SOUNDTRANSIT
RIDE THE WAVE

Lynnwood Link Extension

Phase 2

Transit Ridership Forecasting

Interim Technical Report

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Acronyms and Abbreviations

AA	Alternatives analysis
AAZ	Alternatives Analysis Zones
ACS	American Community Survey
APC	Automatic Passenger Count
AVL	Automatic Vehicle Locator
AWV	Alaska n Way Viaduct
CT	Community Transit
CTR	Commute Trip Reduction
DRAM	Disaggregated Residential Model
EIS	environmental impact statement
EMPAL	Employment Allocation Model
ERP	Expert Review Panel
FAZ	Forecast Analysis Zone
FEIS	Final Environmental Impact Statement
FTA	Federal Transit Administration
GMA	Growth Management Act
HOV	high-occupancy vehicle
IIA	independence from irrelevant alternatives
JTW	journey-to-work
KCM	King County Metro
NTD	National Transit Database
OFM	Washington Office of Financial Management
PSCOG	Puget Sound Council of Governments
PSEF	Puget Sound Economic Forecaster
PSRC	Puget Sound Regional Council
PT	Pierce Transit
RTA	Regional Transit Authority
RTP	Regional Transit Project
ST	Sound Transit
TPI	time point interval
TRB	Transportation Research Board
WSDOT	Washington Department of Transportation

1. INTRODUCTION

This interim report describes the ongoing update to the Sound Transit (ST) incremental model using new data resulting from recent surveys and counts. The updated 2012 version of the ST model is intended to be used to produce ridership forecasts for the Lynnwood Link Extension in support of the application to the Federal Transit Administration (FTA) for entry into Preliminary Engineering as part of the New Starts process. Ridership forecasts for the Lynnwood Link Extension will be included in the next version of this report.

The current version of the ST ridership model was developed using analytical ridership forecasting procedures developed over two decades of incremental methods applications. Over this time period, the methods have been subjected to substantial external review, including two independent Expert Review Panels, and two cycles of review by the FTA over the course of New Starts grant applications for Link light rail projects. This also includes recent review comments FTA provided with respect to the ST incremental modeling procedures and assumptions described in the earlier (December 2010) version of this report. This interim report incorporates FTA's recent review comments. The following presents a brief history of ST transit ridership forecasting.

1.1 History of Transit Forecasting at Sound Transit

The history of transit forecasting analysis at ST began at Seattle Metro (now King County Metro) in 1986. Work by Brand and Benham, of Charles River Associates, led to Metro's consideration of "a quick-responsive incremental travel demand forecasting method" [1] based on the concept of staged forecasting analysis. Subsequently, in 1986, Metro installed "logit mode-choice equations for pivot-point analysis" [2] (as described by Ben-Akiva and Atherton;[3] Koppelman;[4] Nickesen, Meyburg and Turrnquist;[5] and many others) on EMME software. In 1988, Metro staff highlighted the relationship[6] between Metro's transit forecasting methods and the Puget Sound Council of Governments (PSCOG) regional model.

ST and the Regional Transit Project (RTP) further developed forecasting analysis procedures using incremental methods in the early 1990s, prior to the November 1996 voter approval of *Sound Move: The Ten-Year Regional Transit Plan*. An Expert Review Panel (ERP)—formed in 1990 under the auspices of the Legislative Transportation Committee, the Secretary of Transportation, and the Governor—oversaw development of the first generation of the ST incremental model. This model is described in the November 1993 *Travel Forecasting Methodology Report* published by the RTP.

The ST model was updated in the late 1990s in support of the Central Link Light Rail Transit Project Environmental Impact Statement (EIS) and the North Link Light Rail Transit Project Supplementary EISs, including respective Full Funding Grant Agreements with FTA. The underlying ST model procedures used to perform transit ridership forecasting analysis in support of the North Link Light Rail Projects were documented in the *Transit Ridership Forecasting Technical Report,* issued in November 2003 by ST. The ST model was further updated in the mid 2000s in support of the ST Phase 2 expansion program and subsequently for the Alternatives Analysis (AA) Phase of the Lynnwood Link Extension.

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[1] Brand, D., and J.L. Benham, "Elasticity-Based Method for Forecasting Travel on Current Urban Transportation Alternatives," Transportation Research Record No. 895, 1982.
[2] Harvey, R., "Pivot-Point Analysis of Transit Demand Using EMME/2," an Internal Paper, Municipality of Metropolitan Seattle, May 1986.
[3] Ben-Akiva, M. and T. Atherton, "Methodology for Short-Range Travel Demand Predictions," Transportation Economics and Policy, v.7, 1977.
[4] Koppelman, F., "Predicting Transit Ridership in Response to Transit Service Changes," ASCE 109, 1983.
[5] Nickesen A., A. Meyburg, and M. Turnquist, "Ridership Estimation for Short-Range Transit Planning," Transportation Research B, v.17B, 1983
[6] Harvey, R., "Comparison of Metro and PSCOG Modeling" a Memorandum to File, March 7, 1988.

The 2012 version of the ST model interfaces with the Lynnwood Link Extension highway model. This highway model is based on a version of the PSRC model adopted by Washington State Department of Transportation (WSDOT) for performing detailed travel and toll forecasting in support of major capital projects.

1.2 Report Organization

This report contains four chapters. Chapter 1 summarizes the methods used to produce ridership forecasts for ST and discusses important methodological considerations. Chapter 2 describes the individual methods used for each step of the travel forecasting process. Chapter 3 describes validation of the ST model to 2011 conditions. The current model validation exercise has two purposes: (1) to highlight problems with the forecasting process that might have otherwise been overlooked, and (2) to incorporate changes that could improve the forecasting results. Chapter 4 discusses the specific input data and assumptions used to perform staged ridership forecasting analysis. The chapter also includes build-up analysis results for Stages 1 and 2 ridership forecasts as well as ridership estimation for a hypothetical scenario in which the proposed Sound Transit System Plan would already be operating in 2011.

1.3 Sound Transit Incremental Transit Model

The ST incremental model has been updated to a new base year (2011). Development of the base-year transit-trip tables involved a rigorous analysis of actual ridership volumes along each transit route and a realistic simulation of observed transit service characteristics for peak and off-peak periods. External changes in demographics, highway travel time, and costs are distinctly incorporated into the process in phases, prior to estimating the impacts of incremental changes in transit service. The ST model relies on the Puget Sound Regional Council (PSRC) regional model for forecasts of external changes.

In the first stage of ridership forecasting analysis, only changes in PSRC model trip distribution results or demographics are considered. In the second stage, other external non-transit changes, such as highway travel time (congestion), costs (including parking costs), and household income, are taken into consideration.

The first two stages of ridership forecasting analysis result in a forecast of zone-to-zone transit trips within the Regional Transit Authority (RTA) district boundaries, absent any changes in the transit system. In the third and final stage, incremental changes in the transit level of service (e.g., access, wait, and ride travel times) and user costs are considered. Finally, transit trips are assigned to the future-year transit network.

Like all travel forecasting models, the ST model has some limitations. Because it uses average daily ridership, it is not particularly strong at assessing the effects of special events, such as sports games or major festivals, or special generators, like major international airports. Furthermore, the ST model is ill-suited for analyzing structural changes in regional land use beyond those already included in PSRC demographic forecasts or for forecasting in outlying areas of the three-county region where there is minimal existing transit service. Finally, the model does not explicitly take into account any differences in safety, comfort, or user friendliness of bus versus rail transit service.

1.4 Important Considerations and Constraints

This section discusses five important considerations and constraints in travel forecasting methods. Most of these were taken from the FTA guidelines on transit project planning.[7] The following considerations reemphasize the use of best professional practice:

- Careful standards for validation
- Consistent application of policy assumptions across alternatives
- Use of identical land use plans and constant overall travel demand patterns across alternatives
- Generic attributes of modes
- Analysis of service levels and travel forecasts for reasonableness

1.4.1 Careful Standards for Validation

Validation is a vital component of any travel forecasting effort. It demonstrates that the forecasting procedures can replicate observed travel patterns in a region, to sufficiently support reasonably reliable forecasts of future travel patterns. The ST model has relied on surveys and actual ridership data to establish current travel patterns. In project planning, travel forecasting methods are expected to predict changes in travel patterns that are caused by general changes between now and the forecast year and by specific changes introduced by each alternative.

1.4.2 Consistent Policy Assumptions across Alternatives

A large number of inputs to the travel forecasting process are at least partially subject to the policy decisions of local and state agencies. To isolate the differences generated by a specific proposed project (e.g., a fixed guideway rail transit system), all conditions that are not directly attributable to the proposed project must be held constant. It is therefore required that the forecasts hold the policy setting constant across all alternatives evaluated. These policies include:

- Fare level and structure
- Levels of service provided by the transit system
- Zoning policies
- Parking policies and prices
- Right-of-way availability

This constraint means that forecasts prepared for FTA evaluation and EIS presentation should only contain differences between alternatives that are primarily caused by alternatives themselves. For example, service levels on feeder buses should reflect a general service policy that is applied consistently across alternatives. Assumptions on land use development, regional income, parking costs, and other variables not specific to the transit alternatives under consideration in the corridor must also be held constant.

1.4.3 Constant Travel Patterns across Alternatives

Forecasts of the overall travel demand for which transit and HOV facilities compete can also involve confounding factors. The FTA requirement that land use policies be consistently applied removes some sources of variability in population and employment forecasts. This requirement goes beyond the constraint mandating that the population and employment forecasts themselves be held constant. In basic forecasts for modes that have differing levels of grade separation, it eliminates guessing about the extent to which a particular alternative might shift residential and commercial development. Note that the forecasts provided to FTA are required to hold travel

[7] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.

patterns constant. Supplementary analyses and/or tools may be needed to address the non-FTA requirements.

1.4.4 Generic Attributes of Modes

There is currently much discussion of the differences in ridership potential associated with the less tangible qualities of various transit technologies. This discussion typically focuses on the perceived differences between technologies in terms of visibility, comfort, convenience, and other characteristics that are difficult to quantify. Because there is limited data to support inclusion of these less tangible qualities in the analysis, the ST model underlies a conservative assumption and treats transit modes very generically. However, current FTA guidance on methods indicates that FTA will accept forecasts that account for differences in less tangible and difficult-to-measure qualities such as reliability between modes (e.g., bus and rail).

A few studies have directly addressed this question and indicated that some measurable differences can be isolated.[8] One important result is that these differences appear to be associated with physical differences in facilities and services, not with unexplainable factors. For this reason, ST now includes a very small quantified reliability difference in the transit line boarding and waiting times.

1.4.5 Analysis of Transit Service Levels and Travel Forecasts

The development of "forecasts" results in the production of a variety of additional types of information beyond ridership volumes. Examples include population and employment changes in various subareas, increasing congestion levels, travel time savings created by new transit guideways, and transit's share of various travel markets. All of these need careful review for quality check purposes, as well as attaining an understanding of what the forecasts reveal about potential changes between the present and the future, and about the differences between the alternatives.

[8] The interim report TCRP H-37 provides some indications of important transit attributes not yet included in mode choice models.

2. PROCEDURES FOR TRAVEL FORECASTING

This chapter describes the methods and procedures used in the ST transit forecasting model, including the input data required by the ST model and its relationship to the PSRC model. Section 2.1 describes the methodology used to develop transit forecasts, the data requirements, and the data available. Section 2.2 describes the relationships between the ST and PSRC models. For instance, this section provides an overview of the methodology used by the PSRC to produce land use forecasts that are critical to the ST model and the ridership forecasting analysis. The transportation analysis zone system is described in Section 2.3. The mode choice model structure, specification, and coefficients are presented in Section 2.4. Summary descriptions of the process used to develop base-year transit-trip tables are described in Section 2.5. Possible changes in population/employment, highway congestion, and cost (i.e., the application of the staged build-up forecasting analysis) are discussed in Sections 2.6 and 2.7. A discussion on changes in transit service is included in Section 2.8.

2.1 Methodology

2.1.1 Incremental vs. Synthetic Methods

There are two different approaches to developing transit forecasts: synthetic methods and incremental methods. Synthetic methods estimate existing transit travel patterns by using separate sequential models to

- Allocate regional population and employment projections to zones
- Estimate the total number of trips from these zones
- Estimate the origin/destination patterns of these estimated trips
- Estimate the travel mode share likely for each estimated origin/destination pattern
- Estimate specific links and lines in the highway and transit systems used by these synthesized trips

Incremental methods are simpler and more efficient for transit ridership forecasting and analysis because they

- Are directly based on observed (rather than estimated) baseline travel patterns of transit users
- Allow for concentrating efforts on transit network analysis, for studies whose primary goals are questions about alternative transit networks
- Are more conducive to the separate evaluation of population and employment changes, highway congestion and cost, and transit services through the three stages of the forecasting process
- Focus on direct comparisons rather than on complete simulations of travel behavior
- Are more usable for intermediate evaluation
- Eliminate the often laborious and time-consuming calibration of sub-choice models, since they do not require replication of base-year travel patterns for these markets

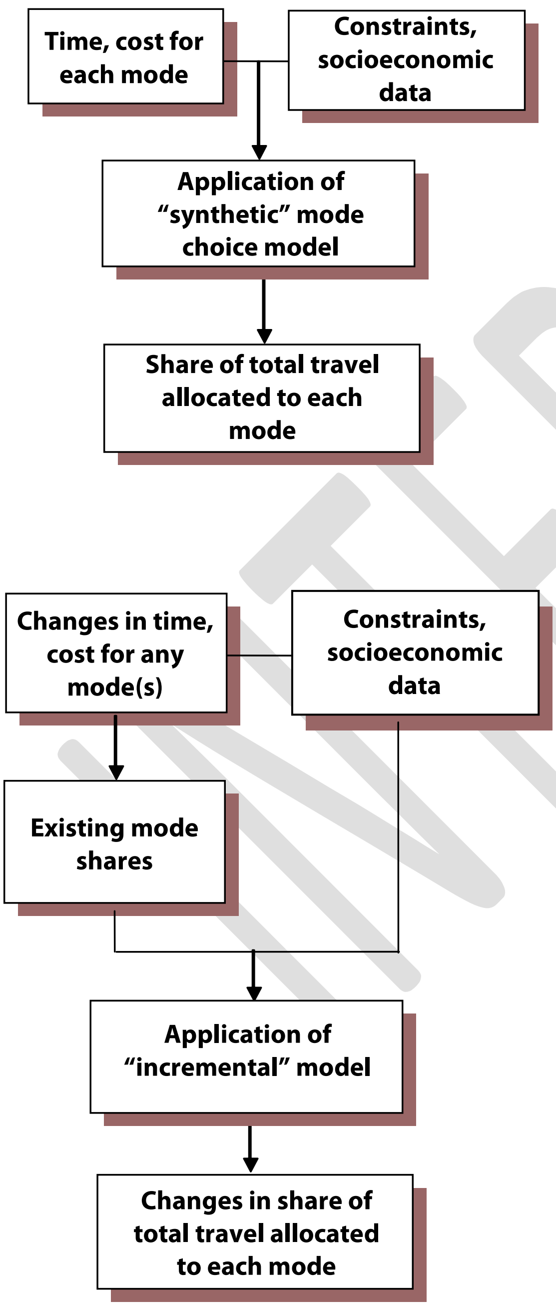
The FTA guidelines on transit project planning[9] summarize the major differences between the two approaches. Figure 2-1 contrasts the setting in which synthetic and incremental methods are applied. The upper part of the figure depicts the application of a conventional mode-choice model—termed "synthetic" because it estimates mode shares entirely from abstract descriptions of times, costs, income levels, etc. The lower part of the figure shows the use of an incremental

[9] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.

approach, so labeled because it starts with baseline transit travel patterns and shares and predicts the changes (or increments) in the shares.

Thus, the major difference between the two approaches is that the incremental method uses existing transit travel patterns and shares as the measure of the current attractiveness of each mode, whereas the synthetic method uses times and costs.[10]

Figure 2-1. Synthetic and Incremental Approaches to Forecasting



SYNTHETIC APPROACH

- Attractiveness of modes described by their time and costs
- Socio-economic variables included automatically (if part of model)
- Each application independent of base conditions
- No guarantee that shares reflect baseline conditions

INCREMENTAL APPROACH

- Changes in service levels for one or more of the modes
- Differentiation by socio-economic groups difficult in some methods
- Initial attractiveness of modes measured by current shares of existing travel
- Each application starts with baseline conditions
- Results certain to be "reasonable" in that they are adjustments to current shares

[10] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.

The FTA guidelines on transit project planning have identified three strong characteristics of the incremental approach that make it attractive for many applications. According to the FTA, the incremental method "is well grounded in the reality of baseline travel patterns; it deals only with marginal changes; and it focuses attention on the changes in land-use and transportation that drive the evolution of travel patterns over time."[11]

The FTA guidelines have also identified a number of limitations that render incremental methods less desirable in some situations. Limitations include "large data requirements, an inability to deal with markets that do not exist today, possible unreliability where markets are poorly developed today, and difficulties in dealing with changes in socio-economic characteristics."[12] Using the following four criteria, the ST model has overcome many of these shortcomings.

1. **Data Requirements**—According to the FTA, "because incremental methods rely solely on data collection to describe base-year travel patterns, data requirements are relatively high."[13] The detailed route-level data by time-of-day from the ridership counts now available via Automatic Passenger Count technology (APC) and from recent ST on-board surveys and Commute Trip Reduction (CTR) surveys provide observed baseline travel patterns within the RTA boundaries for both model validation and applications. ST now has available directional and time-of-day counts for every segment of every transit route in 80 percent of the ST service area and 90 percent of the transit market.
2. **New Markets**—"Because all incremental methods build from base-year conditions, they cannot be used to forecast future travel patterns for a market that does not exist in the base year."[14] The existing transit market and coverage within the RTA boundaries are quite extensive. Therefore, the use of ST incremental methods would only have limitations in application to rural areas beyond the district boundary.
3. **Limited Markets**—According to the FTA, "auto-access to transit is perhaps the primary example of a market that plays an important role with many transit guideways but is only marginally developed in the current bus system."[15] Presently, about 15 percent of bus and rail riders within the RTA boundaries use automobile to access transit via formal and informal park-and-ride sites. Therefore, this particular issue does not restrict the application of ST incremental methods.
4. **Socio-Economic Changes**—"In previous applications of incremental methods to transit project planning, the forecasts have largely ignored the influence of possible changes over time in real income."[16] The ST model has overcome this particular shortcoming by using a normalizing cost variable with respect to income to capture some of the historical trends of decline in transit ridership shares over time resulting from the trend in increased income and car ownership.

It is important to recognize that the sensitivities to change in the incremental approach are not approximations of the sensitivities in the synthetic approach—they are virtually identical. The incremental methods are mathematically parallel to the synthetic methods and are applied in the same level of detail that would be used in a synthetic approach.

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[11] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.
[12] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.
[13] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.
[14] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.
[15] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.
[16] Procedures and Technical Methods for Transit Project Planning, Federal Transit Administration (FTA), 1992.

2.1.2 Data Available for ST Planning

The key sources of data available for ST planning include

- Adopted land used forecasts by the Puget Sound Regional Council (PSRC)
- PSRC regional model version adopted by WSDOT for major capital projects
- Transit operators in the three-county area—Sound Transit, King County Metro, Pierce Transit, Community Transit, and Everett Transit
- Sound Transit Surveys (2003-2012)
- Commute Trip Reduction surveys (2007-2011)
- American Community Surveys (2006-2008)
- The National Transit Database (NTD)
- State and local agencies

The PSRC's land use forecasts and median income estimates are key inputs to the modeling effort. The ST model uses the most current land use forecasts available from the PSRC. The estimates of household income are used in the model to capture the different sensitivities to costs that occur across households with different incomes.

The PSRC regional forecasting model, used by WSDOT for travel forecasting in support of major capital projects and adopted for Lynnwood Link Extension, provides highway travel times for past and future years. This information includes separate travel times for vehicles that qualify for high-occupancy vehicle (HOV) lanes. The Lynnwood Link Extension highway model also provides change in traffic volumes on regional highway facilities for traffic impact analysis, and local jurisdictions provide traffic counts on local arterials for station impact analysis.

The essential basis for incremental mode choice modeling analysis is the detailed route-level transit ridership information by time-of-day for the base year (2011). In addition to earlier on-board surveys, the 2009 and 2011 on-board surveys conducted by ST provide additional detail on riders of all ST services. The ST surveys were supplemented by the 2007-2011 three-county CTR Act surveys to provide a more complete cross section of representative transit trips.

Detailed ridership count data were obtained from each transit agency. These detailed route-level count data were primarily collected using APC technology and hand-collected counts. These data include average weekday passenger loads by route segment, direction, and time of day, which provided the necessary information to establish ridership profiles along each route by time of day. Finally, the combination of the 2007-2011 CTR surveys, 2006-2008 American Community Surveys, and 2003-2012 Sound Transit Surveys data establishes base-year transit shares for 2011.

The following sections discuss how these various databases were developed and include more detail on how they are being used on this project.

2.2 Relationship to PSRC Modeling

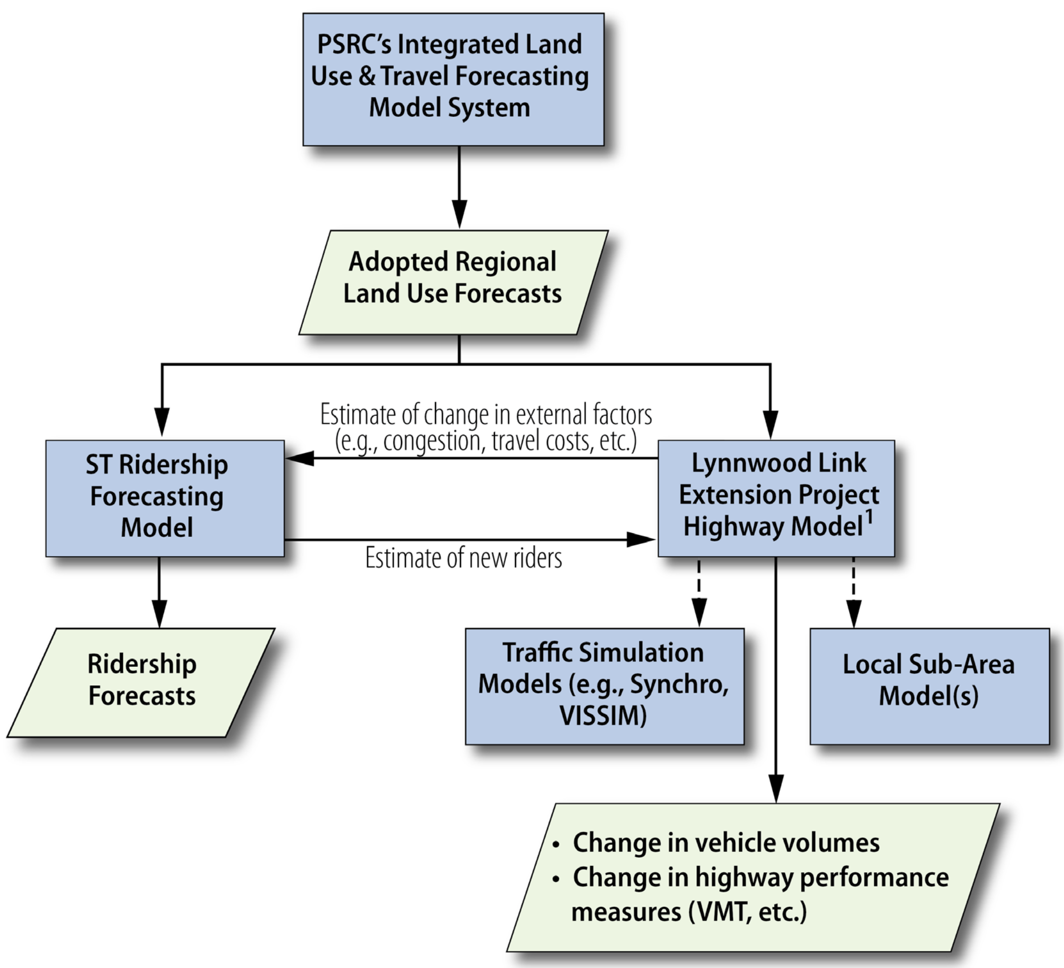
2.2.1 Summary Comparisons of the PSRC and ST Models

The ST and PSRC modeling procedures are closely inter-related and highly complementary. The ST model uses measures of regional change in travel demand and highway congestion derived from the PSRC model. Summary comparisons of the PSRC and ST modeling procedures are highlighted below:

- The PSRC model is a four-county synthetic modeling system comprising land use, trip generation, trip distribution, modal split, and assignment models. It also includes several feedback loops based on intra-regional accessibility.

- The ST model is a three-county, three-stage, fully incremental system purposely designed for detailed corridor-level transit planning and transit patronage forecasting.
- The PSRC's regional population and employment forecasts are used to predict travel demand growth.
- ST uses the PSRC's time and cost coefficients for its mode choice model.
- ST uses PSRC information for all non-transit input to the incremental transit ridership model.
- The current PSRC model version, used to by WSDOT for travel and toll forecasting in support of major capital projects, is adopted for the Lynnwood Link Extension to interface with the ST model. This highway model was further refined and validated to suit the Lynnwood Link Extension as described in Appendix C. Figure 2-2 highlights relationship between the PSRC and ST models.

Figure 2-2. ST Ridership and Lynnwood Link Extension Highway Models Relationship



[1] The Lynnwood Link Extension Project Highway Model is based on the version of the PSRC regional model used for major WSDOT projects (e.g., SR 520 FEIS), with additional network refinements.

2.2.2 Preparation of Demographic Forecasts

This section summarizes the procedures used by the PSRC to forecast regional population and employment.[17] Figure 2-3 summarizes the PSRC land use and travel forecasting process. The demographic projections that are used for the ST forecasts are prepared by PSRC staff and circulated for review by a wide variety of public and private organizations. The PSRC demographic projections are used for the ST forecasts because they

- Are the adopted projections for the region
- Are the product of technically sound methods and reasonable assumptions
- Have undergone thorough review by the region's counties and local jurisdictions within the context of the State Growth Management Act (GMA)

Development of Regional Control Totals

The PSRC produces population and employment forecasts for the central Puget Sound Region (King, Kitsap, Pierce, and Snohomish Counties) using the Puget Sound Economic Forecaster (PSEF) model.[18]

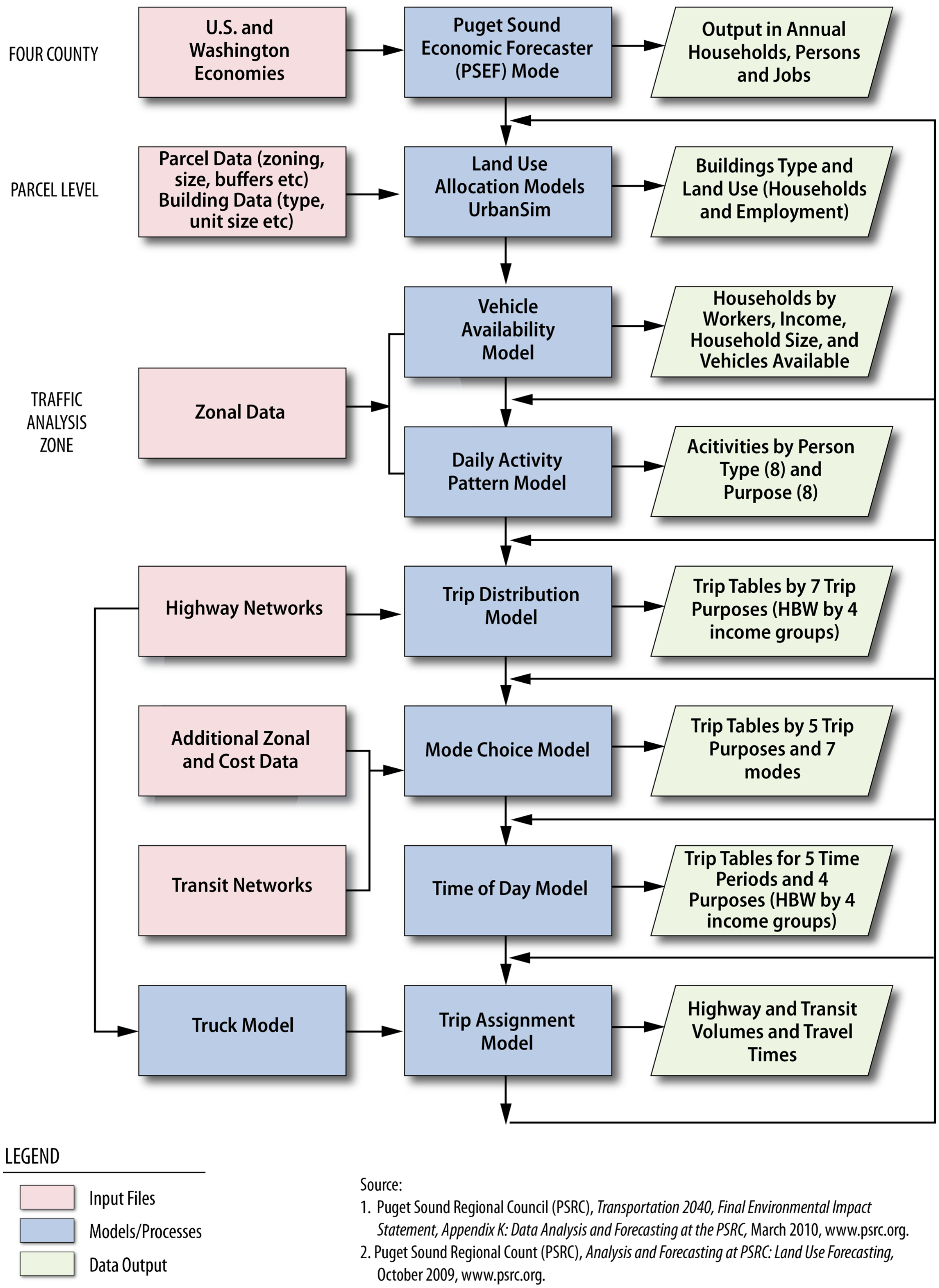
The PSEF model was developed by Dick Conway and Associates and adopted to the agency's needs via a consultant contract. It is an econometric model comprising of a set of simultaneous equations, reflecting economic base theory. Under this concept, growth is directly tied to the growth in sectors that export goods or services outside the region, thereby bringing income and jobs into the region. The PSEF model uses linked equations to forecast 103 variables, with the equations estimated using quarterly data dating back to 1970. Output from the PSEF model includes forecasts of population, employment, and income for the four-county area. These forecasts establish control totals for the subsequent allocation of growth to individual subareas of the region.

Allocation of Growth to Subareas

Within the regional forecasts from the PSEF model, the PSRC uses a new land use forecasting system (i.e., UrbanSim modeling framework)[19] to allocate growth to local planning areas throughout the four-county region. UrbanSim is an urban simulation system developed over the past several years to be able to evaluate public policy choices by simulating long-term, significant effects on growth patterns.

[17] Puget Sound Regional Council, "Transportation 2040, Final Environmental Impact Statement, Appendix K: Data Analysis and Forecasting at the PSRC," March 2010, www.psrc.org.
[18] Puget Sound Regional Council, Macroeconomic Model documentation, http://www.psrc.org/data/models/psef-model/
[19] Puget Sound Regional Council, "Analysis and Forecasting at PSRC: Land Use Forecasting," October 2009, www.psrc.org.

Figure 2-3. Regional Land Use and Travel Demand Forecasting Process



Source:
1. Puget Sound Regional Council (PSRC), *Transportation 2040, Final Environmental Impact Statement, Appendix K: Data Analysis and Forecasting at the PSRC*, March 2010, www.psrc.org.
2. Puget Sound Regional Count (PSRC), *Analysis and Forecasting at PSRC: Land Use Forecasting*, October 2009, www.psrc.org.

UrbanSim models predict the individual decisions of households, workers, jobs, developers, and land owners. The culmination of their decisions, within the policy boundaries set (such as allowable land use development types and densities, transportation systems, etc.), determines the predicted future year use of each parcel in the region. These results can then be summed to arrive at forecasts by Forecast Analysis Zones (FAZ), city, county, or any other geographic unit of interest. UrbanSim's key features include

- Simulating the location decisions for each household and job in the region—each household ultimately is assigned to a specific building, and correspondingly a parcel
- Producing a forecast for each year in the simulation (currently out to 2040)
- Tailoring to interact with PSRC's travel demand models so that the impacts of land use on transportation, and vice-versa, can be modeled
- Predicting land development at a parcel level
- Requiring as an input an interpretation of how many housing units or square feet of building space can be built under existing comprehensive plans, including adjustments for environmentally sensitive areas

Detailed land use forecasts (i.e., households and employment) produced from UrbanSim are usually summarized in 10-year increments at FAZ and smaller geographic levels for review and consultation feedback by local jurisdictions.

