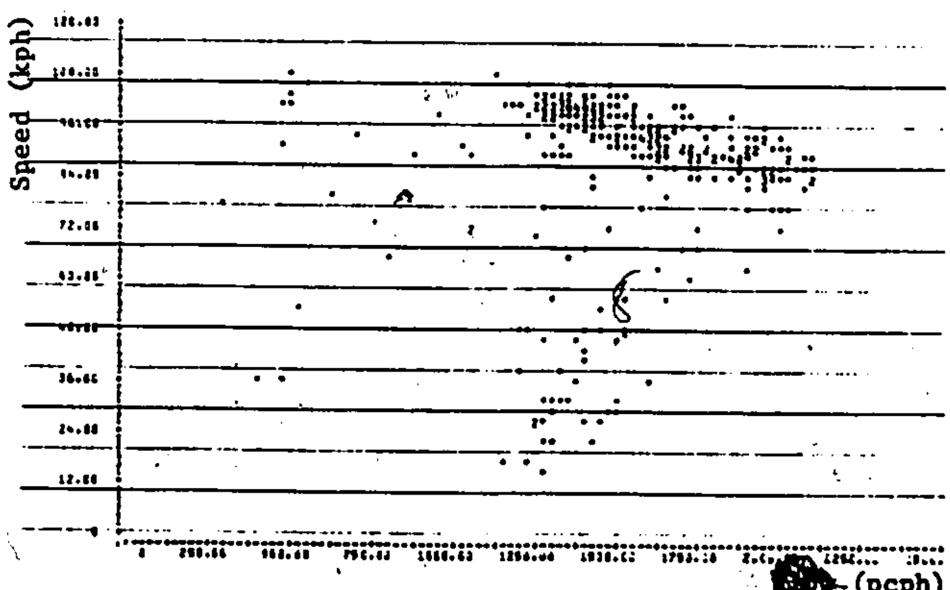


(ii) 15-Minute Flow Rates

Figure A3.4 Speed-Flow Data, Station 8, Shoulder Lane

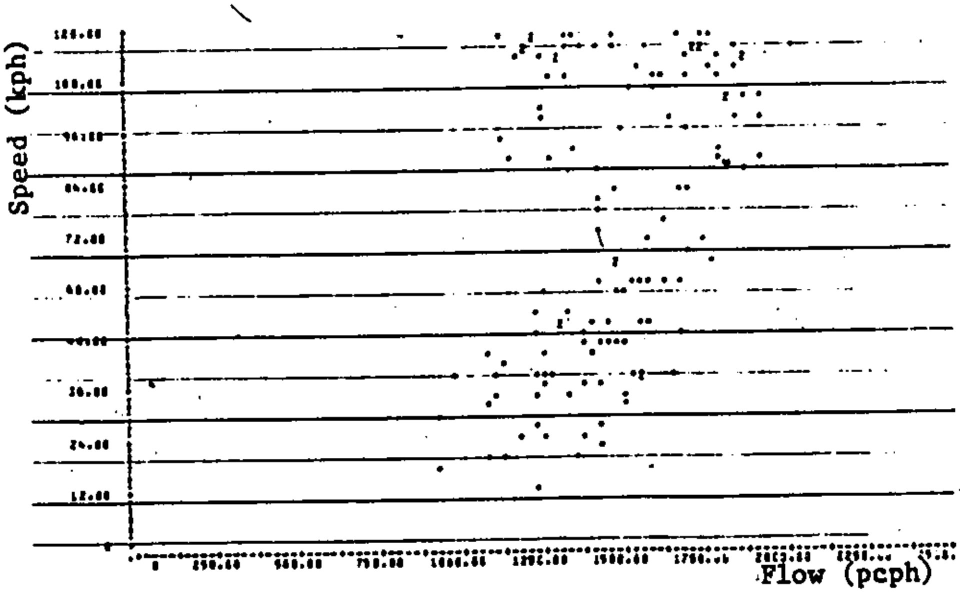


(i) 5-Minute Flow Rates

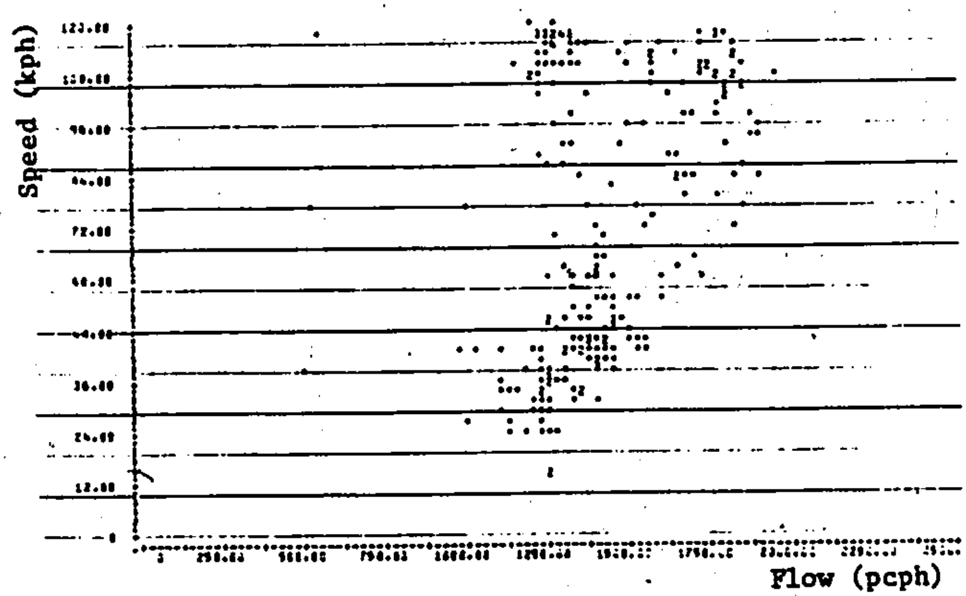


(ii) 15-Minute Flow Rates

Figure A3.5 Speed-Flow Data, Station 2, Middle Lane

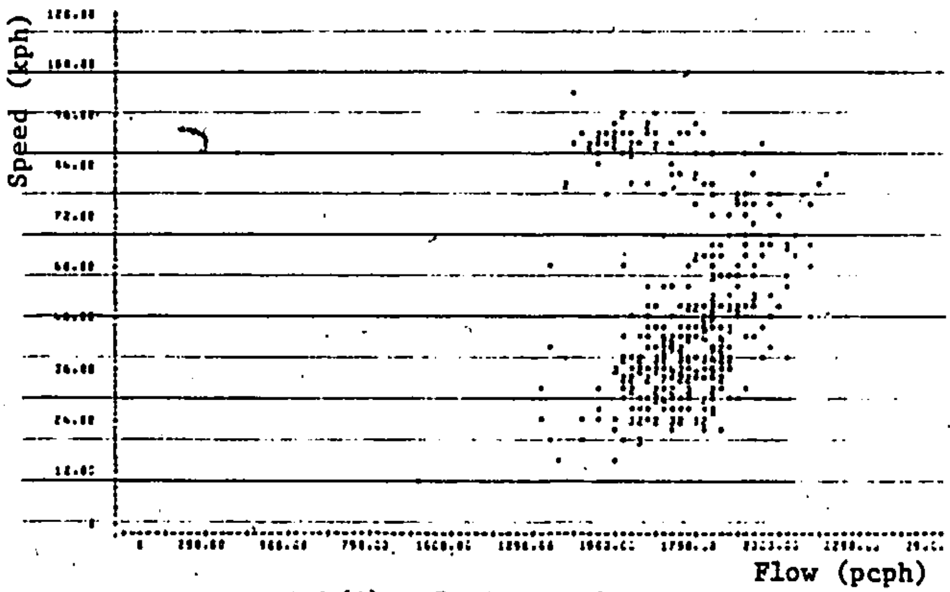


(i) 5-Minute Flow Rates

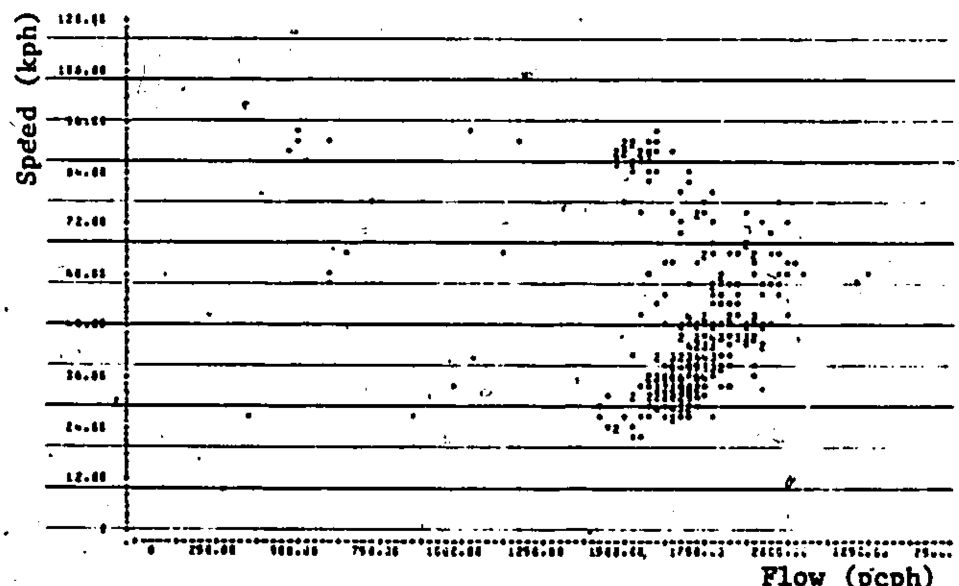


(ii) 15-Minute Flow Rates

Figure A3.6 Speed-Flow Data, Station 4, Middle Lane

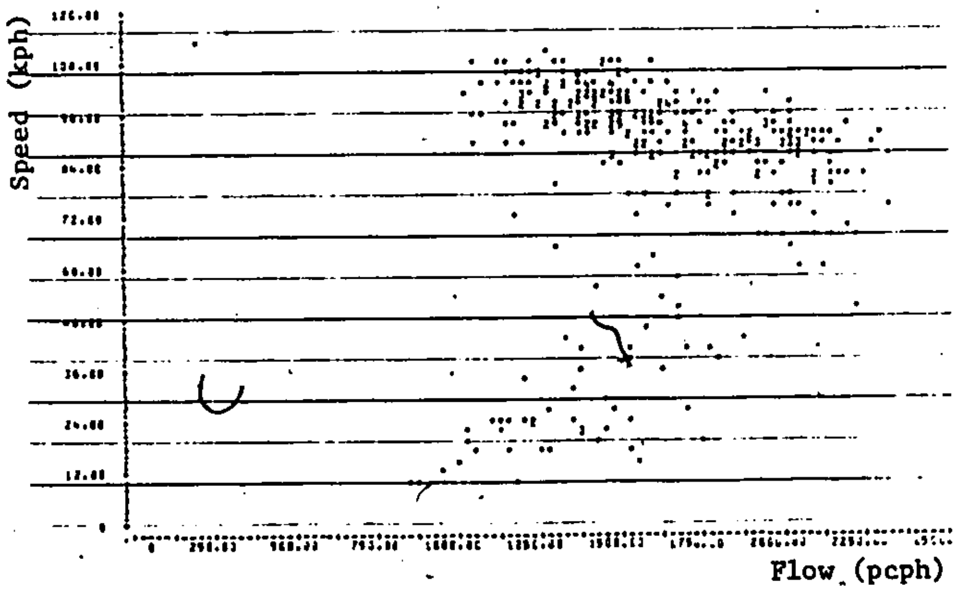


(i) 5-Minute Flow Rates

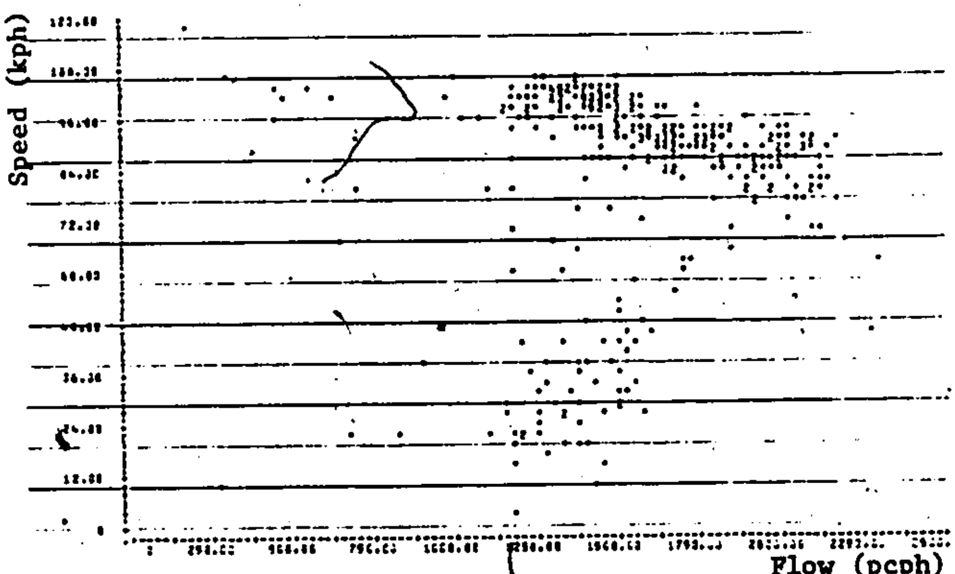


(ii) 15-Minute Flow Rates

Figure A3.7 Speed-Flow Data, Station 8, Middle Lane

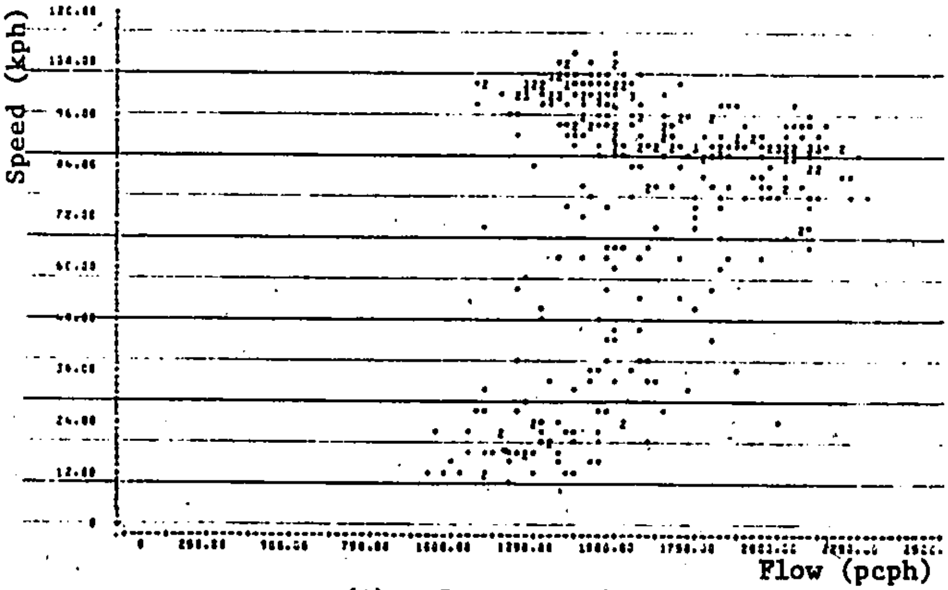


(i) 5-Minute Flow Rates

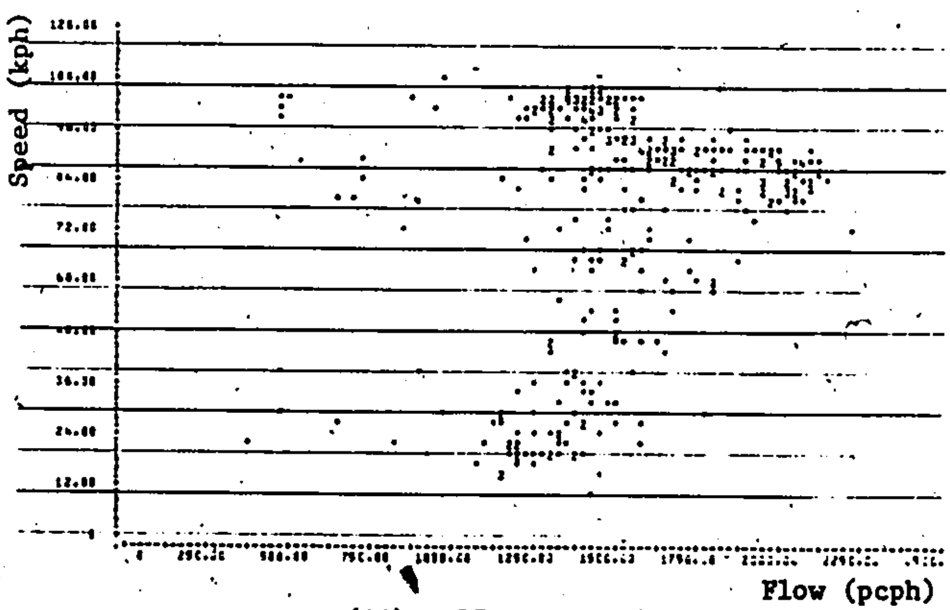


(ii) 15-Minute Flow Rates

Figure A3.8 Speed-Flow Data, Station 2, Median Lane

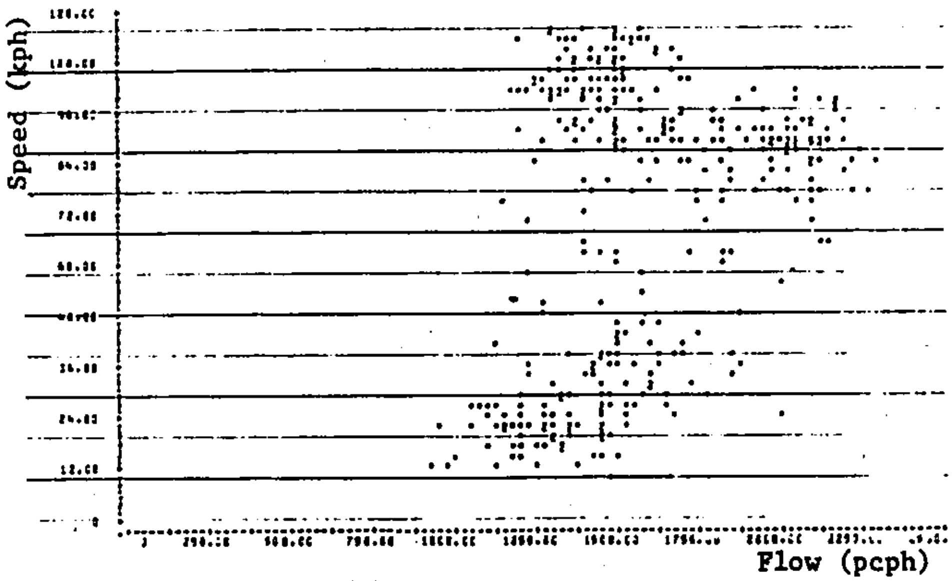


(i) 5-Minute Flow Rates

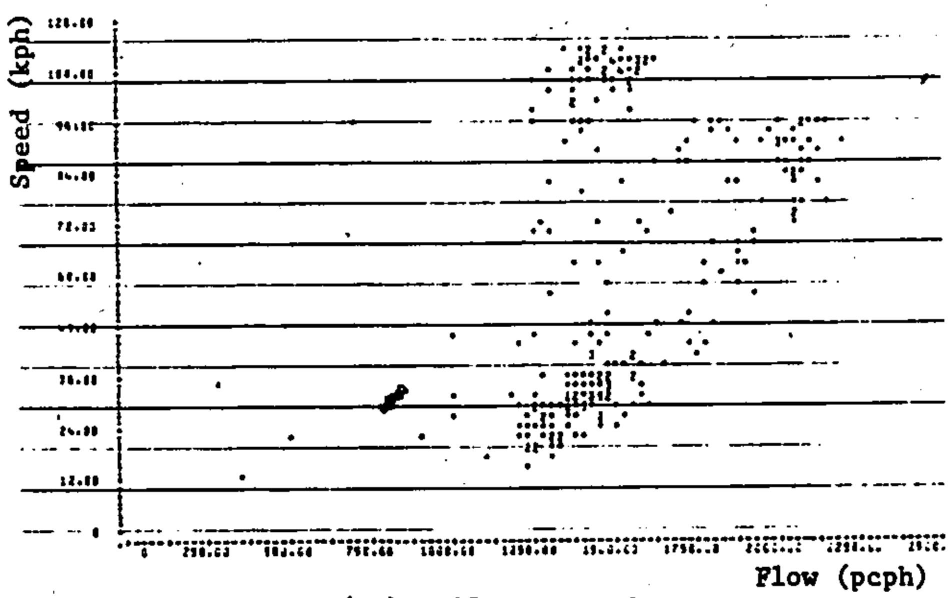


(ii) 15-Minute Flow Rates

Figure A3.9 Speed-Flow Data, Station 3, Median Lane

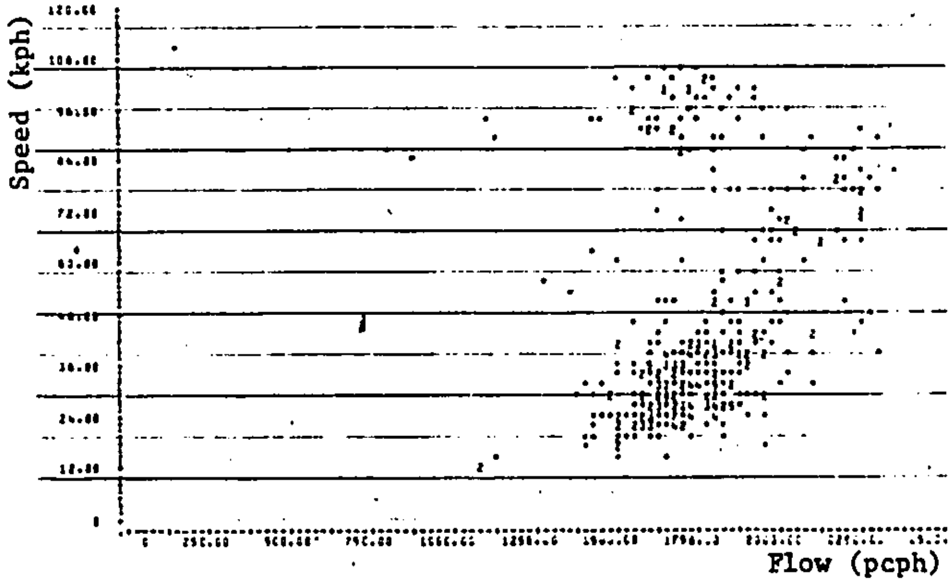


(i) 5-Minute Flow Rates

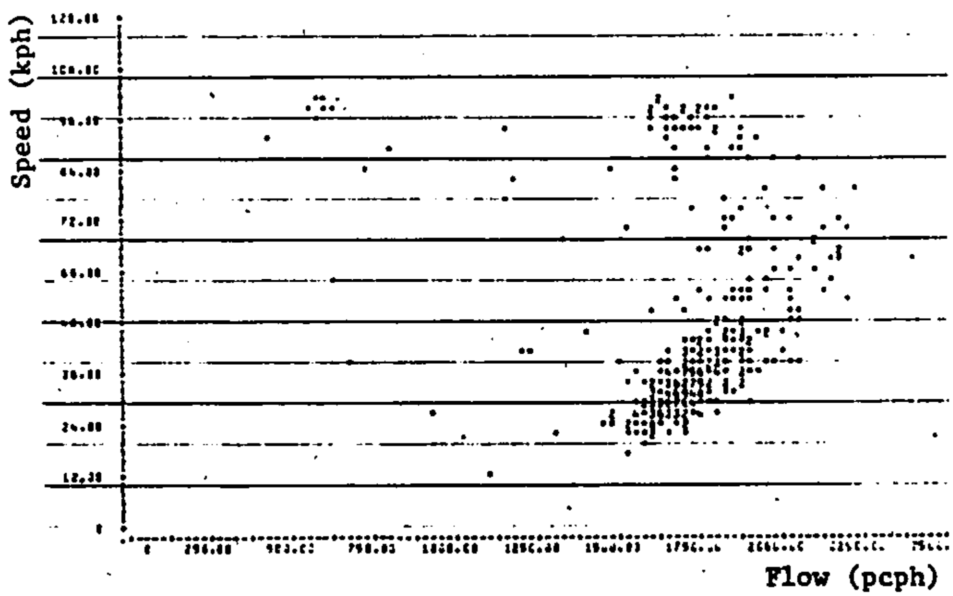


(ii) 15-Minute Flow Rates

Figure A3.10 Speed-Flow Data, Station 4, Median Lane



(i) 5-Minute Flow Rates



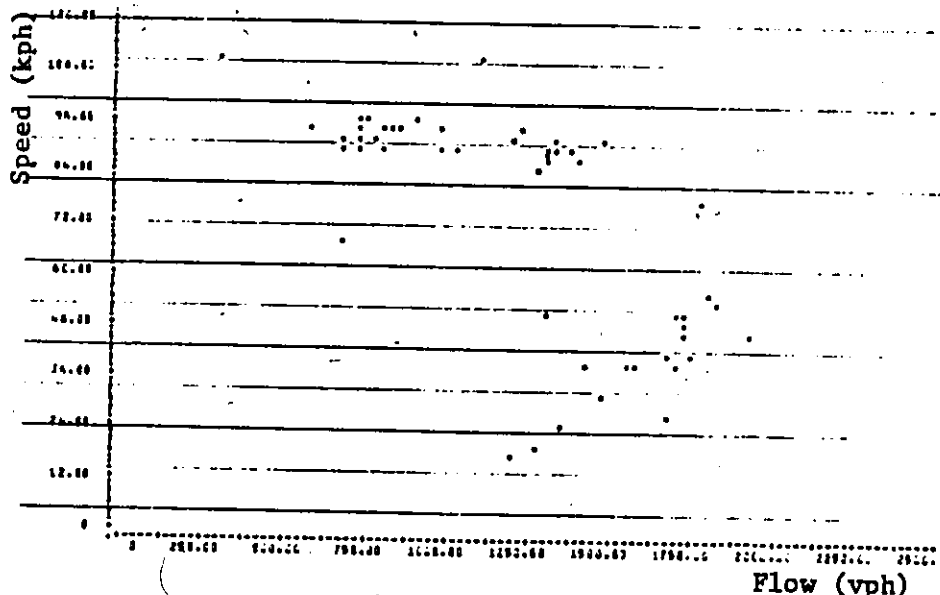
(ii) 15-Minute Flow Rates

Figure A3.11 Speed-Flow Data, Station 8, Median Lane

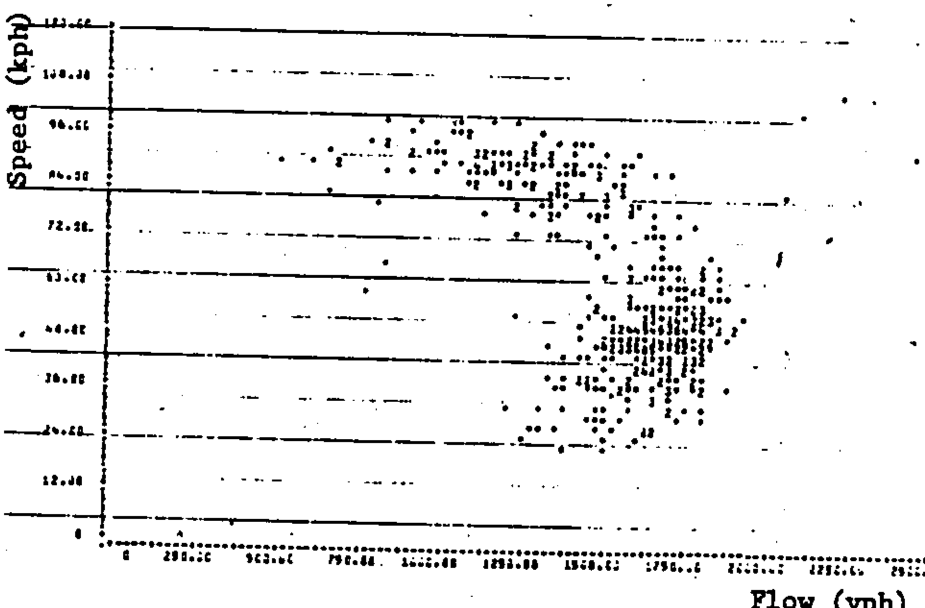
APPENDIX 4

Speed-flow data plots for varying percent trucks

Speed-flow curves are shown on a lane basis for varying percent trucks at stations 2, 4, 7 and 8. 5-minute hourly flow rates are recorded in vehicles per hour (vph). The numbers in each plot represent the number of data points plotted at the same spot, e.g. 2 represents that two points occur at the same spot. The number 9 however, means that nine or more points are located there.

