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ECONOMETRIC ESTIMATION OF PEAK SPREADING IN THE SEATTLE METROPOLITAN AREA

by

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Peak spreading is becoming common on urban roadways as existing facilities reach capacity and traffic volumes continue to grow. Being able to accurately model peak spreading behavior is necessary to accurately assess the travel time saving benefits of capital improvement projects, in addition to other reasons. Several types of peak spreading models have been developed in recent years, each with varying levels of success and limitations. This report used historical data and trends to develop a peak spreading model for the Seattle metropolitan area. A two-part model was used in an attempt to develop a stand-alone peak-spreading model. Although this model did not produce the intended results, it serves as an important step in the process. The use of a logit model to predict the peak spreading phenomenon is an innovative approach that deserves additional study.

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GLOSSARY

These definitions were taken from a report published by Cambridge Systematics in 1997 entitled "Time-of-Day Modeling Procedures."

Congestion. Interference of vehicles with one another as they travel, reducing speed and increasing travel time. Travel time on a link increases as an exponential function of the ratio of the number of cars on the link (volume) to the link's capacity. At low volumes, links are said to be uncongested, since vehicles do not interact much; as volumes approach capacity (defined as the maximum flow rate at the most constructed point on a link), congestion effects become increasingly apparent and travel time increases noticeably. The volume of entering vehicles may exceed the capacity of a link, in which case the excess vehicles form a queue within the link, link traversal times increase exponentially, and flow exits the link at capacity rates.

Off-peak. Occurring during periods of relatively low traffic, not during a peak.

Peak. Whether categorized by purpose or geographic area, trips occur at different rates at different times of the day. A graph of trips by time of day typically reveals one or more peaks. These peaks play a key role in conventional travel demand analysis, which focuses on maximum infrastructure needs in each corridor. The dominant weekday peaks are in the morning (AM peak) and the late afternoon (PM peak), obviously related to the timing of works trips. A peak can be characterized by its maximum trip rate (in trips per unit time) or by a duration over which some threshold trip rate is maintained. The portions of the peak before and after the peak hour are called the "shoulders of the peak."

Peak hour. The hour during which the maximum traffic occurs. The peak hour during which traffic is highest varies from link to link and place to place, a fact which is not fully reflected in traditionally travel demand analysis.

Peak spreading. Lengthening of the peak period usually accompanied by a flattening of the peak.

Peak period. The period of time during both the morning and afternoon when the volume of traffic is the highest. In the model in this report, the am peak is defined as the 3.5-hour period between 6 a.m. and 9:30 a.m. The typical definition of the a.m. peak period is the three-hour period between 6 and 9 a.m.

Regression. A mathematical technique for exploring relationships between sets of observations on two or more variables. A functional relationship between the variables is postulated, and line or curve fit between the plotted observations so as to minimize some function (usually the square) of the deviations between the plotted points ant the line or curve. The result is the equation of the best-fit line or curve describing the dependent variable in terms of the other variables, which is often used for predictive purposes; and measures of how goodness-of-fit. If the postulated relationship is a line, the technique is called linear regression.

Time-of-day factor. The ratio of vehicle trips made in a peak period (or peak hour) to vehicle trips in some given base period, usually a day.

Trip chaining. The traveler's process of linking trips into tours. A trip chain, or tour is defined such that the destination of the first trip is the origin of the second, the destination of the second trip is the origin of the third, and so forth.

LIST OF ABBREVIATIONS

CAAA. Federal Clean Air Act Amendments

CBD. Central Business District

HBO. Home-based other

HBW. Home-based work

HCM. Highway Capacity Manual

HOV. High occupancy vehicle

ISTEA. Intermodal Surface Transportation Efficiency Act of 1991

ITS. Intelligent Transportation Systems

MPO. Metropolitan planning organization

NHB. Non-home based

SOV. Single occupancy vehicle

TODF. Time-of-day factor

TSMC. Traffic System Management Center

TDM. Transportation demand management

VMT. Vehicle miles traveled

WSDOT. Washington State Department of Transportation

CHAPTER 1: INTRODUCTION

There has been interest in recent years in extending the capabilities of traditional travel demand models to go beyond simply providing standard weekday travel estimates to focusing on specific key periods during the day. This move to extend travel demand models is driven by the trend of moving away from simple capital improvement capacity-increasing projects. As the interest in transportation planning has begun shifting focus from capacity improvement projects to project alternatives, transportation demand management strategies, and air quality issues, to name a few, the desire to develop more comprehensive travel demand models has taken hold.

Of particular interest in the development of these models are the conditions during the peak periods. The challenge is to develop travel demand models that can account for peaking trends and duration in order to estimate key measures of travel performance, such as speeds, congestion, and emissions. Traditional travel demand models can only offer highly approximate and not very accurate projections of peaking intensity and duration. Several models have been developed that attempt to account for peak-spreading conditions on congested roadways, each offering its own interpretation of the subject.

The current conditions on Seattle's major roadways are at or near capacity for a significant portion of the peak period, with volumes remaining elevated throughout the day. Many of the roads are exhibiting peak-spreading behavior during the peak periods. In order to more accurately plan and develop congestion management strategies, in addition to the other reasons mentioned above, it is necessary to develop a model that can reflect these current conditions and estimate future conditions. The need for such a model is clear and provided the basis for this project. This report provides an additional interpretation of peak spreading, with the Seattle area as its focus.

Several key locations were studied and used in the development of a peak-spreading model for the Seattle metropolitan area. First, the motivation behind the research was developed, and this is described in more detail in Chapter 2, providing an extensive look into the reasons why this topic is of significance. In Chapter 3, a review of the literature and a look into several other models is provided. The research methodology is outlined in Chapter 4, followed by a look into current conditions in Chapter 5 and the development of a peak-spreading model for the Seattle metropolitan area in Chapter 6. Last, Chapter 7 presents the results and conclusions from the model, and areas for further study are discussed.

CHAPTER 2: MOTIVATION BEHIND THE RESEARCH

Peak spreading is a condition that has been increasingly prevalent on major urban arterials in recent years. Peak spreading is defined as the lengthening of the peak period, usually accompanied by the flattening of the peak. (Cambridge Systematics, 1997) Congestion has traditionally been confined to a few times throughout the day, namely the a.m. and p.m. peak hours. However, as conditions on the roadways deteriorate, more and more commonly they experience congested conditions for several hours throughout the day, often extending beyond the traditional peak hours.

What is happening as congestion expands and the peak period lengthens is the phenomenon known as peak spreading. As the peak period extends and the roads remain at high volumes for extended periods of time, the flattening of the peak may be along capacity lines (the upper limit of the roadway). Alternately, the volume of traffic at the highest point under peak spreading conditions may be lower than at the highest point during traditional peak hours. However, the absolute volume of traffic in a peak period characterized by peak spreading is greater than in traditional conditions. Additionally, the rate of increase in traffic volumes under peak spreading conditions will theoretically be lower than the rate of increasing 24-hour traffic volumes. That is, volumes during peak periods that are characterized by peak spreading will experience increases in volumes at a decreasing rate. (Allen 1991)

To study the impacts of peak spreading on facilities and conditions, accurate modeling techniques are necessary. As roadways become increasingly congested and remain at capacity for longer periods, the challenge to accurately measure existing conditions and predict future conditions becomes greater. Congestion has escalated to a condition that plagues not only central cities, but permeates entire metropolitan areas. The basis for peak spreading is that demand cannot exceed capacity for a given period. (Allen 1991) Although volume-to-capacity (v/c) ratios in excess of 1.0 are sometimes observed, these are extreme conditions and perhaps the result of underestimated capacities. Traditional travel demand modeling is limited in its ability to provide clear estimates of peak hour travel. This has resulted in the development of models with time-of-day capabilities.

Thus, to accurately measure and model peak spreading requires innovative techniques that depart from or expand upon traditional congestion measurement tools. There has been an emphasis in recent years on developing travel demand models that can be used to estimate travel for various times throughout the day. This is known as time-of-day modeling and is in addition to the outcome of traditional travel demand modeling, which is modeling of the average weekday. (Cambridge 1997) Traditional travel demand models deal with peak hour and peak period volumes in ways that provide limited results in terms of accuracy and, consequently, are often not very useful tools in the planning process. The standard method for modeling peaking trends employs the use of time-of-day factors (TODF). Time-of-day factors are used to convert 24 demand rates generated from observed data patterns into peak hour rates. The assumption behind this method is that the same travel patterns will persist in the future. (Cambridge, 1997) The limitations of methods of this type are that they are static processes and therefore not sensitive to changes in policy, capacity constraints, or congestion levels. (Barnes, 1997)

Additionally, many of these models violate a key rule and produce inaccurate results. That rule is this: demand can not exceed supply during any given period. (Allen, 1991) There is a finite capacity at any given time, and this can not be exceeded. If demand is allowed to exceed capacity (supply) the estimates of vehicle delays will be over-estimated as the excess demand results in drivers waiting in extended queues to enter the system and can carry over into the next phase of project determination. This is an unrealistic conclusion to draw. If the delays are over-exaggerated, the benefits of a system that can improve travel times will also be over-exaggerated. If trip makers are assumed to be rational, it is unrealistic to think that drivers will wait in extended queues to enter a system that is at capacity. A more realistic interpretation of a system such as this would be that those making trips would decide to do so at times that are not characterized by such extreme congestion, such as during the shoulders of the peak, or that they would find an alternative route.

Alternative uses for these models (which are beyond the scope of this paper but should be mentioned) include the ability to perform air quality analysis and measure vehicle emissions, a method of performing transit analysis, identification of highway system problems, analysis of travel demand management (TDM) alternatives, and the analysis of intelligent transportation systems (ITS). (Cambridge Systematics, 1997)

Therefore, the motivation behind this study was the challenge to develop a model that could capture the impacts of congestion on the roadways and the peaking characteristics and impacts of the system. As peak spreading becomes the norm for urban highway facilities, it will be necessary to accurately model current conditions and estimate future ones. It is clear that there is a demand for models with these capabilities, and that provided the impetus for this research.

CHAPTER 3: A REVIEW OF THE LITERATURE

Many different approaches have been taken in an effort to effectively document, analyze, and predict peak spreading. There is a considerable amount of literature on studies of peak spreading that have employed various techniques and yet no clear direction as to the "best" or most effective approach. The result is a variety of methods used in an attempt to capture the peak-spreading phenomenon and develop more accurate models and forecasting tools. An extensive literature review on this subject was conducted in the report entitled "Peak Spreading Analysis: Review of Relevant Issues and Synthesis of Current Practice." (Barnes, 1997) For a more comprehensive look into the literature available on this subject, please refer to that report.

Peak spreading literature falls into four major categories. These range from traditional modeling approaches to more innovative and data-intensive methods. The four main categories of peak spreading literature are as follows (Barnes, 1997):

- traditional post-processing techniques
- four-step modeling approaches: link-based, trip-based and system-wide analysis
- sub-models, independent of the four-step process
- stand-alone models.

POST-PROCESSING: STATIC TIME-OF-DAY ANALYSIS

Post-processing techniques are traditional time-of-day analysis techniques, as discussed in the previous chapter. Post-processing involves developing a time-of-day or peaking factor based on historical data and then applying it to the future, assuming that the same trends will persist in the future. (Cambridge 1997) These methods are static and not sensitive to policy changes, congestionm or capacity constraints (Barnes 1997). As a result, the ability to model peaking trends with this technique is highly approximate and often inaccurate. Such methods include post-assignment static techniques, post-mode choice, time-of-day trip table factoring, and two-step, time of day factoring. Each of these methods uses daily forecasted volumes and converts the forecasts to peak hour or peak period factors. They differ primarily in where they are applied during the process. The limitations of these techniques are numerous, but perhaps most significant is the fact that these models do not work well under congested conditions. Because peaking is highly sensitive to congestion, a model must be sensitive to congested conditions. Therefore, the remainder of this literature review focuses on the last three categories of the available literature because they represent innovations in the field that are sensitive to congestion and produce more accurate results.

FOUR-STEP MODELING APPROACHES

The methods discussed here each fall within the confines of four-step travel demand modeling. The four-step modeling process refers to travel demand models, which contain the following steps: trip generation, trip distribution, mode choice, and trip assignment. Peak spreading models can be employed at different stages of the four-step process. The four possible points at which time-of-day travel models may be implemented during the four-step process are as follows:

- after trip assignment
- between mode choice and trip assignment
- between trip distribution and mode choice
- between trip generation and trip distribution.

There are different categories of peak spreading models within the four-step process. The three different model types are as follows:

- link-based peak spreading models
- trip-based peak spreading models
- system-wide peak spreading models

LINK-BASED PEAK SPREADING

Link-based peak spreading techniques are based on the idea of obtaining more realistic traffic assignments. Equilibrium-based traffic assignment methods were developed to account for the effects of congestion on route choice. As congestion has worsened, however, the ability of these equilibrium assignment methods to predict true conditions is greatly limited, as mentioned in the section on post-processing. There have been attempts to improve upon this process in an effort to develop models that are more sensitive to congestion levels. Link-based methods were developed to account for link-level congestion and to divert trips that exceed capacity to the shoulders of the peak hour. (Cambridge, 1997).

A well-known link-based model was developed for Phoenix. (Louden et al 1988) The objective behind developing this model was to create a method that could capture the "net effect of traffic congestion without identifying the magnitude of each type of behavioral response." (Cambridge 1997) The results of the Phoenix model were more accurate and realistic estimates of future traffic volumes and speeds on congested highways, as well as better regional estimates, such as more realistic measures of vehicle-miles traveled (VMT). This model is able to predict peak-hour volumes for each link in the highway network. These volumes represent the level of congestion resulting from the predicted peak-period volume (defined to be three hours) for the forecasted year, as well as the level of capacity for each link. The results also indicate the level of peak-spreading that results from forecasting congestion on a given facility. The goal of this research was to improve the modeling of peak period volumes and speeds by more accurately modeling the peak periods and the peak spreading within the peak periods as the facilities become more congested. (Louden, 1988)

The Phoenix model was based on data from 49 corridors over a 5- to 20-year period. The corridors sampled were in Arizona, California, and Texas and included freeways and major arterials. The day was divided into the a.m. peak, the p.m. peak, and off-peak hours. These periods were chosen because they are thought to be fairly stable. That is, it is thought that trips will not shift significantly outside of each individual period. Regression analysis conducted as a part of this study supported this key assumption. Additionally, this study focused on peak-period trips rather than peak-hour trips.

First the three-hour v/c ratio for each link is calculated. Next, the peak-spreading model is applied, resulting in a peaking factor and a readjustment of the volume. The link level peak-hour v/c ratio is determined from the revised peak hour volume. Lastly, revised speeds are determined from the application of a peak-hour speed model. This process continues updating link volumes throughout the iterative equilibrium process. (Cambridge 1997; Louden 1988)

There are a few limitations to this type of approach. To begin with, it provides no assurance of continuity of flow between the links in peak hour prediction. Each adjacent links may have a different amount of predicted peak spreading because of variations in the predicted three-hour v/c ratios. Additionally, this model predicts peak spreading on the link level, but peak spreading may occur as the result of congestion at some other point in the network or because of the perception of congestion for the entire corridor or network. Last the issue of travel not being able to spread outside of the allotted three-hour peak period. While this was shown to be statistically insignificant in regression analysis, it is not an entirely realistic assumption.

TRIP-BASED PEAK SPREADING

The trip-based method of modeling peak spreading uses selective reductions of trip table interchanges on overassigned links. Trip-based models spread the number of trips for an origin-destination interchange that occur during the peak period (peak hour in some cases. (Cambridge, 1997) This method has been used in a number of studies of large urban areas, including the San Francisco Bay Area (the Tri-Valley model), Boston (Central Artery/Tunnel Project), and Washington, D.C.

The Tri-Valley model served as a sub-model to the San Francisco Bay Area model and focused primarily on the area in Alameda and Contra Costa Counties. Without the trip-based peak-spreading model, the conditions in this area resulted in peak-hour v/c ratios often in excess of 1.0. By using the trip-based model, traffic assignments, which previously resulted in v/c ratios of greater than 1.0, were constrained at the access gateways to produce more reasonable v/c ratios. The approach that was used in this model was to adjust origin-destination matrices to provide a better fit with observed or estimated link volumes.

In the Boston area model, an iterative approach was used to selectively reduce individual origin-destination cells of the trip table. Individual cells were reduced on the basis of the levels of congestion in corridors corresponding to the particular origin-destination pairs. The Boston model is an iterative-factoring model and is applied only to highways. Unconstrained trip-assignment is performed on the entire system, at which point congested links are identified. Traffic is then adjusted sequentially in a method similar to the Fratar method of matrix adjustment. Trips are then reassigned on the basis of the adjusted trip tables. Last, the final link volumes are compared with link capacities for reasonableness. (Cambridge 1997)

The Washington D.C. model is a post-mode choice model that is applied to a.m. peak period auto trips. Trips are broken down by trip purpose, and peak spreading was analyzed for each trip purpose, the assumption being that certain trip types would be more susceptible to peak spreading. Trip distance and congested-minus-free-flow-travel-time was calculated for each trip type. A peak spreading model was then developed using a matrix containing all of the above information and applying it to each cell in the input trip matrix. The output was a matrix of a.m. peak hour auto trips. (Cambridge 1997)

Advantages to this type of model include the use of "selective reduction" over "global reduction" as used in the Boston area model. Additionally, as in the D.C. model, the data used as inputs for the model re readily available household travel survey data. The key limitation for each of the above mentioned methods is the use of a constant three-hour peak period, which may not be able to accurately model trip chaining.