Demographic Forecasting Review Process

The forecasts are for 10-year increments up to 2040 and include detailed allocations for 219 FAZs. These forecasts and allocations are widely used by the state as well as by local governments, public agencies, and private organizations.

The forecasts undergo extensive review by the staff and elected officials of state, county, and local governments. The PSRC makes adjustments to the allocations, predicted by UrbanSim models, in response to concerns of local jurisdictions through a continuing process of review, comments, and negotiation. There are no cases in which the regional control totals are adjusted.

2.2.3 Summary Description of the PSRC Travel Demand Models

The PSRC maintains a four-step conventional synthetic travel-demand modeling system consisting of trip generation, distribution, mode choice, and trip assignment models.[20] Zonal trip ends are estimated using a set of trip rates classified by home-based work, home-based college, home-based shop, home-based other, home-based school, non-home-based work, non-home-based other, and three truck types. Trip distributions are estimated using a "gravity" model. The PSRC mode-choice model structure is a logit-based model comprised of two transit modes, three auto modes, and two non-vehicle modes.

2.3 Development of Zone and District Systems

The ST travel forecasts are produced for a 780-zone system of Alternatives Analysis Zones (AAZ) developed specifically for the ST model but based upon the PSRC's zonal system. The 780-zone system includes about 20 zones splits within the North Corridor around potential station locations as well as 23 external zones representing 6 ferry connections and 17 areas outside the RTA boundaries. Summaries of these forecasts are prepared using 27 summary districts or other levels of aggregation (e.g., by corridor or by county) as needed.

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[20] Puget Sound Regional Council, "Travel Model Documentation," Final Report, September 2007.

2.3.1 Forecast Analysis Zone and Traffic Analysis Zone Systems

The PSRC's FAZ structure is each agency's basic land-use zone structure and consists of 219 FAZs that cover all the land area within the four-county region. It is at this level of detail that local jurisdictions, through the PSRC, agree upon allocations of future population and employment throughout the region. FAZ boundaries encompassing Snohomish, King, and Pierce Counties are shown in Appendix A.

2.3.2 Alternatives Analysis Zone System

The AAZ system used to produce the ST travel forecasts is based on the zones maintained by the PSRC for regional forecasts of travel demand within the four-county central Puget Sound region. The ST zone system differs from the PSRC's system in two aspects.

Most importantly, the ST system does not have the same geographic boundary as the PSRC system. Whereas the PSRC includes a four-county region (Snohomish, King, Kitsap and Pierce Counties), the 1993 state-established RTA excludes the largely rural areas of North and Northeast Snohomish, South and Southeast Pierce, and East King Counties, as well as all of Kitsap County, Vashon Island, and the Gig Harbor peninsula. Areas outside the RTA district are external to the ST model.

Furthermore, in areas along proposed ST fixed-guideway transit investments, the ST zone structure uses smaller zones, split within PSRC zones. Keeping the two zone structures as similar as possible reduces the level of data manipulation that would otherwise be necessary. The ST 780-zone AAZ system is also shown in Appendix A.

2.3.3 Summary Districts

Summary districts were created from the AAZ system in order to

- Provide a consistent basis for aggregation of certain model inputs, when such aggregation is appropriate
- Calculate the modal shares required in the model validation and application phases
- Prepare summary reports on trip tables and travel time skims

The 27 summary district breakdown, 11 summary district breakdown, and 6 summary district breakdown are shown in Appendix A. These districts were carefully constructed to provide distinctive summary travel patterns by geographical area and corridor.

2.4 Sound Transit Mode Choice Model Methodology

2.4.1 Model Structure

The ST mode-choice model structure, which is an incremental logit model, uses a pivot approach in the development of forecasts and uses the PSRC regional mode choice travel time and cost coefficients.

Incremental Logit Model

The incremental approach predicts changes in travel behavior based on existing travel behavior and changes in level of service. The incremental form of the logit model is derived from the standard logit formulation, which is[21]

(1) $$S_i = \frac{\exp(V_i)}{\text{SUM}_j{}^m\ [\exp(V_j)]}$$

where

V_i = utility of mode i in choice set m (j=1,2,3, .., i, ..m) Contains measurable components of transportation systems such as travel time and cost as well as socio-economic attributes of trip makers.

S_i = share of using mode i

Ben-Akiva and Lerman indicate that "using elasticities is one way to predict changes due to modifications in the independent variables. For the linear-in-parameters multinomial logit model, there is a convenient form known as the incremental logit which can be used to predict changes in behavior on the basis of the existing choice probabilities of the alternatives and changes in variables." The incremental form of logit model is[22]

(2) $$S_i^f = \frac{S_i \text{ x } \exp(\text{DIFF } V_i)}{\text{SUM}_j{}^m\ [S_j \text{ x } \exp(\text{DIFF } V_j)]}$$

where

S_i = base-year observed probability of using mode i from choice set m

S_i^f = new share (i.e., forecast year) of using mode i (interzonal average)

DIFF V_i = change in utility of mode i (interzonal average)
= V_i^f—V_i = (DIFF CONST_i) + B_k x (DIFF $\text{VAR}_{i,k}$)

and

DIFF CONST_i = difference (future—base) in mode-specific constant for mode i,

B_k = coefficient for attribute k

DIFF $\text{VAR}_{i,k}$ = difference in numeric variable VAR k of alternative i

f = variable with superscript "f" represents value in forecast year.

All transportation models, including the PSRC synthetic model, assume that the difference between the unmeasured attributes (e.g., comfort and image) between transportation systems in the base year and future years is negligible. As a result, the term representing the difference in mode-specific constants (i.e., DIFF CONST_i) falls out of the computations. The only terms remaining

[21] Domenich, T., and D. McFadden, "Urban Travel Demand—A Behavioral Analysis," North Holland, Amsterdam, 1975.
[22] Ben-Akiva, M. and S.R. Lerman, *Discrete Choice Analysis Theory and Application to Travel Demand*, The MIT Press, Cambridge, MA, 1985.

in Equation 2 pertain to those attributes (e.g., travel times and costs) for which a measured change might occur, as well as Equation 3:

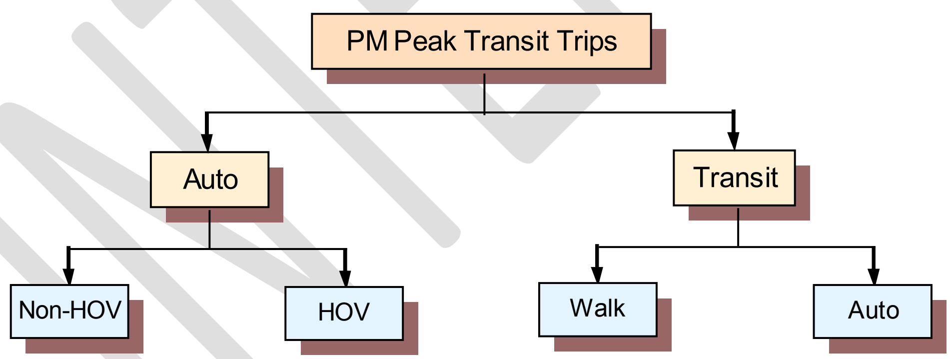
(3) $\text{DIFF } V_i = B_k \text{ x DIFF VAR}_{i,k}$

The mode-specific constants in a synthetic model theoretically represent the effects of unmeasured attributes and often account for over half of the explanatory power in synthetic mode choice models. In practice, these constants are quite large and compensate for all types of errors in synthetic models, even network coding idiosyncrasies. They are used as overall adjustment factors to move the base year model results close to targeted base year regional totals.

Nested Logit Model

According to the Independence from Irrelevant Alternatives (IIA) assumption, logit models require that all of the modes defined in the choice set m (for travelers) be independent of one another. However, the IIA requirement is usually difficult to maintain in a simultaneous structure, such as the synthetic model used at the PSRC. In practice, a sequential (or nested) logit model that is less restrictive than the simultaneous form is often used. The nested logit model groups appropriate submodes under the primary modes (i.e., auto and transit), as shown in Figure 2-4. For the auto mode, the sub-choice is between single and multiple occupancy. For the transit mode, the sub-choice is between access to transit by walking or by automobile. Suggestions from the FTA on the appropriateness of nesting can be found in the FTA presentation by Jim Ryan at the January 2004 Transportation Research Board (TRB) Annual Meeting.[23]

Figure 2-4. Mode Choice and Model Structure



[23] Travel Forecasting for New Starts Projects, TRB 83rd Annual Meeting, Session 501, January 13, 2004.

The natural logarithm of the denominator of a logit model (Equation 1) is a single "inclusive" index I_m[24] indicating the desirability of the main mode m and taking into account the attributes of access modes. This index is often called "LogSum" and calculated from

$$\text{(4)} \qquad \text{LogSum} = \text{Ln}\ \{\text{SUM}_j^m\ [\exp(V_j)]\}$$

where

V_j was defined before for Equation (1)

McFadden[25] has identified the coefficients K for the LogSum variable as indices of similarity of the alternatives comprising the inclusive price.

For the transit lower level, the composite disutility of the sub-modes (walk- and auto-access) represents transit to the upper level choice. For transit mode t, the LogSum is

$$\text{(5)} \qquad \text{LogSum}^t = \text{Ln}\ [\exp(V_{walk}) + \exp(V_{auto})]$$

where

V_{auto} = utility of the auto-access mode
V_{walk} = utility of the walk-access mode

The structure for PM peak period shown in Figure 2-4 is fully incremental[26] because it uses the incremental logit model at both the lower-level and upper level nests. The incremental form is highly desirable because it relies on observed data that describes current conditions, rather than using models to estimate these conditions.

Derivation of Changes in LogSum Variable

In a fully-incremental mode choice model, the changes in ridership between future and base-year conditions are calculated based on the incremental logit formulation (Equation 2) both at the primary level of hierarchy (i.e., auto vs. transit) and at the lower levels (i.e., auto occupancy and mode of access).

Because the incremental model requires the difference in the values of LogSum variable (i.e., DIFF LogSum^t for the mode of access), the underlying components of this difference need to be spelled out first within the context of standard logit formulation (Equation 1). The derivation process starts by using the definition of difference in the LogSum values and ends up with a simple formula consisting of the logarithmic summation of the exponential difference in the utility of each mode (i.e., future—base year) weighted by the respective base year observed share. The mathematical derivation is presented below.

[24] McFadden,E., A. Talvities and Associates, "Demand Model Estimation and Validation, Urban Travel Demand Forecasting Project (UTDFP) Final Report," Vol. V, University of California, Berkeley, CA, 1977.
[25] McFadden,E., A. Talvities and Associates, "Demand Model Estimation and Validation, Urban Travel Demand Forecasting Project (UTDFP) Final Report," Vol. V, University of California, Berkeley, CA, 1977.
[26] Dehghani, Y. and R. Harvey, "A Fully Incremental Model for Transit Forecasting: Seattle Experience," Transportation Research Board, Record # 1452, 1994.

Incremental change in $LogSum^t$ of Equation 5 can be represented by

$$\text{(6)} \qquad \text{DIFF LogSum}^t = \text{Ln}[\exp(V^f_{walk}) + \exp(V^f_{auto})] - \text{Ln}[\exp(V^b_{walk}) + \exp(V^b_{auto})]$$

Incremental change in LogSum for mode m (i.e., transit or auto), representing the upper-level of the nested logit structure, can be written as

$$\text{DIFF LogSum}^m = \text{Ln}\,\{\text{Sum}^n_i[\exp(V_i + \text{DIFF } V_i)]\} - \text{Ln}\,\{\text{Sum}^n_i\,[\exp(V_i)]\}$$

or

$$= \text{Ln}\left[\frac{\text{Sum}^n_i\,[\exp(V_i + \text{DIFF } V_i)]}{\text{Sum}^n_i\,[\exp(V_i)]}\right]$$

$$= \text{Ln}\left[\frac{\text{Sum}^n_i\,[\exp(V_i) \times \exp(\text{DIFF } V_i)]}{\text{Sum}^n_i\,[\exp(V_i)]}\right]$$

$$\text{(7)} \qquad = \text{Ln}\,[\text{Sum}^n_i\,(S_i \times \exp(\text{DIFF } V_i))]$$

where

DIFF LogSum^t	=	difference in LogSum term for transit mode t (future–base year)
V^f_{walk}, V^f_{auto}	=	the utility of walk and auto access modes in future
V^b_{walk}, V^b_{auto}	=	the utility of walk and auto access modes in the base year
DIFF LogSum^m	=	difference in LogSum term for mode m (e.g., auto or transit) in the upper level of the nested structure (future–base year)
V_i	=	the utility of submode i (e.g., walk or drive access attributes) under nest n (e.g., transit)
S_i	=	base-year observed share of using submode (e.g., walk or drive access) under nest n
$\text{DIFF } V_i$	=	difference in the utility (e.g., travel time) of submode i under nest n (future–base year).

The coefficients of variables (e.g., travel time) included in the utility of a sub-mode i are equal to comparable mode-choice coefficients from the upper-level nest for the same variables (e.g., travel time), scaled by the corresponding LogSum coefficient (K^i).

Values for DIFF LogSum variables resulting from Equation 7 are used in the incremental logit formulation (Equation 2) to estimate new interzonal modal shares. Nesting coefficients vary between 0.0 and 1.0 and measure the degree of similarity and dissimilarity of a group of sub-modes from other modes in the upper-level nest. For example, a nesting coefficient of 1.0 on the transit nest of Figure 2-4 indicates that auto- and walk-access sub-modes are dissimilar (independent) from auto mode, implying that they should have been structured simultaneously instead of having a nested form. In the absence of any information to inform the selection of a nesting coefficient, an assumption of 0.50 is as non-committal as possible. This nesting coefficient of 0.50 is used in the ST model for the PM peak period.

2.4.2 Model Specification and Coefficients

As indicated in the previous section, since the mode-choice model structure is fully incremental, the mode-specific constants fall out of the computations. Therefore, it is not necessary to estimate values for modal constants. The model includes:

- Travel time and cost variables in the utilities of the transit sub-modes, walk and drive access (e.g., in-vehicle, out-of-vehicle times, transit fares)
- Travel time and cost variables in the utilities of the auto occupancy sub-modes.

The auto travel cost is a composite variable and combines auto operating, car insurance and parking-related costs. This composite variable is divided by the ratio of zonal median income over the base-year regional median income and used in Stage 2 of the ST ridership forecasting analysis. Transit fares are also treated similarly with respect to zonal median income and used in Stage 3 of the ST ridership forecasting analysis. This will not cause differences in forecasts between pairs of alternatives since transit fares in the ST model remain constant across alternatives.

The reason for the normalization of the cost variable is to capture change in income and its effect on transit ridership shares over time. The long-term decline in transit shares over the past half-century is primarily due to the spreading of population and employment beyond traditional geographic markets. This has occurred while car ownership and use have experienced substantial long-term growth even in solid urban transit markets. The normalization of cost variable is primarily longitudinal rather than cross-sectional. Real personal income per capita in the Puget Sound Region has recorded an average growth rate of about two percent annually over the last 40 years in spite of fluctuation in local economy. The increased personal wealth has contributed to the growing dominance of auto travel as driving has become increasingly affordable over time. To capture the dampening effect of increasing real income on ridership growth, total travel cost is divided by income. The ST model assumes a conservative 1-percent annual (real) growth in income. The ST model uses travel time and cost coefficients similar to the PSRC mode choice models. The coefficients used in the ST model are:

- -0.0253 for in-vehicle travel time (which falls within the FTA's acceptable range of -0.02 to -0.03)
- -0.0019 for travel cost (in 2011 dollars), implying a value of travel time of $8.10/hour (in 2011 dollars), which was about one-third of the average wage rate in 2011 in the Puget Sound Region
- A relative ratio of 2.0 for out-of-vehicle over in-vehicle transit travel times, which falls within the FTA's acceptable range of 2.0 to 3.0

2.4.3 Base Mode Shares

Equation 2 highlights the importance of having a reasonable estimate of S_i (the existing shares for transit relative to alternative modes) including existing mode of access shares. Development of these base shares, used in the ST incremental model, is described below.

Transit Shares

Earlier versions of the ST incremental model relied on the U.S. Census Journey-to-Work (JTW) information to provide the base interzonal auto and transit shares. The JTW data exhibited relatively small changes in transit shares over the years as highlighted in Table 2-1 for three Census cycles (1980, 1990 and 2000). For the 2012 ST model version and in the absence of 2010 U.S. Census JTW data, a combination of data from the Washington CTR Act survey and American Community Survey (ACS) is used to establish base year transit shares.

Table 2-1. Summary Share of Transportation Means Used by Workers (1980, 1990, and 2000 Census Journey-to-Work Data Files)

Location (Home End)	Year	SOV	Carpool	Transit	Total
Snohomish County	1980	74.0%	22.9%	3.2%	100.0%
	1990	83.4%	13.2%	3.4%	100.0%
	2000	84.6%	11.7%	3.7%	100.0%
King County	1980	68.0%	19.5%	12.5%	100.0%
	1990	78.5%	12.3%	9.2%	100.0%
	2000	76.4%	12.9%	10.7%	100.0%
Pierce County	1980	77.6%	19.2%	3.2%	100.0%
	1990	83.5%	14.4%	2.1%	100.0%
	2000	83.2%	13.1%	3.7%	100.0%
Total	1980	70.6%	19.9%	9.5%	100.0%
	1990	80.4%	12.9%	6.7%	100.0%
	2000	79.5%	12.7%	7.8%	100.0%

Note: The mode shares shown here take into account only the motorized modes. Non-motorized modes, such as walk and bicycle, have not been included. The "motorcycle" mode was included under the SOV mode, and the "ferry" mode was included under the transit mode.

The State of Washington passed the CTR Law in 1991 to encourage commuters to consider transportation alternatives, such as ridesharing or taking the bus. As part of this law, employers with 100 or more employees are required to conduct a survey once every two years to record the commute options used by their employees. The ACS is conducted on an on-going basis rather than every 10 years and so it can provide up-to-date information for the planning process. Further information about the CTR surveys and ACS are provided in Appendix B.

The CTR (2007-2011) surveys provide transit shares at the zonal level with some limitations. These limitations include an over-representation of transit users in the surveyed sample which may not accurately reflect the transit share at the zonal level. The ACS data also has some limitations as it represents a sample of residences—about 1 in 40 households annually. The Census Bureau produces three ACS data series: *one-year, three-year, and five-year estimates*. Only three-year (2006-2008) estimates of ACS home-to-work flow by mode are currently available at the County or Census Place geographies. To address the ACS data limitations, transit shares were calculated at the 6-district level for maintaining statistical significance at a 90 percent level.

A 6-district level summary comparison of transit shares indicated that

- CTR shares are higher than those obtained from the ACS
- ACS shares are somewhat higher than those obtained from the 2000 U.S. JTW data

Based on the findings from the above analysis, it was determined that it would be reasonable to adjust CTR transit shares relative to ACS shares in the following manner:

- Aggregate 2007-2011 surveys to the 27 districts at the work ends and 165 FAZs at the home end and calculate transit shares accordingly. Calculating the shares at this level (i.e., 27-district-to-FAZ) preserves the variation in current mode-choice behavior for PM peak and, therefore, the elasticities in the logit model.

- Adjust 27-district-to-FAZ level base transit shares based on using 6-district-to-6-district level transit shares calculated from the ACS (2006-2008 three-year estimates) as follows:
    - Use ACS share if a CTR share is higher than 6-district level ACS share
    - Keep CTR share if a CTR share is lower than 6-district level ACS share

For calculating off-peak base shares, a procedure similar to the one described above was used with the following exceptions:

- Aggregate CTR surveys at 27-district-to-27-district level and calculate shares accordingly
- Adjust CTR shares based on using 6-district level ACS shares similar to those for PM peak
- Balance the resulting 27-district-to-27-district share matrix by adding with its transpose and averaging
- Apply a factor of 0.5 to reflect the difference in base off-peak transit share relative to peak—This factor was calculated based on using past survey data. ST 2011 transit on-board survey data will be used to update this factor as well as any other desirable splits in transit (e.g., commute versus non-commute) trips.

Note that a procedure similar to the above was used to update base auto occupancy related shares with the ACS data. The base auto occupancy level shares were originally derived from the 2000 U.S. JTW data.

Access Shares

In the past, available on-board survey data were used to develop mode of access shares. The resulting share included a considerable number of zero cells. To alleviate this shortcoming, access shares are obtained as a by-product of the matrix estimation process rather than from a relatively small on-board set of survey data. The 2012 ST model version relies on a matrix estimation process for the development of base-year trip tables that is based on using a seed matrix with considerable non-zero cells. This also includes seeding of counts on appropriate segments to capture potential demand usage at each park-and-ride facility. These considerations, together with the fact that park-and-ride facilities are adequately represented throughout the region and particularly within the North Corridor markets, provide a good database from which to calculate access shares. Steps used to calculate access shares are summarized below:

- Perform a select segment analysis on segments representing potential peak demand to park-and-ride facilities
- Aggregate resulting demand matrix for PM peak auto-access trips and total PM peak transit trip table at 27 districts (work ends) and 165 FAZs (home ends)—dividing aggregated trip tables provides auto-access base shares at 27-district-to-165 FAZ aggregation level.

2.4.4 Discussion of Staged Build-up Analysis Application

The patronage forecasting procedures described in the previous sections are applied in three distinct stages. This application method explicitly recognizes a build-up approach to the ridership forecasts and encourages the analysis of intermediate results in the process as well as checking results for reasonableness. Specific contributions to changes in ridership at each stage are calculated and analyzed separately as they build on each other. The three stages are

- Overall growth in travel related to population and employment growth
- Changes in ridership related to changes in highway congestion and costs
- Changes in ridership related to transit service changes, including transit fares

By applying forecasting analysis in stages, the method also ensures that only those changes that are important to the study question will be considered. For example, it is common in ridership

forecasting (and preferred by the FTA) that only the change in transit service be carried into the future year analysis of transit alternatives. Therefore, all demographics, such as land use, trip distributions, as well as gas and parking prices, are effectively held constant when comparing transit alternatives.

Staging the forecasts in this way makes these consistencies transparent and reduces superfluous calculations. When only variations in the transit service are under consideration, Stage 3 is the only step needed to calculate each variation.

This method does not preclude varying inputs other than the transit service (i.e., for sensitivity testing) but allows such variation to be addressed simply and specifically rather than as a hidden piece of a very large and/or complex model.

2.5 Base-Trip Table Development

The essential basis for incremental mode choice modeling analysis is the need to rely on actual transit travel patterns. Capturing existing travel patterns was achieved in the ST model by using available, pertinent data that provided a complementary balance between survey data and detailed route-level transit ridership information by direction and time-of-day for the base year. Chapter 3 includes a detailed discussion of the process used to develop base year (2011) peak and off-peak transit-trip tables.

2.6 Stage 1—Changes in Demographics

2.6.1 Formulation of Stage 1 Forecasting Analysis

The ST ridership forecasting analysis depends on PSRC model databases for the overall growth in travel demand. Growth estimates could either be derived from PSRC model trip distribution results or directly based on forecasts of demographics. The PSRC is currently developing and testing new generation (i.e., activity-based) models and, until reasonable and stable trip distribution results become available and validated, travel growth will be derived from forecasts of households and employment. A summary tabulation of the demographic forecasts adopted by PSRC is presented in Table 2-2.

Table 2-2. Summary of PSRC Four-county Demographic Forecasts

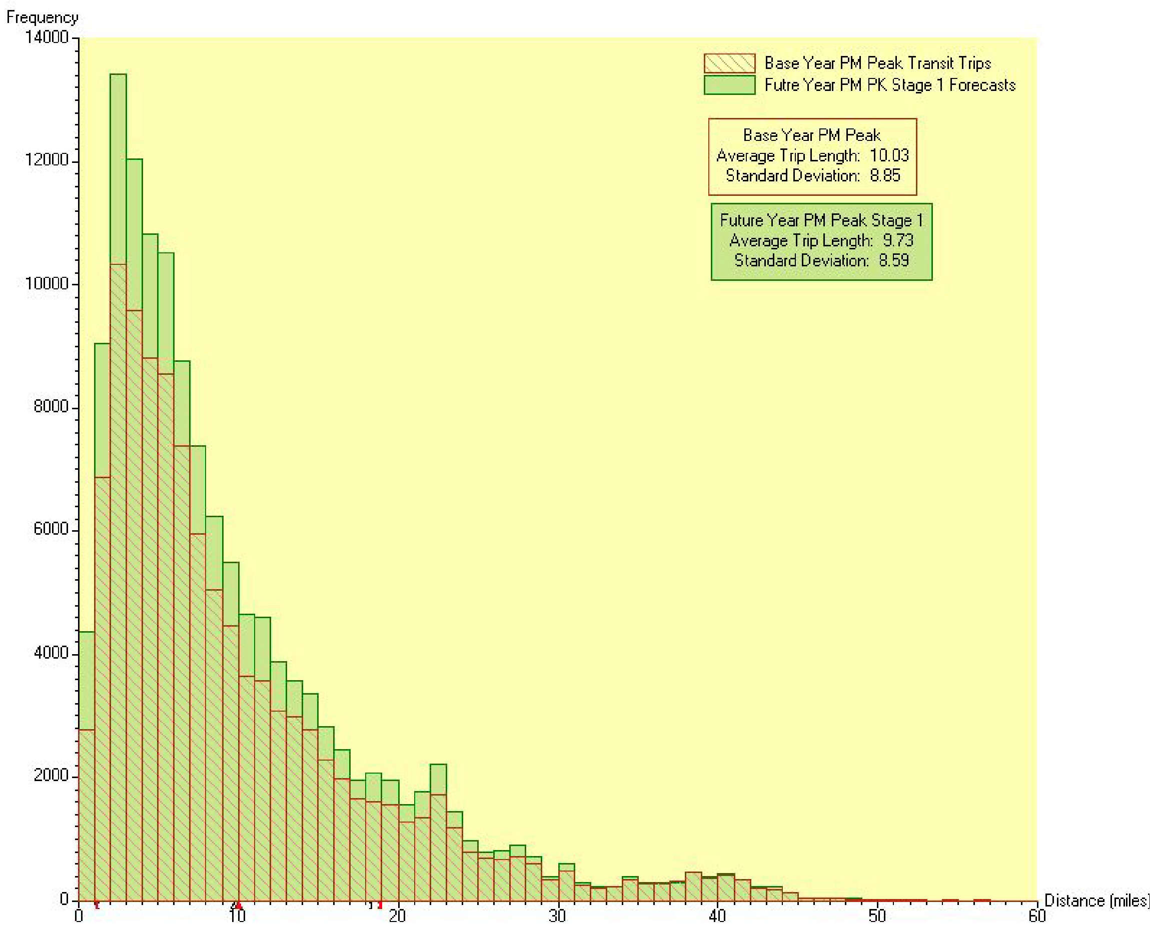
Forecast Year	Total Employment	Households	Population
1970	740,000	630,000	1,939,000
1980	1,033,000	845,000	2,240,000
Percent Change from 1970	*40%*	*34%*	*16%*
1990	1,445,000	1,071,000	2,749,000
Percent Change from 1980	*40%*	*27%*	*23%*
2000	1,718,000	1,283,000	3,276,000
Percent Change from 1990	*19%*	*20%*	*19%*
2010			
Percent Change from 2000			
2030			
Percent Change from 2010			
2035			
Percent Change from 2030			
2040			
Percent Change from 2035			

Note: This table will be updated after the adoption of land-use forecasts by PRSC.

Growth in total households and employment between 2011 and a future year is calculated at FAZ-level and applied to the base year (2011) transit-trip tables using two-dimensional matrix balancing (i.e., Fratar) method. The results of the Stage 1 analysis are the estimated transit trips for a future year. The secondary impacts of growth on transit demand (i.e., increased highway congestion) are not yet accounted for at the end of Stage 1. Note that an examination was performed to determine the degree of alteration in average trip length in the Stage 1 forecasting process. As highlighted in Figure 2-5, the Fratar method has only slightly changed the underpinning average trip length frequency distribution exhibited in the base year (2011) transit trip table.

Note that if an activity-based trip generation procedure is adequately tested by PSRC and subsequently adopted by WSDOT for travel forecasting in support of major projects, ST will be able to make an interim shift in the Stage 1 forecasting analysis. This will involve applying activity-generation growth rates at the FAZ level.

Figure 2-5. Average Trip Length Frequency Distribution Comparison



2.7 Stage 2—Changes in Highway Congestion and Cost

2.7.1 Formulation of Stage 2 Forecasting Analysis

Stage 2 considers how changes in highway congestion, auto costs (including parking and auto ownership costs), and income will influence mode choice.

The ST patronage forecasts use the PSRC model version, adopted by WSDOT for travel forecasting in support of major projects (see Appendix C), to estimate highway travel times. These times are tabulated in the form of 219 x 219 FAZ-to-FAZ times for each highway network. A weighted averaging process is used to convert the more detailed PSRC TAZ-based travel times to FAZ-level travel times. When a transit alternative significantly affects the highway system (e.g., taking freeway lanes for transit facilities), additional analysis of future highway networks and congestion using the PSRC model is required.

In the Puget Sound region, transit fares and auto costs (except parking costs) are usually assumed to increase only at the rate of overall inflation; therefore, they are usually immaterial to the ST model. The ST model, however, includes these variables for use in sensitivity tests that are not directly part of project planning ridership forecasts.

Stage 2 transit trip forecasts are calculated using the following incremental logit equation:

(8) $$\text{Stg2Trn} = \frac{\text{Stg 1Trn}}{\text{S}_\text{t} + (1 - \text{S}_\text{t})\text{X}[\exp(\text{K} \times \text{DIFF LogSum}_\text{h})]}$$

where

Stg2Trn	=	Stage 2 transit trip forecasts
Stg1Trn	=	Stage 1 transit trip forecasts
S_t	=	the base year observed transit shares from census data
K	=	nesting coefficient on the auto nest
DIFF LogSum_h	=	Difference in the LogSum values due to changes in highway congestion and auto costs (future—base year). Data from the U.S. Census and CTRA surveys (for the baseline share), highway skims, and auto costs are used in Equation 8 to estimate the DIFF LogSum_h on the auto side.

Stage 2 transit-share forecasts (Stg2Shr) are also calculated as follows:

(9) $$\text{Stg2Shr} = \frac{\text{Stg 2Trn} \times \text{S}_\text{t}}{\text{Stg 1Trn}}$$

Resulting from the Stage 2 forecasting analysis are the transit trips for a future year, having accounted for factors external to the transit service itself. These results then serve as a platform for analysis of ridership on alternative transit networks. Note that bus speed degradations are used in the Stage 3 forecasting analysis. They are, however, based on the level of highway congestion and estimated using the PSRC model.

In most project planning ridership forecasting, Stages 1 and 2 need not be calculated as often as Stage 3. It is only when a transit alternative is presumed to have a strong effect on external factors, such as land use or the regional highway network, that the entire process would have to be cycled through. However, for the New Starts project rating purposes, FTA does not accept forecasts that are based on different person-trip tables for different alternatives.

2.7.2 Representation of Conditions on the Highway/HOV Networks

The PSRC and WSDOT maintain a number of coded highway networks that represent the highway system in the Puget Sound region at various points in time. Future highway networks represent the adopted highway and HOV improvement plans, including such changes as tolls on the SR 520 Bridge, for future years. ST usually relies on a recent version of the PSRC model that has been used by WSDOT for major capital projects, such as the SR 520 project, SR 99 Alaskan Way Viaduct (AWV) & Seawall Replacement project, or the I-5 tolling analysis project, after that version has been through a documented project level validation.

The PSRC model version used to interface with the ST model reflects project-level base year validation and future network updates in support of the Final Environmental Impact Statement (FEIS) and toll modeling/forecasting for the SR 520 and AWV projects. It also includes additional network refinements and validation analysis performed specifically for the Lynnwood Link Extension (see Appendix C).

2.7.3 Estimation of Parking Costs

A conservative 1.4-percent annual (real) growth in parking costs is assumed in the ST model. This is a significant reduction from the 3-percent real growth that was previously assumed by ST and the PSRC. According to the limited historic information available, parking costs have averaged 1.5-percent growth per year since 1960. This could be primarily attributed to the change in employment density which has averaged similar growth over the last five decades.