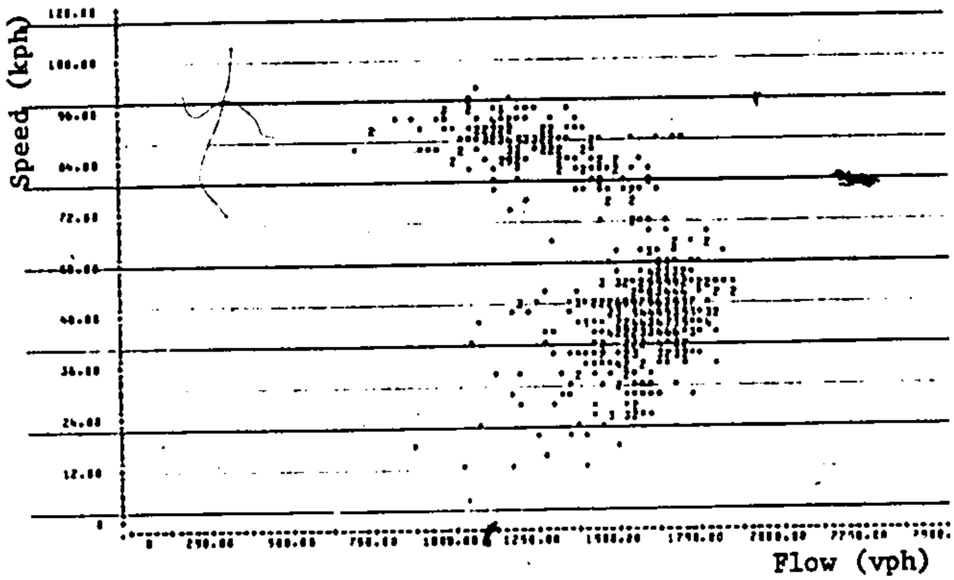


(i) 0-5% Trucks

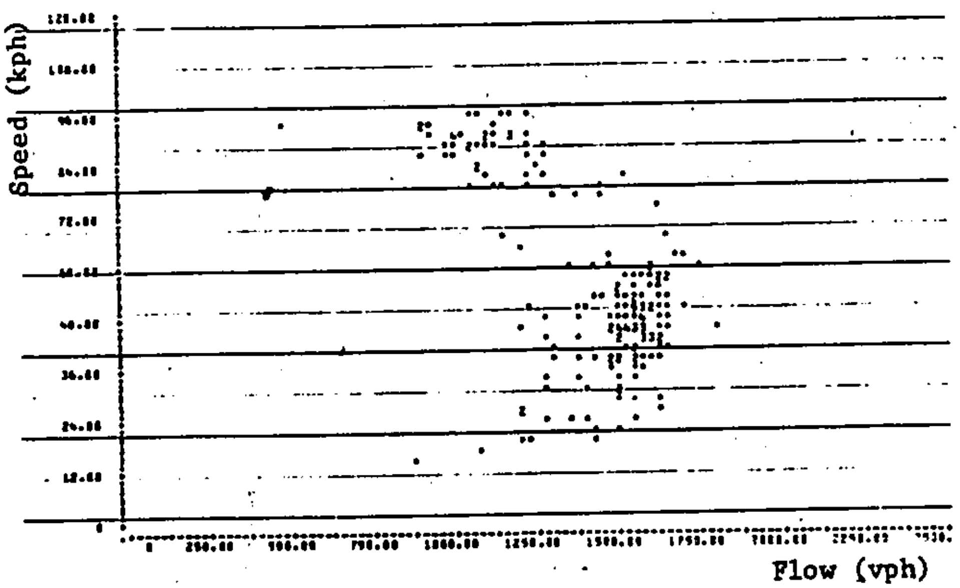


(ii) 5-10% Trucks

Figure A4.1 Speed-Flow (vph) Data at Varying Percent Trucks, Station 7, Shoulder Lane

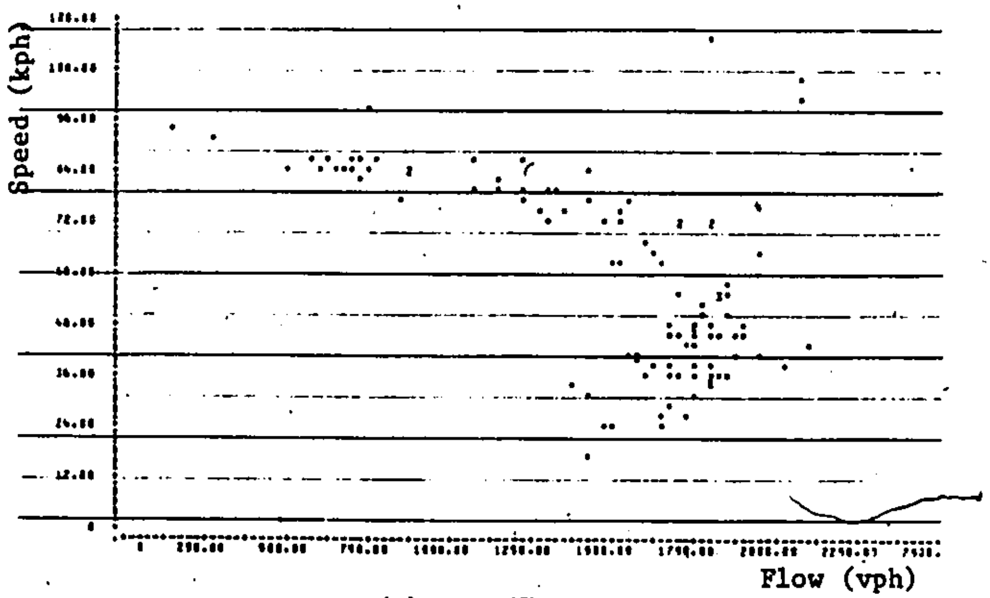


(iii) 10-15% Trucks

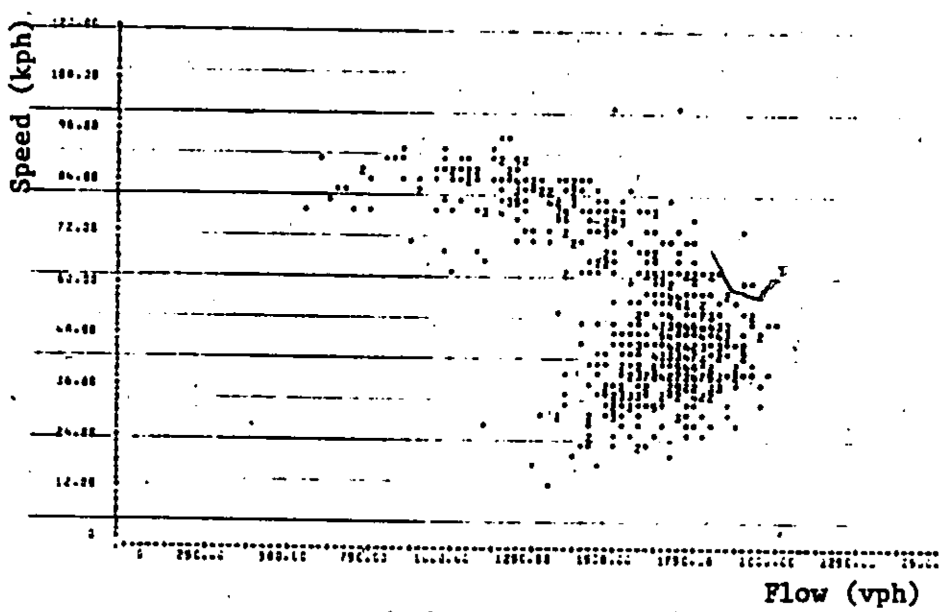


(iv) 15-20% Trucks

Figure A4.1 Speed-Flow (vph) Data at Varying Percent Trucks, Station 7, Shoulder Lane

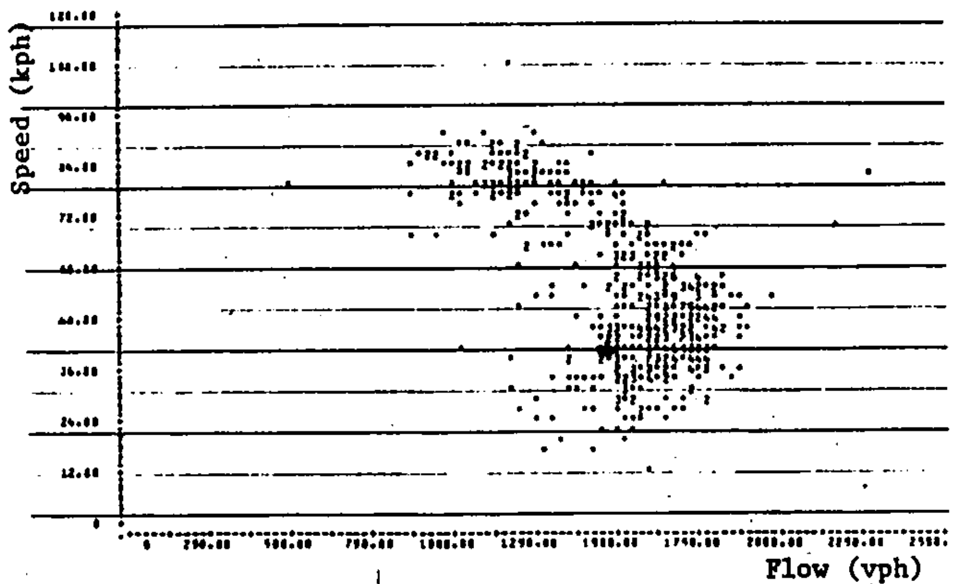


(i) 0-5% Trucks

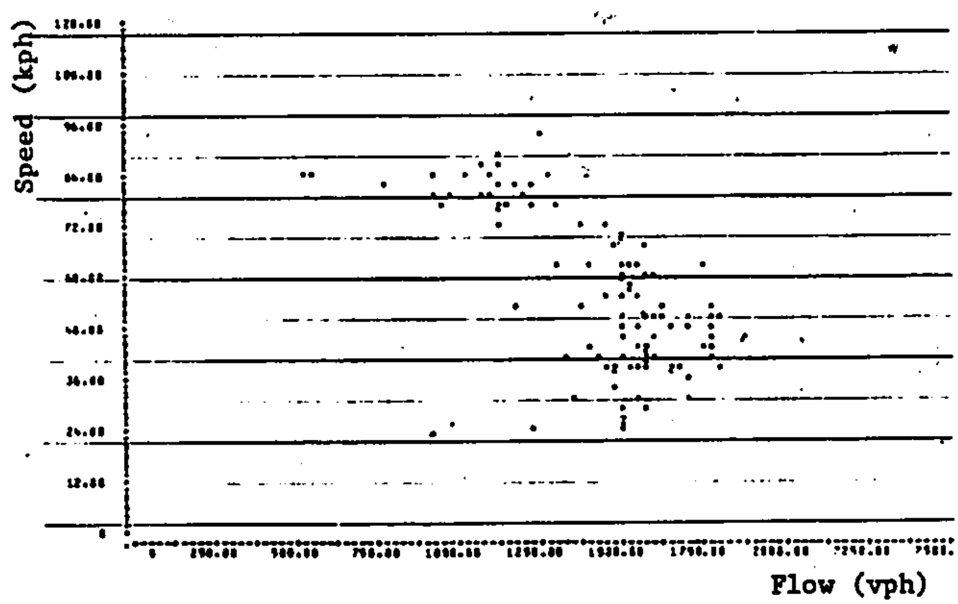


(ii) 5-10% Trucks

Figure A4.2 Speed-Flow (vph) Data at Varying Percent Trucks, Station 8, Shoulder Lane

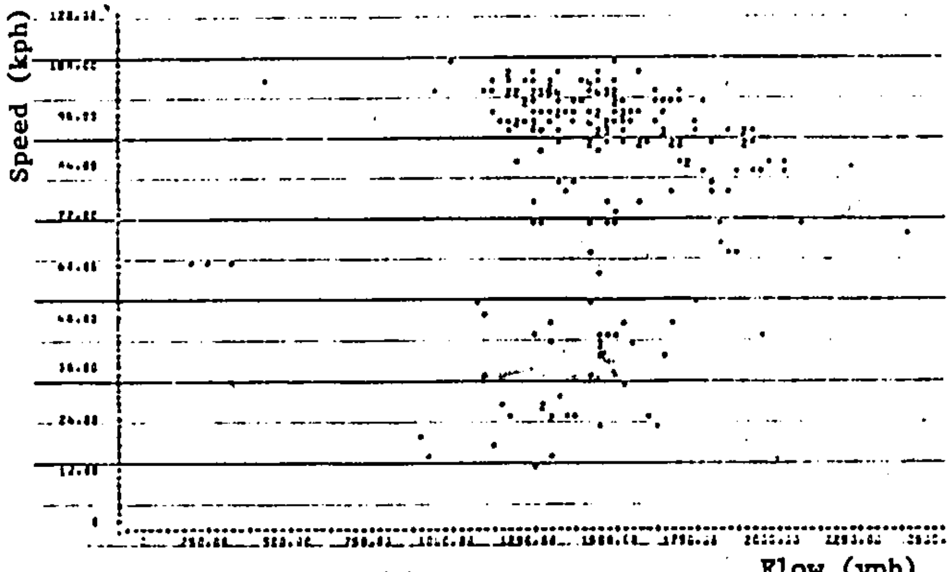


(iii) 10-15% Trucks

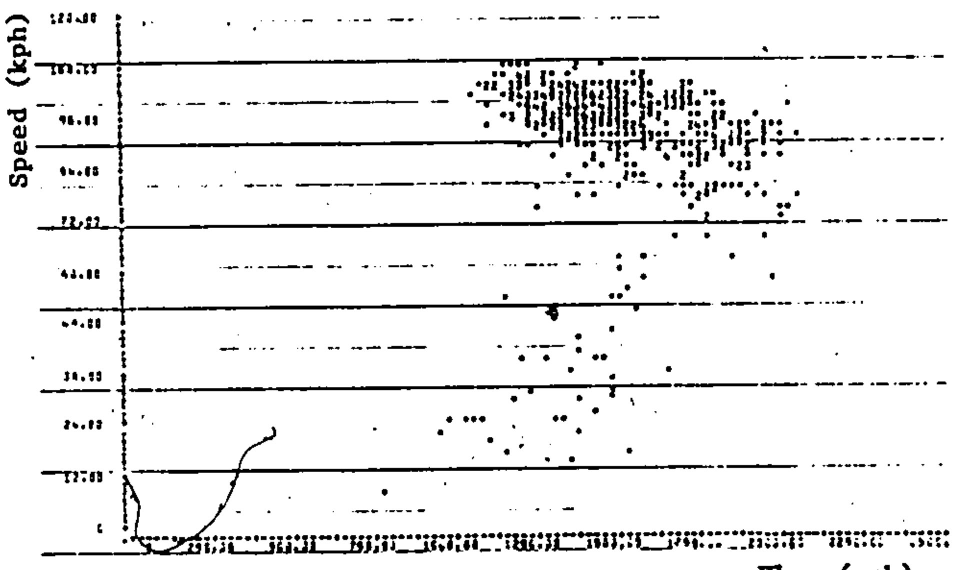


(iv) 15-20% Trucks

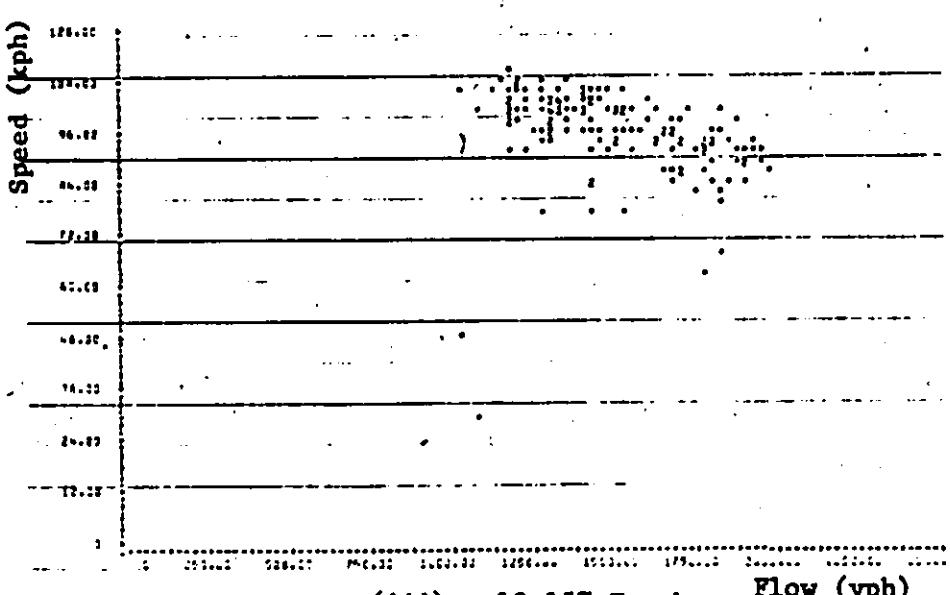
Figure A4.2 Speed-Flow (vph) Data at Varying Percent Trucks, Station 8, Shoulder Lane



(i) 0-5% Trucks

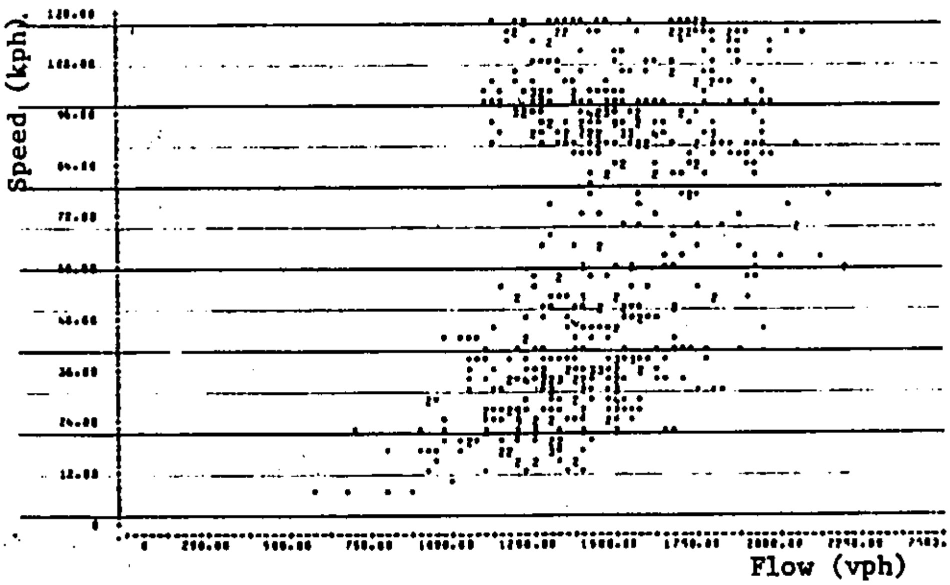


(ii) 5-10% Trucks

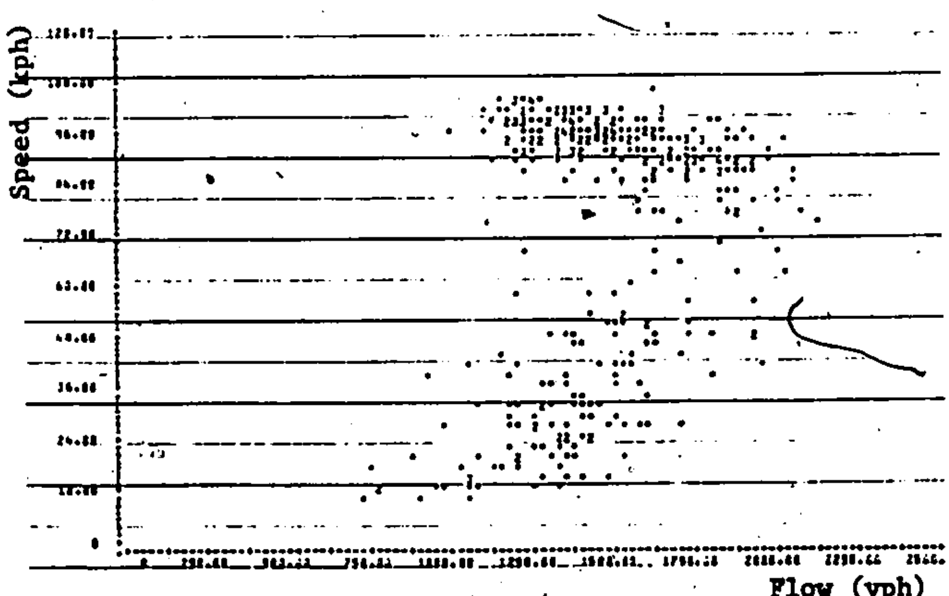


(iii) 10-15% Trucks

Figure A4.3 Speed-Flow (vph) Data at Varying Percent Trucks, Station 2, Middle Lane



(i) 0-5% Trucks



(ii) 5-10% Trucks

Figure A4.4 Speed-Flow (vph) Data at Varying Percent Trucks, Station 4, Middle Lane