SYSTEM-WIDE PEAK SPREADING

The third type of model that falls under the four-step modeling approach is a systemwide peak-spreading model. This model was developed by Volpe National Transportation System Center (VNTSC) in an effort to model intelligent transportation systems. The peak spreading aspect of the VNTSC model to evaluate peak spreading can also be used as a traditional travel demand model independent of its ITS applications. The main idea behind this model is that it is neither a link-based or trip-based model. Rather, because it was developed to model the effects of ITS deployment on travel, it assumes that there a significant amount of information is available to the traveler, and therefore, the temporal response made by the traveler can be modeled on a systemwide basis. There are a few key limitations to this type of model. The first is that it is not sensitive to different trip purposes. Also, certain trip types are less flexible to temporal distribution than others. Additionally, this type of model is not sensitive to link-specific congestion or specific origin-destination flows. (Cambridge, 1997)

PEAK-SPREADING SUB-MODELS

The next category of models found in the literature is referred to as "sub-models." These are models that stand alone but could be used as sub-models in the four-step modeling process. Several models of this type are found in the literature, so only an overview of the key points of the literature is given here. For a more detailed look into these types of models, please refer to the report mentioned earlier. (Barnes 1997)

Models in this category include models of "active" peak spreading (the New Jersey Interstate-80 Model (Allen, 1991)), models that incorporate land-use and network characteristics (Replogle, 1990), and models that include independent variables beyond just congestion, such as the Dulles Transportation Corridor Study (Allen and Schultz, 1996), to name a few. Additionally, models within this category include those that attempt to incorporate travel demand management (TDM) measures into the peaking activity (Austin et al, 1994), a sub-model to the SATURN model, which includes behavioral responses (Arezki et al, 1992), and a utility maximization approach to peak spreading that utilized stated-preference surveys to expand upon the data collected. (Johnson, 1991)

STAND-ALONE MODELS

The last type of model in the literature is the stand-alone model. This category is important because the model developed in Chapter 6 is of this type. These models are developed completely independent of the four-step modeling process and attempt to exogenously model peak spreading. Two key articles influenced various aspects of the model developed later, both of which were developed in the U.K.

The first paper investigated the incidence of peak spreading at several bridges across the Tyne River in England. (Ramsey, 1995) There were six key river crossings in this area of England between Newcastle and Gateshead at the time the Cross-Tyne study was begun and therefore six key areas for study. The motivation behind the study was to determine whether a seventh crossing was justifiable. An important aspect of this study was that with a finite number of bridge crossings, there was little room for taking alternative routes to avoid congestion. One of the only methods for combating congestion was to change the time the trip was taken. (Ramsey, 1995) The objective of this model was to determine if indeed peak spreading was occurring.

Historical traffic data at each of the six river crossings were collected for ten years. The hours from 6 a.m. to 10:00 a.m. were chosen as the period to study. From observing the data trends, it was clear that peak spreading was occurring. The next step was to develop what is referred to as the Peak Spreading Road Efficiency percentage (PSREP). The PSREP was an indicator of the degree to which peak spreading is occurring. The time period used as input for this measure was from 7 to 9:30 a.m. The PSREP was then calculated to determine the degree of peak spreading taking place. The limitation of this model is that although the PSREP was developed to show the degree of peak spreading taking place, it did not go to the next step, to say how the spreading would affect future road conditions and how the traffic profiles would be altered as a result of peak spreading. Despite the limits of this model, however, it has several important characteristics that were adopted in the development of the model in Chapter 6.

The first similarity between this model and the one developed in Chapter 6 is the data used for each. Ten years of historical data were used in both models to try to determine peak spreading conditions. Additionally, the Cross-Tyne study discussed the nature of increasing traffic volumes on congested arterials. Initially, traffic growth is exponential, but as the facilities become increasingly congested and approach capacity, the limit (the road's capacity) is approached asymptotically. That is, as the volumes approach a certain percentage of capacity, the increase in volume occurrs at a decreasing rate. This key behavioral characteristic of congestion is developed in more detail in the model in Chapter 6. Last, the location of the study in England as loosely parallel to Seattle in that both have a limited number of city access points because of geographical boundaries. In England, the River Tyne and the limited number of river crossings were somewhat comparable to Seattle's geographical boundaries with the lakes, the Puget Sound, and a finite number of main arterials connecting to the downtown. For these reasons, this study was significant in developing a peak-spreading model for the Seattle area.

The final piece of literature on stand-alone models that served as an influence was a paper that combined results from several peak-spreading models and compared the findings of each to determine the evidence of peak spreading in the U.K. (Porter, 1995) The significance of this publication is that it analyzed several different models and methods of capturing peak spreading and compared the results of each. Peak spreading was found to be widespread, but the relationship was complex to model. Exponential methods provided the best measure of increasing v/c ratios, and negative exponential models provided the best fit with the v/c ratio as the explanatory variable. Last, it as observed that the rate of peak spreading slows as congestion increases, leading to the development of more complex models. This step, it was concluded, was beyond the scope of the limits of this study. It is at this point where the model developed in Chapter 7 begins.

A SUMMARY OF THE LITERATURE ON PEAK SPREADING

A number of approaches have been taken in an attempt to model peak spreading. The models to date have fallen into four main categories: 1) traditional time-of-day factoring, 2) models that fall into the four-step process, 3) models that are independent of the four-step process but that could serve as sub-models, and 4) stand-alone models. Some fairly standard assumptions re prevalent in most if not all of the literature. Most models defined a peak period of three to four hours in length and modeled peak spreading within this peak period. Additionally, many models limited their study to the a.m. peak period because it is more straightforward and easier to model. Most models were developed as some type of adjustment or modification of the four-step modeling process. A few models are based on traveler surveys, but these are difficult because of the number of varied responses. There has not been evidence in support of the effects of TDM measures on congestion; however, some findings have suggested that ignoring peak spreading can exaggerate the benefits of capital improvements. Last, models can be developed with the data currently available in most urban models. However, stand-alone models are likely to require significant amounts of time and data. (Barnes, 1997)

CHAPTER 4: RESEARCH METHODOLOGY

DATA COLLECTION

ASSUMPTIONS

The objective behind the model described over the next few chapters was to design a method for predicting future volumes and then distributing those volumes in a manner that accurately modeled peak spreading during the a.m. peak period in the Seattle metropolitan area. The goal was not to develop an end-all model but rather a short-term model that could be used as a basis for the development of a more sophisticated peak-spreading model. This is consistent with the short-term approach recommended in "Peak Spreading Analysis: Review of Relevant Issues and Synthesis of Current Practice," a September 1997 report written for WSDOT.

To develop a model, it is necessary to make some basic assumptions upon which the model will be based. The first key assumptions were related to the concept of a "typical day" on the highways in and around Seattle. It was necessary to define what a typical day would be for this study, bearing in mind the amount of data available, the need for a representative sample number of locations, and the time limitations involved. What constitutes a typical day for this model is similar to the criteria for a typical day used by traffic analysts at the Traffic Systems Management Center (TSMC) of the WSDOT Northwest Region.

To capture the true conditions on the area highways, it was determined that the data should be collected for the same month for each year of the study. The possible months were narrowed down to April and October. The reasons for choosing data collected in either of these months were, first, that the University of Washington is in session during both of these months. Any analysis of traffic conditions in Seattle needs to bear this in mind, as the University of Washington is a major trip generator. When the University is not in session the number of trip attractions to the zone is greatly diminished, thus affecting traffic volumes accordingly. Additionally, lower summer enrollments at the University make the summer months unusable, as they do not truly represent actual annual road conditions. The fact that schools of all levels also are not in session and that more people take vacations during the summer months again probably results in lower peak period volumes during the summer months. Another reason for choosing October or April is the idea that, in theory, the weather is more predictable and less of a problem. While this might not be the case in all years, it is true on average more than during other winter months. Also, the time between Thanksgiving and New Years is not "typical" because travel is increased for the holidays, ruling out those months.

Bearing all of the above in mind, April was chosen as the representative month over October for the reason that it might be possible to squeeze one additional year's data into the model with April 1998. One potential drawback to note is that the Easter holiday and spring break of local area schools may affect April volumes during some years. The overall effect of this, however, is questionable, as different districts have different weeks off and most students are not of driving age. One possible manifestation of this could be a slight reduction in commuters if some chose to take a family vacation during the week their children were off from school. Because the University of Washington is on the quarter system, however, and its spring break vacation is always during March, any problems associated with UW generated traffic volumes were avoided.

Additionally, only data from the middle of the week—that is, data collected Tuesdays, Wednesdays and Thursdays—were used to determine the typical day. This is standard procedure because volumes on Mondays and Fridays may be affected by weekend travel, potentially skewing the data. With flextime and people taking long weekends, these could indeed be reasons that the volumes for these days appear lower than normal. Holiday weekends (in this case Good Friday and Easter during some years), which can have an increased effect on volumes, are also eliminated from the data pool by using only Tuesday through Thursday data.

It was also decided that two weeks', or 6 days', worth of data from each April would be used to average together for an average day. Again, this was consistent with the methods used by researchers at the TSMC. In most years, the first two weeks of April were chosen. However, in a few years, the data available for this time were unusable, in which case, the middle two weeks of April were used. Again, this is similar to the procedure used by the TSMC at the Northwest Region. Finally, given different time constraints and resources, it would be ideal to collect more data to use in determining the "typical" or "representative" day for each year. It would be ideal to collect two weeks from both April and October and average these data together to more accurately determine the "typical" day. For this study, however, doing so was not possible.

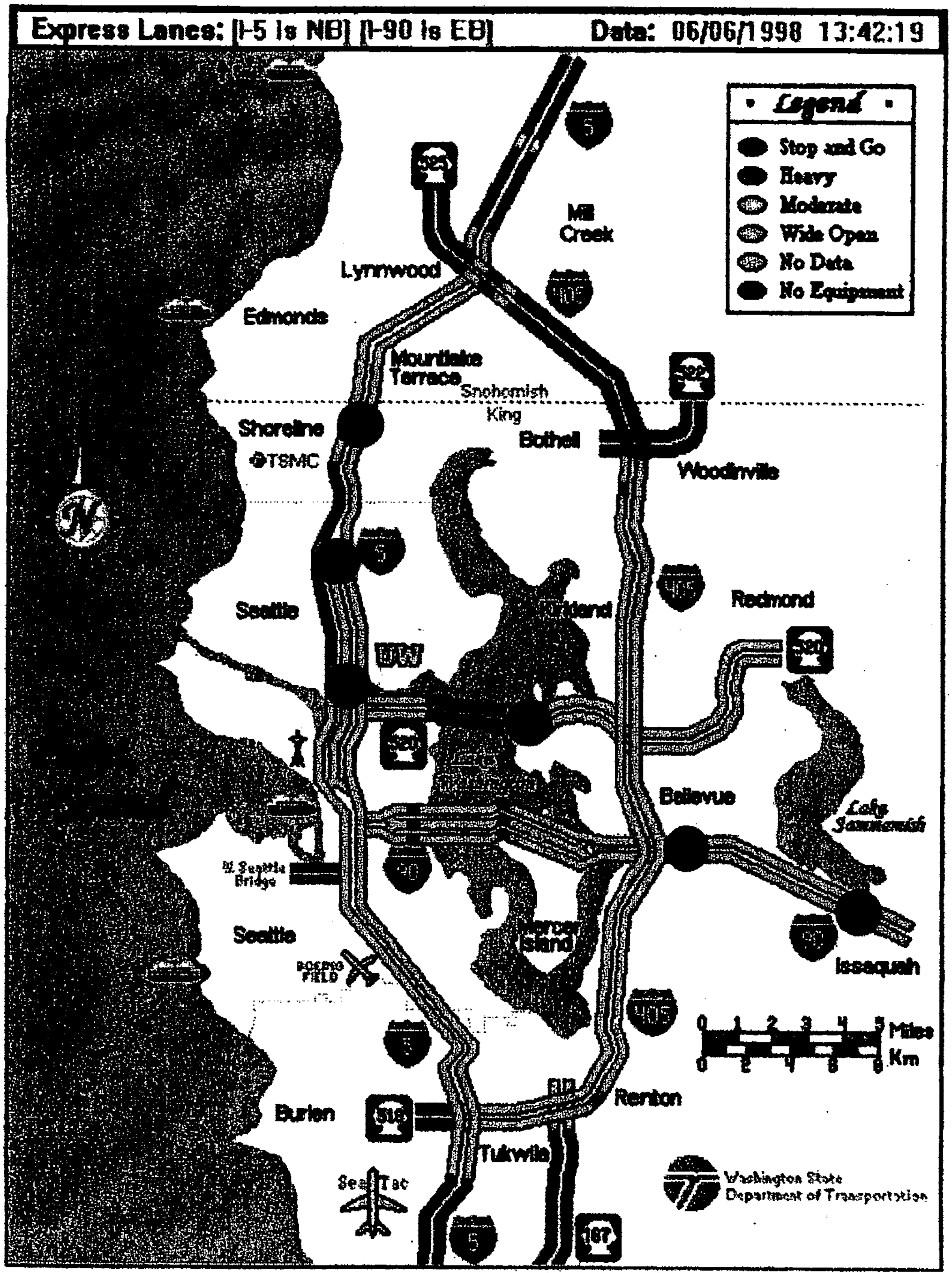
A final assumption pertains to the data manipulation section later in this chapter. The capacities used when determining the v/c ratios for each location were specific to each location. They were determined by closely examining the 5-minute volume data for each lane at each location during the peak periods. During the periods with highest volumes, the same number or similar numbers occur over and over. This recurring number, when it is the highest number, reflects the true capacity of the location. The standard 2200-2300 pvpl figure is not indicative of the true capacities at each location, especially when one lane serves as an entrance/exit to and from the freeway. (Jay Burgin, WSDOT)

LOCATIONS

Once the above details had been determined, the next step was to determine which locations in the Seattle area would provide an accurate representation of the road conditions. Additionally, it was necessary to consider key corridors in the area that might sequentially exhibit peak spreading symptoms farther from the central business district (CBD). The growth in the region has been significant to the east and to the north of the city; therefore, the decision was made to study the main highways serving these areas.

An additional consideration was the availability of data. Some of the loops have only been in place for the last few years. It was necessary to first determine the general area and then to look at what data were available to decide the exact location to use. Also, good, consistent data for most, if not all, locations, were only available from 1987 to the present. Before to 1987, the data were either nonexistent or incomplete. The locations that were checked for data availability before 1987 offered unrealistic volumes, reported either as "0" or the same number across all time periods. By default, then, 1987 was chosen as the first year from which to begin collecting data. In defense of this decision, years before this on I-90 would not have been necessary, as this arterial was in the early stages of its lifecycle around 1987 and only recently (in the past few years) has experienced volumes anywhere near capacity. The drawback of this, however, can be seen on I-5, which already had significant volumes and congestion in 1987. With the exception of 1991 in all locations and a few other years in various locations, the data were fairly comprehensive for the years 1987 to 1997. The locations that best fit the criteria and were felt to offer the best representative sample of conditions in the area are listed in the following tables, along with the mileposts, direction, and station number.

Figure 1 is a map indicating the locations. Appendix A contains additional maps indicating the road geometry at each of these locations. Again, under ideal conditions, with no time constraints and readily available data, an additional location along I-90 toward Issaquah or North Bend would have nicely completed the I-90 corridor data. Also, an additional location on SR 520 near Redmond would have been helpful in determining trends in this corridor.



http://www.wsdot.wa.gov/regions/northwest/NWFLOW/

Figure 1. Map of Locations

Table 1: I-5 Corridor: North of the CBD

Location	**# lanes (gp lanes)**	**Capacity**	**Mile-posts**	**Data stations: '93 & earlier**	**Data stations: '94 and later**
I-5 Ship Canal (sb)		9060	168.84	35	ES-130
I-5 Ship Canal (nb)		9180	168.84	36	ES-130
Northgate (sb)		8136	172.16	44	ES 154d
Northgate (nb)		7764	172.16	45	ES 154d
NE 185th St. (sb)		6840	176.73	56	ES-177d
NE 185th St. (nb)		7080	176.73	57	ES-177d

Table 2: I-90 Corridor: East of the CBD

Location	**# lanes (GP)**	**Capacity**	**Mileposts**	**Data stations: '93 & earlier**	**Data stations: '94 and later**
I-90 (136th) (eb)	5	10280	10.7 (before '94) 10.82 ('94-after)	108	ES-903d
I-90 (136th) (wb)	4	8460	10.7/10.82	107	ES-903d
I-90 (188th) (eb)	3	6348	14.65	112	ES-928d
I-90 (188th) (wb)	3	6348	14.65	111	ES-928d

Table 3: SR 520 at the Toll Plaza

Location	**#lanes**	**Capacity**	**Mileposts**	**Data stations: '93 & earlier**	**Data stations: '94 and later**
SR-520 (wb)	2	4020	4.17	117	ES 514d
SR-520 (eb)	2	4020	4.17	118	ES 514d

DATA COLLECTION

Once these locations were chosen, the data collection process began. The data were available in two different forms. From 1987-1993, the data were available in magnetic tape at the TSMC at the Northwest Region. This data were available in 15-minute time periods for 24 hours each day. The data for 1994 and later were available on CD-ROM produced by the TSMC every six months. These data were more detailed because they were collected in 5-minute intervals and also included the percentage of time the loop was occupied during that 5-minute period. Additionally, the program "flagged" the data on the basis of whether the loop detector as working properly. A "1" indicated good data, a "2" indicated questionable data, and a "0" indicated the data were bad. Thus, it was possible to throw out bad data, if necessary, on the basis of the "flag" beside each data point. The locations chosen were fairly consistent between the two types of data. In at least one case, however, the loop detector at a given location in the early data set was approximately one-tenth of a mile away from the loop detector in the later data set. Care was taken, however, to choose locations where consistent data were available. If it was necessary to use a location with loop detectors in slightly different locations over the years, locations were chosen on the basis of similar road characteristics. Only locations with the same road geometries were used in these situations to preserve the integrity of the data.

DATA MANIPULATION

Once the data has been obtained, the six days from each year were averaged together in two ways. First, the data was averaged together by hour to obtain an average 24-hours for each year. These data were then graphed to show the average day for each year and to show how the traffic volume profiles were changing over the 10-year period. These graphs can be referenced in Appendix A. The objective behind these plots was to provide a graphical representation by which peak spreading could be observed. The next way the data were manipulated was concentrated only on the a.m. peak period. The a.m. peak period was chosen to model because it is more straightforward with respect to trip purpose. There are more home based work (HBW) trips at this time of day than at any other. Additionally, the a.m. peak period consists of more direct or HBW trips than work-to-home trips in the evening. The p.m. peak is made up of a greater variety of trips (non-home based trips (NHB)), with "trip-chaining" a common occurrence. (PSRC, 1997) The a.m. peak is preferable in that it is considered to be consistent and predictable and nearly uniform. (Lomax, 1997) For the purposes of this report, the a.m. peak period was defined to be the hours between 6:00 a.m. and 9:30 a.m. This time period was then further divided into half-hour time slices. For each half-hour during the a.m. peak for every year, the average volumes were determined. These data were then used as input into the next step in the process, the development of the peak-spreading model.