2.7.4 Estimation of Other Costs and Median Income

Because auto operating costs in the Puget Sound region are usually assumed to increase only at the rate of overall inflation, they are less significant to ST models. Base-year (2011) and future auto operating costs are estimated at about $0.24 per mile (in 2011 dollars). The ST model assumes a conservative 1-percent annual (real) growth in income as indicated previously. When travel costs are assumed to remain constant over time, the terms drop out of the incremental equation and they have no effect on the forecasts of future transit ridership, other than the effect related to any assumed real increase in regional income.

2.8 Stage 3—Changes in Transit Service

2.8.1 Formulation of Stage 3 Forecasting Analysis

In the third and final stage of the forecasting analysis, the incremental changes in the transit level of service, including transit fares, are considered. This change (as indicated in Section 2.4.1) is reflected in the resulting relative values of the $LogSum^t$ variable using the base-year and future transit networks.

The Stage 3 transit shares and ridership forecasts are calculated as follows:

$$(10) \qquad P'ac = \frac{P_{ac} \times LOS_{ac}}{P_{ac} \times LOS_{ac} + (1 - P_{ac}) \times LOS_{wlk}}$$

and

$$(11) \qquad Stg3Trn = \frac{Stg2Trn \times [\exp(K \times DIFF\ LogSum_{t})]}{Stg2Shr \times [\exp(K \times DIFF\ LogSum_{t})] + [1 - Stg2Shr]}$$

where

LOS_{ac}	=	Difference in (future—base year) utility of the park-and-ride access submode
LOS_{wlk}	=	Difference in (future—base year) utility of the walk-access submode
$P'ac$	=	Forecasted Stage 3 shares for the auto-access mode
P_{ac}	=	Base-year observed shares for the auto-access mode, derived from the base-trip table development process reflecting actual counts on park-and-ride facilities.
$DIFF\ LogSum_{t}$	=	Difference in the LogSum values due to changes in transit level-of service (future—base year)

Actual transit service that is taken into consideration in the ST model Stage 3 forecasting analysis is represented by means of a "coded network." Specific details on transit network preparation are included in Appendix D. Treatment of bus speed in the ST model is based on the degradation of roadway congestion, estimated by the PSRC multi-modal model in a manner developed in consultation with the FTA.[27] Bus speed degradation is considered in Stage 3 forecasting analysis and held constant between alternatives. It is applied only to bus run time (excluding on HOV lanes) and not to dwell and lay-over time components.

2.8.2 Transit Fares

Any changes in transit fares are considered in Stage 3 of the ST model, along with changes in transit service. Fares are held constant between alternatives. Transit fare matrices were developed for the ST model, and were assumed to be (a) the zone-to-zone averages in effect in 2011 (for the base year) and in late 2012 (for all future years), and (b) independent of transit path choices.

Independence from path choice is a reasonable approach to fares with the RTA District. The path-independent approach to transit fares also aligns with FTA's guidance to keep any fare-related utility differences between alternatives to a minimum. Upon the introduction of the Orca smart card as the primary fare medium for all transit operators in the District, zonal fares are more appropriate than path-based fares. For most trips within the District path choice and transfers have become less relevant due to the very high market penetration of the regional employer pass programs and to the logic used in assigning cash value to trips involving more than one vehicle.

[27] Billen, D., Sound Transit, "Updated Treatment of Bus Speeds in the Sound Transit Model," Memorandum to Eric Pihl of FTA, dated August 1, 2002. A copy of this memorandum is included in Appendix D.

3. VALIDATION

Before a model can be used for analysis, it must be validated. The purpose of validation is to compare the performance of the model to the most recent observed data sources available in order to confirm that the model is accurately replicating current transit travel patterns and transportation system performance.

In project planning, travel forecasting models are expected to predict changes in travel patterns caused by

- General changes, such as population, employment, and economic changes, between the base year and the forecast year
- Specific changes introduced by each alternative

Consequently, the best validation tests are those that test the ability of the forecasting methods to accurately capture response to changes in population and employment levels, parking and gasoline prices, transit fares and service levels, as well as other conditions.

The incremental approach, which is used in the ST model, generally reduces the need for validation because it relies on surveys and actual ridership data to establish current transit travel patterns. However, it is still useful to check the overall performance of the forecasting against current known conditions.

This chapter is organized into two sections. The first section describes the overall analysis process for creating the 2011 PM peak and off-peak transit-trip tables, while the second section presents validation analysis results.

3.1 Base Year (2011) Transit Trip Table Development

A centerpiece of the ST incremental model is its reliance on “observed” transit travel patterns, as determined through transit ridership data, to create base year (2011) PM peak and off-peak transit-trip tables. The ridership data used to develop transit-trip tables includes the following:

- **2011 Passenger Load Data**—Detailed ridership counts data were obtained from each transit agency. These detailed route-level counts data were primarily collected using APC technology and hand-collected counts. These data include average weekday passenger loads by route segment, direction, and time of day, which provided the necessary information to establish ridership profiles along each route by time of day. In light of evolving service level changes as well as transition into a new data collection technology, the selection of a shake-up period specific to each transit agency was deemed necessary. This was to be able to establish a representative current ridership counts data profile. Ridership counts data for the following shake-up periods were used:
    - King County Metro (KCM) bus routes: Spring 2011 (February 2011 to June 2011)
    - ST Express routes: Summer 2011 and Fall (June 2011 to February 2012)
    - ST Sounder commuter trains and LINK light rail: Fall 2011 (October 2011 to February 2012)
    - Community Transit (CT) bus routes: Spring 2011 (March 2011 to February 2012)
    - Pierce Transit (PT) bus routes: Fall 2010 (October 2010-February 2011)
- **2004 and 2009 Sound Transit On-Board Surveys**—Between September 2003 and May 2004, ST conducted an extensive on-board survey of all of its transit services over a 9-month period. A similar on-board survey was conducted in 2009.
- **2011 Boarding Counts**—Route-level total boardings were obtained from all transit agencies, including KCM, ST, CT, PT, and Everett Transit.

- **1992 On-Board Transit Surveys**—In 1992, transit agencies in the Puget Sound region conducted six on-board transit surveys that provided the required data to develop the base-year (1992) transit-trip tables for the earlier versions of the ST model.[28]
- **2006 PSRC Household Activity and Travel Survey**—In 2006, PSRC undertook a survey to obtain region-wide information on household activities and the travel these activities generate. It surveyed about 4,700 households during a consecutive 48-hour time period.
- **2011 Sound Transit On-Board Survey**—In 2012 ST will be completing its Before and After Study for the Initial Segment light rail project. One component of the study is to investigate ridership characteristics of the project. To study these characteristics, ST undertook an on-board passenger survey, on all routes through the Initial Link Segment Study Area, to collect data about passenger trip characteristics such as origins, destinations, fare payment, transfers, etc. The survey was conducted in October and November 2011 on weekdays during peak and off-peak periods. A sample of trips of Link trains and King County Metro buses was developed for the survey. For each sampled trip, survey staff attempted to approach all passengers to distribute a survey form. Passengers could return the survey on-board, through postal mail, or complete a web-based survey. This survey data was used to open additional cells in the base year trip tables.
- **2012 Sound Transit On-Board Survey**—In 2012 ST will be completing on-board surveys on ST bus routes, Sounder Commuter Rail, and Tacoma Link light rail. The Tacoma Link light rail survey was available and used to open additional cells in the base year trip tables.
- **2007-2011 Commute Trip Reduction (CTR) Act Surveys**—The State of Washington passed the CTR law in 1991 to encourage commuters to consider transportation alternatives, such as ridesharing or taking bus. As part of this law, employers with 100 or more employees are required to conduct a survey once every two years to record commute options by their employees. Surveys from the 2007 through 2011 series were processed to obtain origin-destination and modal information on commuters. The CTR surveys have contributed considerably in opening new cells in the base year seed matrix as well as providing base shares in the absence of 2010 U.S. Census JTW data.
- **Other Counts and Survey Data**—Supplementary counts data from transit operators and from the National Transit Database (NTD) provided control totals for development of the 2011 base transit trips. Other survey data included a special survey of SR 520 riders in 2005 and the 2000 U.S. Census JTW data.

Although on-board transit surveys provide the most accurate origin-destination data, it is extremely difficult and costly, if not impossible, for transit agencies to establish "observed" transit travel patterns solely from survey data. A typical on-board transit survey collects origin and destination data for only 20 to 35 percent of riders. Furthermore, survey experience indicates that surveys include strong sample biases that cannot easily be corrected. These sample biases would compromise the accuracy of base-trip tables, should they be based solely on survey responses. Because of these shortcomings, an alternative approach to building base-year transit trip tables was developed using ridership count data, as well as survey data.

The survey data was primarily used to establish a "seed" transit-trip table embodying representative cells (i.e., zone interchanges) in the matrices, thus ensuring that important transit markets were represented in the base-trip tables. This process also included an analysis of the

[28] "Transit Ridership Forecasting Technical Report," Central Link Light Rail Transit Project (North Link), Sound Transit, November 2003.

survey data in order to replicate the average trip length frequency distribution exhibited in a transit-trip table produced by the PSRC model and passenger miles as well as boardings in 2010 NTD. This particular analysis assisted in further expansion of the open cells in the final seed matrix.

Passenger load profiles from the APC database and other counts provided segment level counts by direction and time period on each route. The frequency of segment-load points required for a given route in the trip development process depended on the variability of load profile for that route. For example, a route that experiences fairly uniform passenger loads throughout its trip did not require more than two or three locations for seeding directional passenger count volumes. Other routes, with more variability in passenger loads, require seeding of counts at more than three or four locations on each direction. About 1,800 segment-load locations were selected to hand-code passenger volumes into the 2011 database for matrix estimation, representing over 25 percent of the route segments or time point intervals (TPI).

The base-trip-table development process relied on a validated base transit network as well as supplementary ridership count data, control totals, and actual average trip length measures. This process involved pursuit of a rigorous analysis, the results of which are discussed below.

3.1.1 Transit Network Preparation

The preparation of the base-year transit network was an important and significant part of the overall development of the base-year trip table. The accuracy of the resulting base-trip tables depended directly on the validity and quality of the base transit network, as well as ridership counts. Therefore, the base-year (2011) transit network was prepared and validated to accurately reflect transit service levels, as published in 2011, as well as actual travel times by time-of-day for bus routes and on-time performance data for LINK light rail and Sounder commuter trains.

Systemwide travel times for each TPI had been established according to the actual travel time data for the KCM routes and on-time performance reports for other routes as part of the previous ST model update. Upon further examination, certain routes required an update to actual travel time for each TPI segment. This update of base travel times included KCM trolley routes and other representative KCM, CT, and PT routes, including local and express routes. The route-level dispersion between estimated and actual transit travel times around a simple regression line resulted in an R-square value over 0.91 and a slope close to one. This indicated a well-calibrated transit network that is capable of accurately reflecting service levels. Another base year (2011) transit network validation check included comparison of estimated and reported operating parameters. Estimates of revenue hours, miles, and miles per hour came within 5 percent of those reported in the NTD for all these measures.

3.1.2 Validation of Transit Service Reliability

The current ST model relies on actual transit vehicle speeds to more realistically represent transit service reliability. Although the long-term decline in bus operating speeds has been measured for the past 40 years, it has not been easy to measure the accompanying decline in service reliability until recently. However, Metro's AVL data now give complete information on actual bus times and bus schedule adherence. According to a recent analysis performed using AVL data, a rider must plan on a 9.2-minute delay for bus services. This corresponds to a 1.5-minute delay planning requirement for rail services.[29]

ST models have been using a boarding penalty to account for uncertainties related to using the transit system, including uncertainties about transferring between vehicles. Recent research on the

[29] Billen, D., "Application of Transit to LOS Measures in the Seattle North Link Light Rail Corridor," 10th TRB—Transportation Planning Applications Conference, Portland, OR, 2005.

perceptions of transit users has clarified that schedule adherence and transit stop attributes concerning personal safety are more important to the use of transit than are other station amenities. [30] Consequently, boarding penalties are reduced at stations with documented schedule adherence superiority and at transit centers and stations with positive security attributes (e.g., improved lighting and communication, 20-hour security patrols, fare-controlled platforms, and on-board fare inspectors).

Table 3-1 presents the model's boarding penalties, including wait time factors and time penalties that are assumed on escalator links. Note that in the ST model, walk and wait time resulting from a transfer is accounted for separately, including pedestrian and escalator links at rail stations, and all out-of-vehicle time is factored by 2.0.

Validation results using the boarding penalties indicated in Table 3-1 netted a much closer match to observed transfer behavior. These improvements occurred at the system level, the route level, and at transit center locations.

A special analysis was undertaken for transfers to and from Sounder. According to the prior model, 90 percent of commuter rail riders were estimated to arrive at King Street Station. Consequently, the assignment of transfers between the downtown commuter rail station and the downtown bus tunnel were of particular concern. ST surveys have shown that only 43 percent of PM peak commuter rail riders arrive via downtown bus transfers, whereas approximately 50 percent access the King Street Station by walking. Although the current model's estimate of 60 percent arrival by bus is still somewhat high, it is much closer to the observed access pattern.

The current updated ST model also more accurately replicated the 2011 three-county transfer rate compared to the earlier ST model versions. Further evaluation will be made when new information on transfers will be available both from the 2011 ST onboard survey and from new data which can be derived from the Orca smart card fare payment database.

[30] Iseki, H. and B. Taylor, "Style vs. Service? An Analysis of User Perceptions of Transit Stops and Stations," *Journal of Public Transportation*, Center for Transportation Research, Vol. 13, No. 3, 2010.

Table 3-1. Boarding Penalty, Wait Time Factor, and Escalator Link Assumptions in the 2011 ST Model

	PM Peak	Off Peak
Regular Bus Stops		
Boarding penalty	5.0 min	5.0 min
Wait time factor	0.60	0.60
Escalator link	NA	NA
Transit Centers[1]		
Boarding penalty	3.0 min	3.0 min
Wait time factor*	0.50	0.50
Escalator link	NA	NA
Downtown Bus Tunnel		
Boarding penalty	3.0 min	3.0 min
Wait time factor	0.50	0.50
Escalator link	1.0 min	1.0 min
Rail Stations (surface)		
Boarding penalty	2.0 min	2.0 min
Wait time factor	0.50	0.50
Escalator link	0.5 min	0.5 min
Rail Stations (tunnel or elevated)		
Boarding penalty	2.0 min	2.0 min
Wait time factor	0.50	0.50
Escalator link	1.0 min	1.0 min

Note: In both the path-building and the mode choice applications, all of these out-of-vehicle times are multiplied by 2.0.

[1] List of Transit Centers:

1) Bellevue Transit Center (TC)
2) Federal Way TC
3) Northgate TC
4) Burien TC
5) Kent Station TC
6) Auburn Station TC
7) Kirkland TC
8) Overlake TC
9) Aurora Village TC
10) Renton TC
11) Lynnwood TC
12) Tacoma Dome Station
13) Lakewood TC
14) Everett Station
15) Tacoma Community College TC
16) Tacoma Commerce Street TC

3.1.3 Ridership Counts Data Preparation

Ridership counts data for 2011 were obtained from transit agencies in the region.

- KCM provided TPI segment ridership information that included boardings, alightings, and several loading variables for each segment on each trip for each route. This data was collected using APC equipment located on a subset of buses that are rotated on to each trip across KCM's system. This system began operation in 1985 and has been re-calibrated and improved many times over the past 25 years.
- CT provided stop-level segment ridership information that included boardings, alightings, and loads between each stop. CT's data was collected using hand-collected counts on each trip in the agency's system.
- PT also provided stop-level segment ridership information that included boardings, alightings, and loads. These counts data were collected using APCs that are installed on all of PT's buses.
- For ST Express bus, LINK light rail, and Sounder commuter rail, the stop-level boardings and alightings data were collected primarily by APC, supplemented by additional and hand-collected observations.

Using the loads from the count data, segment totals were extracted for the 3-hour PM peak period (3:00 to 6:00 PM) and for the daily 24 hours total. These aggregated segment-level loads are the observed transit volumes that are then seeded into transit segments in the model network to best replicate loading on each route and by time of day and by direction. In all cases, the off-peak segment volumes represent subtractions from weekday reported volumes by segment so that the weekday total volumes remain the control totals for each segment and line.

3.1.4 Matrix Adjustment Process

A trip matrix adjustment methodology developed by Heinz Spiess[31] was used to assist in the development of the base year (2011) PM peak and off-peak transit-trip tables. This methodology, which has been used extensively, minimizes the difference between estimated and observed volumes seeded at designated segment-load locations for each route. While this methodology achieves a close match of estimated to actual segment loads, additional refinements were necessary to improve accuracy in the resulting transit-trip tables. These refinements included the use of

- New surveys, particularly CTR surveys data that allowed opening of additional non-zero cells in the seed matrices. About 23 percent of the matrix cells are now opened in the updated ST model 2012 version.
- Segment-based count data from all transit operators as highlighted in the previous section allowed the load profile to be more accurately replicated on each transit route by time-of-day. This was achieved by using an extensive iterative process and resulted in the identification of about 1,800 segment load locations. This constituted about 25 percent of the total TPI segments in the APC databases.
- Performing matrix adjustment in steps rather than in one step as in earlier ST model updates allowed better alignment of counts data to underlying service characteristics in each geography, resulting in a more representative base transit trip table.

Further elaboration on the items highlighted above is provided below.

3.1.5 Seed Matrix Development

The need for careful preparation of a seed matrix is critical, as it underlies the shape of transit travel patterns and representation of transit markets. During earlier ST model updates, it became evident that available surveys data were allowing only 3 percent of non-zero cells to open as highlighted in Table 3-2. A relatively significant 14 percent contribution to cell openings resulted from adding average trip length frequency distribution of base transit trips exhibited in the PSRC model, as highlighted in Table 3-2. This process basically amounted to opening of new cells and seeding of a fractional (e.g., 0.5) transit trip in these cells.

For the 2012 ST model version, new survey data were used to open new cells and adjust the shape of the matrices. Most importantly, CTR surveys contributed considerably to opening of an additional 10 percent of non-zero cells. Total non-zero cells represented in base trip tables in the 2012-based ST model is about 28 percent as highlighted in Table 3-2.

[31] Spiess, H., "A Gradient Approach for the O-D Matrix Adjustment Problem," Formerly with INRO (EMME/2 Support Center), Haldenstrassee 16, CH-2558 Aegerten, Switzerland.

Table 3-2. Progression of Non-zero Cells Opened between ST Model Versions

Contribution Source	% Non-Zero Cells	1992 Version	2004 Version	2012 Version
1992 Comprehensive Onboard Surveys	3%	3%		
2000-2004 Surveys - 2000 U.S. Census Journey-to-Work - 2003/2004 ST Survey Transit Trip Length Distribution - PSRC Model	1% 13%		17%	
2007-2011 Surveys - CTR Surveys (2007-2011) - Other Surveys - 2009 ST Survey - 2006 PSRC Household Survey 2011-2012 ST On-Board Surveys	 10.1% 0.1% 0.4%			28%

3.1.6 Matrix Adjustments in Steps

As indicated above, matrix adjustment was performed for the first time in steps. This mitigates dominance of routes with relatively large segment loads in the matrix estimation process. This also allowed better alignment of counts data to underlying service characteristics in each geographic subarea. The specification of the matrix adjustment process and segment loads considered in each step is shown in Table 3-3.

Table 3-3. Specification of Matrix Adjustment in Steps

Step No.	Segment-Loads Considered	Number of Matrix Adjustment iterations
Step 1	Initial run, include all segment-loads and routes	10 iterations
Step 2	Include only segment-loads from Pierce Transit, Everett Transit, and Community Transit + Include Tacoma LINK Light Rail	15 iterations
Step 3	Segment-loads from Step 2 + segment-loads for King County Metro (KCM) locals and streetcar	15 iterations
Step 4	Segment-loads from Step 3 + segment-loads for KCM Trunk Routes, KCM Trolleys, all ST Express Bus Routes, and Sounder Commuter Rail	15 iterations
Step 5	Include all segment-loads (adding LINK Light Rail posted segment-loads to Step 4)	20 iterations

The matrix adjustment was performed in a sequential and cumulative manner. The segment counts were first grouped based on the markets and the service type. For example, all Pierce Transit segment counts were grouped together. Then the matrix adjustment was performed on each group by cumulatively including the segment loads from all the previous groups. Such a step-wise matrix adjustment method allowed adjusting the transit-trip table for low volume segments before including the next level of high volume segments. The intent is to give the matrix adjustment method as much of an opportunity to adjust segments with low volumes as segments with high volumes.

Conditions outlined above were complemented by an extensive and rigorous analysis effort. This involved comparisons over many runs against NTD data and agency data on boardings, trip lengths, route volumes, and other available 2011 data. The analysis results for base-year (2011) transit trip development are discussed below.

3.2 Base-Year (2011) Validation Analysis Results

The validation analysis focused on evaluating (1) the updated transit-trip tables from the matrix adjustment process and (2) the accuracy of the assignment results, which is reflected in

- Systemwide boardings and transfer rate
- Boardings comparison for all Rail and Regional Express Bus routes
- Trip length frequency distribution of trip tables
- Route-level boardings
- Route-segment volumes by direction and time period
- Passenger-miles by mode and operator

Table 3-4 presents systemwide linked and unlinked transit trips, including a comparison of average weekday (daily) boarding estimates to respective actual boardings. As shown in Table 3-4, the number of estimated versus actual trips is close, reflecting the breadth and quality of the underlying network and ridership counts data used in the trip table development process. The total estimated PM peak transit trips was about 108,000, which is about 28 percent of the total 384,000 daily transit trips. Daily transit boarding results closely match those reported in the NTD. The systemwide daily boardings reflect an overall transfer rate of 1.39. The estimated transfer rate compares closely to actual daily transfer rates reflected in current surveys and systemwide ORCA (smart-card fare collection) data. The validation analysis also closely replicated actual boardings on Central Link and Tacoma light rail and regional express bus.

Table 3-4. Systemwide 2011 Linked and Unlinked Transit Trips Comparison

	PM Peak[1] Estimated	Off-Peak[2] Estimated	Average Weekday[3]		
			Actual[4]	Estimated[5]	Est/Act
Linked transit trips	108,400	167,400	384,000	384,000	1.00
Total Boardings by Operator					
KC Metro	93,300	173,300	374,000	360,000	0.96
Sound Transit	28,400	32,500	84,000	89,000	1.06
Pierce Transit	10,700	21,100	39,000	43,000	1.10
Community Transit	11,200	10,300	30,000	33,000	1.10
Everett Transit	2,500	3,700	8,000	9,000	1.13
Three-county total boardings	**146,100**	**240,900**	**535,000**	**534,000**	**1.00**
Systemwide transfer rate	1.35	1.44	1.39	1.39	1.00
Rail and Regional Bus Boardings					
Central Link Light Rail	6,400	12,500	24,000	25,000	1.04
Tacoma Link Light Rail	600	1,800	3,000	3,000	1.00
Commuter Rail	5,800	NA	10,000	11,600	1.16
ST Express Bus	15,400	18,100	47,000	49,000	1.04

[1] PM peak period represents three hours between 3 and 6 PM.
[2] Off-peak period represents 18 hours outside 6 to 9 AM and 3 to 6 PM peak periods.
[3] Daily linked and unlinked transit trips were calculated based on PM peak times two plus off-peak values.
[4] Actual boardings were obtained from the National Transit Database and supplemented by available data from transit agencies.
[5] Estimated transit trips in the ST model reflect transit markets only within the ST boundaries.

To evaluate further reasonableness of the outcome from the matrix adjustment process described above, analyses of trip length frequency distributions between the seed matrix and final daily transit-trip table as well as a comparative analysis of load volumes at segment locations, were performed throughout the process.

Figure 3-1 shows the similarity in the trip length frequency distributions between the seed matrix and final demand matrix which resulted from the matrix adjustment process. Average trip length estimates produced for routes operated by each transit agency are shown in Table 3-5. Trip lengths in the ST model for community transit are always shorter in the ST model because the CT service area and routes extend far beyond the ST district boundary and model area.

Figure 3-1. Trip Length Frequency Distribution Comparison for 2011 Average Weekday Transit Trips

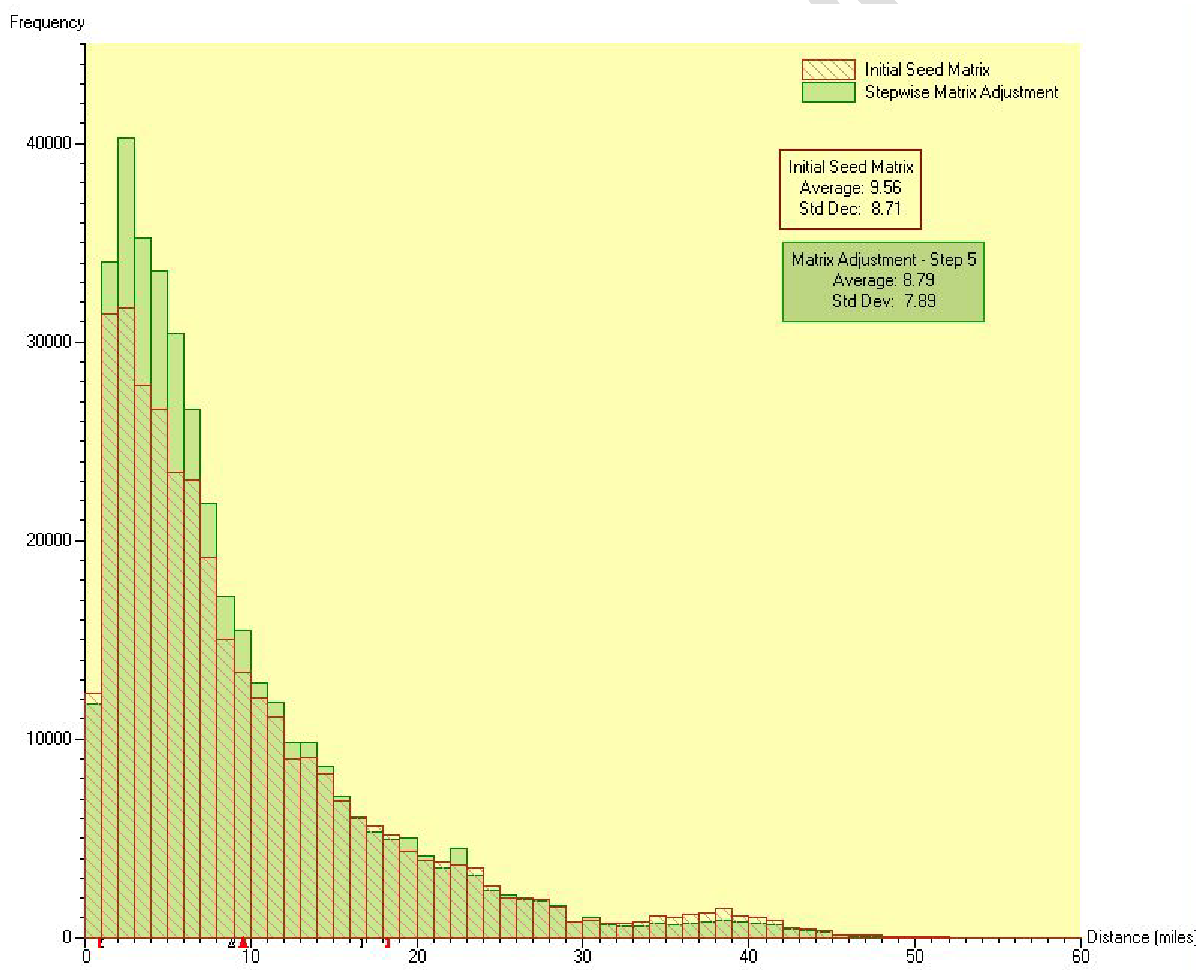


Table 3-5. Average Weekday Trip Length Comparison

	2011 Average Trip Length (miles)		
	Actual	**Estimated**	**Est/Obs**
Transit Operator			
King County Metro	4.4	4.4	1.00
Pierce Transit	4.3	3.8	0.88
Community Transit[1]	10.5	9.3	0.89

[1] Community Transit service area extends beyond the RTA Area.

Figure 3-2 and Figure 3-3 highlight the very close match of estimated to actual loads at segment locations for 2011 PM peak direction and off-peak transit trips as exhibited in the respective slope and R-squared statistics for goodness-of-fit measures. This represents a detailed line load comparison encompassing over 1,000 segment locations for PM peak and about 800 for off-peak periods. Note that these comparisons by route are a far more rigorous validation test than the typical comparison against counts across a limited selection of transit screenlines. This attention to line segment detail is particularly important when a network-based model is to be used to estimate line segment volumes on future rail line extensions.