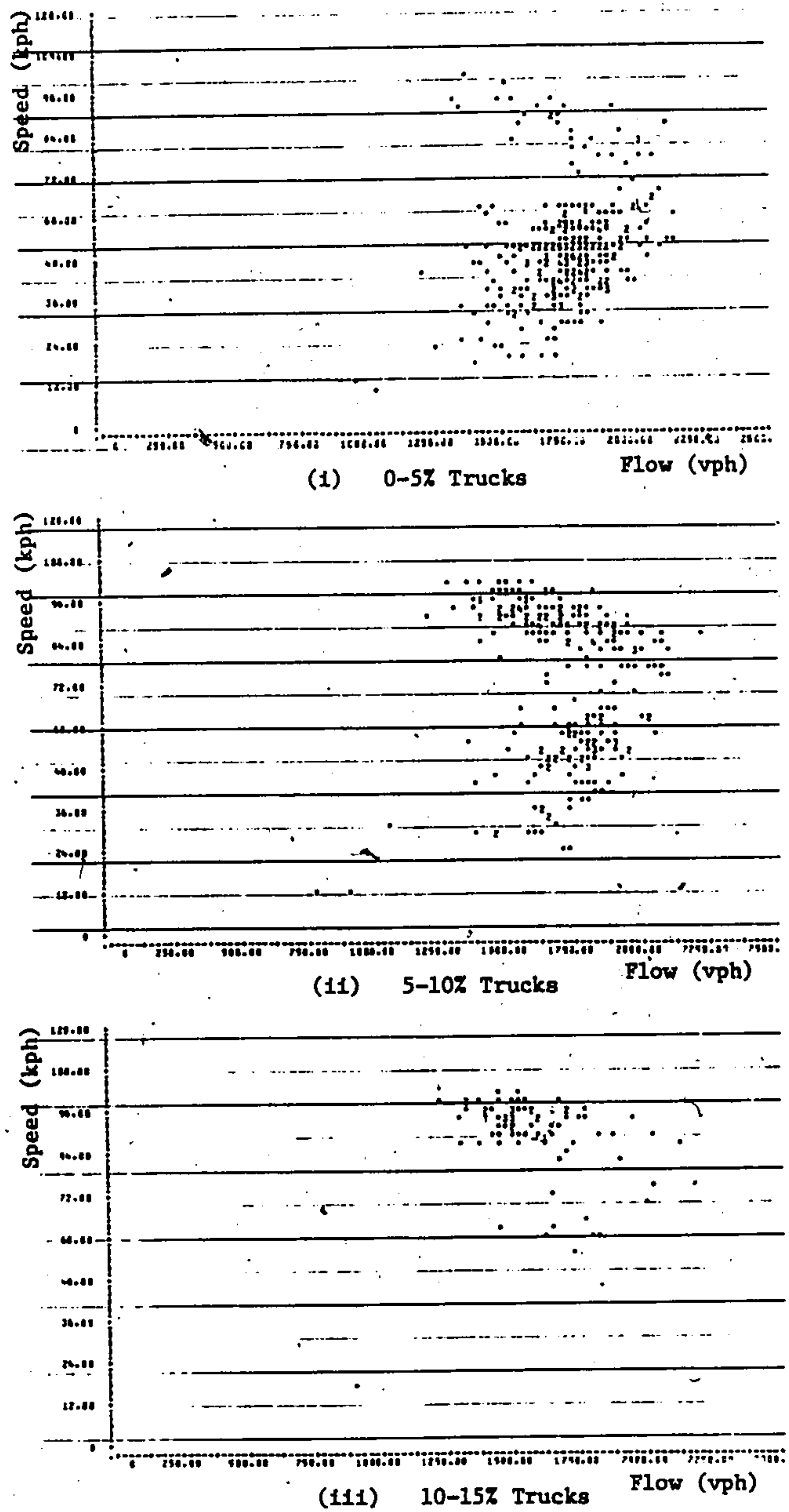
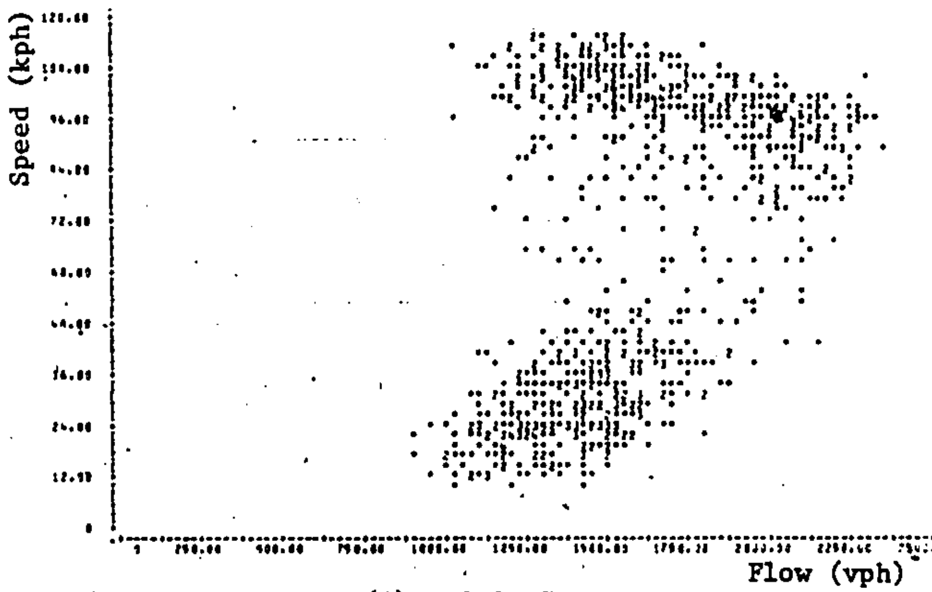
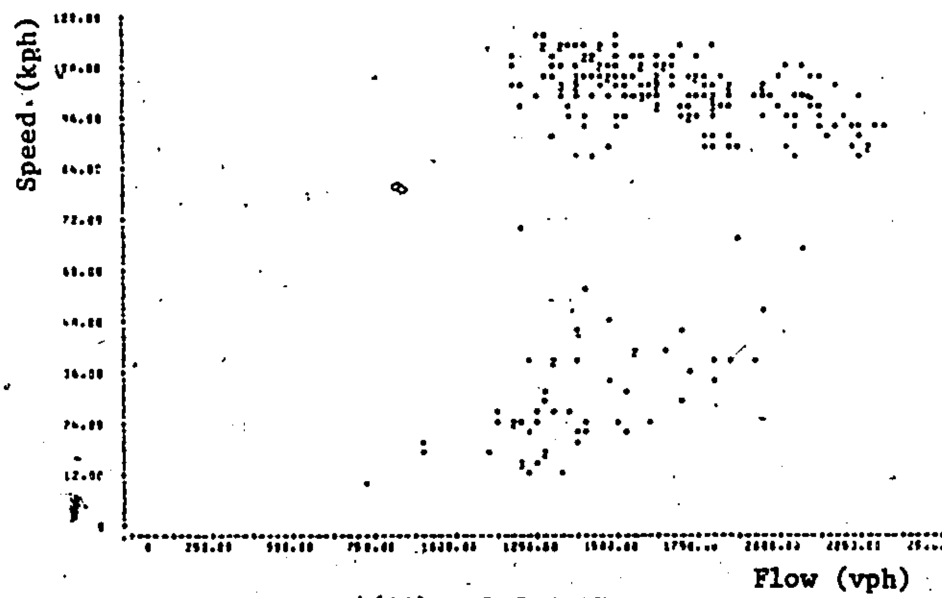


Figure A4.5. Speed-Flow (vph) Data at Varying Percent Trucks, Station 7, Middle Lane

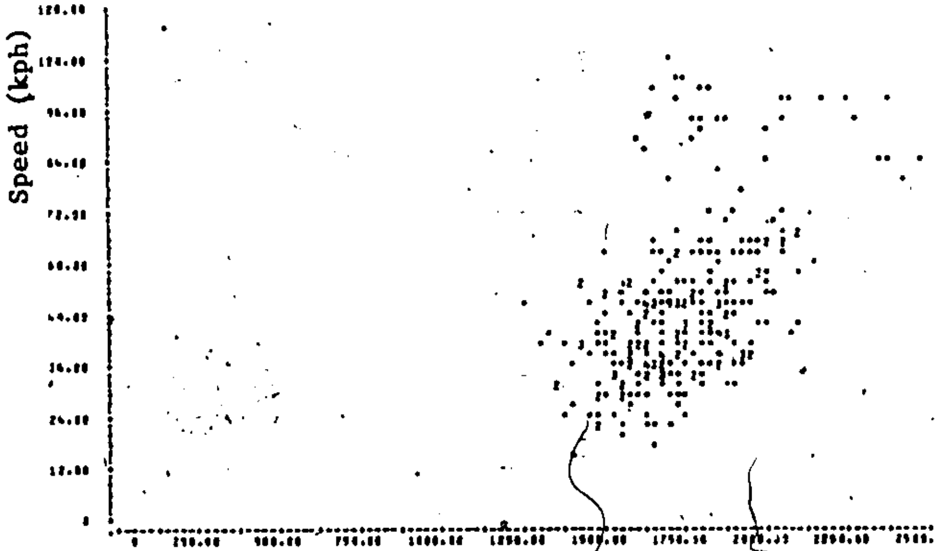


(i) 0-2.5% Trucks

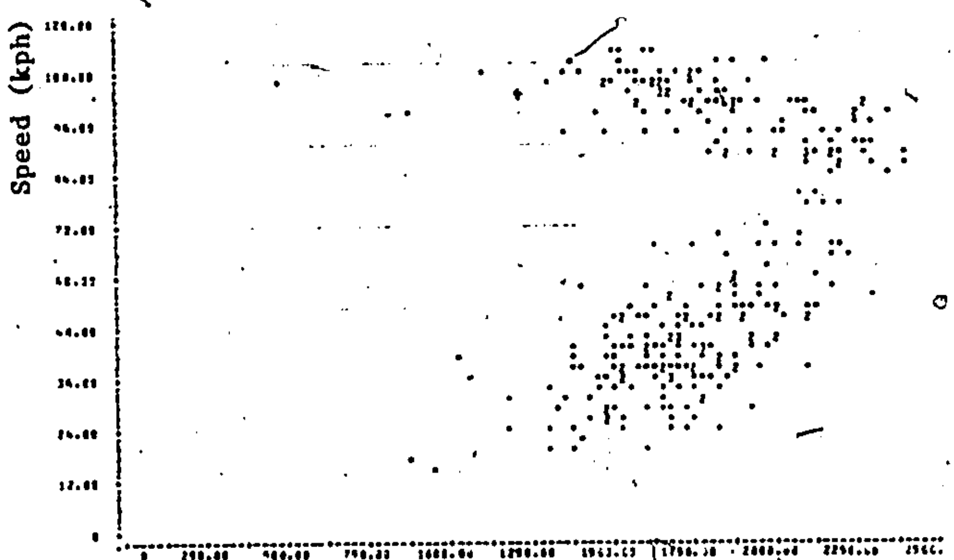


(ii) 2.5-5.0% Trucks

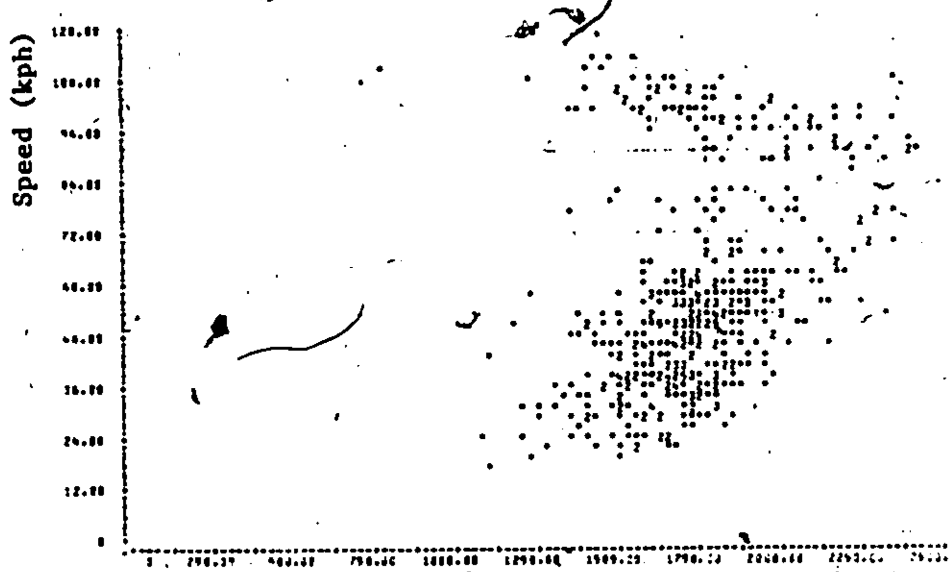
Figure A4.6 Speed-Flow (vph) Data at Varying Percent Trucks, Station 4, Median Lane



(i) 0-2.5% Trucks

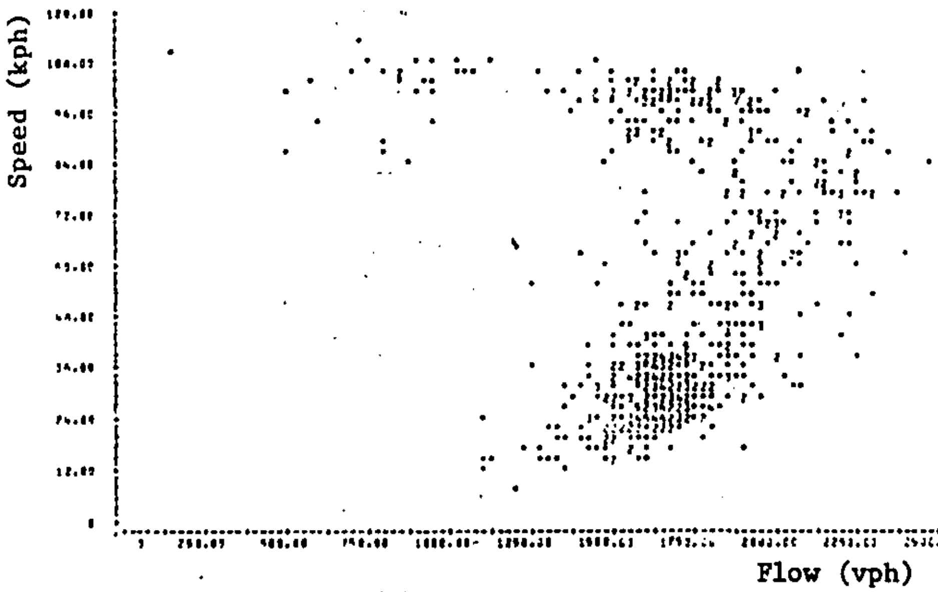


(ii) 2.5-5.0% Trucks

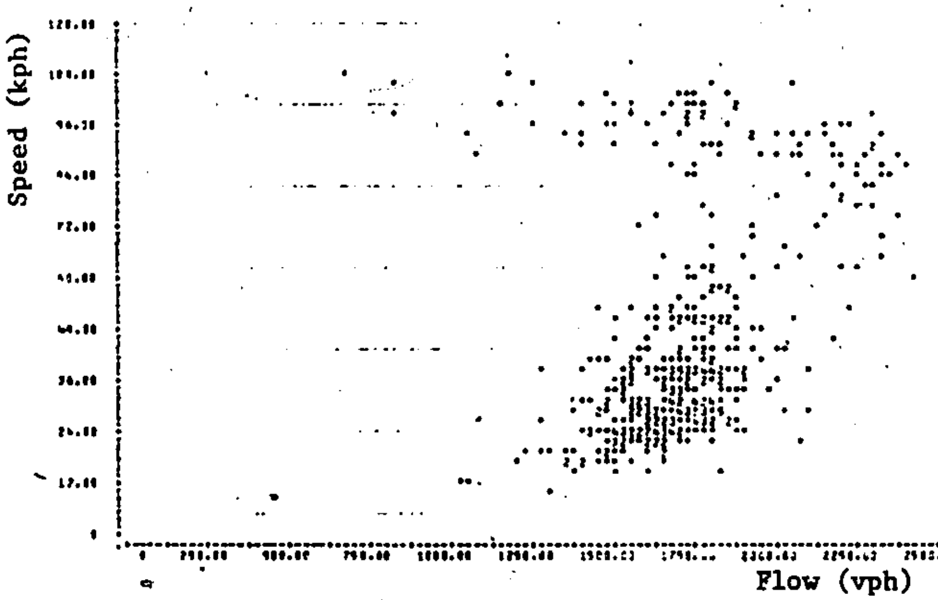


(iii) 5.0-7.5% Trucks

Figure A4.7 Speed-Flow (vph) Data at Varying Percent Trucks, Station 7, Median Lane



(i) 0-2.5% Trucks



(ii) 2.5-5.0% Trucks

Figure A4.8 Speed-Flow (vph) Data at Varying Percent Trucks, Station 8, Median Lane

APPENDIX 5

Speed-flow data plots for adverse weather conditions.

For rainy and snowy weather conditions, speed-flow curves are shown for the QEW (Mississauga) on a lane basis. Data are shown for rain at Stations 8 and 9 and for snow at Stations 1-9. The numbers in each plot represent the number of data points plotted at the same spot, e.g. 2 represents that two points occur at the same spot. The number 9 however, means that nine or more points are located there.

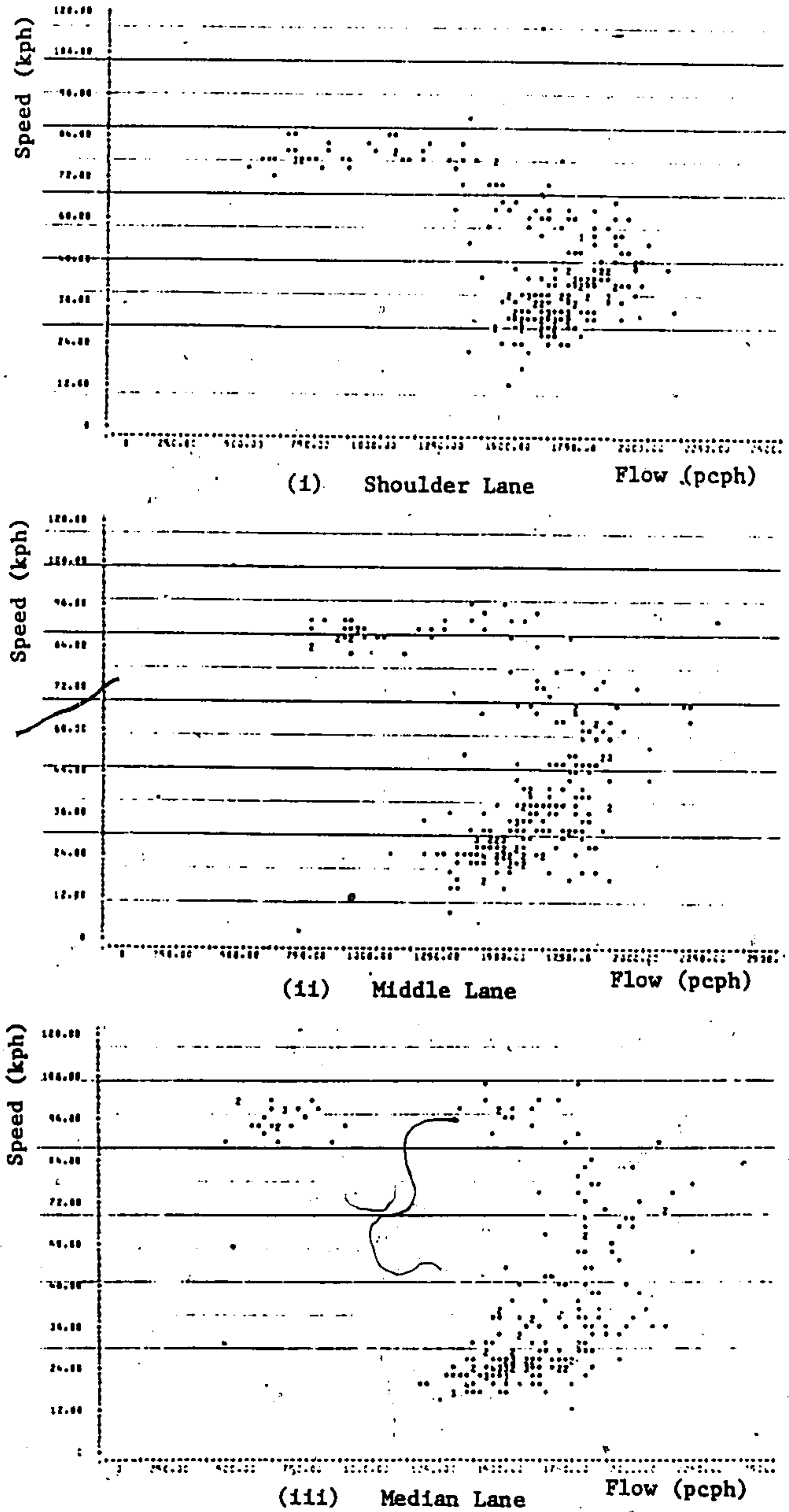


Figure A5.1 Speed-Flow Data, Station 8, Rain

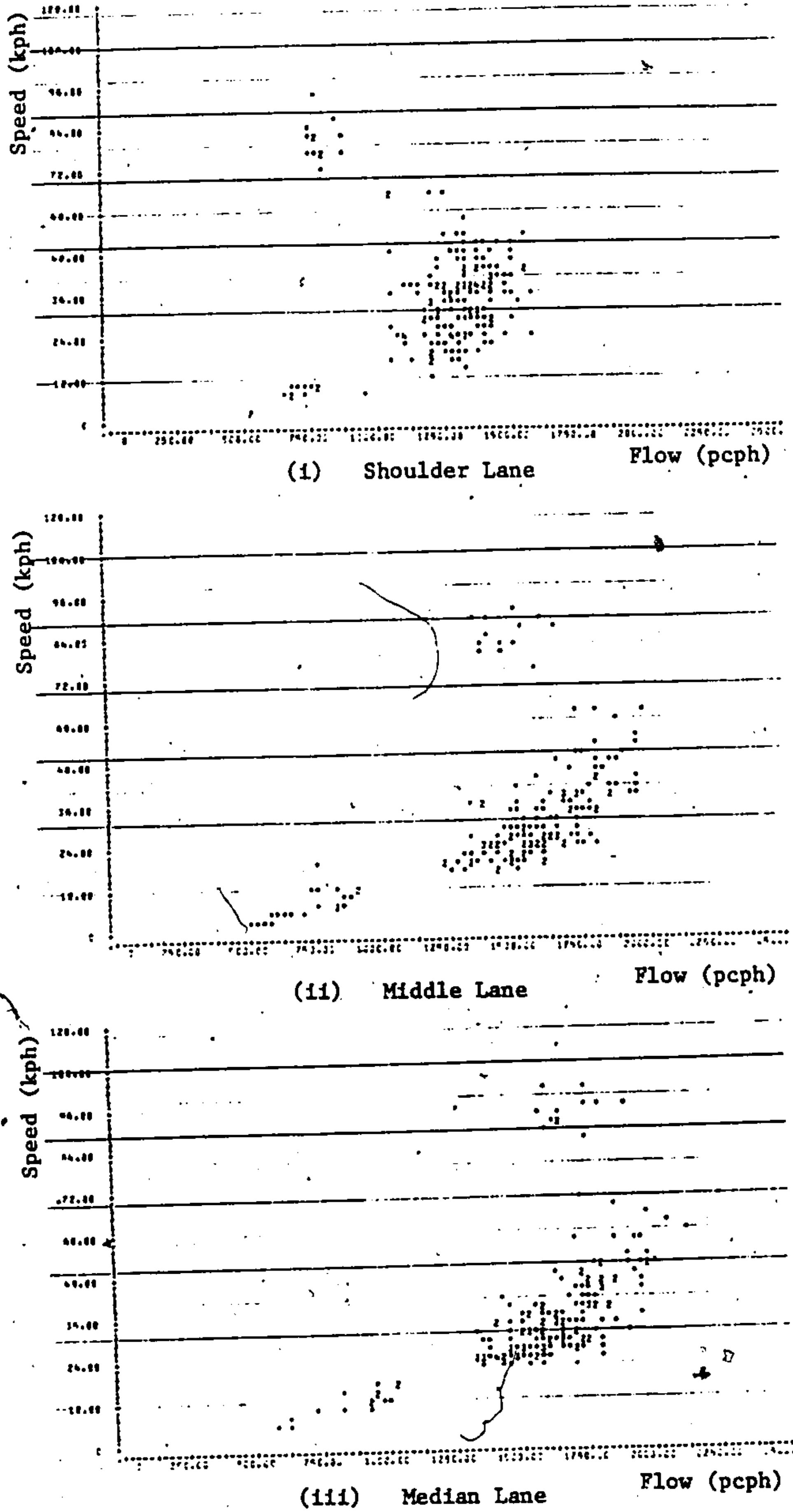
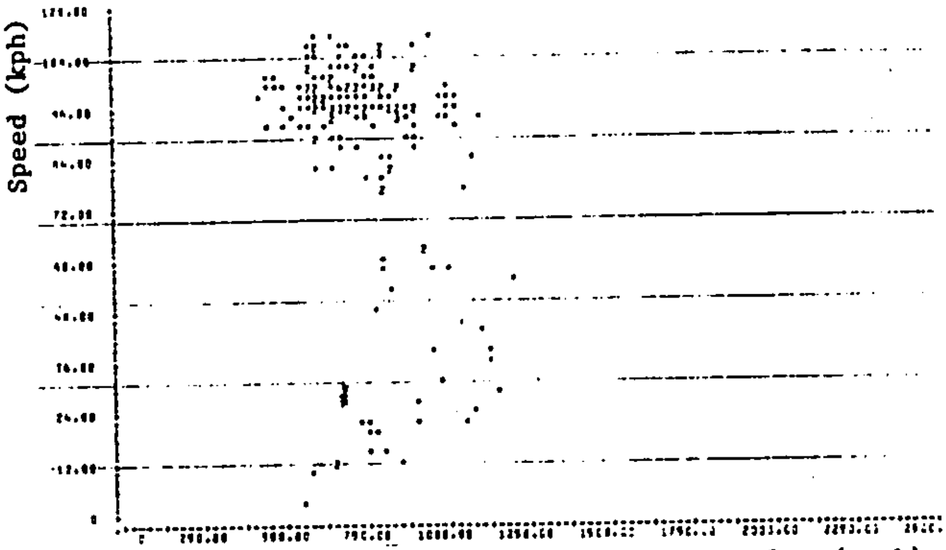
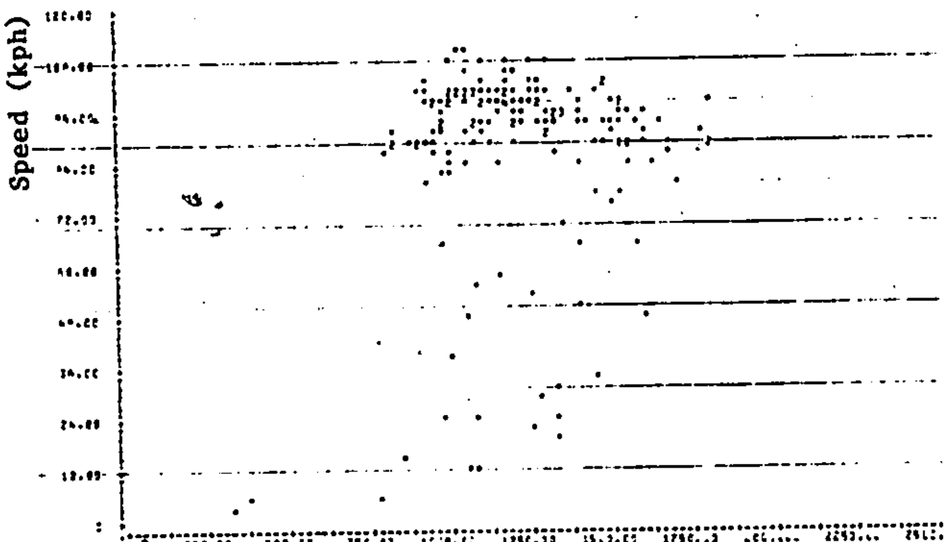