CHAPTER 5: CURRENT CONDITIONS

The current conditions at the various locations chosen for this study can be seen in the graphs in the Appendix. Before discussing each location individually, some general observations can be made about the locations as a group. These observations are based on the data used in the model in the next chapter. The potential limitations of the data are discussed in the previous chapter on research methodology. With that in mind, the following observations have been made. The graphs clearly indicate that most of the roads in question are at or near capacity. For the purposes of this report, congestion has been defined to be a certain percentage of capacity. So, it is assumed here that as volumes reach 70 percent of capacity and higher, the road is exhibiting signs of congestion. There are varying levels of congestion, with conditions obviously worsening as the v/c ratio approaches 1.0.

The I-5 and SR 520 corridors are in worse condition than the I-90 corridor, although if trends continue as they have been for the past 10 years, I-90 will fast approach the other locations in terms of congestion. Conditions on I-5 and SR 520, in the southbound direction for I-5 locations and both directions for SR 520, during the a.m. peak period were already at a significant percentage of capacity at the beginning of the time for which data were available. Conditions have worsened in general, despite some subsequent years posting better result than the previous years. In these instances it is important to realize that many factors would contribute to this. It might merely be a case of a given year being an outlier. Other possible explanations are adverse weather during the year in question or potentially, especially in years before 1994, the possibility of bad data or a malfunctioning loop detector. An additional factor that could explain higher volumes includes special events in the CBD, such as sporting events that generate increased volumes. Although there is no way to determine what the explanation is for sure, these factors should be kept in mind when reviewing at the data presented here. A discussion on corridor- and site-specific conditions follows.

I-5 CORRIDOR

Conditions along the I-5 corridor were heavily congested even in the early part of this study, with v/c ratios consistently at 70 percent and above for the southbound locations in during much of the a.m. peak. Subsequent years have fluctuated, with v/c ratios ranging from 0.7+ to above 1.0. The northbound locations during the a.m. peak have shown significant growth in volumes during this time, although the bulk of the traffic in the northbound direction occurs as the day progresses toward and into the p.m. peak period. This is consistent with expectations, as the northbound traffic is heading away from the CBD, the main trip attraction for the a.m. peak period.

NE 185th St.

The northernmost location in this study was at I-5 and NE 185th. In the northbound direction, there was steady growth in the a.m. peak, with volumes reaching approximately 50 to 60 percent of capacity. The p.m. peak experienced much higher volumes and a more traditional peak spreading profile. The initial year of the data (1987) showed the highest absolute volume, while subsequent years exhibited wider, somewhat lower and flatter profiles, consistent with the definition of peak spreading. Volumes in 1987 surpassed 7000, indicating a v/c ratio of nearly 1.0. By 1997, the highest recorded volumes were just above 6000, with the shoulders of the peak absorbing the additional volume. The southbound direction experienced a similar flattening of the peak during the a.m. peak period. 1987 and 1989 produced higher absolute volumes, with v/c ratios consistently above 80 percent and often above 90 percent. However, toward the end of the study, the v/c ratios were almost all in the 80 percent range, with the occasional 70 percent and 90 percent statistic. The graph clearly shows the flattening of the peak and the increase in volumes during the shoulder of the peak. The pre-peak shoulder absorbed little or none of the spillover, while the post-peak shoulder experienced fairly significant increases in volume.

I-5 at Northgate

The Northgate location is at NE 97th St.. The northbound location has continued with an upward trend during both the a.m. and p.m. peak periods. The peaks have become wider and higher over the past ten years, with the road remaining around 70 percent of capacity for much of the day. The most congested part of the day is the p.m. peak, as this captures much of the traffic that leaves the city. In 1997, the p.m. peak experienced v/c ratios in the upper 80 percent range for the time period studied. The southbound location did not experience much change over the 10 years. The a.m. peak remained at the same absolute level and spread slightly to the shoulders on both sides of the peak. There was more indication of growth during the p.m. part of the day. From approximately 7 a.m. until 7 p.m., the conditions on the road exhibited a v/c ratio upwards of 70 percent, with no off-peak period conditions except between 7 p.m. to 7 a.m. The volumes remained elevated throughout the middle part of the day. Note that the express lanes are open to southbound traffic during the a.m. peak period and to the northbound traffic during the p.m. peak period. Data for this study were only collected for general-purpose lanes, however. Therefore, volumes during the a.m. peak only reflect vehicles using general-purpose lanes. The total volume at this location during the a.m. peak period would actually be higher if the express lanes were included. So even though the southbound p.m. peak volumes appear to be as high as those are during the a.m. peak, this is not necessarily the case. This should also be noted for the graphs at the Ship Canal Bridge.

I-5 at the Ship Canal Bridge

The conditions at the Ship Canal bridge locations both closely resemble the Northgate locations. The northbound Ship Canal Bridge location rises to a v/c percentage in the upper sixties during the a.m. peak and climbs steadily throughout the day until the p.m. peak, with v/c ratios of .85 and above since 1993 onward. Again, the peak spreading taking place is more of the entire profile growing in height and width and a flattening taking place at higher v/c ratios. The difference between this and traditional peak spreading is that the flattening is occurring at the highest level; it is not occurring at volumes lower than the highest point. The Southbound Ship Canal location remained at the same volume at its highest point for the entire study period. The spreading is slight and is taking place during the hours immediately adjacent to the 8:00 hour. Conditions level off slightly post a.m. peak and climb during the noon hour and afternoon where they remain elevated (above 70 percent of capacity) until after the p.m. peak.

I-90 CORRIDOR

Conditions on I-90 are at a different stage than at the other locations. I-90 can provide a unique opportunity to study traffic growth and peak spreading over the next 10 to 20 years. The data available for the earliest part of the sample showed extremely low levels of traffic and virtually no congestion, often with v/c ratios of 0.2 or less and almost always below 0.5. As the years have progressed, however, the traffic profiles and v/c ratios have grown significantly, with v/c ratios climbing above 0.7 and in some cases above 0.8. The difference in the I-90 corridor is that peak spreading is only in the beginning stages. As volumes are approaching 70 to 80 percent of capacity and greater, the growth continues at the highest levels of the peak, but not at the rate of the growth during the shoulders of the peak, which implies the beginning of peak spreading. One difference between the I-90 locations and the other locations in this study is that only one peak in each direction is really pronounced. During the a.m. peak period, the westbound lanes have a sharp peak, but volumes level off and remain fairly constant through midday and the p.m. peak. The eastbound lanes experience the opposite of this, with the pronounced peak being during the p.m. peak period.

I-90 at 136th Avenue SE

At 136th Avenue SE, there are five general-purpose lanes in the eastbound direction and four westbound, which allows for the most capacity of any location in this study. Eastbound traffic volumes have continued to grow significantly over the past ten years, but because of the capacity at the site, v/c ratios tend to be only just above 0.4 during the a.m. peak. The p.m. peak experiences significantly higher volumes, reaching 60+ percent of capacity. Westbound I-90 at this location has also experienced high growth in traffic volume. During the a.m. peak in the earliest data, v/c ratios were rarely above 0.5. In the last few years, v/c ratios have increased to 0.7+ during several of the half-hour time periods that make up a.m. peak.

I-90 at 188th Avenue SE

At this location I-90 consists of three general-purpose lanes and an HOV lane in each direction. The profiles at this location are similar to those at 136th Avenue SE in shape, but the capacity is considerably lower. As a result, the v/c ratios at 188th Avenue are higher. During the a.m. peak period, the westbound location commonly experiences v/c ratios in the 0.7- 0.8+ range. Eastbound has also exhibited significant growth, the majority during the p.m. peak with v/c ratios often above 0.7.

SR 520 AT THE TOLL PLAZA

The key characteristic of the SR 520 data over the past 10 years is that conditions have not changed very much. The peaks on SR 520 have been described as modest because of the facility operating at or very near capacity throughout the day. (PSRC, 1997)

Historical data indicate that conditions in 1987 were already poor. The v/c ratios for both directions are above 0.9 for most of the years. V/c ratios in excess of 1.0 were also recorded. There is a more defined a.m. peak in the eastbound direction, with volumes tapering slightly before increasing during the afternoon and evening rush. In the westbound direction the profile is fairly symmetric, with the a.m. and p.m. peak periods mirroring each other. Volumes remain high through midday, with v/c ratios of 0.7 and above for this time. As one of only two bridges that cross Lake Washington, SR 520 has been stretched beyond its limits. During the years for which data were available, SR 520 had already reached its capacity and the peak periods had already spread. If data were available from before 1987 for this location, evidence of peak spreading could probably be found dating back 15 to 20 years.

CHAPTER 6: PEAK SPREADING MODEL

This chapter documents the development of a stand-alone peak-spreading model for the Seattle metropolitan area. As mentioned in the previous chapter, the focus of this model is the a.m. peak period, defined to be 6:00 a.m. to 9:30 a.m. The model has two parts, the first of which is an ordinary least squares (OLS) regression to determine the peak period volumes at each of the 12 locations. The second part of the model uses a logit model to distribute the volumes developed in the first part into the seven half-hour periods of the a.m. peak. The statistical software used for the first part of the model was Eviews (Quantitative Micro Software, 1995), and LIMDEP (Econometric Software, 1992) was used for the LOGIT estimation.

OLS REGRESSION

The specification of the OLS model is as follows:

$$\textbf{Volume}_{t} =$$

$$\textbf{c} + \textbf{adt}_{t-1} + \textbf{ppf}_{t-1} + \textbf{voll2} + \textbf{voll8} + \textbf{sb185} + \textbf{sbng} + \textbf{sbsc} + \textbf{wb136}$$

where:

Volume_t = predicted a.m. peak period volume in the current year
Adt_{t-1} = average daily traffic volume lagged one year
Ppf_{t-1} = peak period factor lagged one year
Voll2=volume @ southbound 185th lagged one year
Voll8= volume @ westbound 136th Ave SE lagged one year
SBNG = location dummy for I-5 at Northgate in the southbound direction
SBSC = location dummy variable for the Ship Canal Bridge- southbound
WB136= location dummy variable for I-90 @ 136th Ave SE -southbound

Variable: adt_{t-1}

This variable was included in the model because average daily traffic during the previous year was thought to be a good indicator of volume in the present time period. The idea was that the ADT is reflected in the peak period volumes. This variable was found to be highly positively significant with a t-statistic of 19.97.

Variable: ppf_{t-1}

This variable was the peak period factor lagged one year. The peak period factor is the peak period volume divided by the ADT. This variable tells what percentage of ADT is accounted for during the 3.5-hour a.m. peak period. The t-statistic (11.124) was also found to be positive and significant, indicating that the percentage of daily traffic that falls into the a.m. peak period is a good predictor of peak period volume next period.

Variables: voll2 and voll8

These are indicator variables for volume by location. The two locations that were found to have a significant impact on volume were I-5 southbound at NE 185th St and I-90 westbound at 136th Ave SE. The rest of the volume indicator variables were found not to be significant for estimating volume. The voll2 variable is negatively significant at the 80 percent confidence level, which means that the predicted volume is negatively affected by the volumes at this location. The voll8 variable is positive and significant at the 95 percent confidence level, meaning that the estimated volume is positively affected by volumes at this location.

Variables: location dummy variables

The rest of the variables included in the model are location indicator variables. The locations that had significant explanatory power for predicting volume are I-5 southbound at NE 185th St, Northgate and the Ship Canal Bridge, and I-90 at 136th Ave SE. All were positive and significant except for the I-90 location. There may be multicollinearity between these indicator variables and the location indicator variables because southbound 185th and westbound 136th are significant in both sets.

The model was tested with dummy variables for each location, with the significant ones remaining in the equation above. The results of the model are given in

Table 4. The adjusted R^2 is quite high at 0.950634. While this is would seem to indicate an excellent goodness-of-fit for the model, it is sufficiently high that one should be suspicious. An adjusted R^2 above 0.4 could be the result of having data with little variance. The data used were all quite similar to each other and possibly highly related. The Durbin-Watson statistic, an indicator of serial correlation among the disturbances, is also low at 1.044. This is a pretty good indicator of the presence of positive serial correlation among the error terms. This is a common occurrence when time series data are used. Serial correlation results in estimates that are still unbiased and consistent but not efficient. The F-statistic is significant with a value of 169.5, which indicates that the relationship the model is estimating exists and is significant. The results from this model should therefore be considered with the above factors in mind. That said, the actual volume estimates that resulted from this model appear to be in line with previous year's volumes.

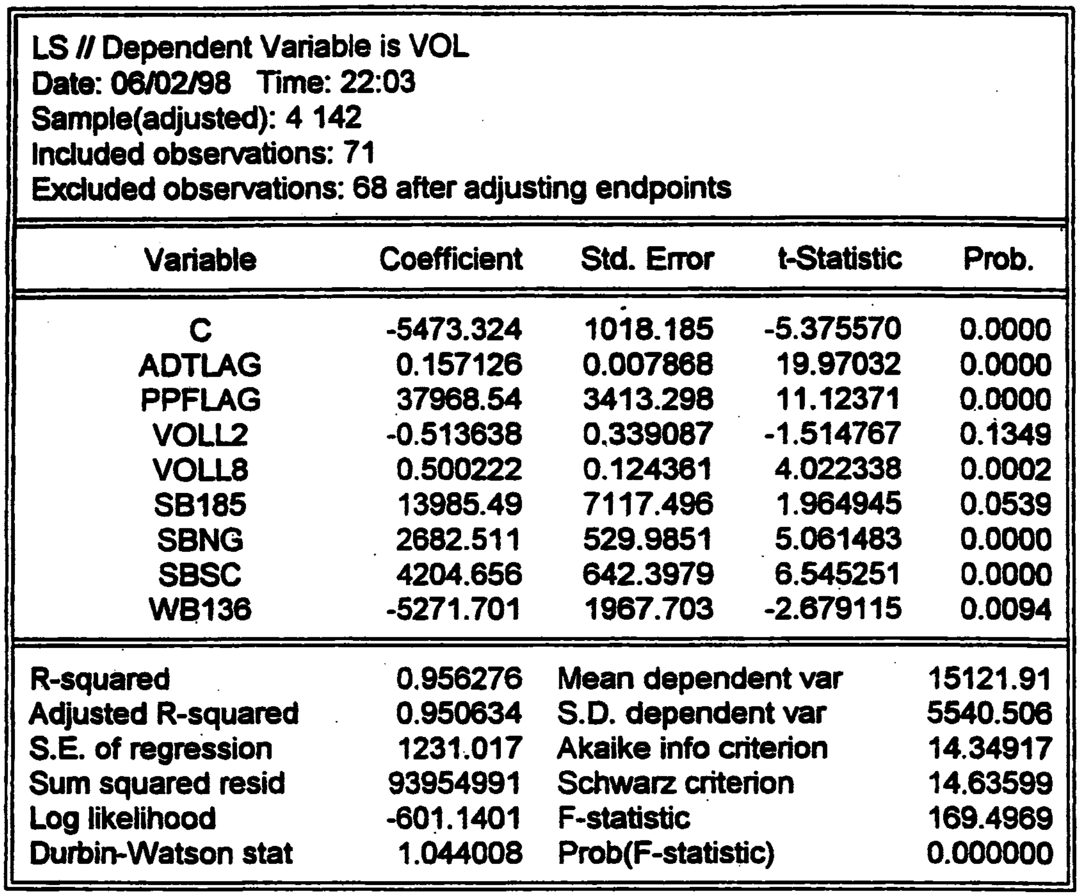
LOGIT MODEL ESTIMATION OF VOLUMES IN EACH TIME PERIOD

The second part to this model is using a logit model to distribute the predicted volumes into each of the seven half-hour time slices of the a.m. peak period. A logit model was used because of its ability to account for the "spill-over" effect of volumes from one time slice to the adjacent time slices as the initial time slice reaches capacity. The logit model is based on the cumulative logistic probability function, which means that the individual probabilities of each of the seven choices occurring sums to 1.0. A separate utility function is estimated for each of the seven possible time choices. The functional form of the logit model is

$$P_i = \frac{e^{vi}}{e^{v1}+\ldots+e^{v7}}$$

where: P_i= the proportion of estimated volume for time slice i, where i = 1 to 7
V_i= the utility function for the i^{th} alternative

Table 4: OLS Regression Output



```
LS // Dependent Variable is VOL
Date: 06/02/98   Time: 22:03
Sample(adjusted): 4 142
Included observations: 71
Excluded observations: 68 after adjusting endpoints

        Variable        Coefficient    Std. Error    t-Statistic    Prob.

            C            -5473.324     1018.185      -5.375570     0.0000
         ADTLAG           0.157126     0.007868       19.97032     0.0000
         PPFLAG           37968.54     3413.298       11.12371     0.0000
          VOLL2          -0.513638     0.339087      -1.514767     0.1349
          VOLL8           0.500222     0.124361       4.022338     0.0002
          SB185           13985.49     7117.496       1.964945     0.0539
          SBNG            2682.511     529.9851       5.061483     0.0000
          SBSC            4204.656     642.3979       6.545251     0.0000
          WB136          -5271.701     1967.703      -2.679115     0.0094

R-squared                 0.956276   Mean dependent var       15121.91
Adjusted R-squared        0.950634   S.D. dependent var       5540.506
S.E. of regression        1231.017   Akaike info criterion    14.34917
Sum squared resid         93954991   Schwarz criterion        14.63599
Log likelihood           -601.1401   F-statistic              169.4969
Durbin-Watson stat        1.044008   Prob(F-statistic)        0.000000
```

This model will result in seven utility functions (V_1,V_2,...V_7), one for each time slice. The utility functions take the following form:

$$V_i = \beta' X_i$$

Therefore, the model will estimate the coefficient on X_i. The dependent variable in the model is:

X_1=percent of the total peak period volume that falls into each time slice

The independent variable is:

X_2= v/c ratio lagged on year

Other independent variables that were tried but found to be insignificant were

X_3= peak period volume, entered in three of seven time slices, '0' otherwise

X_4= peak period volume/peak period capacity, entered in three of seven time slices, '0' otherwise

X_5= v/c ratio of 0.7-0.7999 indicator variable. If the value falls within this range a value of '1' is given, otherwise the value is zero.

X_6= v/c ratio of 0.8-0.8999 indicator variable.

X_7= v/c ratio of 0.9-0.9999 indicator variable.

X_8= v/c ratio of 1.0+ indicator variable.

X_9-X_{12}= same as X_5-X_8, except instead of a value of '1' or '0', it is the v/c ratio or '0'.

X_{13}-X_{23}= indicator variable for location

X_{24}-X_{29}= indicator variables for each half-hour time slice in the a.m. peak.

The computer output and the variable statistics can be found on the next two pages.