Figure 3-2. Comparison of 2011 PM Peak (Peak-direction) Actual vs. Estimated Segment Loads for All Transit Agencies

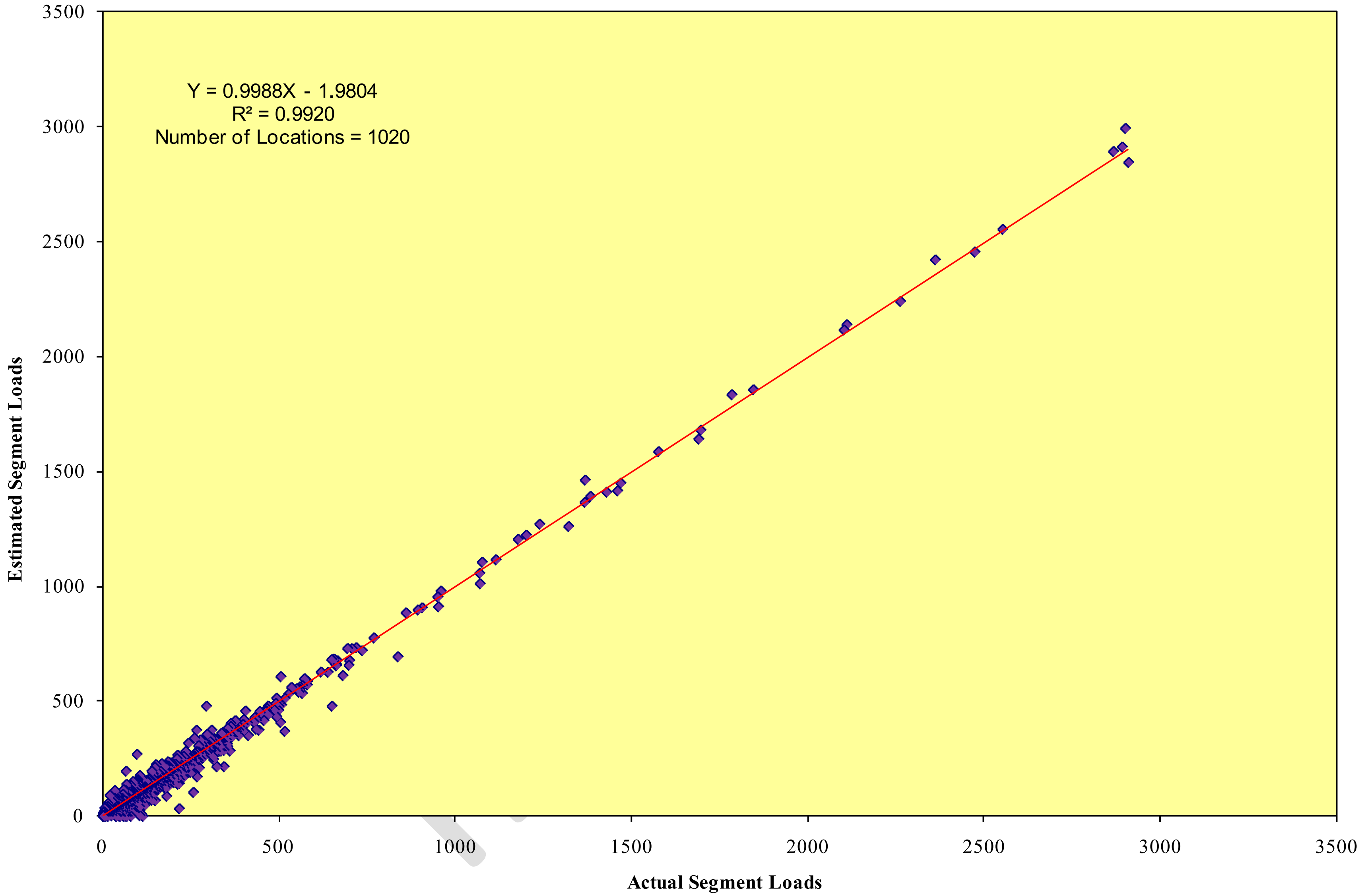
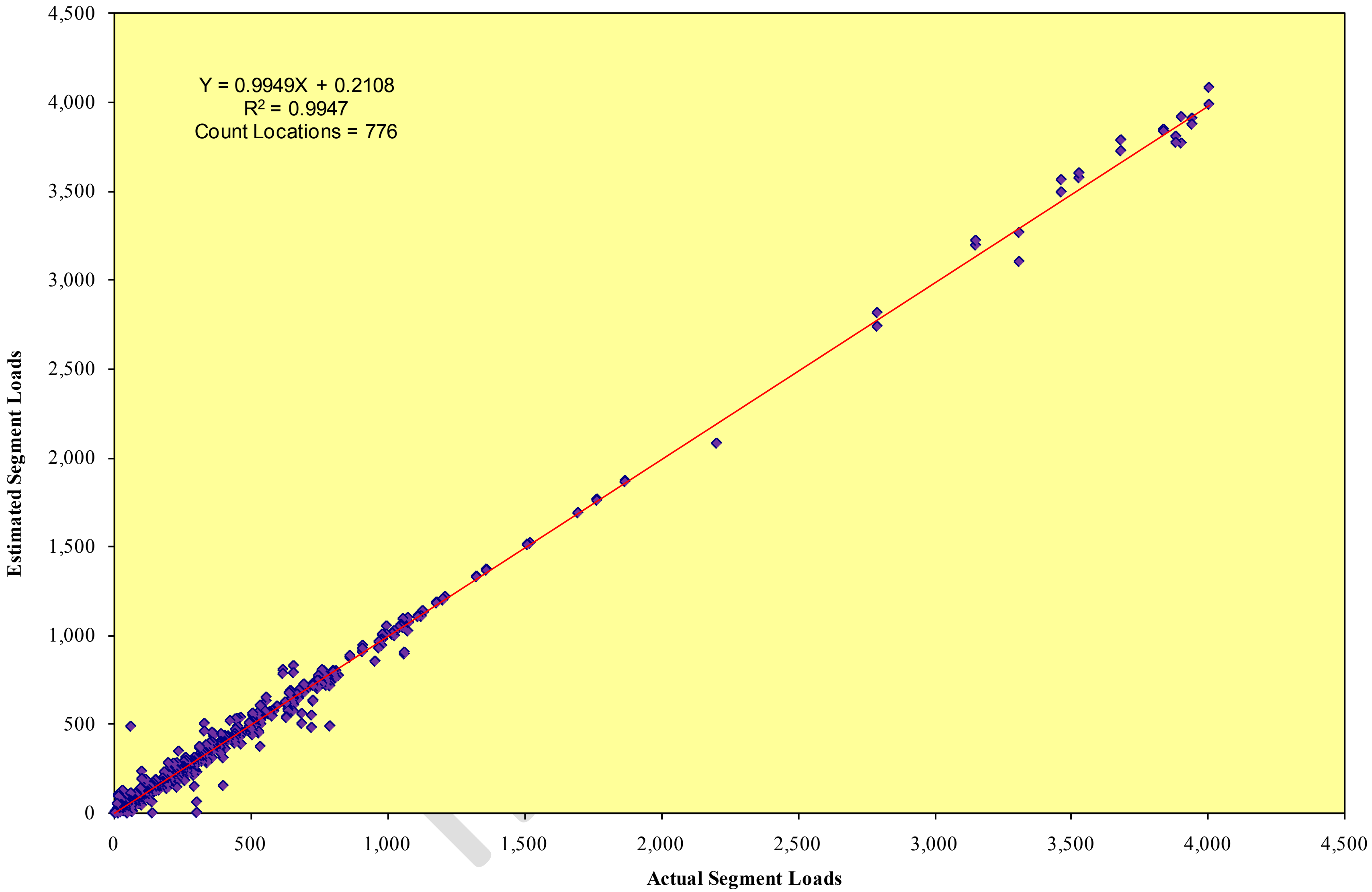


Figure 3-3. Comparison of 2011 Off-Peak (Both Directions) Actual vs. Estimated Segment Loads for All Transit Agencies



4. PRIMARY ASSUMPTIONS AND BUILD-UP FORECASTING ANALYSIS RESULTS

This chapter discusses the specific input data and assumptions used to perform staged forecasting analysis in support of the application of the Lynnwood Link Extension to FTA for entry into Preliminary Engineering as part of the New Starts process. It is divided into two parts. First, the underlying data and assumptions used in the modeling process are presented. Second, the interim (Stages 1 and 2) forecasting analysis results for 2035 are presented. Presented here is also a test, influenced by suggestions from FTA headquarters staff. This included estimating transit ridership for a hypothetical scenario in which the proposed Sound Transit System Plan would be already operating in 2011, thus eliminating the future year "forecasting" portion of the model inputs.

4.1 Key Input Data Assumptions

Year 2025 and 2035 staged forecasting analyses were developed from the validated 2011 transit-trip tables. These forecasts include the effects of

- Population and employment growth and the transportation and transit projects included in the PSRC's Metropolitan Transportation Plan
- Highway congestion forecasts based on available PSRC model databases
- Transit service levels assumed for the Lynnwood Link Extension—this effort is in progress and will be documented in a subsequent version of this report, including Stage 3 ridership forecasts

The specific assumptions and input data used to produce 2025 and 2035 interim ridership forecasts are described in the following sections.

4.1.1 Demographic Forecasts

PSRC has produced preliminary 2012 Draft Land Use forecasts as of March 2012. However, these forecasts have not yet been formally adopted and are still under review by municipalities in the region. Therefore, in order to meet the project schedule for developing ridership forecasts for the Draft EIS, an interim land use forecast is being used. This interim forecast relied on county-level totals from the PSRC's 2012 Draft Land Use forecasts as well as FAZ-level distribution from the previously adopted PSRC 2006 Small Area Land Use forecasts. This was used for base year (2011) households and future base year (2035) households and employment on the advice of PSRC staff knowledgeable about the likely course of the local review process.

For base year (2011) employment, county-level information from the Washington Office of Financial Management (OFM) was also used to update the employment forecasts for the base year, as described below. The OFM-based employment figures are considered more accurate than the PSRC forecasts at the county level. However, the OFM employment figures do not include all employment categories (excluded categories include "uncovered" jobs, such as those in construction). Therefore, the relative ratio of total employment to covered employment was developed from the PSRC's 2012 Draft Land Use Forecasts, and that ratio was then used to modify the 2010 OFM employment figures to estimate total employment at the county level. Finally, similar procedures as described above were used to distribute the county-level data to the FAZ level using distribution from the 2006 Small Area Land Use forecasts, i.e., PSRC's 2012 draft county-level totals were allocated to the FAZ-level based on proportions reflected in the 2006 Small Area Land Use Forecasts.

Table 4-1 presents district-level interim 2011 and 2035 land use forecasts. Figure 5-1 shows a map of district boundaries. FAZ-level interim 2011 and 2035 total households, population, and employment forecasts will be shown in Table E1 in Appendix E.

4.1.2 Highway Congestion and Bus Speed Degradation

The current version of the PSRC model adopted by WSDOT for performing detailed travel and toll forecasting in support of two major capital projects (FEIS Phase), the SR 520 Bridge Replacement and HOV Project and SR 99 AWV Replacement & Seawall Project, was used to produce peak and off-peak highway travel times.

The background (baseline) network assumed in both the SR 520 and AWV models included only financially committed projects. Base year, 2025, and 2035 highway networks within the North Corridor area were examined and further refined to better reflect the current highway network and its performance. Subsequently, model runs were performed to produce peak and off-peak highway travel times required for 2025 and 2035 Stage 2 ridership forecasting analyses. Descriptions of the WSDOT-preferred PSRC model version and the version that was further refined and tested for application to the Lynnwood Link Extension are included in Appendix C.

In addition, model databases were used to develop arterial and freeway speed degradation rates required for Stage 3 forecasting analysis (see Tables D3a and D3b in Appendix D). Speed degradation estimates are based on a method (see Appendix D) that ST and FTA have agreed to. Changes in roadway performance will be examined as part of a benefit analysis for the transit investment packages.

4.1.3 Parking Costs

Zonal parking costs used in the ST model reflected a conservative 1.4-percent annual (real) growth in parking costs. This is a significant reduction from the 3-percent real growth assumed by ST and the PSRC prior to 2005. However, according to the limited historic information available, parking costs have averaged 1.5-percent growth per year since 1960. This could be primarily attributed to the change in employment density which has averaged similar growth.

For the purpose of representing daily and hourly parking costs more accurately (used in Stage 2), a survey of downtown parking costs, scattered around the larger downtown (including Fist Hill and Belltown) was recently conducted. Based on the finding from this survey, base year (2011) daily parking costs were updated and 30 percent of daily parking costs were used to represent off-peak parking costs in the ST model. Zonal parking costs are shown in Table E2 in Appendix E.

4.1.4 Other Costs and Income

Automobile operating costs for travel demand models are expressed in cents-per-mile. Typically, the costs include some or most of the out-of-pocket costs of driving a car, but none of the ownership costs. Automobile operating costs for these forecasts are assumed to remain constant, in real terms, from 2011 to 2035, at 23.60 cents-per-mile in real 2011 dollars. Because this basic assumption is that the costs of driving will increase only at the rate of inflation, this input has very little effect on these ridership forecasts, solely related to any forecasts of changes in income.

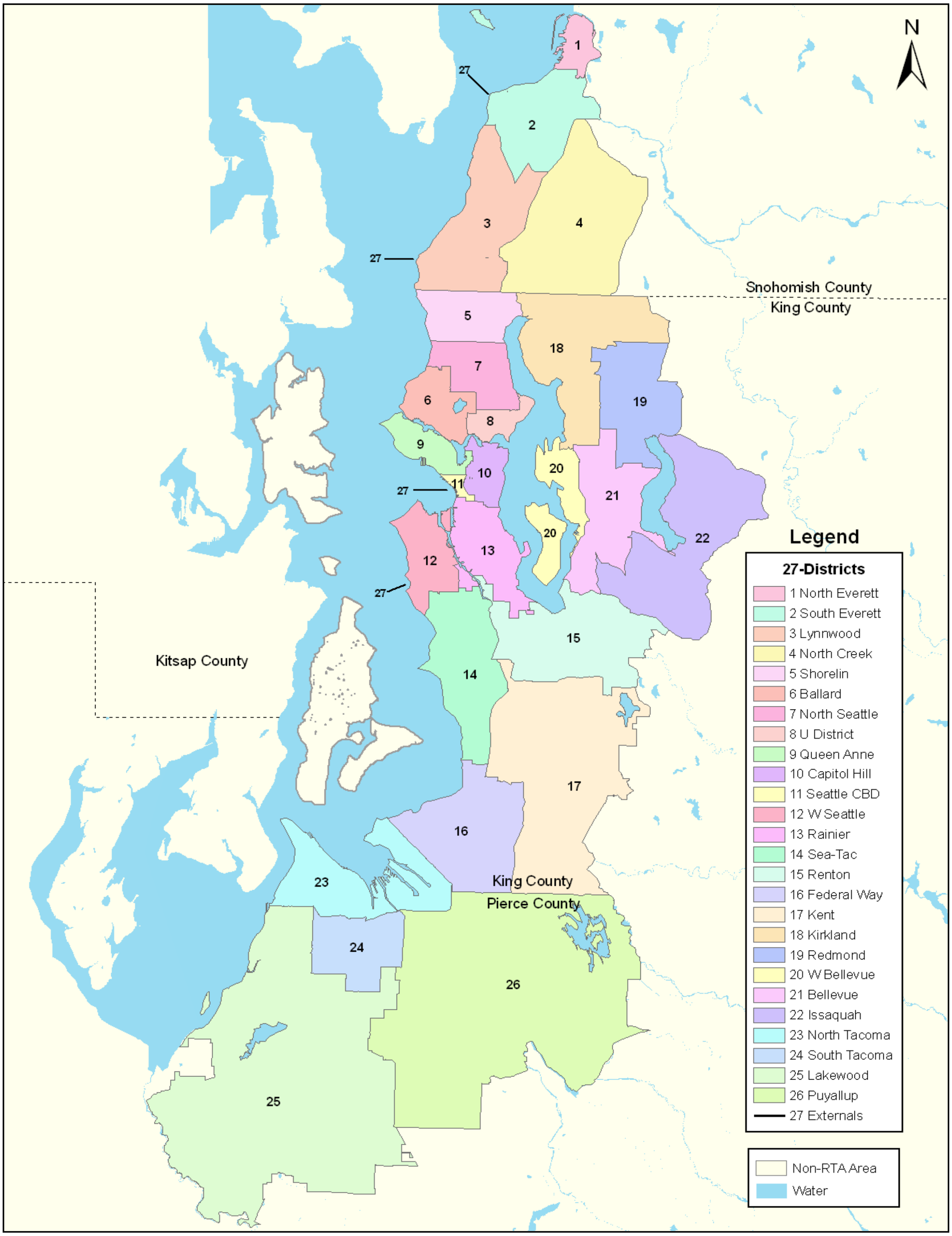
Because PSRC no longer forecasts household income at the zonal level, the current set of ST ridership forecasts apply PSRC forecasts of the change in regional average household income to base-year zonal income data to estimate future-year zonal income. The ST model database represents (real) growth in income at 1 percent per year. This is consistent with the long-term historical rate of (real) growth in income in the Puget Sound Region.

Table 4-1. Total Households, Population, and Employment Interim Forecasts for 2011, 2025, and 2035

No.	District Name	Base Year 2011			Year 2025			Year 2035		
		Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
1	North Everett	60,400	164,500	62,300				86,000	229,800	105,500
2	South Everett	37,700	93,200	58,900				47,800	116,400	89,300
3	Lynnwood	62,200	153,400	53,600				82,900	200,300	93,000
4	North Creek	107,800	302,200	51,500				152,900	418,500	92,000
5	Shoreline	26,900	69,500	16,700				28,200	74,800	19,200
6	Ballard	48,700	99,500	31,600				56,400	119,400	49,100
7	North Seattle	44,500	97,300	35,600				52,800	118,700	47,200
8	University District	17,600	46,100	44,300				20,700	54,000	51,700
9	Queen Anne	34,400	64,400	70,100				46,600	88,300	94,900
10	Capitol Hill	45,100	85,700	62,100				51,200	100,800	67,300
11	Seattle CBD	18,100	32,100	156,100				33,700	59,900	211,100
12	W Seattle	35,800	80,400	18,200				37,500	86,700	27,100
13	Rainier	32,200	92,400	89,500				37,900	110,200	114,000
14	Sea-Tac	51,700	132,600	56,000				60,500	158,400	72,900
15	Renton	52,100	127,600	105,700				67,100	167,000	155,400
16	Federal Way	47,200	126,800	34,500				53,800	146,900	44,900
17	Kent	110,600	302,800	117,800				151,800	423,900	164,800
18	Kirkland	68,400	174,900	74,900				85,900	223,700	102,900
19	Redmond	34,200	88,000	91,200				46,000	115,600	126,000
20	West Bellevue	23,900	54,000	65,800				35,100	76,000	98,700
21	Bellevue	42,700	105,400	80,100				54,600	134,900	101,800
22	Issaquah	50,500	140,500	33,000				66,400	187,400	53,000
23	North Tacoma	74,800	184,200	90,700				97,600	222,400	161,200
24	South Tacoma	33,000	89,500	32,900				40,000	100,300	55,800
25	Lakewood	72,100	189,600	74,100				84,900	205,100	119,700
26	Puyallup	120,200	332,200	55,200				180,000	456,100	115,200
27	Rest of Region	101,700	262,000	80,500				152,500	374,900	118,800
ST Area Total		**1,352,800**	**3,428,800**	**1,662,400**				**1,758,300**	**4,395,500**	**2,433,700**
	Growth rate relative to 2011	-	-	-				1.30	1.28	1.46
PSRC Four-County Total		**1,454,500**	**3,690,800**	**1,742,900**				**1,910,800**	**4,770,400**	**2,552,400**
	Growth rate relative to 2011	-	-	-				1.31	1.29	1.46

Note: This table will be updated after the adoption of land-use forecasts by PSRC

Figure 4-1. 27-District Boundary



4.1.5 Transit Fares

In all model applications to date, fares have been assumed to increase at the same rate as the overall rate of inflation in the region. This is a policy assumption consistent with the local transit agencies' practice of periodically adjusting fares to keep up with inflation. Transit fares for future years have been recently updated to reflect prevailing transit fares in 2011. Base year 2011 and future years (e.g., 2025 and 2035) transit fares used in the ST model are, respectively, presented in Tables D2a and D2b in Appendix D. The one change between the fares in 2011 and all future years was the elimination of the ride-free area in downtown Seattle in 2012.

4.2 Transit Service Levels

This section will summarize the underlying service levels assumed for the Lynnwood Link Extension. This effort is not described in this version of the technical report because the alternatives are not yet fully defined. This section will be completed in a subsequent version of this report.

4.3 Ridership Forecasting Analysis Results

This section presents staged interim ridership forecasting analysis results. Stage 3 ridership forecasts will be included in a subsequent version of this report.

4.3.1 Build-up Analysis Results

As discussed in detail in Chapter 2, the ST patronage forecasting analyses are performed in three separate stages. This process distinguishes and facilitates the evaluation of incremental changes in demographics, costs, and highway and transit travel times.

In Stage 1, implied growth in land use forecasts (at the FAZ level) adopted by PSRC are used to expand base-year transit demand from a base year to a forecast year. Stage 2 of the ST modeling process considers the influence of changes in highway congestion, auto operating costs, and parking costs. Changes in transit service levels and fares are considered in Stage 3. The staged forecasting analysis results for 2025 and 2035 PM peak and daily will be summarized in Table 4-2 through Table 4-5.

District-level transit-trip table summaries for the base year are shown in Table 4-6 and Table 4-7 for PM peak and daily, respectively. Similar summaries will be presented for Stage 3 forecasts in a next version of this report.

4.4 Build-out Sensitivity Test on Existing Conditions

This section presents a special look at the proposed ST2 System Plan currently under development at ST and scheduled for completion by the end of 2023. Forecasts for this plan will be performed for the horizon years 2025 and 2035 as part of the Lynnwood Link Extension DEIS. For this special sensitivity test, the known 2011 transit demand was entered directly in to the Stage 3 mode choice model and assignments, ignoring all growth forecasts and external inputs used in the Stage 1 (regional growth) and Stage 2 (highway times and costs) model stages.

This test effectively strips away all consideration of future time horizons in order to observe what today's ridership would be on the future system. Standard output tables have also been prepared and reviewed for reasonableness. Table 4-8 includes a comparison of average weekday transit ridership between 2011 no build and build. Transit passenger volumes for the year 2011 three-hour PM-peak period, as well as average weekday volumes, are shown on Figure 4-2. For the North Corridor segment currently in environmental analysis, the Lynnwood Link Extension, the average weekday two-way daily passenger volume between Northgate and NE 145th Street is 42,000. The PM-peak maximum load point for the Link system is southbound from Pioneer Square Station in the Downtown Seattle Transit Tunnel and is 15,400 for three hours, which is approximately 6,000 for the highest hour.

Table 4-2. Build-up Analysis: 2011 to 2025 PM Peak Transit Trip Ends by PM Origins and PM Destinations

No.	District Name	PM Origins				PM Destinations			
			2025				2025		
		2011	Stage 1	Stage 2	Stage 3	2011	Stage 1	Stage 2	Stage 3
1	North Everett	1,690				1,950			
2	South Everett	1,760				3,110			
3	Lynnwood	1,830				4,660			
4	North Creek	610				3,430			
5	Shoreline	940				2,710			
6	Ballard	3,240				7,960			
7	North Seattle	3,630				6,230			
8	University District	9,130				3,300			
9	Queen Anne	4,820				4,480			
10	Capitol Hill	9,880				9,610			
11	Seattle CBD	34,670				8,030			
12	W Seattle	1,680				3,850			
13	Rainier	8,430				7,510			
14	Sea-Tac	2,410				4,010			
15	Renton	3,160				3,760			
16	Federal Way	760				2,090			
17	Kent	2,830				5,300			
18	Kirkland	1,230				2,530			
19	Redmond	1,880				1,980			
20	West Bellevue	2,940				1,780			
21	Bellevue	2,180				3,470			
22	Issaquah	250				1,960			
23	North Tacoma	3,400				4,380			
24	South Tacoma	2,030				2,560			
25	Lakewood	2,080				2,650			
26	Puyallup	660				2,860			
27	External	260				2,220			
Total PM Peak Transit Trips		**108,380**				**108,380**			
% Change Relative to 2011									
% Change Relative to Previous Step in Build-up Analysis									

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table 4-3. Build-up Analysis: 2011 to 2025 Build-Up Daily Transit Trip Ends (in origin/destination format)

		PM Origins			
			2025		
No.	**District Name**	**2011**	**Stage 1**	**Stage 2**	**Stage 3**
1	North Everett	5,840			
2	South Everett	7,350			
3	Lynnwood	9,690			
4	North Creek	5,400			
5	Shoreline	6,300			
6	Ballard	21,540			
7	North Seattle	17,730			
8	University District	22,190			
9	Queen Anne	18,390			
10	Capitol Hill	39,540			
11	Seattle CBD	77,810			
12	W Seattle	10,450			
13	Rainier	29,050			
14	Sea-Tac	13,770			
15	Renton	11,900			
16	Federal Way	4,480			
17	Kent	11,860			
18	Kirkland	6,120			
19	Redmond	5,920			
20	West Bellevue	7,140			
21	Bellevue	8,800			
22	Issaquah	2,930			
23	North Tacoma	15,130			
24	South Tacoma	8,420			
25	Lakewood	8,070			
26	Puyallup	4,640			
27	External	3,670			
Total PM Peak Transit Trips		**384,130**			
% Change Relative to 2011					
% Change Relative to Previous Step in Build-up Analysis					

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table 4-4. Build-up Analysis: 2011 to 2035 PM Peak Transit Trip Ends by PM Origins and PM Destinations

No.	District Name	PM Origins				PM Destinations			
			2035				2035		
		2011	Stage 1	Stage 2	Stage 3	2011	Stage 1	Stage 2	Stage 3
1	North Everett	1,690				1,950			
2	South Everett	1,760				3,110			
3	Lynnwood	1,830				4,660			
4	North Creek	610				3,430			
5	Shoreline	940				2,710			
6	Ballard	3,240				7,960			
7	North Seattle	3,630				6,230			
8	University District	9,130				3,300			
9	Queen Anne	4,820				4,480			
10	Capitol Hill	9,880				9,610			
11	Seattle CBD	34,670				8,030			
12	W Seattle	1,680				3,850			
13	Rainier	8,430				7,510			
14	Sea-Tac	2,410				4,010			
15	Renton	3,160				3,760			
16	Federal Way	760				2,090			
17	Kent	2,830				5,300			
18	Kirkland	1,230				2,530			
19	Redmond	1,880				1,980			
20	West Bellevue	2,940				1,780			
21	Bellevue	2,180				3,470			
22	Issaquah	250				1,960			
23	North Tacoma	3,400				4,380			
24	South Tacoma	2,030				2,560			
25	Lakewood	2,080				2,650			
26	Puyallup	660				2,860			
27	External	260				2,220			
Total PM Peak Transit Trips		**108,380**				**108,380**			
% Change Relative to 2011									
% Change Relative to Previous Step in Build-up Analysis									

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table 4-5. Build-up Analysis: 2011 to 2035 Build-Up Daily Transit Trip Ends (in origin/destination format)

No.	District Name	PM Origins			
			2035		
		2011	Stage 1	Stage 2	Stage 3
1	North Everett	5,840			
2	South Everett	7,350			
3	Lynnwood	9,690			
4	North Creek	5,400			
5	Shoreline	6,300			
6	Ballard	21,540			
7	North Seattle	17,730			
8	University District	22,190			
9	Queen Anne	18,390			
10	Capitol Hill	39,540			
11	Seattle CBD	77,810			
12	W Seattle	10,450			
13	Rainier	29,050			
14	Sea-Tac	13,770			
15	Renton	11,900			
16	Federal Way	4,480			
17	Kent	11,860			
18	Kirkland	6,120			
19	Redmond	5,920			
20	West Bellevue	7,140			
21	Bellevue	8,800			
22	Issaquah	2,930			
23	North Tacoma	15,130			
24	South Tacoma	8,420			
25	Lakewood	8,070			
26	Puyallup	4,640			
27	External	3,670			
Total PM Peak Transit Trips		**384,130**			
% Change Relative to 2011					
% Change Relative to Previous Step in Build-up Analysis					

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table 4-6. PM Peak Transit Trips—Base Year 2011

DESTINATION		North Everett	South Everett	Lynnwood	North Creek	Shoreline	Ballard	North Seattle	University District	Queen Anne	Capitol Hill	Seattle CBD	W Seattle	Rainier	Sea-Tac	Renton	Federal Way	Kent	Kirkland	Redmond	West Bellevue	Bellevue	Issaquah	North Tacoma	South Tacoma	Lakewood	Puyallup	External	Origin Totals	Origin Shares
ORIGIN		**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**	**25**	**26**	**27**		
North Everett	1	550	670	170	160	20	20	20	10	10	10	20	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	20	**1,690**	**1.6%**
South Everett	2	510	520	180	130	10	20	30	–	10	10	20	–	–	–	40	–	30	10	–	–	10	–	–	–	–	–	190	**1,760**	**1.6%**
Lynnwood	3	110	370	660	150	60	40	120	30	20	70	50	–	20	10	–	10	–	30	10	–	10	–	–	–	10	–	40	**1,830**	**1.7%**
North Creek	4	80	130	120	60	20	10	60	10	–	10	20	–	–	–	–	10	–	40	–	–	10	–	–	–	–	–	–	**610**	**0.6%**
Shoreline	5	10	50	110	10	110	120	220	50	30	40	60	10	40	10	–	–	–	30	–	–	–	–	–	–	–	–	30	**940**	**0.9%**
Ballard	6	20	50	100	30	140	610	470	290	390	330	360	60	100	20	30	10	20	30	40	20	40	10	10	–	10	20	30	**3,240**	**3.0%**
North Seattle	7	10	60	180	60	420	580	560	230	200	190	420	50	240	40	40	10	50	110	30	10	30	20	10	–	10	30	30	**3,630**	**3.3%**
University Dist	8	90	280	730	460	410	1,160	1,710	420	240	840	320	110	200	200	100	100	130	440	290	90	410	100	110	40	40	70	40	**9,130**	**8.4%**
Queen Anne	9	50	80	160	100	100	580	320	310	430	680	360	130	340	160	100	60	120	60	50	50	60	60	60	20	100	110	180	**4,820**	**4.5%**
Capitol Hill	10	60	80	260	220	230	1,030	680	570	430	1,270	1,380	410	1,450	320	210	140	230	60	80	90	110	90	70	30	40	110	210	**9,880**	**9.1%**
Seattle CBD	11	350	560	1,540	1,510	930	2,790	1,380	810	2,060	4,020	2,500	1,730	2,810	1,290	1,150	770	1,470	740	460	700	870	1,030	530	120	350	1,060	1,130	**34,670**	**32.0%**
W Seattle	12	–	10	10	–	10	40	10	10	80	170	220	500	190	220	90	20	20	–	10	–	–	–	–	–	–	10	40	**1,680**	**1.5%**
Rainier	13	40	80	130	210	100	290	170	210	300	1,120	930	440	1,210	540	550	190	620	120	100	140	170	150	100	30	50	230	200	**8,430**	**7.8%**
Sea-Tac	14	20	10	10	–	10	30	20	20	50	150	310	180	240	440	250	150	190	–	–	10	20	10	110	20	10	130	10	**2,410**	**2.2%**
Renton	15	–	10	20	10	10	40	20	20	40	100	180	90	250	430	480	140	720	10	10	30	90	20	190	50	40	160	20	**3,160**	**2.9%**
Federal Way	16	–	–	–	–	–	–	–	–	10	20	90	20	30	100	40	200	160	–	–	–	–	–	40	10	10	30	–	**760**	**0.7%**
Kent	17	–	–	10	–	10	20	10	10	20	60	160	30	90	100	260	140	1,340	–	–	–	10	10	210	50	30	230	10	**2,830**	**2.6%**
Kirkland	18	–	30	50	40	50	80	70	40	10	40	20	–	10	–	10	–	10	330	170	110	110	20	–	–	–	–	–	**1,230**	**1.1%**
Redmond	19	10	30	50	90	30	190	120	100	40	150	60	30	40	20	10	20	10	130	240	60	280	120	20	–	10	10	10	**1,880**	**1.7%**
West Bellevue	20	20	70	110	150	30	140	130	50	50	140	160	10	70	40	230	10	60	250	160	190	610	210	10	–	–	10	10	**2,940**	**2.7%**
Bellevue	21	–	20	30	20	20	100	70	50	30	90	120	10	60	20	100	10	30	130	310	240	610	90	–	–	–	10	10	**2,180**	**2.0%**
Issaquah	22	–	–	–	–	–	20	10	10	10	30	50	–	20	–	10	–	–	10	20	10	20	20	–	–	–	–	–	**250**	**0.2%**
North Tacoma	23	–	–	–	–	–	10	10	10	10	20	40	10	20	20	–	80	60	–	–	–	–	–	1,870	640	400	190	–	**3,400**	**3.1%**
South Tacoma	24	–	–	–	–	–	–	–	–	–	–	20	–	–	–	–	10	10	–	–	–	–	–	460	860	610	50	–	**2,030**	**1.9%**
Lakewood	25	–	–	–	–	–	10	–	–	–	–	10	–	–	–	–	10	–	–	–	–	–	–	440	620	840	140	–	**2,080**	**1.9%**
Puyallup	26	–	–	–	–	–	10	–	–	–	10	70	–	20	10	10	20	20	–	–	–	–	–	140	60	70	210	–	**660**	**0.6%**
External	27	10	10	10	10	10	10	10	10	20	30	80	10	30	10	10	–	–	–	–	–	–	–	–	–	–	–	–	**260**	**0.2%**
Destination Totals		**1,950**	**3,110**	**4,660**	**3,430**	**2,710**	**7,960**	**6,230**	**3,300**	**4,480**	**9,610**	**8,030**	**3,850**	**7,510**	**4,010**	**3,760**	**2,090**	**5,300**	**2,530**	**1,980**	**1,780**	**3,470**	**1,960**	**4,380**	**2,560**	**2,650**	**2,860**	**2,220**	**108,380**	**100.0%**
Destination Shares		**1.8%**	**2.9%**	**4.3%**	**3.2%**	**2.5%**	**7.3%**	**5.7%**	**3.0%**	**4.1%**	**8.9%**	**7.4%**	**3.6%**	**6.9%**	**3.7%**	**3.5%**	**1.9%**	**4.9%**	**2.3%**	**1.8%**	**1.6%**	**3.2%**	**1.8%**	**4.0%**	**2.4%**	**2.4%**	**2.6%**	**2.0%**	**100.0%**	