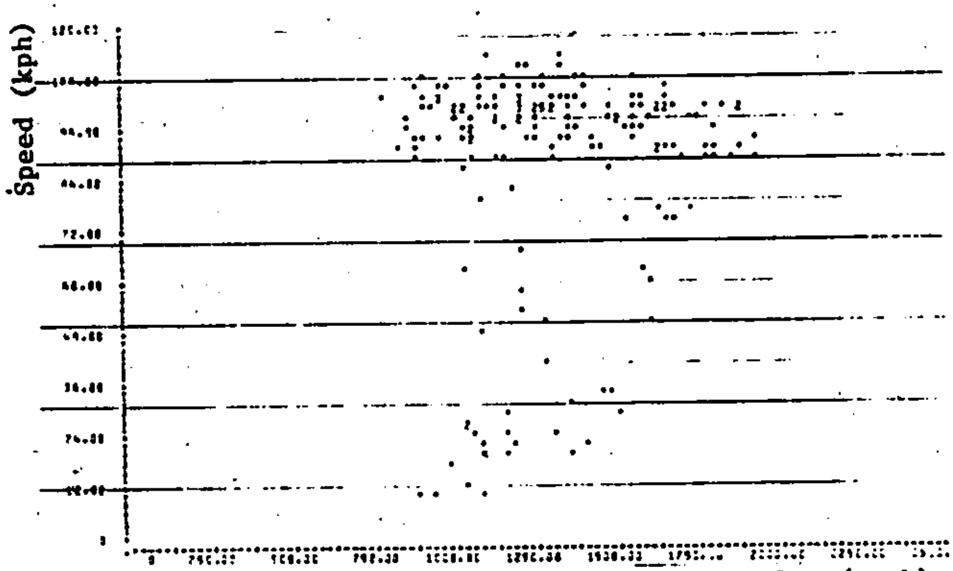
Figure A5.2 Speed-Flow Data, Station 9, Rain



(i) Shoulder Lane

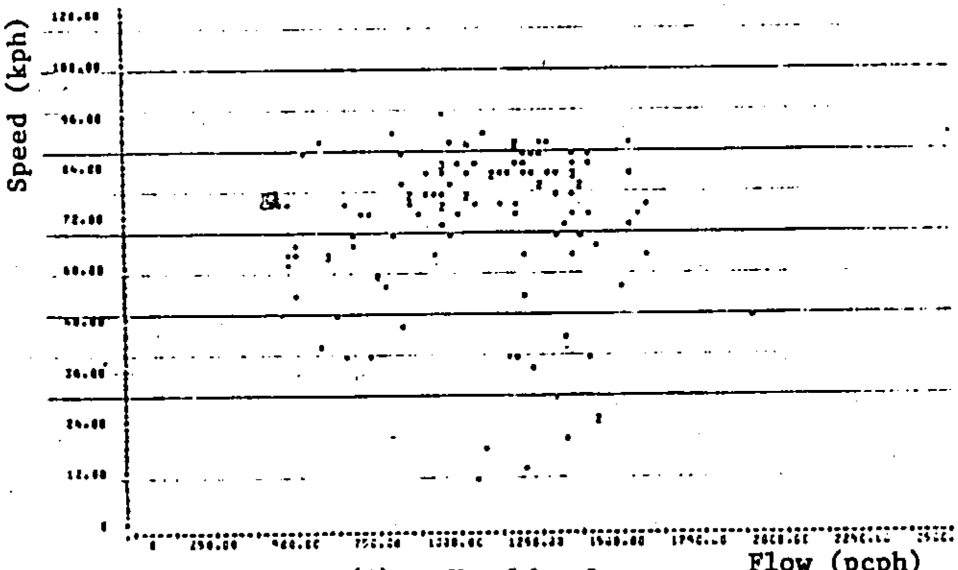


(ii) Middle Lane

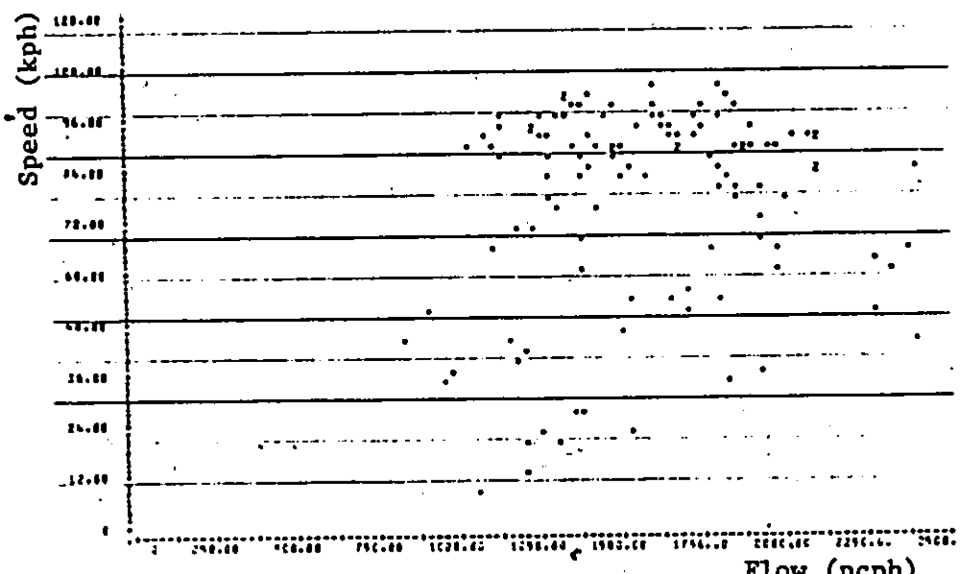


(iii) Median Lane

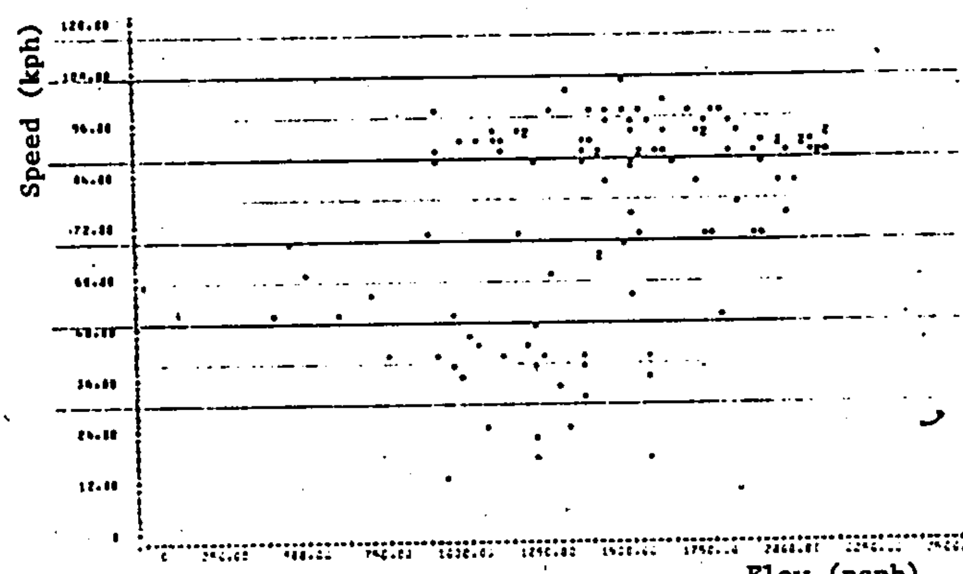
Figure A5.3 Speed-Flow Data, Station 1, Snow



(i) Shoulder Lane

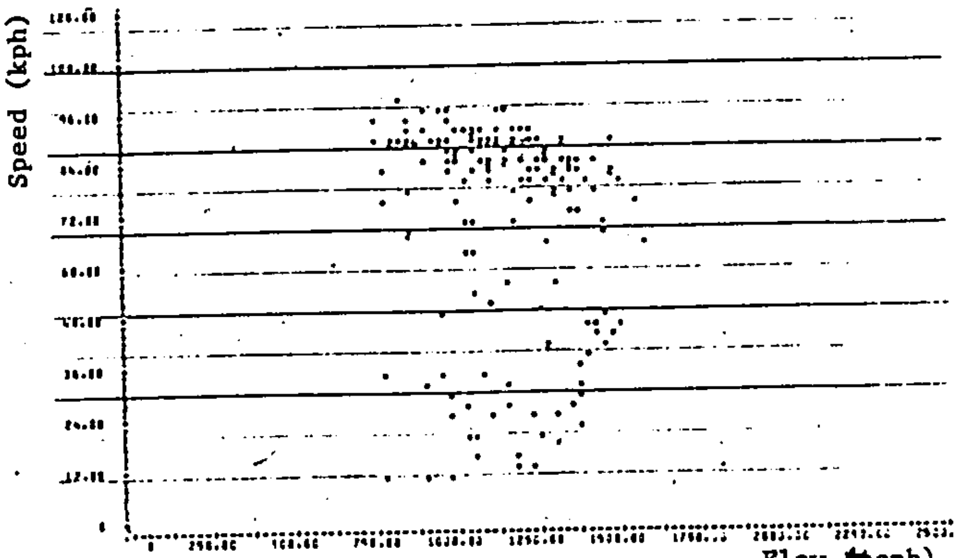


(ii) Middle Lane

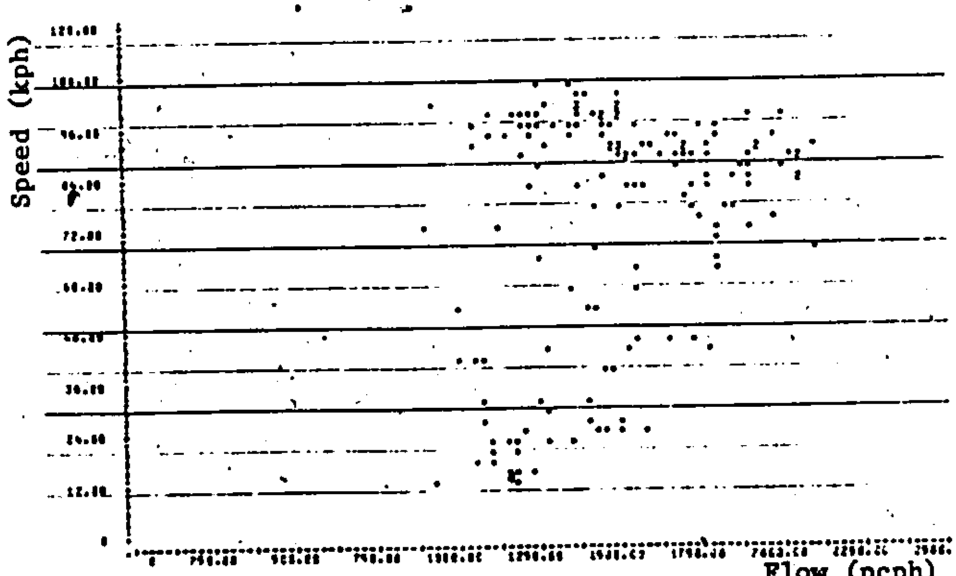


(iii) Median Lane

Figure A5.4 Speed-Flow Data, Station 2, Snow

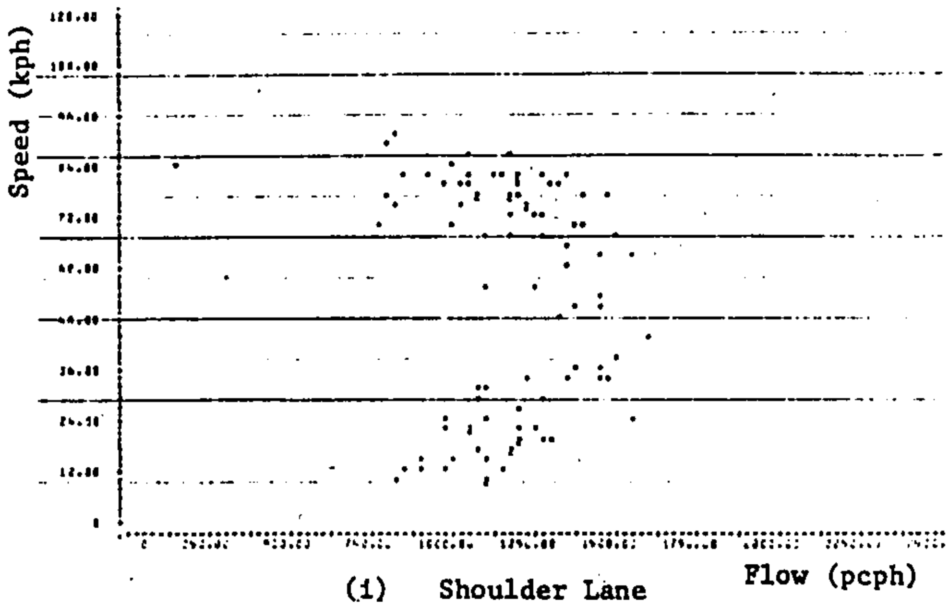


(i) Shoulder Lane

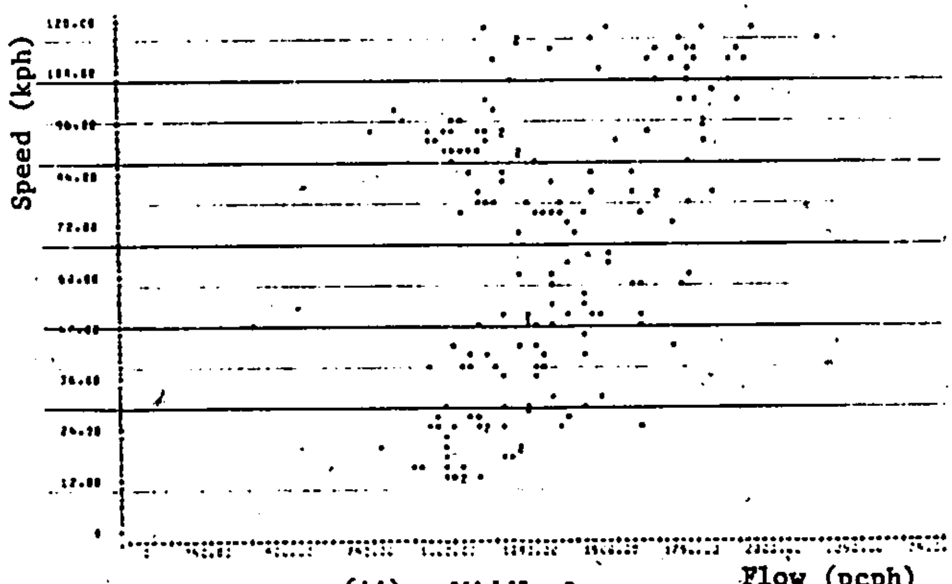


(ii) Median Lane

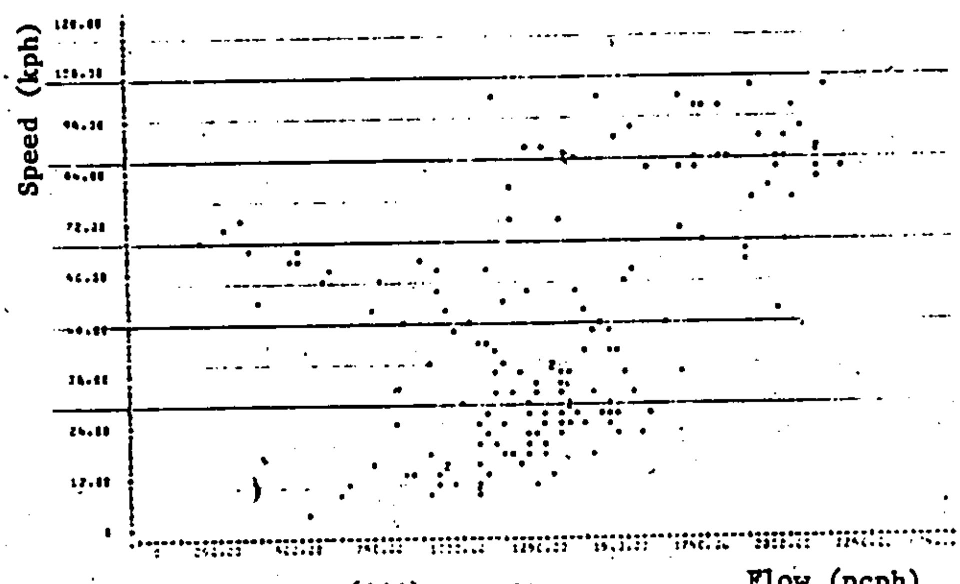
Figure A5.5 Speed-Flow Data, Station 3, Snow



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A5.6 Speed-Flow Data, Station 4, Snow

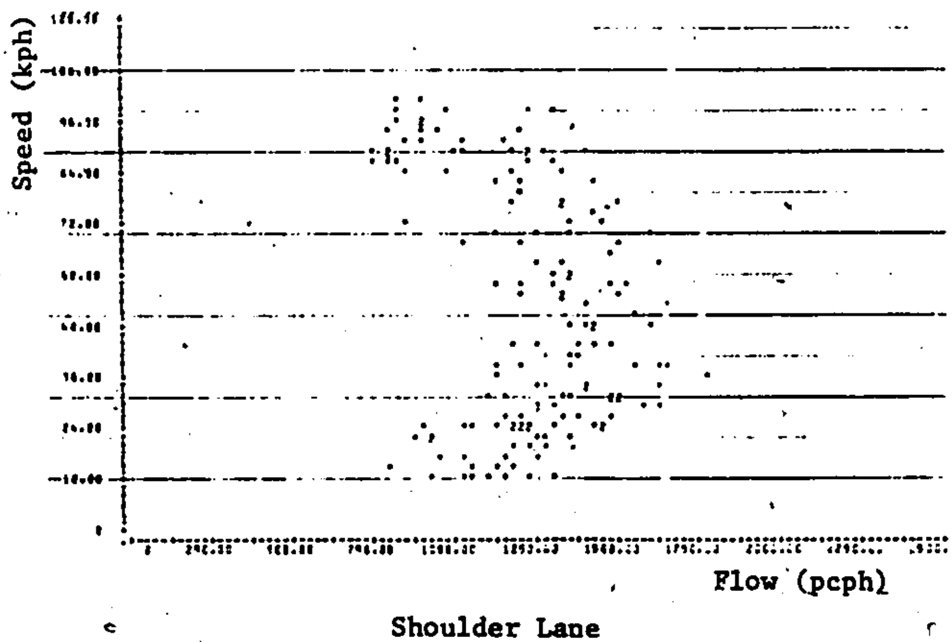
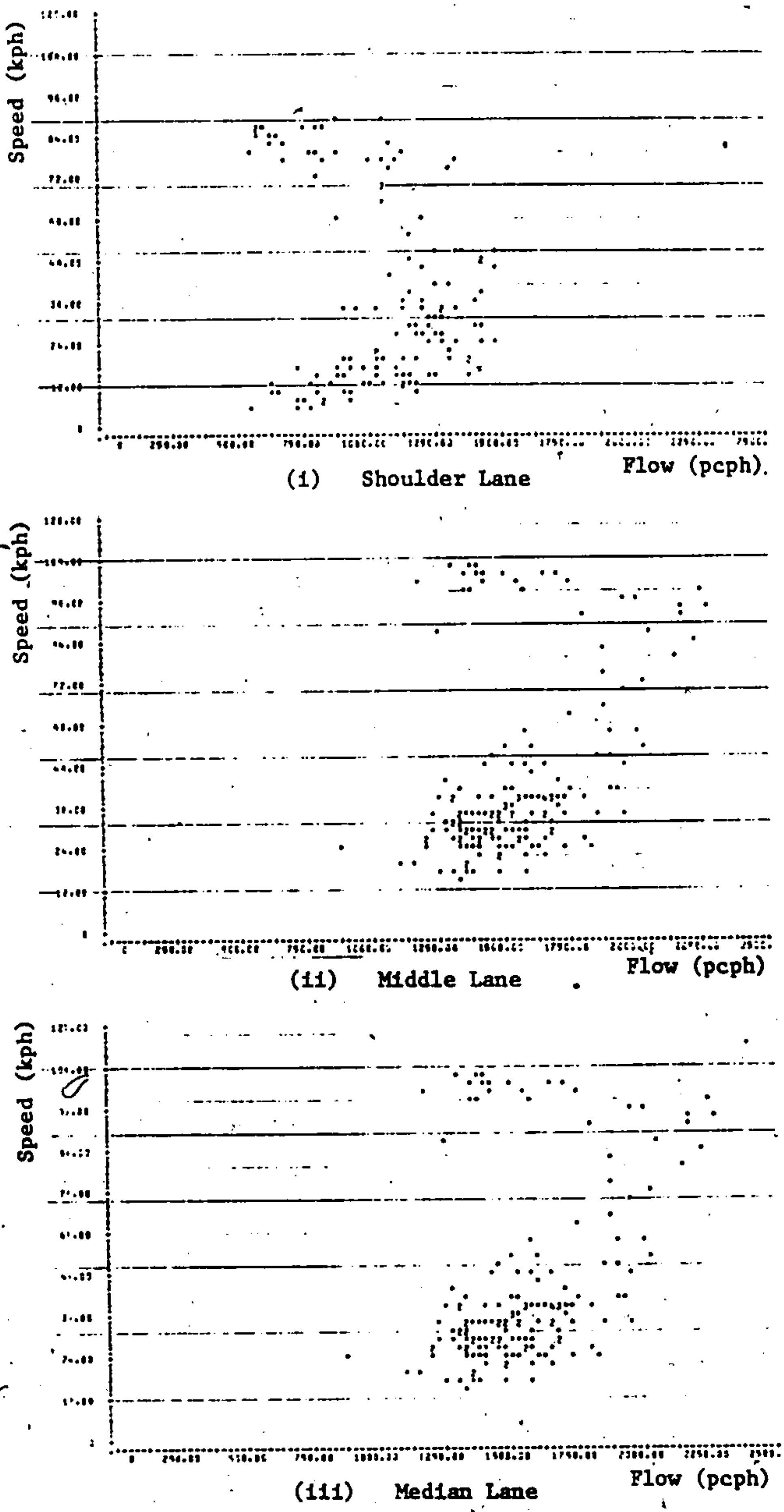