MODEL RESULTS AND CONCLUSIONS

Several independent variables were included in the data set, but almost all were determined to be statistically insignificant. When included in the model, the location dummy variables each yielded equations that resulted in singular Hessian matrices, so none of them was included in the end model. Other variables tried included the total peak period volume entered in three of the seven time slices and the peak period volume to capacity ratio entered in three of the seven time slices. The idea behind these variables was to determine whether the total volume for the peak period had any impact on specific time slices within the a.m. peak period. These variables were found to be insignificant. Specific v/c variables were also tried to determine any incremental change in conditions as the road reached various levels. For example, different variables were tried for v/c ratios from 7.0-7.999, 8.0-8.999, 9.0-9.999, and above 1.0, respectively. Additionally, various combinations of these independent variables, excluding the location dummies, were tried, yet the only variable to be significant in any of these attempts was X_2, the v/c ratio lagged.

So the utility function that resulted for each time period was simply the lagged v/c ratio regressed on the percentage of peak period volume in each time slice. This variable was only significant at the 80 percent confidence level, with a t-statistic of 1.452. The likelihood ratio test was 2.26, which was insignificant at the 90 percent level but significant at the 75 percent level. So the null hypothesis that all coefficients are statistically insignificant from zero was rejected at the 75 percent level but not at 90 percent. This is consistent with the t-statistic for X_2, which is significant at 80 percent but not at a higher level of significance. Additionally, because there was only one variable in this model, the t-statistic served the same function of the f-statistic in models with more than one independent variable. So with 80 percent confidence it can be concluded that X_2 belongs in the model. However, these statistics are not overwhelmingly in favor of this model. Clearly, this model is not able to accurately explain the distribution of peak period volume over the seven half-hour time slots of the peak period. The output from this model is in Table 5. The statistics on the variables are in Table 6.

A possible explanation for these results is that there is very little variance among the data, which limits the explanatory power of the model. If there is a small amount of variance among the data, it is difficult to obtain accurate results, as it can be difficult to determine the line that best fits the data. The following tables contain the minimum and maximum values for each time period, as well as the average and standard deviations (Table 7) and the proportion of peak period volume in each time slice (Table 8). Aside from the 6 a.m. time period, the rest of the data are uniformly distributed among each time slice, with very little variation in the data. Additionally, with only one of a possible 28

Table 5: Multinomial Regression Output

```
MODEL COMMAND:
DISC;LHS=X1;RHS=X2;CHOICES=SIX,SIXT,SEVEN,SEVENT,EIGHT,EIGHT
T,NINE;RES=NAMES$

Discrete Choice Model
Observations =      96
Choice:  SIX      SIXT      SEVEN     SEVENT    EIGHT     EIGHTT    NINE
Sample Prop:  0.0991   0.1476   0.1528   0.1500   0.1505   0.1589   0.1412

******************************************************************************

                        Method=NEWTON; Maximum iterations= 25
  Convergence criteria: Gradient=    0.1000000E-03
                        Function  =    0.1000000E-03
                        Parameters=    0.1000000E-03
  Starting values:   0.0000

Iteration:    1 Fn=  -186.8074
Param    0.000
Gradnt    1.43

Iteration:    2 Fn=  -185.6852
Param     1.49
Gradnt   0.121

Iteration:    3 Fn=  -185.6759
Param     1.64
Gradnt   0.116E-02

Iteration:    4 Fn=  -185.6759
Param     1.64
Gradnt   0.111E-06
* Gradient has converged.
* Function has converged.
* B-vector has converged.

******************************************************************************


Discrete Choice Model
Maximum Likelihood Estimates
Log-Likelihood.............     -185.6759
Restricted (Slopes=0) Log-L.    -186.8074
Chi-Squared ( 1)...........      2.262918
Significance Level.........     0.1325042
N[0,1] used for significance levels.
Variable  Coefficient  Std. Error   t-ratio Prob|t|≥x   Mean of X  Std.Dev.of X
-------------------------------------------------------------------------------
X2          1.6424        1.131        1.452  0.14639
```

Table 6: Statistics on Logit Model Variables

```
MODEL COMMAND:
DSTAT;RHS=X2,X3,X4,X5,X6,X7,X8,X9,X10,X11,X12,X13,X14,X15,X1
6,X17,X18,X19,X20,X21,X22,X23,X24,X25,X26,X27,X28,X29$
Descriptive Statistics
Variable      Mean       Std. Dev.       Skew.    Kurt.    Minimum      Maximum    Cases
X2         0.58485       0.24351        -0.188    2.135   0.3900E-01   1.144         672
X3          6322.9        8110.2         0.803    2.156   0.0000      0.2607E+05     672
X4         0.25800       0.32749         0.714    1.852   0.0000       1.013         672
X5         0.10863       0.31141         2.514    7.316   0.0000       1.000         672
X6         0.14137       0.34866         2.057    5.231   0.0000       1.000         672
X7         0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X8         0.13393E-01   0.11504         8.460   72.572   0.0000       1.000         672
X9         0.82460E-01   0.23476         2.496    7.245   0.0000      0.7980         672
X10        0.12040       0.29713         2.062    5.261   0.0000      0.9000         672
X11        0.78141E-01   0.25946         3.017   10.114   0.0000      0.9990         672
X12        0.14393E-01   0.12373         8.482   73.070   0.0000       1.144         672
X13        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X14        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X15        0.93750E-01   0.29170         2.785    8.757   0.0000       1.000         672
X16        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X17        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X18        0.93750E-01   0.29170         2.785    8.757   0.0000       1.000         672
X19        0.72917E-01   0.26019         3.283   11.775   0.0000       1.000         672
X20        0.72917E-01   0.26019         3.283   11.775   0.0000       1.000         672
X21        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X22        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X23        0.83333E-01   0.27659         3.013   10.076   0.0000       1.000         672
X24        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
X25        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
X26        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
X27        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
X28        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
X29        0.14286       0.35019         2.040    5.159   0.0000       1.000         672
```

Table 7: Statistics on X_2

Time	Max	Min	Mean	Stnd dvn
6 a.m.	1.030	0.039	0.428	0.239
6:30a.m.	1.111	0.082	0.614	0.246
7 a.m.	1.123	0.084	0.624	0.238
7:30a.m.	0.994	0.104	0.595	0.229
8 a.m.	1.075	0.098	0.607	0.238
8:30a.m.	1.144	0.112	0.649	0.231
9 a.m.	1.043	0.109	0.576	0.222

Table 8: Proportion of Peak Period Volume in Each Time Slice

	Proportion
6 a.m.	0.0991
6:30am	0.1476
7 a.m.	0.1528
7:30am	0.15
8 a.m.	0.1505
8:30am	0.1589
9 a.m.	0.1412

independent variables found to be significant, there are obviously variables with explanatory power that are not included in this model. This means that there is probably omitted variable bias, which means that the results may be biased and inconsistent.

AREAS FOR FURTHER STUDY

Possible ways to improve upon the results of this model include taking the log of the dependent variable to see whether the results can be improved. However, perhaps a more effective method of improving the model would be to find and include more independent variables with greater explanatory power. Such variables might include demographic data such as population growth, employment trends, and housing starts broken down by region. Data such as this might help to explain traffic patterns and growth and could potentially be helpful in predicting future trends.

CHAPTER 7: CONCLUSION

Peak spreading is becoming common on urban roadways as existing facilities reach capacity and traffic volumes continue to grow. Being able to accurately model peak spreading behavior is necessary to accurately assess the travel time saving benefits of capital improvement projects, in addition to other reasons. Several types of peak spreading models have been developed in recent years, each with varying levels of success and limitations. This report used historical data and trends to develop a peak spreading model for the Seattle metropolitan area. A two-part model was used in an attempt to develop a stand-alone peak-spreading model. Although this model did not produce the intended results, it serves as an important step in the process. The use of a logit model to predict the peak spreading phenomenon is an innovative approach that deserves additional study. Further research and additional data are needed to explore this method more fully.

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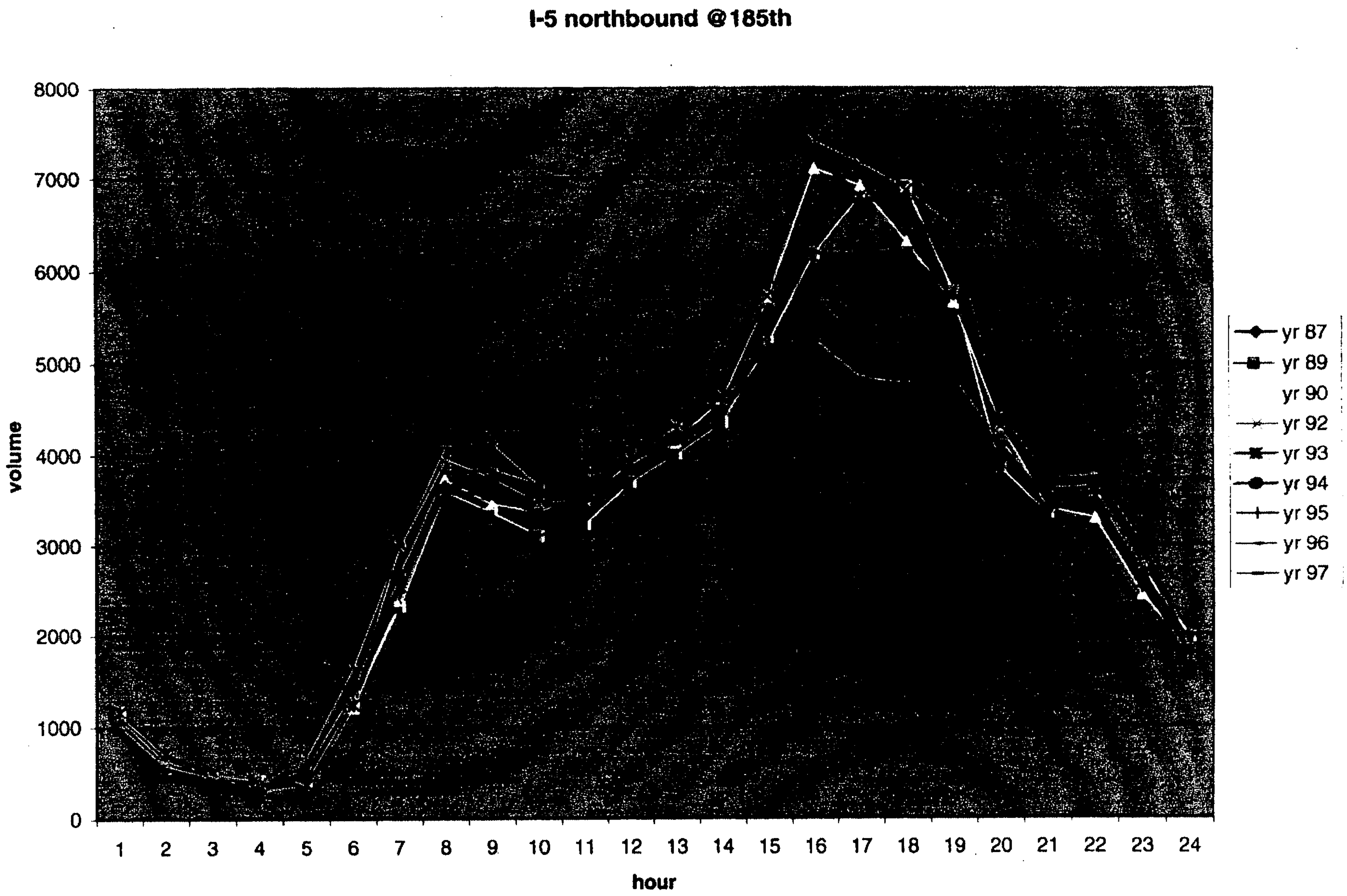
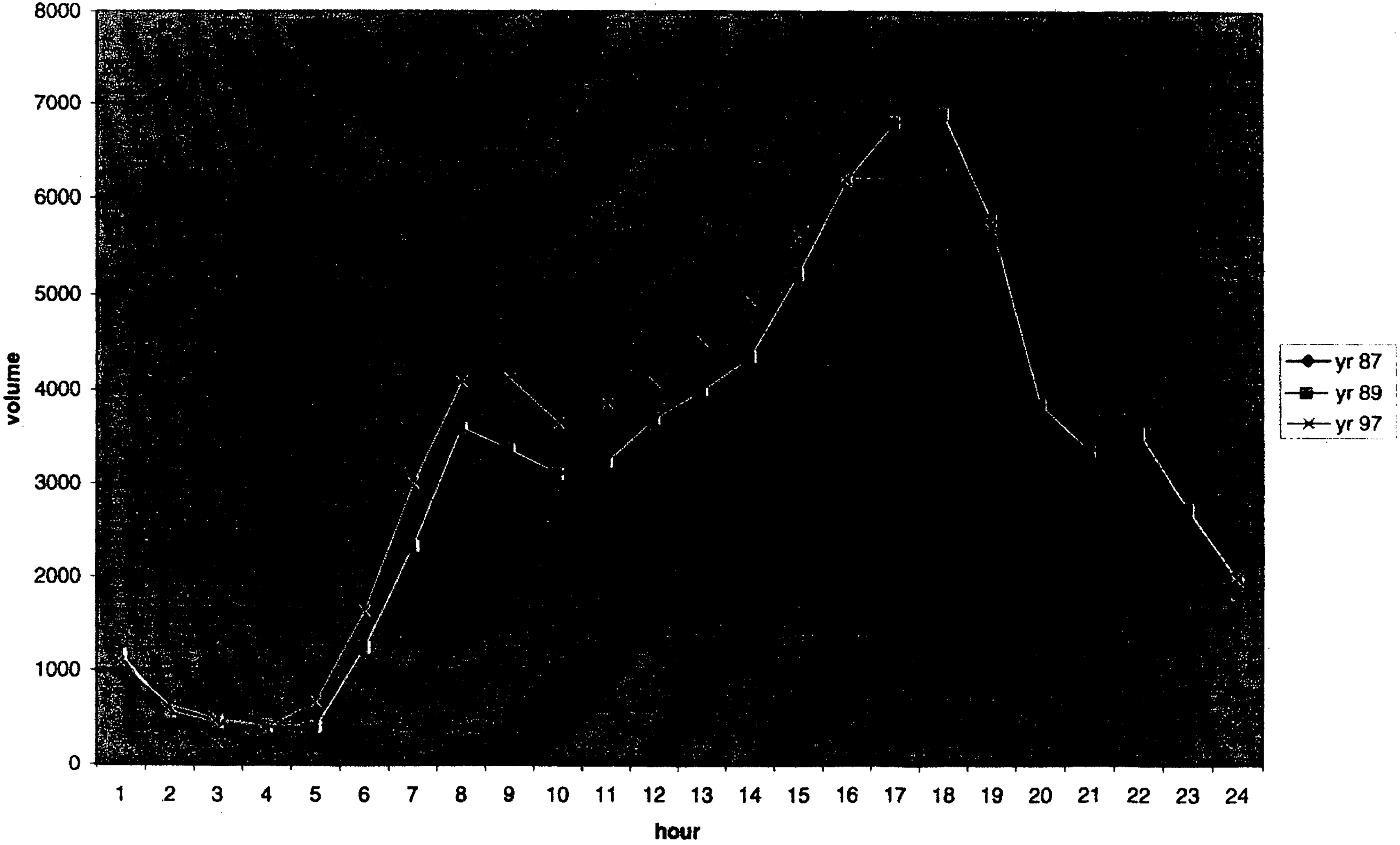
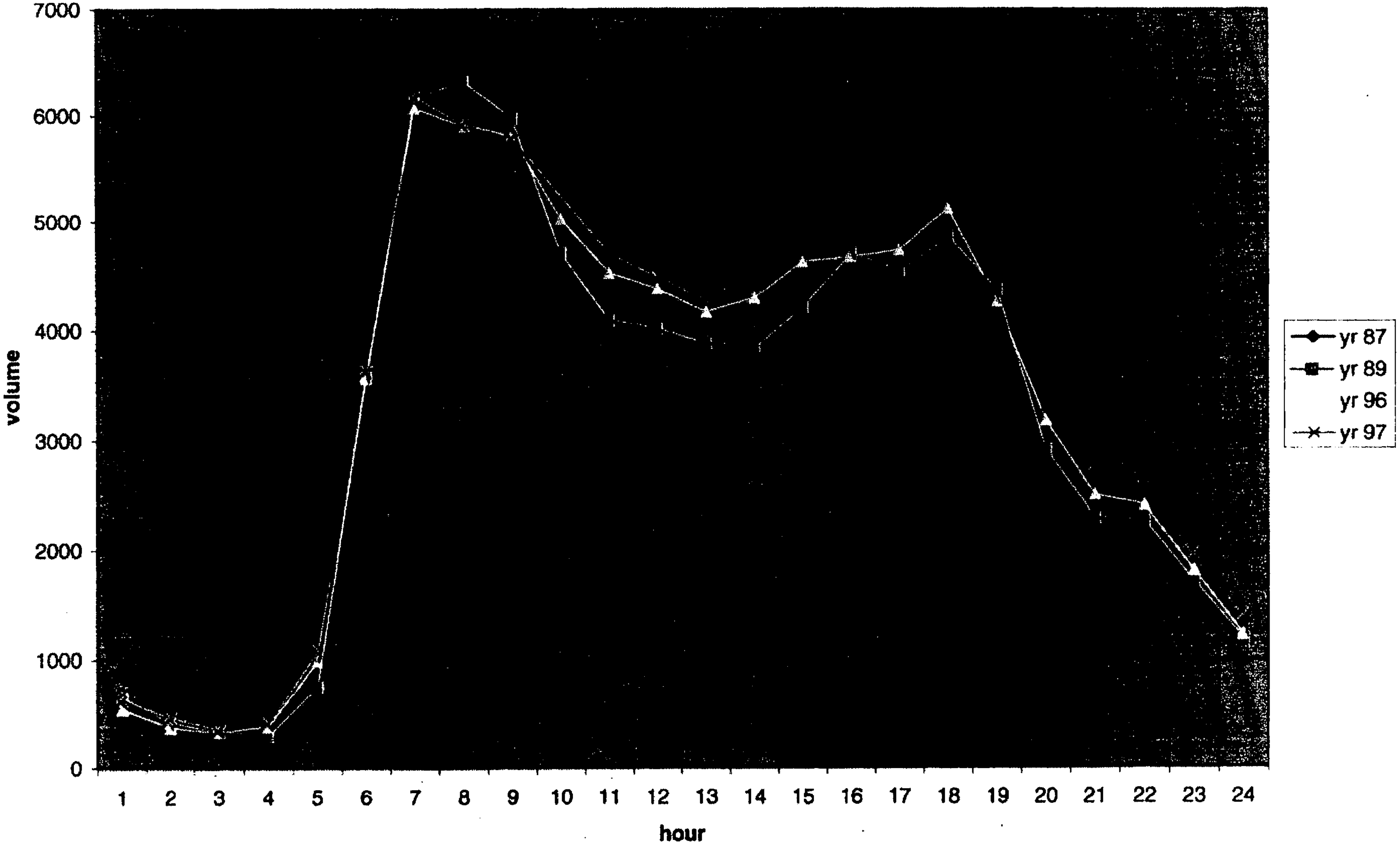
APPENDIX A: MAPS