Table 4-7. Daily Transit Trips—Base Year 2011

ORIGIN \ DESTINATION		North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26	External 27	Origin Totals	Origin Shares
North Everett	1	1,760	2,140	470	410	70	50	50	120	70	90	410	10	60	30	–	–	10	10	10	30	10	–	–	–	–	–	30	**5,840**	**1.5%**
South Everett	2	2,140	1,510	760	430	110	90	130	360	130	150	820	10	140	20	60	10	40	60	40	80	30	10	–	–	–	–	220	**7,350**	**1.9%**
Lynnwood	3	470	760	2,310	500	330	220	630	950	250	450	1,960	10	250	30	40	10	20	140	70	140	50	–	–	–	10	–	70	**9,690**	**2.5%**
North Creek	4	410	430	500	200	90	80	140	580	140	290	1,750	10	250	20	20	10	10	110	120	170	40	10	–	–	–	–	10	**5,400**	**1.4%**
Shoreline	5	70	110	330	90	410	470	1,030	740	350	540	1,460	50	260	30	20	–	20	140	50	40	30	–	10	–	10	–	60	**6,300**	**1.6%**
Ballard	6	50	90	220	80	470	2,520	2,020	3,330	1,840	2,900	5,140	280	880	160	240	30	60	160	300	300	230	90	30	–	10	30	90	**21,540**	**5.6%**
North Seattle	7	50	130	630	140	1,030	2,020	1,930	3,380	1,140	1,660	3,160	200	800	240	140	10	80	220	200	220	150	50	20	10	10	40	70	**17,730**	**4.6%**
University Dist	8	120	360	950	580	740	3,330	3,380	1,950	1,180	2,860	2,070	230	850	310	230	110	190	710	480	260	670	150	130	40	40	80	200	**22,190**	**5.8%**
Queen Anne	9	70	130	250	140	350	1,840	1,140	1,180	2,020	2,380	4,420	550	1,430	490	340	90	220	150	140	180	140	100	80	20	100	130	290	**18,390**	**4.8%**
Capitol Hill	10	90	150	450	290	540	2,900	1,660	2,860	2,380	5,470	12,100	1,320	4,680	970	670	210	420	240	330	390	320	200	110	30	50	130	590	**39,540**	**10.3%**
Seattle CBD	11	410	820	1,960	1,750	1,460	5,140	3,160	2,070	4,420	12,100	16,810	3,070	7,170	2,870	2,060	1,040	2,000	1,200	780	1,160	1,210	1,280	630	150	380	1,200	1,520	**77,810**	**20.3%**
W Seattle	12	10	10	10	10	50	280	200	230	550	1,320	3,070	2,010	1,010	960	340	70	80	20	60	30	30	10	10	–	–	10	60	**10,450**	**2.7%**
Rainier	13	60	140	250	250	260	880	800	850	1,430	4,680	7,170	1,010	4,350	1,880	1,410	380	1,070	200	210	350	350	240	150	40	60	280	290	**29,050**	**7.6%**
Sea-Tac	14	30	20	30	20	30	160	240	310	490	970	2,870	960	1,880	2,170	1,340	700	600	20	50	170	120	30	220	50	70	200	40	**13,770**	**3.6%**
Renton	15	–	60	40	20	20	240	140	230	340	670	2,060	340	1,410	1,340	1,730	360	1,370	60	50	390	370	50	220	60	50	220	40	**11,900**	**3.1%**
Federal Way	16	–	10	10	10	–	30	10	110	90	210	1,040	70	380	700	360	570	470	10	20	30	20	10	190	30	50	50	–	**4,480**	**1.2%**
Kent	17	10	40	20	10	20	60	80	190	220	420	2,000	80	1,070	600	1,370	470	4,140	20	20	100	50	10	370	90	100	300	20	**11,860**	**3.1%**
Kirkland	18	10	60	140	110	140	160	220	710	150	240	1,200	20	200	20	60	10	20	1,020	520	580	470	40	–	–	–	–	10	**6,120**	**1.6%**
Redmond	19	10	40	70	120	50	300	200	480	140	330	780	60	210	50	50	20	20	520	800	400	1,050	160	20	–	10	10	20	**5,920**	**1.5%**
West Bellevue	20	30	80	140	170	40	300	220	260	180	390	1,160	30	350	170	390	30	100	580	400	560	1,280	230	10	–	–	20	20	**7,140**	**1.9%**
Bellevue	21	10	30	50	40	30	230	150	670	140	320	1,210	30	350	120	370	20	50	470	1,050	1,280	1,980	170	10	–	–	20	10	**8,800**	**2.3%**
Issaquah	22	–	10	–	10	–	90	50	150	100	200	1,280	10	240	30	50	10	10	40	160	230	170	70	–	–	–	10	10	**2,930**	**0.8%**
North Tacoma	23	–	–	–	–	10	30	20	130	80	110	630	10	150	220	220	190	370	–	20	10	10	–	8,540	2,140	1,590	630	10	**15,130**	**3.9%**
South Tacoma	24	–	–	–	–	–	–	10	40	20	30	150	–	40	50	60	30	90	–	–	–	–	–	2,140	2,980	2,480	290	–	**8,420**	**2.2%**
Lakewood	25	–	–	10	–	10	10	10	40	100	50	380	–	60	70	50	50	100	–	10	–	–	–	1,590	2,480	2,700	320	–	**8,070**	**2.1%**
Puyallup	26	–	–	–	–	–	30	40	80	130	130	1,200	10	280	200	220	50	300	–	10	20	20	10	630	290	320	640	–	**4,640**	**1.2%**
External	27	30	220	70	10	60	90	70	200	290	590	1,520	60	290	40	40	–	20	10	20	20	10	10	10	–	–	–	10	**3,670**	**1.0%**
Destination Totals		**5,840**	**7,350**	**9,690**	**5,400**	**6,300**	**21,540**	**17,730**	**22,190**	**18,390**	**39,540**	**77,810**	**10,450**	**29,050**	**13,770**	**11,900**	**4,480**	**11,860**	**6,120**	**5,920**	**7,140**	**8,800**	**2,930**	**15,130**	**8,420**	**8,070**	**4,640**	**3,670**	**384,170**	**100.0%**
Destination Shares		**1.5%**	**1.9%**	**2.5%**	**1.4%**	**1.6%**	**5.6%**	**4.6%**	**5.8%**	**4.8%**	**10.3%**	**20.3%**	**2.7%**	**7.6%**	**3.6%**	**3.1%**	**1.2%**	**3.1%**	**1.6%**	**1.5%**	**1.9%**	**2.3%**	**0.8%**	**3.9%**	**2.2%**	**2.1%**	**1.2%**	**1.0%**	**100.0%**	

Table 4-8. Preliminary Average Weekday Transit Ridership Estimates, 2011 No-Build and Build Comparison

Description	2011 No-Build	2011 Build-out
Total daily (24 hours) transit trips	384,000	431,000
Total daily transit boardings	534,000	671,000
Daily light rail boardings	25,000	198,000
Daily project riders (Northgate–Lynnwood)	NA	44,000

Figure 4-2. 2011 Sensitivity Test PM Peak and Daily Transit Passenger Volumes

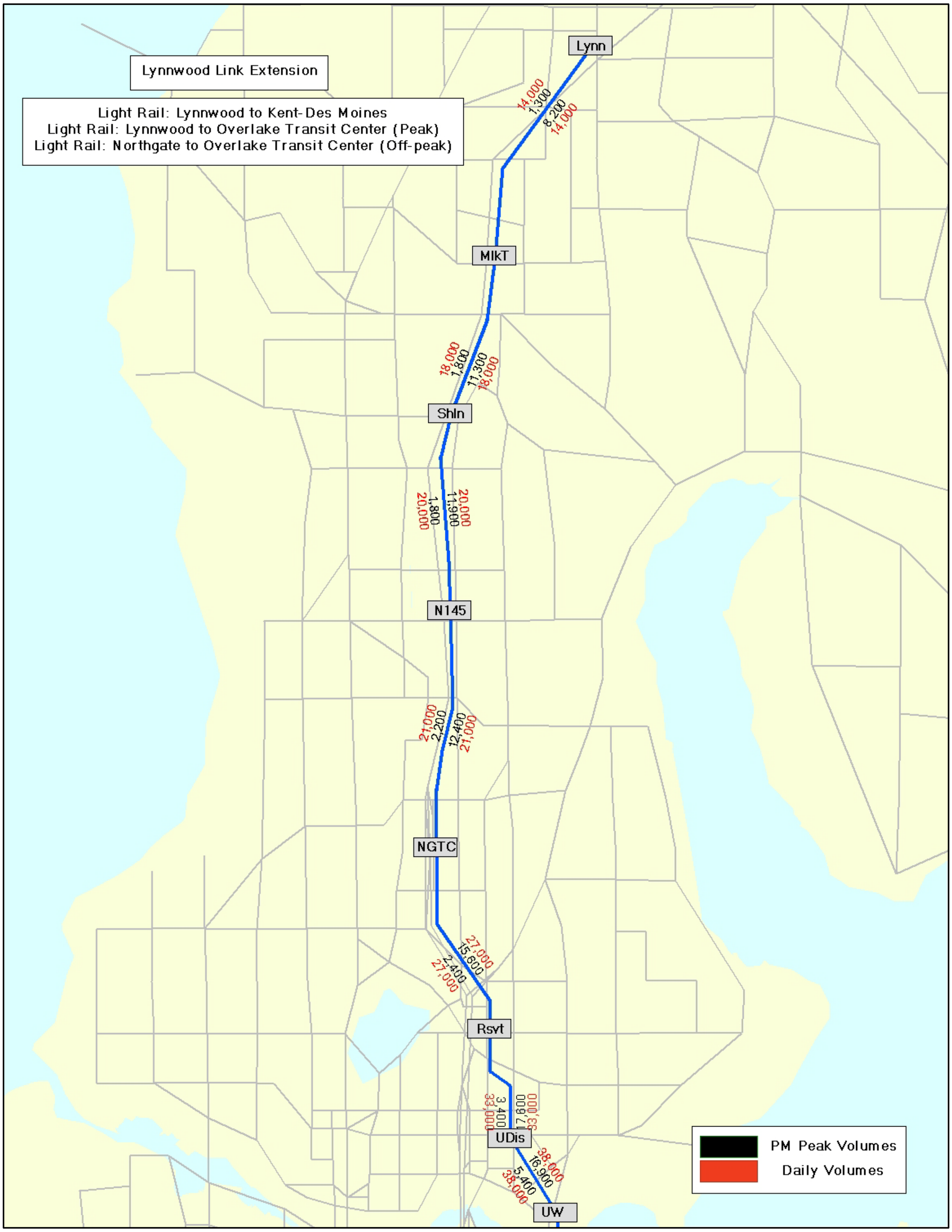


Figure 4-2. 2011 Sensitivity Test PM Peak and Daily Transit Passenger Volumes (continued)

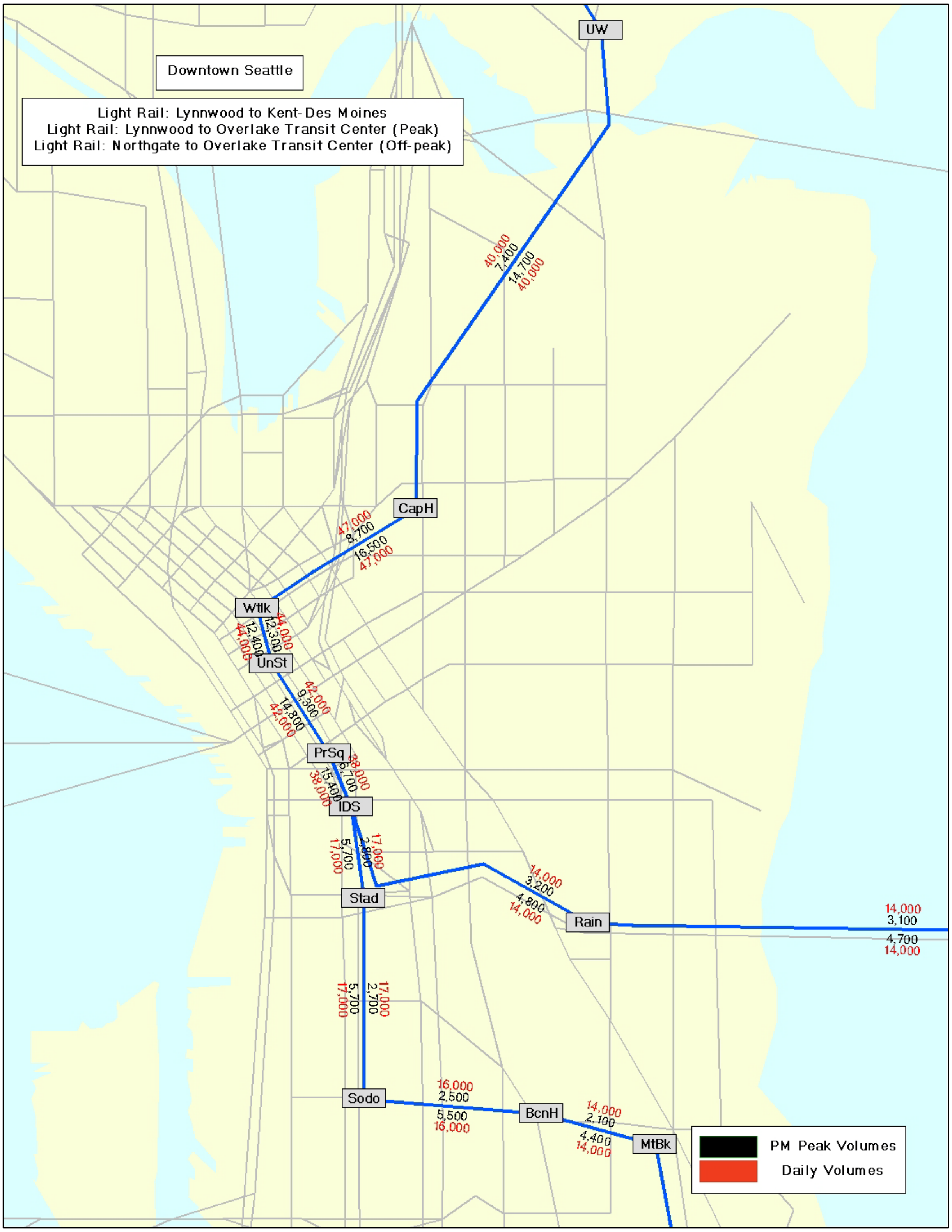


Figure 4-2. 2011 Sensitivity Test PM Peak and Daily Transit Passenger Volumes (continued)

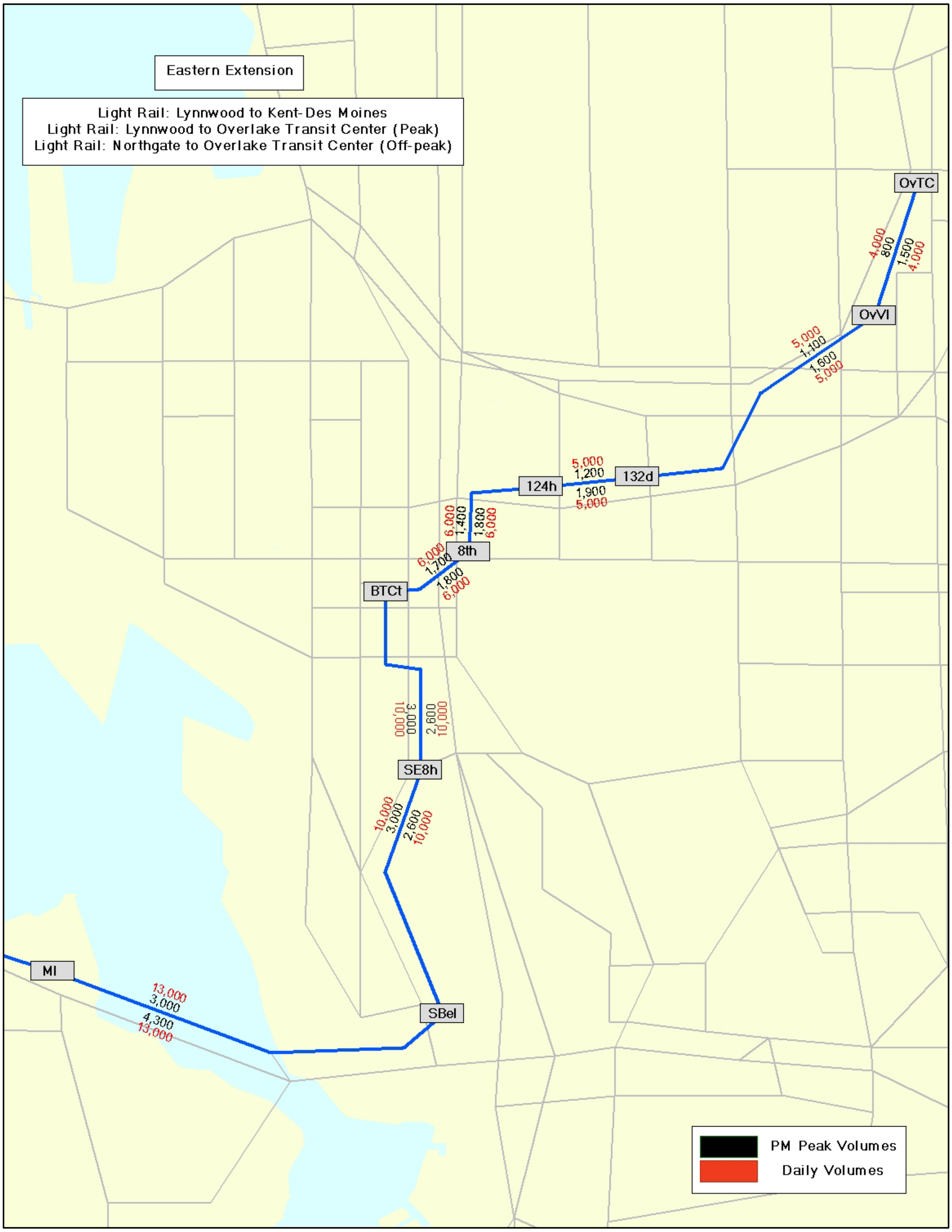


Figure 4-2. 2011 Sensitivity Test PM Peak and Daily Transit Passenger Volumes (continued)

Appendix A: Maps

- ***Forecasting Analysis Zones (FAZs)***
- ***Alternative Analysis Zones (AAZs)***
- ***27, 11, and 6 Summary Districts***