Figure A5.7 Speed-Flow Data, Station 5, Snow

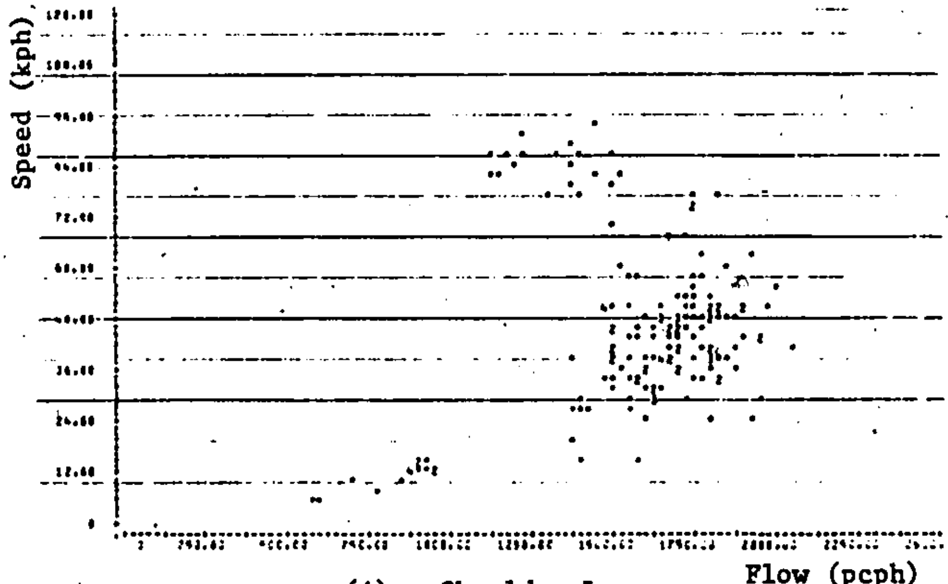


(i) Shoulder Lane

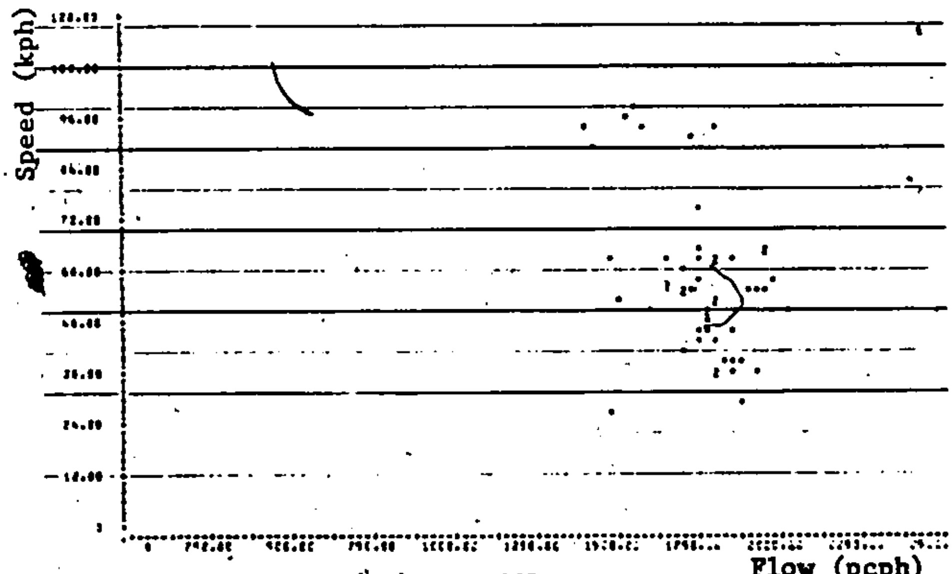
(ii) Middle Lane

(iii) Median Lane

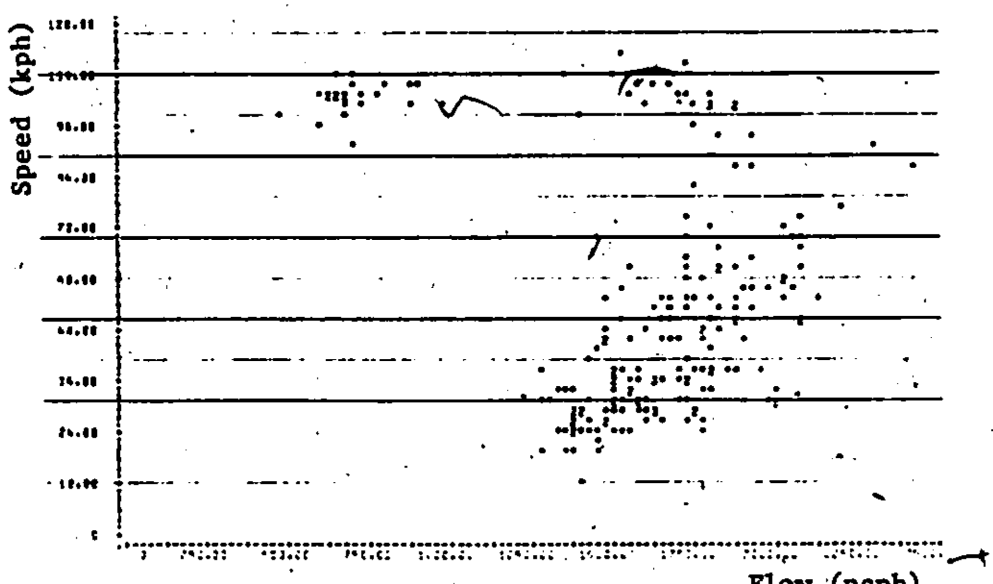
Figure A5.8 Speed-Flow Data, Station 6, Snow



(i) Shoulder Lane

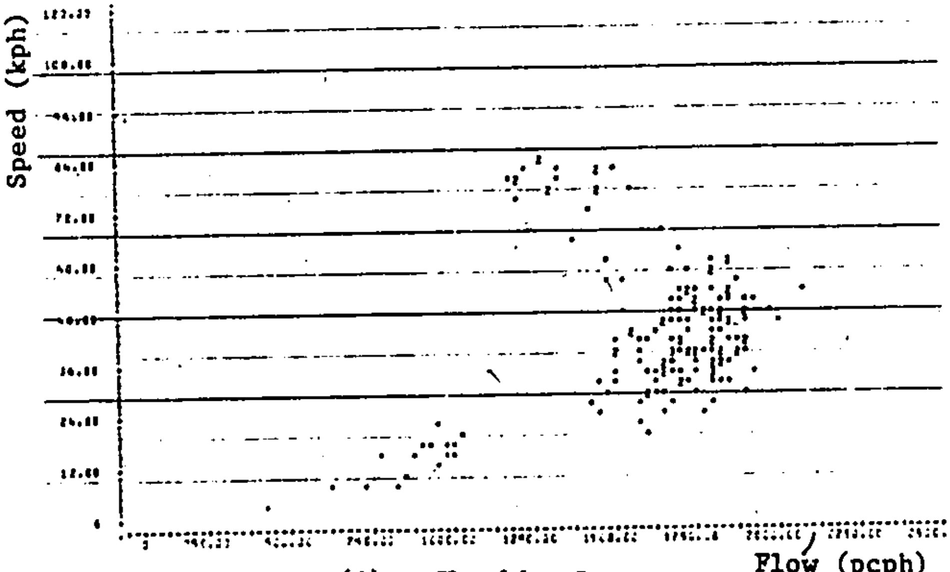


(ii) Middle Lane

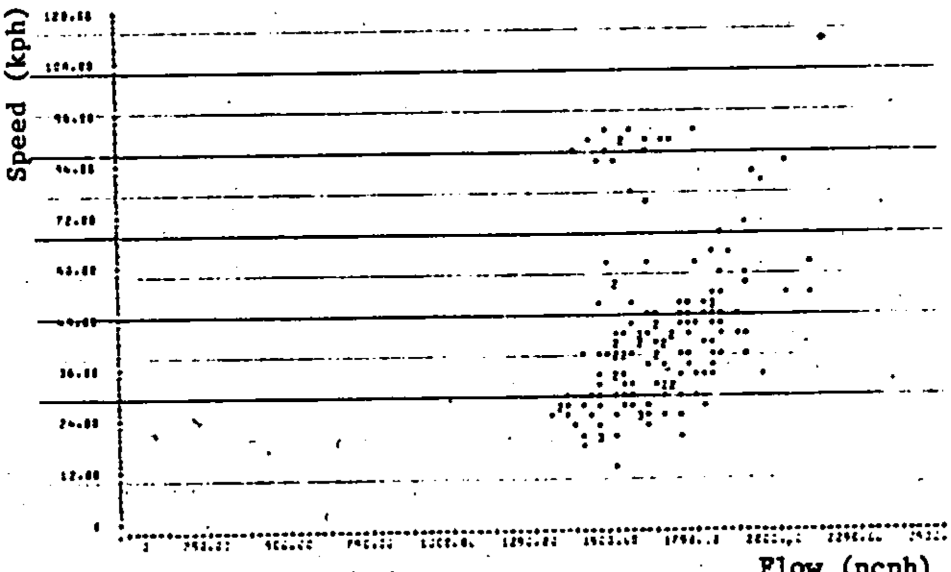


(iii) Median Lane

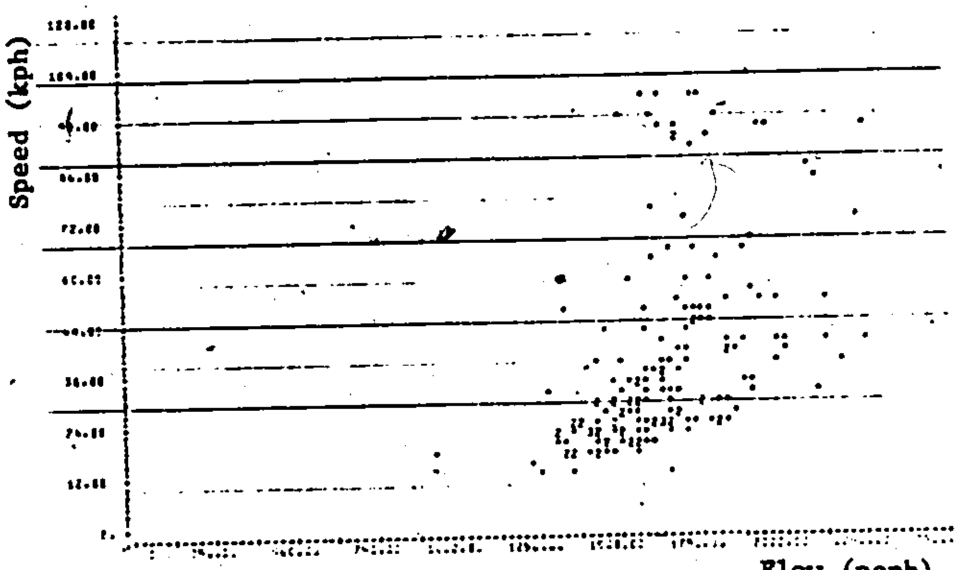
Figure A5.9 Speed-Flow Data, Station 7, Snow



(i) Shoulder Lane

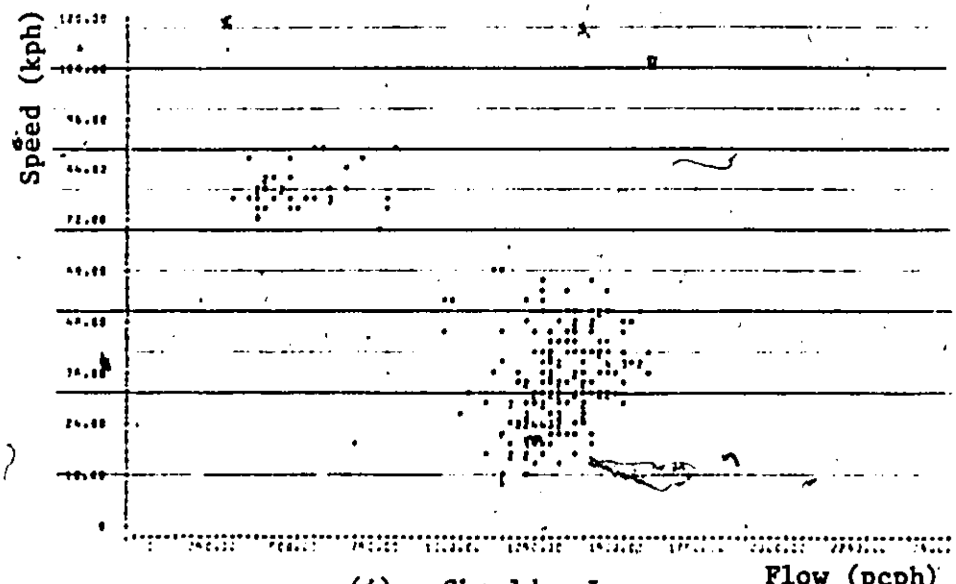


(ii) Middle Lane

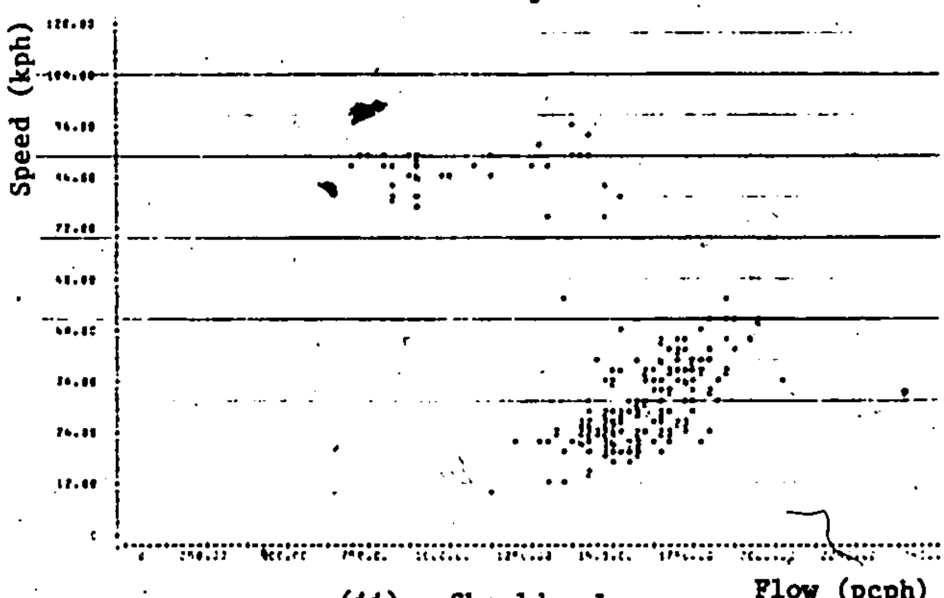


(iii) Median Lane

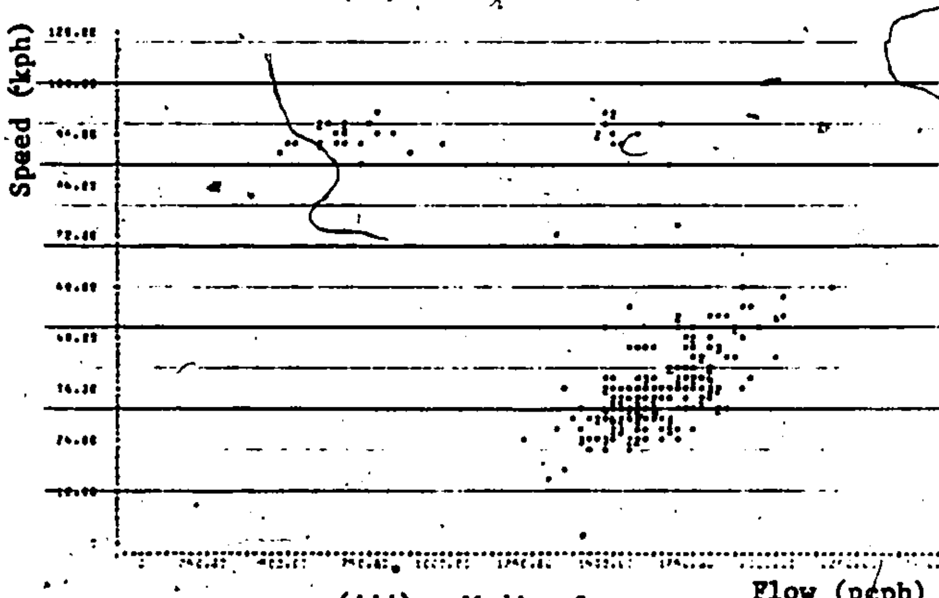
Figure A5.10 Speed-Flow Data, Station 8, Snow



(i) Shoulder Lane



(ii) Shoulder Lane



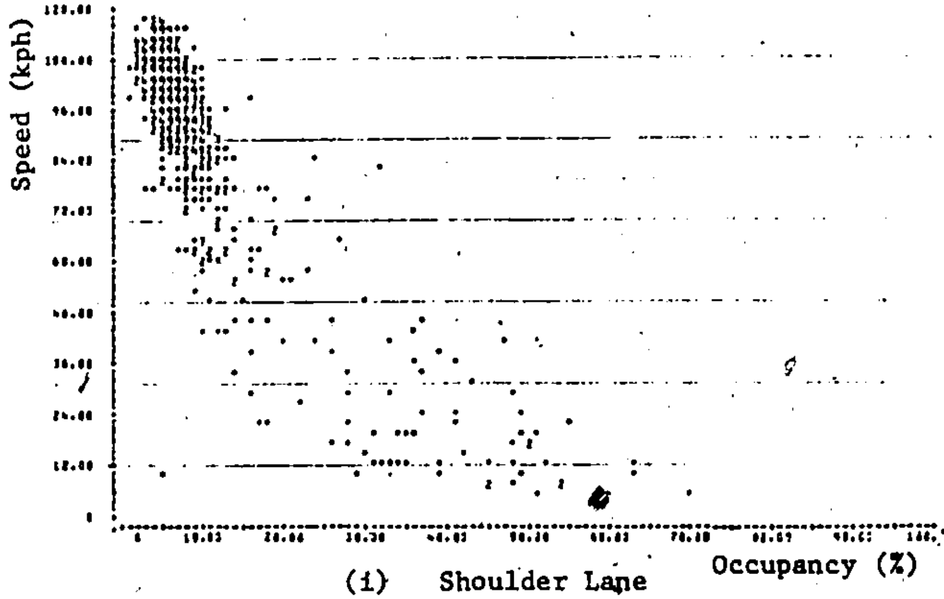
(iii) Median Lane

Figure A5.11 Speed-Flow Data, Station 9, Snow

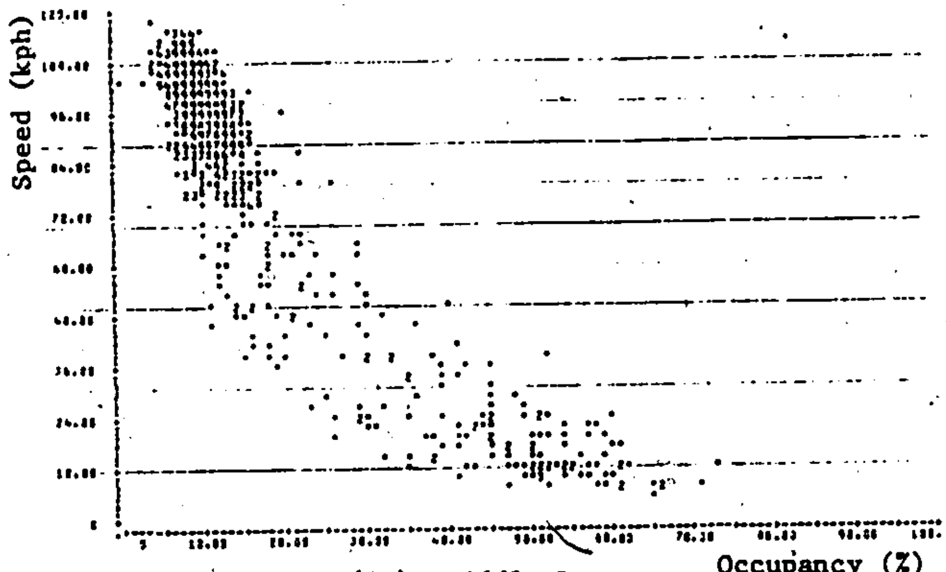
APPENDIX 6

Occupancy, speed and flow relationships.

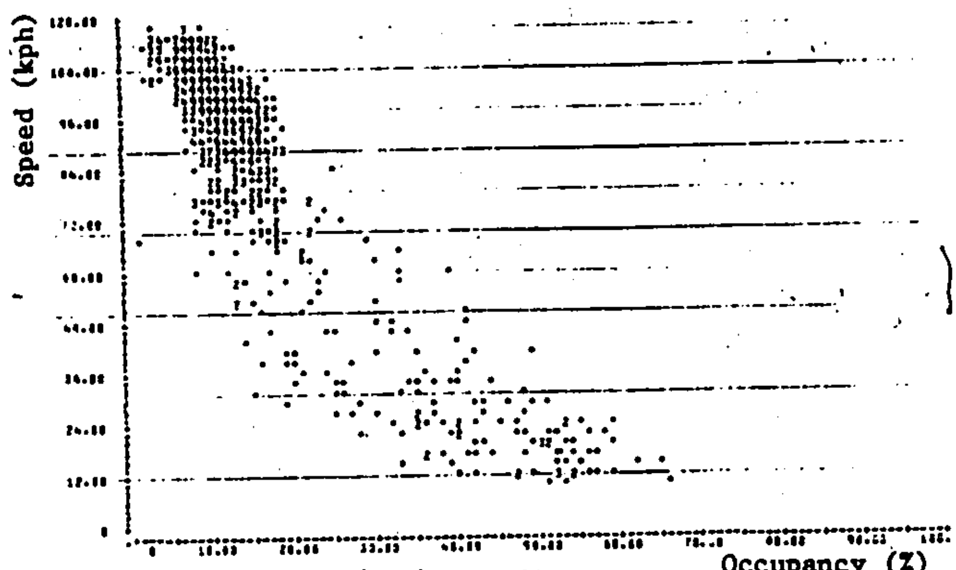
Speed-occupancy and occupancy-flow plots are included herein for Stations 1-9 on a lane basis. Speed, flow and occupancy values are recorded in kph, pcph and percentages respectively. The numbers in each plot represent the number of data points plotted at the same spot, e.g. 2 represents that two points occur at the same spot. The number 9 however, means that nine or more points are located there.