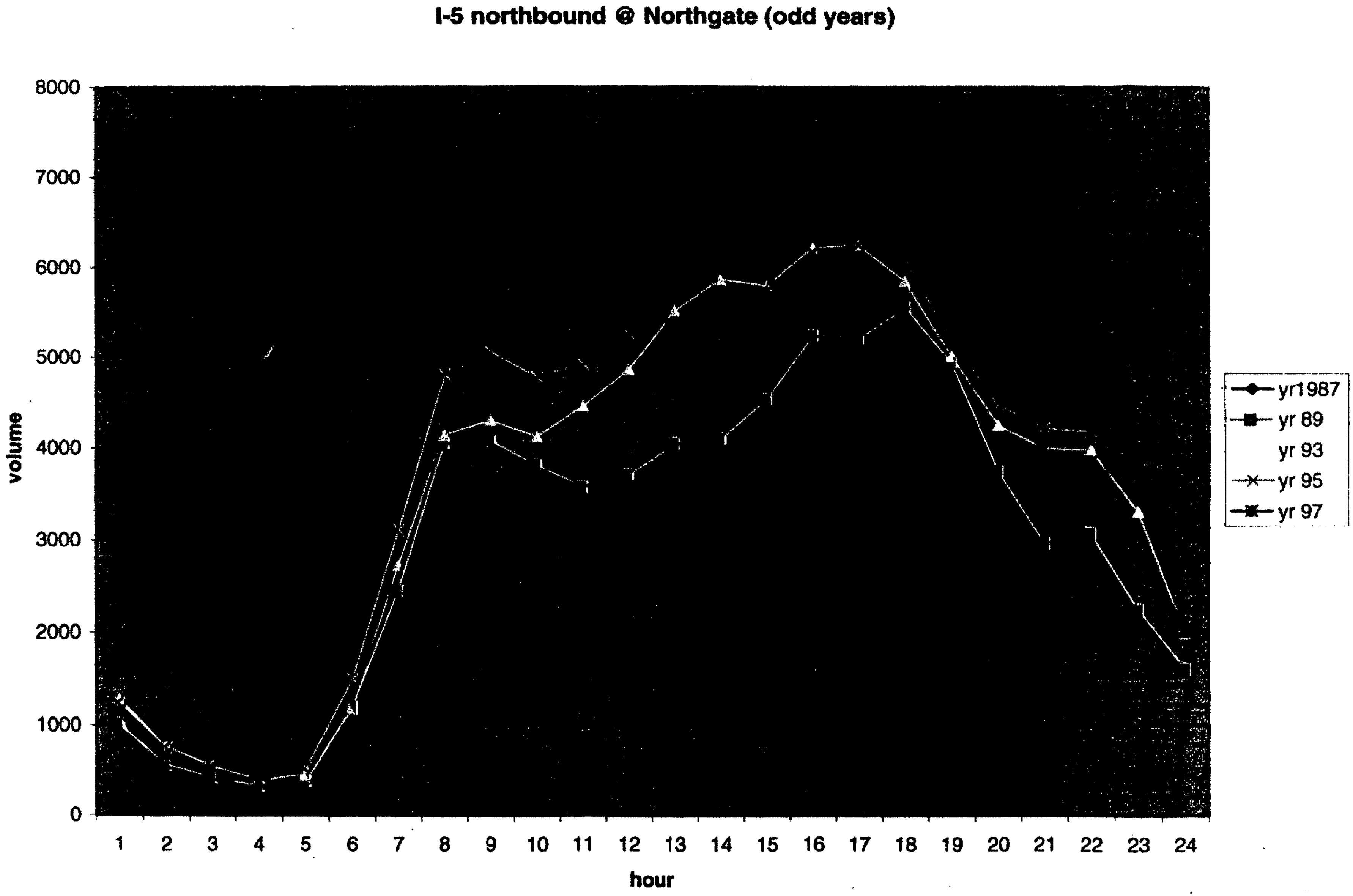

I-5 northbound @185th
8000
7000
6000
5000
4000
3000
2000
1000
0
volume
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
hour
yr 87
yr 89
yr 90
yr 92
yr 93
yr 94
yr 95
yr 96
yr 97

I-5 northbound @185th (yrs 87, 89, 97)

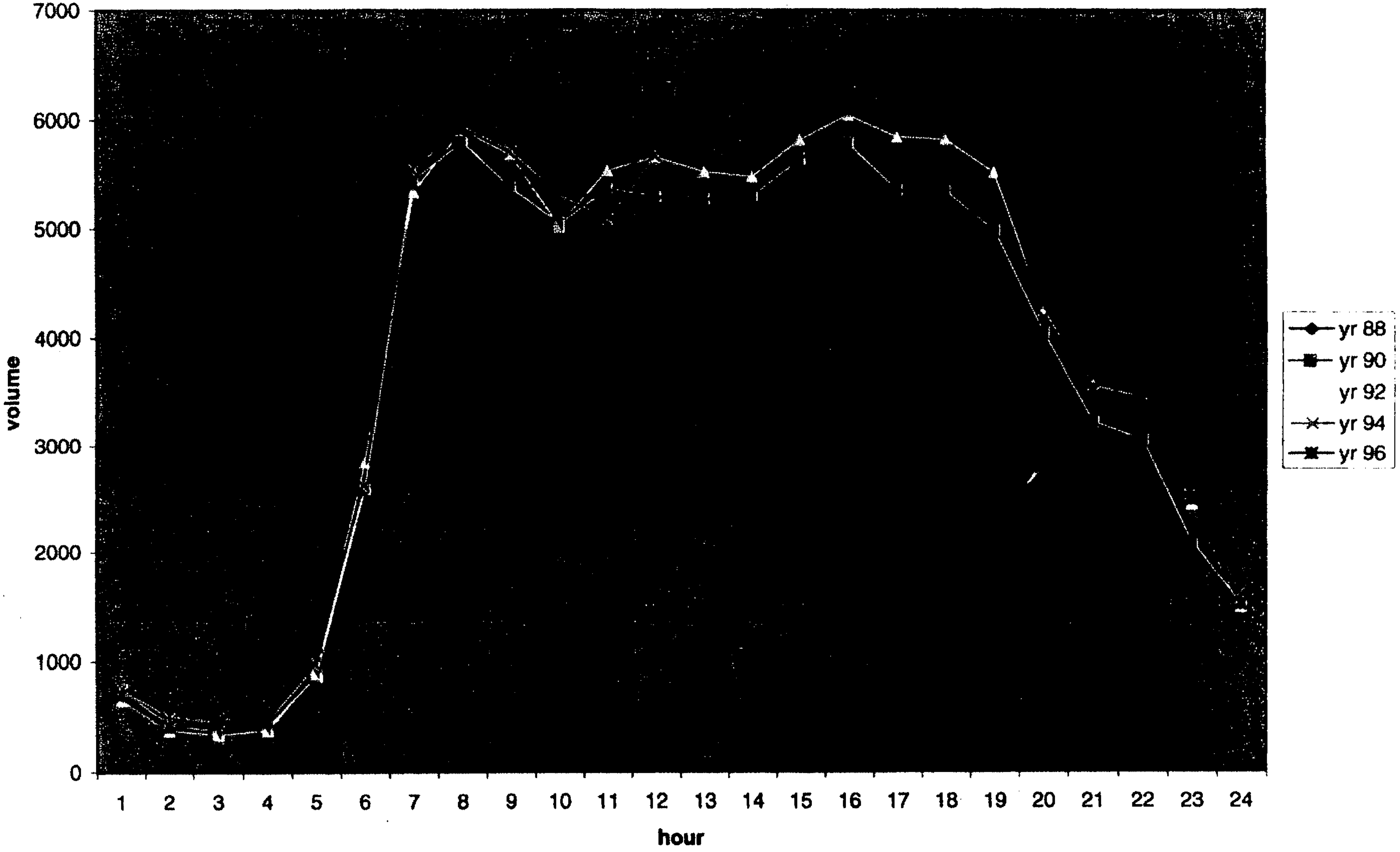


I-5 southbound @ 185th (87, 89, 96, 97)

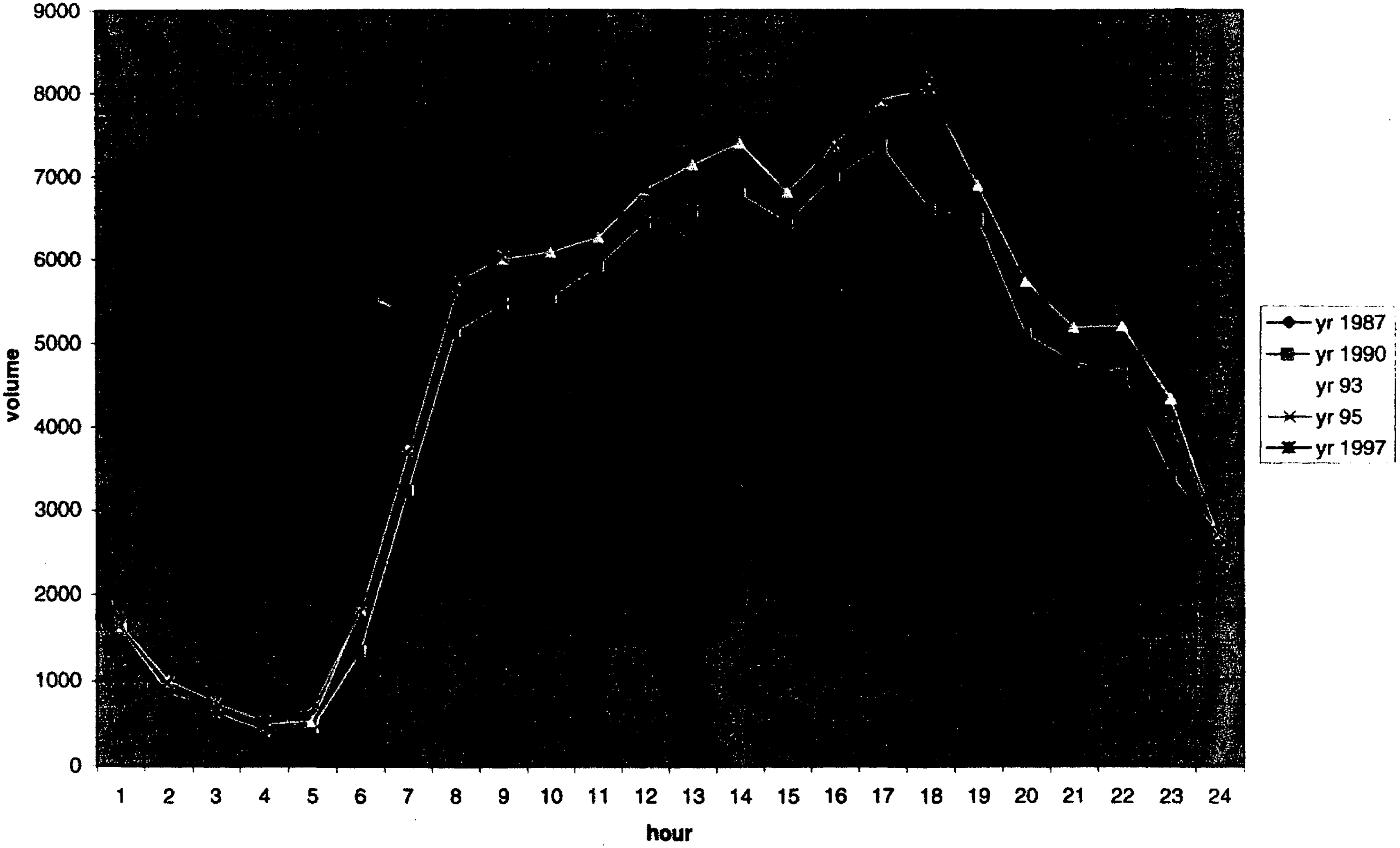



I-5 northbound @ Northgate (odd years)
volume
8000
7000
6000
5000
4000
3000
2000
1000
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
hour
yr1987
yr 89
yr 93
yr 95
yr 97

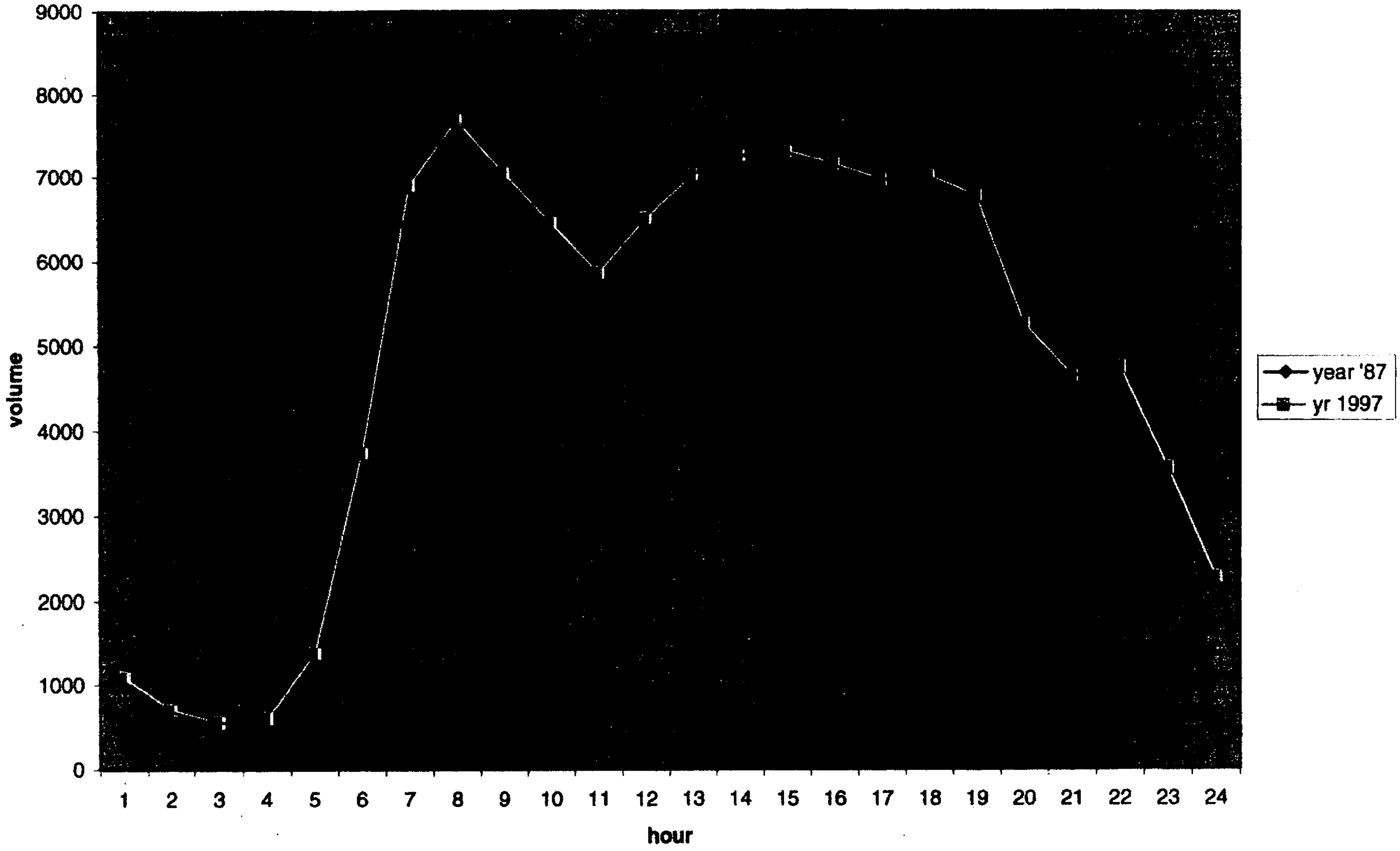
I-5 southbound @ Northgate (even years)