Figure A1: PSRC FAZ Map—Snohomish County

Figure A2: PSRC FAZ Map—King County

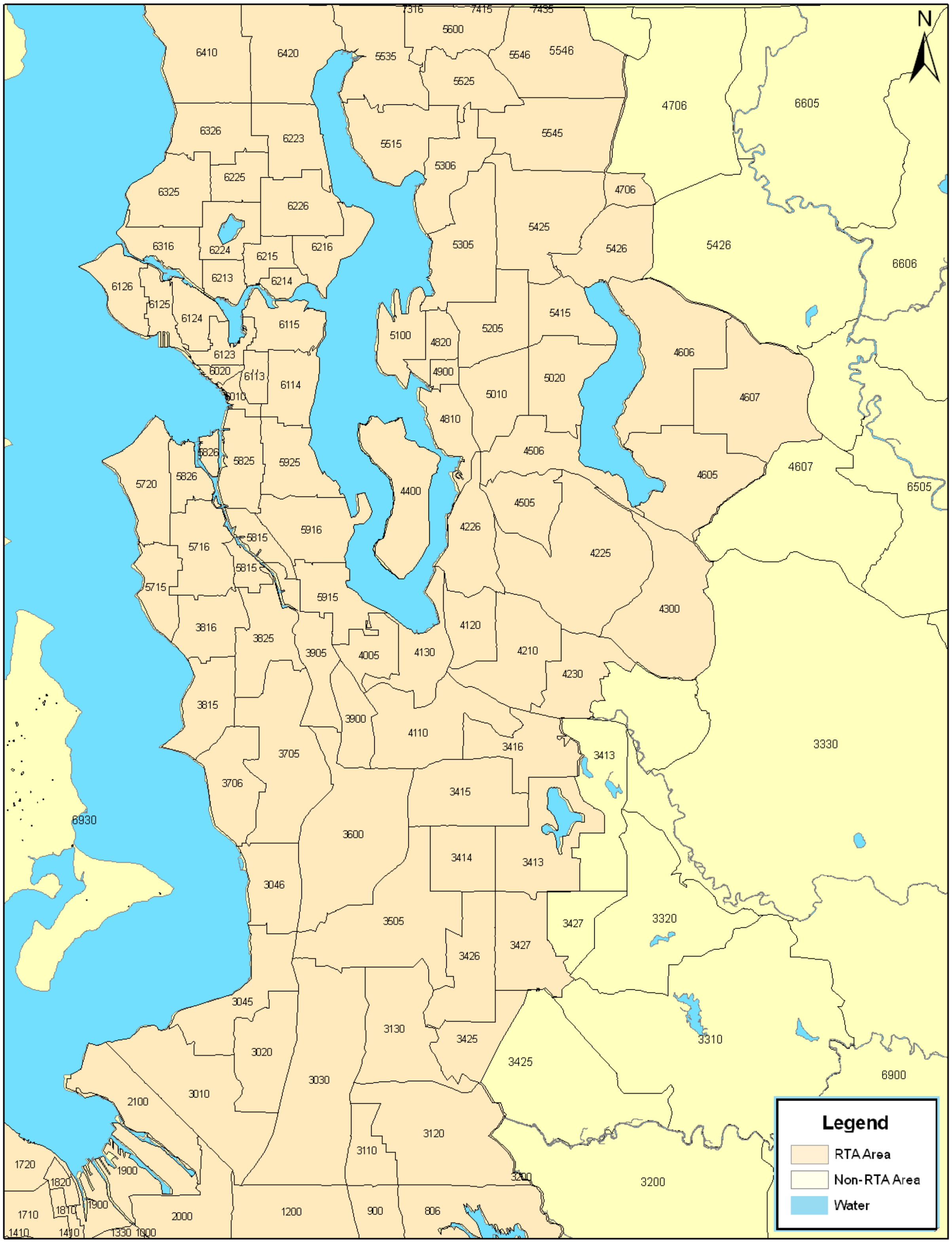


Figure A3: PSRC FAZ Map—Pierce County

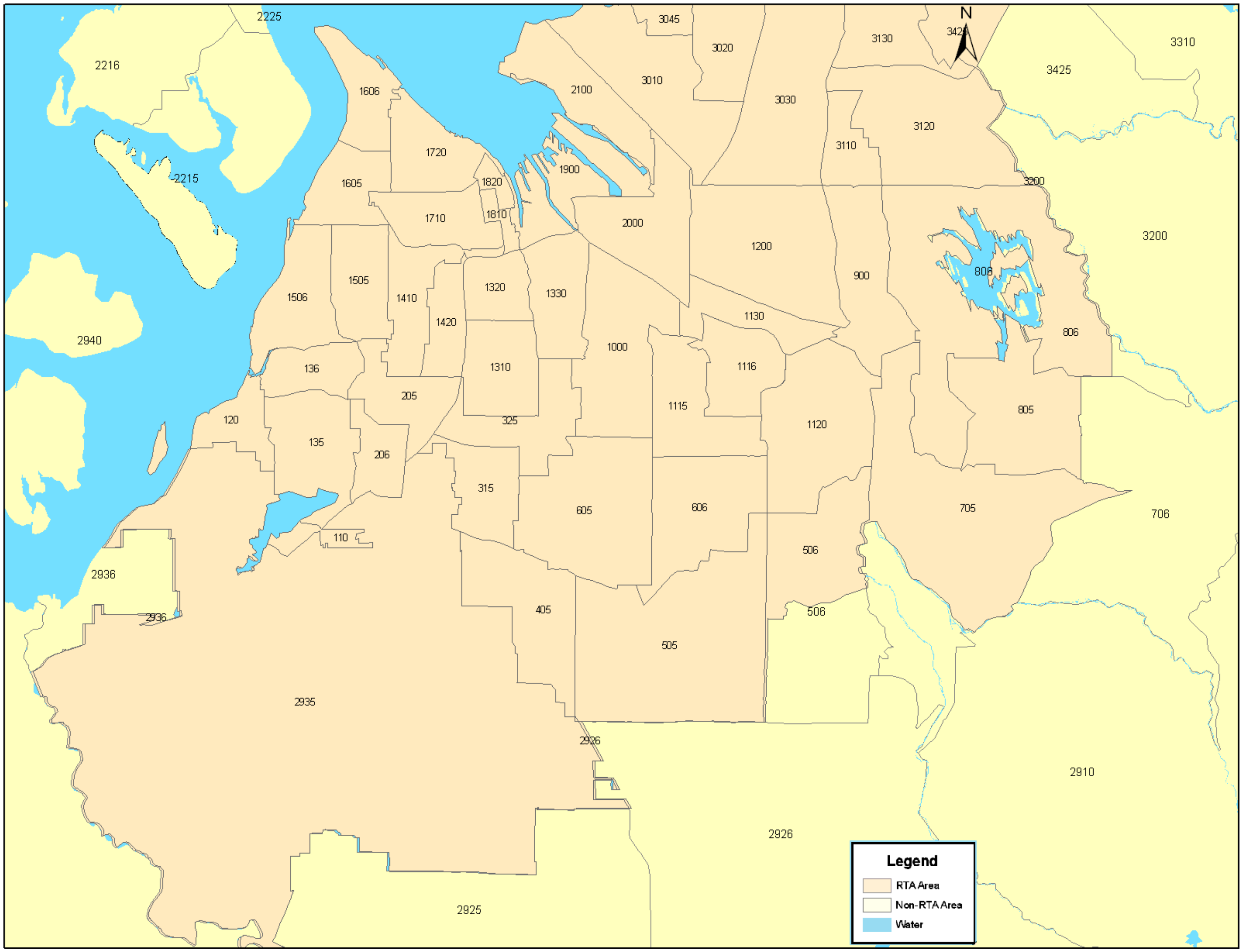


Figure A4: 780 Zonal System—King County

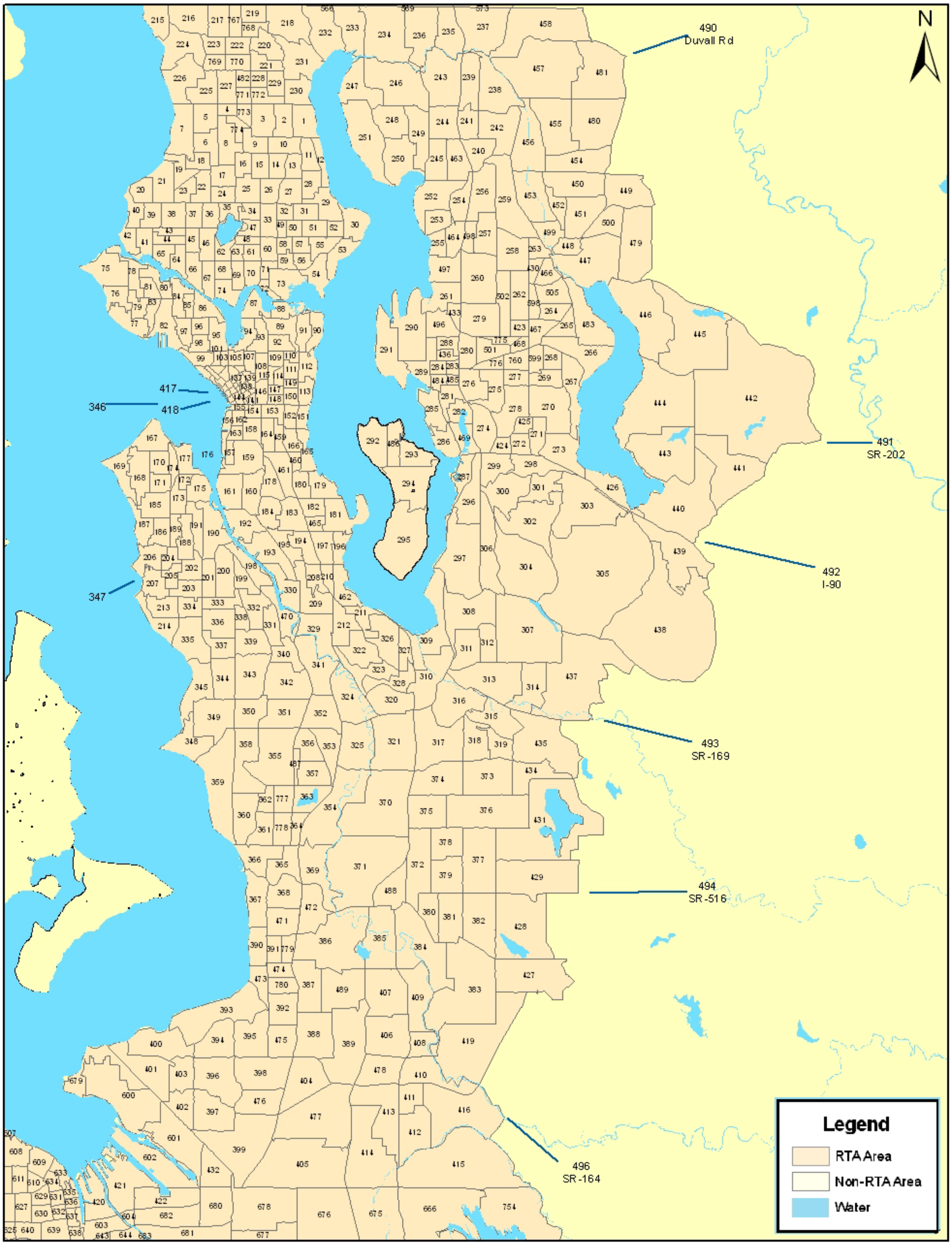


Figure A4a: 780 Zonal System—Central Seattle

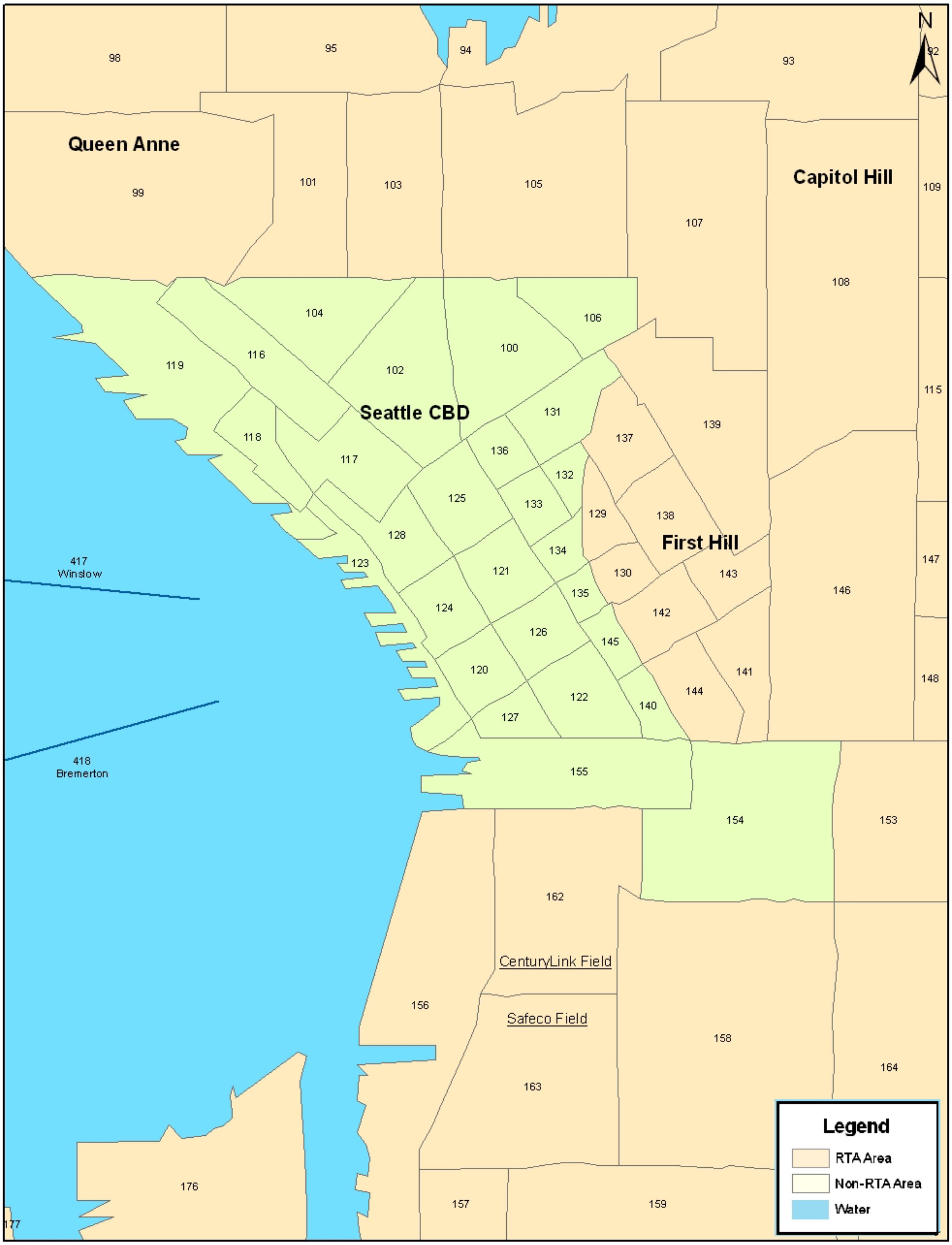


Figure A4b: 780 Zonal System—Capitol Hill, First Hill, Ballard & Queen Anne

Figure A4c: 780 Zonal System—North Seattle

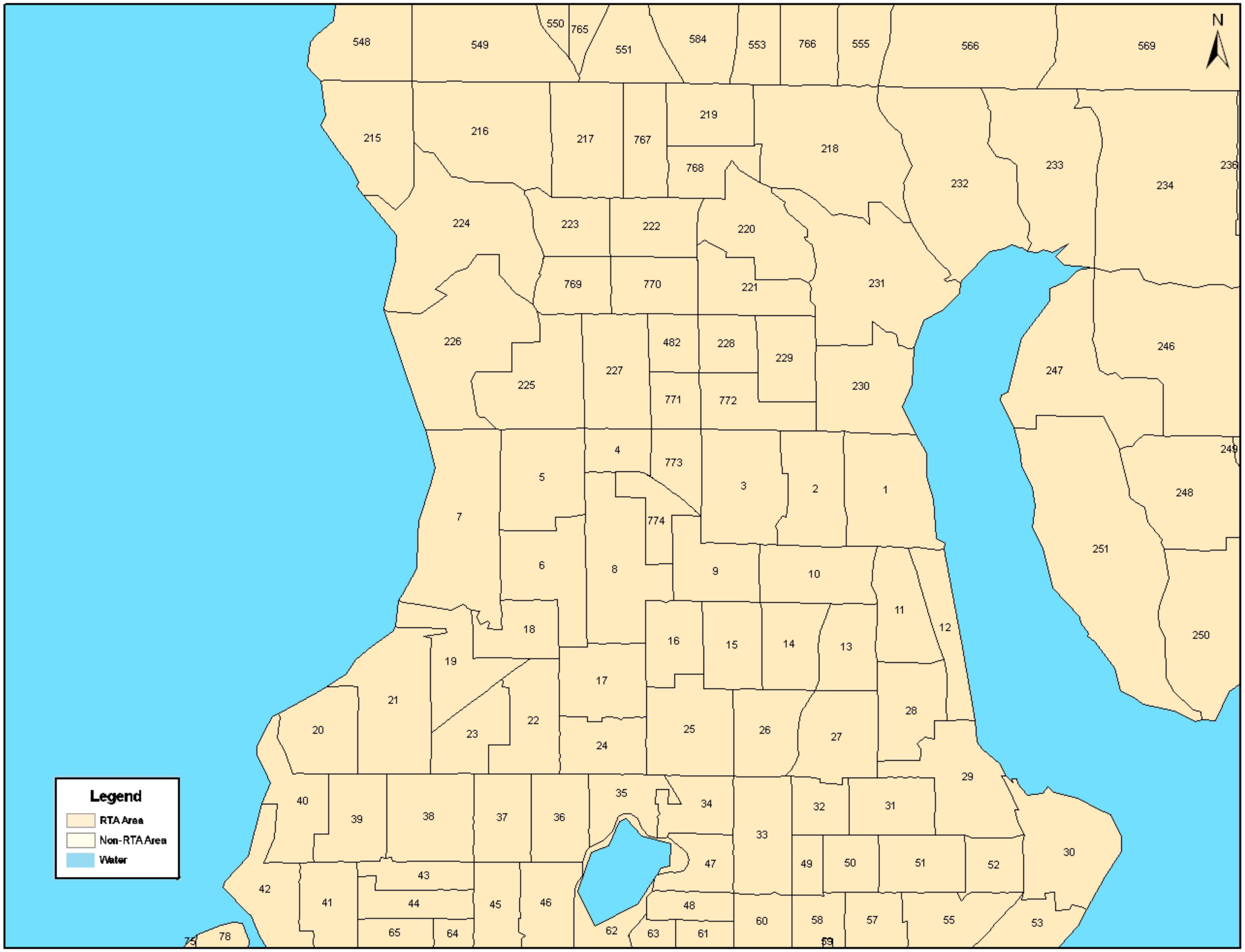


Figure A4d: 780 Zonal System—East King County

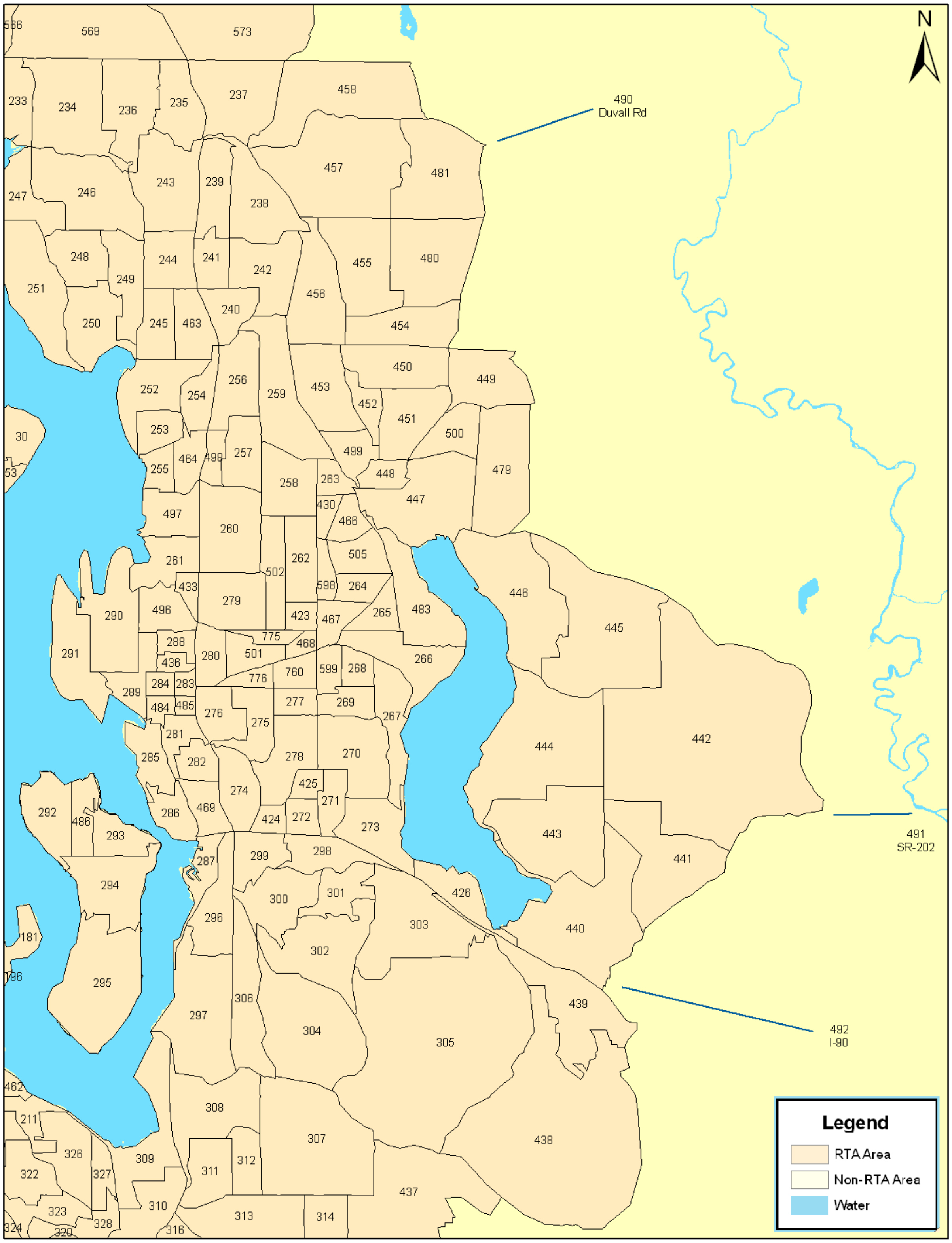


Figure A4e: 780 Zonal System—Southeast/West Seattle

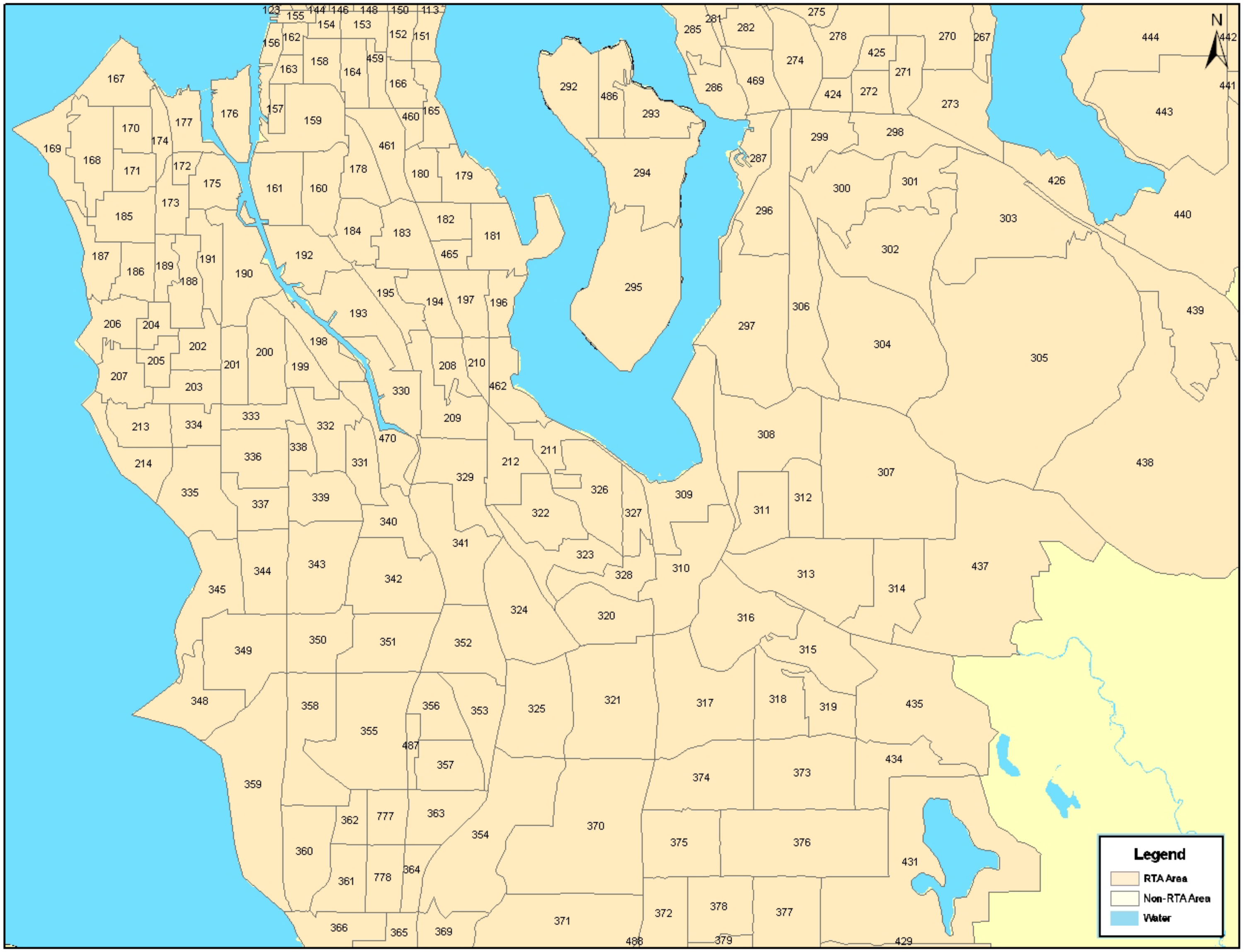


Figure A4f: 780 Zonal System—South King County

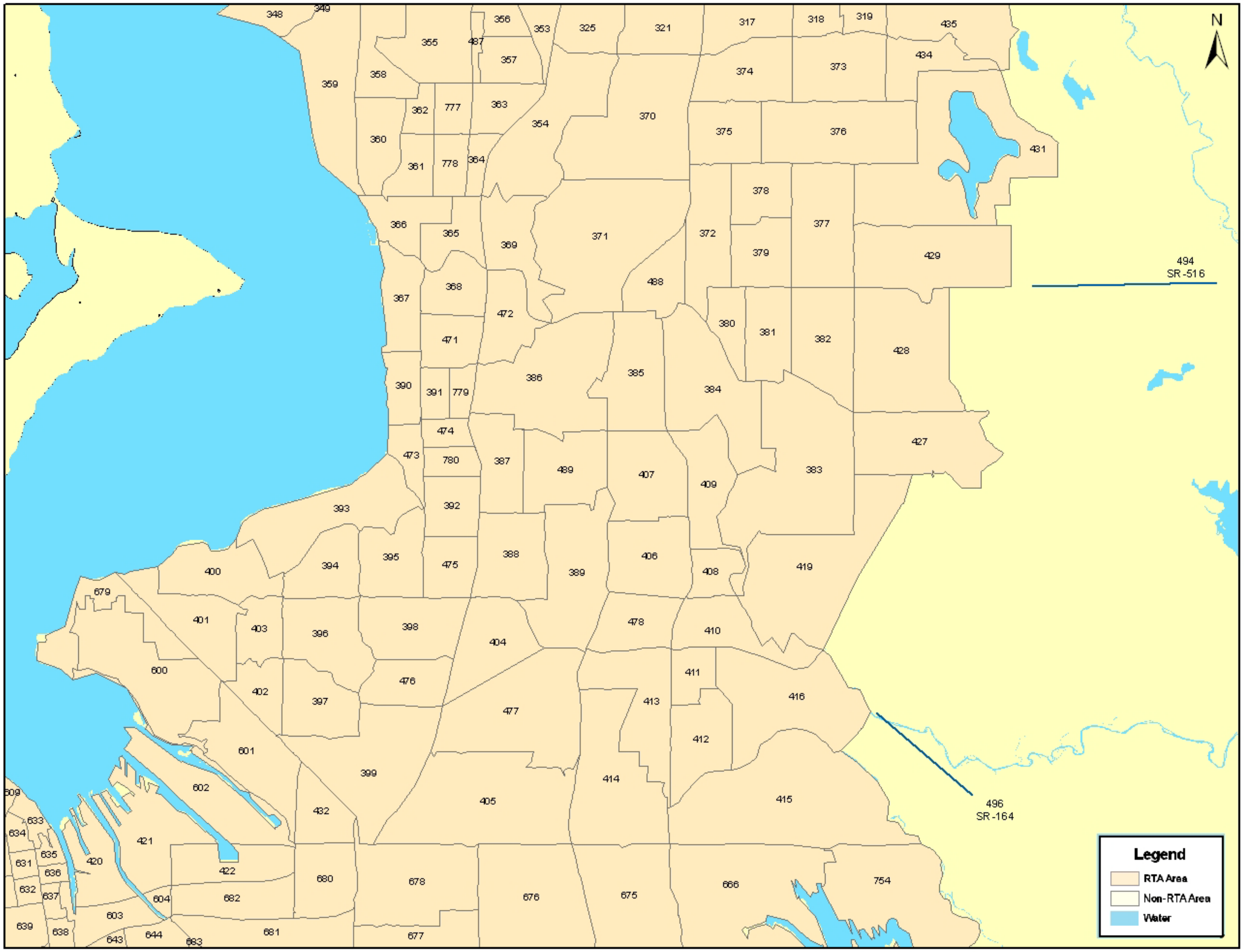


Figure A5: 780 Zonal System—Snohomish County

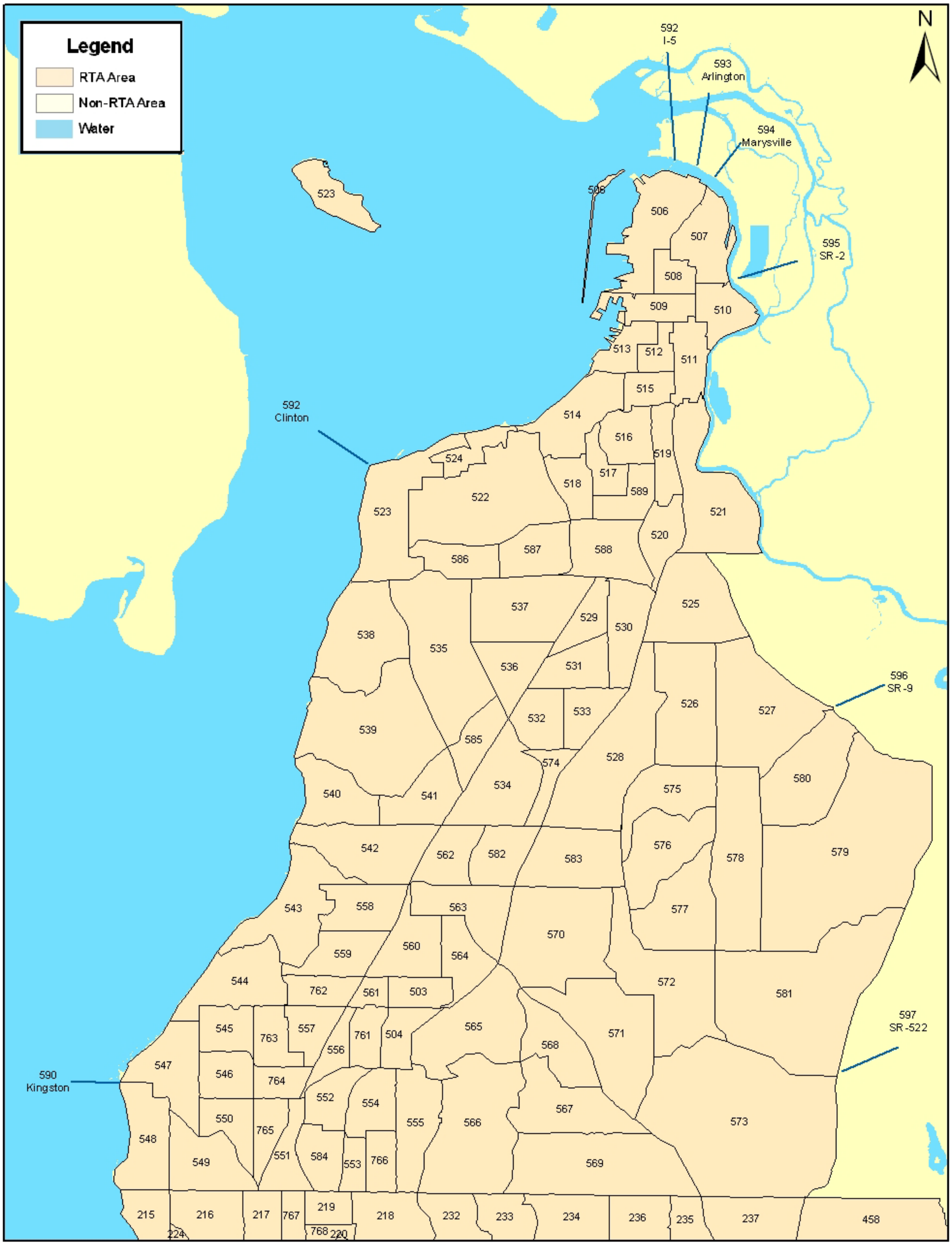


Figure A6: 780 Zonal System—Pierce County

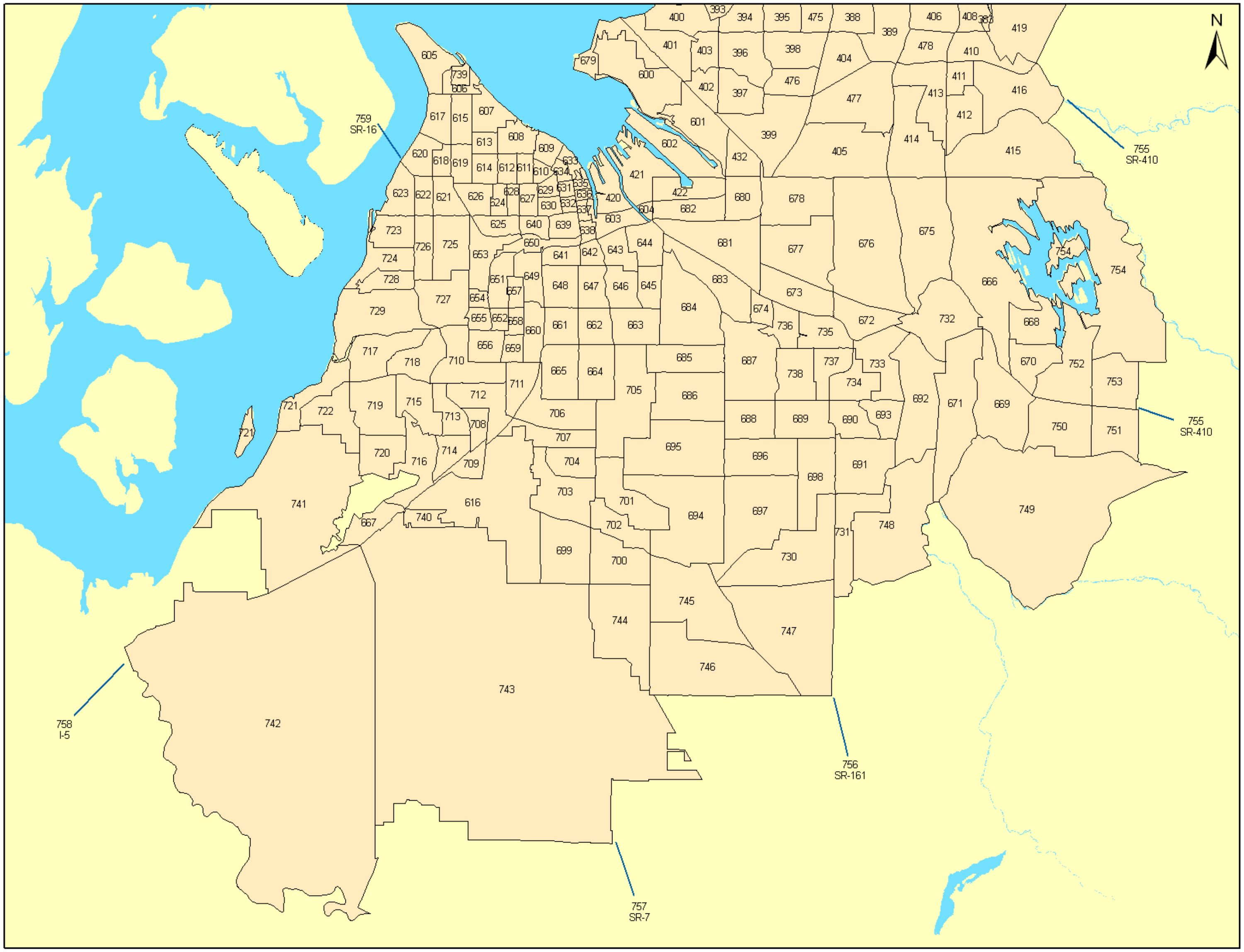


Figure A6a: 780 Zonal System—Tacoma

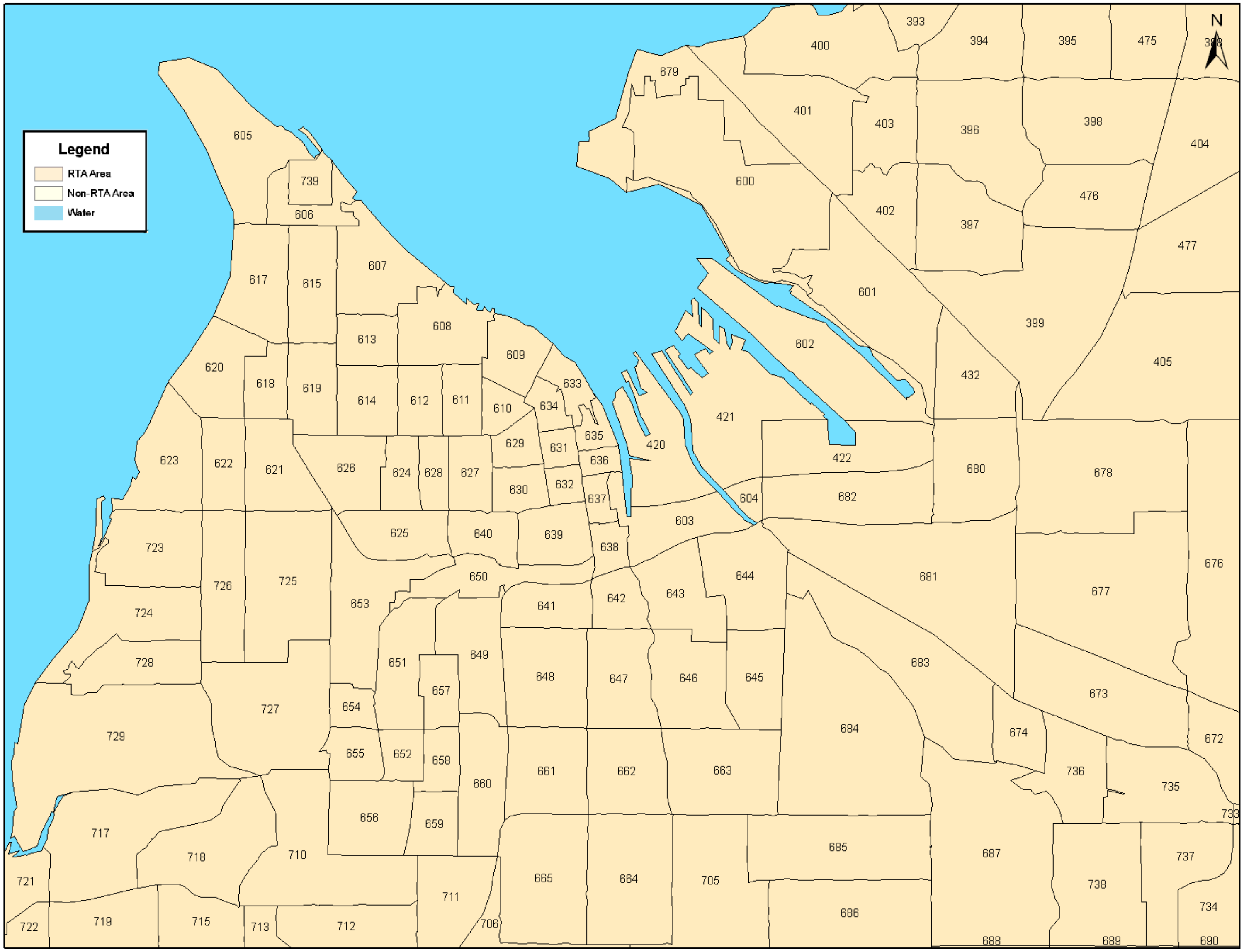


Figure A7: 27-District Boundary

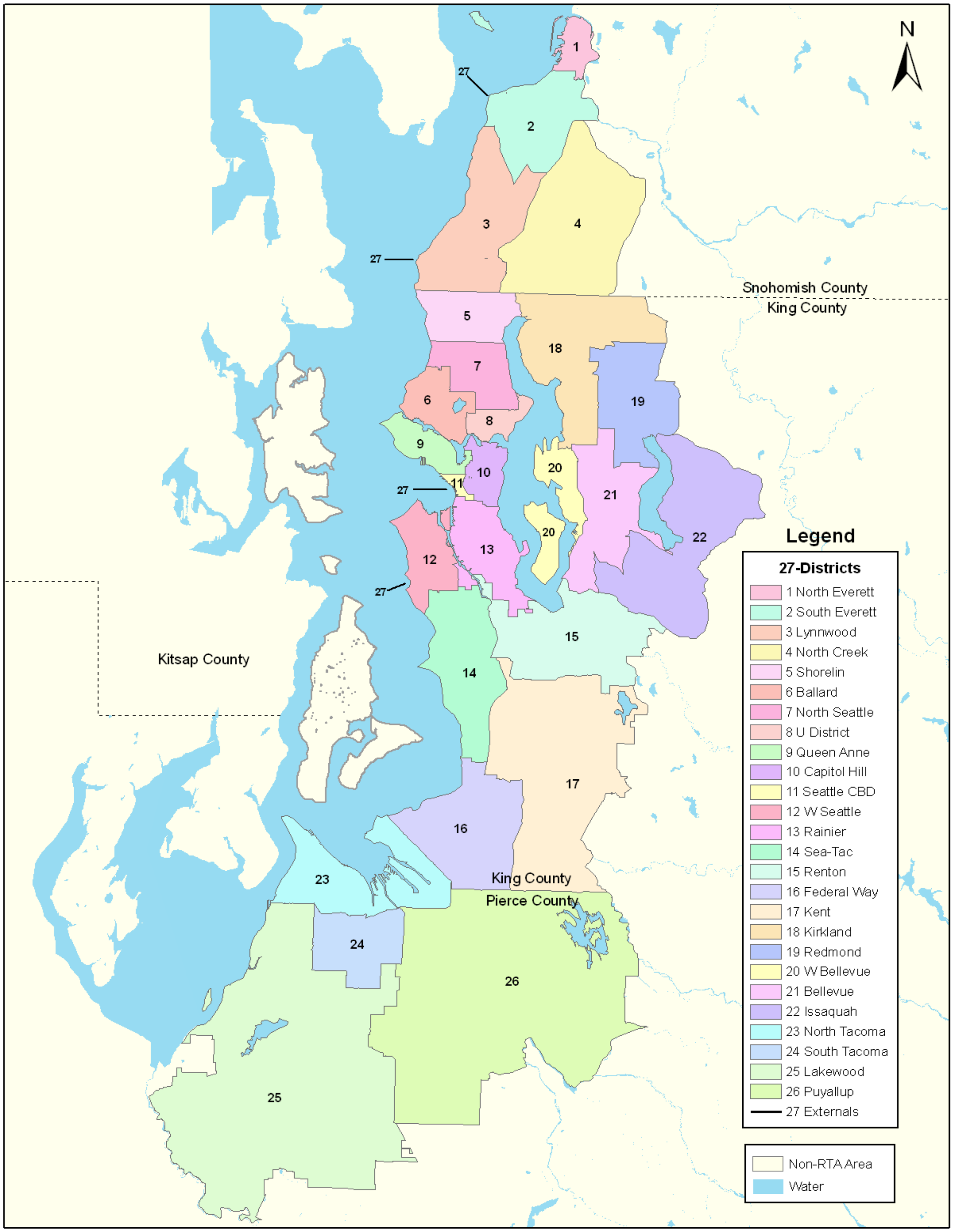


Figure A8: 11-District Boundary

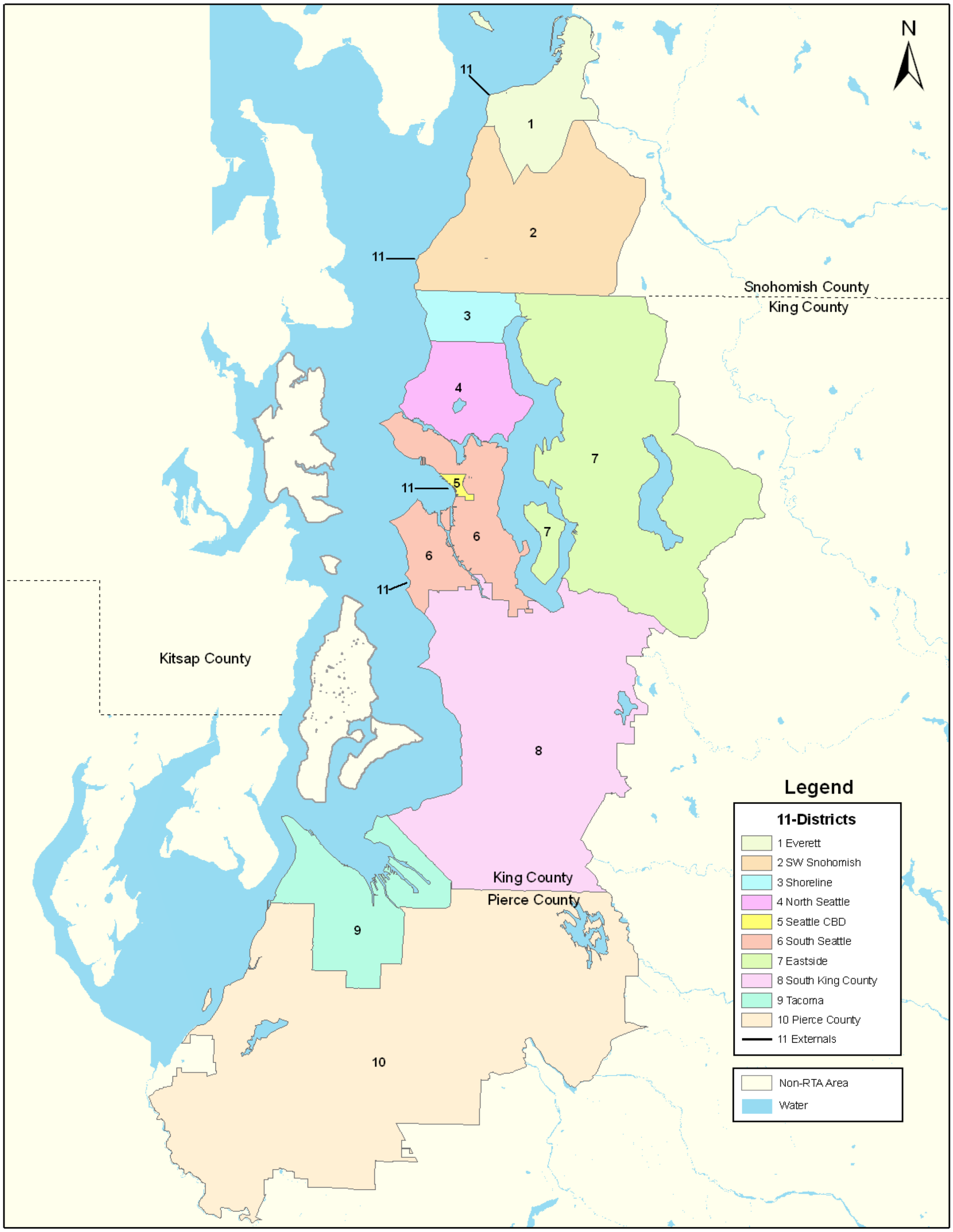
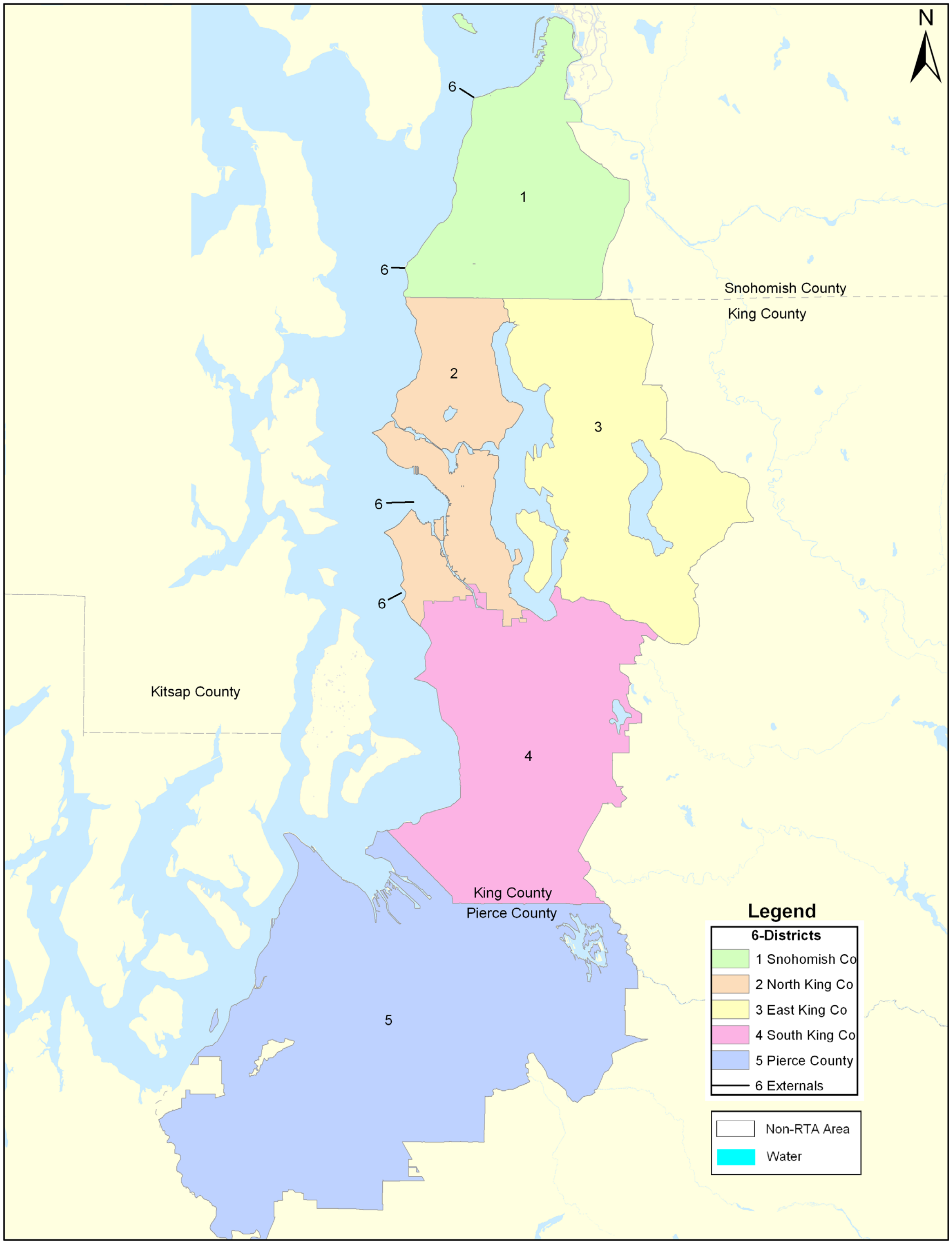


Figure A9: 6-District Boundary



Appendix B: Surveys

Appendix B: Surveys

This appendix includes a summary of the recent surveys which are available to supplement past surveys that were used in the initial development of the Sound Transit (ST) Ridership Model. The new surveys were geo-coded to the ST model alternatives analysis zonal system and analyzed to provide pertinent information in support of the ST model update (version 2012). This included information for development of the base year (2011) transit trip table, base shares, average trip length, trip purpose, and transfer rates.

B.1 Sound Transit Surveys—2003 to 2012

B.1.1 ST Survey—2003/2004

ST conducted an extensive survey of riders using Sounder Commuter trains and buses between September 2003 and May 2004. This survey yielded a variety of data, including route number, time period of trip, origin and destination locations, and an expansion factor. The data was subsequently sorted into usable and unusable records, each of which was assigned an origin and destination Alternative Analysis Zone (AAZ). Finally, expansion factors were revised to reflect the lower number of usable records.

Records were deemed unusable if they were missing x,y coordinates either for the origin or the destination. Table B1 summarizes the percentage of "usable" records.

Table B1: Usable Records

Location (Home End)	Bus	Sounder
Total records	10,386	2,618
Total usable records	6,867	1,966
% usable records	66%	75%

Some of the usable records had either an origin or destination that did not lie within the ST district but did lie within the PSRC region. These records were overlayed with the PSRC transportation analysis zones (TAZ) map and were assigned the corresponding PSRC TAZ. An equivalency table was then used to assign an appropriate external AAZ from the ST zonal system to these records. Table B2 summarizes the number of usable records by mode and time period.

Table B2: Usable Records by Mode and Time Period

Location (Home End)	Bus	Sounder
AM total records	2,470	1,243
AM usable records	1,784	985
AM % usable records	72%	79%
PM total records	3,193	1,375
PM usable records	2,130	981
PM % usable records	67%	71%
Off-peak total records	4,723	n/a
Off-peak usable records	2,953	n/a
Off-peak % usable records	63%	n/a

B.1.2 ST Survey—2009

ST conducted an extensive survey of riders using Sounder Commuter trains, ST Express bus routes, and Tacoma Link light rail in February and March 2009. Bus and commuter rail riders were surveyed between Tuesday and Thursday throughout the day, while Tacoma Link also included a Saturday survey. About 6,700 riders were approached for the survey with a total of 4,274 responding. This resulted in a response rate of 63 percent.

This survey yielded a variety of data, including route number, time period, origin and destination locations, as well as an expansion factor to expand from the surveyed sample to an average weekday. The data was subsequently sorted into usable and unusable records, each of which was assigned an origin and destination AAZ. Finally, expansion factors were revised to reflect the lower number of usable records.

Records were deemed “unusable” if they were missing x,y coordinates either for the origin or the destination. Table B3 summarizes the percentage of “usable” records. Only the records that have both origin and destination within the ST district are considered usable records.

Table B3: Usable Records

Location (Home End)	Bus	Sounder	Tacoma Link
Total records	2,771	1,078	425
Total usable records	2,027	847	186
% usable records	73%	79%	44%

The survey records were further classified based on the time of the day (TOD) the transit trip had taken place. This classification was necessary to use the survey data for ST modeling purposes. Three TODs were used for the classification purposes—AM period between 6 AM and 9 AM, PM period between 3 PM and 6 PM, and an off-peak period that represents all time periods that are not the AM or PM period. The distribution of trips for various ST services between these periods is shown in Table B4.

Table B4: Usable Records by Mode and Time Period

Location (Home End)	Bus	Sounder	Tacoma Link
AM period (6 AM to 9 AM)	593	208	20
PM period (3 PM to 6 PM)	368	216	34
Off-peak period	1,066	423	132
Total daily	2,027	847	186

B.1.3 ST Survey—2011

Sound Transit conducted a survey in October and November 2011 on weekdays during peak and off-peak periods. This survey was in support of the FTA Before-and-After Study for the Initial Segment light rail project. A sample of riders on Link light rail and King County Metro buses was surveyed. For each sampled trip, survey staff attempted to approach all passengers to distribute a survey form. Passengers could return the survey on-board, through postal mail, or complete a web-based survey. One component of the study was to investigate ridership characteristics of the project. To study these characteristics, ST undertook an on-board passenger survey to collect data about passenger trip characteristics, such as origins, destinations, fare payment, transfers, etc. This survey was processed and geo-coded to the ST model zonal system for further analyses that included opening of additional new cells in the base year trip tables.

Like the 2009 survey, the data contained information, including expansion factors to expand the dataset to represent an average weekday. Only unweighted records were used, since this expansion is performed through the matrix estimation process based on actual segment counts. Records were deemed "unusable" if they were missing x,y coordinates either for the origin or the destination. Additional analysis also resulted in rejection of some records if they did not meet certain criteria for reasonability. Records were also deemed unusable if either the origin or destination was not within the ST district. Table B5 summarizes the percentage of "usable" records.

Table B5: Usable Unweighted Records

Location (Home End)	Records
Total records	12,978
Total usable records	8,737
% usable records	67%

The survey records were further classified based on the time of day (TOD) the transit trip had taken place. This classification was necessary to use the survey data for ST modeling purposes. Three TODs were used for the classification purposes—AM period between 6 AM and 9 AM, PM period between 3 PM and 6 PM, and an off-peak period that represents all time periods that are not the AM or PM period. The distribution of trips for various ST services between these periods is shown in Table B6.

Table B6: ST 2011 Usable Unweighted Records by Time Period

Location (Home End)	Records
AM period (6 AM to 9 AM)	2,033
PM period (3 PM to 6 PM)	2,384
Off-peak period	4,320
Total daily	8,737

B.1.4 ST Survey—2012

ST completed on-board surveys on ST bus routes, Sounder Commuter Rail, and Tacoma Link light rail in February 2012. These surveys were performed on two weekdays and one weekend day. The processed and geo-coded survey data for the Tacoma Link light rail was available for further analyses that included opening of additional new cells in the base year trip tables.

Similar once again to the 2009 ST Survey, the data contained information, including expansion factors to expand the dataset to represent an average weekday. However, only unweighted records were used, since this expansion is performed through the matrix estimation process based on actual segment counts. Records were deemed "unusable" if they were missing x,y coordinates either for the origin or the destination. Additional analysis also resulted in rejection of some records if they did not meet certain criteria for reasonability, and records were also unusable if either the origin or destination was not within the ST district. Both weekday and weekend records were used. Table B7 summarizes the percentage of "usable" records.

Table B7: Usable Unweighted Records

Location (Home End)	Records
Total records	658
Total usable records	415
Total usable weekday records	295
% usable records	45%

The survey records were further classified based on the time of the day (TOD) the transit trip had taken place. This classification was necessary to use the survey data for ST modeling purposes. Three TODs were used for the classification purposes—AM period between 6 AM and 9 AM, PM period between 3 PM and 6 PM, and an off-peak period that represents all time periods that are not the AM or PM period. The distribution of trips for various ST services between these periods is shown in Table B8.

Table B8: ST 2012 Usable Unweighted Records by Time Period

Location (Home End)	Records
AM period (6 AM to 9 AM)	83
PM period (3 PM to 6 PM)	85
Off-peak period	127
Total daily	295

B.2 Commute Trip Reduction Surveys—2007 to 2011

In 1991, Washington State enacted the Commute Trip Reduction (CTR) Law as part of the Clean Air Act in order to encourage alternatives to drive-alone commuting. This law requires employers with over 100 employees to develop and implement a CTR plan. In order to measure employer and regional progress toward the stated goal of reducing single-occupant vehicle (SOV) trips, the CTR survey was developed to collect data about commute patterns and measure progress of each company toward its goals as well as area-wide goals. This survey is performed biannually for each employer, and the results are stored and analyzed by the Washington State Department of Transportation (WSDOT). This rich data source is unique to Washington State and is attractive as a replacement data source for the U.S. Census Journey-to-Work (JTW) survey, which is no longer performed.

B.2.1 CTR Survey Data Collection

Employers subject to the CTR law are required to have their employees complete the CTR survey every other year. However, surveys are not done at the same time for all employers given the large number of respondents, so surveys are staggered over the two-year period. The survey asks employees whether or not they commuted to work on each day of an ordinary work week (no public holidays during the week prior to or during the survey week) and, if so, what mode was primarily used for travel to work. The survey also asks respondents to estimate their one-way travel distance to work and provide their home zip code as well as answer questions about carpooling, paid parking, and drive-alone commuting. The CTR data is collected by each county but ultimately resides in a database maintained by WSDOT and is freely available for public use.

B.2.2 Analysis Process

CTR data was requested for King, Snohomish, and Pierce counties for several survey cycles: 2007-2008, 2009-2010, and the 2011 portion of the 2011-2012 survey cycle. The 2011 data only included information from King County, as most employers in Pierce and Snohomish Counties are surveyed in the second year of each survey cycle. The general approach was to use survey responses to build an origin-destination (O-D) table for all commuters as well as the transit travel flow matrix. Unlike former data sources, such as JTW census survey where the home address is known and the workplace location is vague, the CTR dataset is unique in that the workplace addresses are well-known, but respondent home addresses are only at the ZIP code level. To disaggregate home ZIP codes to TAZs, trips occurring at the ZIP code level were disaggregated based upon the distribution of households over the ZIP code, implying an assumption of similar travel characteristics between households in a ZIP code. Household information at the census block level was used to perform this disaggregation in ArcGIS through geospatial analysis. Workplaces were also mapped by their coordinates (provided by WSDOT) in ArcGIS to determine within which TAZ each worksite is located, thus obtaining the destination TAZ. Individual survey responses were then used to fill the O-D table for a typical workday.

This data is used to enrich base year transit trip tables to include new non-zero cells as well as a new database on which to rely to establish base transit shares. Since results from several survey cycles were used, elimination of repeated observations was important. Generally, the latest survey cycle was used for each employer while discarding most survey results from previous cycles. However, previous cycles with response ZIP codes that were not observed in later survey cycles are preserved since they represent unique trips that were not observed. This is done to maximize the number of non-zero cells in the O-D table. This is considered reasonable since it is likely that such ZIP codes went unobserved in subsequent years because the respondent moved but remained with the same employer or the respondent transferred employers. In either case, the travel characteristics for each trip are different given the different origin and/or destination, so it is no longer a repeated observation.

B.2.3 General Results

The 2007-2008 CTR dataset had a total of 224,802 records, the 2009-2010 CTR dataset had a total of 270,295 records, and the 2011 dataset had 138,748 records. All of the 2011 survey responses used are from King County, as most Snohomish and Pierce County employers will be surveyed in 2012. However, as mentioned previously regarding the avoidance of double-counting, the combined dataset from 2007-2011 is less than the sum of all the observations (285,275 records). Other data cleaning due to invalid employer ID or ZIP codes and non-commuter responses further decreased the number of records. Table B9 provides results for the analysis of the 2007-2011 combined dataset. Non-motorized modes, such as walking and biking, were removed from consideration as commute modes in order to be consistent with the ST model. This shows that in the Puget Sound region, the overall transit mode share (excluding non-motorized trips as commute trips) for CTR survey respondents is 20.3 percent.

Table B9: Summary of Surveyed CTR Commute and Transit Travel