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A6.1 Speed-Occupancy Data, Station 1

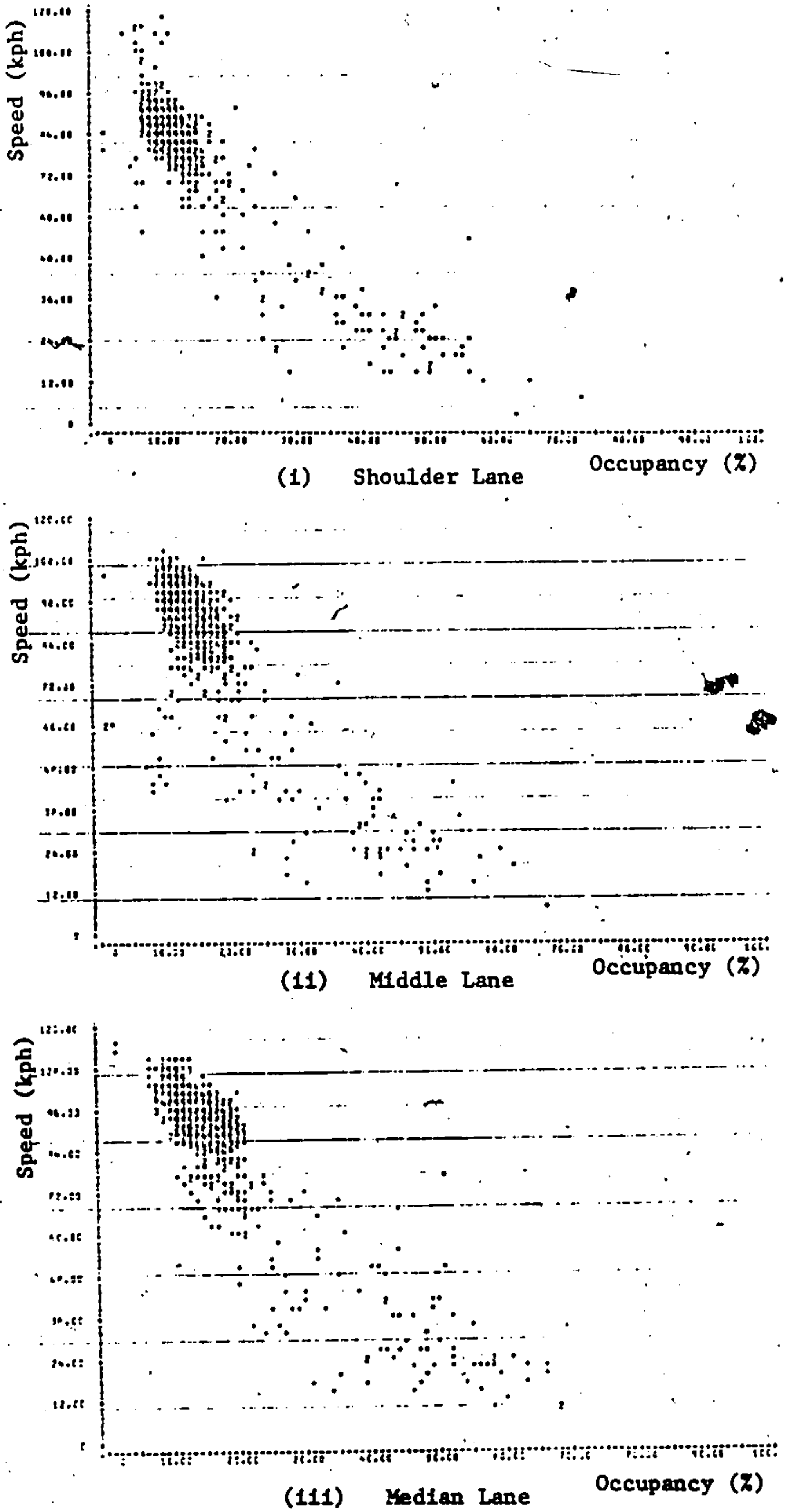
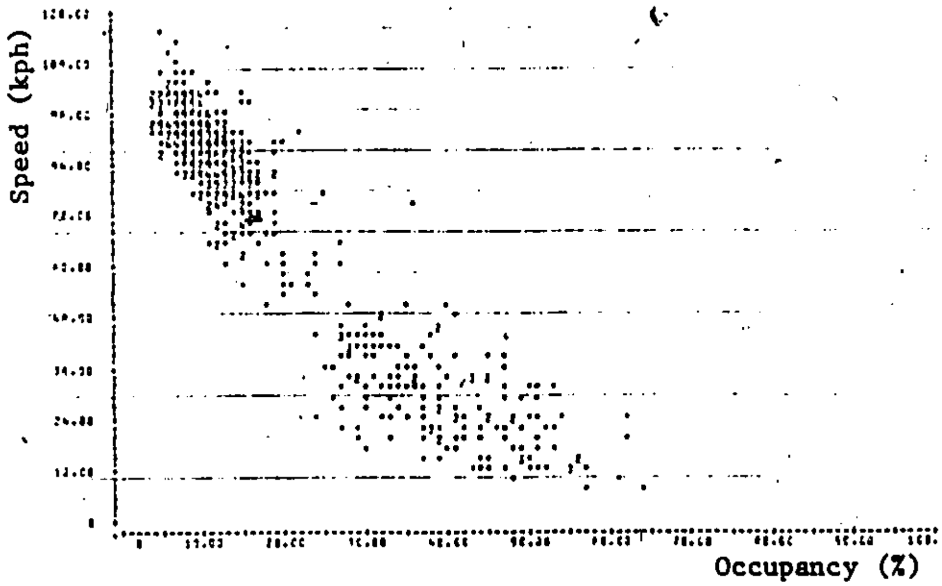
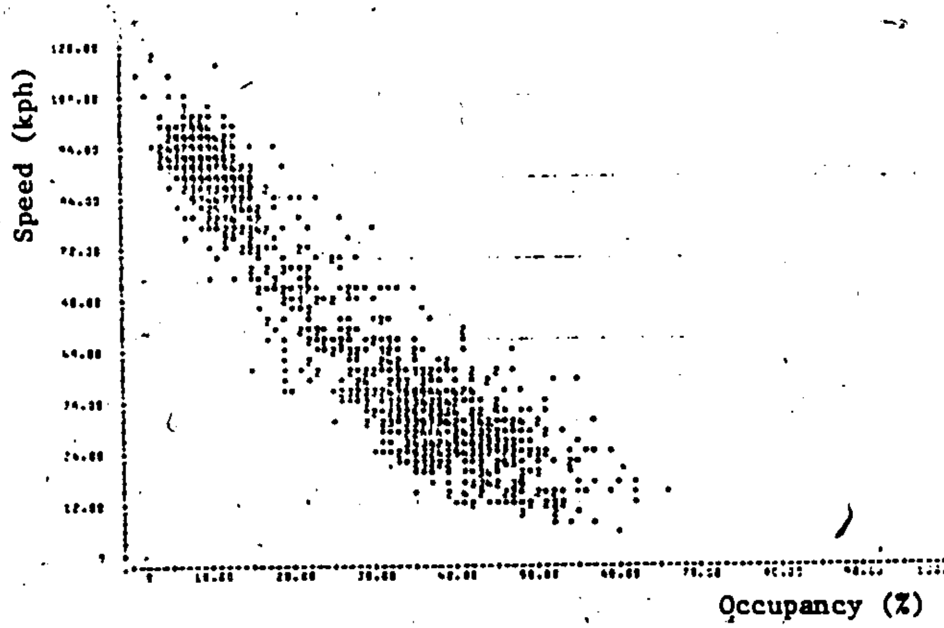


Figure A6.2 Speed-Occupancy Data, Station 2

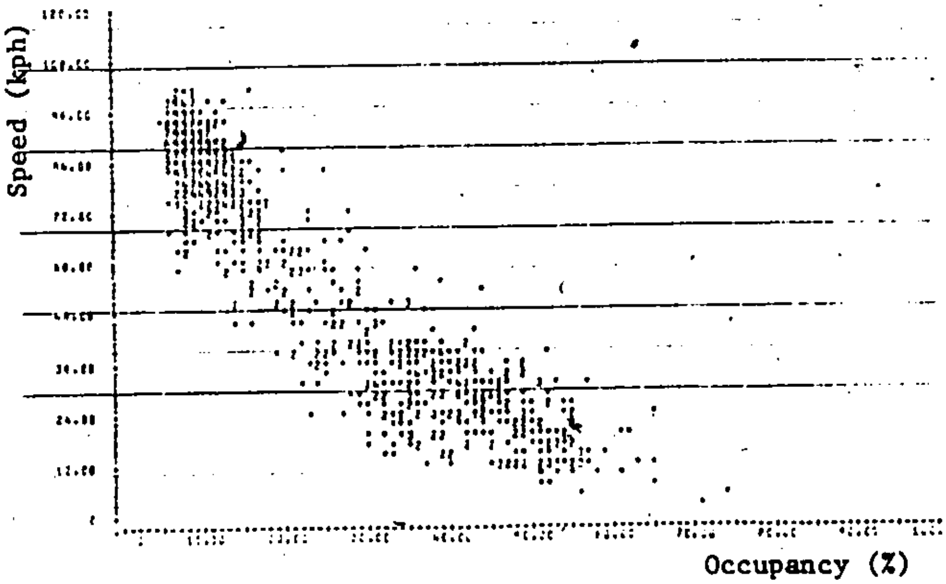


(i) Shoulder Lane

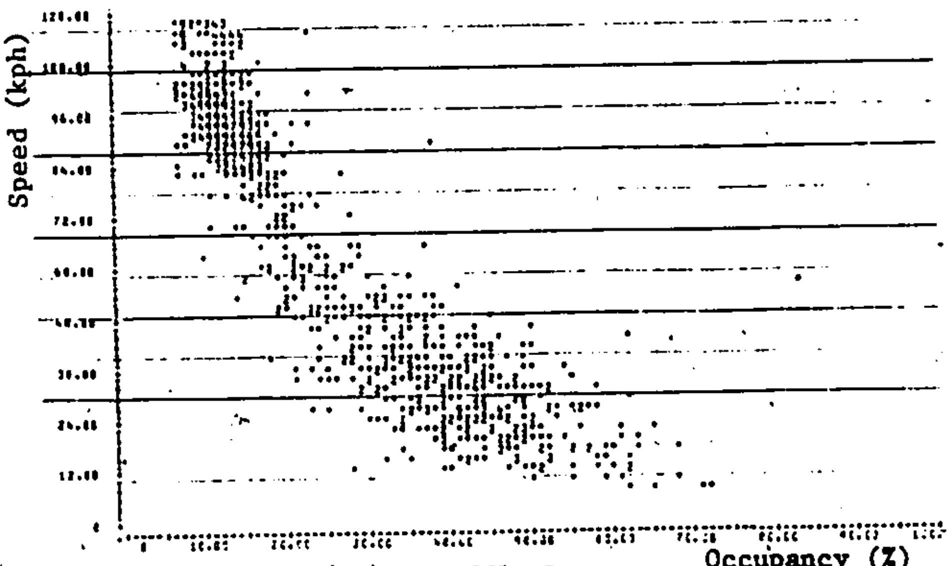


(ii) Median Lane

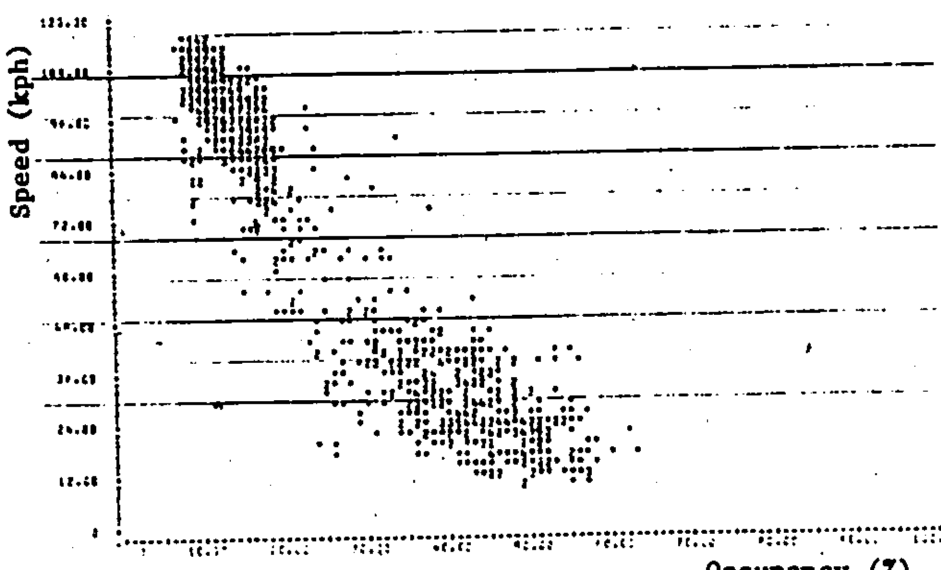
Figure A6.3 Speed-Occupancy Data, Station 3



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A6.4 Speed-Occupancy Data, Station 4

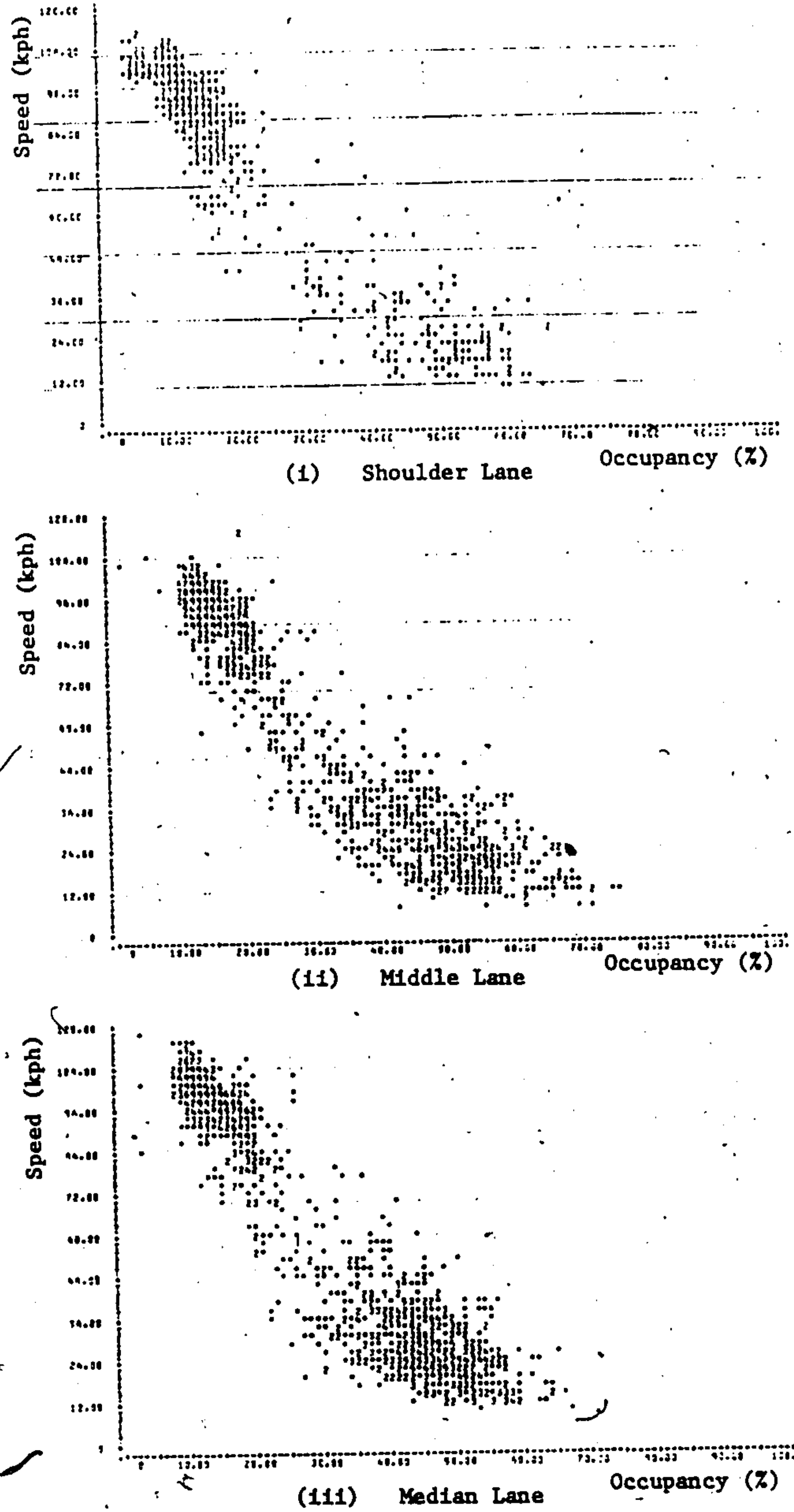


Figure A6.5 . Speed-Occupancy Data, Station 5

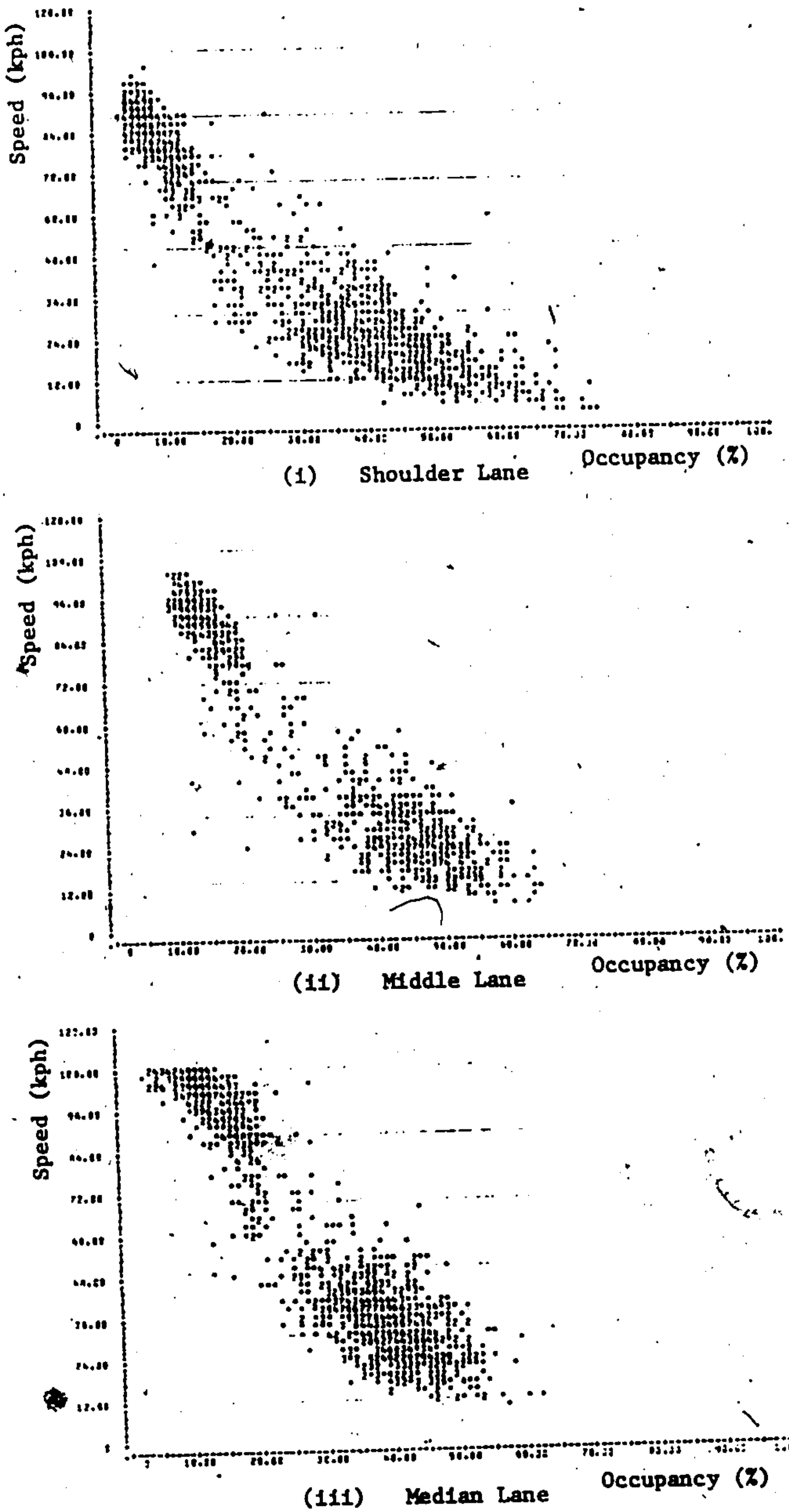
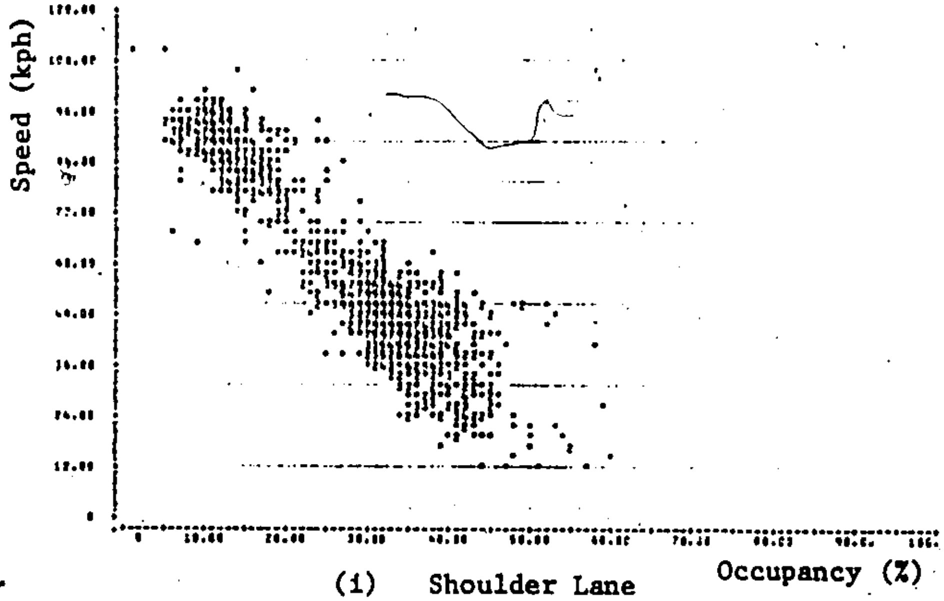
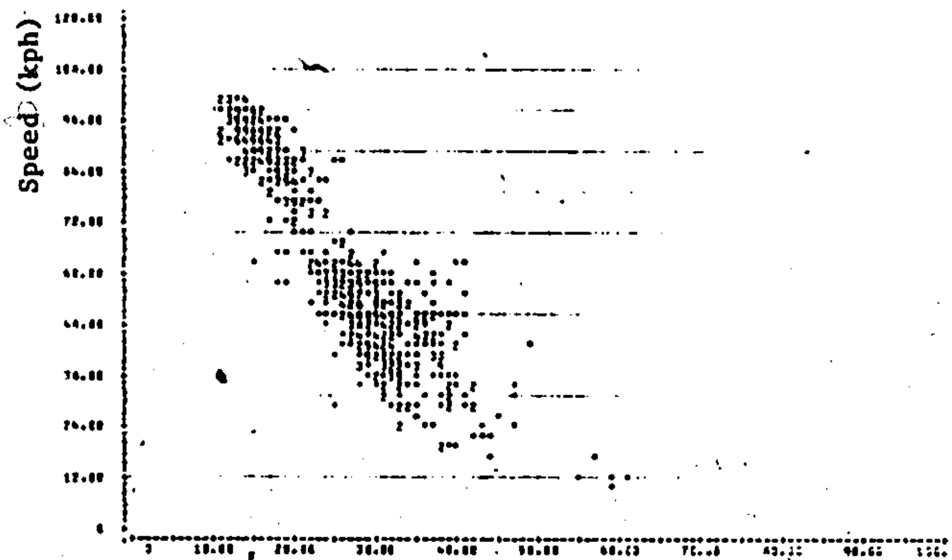


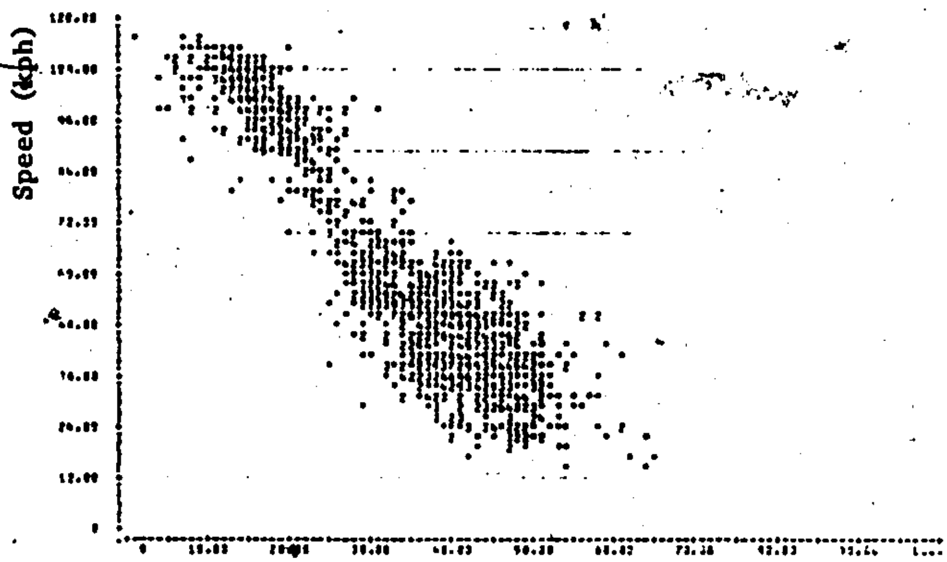
Figure A6.6 Speed-Occupancy Data, Station 6