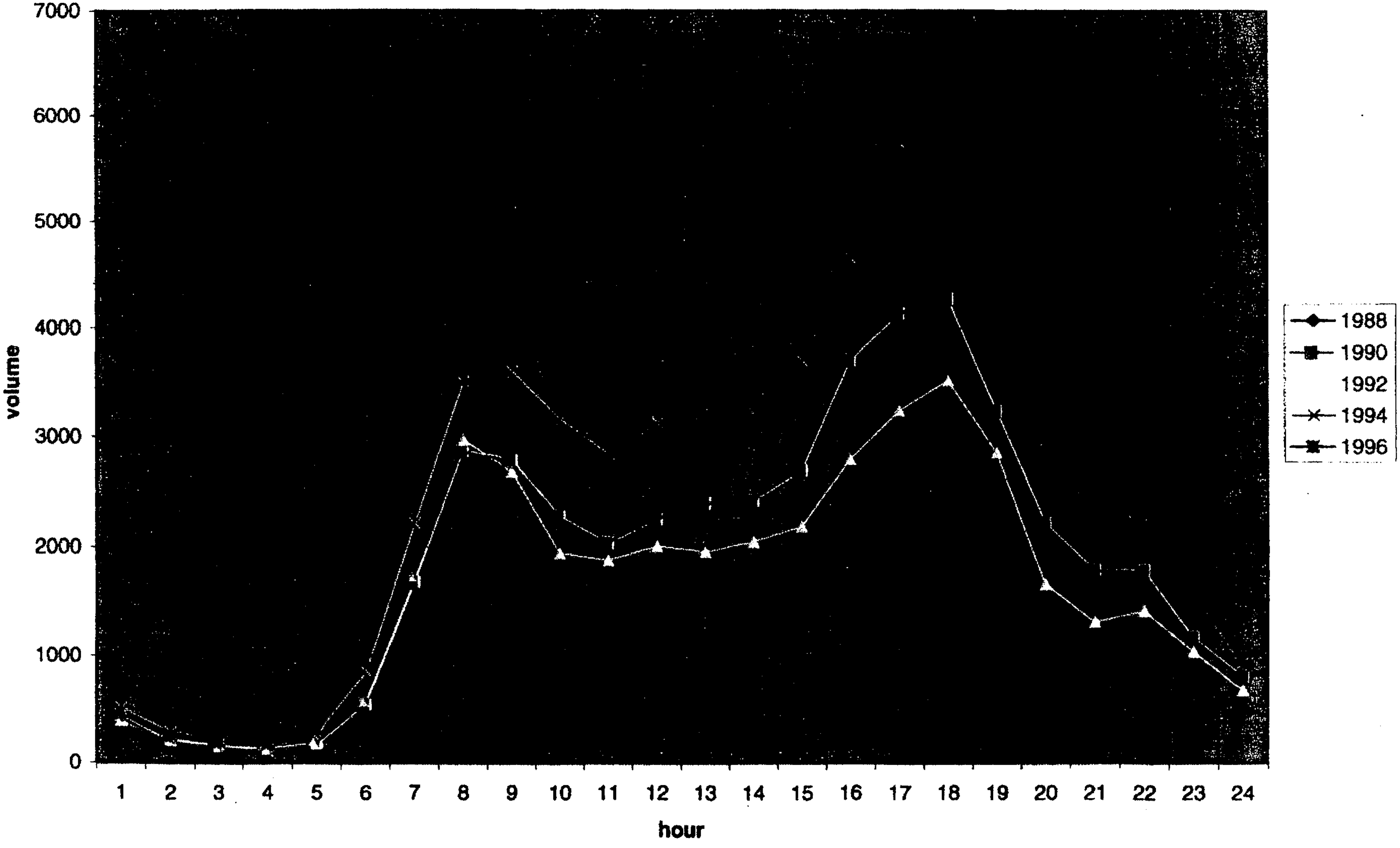
I-5 northbound @ Ship Canal



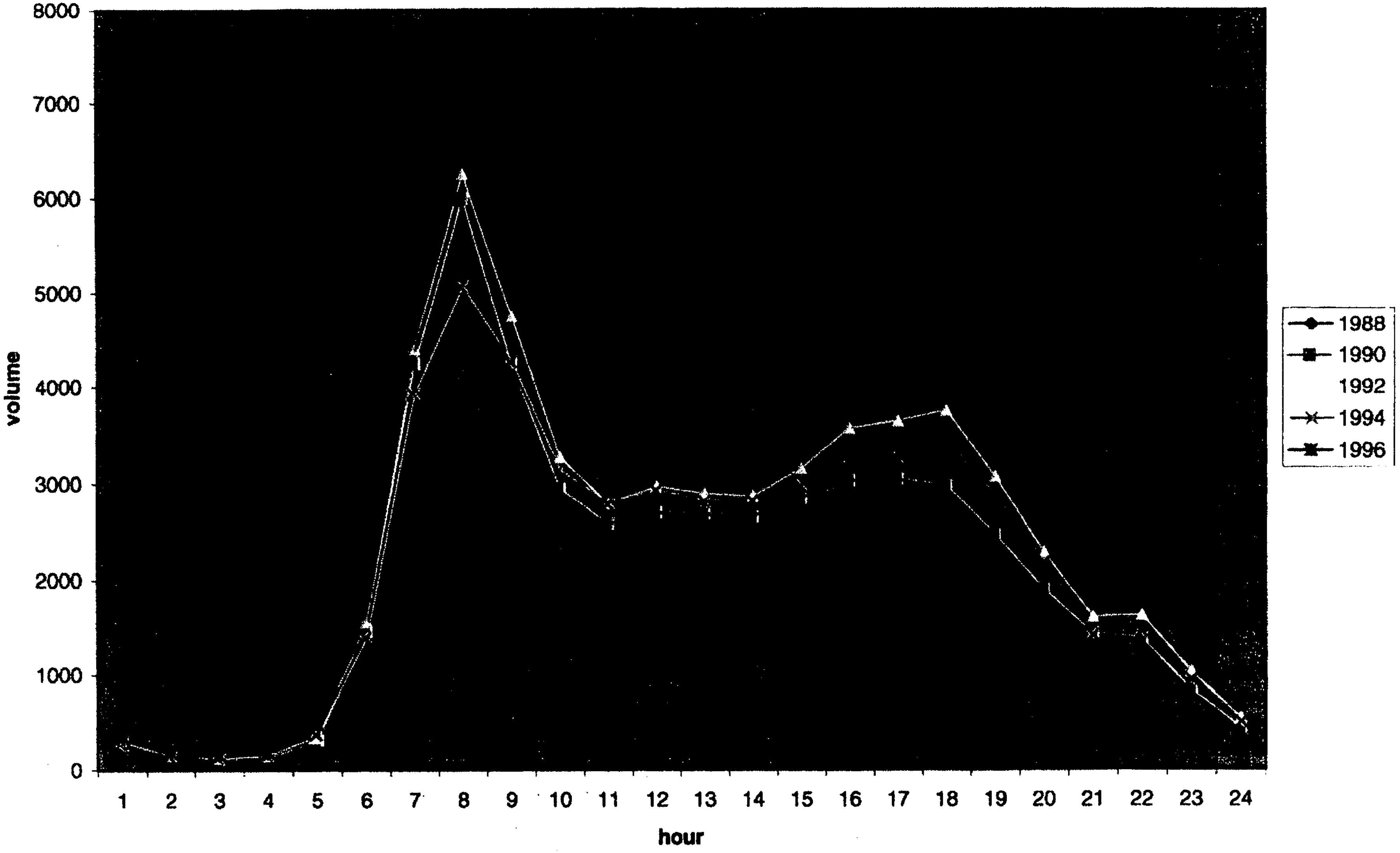
I-5 southbound @ Ship Canal (1987 &1997)

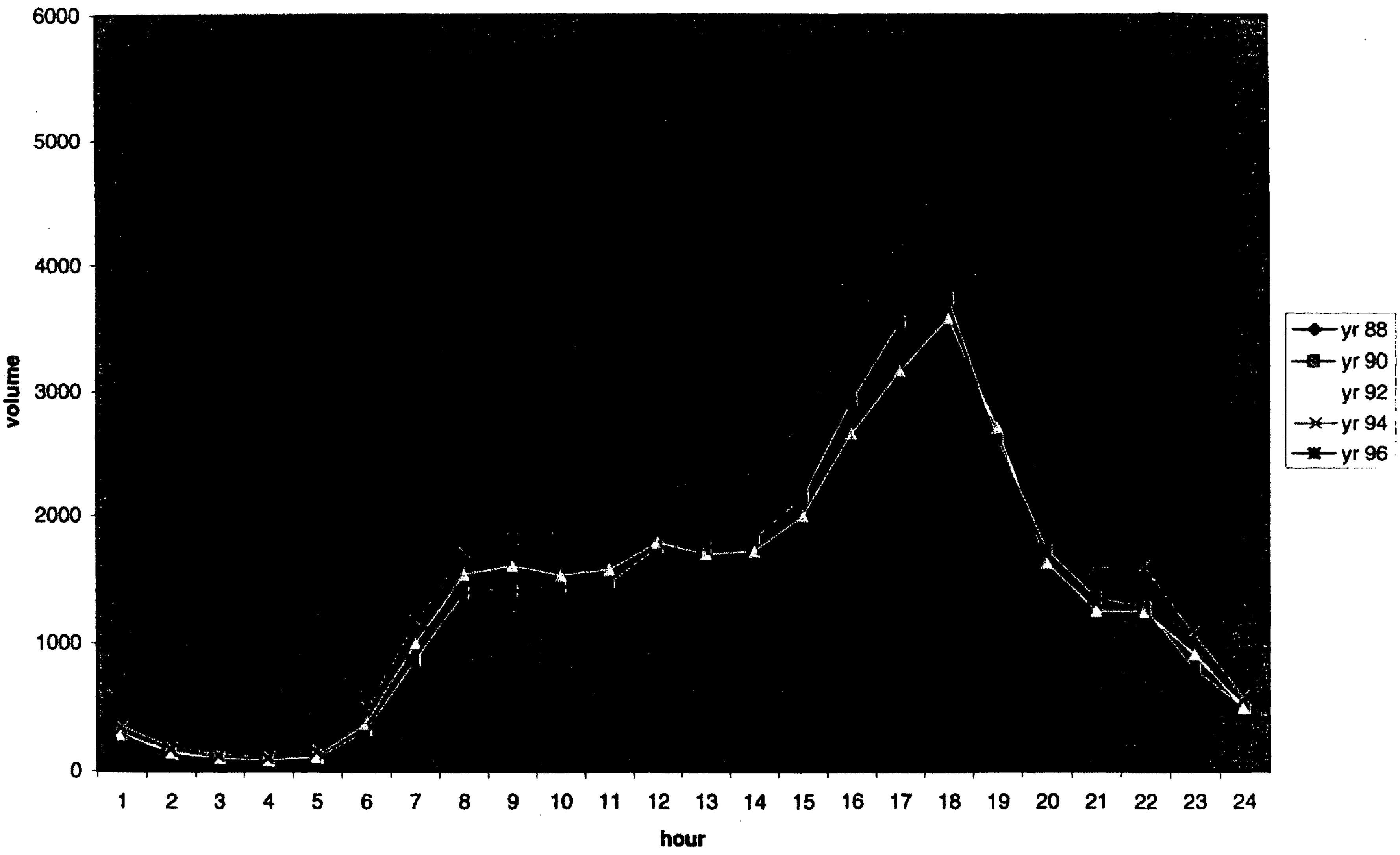


I-90 eastbound @ 136th (even years)

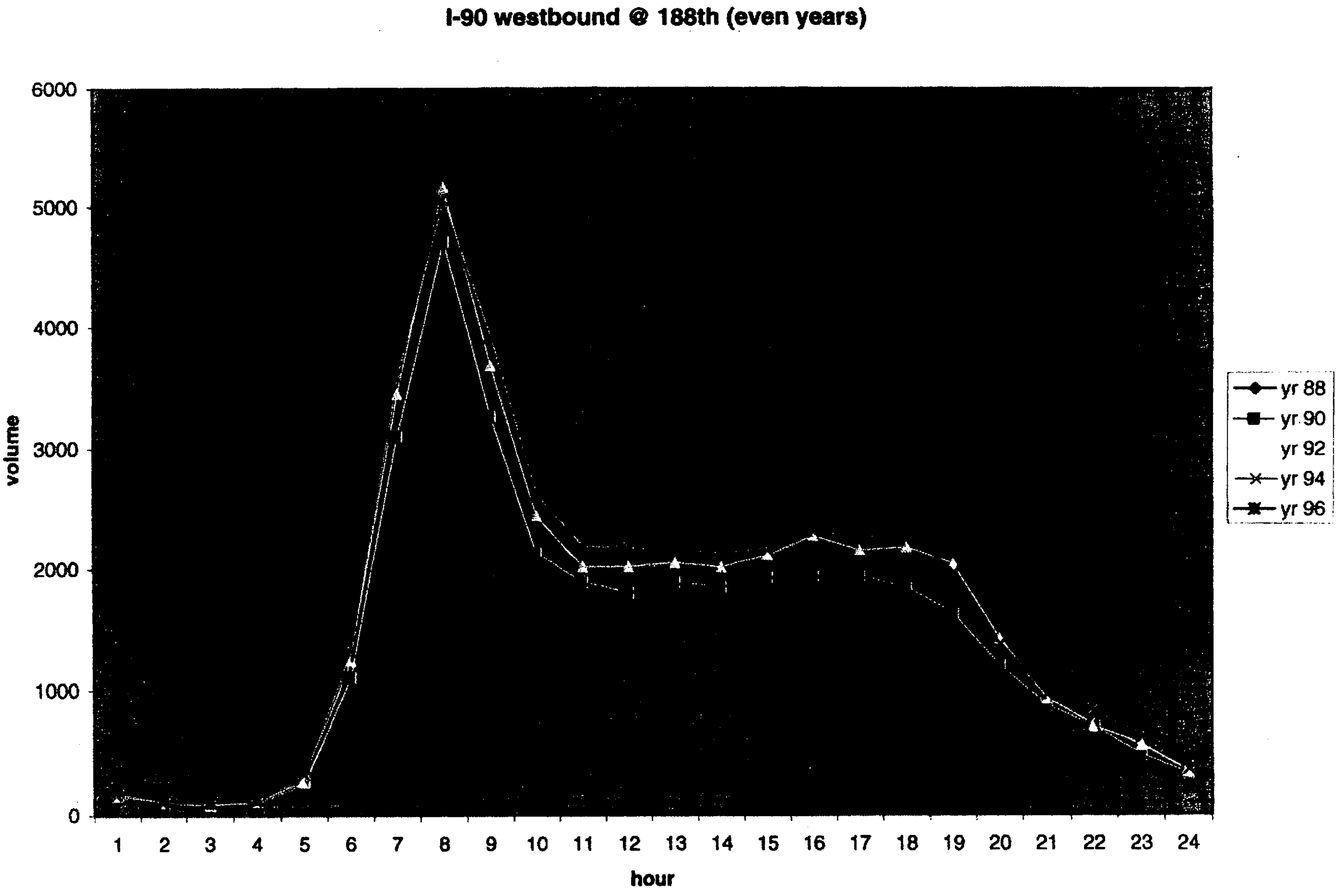


I-90 westbound @ 136th (even years)

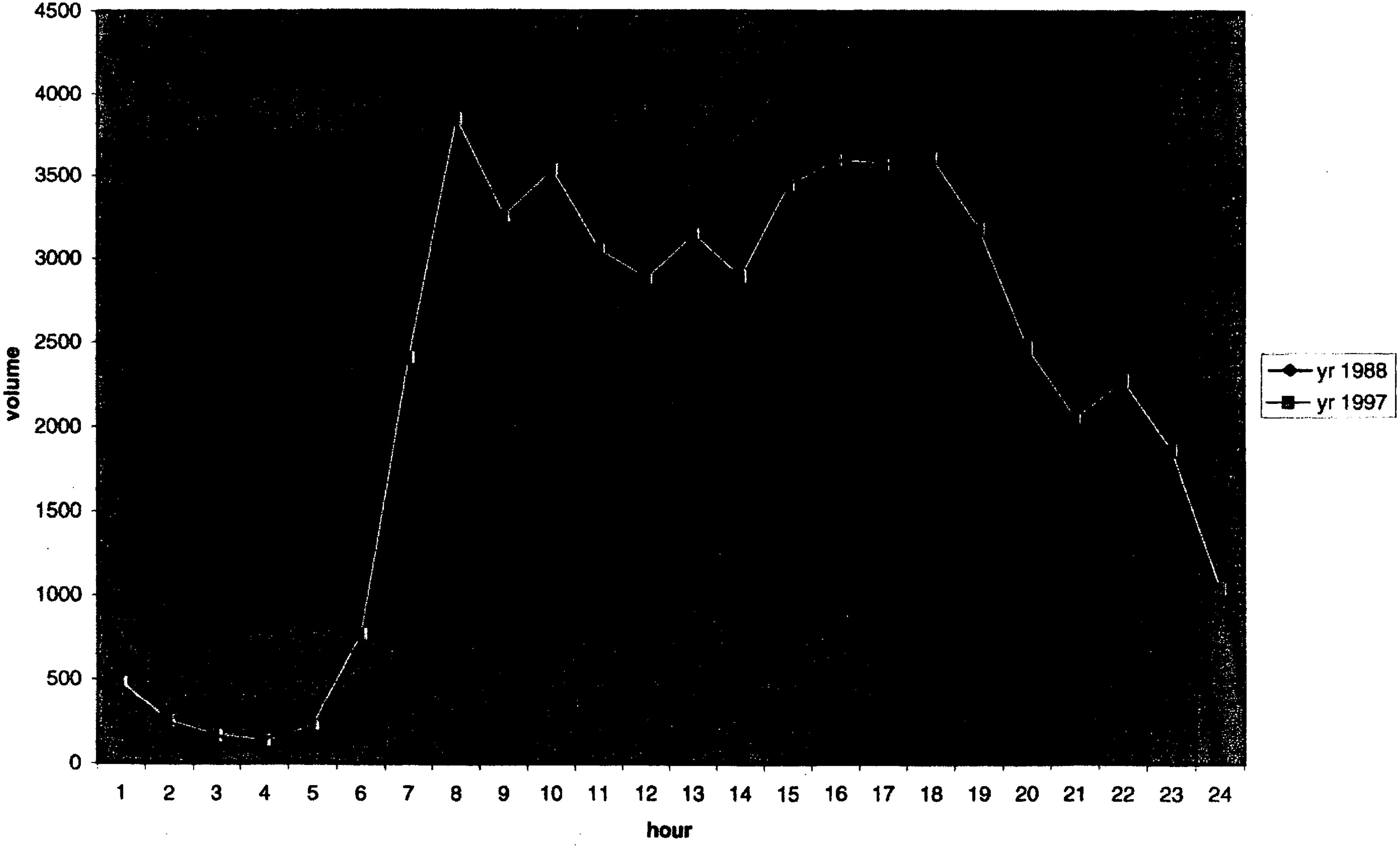


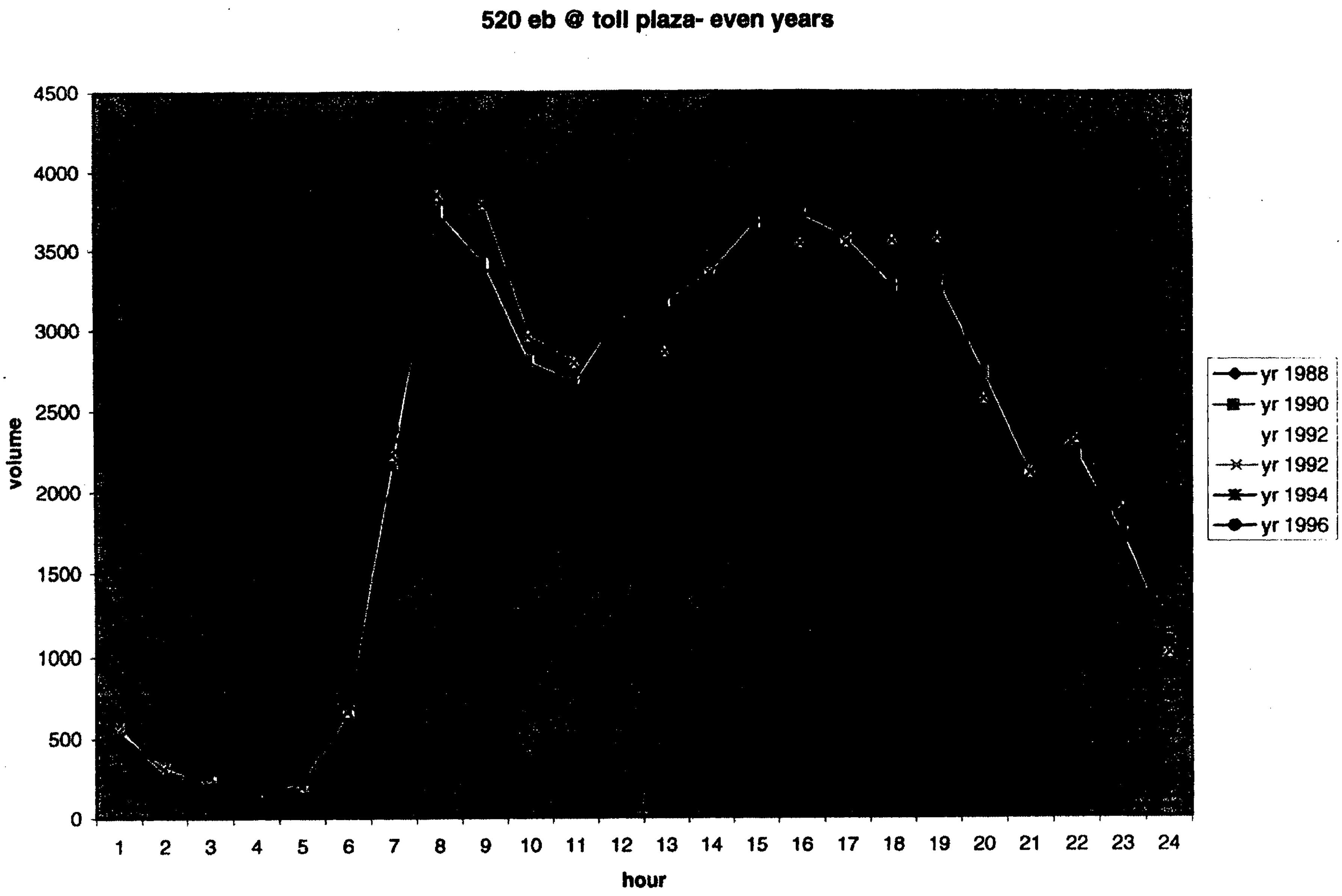


I-90 eastbound @ 188th (even years)