	All Commute Modes	Non-Motorized Modes	Commute Modes (excluding Non-motorized)	Transit Mode
Total surveyed CTR trips	1,158,137	42,659	1,115,478	226,277
Average weekday surveyed CTR trips	231,627	8,532	223,096	45,255
Surveyed trips allocated to O-D table	971,423	38,291	933,132	200,934
Average weekday allocated trips	194,285	7,658	186,626	40,187
% surveyed trips not allocated to O-D table	16.12%	10.24%	16.35%	11.20%

Transit is defined as bus, train, light rail, streetcar, or walking on a ferry

B.3 American Community Surveys—2006-2008

The U.S. Census JTW data was provided as part of the Census Transportation Planning Package (CTPP), put together using the Census Bureau long form survey. From 2010 onwards, the Census long form has been replaced by the American Community Survey (ACS). The ACS provides up-to-date planning data for communities on an annual basis. Every month, the ACS is distributed to a sample of residences around the country—about 1 in 40 households annually. From the survey responses, the Census Bureau produces three ACS data series: ***one-year, three-year, and five-year estimates***. ACS data are accumulated and released once a year for large geographic places (those with 65,000 people or more). Further information about ACS can be found in a document provided by PSRC.[1]

The FHWA has used the ACS to extract one-year and three-year JTW worker flow estimates for 2008. The three-year worker flow estimates are provided only at the County or the Census Place geographies from "Home-to-Work." These geographies are at an aggregate level and cannot be directly used to calculate TAZ level base year transit shares. Note that home-to-work flows for the ACS five-year estimates are not yet available.

Upon further examination and analyses, transit shares produced from the currently available ACS three-year estimates deemed to be useful as long as an appropriate geographic aggregation level was maintained to minimize sampling error. Transit shares calculated at the 5-district level were significant at the 90-percent significance level. District-level shares from ACS data were used to scale the zonal transit shares from the CTR survey.

[1] http://psrc.org/assets/1030/ACS_User_s_Guide_Dec-08.pdf

B.4 Survey of SR 520 Riders—2005

A special survey of SR 520 riders was conducted by Northwest Research Group, Inc., in May 2005. This survey provided 944 usable O-D records, of which 217 zone-pairs were not represented before in other surveys.

B.5 PSRC Household Activity and Travel Survey—2006

In 2006, PSRC undertook a survey to obtain region-wide information on household activities and the travel these activities generate. It surveyed about 4,700 households during a consecutive 48-hour time period.

B.6 ORCA Smart Card Fare Payment Database

The ORCA card is a smart card technology to allow transit users to easily pay fares by tapping the card against an electronic card reader. The card enables seamless transfers between transit systems thanks to revenue-sharing agreements between transit agencies in the region. Transit users are incentivized to use the card instead of cash since they receive free or discounted transfers between agencies only if they use an ORCA card. The ORCA card allows for enhanced data collection as well, since the particular route, time of boarding, and transfers are logged; additionally for rail, the boarding and alighting locations are also logged.

The ORCA database is expected to provide useful information for the ST model update. This dataset can be used to provide insights into the percentage of transfers, both at a systemwide level as well as for particular agencies or technologies (e.g., transfers to and from Link light rail and Washington State Ferries). ORCA information can also be used to augment O-D information used to develop the seed matrix for ridership forecasting by noting the origin and destination of each rail trip. Finally, the ORCA dataset provides a partial illustration of revealed transit ridership against which the model results may be compared in order to implement refinements to the model.

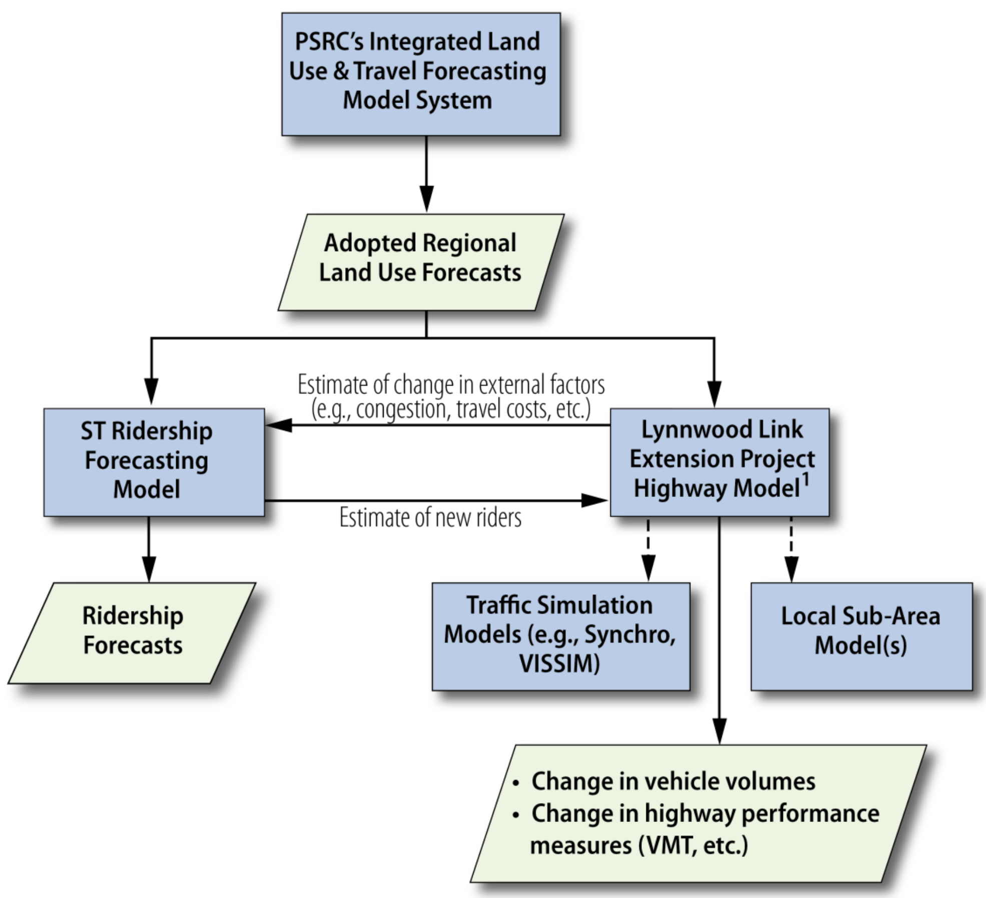
Appendix C: Highway Model

- ***Overview***
- ***Network Refinements***
  - ***Base Year***
  - ***Future Baseline***
- ***Validation Results***

Appendix C: Highway Model

The Sound Transit (ST) Lynnwood Link Extension Highway model provides key inputs into the ST model. It also provides key performance measures, as highlighted in Figure C1, which shows the relationship between the ST model and highway model, along with other related processes. This appendix discusses the background of this highway model and highlights efforts to improve the results from the model to best reflect observed conditions and provide quality inputs into the ST model. This includes presentation of some base year validation results.

Figure C1: ST Ridership and Lynnwood Link Extension Highway Models Relationship



[1] The Lynnwood Link Extension Project Highway Model is based on the version of the PSRC regional model used for major WSDOT projects (e.g., SR 520 FEIS), with additional network refinements.

C.1 Overview

The Lynnwood Link Extension Highway Model is based on the model used for the SR 520, I-5 to Medina: Bridge Replacement and HOV Project Final EIS. Experience from the modeling of the Alaskan Way Viaduct (AWV) and Seawall Replacement Program as well as observations and data regarding the operation of facilities in the North Corridor area have provided insight to guide enhancements to the model for the Lynnwood Link Extension.

The SR 520 model is based on the most recent version of the region's planning model, PSRC model version 1bb. Development of the PSRC model is documented in *PSRC Travel Model Documentation (for Version 1.0), Updated for Congestion Relief Analysis* (PSRC 2007b). This version of the PSRC model has been adopted by WSDOT for use on several projects, including environmental impact analyses and other planning/tolling studies. The SR 520 model was developed to incorporate network and procedure modifications that were used in other local modeling efforts in Seattle, Bellevue, Kirkland, and Redmond. These updates allowed this model to represent traffic conditions with relative accuracy, particularly conditions on I-90 and SR 520 across Lake Washington and other facilities that connect to them. Further detail on the model development and validation are documented in *SR 520 Bridge Replacement and HOV Program Final FEIS Travel Demand Model: Base Year Validation Analysis Tech Memo* (Parsons Brinckerhoff 2010). The SR 520 model has also been used by WSDOT for various toll studies, including SR 167, SR 509, and I-5 express lanes.

The model used for the AWV Replacement Project Final EIS is based on the City of Seattle model, which is also based on the most recent version of the PSRC model. This model contains greater detail of the highway network and zones within the City of Seattle. Nearly a decade's worth of knowledge learned from demand modeling, operational analysis, and field observations allowed this model to perform quite well, particularly for downtown Seattle and surrounding areas. Details on the model development and validation are documented in *Alaskan Way Viaduct & Seawall Replacement Program Travel Demand Model Refinement and Validation Report* (2010).

As part of the ongoing analysis for the SR 99 tunnel toll traffic and revenue analysis, a Dynamic Traffic Assignment (DTA) model has been created to analyze traffic and revenue that would be affected by tolling of the new tunnel. The mesoscopic DTA model provides a level of detail between a demand model and operational models, while still using the zonal system from the City of Seattle model.

Using the above model background information, the Lynnwood Link Extension Highway model incorporated network attributes and model procedures that would provide the best representation of travel conditions within the North Corridor study area and other areas served by Link light rail. In addition to knowledge provided from these models, additional review of network attributes and existing roadway conditions was performed in proximity to the Lynnwood Link Extension area to provide additional updates that might not necessarily have been included in the focus of other recent modeling efforts.

C.2 Network Refinements

C.2.1 Base Year

Highway Network

While many adjustments to Central Seattle and major facilities across Lake Washington had been made as part of the SR 520 Final EIS and the AWV Final EIS, additional changes were made throughout the model, including within the North Corridor study area, to better reflect congestion for automobiles and transit. To better reflect existing roadway configurations, the model link attributes

were compared to actual conditions. Appropriate adjustments to speed, capacities, and congestion factors were made accordingly including, but not limited, to the following:

- **Arterial Speeds**—The model free-flow speeds were compared to the posted speeds from North Seattle to Lynnwood, and model speeds were adjusted to match those legal speeds.
- **Arterial Capacities**—Arterials from North Seattle to Lynnwood were reviewed for unusually high or low lane unit capacities, and a check was performed for the number of lanes. Capacity assumptions were decreased at some locations, particularly where signalized intersections would constrain capacities, as also reflected in the observed traffic counts. Capacities for other facilities were increased in conjunction with recent lane changes and roadway rechannelizations. The numbers of lanes were adjusted to match actual roadway configurations, including time-of-day parking restrictions.
- **Freeway Capacities**—Freeway capacities were reduced by up to 200 vehicles per hour per lane region-wide to better reflect maximum observed traffic counts. This was performed in areas where this had not already been performed for the project EIS work for WSDOT described above.
- **Reversible Lanes**—The reversible lanes on I-5 have greater observed peaking characteristics and low usage in off-peak periods while also frequently having one or two congested lanes with adjacent lanes operating at free-flow speeds. The model volume delay function for this facility was adjusted to reflect both peaking and how speeds change at different volume levels than the I-5 mainline.

Transit Network

The base year transit network in the ST model was used as a guide to update the base transit network in the Lynnwood Link Extension Highway model.

Additional Refinements

In addition to refinements to the base year network, a number of other refinements were made to the SR 520 model. These refinements include:

- **Time-of-Day Functionality**—The PSRC relies on a choice-based time-of-day procedure. This procedure has been oversensitive for corridors where congestion reaches an oversaturation condition, such as the cross-lake and North Corridor market areas. For example, trips in higher volume corridors shift from the morning period to the night period. For the purpose of mitigating oversensitivity to congestion and thus having a more stable highway model, the choice-based time-of-day procedure was replaced with the traditional time-of-day constant factors. This change in the highway model is believed to provide better estimates of deltas in congestion level and highway performance measures (such as vehicle-hours of travel and vehicle-miles of travel) as required for the interface with the ST model. This change is also consistent with the SR 520 FEIS model and better reflects observed vehicle volumes. Use of this model for other WSDOT projects has mostly relied on the PSRC variable time-of-day procedure.
- **Peak Hour Factors**—A comparison of observed peak hour counts to peak period model volumes showed different peaking characteristics in the NTCP area than closer to Seattle or across Lake Washington. Therefore, the peak hour factors in the model volume delay functions were adjusted to reflect observed counts. While the factors were different in the SR 520 FEIS model, that model included factors that reflected peaking within that project's study area.

- **HOV Cost Sharing**—Traditionally, regional models assume that travel costs are split equally among occupants for vehicles with two or more occupants. This assumption was modified in the Lynnwood Link Extension Highway model to reflect anecdotal observations that travel costs may not be equally shared among family members who travel together in one vehicle. Travel costs are split based on using *1/ln(1+average number of occupants)*[1] for both work and non-work trip purposes. Specifically, total travel costs is factored by 0.91 for two-occupant auto vehicles, 0.66 for auto vehicle with three or more occupants, and 0.88 for auto vehicles with two or more occupants.

C.2.2 Future Baseline

The future baseline for the highway model includes several major and minor highway and transit projects that will be constructed and operating during the future year. Projects that are planned, but not funded, were not included in the model. A single baseline network is used in the Lynnwood Link Extension for the no-build and build alternatives since none of the build alternatives affect the design of any roadways and there are no surface rail alternatives being considered for the rail line.

Highway Projects

Several major highway projects were included in the future baseline highway model. The majority of these include the SR 99 Tunnel in downtown Seattle, SR 520 Bridge replacement and widening across Lake Washington, Mercer Street corridor reconstruction just north of downtown Seattle, and the Spokane Street viaduct widening just south of downtown Seattle.

Transit Projects

Rail and bus changes were also included in the future baseline highway model. The future model assumes that the ST Link light rail network extends from Kent-Des Moines Road in the south to Lynnwood Transit Center in the north and Overlake Transit Center to the east. Bus routes and frequencies were adjusted to reflect updated connections to light rail service as well as RapidRide BRT service as part of King County's Transit Now program. Additionally, the First Hill streetcar in Central Seattle is included.

Demographic Forecasts

The ST North Corridor Highway model uses the most recent PSRC-adopted land use forecasts. The next land use forecast update is expected to be approved in June 2012.

C.3 Validation Results

The focus of the validation analysis was to improve the Highway model's performance for areas critical to the Lynnwood Link Extension.

Screenline Total Vehicle Volumes Comparison

Model-estimated vehicle volumes were compared to recent observed traffic counts on arterials and highways in and near the Lynnwood Link Extension study area. The screenlines that were used are shown on the map in Figure C2. As seen in Table C1 though Table C3, the estimated screenline total volumes are within 10 percent of observed during the peak hours and over the entire day.

[1] Dehghani, Y., Adler, T., et al, "Development of New Toll Mode Choice Modeling System for Florida's Turnpike Enterprise," Transportation Research Board Record #1858, 2003.