(i) Shoulder Lane

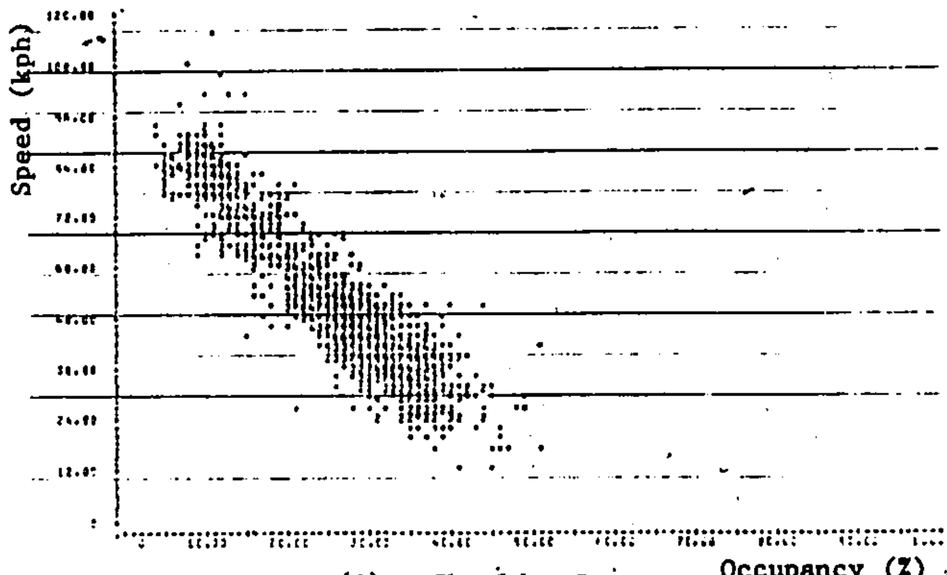


(ii) Middle Lane

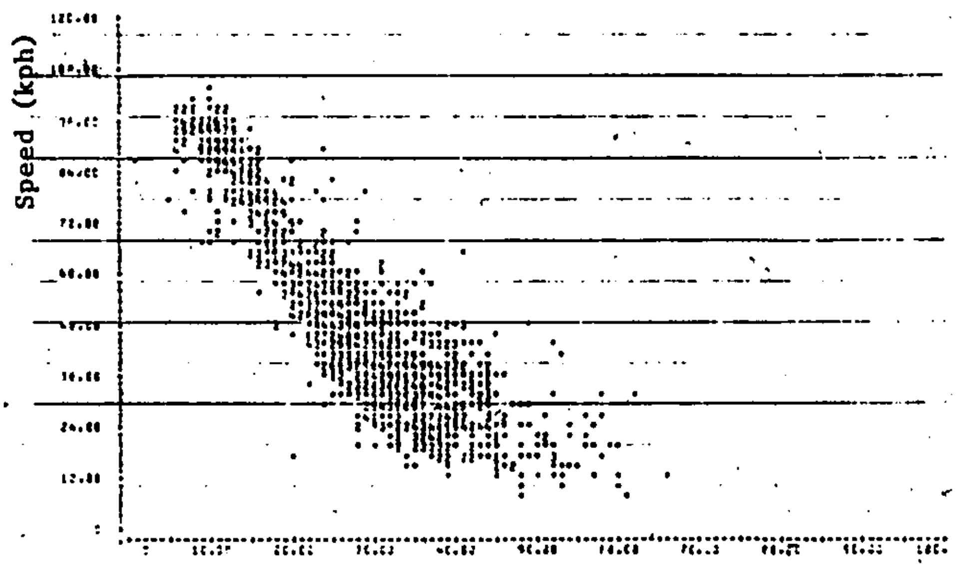


(iii) Median Lane

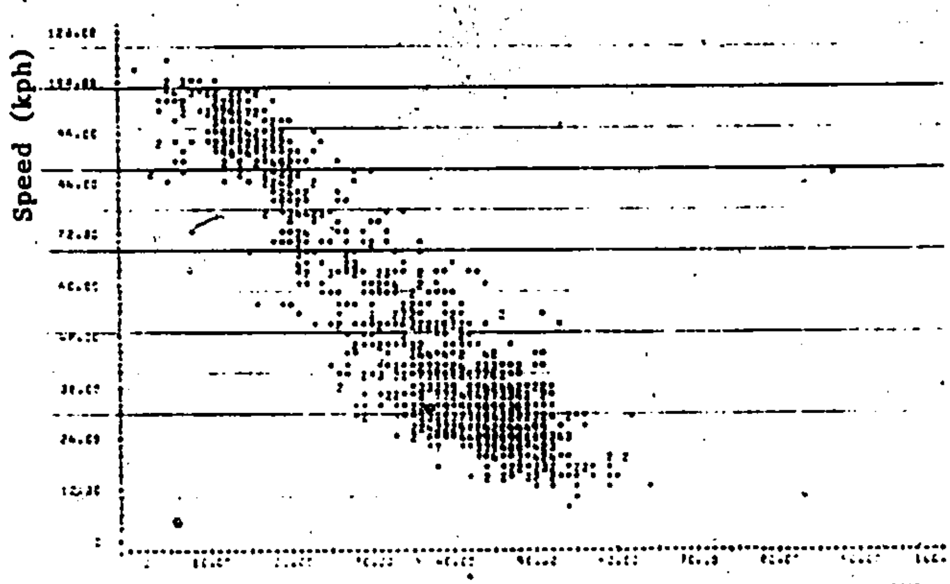
Figure A6.7 Speed-Occupancy Data, Station 7



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A6.8 Speed-Occupancy Data, Station 8

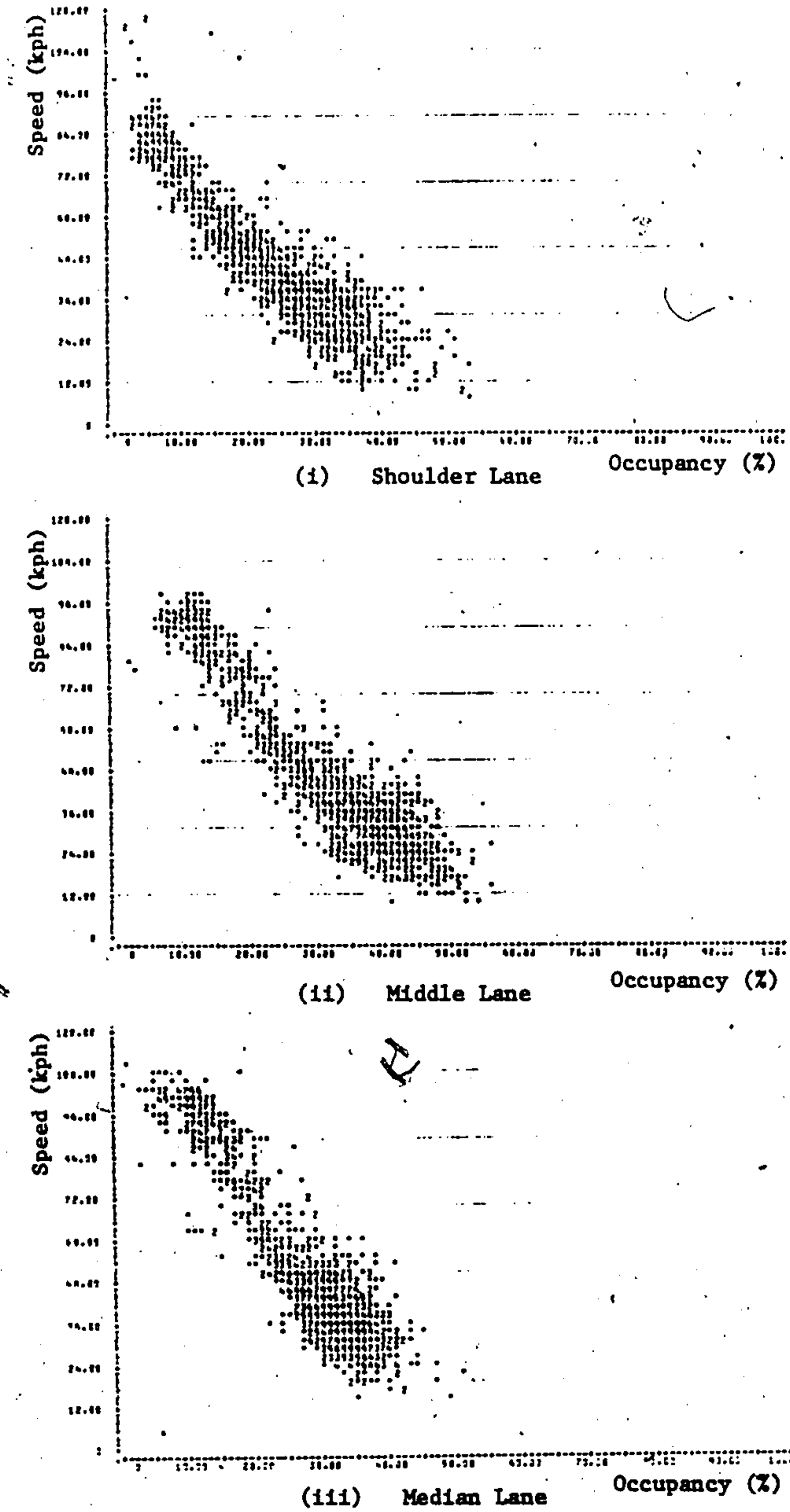
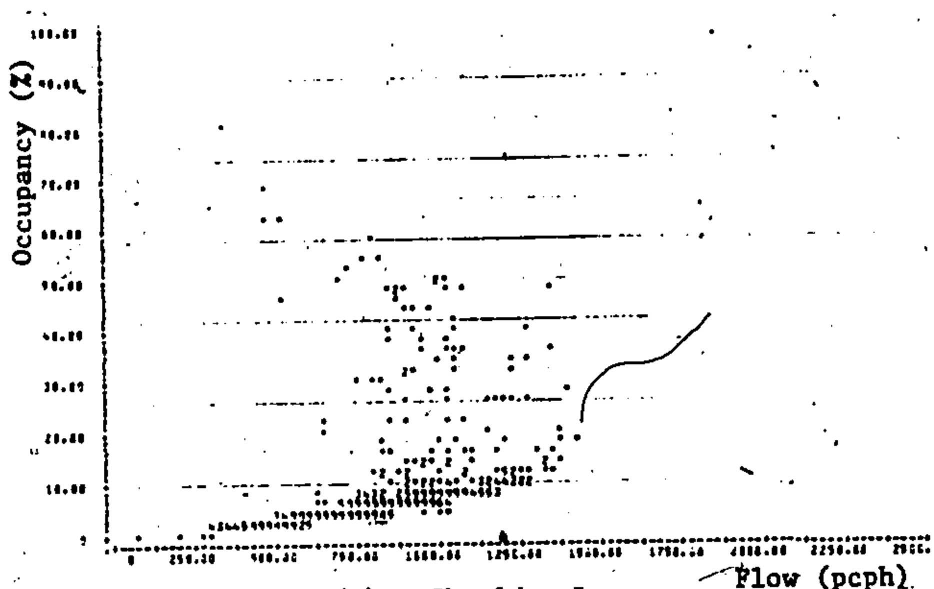
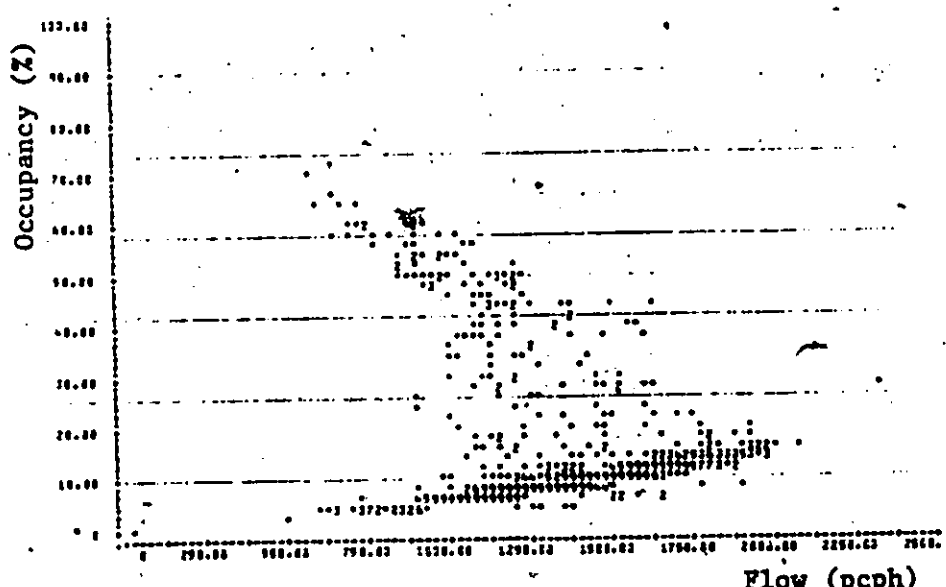


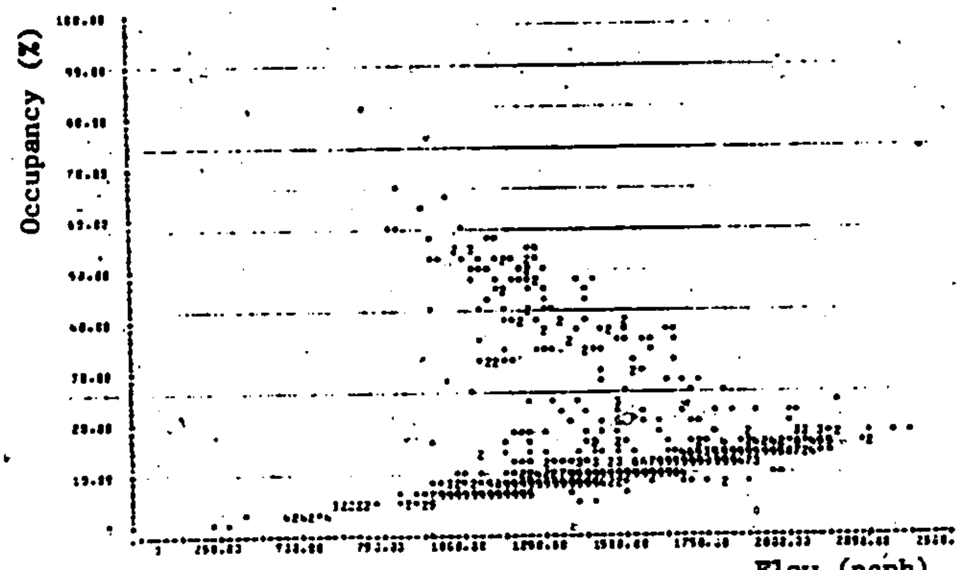
Figure A6.9 Speed-Occupancy Data, Station 9



(i) Shoulder Lane

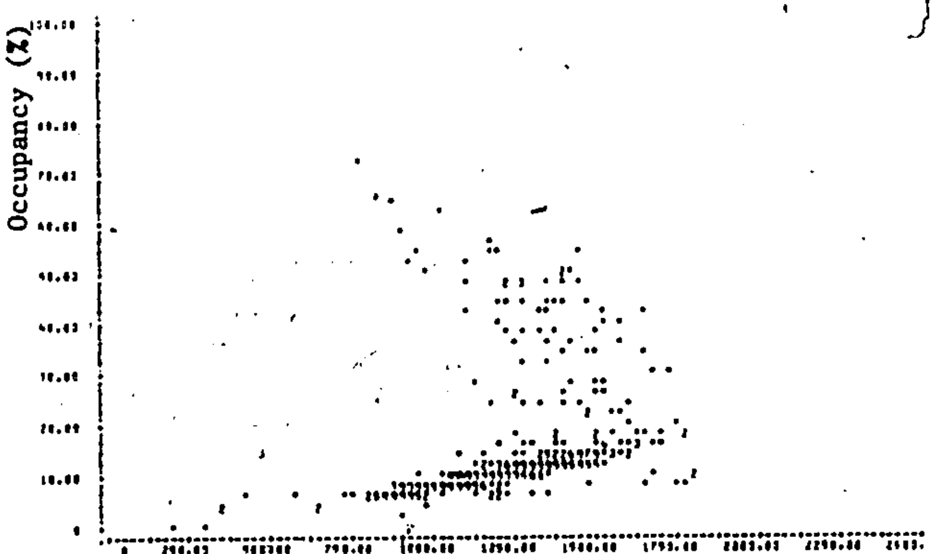


(ii) Middle Lane

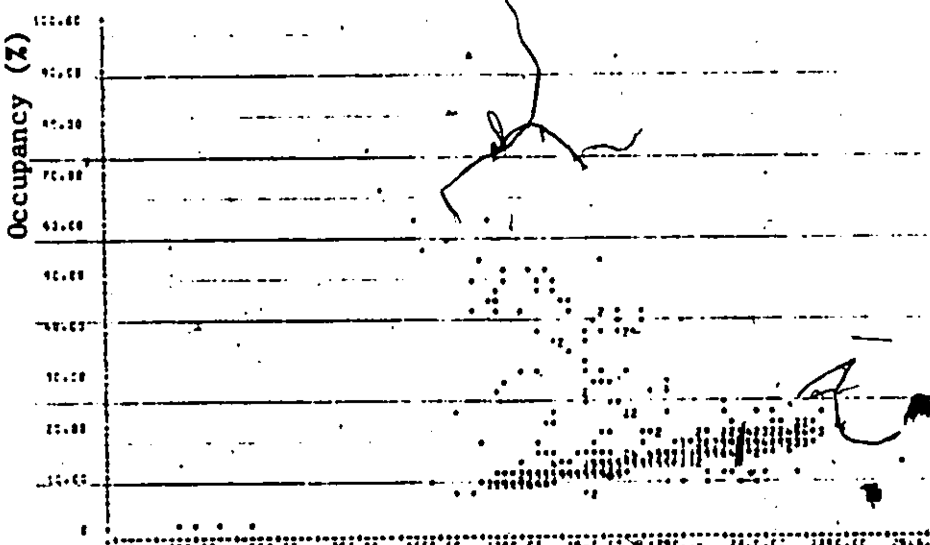


(iii) Median Lane

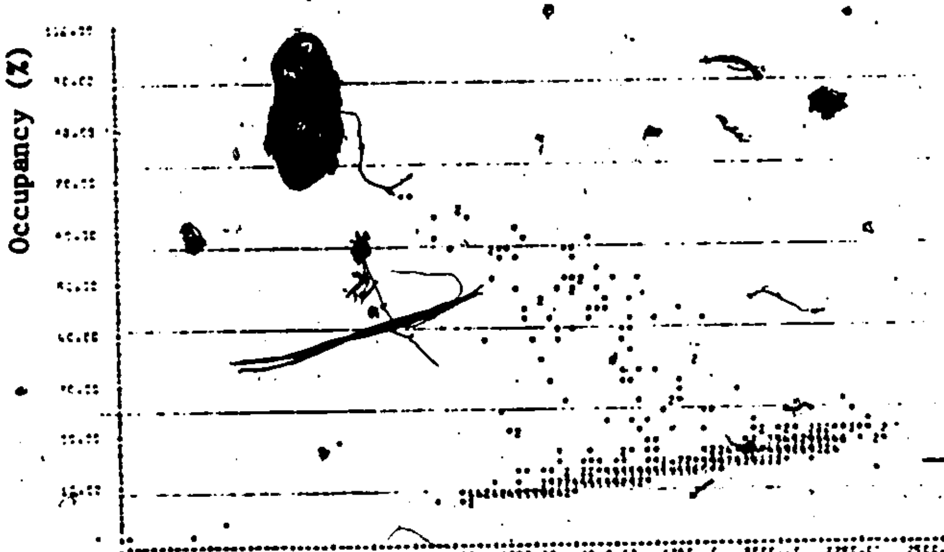
Figure A6.10 Occupancy-Flow Data, Station 1



(i) Shoulder Lane

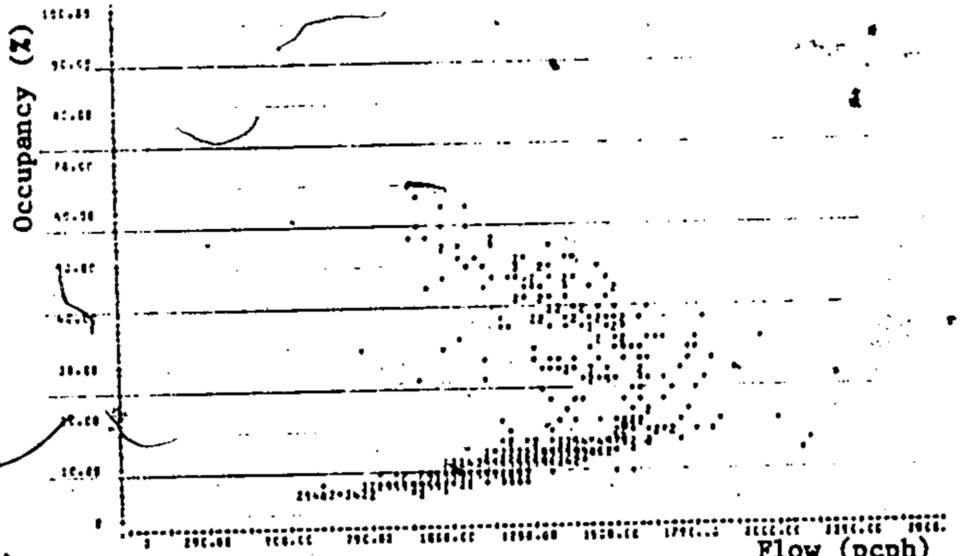


(ii) Middle Lane

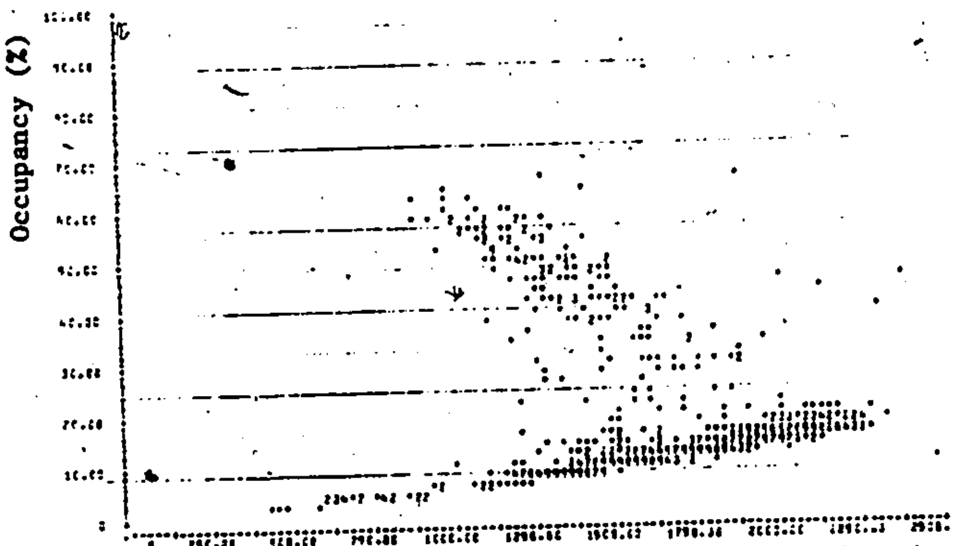


(iii) Median Lane

A6.12 Occupancy-Flow Data, Station 2

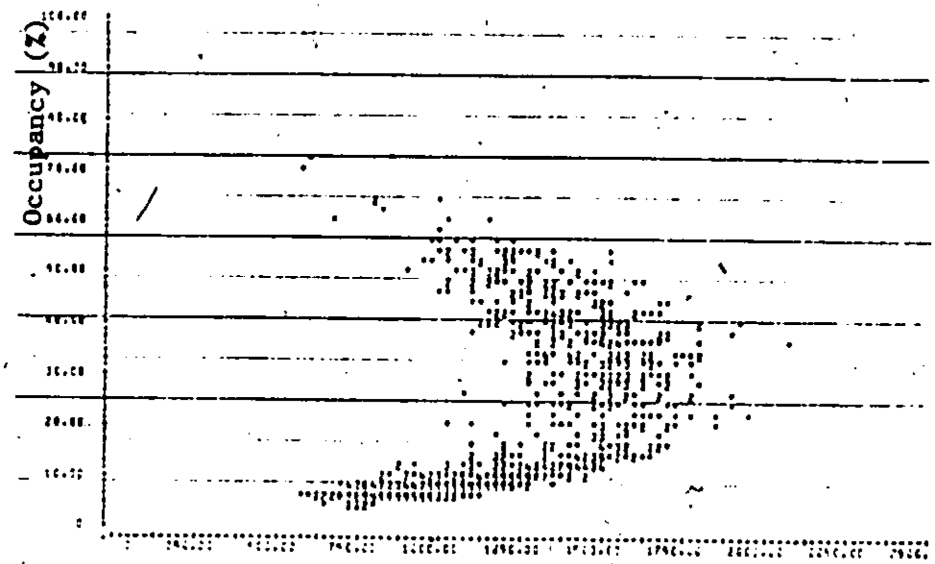


(i) Shoulder Lane

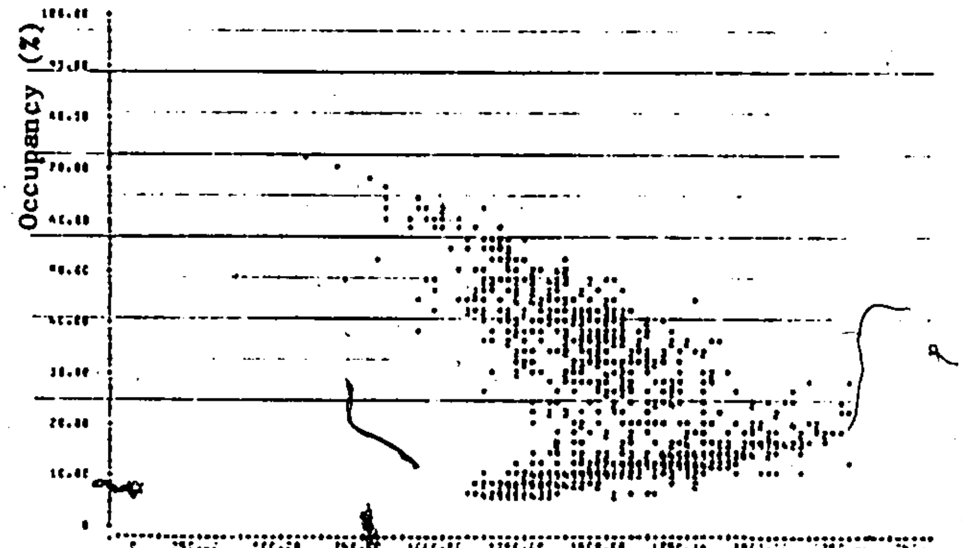


(ii) Median Lane

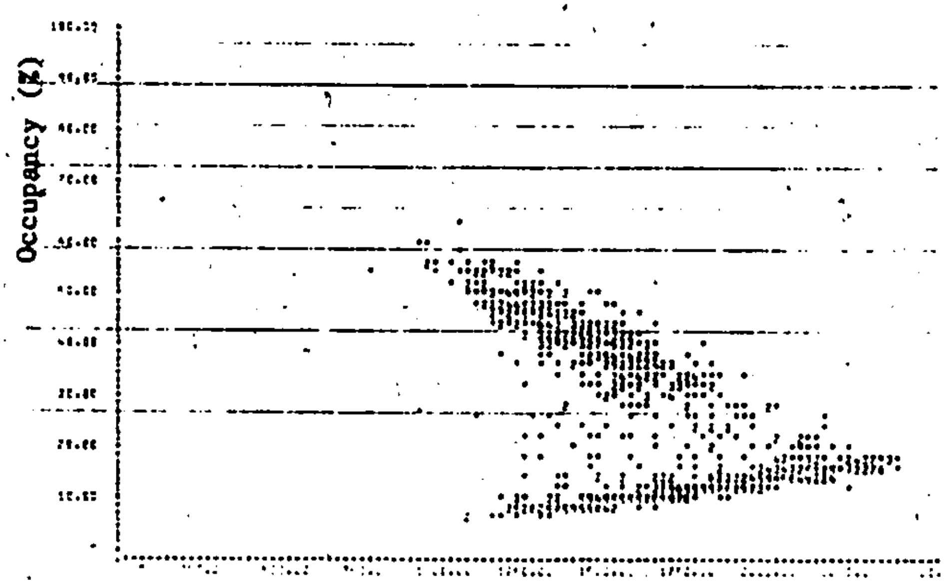
Figure A6.12 Occupancy-Flow Data, Station 3