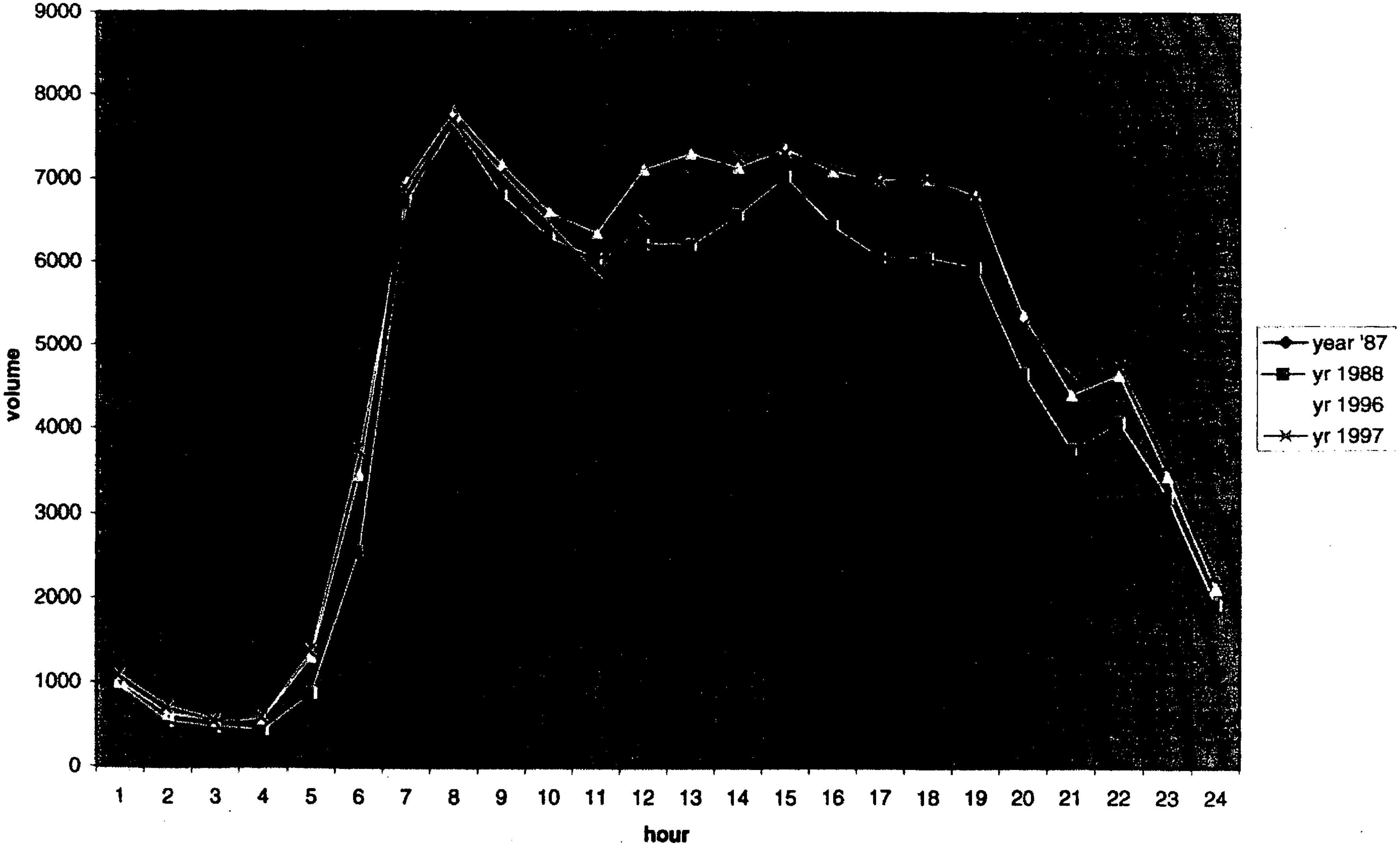

I-90 westbound @ 188th (even years)
volume
6000
5000
4000
3000
2000
1000
0
hour
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
yr 88
yr 90
yr 92
yr 94
yr 96

520 eb 1988 & 1997

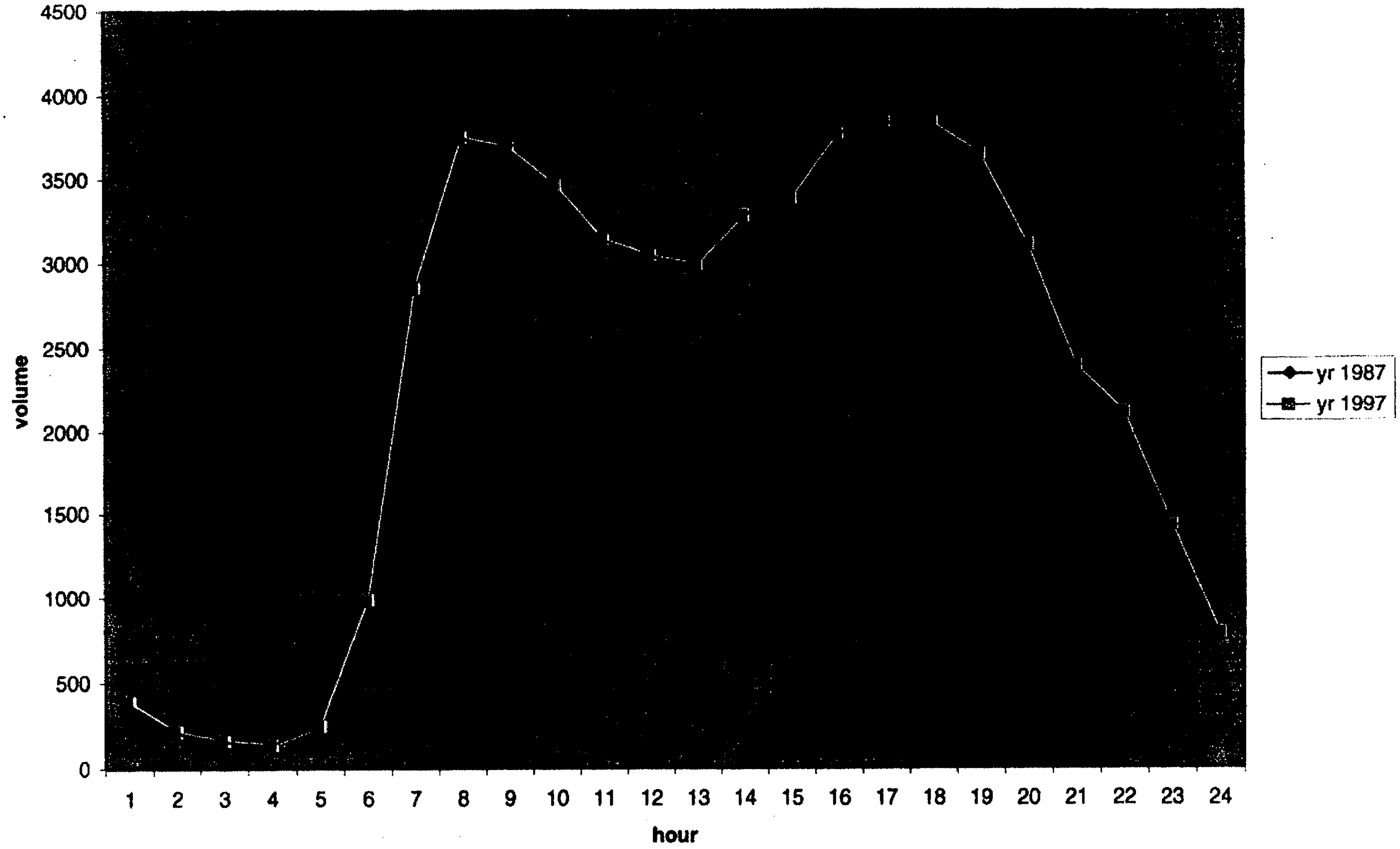


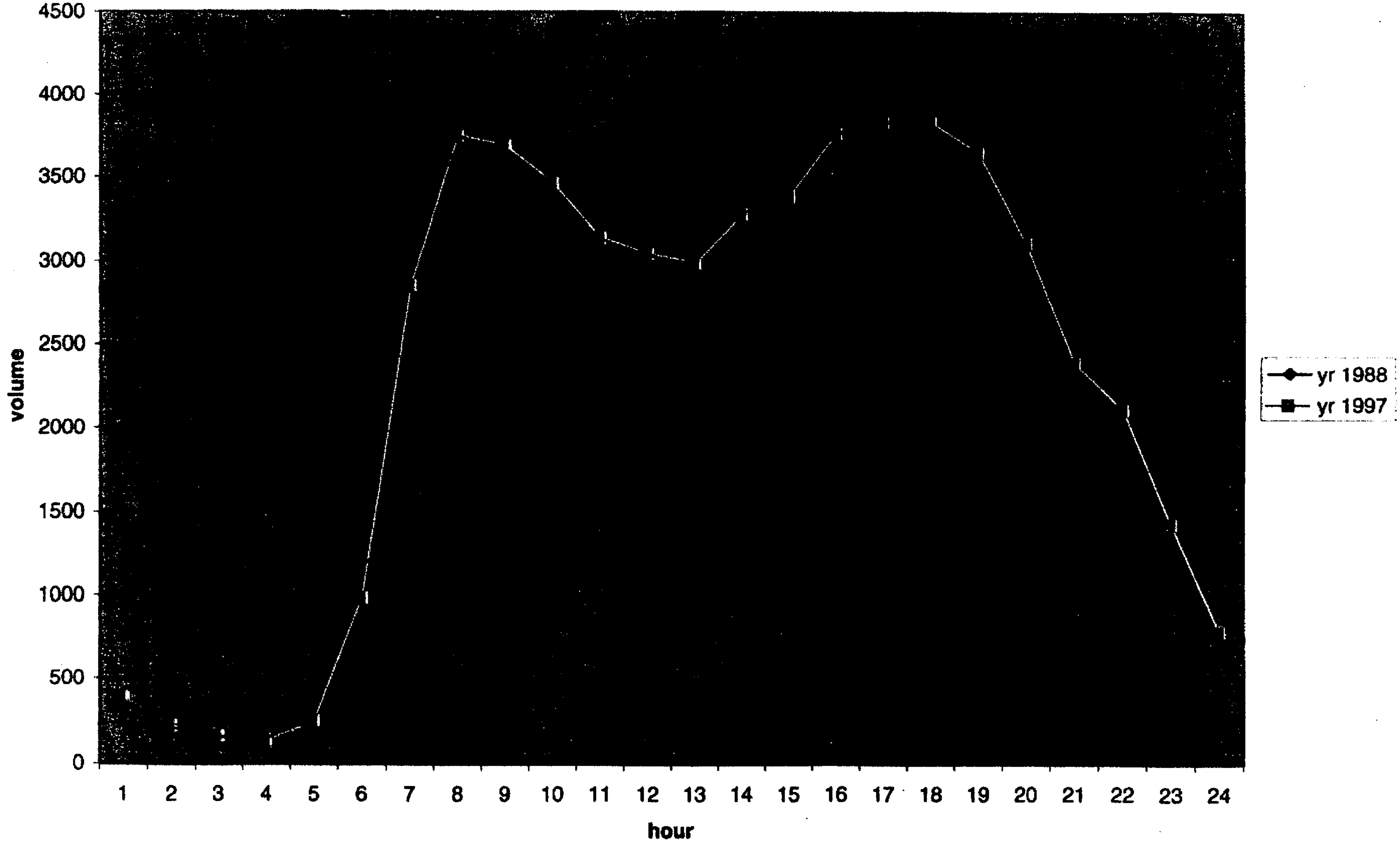

520 eb @ toll plaza- even years
volume
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
hour
yr 1988
yr 1990
yr 1992
yr 1992
yr 1994
yr 1996

I-5 southbound @Ship Canal (1987-8 & 1996-7)

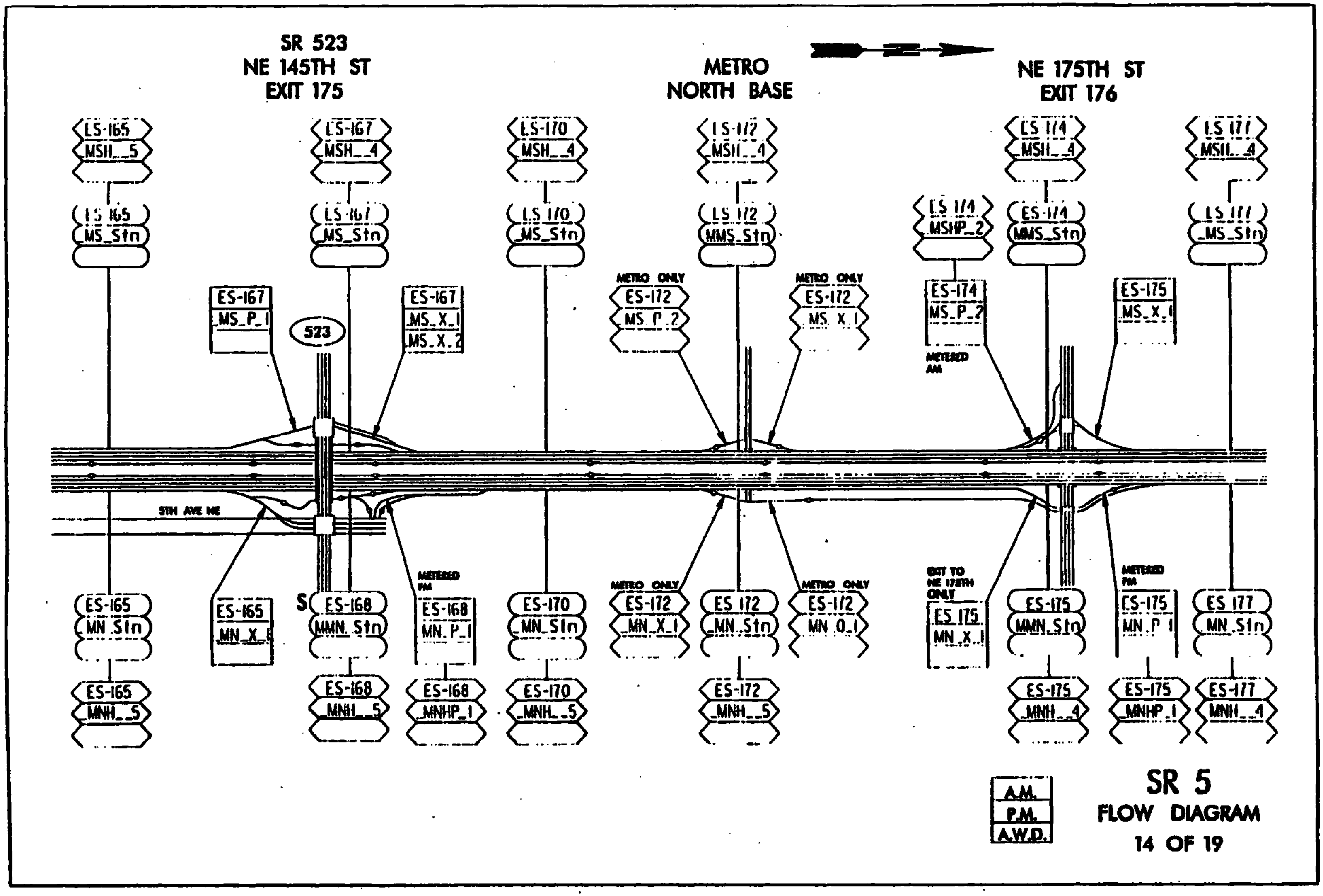


520 westbound @ Toll Plaza (1987 & 1997)

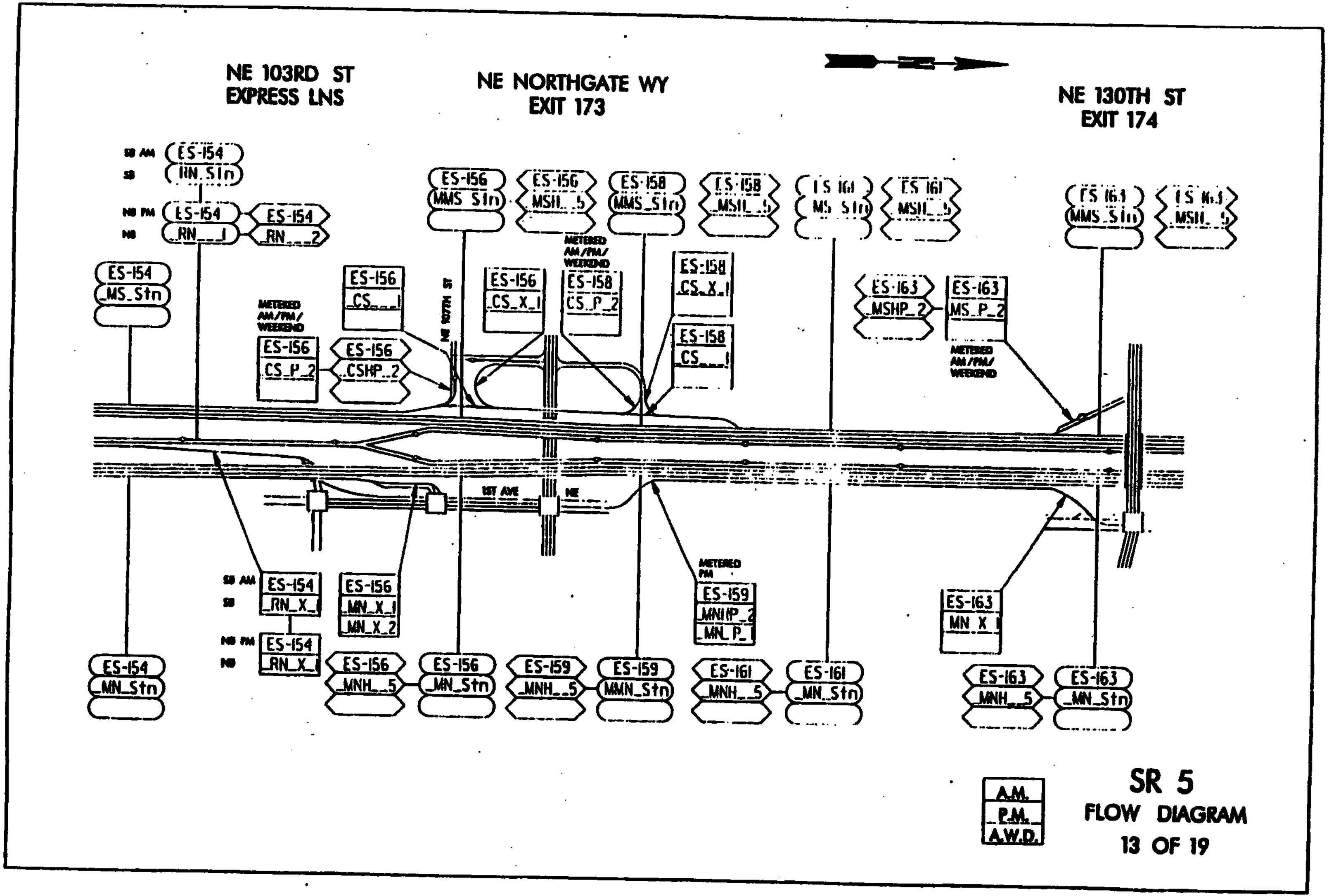




520 westbound @ Toll Plaza (1988 &1997)



TSMC, Northwest Region, WSDOT, 1996.



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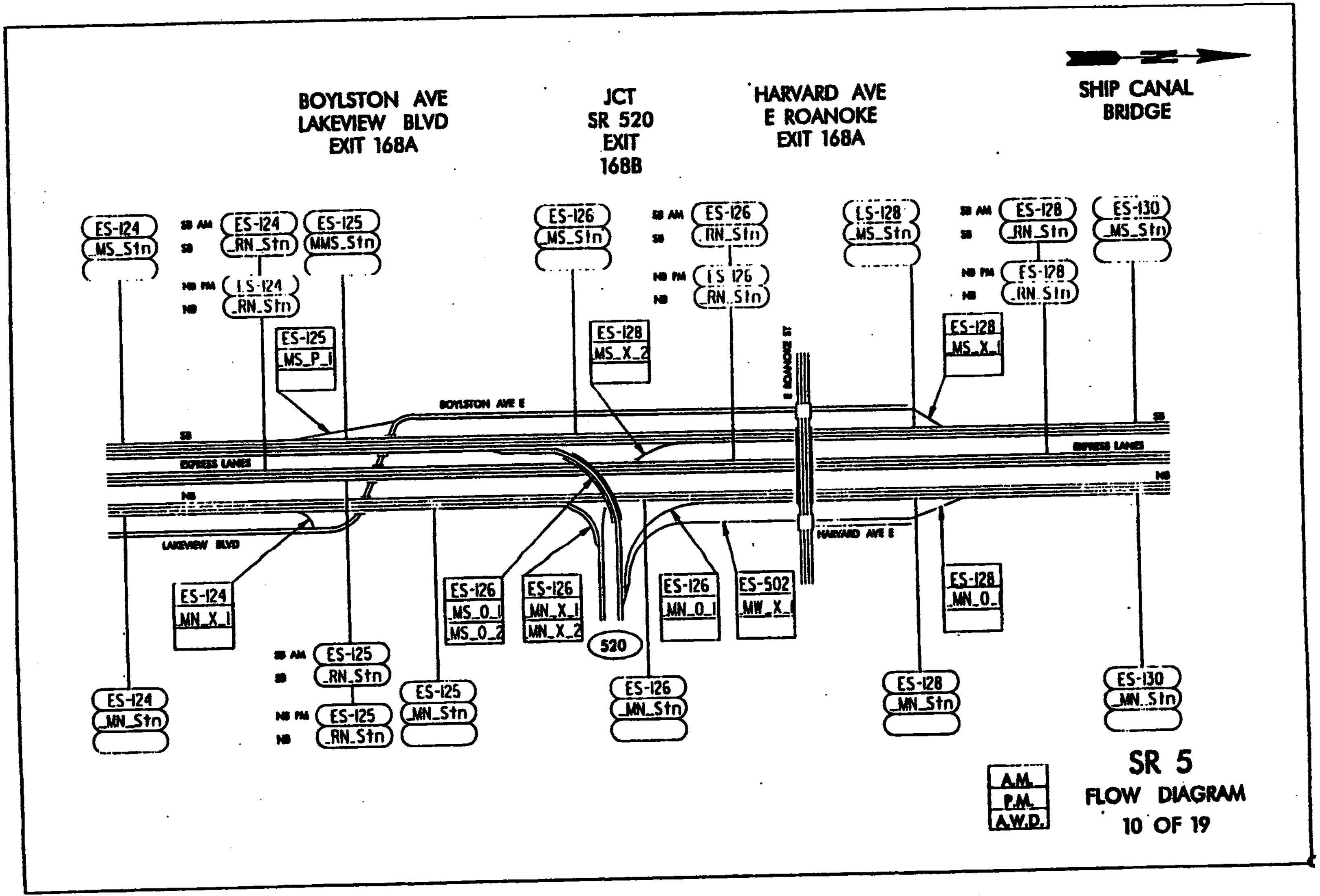

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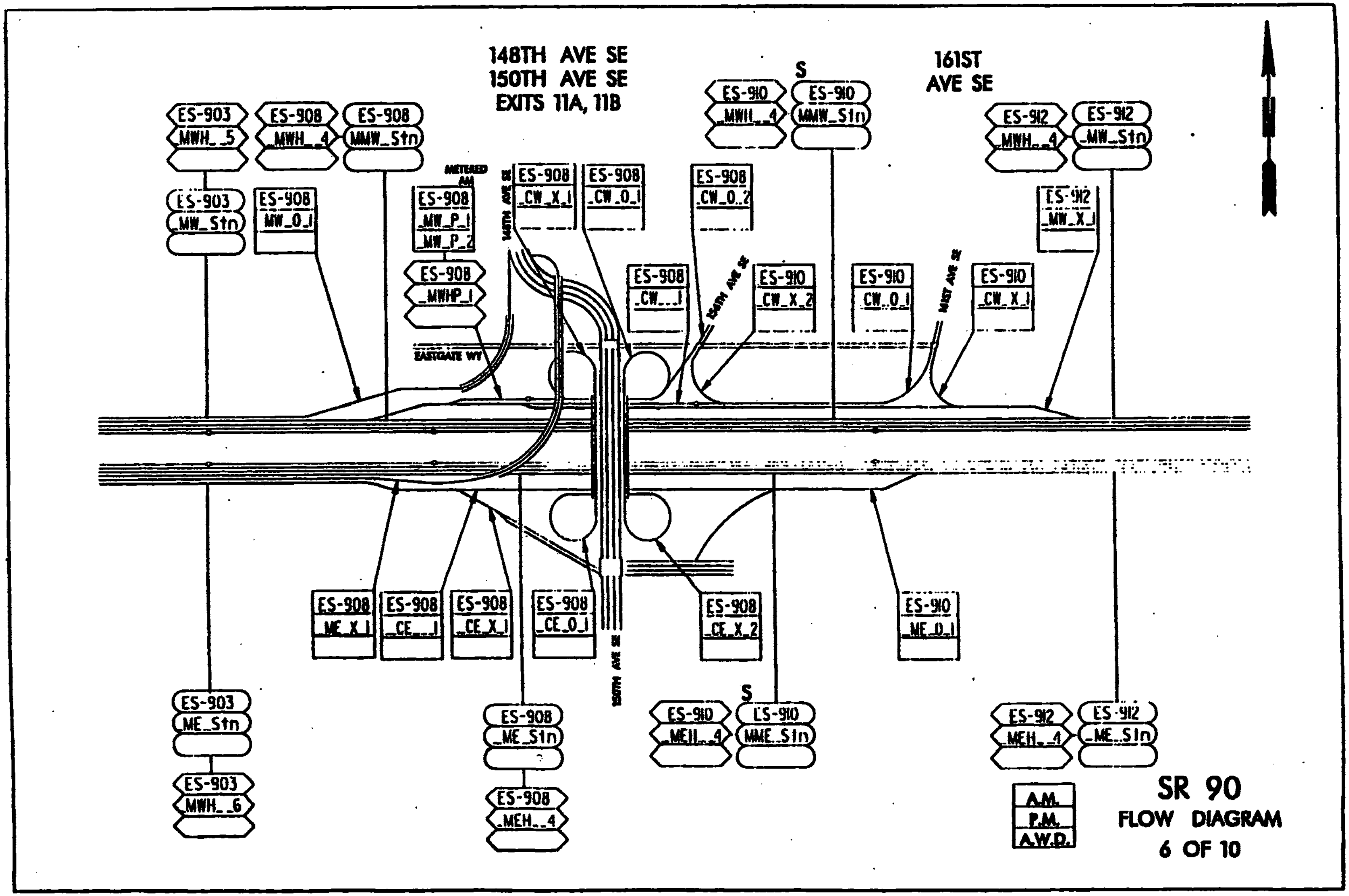

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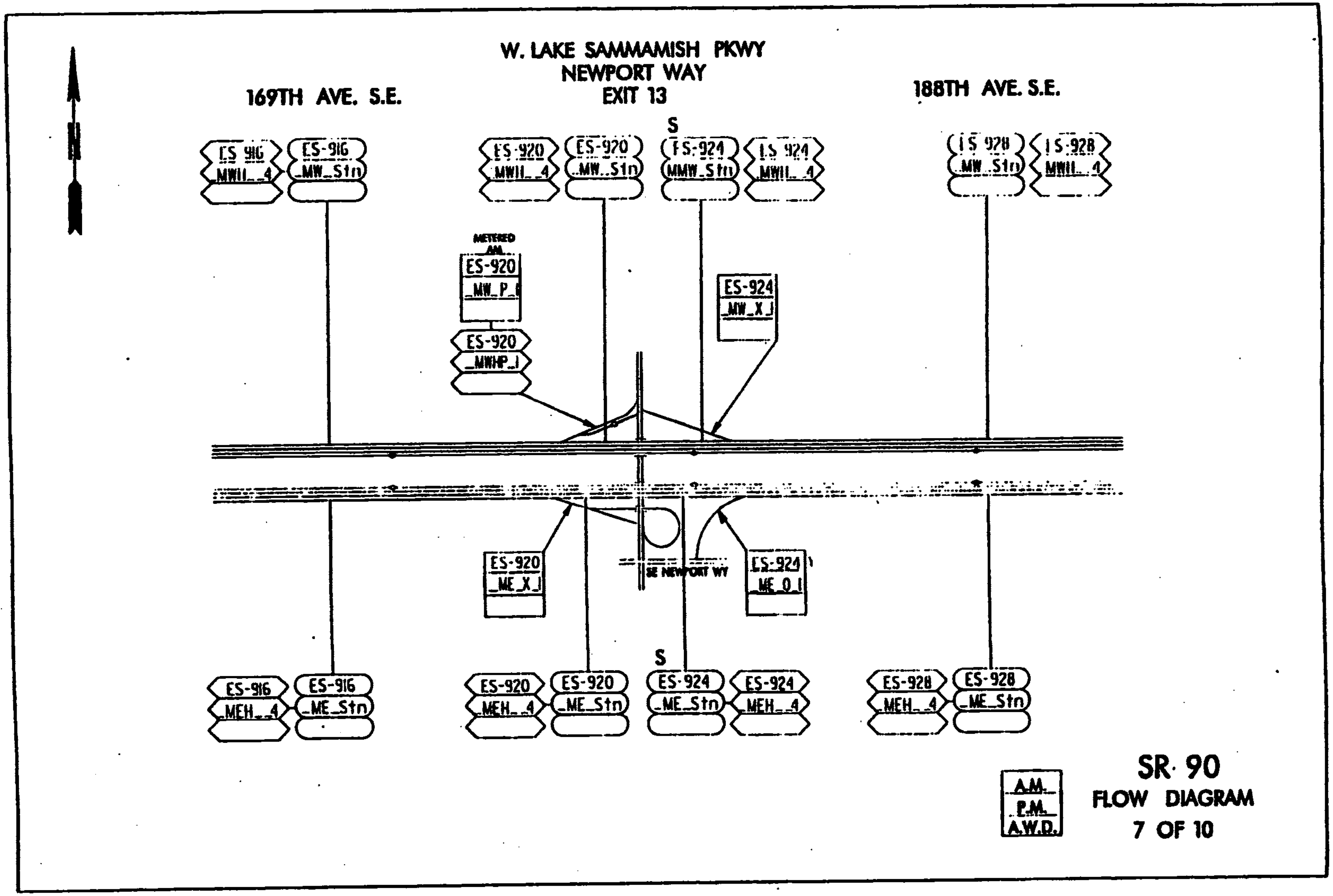

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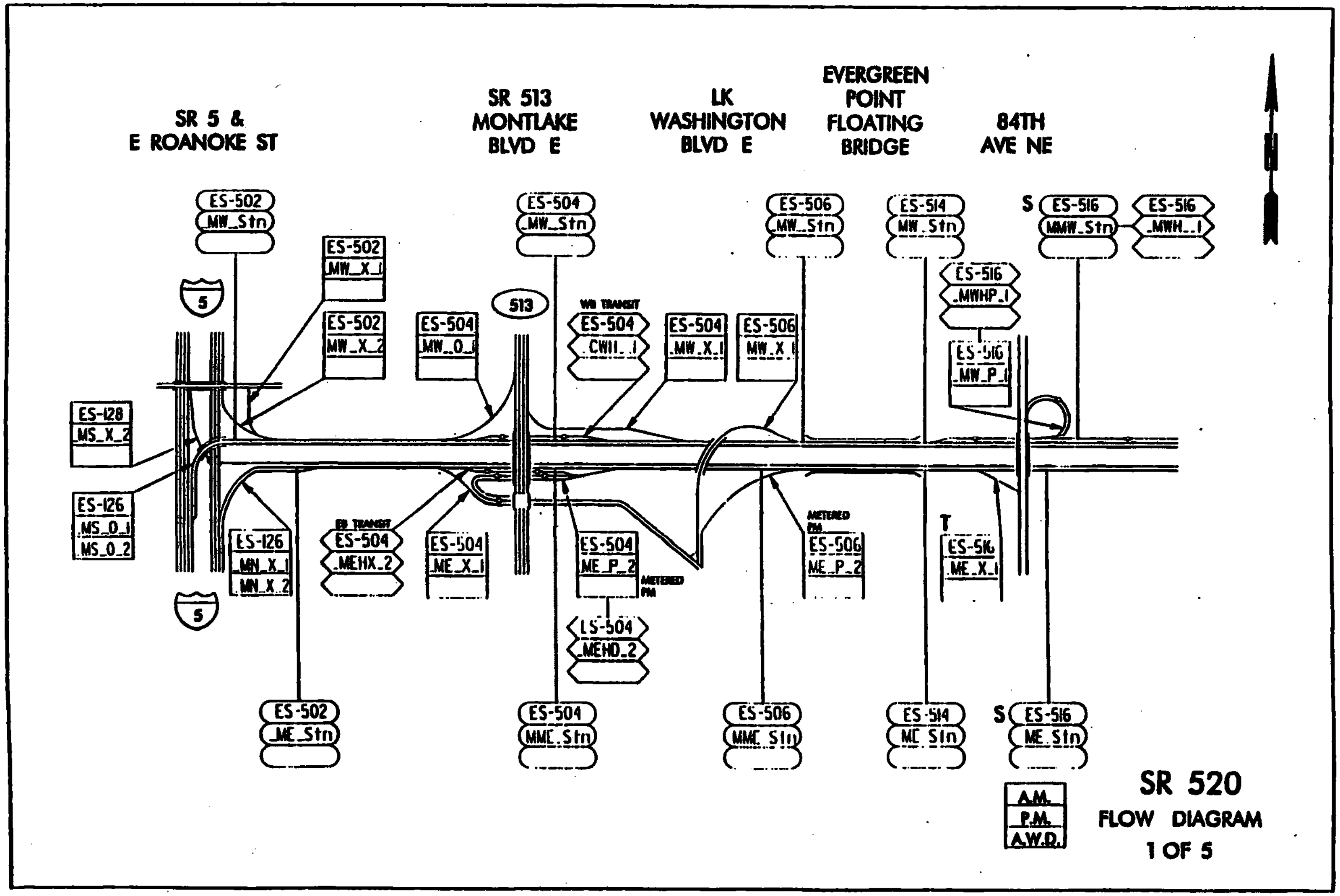

SR 520
FLOW DIAGRAM
1 OF 5

TSMC, Northwest Region, WSDOT, 1996.