(i) Shoulder Lane

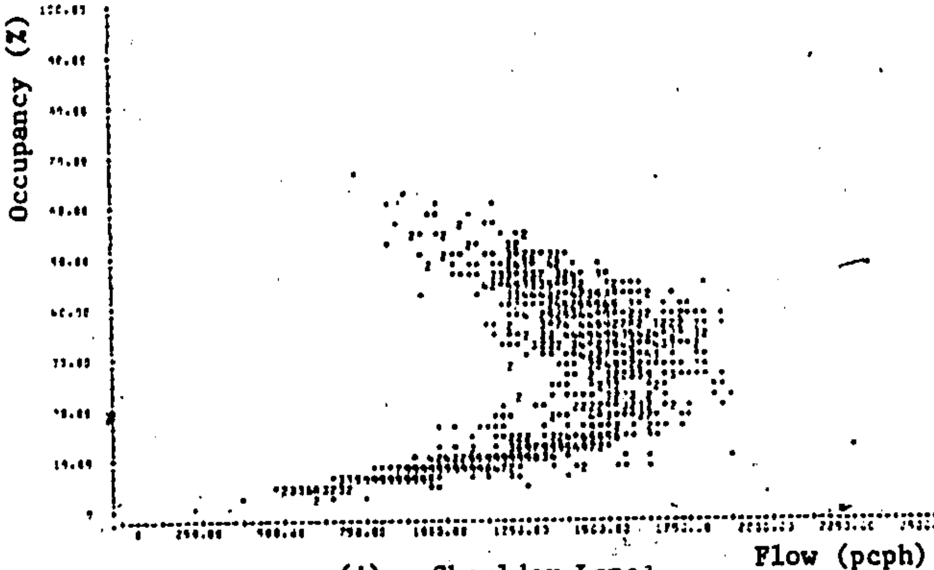


(ii) Middle Lane

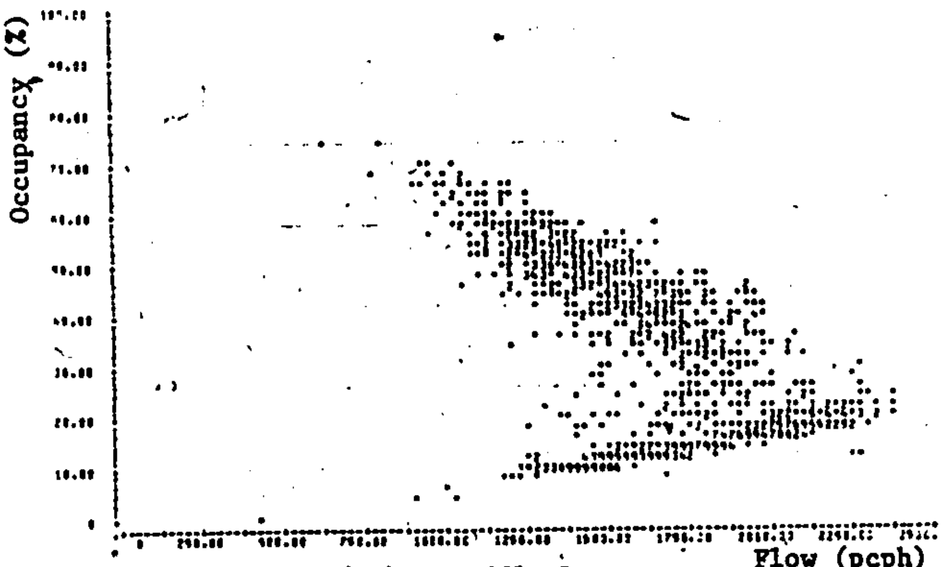


(iii) Median Lane

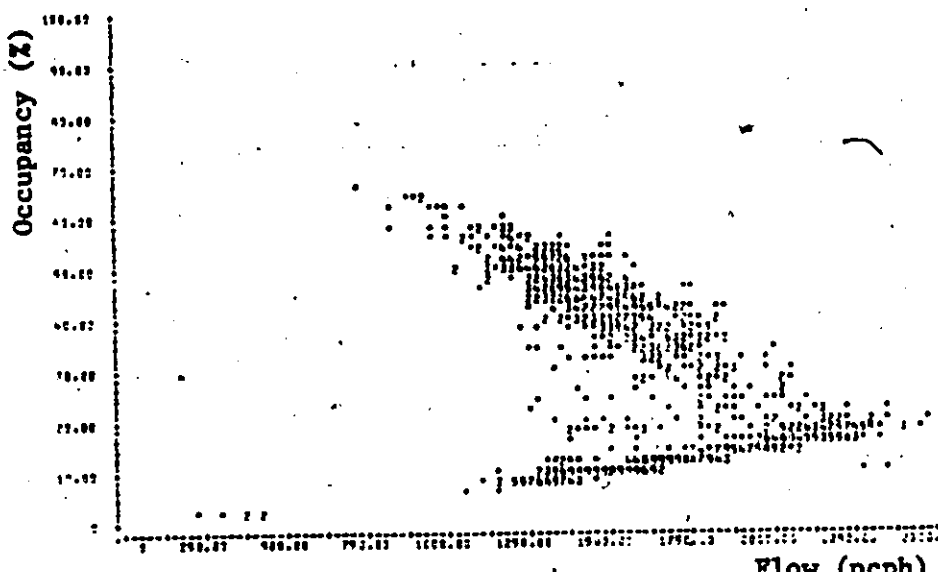
Figure A6.13 Occupancy-Flow Data, Station 4



(i) Shoulder Lane

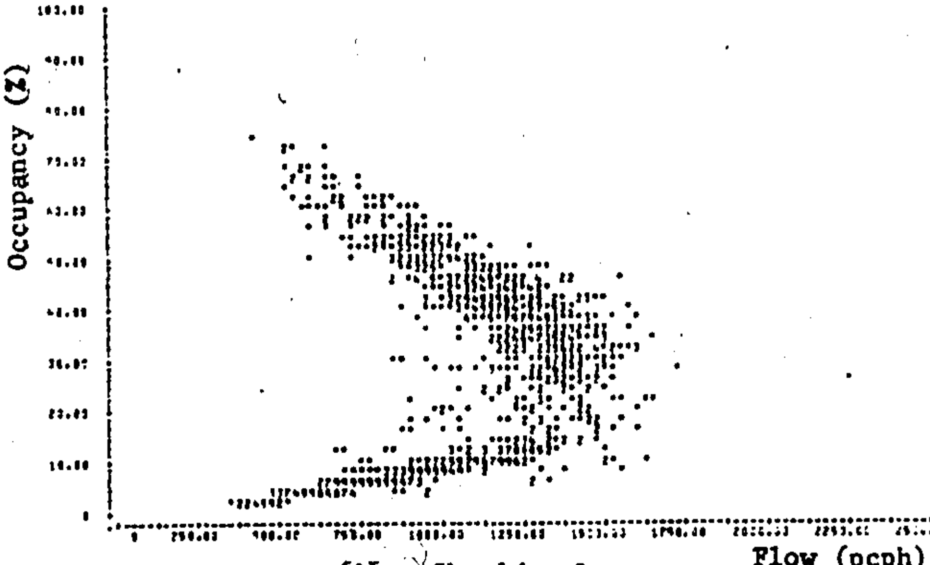


(ii) Middle Lane

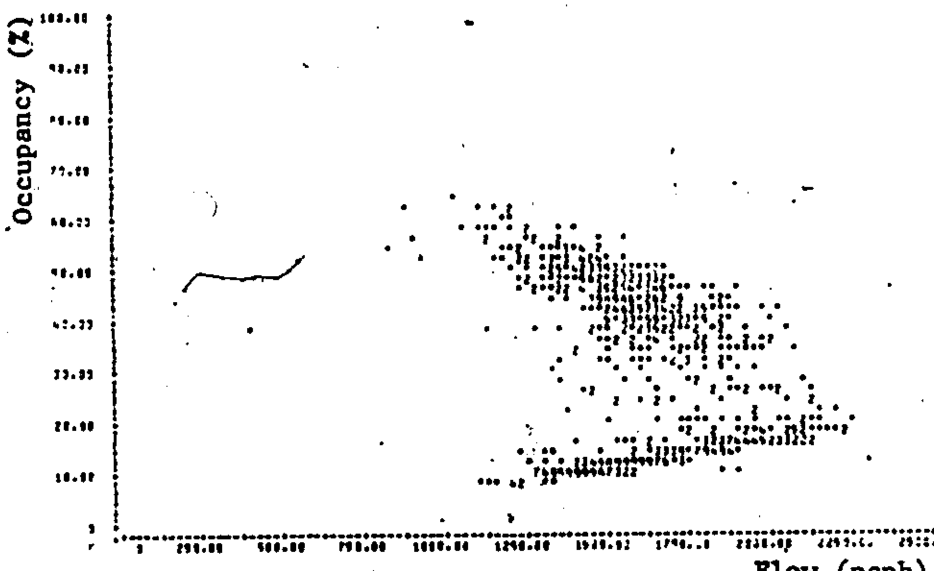


(iii) Median Lane

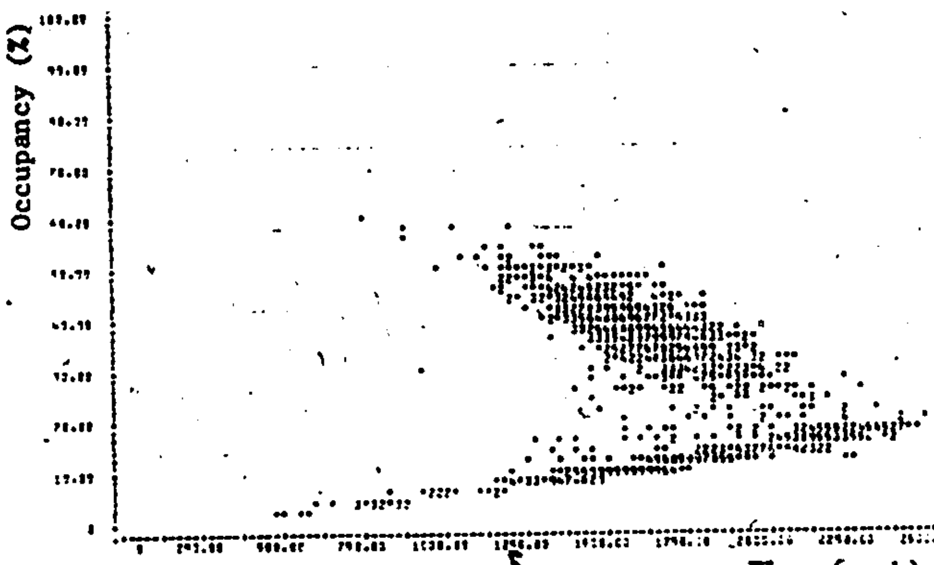
Figure A6.14 Occupancy-Flow Data, Station 5



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A6.15 Occupancy-Flow Data, Station 6

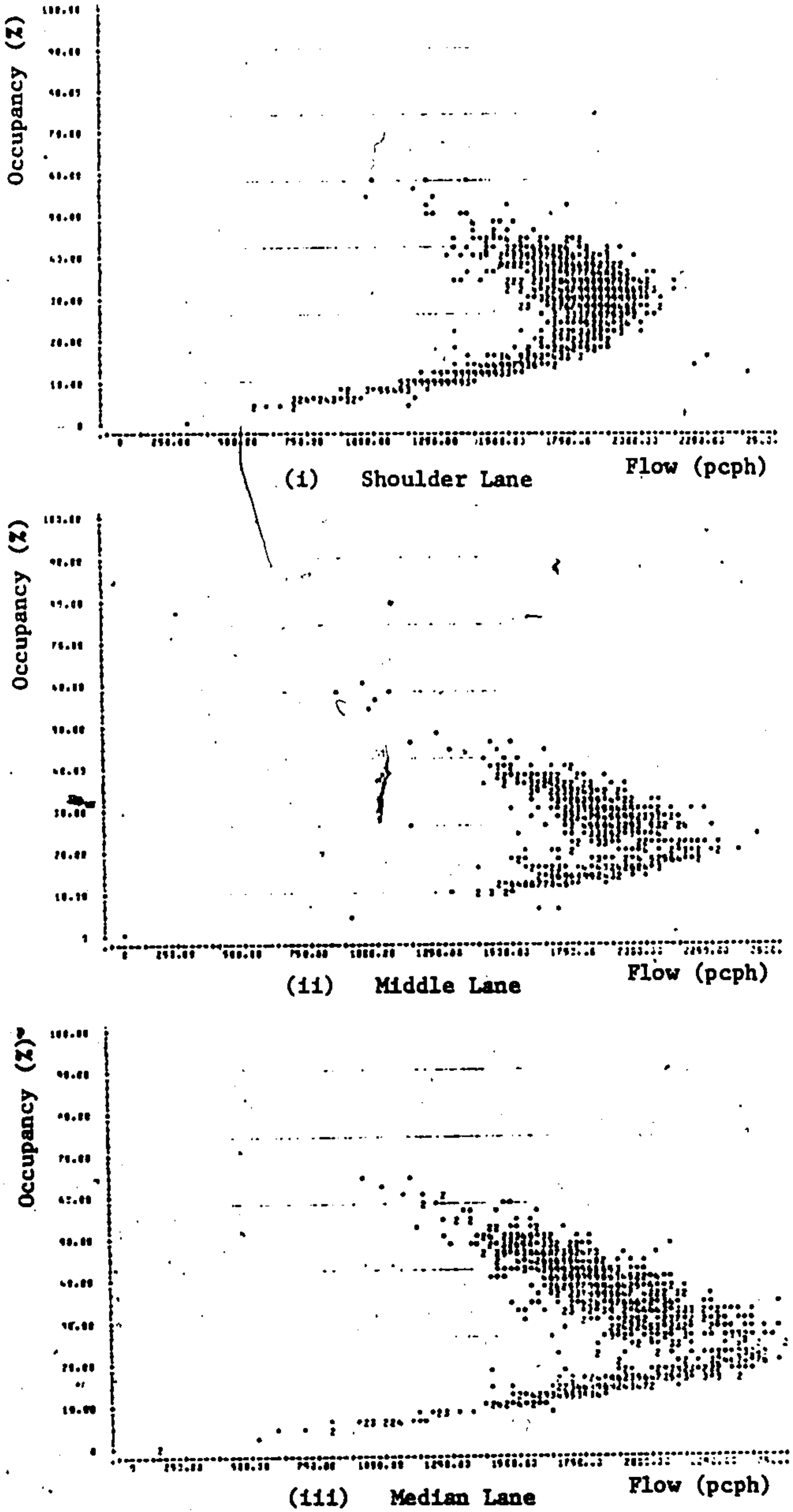
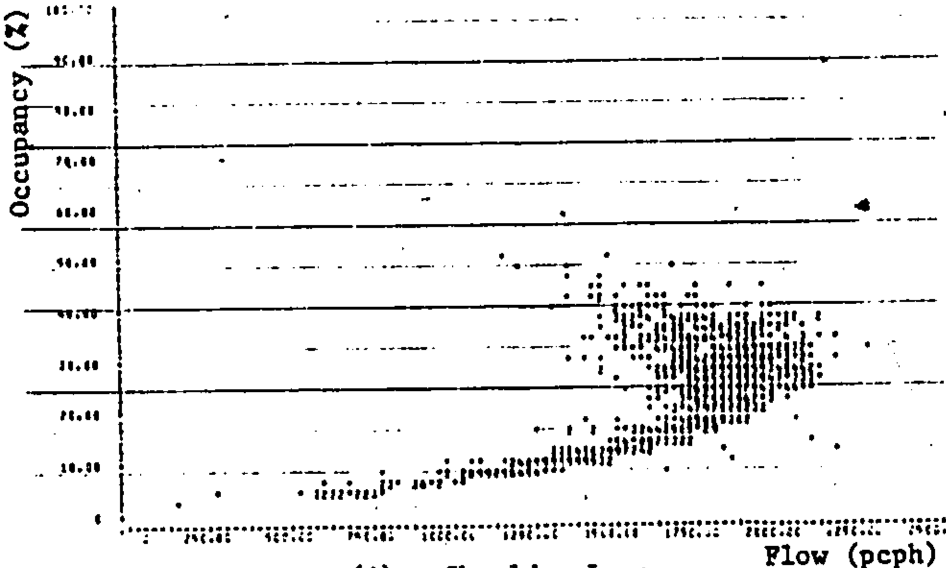
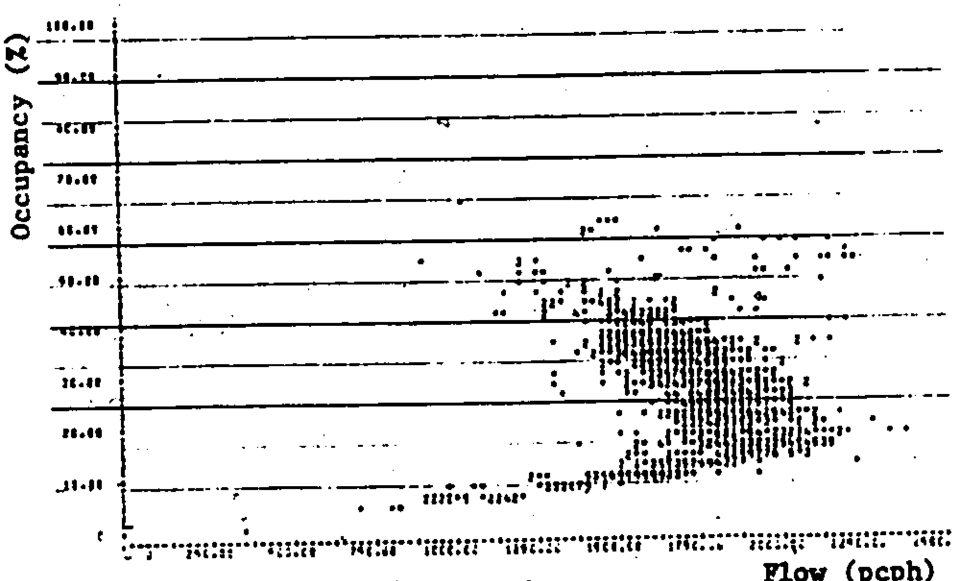


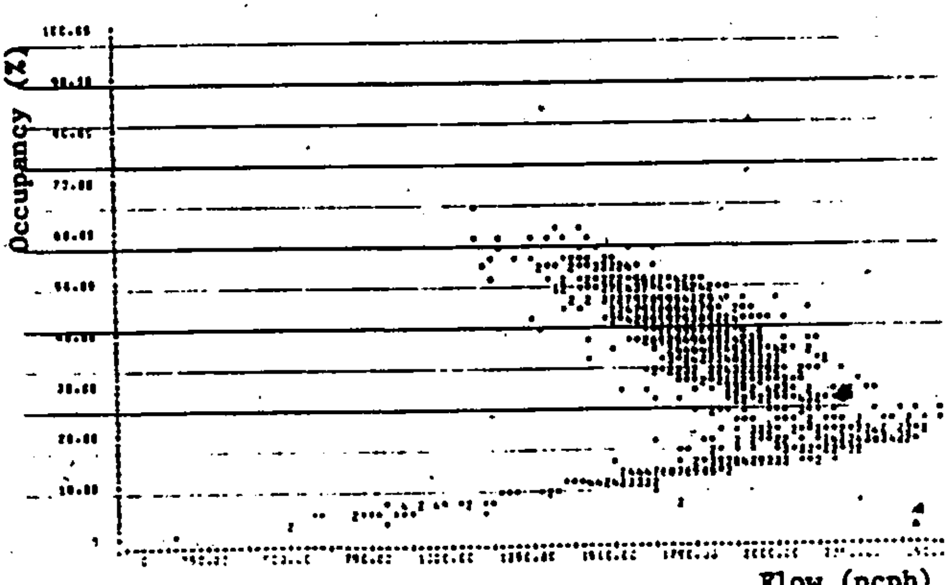
Figure A6.16 Occupancy-Flow Data, Station 7



(i) Shoulder Lane



(ii) Middle Lane



(iii) Median Lane

Figure A6.17 Occupancy-Flow Data, Station 8

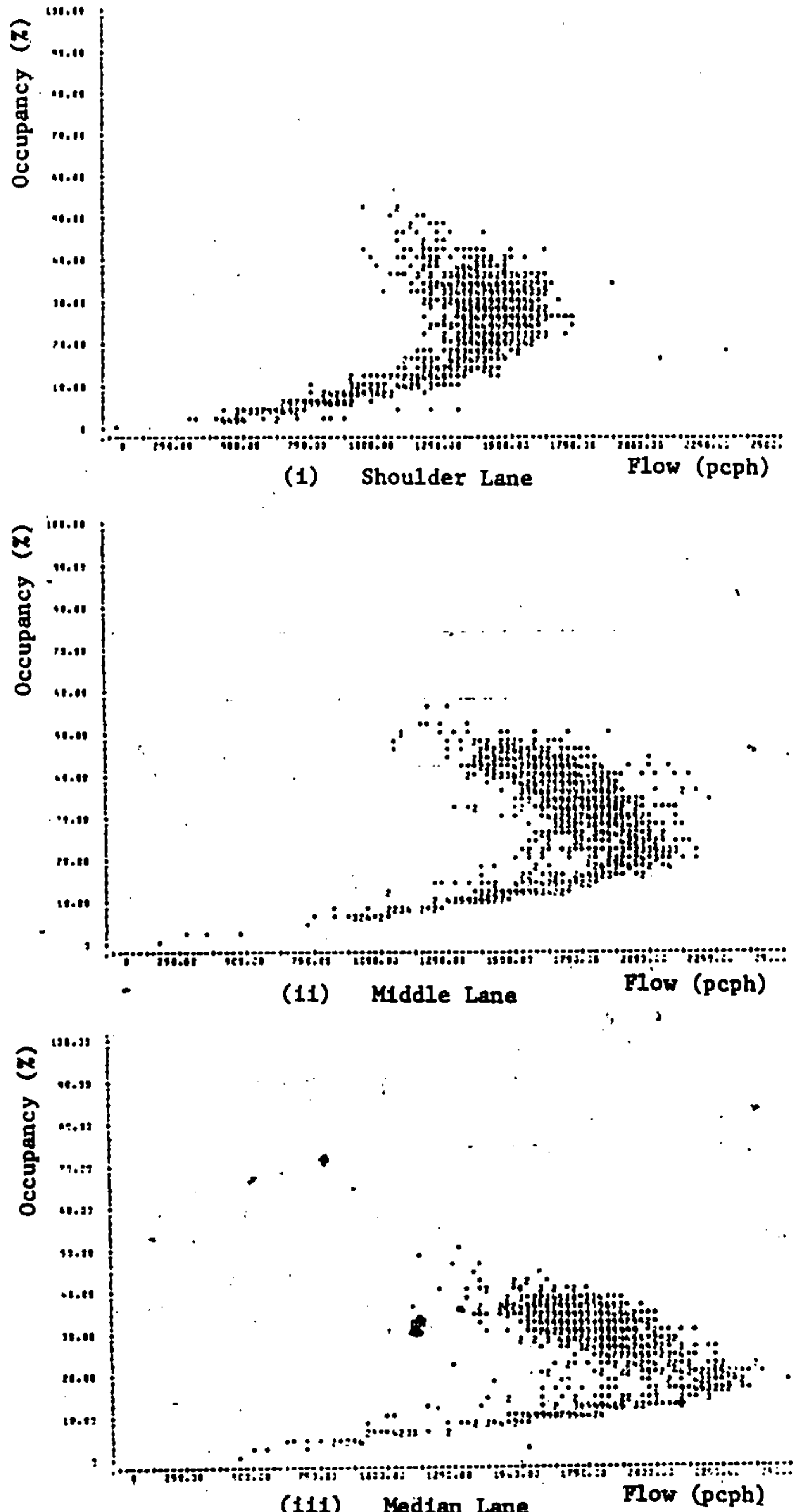


Figure A6.18 Occupancy-Flow Data, Station 9