Figure C2: Highway Screenlines Map

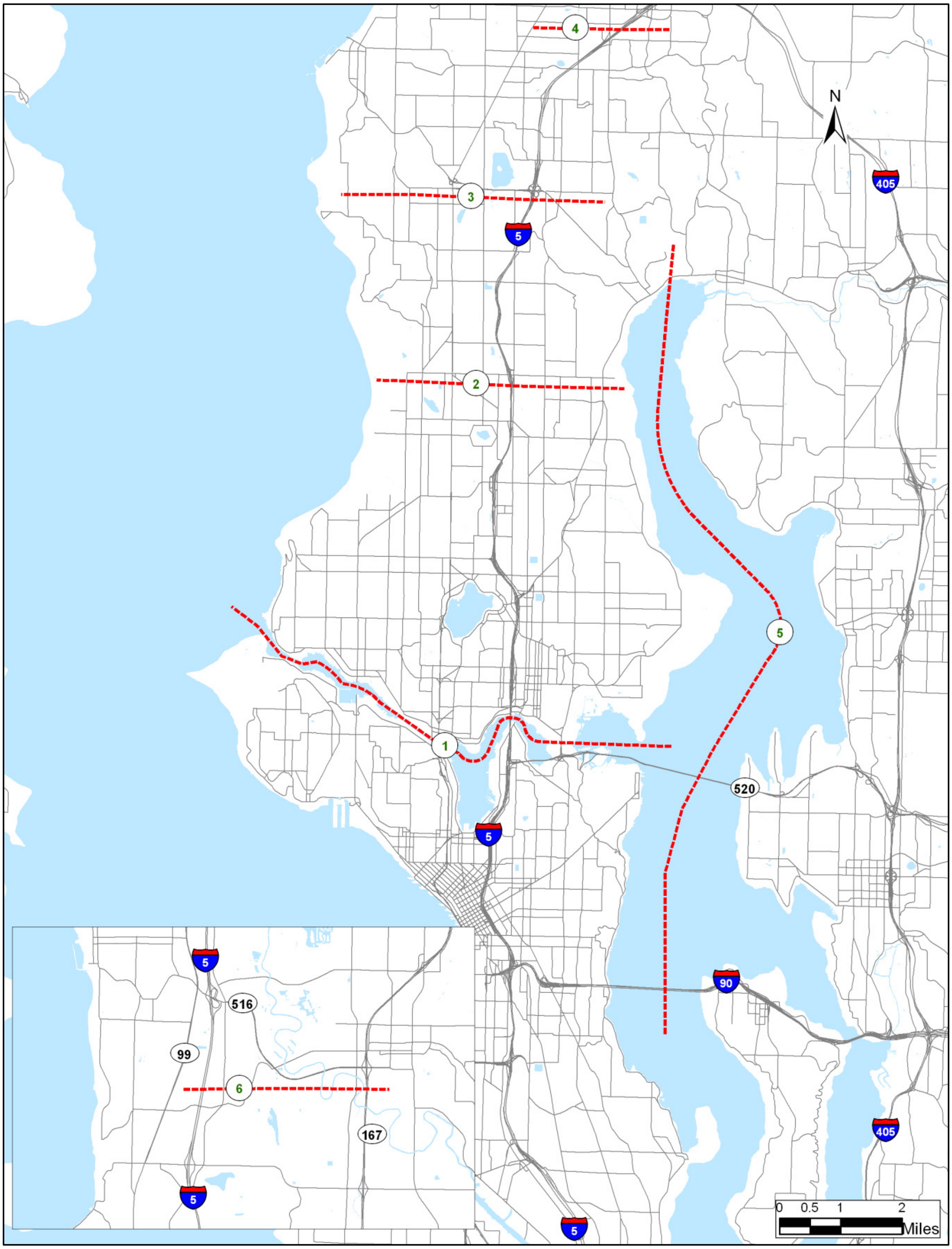


Table C1: Base Year (2011)Total Vehicle Volume Screenline Comparison (AM peak hour)

	Actual Volumes			Estimated Volumes			
	NB/WB	SB/EB	Total	NB/WB	SB/EB	Total	Est/ Act
Screenline 1 - Ship Canal							
Ballard Bridge	1,840	2,950	4,790	1,000	2,200	3,200	0.67
Fremont Bridge	840	1,030	1,870	1,300	2,100	3,400	1.82
SR 99	2,540	4,740	7,280	2,100	4,500	6,600	0.91
I-5 GP	6,670	7,230	13,900	7,000	8,100	15,100	1.09
I-5 Express Lanes	NA	5,810	5,810	NA	5,500	5,500	0.95
University Bridge	1,050	1,740	2,790	900	1,500	2,400	0.86
Montlake Bridge	1,930	1,700	3,630	2,200	2,000	4,200	1.16
Screenline Total			**40,070**			**40,400**	**1.01**
Screenline 2 – South of N 145th Street							
3rd Avenue NW	330	360	690	0	400	400	0.58
Greenwood Avenue N	640	1,290	1,930	600	1,400	2,000	1.04
SR 99	1,090	1,400	2,490	400	2,300	2,700	1.08
Meridian Avenue N	120	280	400	0	400	400	1.00
I-5 GP	4,980	7,540	12,520	4,700	7,900	12,600	1.01
I-5 HOV	290	1,600	1,890	0	1,800	1,800	0.95
5th Avenue NE	270	240	510	300	700	1,000	1.96
15th Avenue NE	360	850	1,210	300	1,400	1,700	1.40
20th Avenue NE	80	80	160	0	100	100	0.63
30th Avenue NE	200	320	520	0	600	600	1.15
SR 522	980	1,870	2,850	1,000	2,200	3,200	1.12
Screenline Total			**25,170**			**26,500**	**1.05**
Screenline 3 – South of N 205th Street/ 244th Street SW							
8th Avenue NW	-	-	-	100	400	500	-
3rd Avenue NW	-	-	-	300	700	1,000	-
Fremont Avenue N	-	-	-	0	500	500	-
SR 99	-	-	-	1,000	2,400	3,400	-
Meridian Avenue N	-	-	-	400	1,000	1,400	-
1st Avenue NE	-	-	-	0	500	500	-
5th Avenue NE	-	-	-	0	500	500	-
I-5 GP	-	-	-	4,000	6,300	10,300	-
I-5 HOV	-	-	-	0	1,800	1,800	-
15th Avenue NE	-	-	-	300	700	1,000	-
SR 104	-	-	-	600	400	1,000	-
19th Avenue NE	-	-	-	100	700	800	-
Screenline Total			-			**22,700**	-
Screenline 4 – South of 196th Street SW							
44th Avenue W	600	760	1,360	600	1,200	1,800	1.32
I-5 GP	4,510	5,370	9,880	3,700	6,000	9,700	0.98
I-5 HOV	350	1,280	1,630	0	1,700	1,700	1.04
Screenline Total			**12,870**			**13,200**	**1.03**
Screenline 5 – Midlake							
SR 522	1,210	1,950	3,160	1,800	1,900	3,700	1.17
SR 520	3,850	4,180	8,030	4,300	3,900	8,200	1.02
I-90 GP	5,590	5,690	11,280	5,900	4,900	10,800	0.96
I-90 HOV	1,740	NA	1,740	1,400	NA	1,400	0.80
Screenline Total			**24,210**			**24,100**	**1.00**
Screenline 6 – South of SR 516 (Kent-Des Moines Road)							
I-5 GP	7,610	4,450	12,060	8,600	4,000	12,600	1.04
I-5 HOV	1,600	440	2,040	1,900	100	2,000	0.98
SR 167 GP	4,000	3,000	7,000	4,700	2,800	7,500	1.07
SR 167 HOV	800	350	1,150	2,000	100	2,100	1.83
Screenline Total			**22,250**			**24,200**	**1.09**

Table C2: Base Year (2011) Total Vehicle Volume Screenline Comparison (PM peak hour)

	Actual Volumes			Estimated Volumes			
	NB/WB	**SB/EB**	**Total**	**NB/WB**	**SB/EB**	**Total**	**Est/ Act**
Screenline 1 - Ship Canal							
Ballard Bridge	3,200	2,010	5,210	2,200	1,700	3,900	0.75
Fremont Bridge	1,490	1,140	2,630	2,100	1,800	3,900	1.48
SR 99	4,800	3,650	8,450	4,800	3,800	8,600	1.02
I-5 GP	7,450	6,860	14,310	7,300	7,600	14,900	1.04
I-5 Express Lanes	5,000	NA	5,000	5,700	NA	5,700	1.14
University Bridge	1,570	1,740	3,310	1,800	1,700	3,500	1.06
Montlake Bridge	2,330	1,950	4,280	2,100	2,200	4,300	1.00
Screenline Total			**43,190**			**44,800**	**1.04**
Screenline 2 – South of N 145th Street							
3rd Avenue NW	490	350	840	400	0	400	0.48
Greenwood Avenue N	1,340	870	2,210	1,300	900	2,200	1.00
SR 99	1,630	1,220	2,850	2,100	1,300	3,400	1.19
Meridian Avenue N	430	200	630	500	100	600	0.95
I-5 GP	7,500	5,500	13,000	7,400	5,400	12,800	0.98
I-5 HOV	1,560	690	2,250	1,500	500	2,000	0.89
5th Avenue NE	400	180	580	800	400	1,200	2.07
15th Avenue NE	910	550	1,460	1,300	600	1,900	1.30
20th Avenue NE	110	70	180	200	100	300	1.67
30th Avenue NE	470	230	700	500	100	600	0.86
SR 522	1,750	1,250	3,000	2,000	1,600	3,600	1.20
Screenline Total			**27,700**			**29,000**	**1.05**
Screenline 3 – South of N 205th Street/ 244th Street SW							
8th Avenue NW	-	-	-	400	200	600	-
3rd Avenue NW	-	-	-	600	400	1,000	-
Fremont Avenue N	-	-	-	500	0	500	-
SR 99	-	-	-	2,300	1,800	4,100	-
Meridian Avenue N	-	-	-	1,000	800	1,800	-
1st Avenue NE	-	-	-	500	0	500	-
5th Avenue NE	-	-	-	500	0	500	-
I-5 GP	-	-	-	5,800	4,600	10,400	-
I-5 HOV	-	-	-	1,600	500	2,100	-
15th Avenue NE	-	-	-	700	400	1,100	-
SR 104	-	-	-	500	500	1,000	-
19th Avenue NE	-	-	-	600	300	900	-
Screenline Total			**-**			**24,500**	**-**
Screenline 4 – South of 196th Street SW							
44th Avenue W	1,190	870	2,060	1,300	1,000	2,300	1.12
I-5 GP	5,790	5,450	11,240	5,500	4,300	9,800	0.87
I-5 HOV	1,070	860	1,930	1,500	400	1,900	0.98
Screenline Total			**15,230**			**14,000**	**0.92**
Screenline 5 – Midlake							
SR 522	2,300	1,480	3,780	1,800	1,900	3,700	0.98
SR 520	3,850	3,710	7,560	4,100	4,000	8,100	1.07
I-90 GP	5,490	5,160	10,650	5,700	5,800	11,500	1.08
I-90 HOV	NA	2,140	2,140	NA	1,600	1,600	0.75
Screenline Total			**24,130**			**24,900**	**1.03**
Screenline 6 – South of SR 516 (Kent-Des Moines Road)							
I-5 GP	5,150	7,600	12,750	5,500	7,800	13,300	1.04
I-5 HOV	600	1,600	2,200	500	1,700	2,200	1.00
SR 167 GP	3,380	3,810	7,190	3,100	4,200	7,300	1.02
SR 167 HOV	510	1,010	1,520	400	1,700	2,100	1.38
Screenline Total			**23,660**			**24,900**	**1.05**

Table C3: Base Year (2011) Total Vehicle Volume Screenline Comparison (average weekday)

	Actual Volumes			Estimated Volumes			
	NB/WB	SB/EB	Total	NB/WB	SB/EB	Total	Est/ Act
Screenline 1 - Ship Canal							
Ballard Bridge	31,200	30,700	61,900	23,800	25,600	49,400	0.80
Fremont Bridge	14,800	14,400	29,200	24,400	25,200	49,600	1.70
SR 99	40,700	44,900	85,600	47,000	51,800	98,800	1.15
I-5 GP	109,400	111,700	221,100	99,300	108,300	207,600	0.94
I-5 Express Lanes	33,700	22,800	56,500	37,200	24,400	61,600	1.09
University Bridge	14,900	17,700	32,600	18,300	20,000	38,300	1.17
Montlake Bridge	30,500	28,100	58,600	27,900	29,600	57,500	0.98
Screenline Total			**545,500**			**562,800**	**1.03**
Screenline 2 – South of N 145th Street							
3rd Avenue NW	4,700	4,000	8,700	1,000	1,000	2,000	0.23
Greenwood Avenue N	12,100	12,800	24,900	13,200	14,800	28,000	1.12
SR 99	17,900	17,900	35,800	17,800	20,300	38,100	1.06
Meridian Avenue N	2,600	2,500	5,100	2,300	2,100	4,400	0.86
I-5 GP	96,500	97,000	193,500	88,300	87,500	175,800	0.91
I-5 HOV	9,600	11,800	21,400	10,000	11,000	21,000	0.98
5th Avenue NE	4,000	2,500	6,500	8,200	7,700	15,900	2.45
15th Avenue NE	7,400	8,000	15,400	10,100	10,800	20,900	1.36
20th Avenue NE	1,000	700	1,700	1,000	800	1,800	1.06
30th Avenue NE	4,000	3,000	7,000	2,500	2,500	5,000	0.71
SR 522	17,900	19,600	37,500	22,800	24,400	47,200	1.26
Screenline Total			**357,500**			**360,100**	**1.01**
Screenline 3 – South of N 205th Street/ 244th Street SW							
8th Avenue NW	3,500	3,200	6,700	3,100	3,100	6,200	0.93
3rd Avenue NW	2,000	1,600	3,600	6,200	6,400	12,600	3.50
Fremont Avenue N	2,900	2,400	5,300	1,300	1,400	2,700	0.51
SR 99	14,800	17,200	32,000	25,600	27,300	52,900	1.65
Meridian Avenue N	5,600	5,000	10,600	10,600	11,300	21,900	2.07
1st Avenue NE	1,600	1,600	3,200	2,500	2,400	4,900	1.53
5th Avenue NE	800	1,100	1,900	1,400	1,300	2,700	1.42
I-5 GP	92,800	87,100	179,900	73,300	72,600	145,900	0.81
I-5 HOV	10,500	12,700	23,200	10,800	11,700	22,500	0.97
15th Avenue NE	4,700	4,200	8,900	6,100	6,600	12,700	1.43
SR 104	11,600	10,700	22,300	7,700	7,600	15,300	0.69
19th Avenue NE	4,100	3,200	7,300	4,600	5,000	9,600	1.32
Screenline Total			**304,900**			**309,900**	**1.02**
Screenline 4 – South of 196th Street SW							
44th Avenue W	13,600	12,200	25,800	14,000	14,500	28,500	1.10
I-5 GP	78,000	77,800	155,800	67,300	68,000	135,300	0.87
I-5 HOV	8,200	10,900	19,100	8,700	9,600	18,300	0.96
Screenline Total			**200,700**			**182,100**	**0.91**
Screenline 5 – Midlake							
SR 522	-	-	49,000	23,400	24,200	47,600	0.97
SR 520	56,800	56,700	113,500	53,800	52,500	106,300	0.94
I-90 GP	68,900	66,800	135,700	73,400	70,800	144,200	1.06
I-90 HOV	5,300	8,800	14,100	7,500	9,800	17,300	1.23
Screenline Total			**312,300**			**315,400**	**1.01**
Screenline 6 – South of SR 516 (Kent-Des Moines Road)							
I-5 GP	91,800	90,700	182,500	93,900	91,600	185,500	1.02
I-5 HOV	10,200	11,100	21,300	14,200	11,900	26,100	1.23
SR 167 GP	57,140	53,880	111,020	53,000	52,700	105,700	0.95
SR 167 HOV	8,820	9,740	18,560	11,900	10,000	21,900	1.18
Screenline Total			**333,380**			**339,200**	**1.02**

Other Documentation

Further documentation on the use of SR 520 and AWV models for major WSDOT projects includes:

- SR 520 Toll Traffic and Revenue Technical Report (April 2009)—Analysis of the SR 520 Finance Plan Draft 2008 Update Toll Scenarios http://www.wsdot.wa.gov/Projects/SR520Bridge/Library/technical.htm#finance
- Technical Analysis to Support the SR 99 Alaskan Way Viaduct Replacement Finance Plan (February 2010)—Traffic & Revenue and Toll Feasibility http://www.wsdot.wa.gov/Projects/Viaduct/Library.htm

Appendix D

- **Procedures for Transit Network Preparation**
- **Transit Fares**
- **ST Memorandum to FTA (Speed Degradation Procedures)**
- **Bus Speed Degradation Rates**

Appendix D: Procedures for Transit Network Preparation

Actual transit service is represented in a transit ridership forecasting model by means of a "coded network." This service representation actually consists of two elements:

- A highway network, or "base network," is coded to create a computerized representation of existing and planned roads and exclusive transit right-of-ways in the study region
- Transit service assumptions are overlaid on this base highway network

Significantly, for Sound Transit studies, the base network does not vary among alternatives. A single base network is used for all alternatives—meaning that for each alternative, elements of the base network may exist on which no transit service is coded. For example, rail rights-of-way are coded in every network although no rail service is coded for an all-bus alternative.

ST decided to construct a single base network for several reasons. One advantage of keeping the base network constant is that it eliminates spurious errors caused by roads or walkways which would be coded differently in different alternatives. A second reason for maintaining a single base network is that it minimizes differences in results due to accidental *differences* in access coding. Because a major aim of any forecasting effort is to capture differences among various alternatives, it is important that these differences are attributable to actual differences among the alternatives, rather than coding inconsistencies.

In contrast to the base network, the transit service that operates on this network does vary, both by forecast year and by alternative. The transit service network created for each alternative is represented by a set of bus and rail transit routes operated by local transit agencies.

D.1 Development of the Base Network

The base network is coded within this boundary and consists of links and nodes that represent the road system on which transit and automobiles travel. As mentioned previously, exclusive rights-of-way for transit and HOVs (e.g., transitways and rail tracks) are also coded, although they may not be used in every alternative. Park-and-ride lots are also coded, although they too may not be served by transit in every alternative.

Each of the links coded in the base network has a set of attributes consisting of the length of the link, the link type, the modes allowed on the link, the number of lanes on the link, a link speed, and the volume delay function. The link type codes, the modes, the volume delay functions, and link speeds are described in more detail below.

The network outside the study area is not coded, although the major roads leaving the study area are coded by means of external links. These links serve as a method of accounting for travel into the study area from areas beyond the study area boundaries.

Link Type Codes

A two-digit number is used to code the link type. The first digit represents a facility type. The second digit can be used in a variety of ways, such as summing by cordons or by geographic area. The chart below shows the convention used for the first digit of the link type code:

Code	Link Type
0	Freeway HOV
1	Freeway HOV
2	Expressway or highway
3	Arterial HOV
4	Arterial HOV
5	External roads
6	Rail
7	Pedestrian only links
8	Walk access to zone centroids
9	Auto access to zone centroids

The link type coding does not directly affect the mode-choice model or the representation of transit service.

Mode Types

The following eight modes are specified on links within the base network:

Symbol	Mode Represented
c	Car
b	Bus
t	Trolley
r	Rail
a	Auto access
w	Walk access
p	General pedestrian links
x	Park-and-ride lot connection (directional link)

The access modes (i.e., modes "a," "w," "p," and "x") are an important aspect of the base network. There is a minor variation in the way these access modes are represented in the PM-peak and off-peak networks. In the peak networks, both auto access and walk access modes are allowed, while in the off-peak only walk access is allowed.

Walk-access links are coded with a speed of 3 miles per hour (mph). The "w" mode allows walking from the base network to the zone centroid. The "p" mode permits all other walking, including walking from the zone centroid to the base network and streets. The separation of these two walk access modes makes it possible to differentiate between walk access transit trips and auto access transit trips.

The other two access modes, modes "a" and "x," are associated with the use of park-and-ride lots to access transit. Mode "a" allows auto trips between zone centroids and park-and-ride lots, and mode "x" represents walking within park-and-ride lots. A sample representation of the PM-peak network using the access modes is shown in Figure D1a.

There are several reasons for using x-links to represent park-and-ride access to transit. First, using such links allows for counting the number of trips that use park-and-ride lots to access transit. Second, the use of such links will allow for modeling the effect of charging fees at park-and-ride lots should this be desired. Third, there is a certain disutility associated with having to park one's car and walk through a park-and-ride lot in order to get on a bus or train. Using x-links allows for the inclusion of this disutility in the model.

Finally, the use of x-links allows for a more even-handed comparison of park-and-ride access to transit between rail and non-rail alternatives. The use of x-links allows one to connect a single park-and-ride lot to both the street network and rail tracks. This means that under both an all-bus alternative (where transit would access the park-and-ride lot via the street network) and a rail alternative (where transit, such as rail transit, would access the same park-and-ride lot via the rail system), the park-and-ride lot in question would be connected to the exact same zones.

In the off-peak network, each of the AAZs in the network is connected with walk access links only. As in the PM peak, the walk access links are coded with a speed of 3 mph. Both modes "w" and "p" allow walking from the base network to the zone centroid and vice versa. Mode "p" also allows walking on all surface streets in the network. The other two access modes, modes "a" and "x," are not used in the off-peak network. A sample representation of the off-peak network using the access modes is shown in Figure D1b.

Development of the Future Transit Service Networks

Transit service networks are created to represent the transit service planned for each alternative and forecast year, as well as the service operated in the base years used to validate the model. Each service network is characterized by a unique set of routes, which may include rail lines, service on exclusive transitways, or HOV lanes. Each route is described by the nodes and links over which it travels, the travel time on each link, the locations where it stops, and its peak and off-peak headways. Each of these characteristics is described in detail below.

Route Patterns

Each route can be described by its route alignment, or the set of nodes and links over which it travels. The places where passengers are picked up and dropped off are coded by placing a dwell time on the nodes that represent bus stops for each particular route. All Sound Transit, King County Metro, Community Transit, Everett Transit, and Pierce Transit routes within the forecasting study area are coded for each alternative and forecast year, with the exception of any dial-a-ride service and routes that have less than three trips per direction per day.

Figure D1a: Sample Mode Coding on Base Network Links (PM peak)

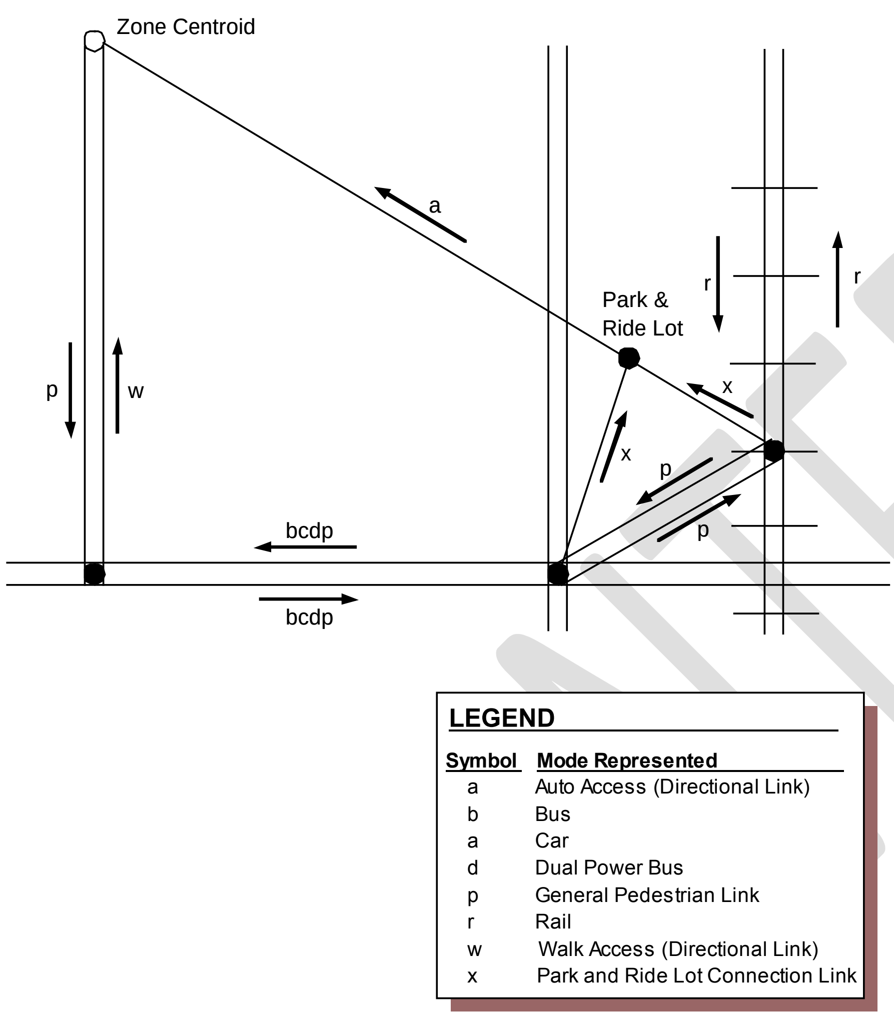
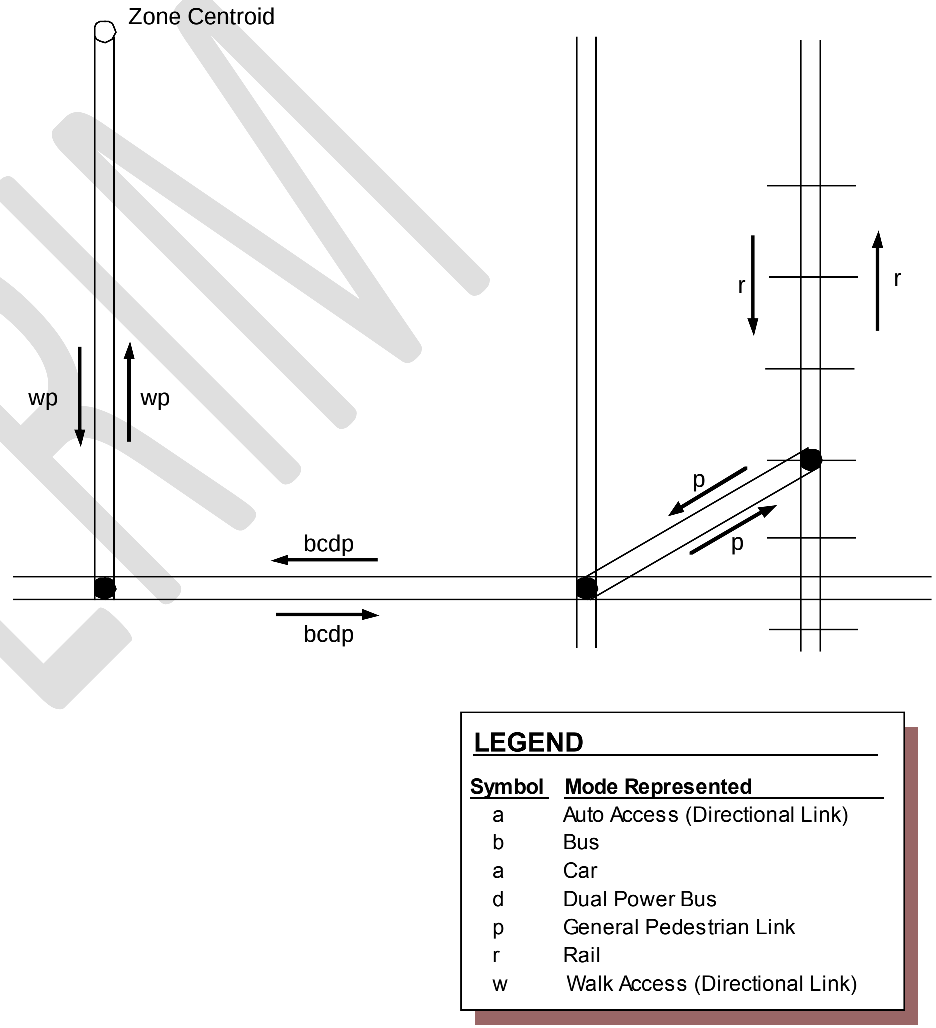


Figure D1b: Sample Mode Coding on Base Network Links (Off-peak)



Route Headways

PM-peak and off-peak headways are specified for each route in each transit service network. The PM-peak headway reflects the number of trips between 3:00 and 6:00 PM, and the off-peak headway reflects the base headway between 9:00 a.m. and 3:00 p.m. For the base-year network, headways are determined directly from the printed bus schedules from the transit agencies.

Future networks will be developed according to the specific definition of alternatives to be defined in support of the New Starts application of the Lynnwood Link Extension to the Federal Transit Administration (FTA) for entry into Preliminary Engineering.

Link Speeds and Bus Speeds

For fixed guideway facilities, link speeds representing travel time between two successive stations are calculated as part of the operating plan development that is unique to each alternative under consideration. Bus speeds under mixed operation with general traffic are calculated as follows:

- **For the base year**—link speeds are coded so that they result in network bus travel times equal to observed bus travel times.
- **For future years**—base-year link speeds are degraded according to the change in general roadway congestion level estimated by the PSRC model for arterial and freeway facilities and by geographic area.

Since the ST model's development in the early 1990s by the RTA, future-year link speeds have been estimated using a constant degradation rate of 7 to 9 percent per decade. This degradation rate is consistent with historic trends in bus speeds. FTA staff, however, recently expressed concern about extrapolating historical trends in bus speed degradation into future projections. Instead, the FTA suggested basing link speeds degradation on roadway congestion estimated by the PSRC multi-modal model. Subsequently, a number of experimental analyses were performed in consultation with PSRC and City of Seattle travel modeling staff. As a result of this effort, analysis results and a recommended procedure were developed and documented by Sound Transit staff in a memorandum to the FTA. A copy of this memorandum follows Section D2.

D.2 Transit Fares

Historically, most transit agencies in the Puget Sound Region have increased transit fares at the rate of inflation. Consequently, transit fares are kept unchanged (in constant dollars) in the ST model between the base year (2011) and a future year. Transit fares for future years have been recently updated to reflect prevailing transit fares in 2011, except for the Seattle intra-downtown, where it is currently a free-ride area. According to an agreement between Sound Transit and King County Metro, fares also will be collected for the intra-downtown rides starting in 2013. Base year 2011 and future year (e.g., 2035) transit fares used in the ST model are presented in Tables D2a and D2b.

Table D2a: Base Year 2011 Peak and Off-peak Transit Fares (in 2011 constant dollars)

ORIGIN \ DESTINATION		North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26
North Everett	1	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
South Everett	2	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
Lynnwood	3	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$2.50	$2.50	$2.50	$2.50	$2.50	$3.00	$3.00	$3.00	$3.00	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
North Creek	4	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$2.50	$2.50	$2.50	$2.50	$2.50	$3.00	$3.00	$3.00	$3.00	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Shoreline	5	$2.00	$2.00	$2.00	$2.00	$1.75	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Ballard	6	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
North Seattle	7	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
University District	8	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Queen Anne	9	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Capitol Hill	10	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Seattle CBD	11	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$0.00	$1.75	$1.75	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
W Seattle	12	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Rainier	13	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Sea-Tac	14	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Renton	15	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Federal Way	16	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Kent	17	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Kirkland	18	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Redmond	19	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
West Bellevue	20	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Bellevue	21	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Issaquah	22	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
North Tacoma	23	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
South Tacoma	24	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
Lakewood	25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
Puyallup	26	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75

Table D2b: Future Years Peak and Off-peak Transit Fares (in 2011 constant dollars)

ORIGIN	DESTINATION	North Everett 1	South Everett 2	Lynnwood 3	North Creek 4	Shoreline 5	Ballard 6	North Seattle 7	University District 8	Queen Anne 9	Capitol Hill 10	Seattle CBD 11	W Seattle 12	Rainier 13	Sea-Tac 14	Renton 15	Federal Way 16	Kent 17	Kirkland 18	Redmond 19	West Bellevue 20	Bellevue 21	Issaquah 22	North Tacoma 23	South Tacoma 24	Lakewood 25	Puyallup 26
North Everett	1	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
South Everett	2	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50
Lynnwood	3	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$2.50	$2.50	$2.50	$2.50	$2.50	$3.00	$3.00	$3.00	$3.00	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
North Creek	4	$1.00	$1.00	$1.50	$1.50	$2.00	$2.25	$2.25	$2.25	$2.50	$2.50	$2.50	$2.50	$2.50	$3.00	$3.00	$3.00	$3.00	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Shoreline	5	$2.00	$2.00	$2.00	$2.00	$1.75	$2.00	$2.00	$2.00	$2.50	$2.50	$2.50	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Ballard	6	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
North Seattle	7	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
University District	8	$2.25	$2.25	$2.25	$2.25	$2.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.25	$2.50	$2.50	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Queen Anne	9	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Capitol Hill	10	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Seattle CBD	11	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
W Seattle	12	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Rainier	13	$3.50	$3.50	$2.50	$2.50	$2.75	$2.25	$2.25	$2.25	$1.75	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50
Sea-Tac	14	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Renton	15	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Federal Way	16	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Kent	17	$3.50	$3.50	$3.00	$3.00	$2.75	$2.75	$2.75	$2.75	$2.50	$2.50	$2.75	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50
Kirkland	18	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Redmond	19	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
West Bellevue	20	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Bellevue	21	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
Issaquah	22	$2.50	$2.50	$2.50	$2.50	$2.75	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$2.50	$1.75	$1.75	$1.75	$1.75	$1.75	$3.50	$3.50	$3.50	$3.50
North Tacoma	23	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
South Tacoma	24	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
Lakewood	25	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75
Puyallup	26	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$3.50	$2.50	$2.50	$2.50	$2.50	$3.50	$3.50	$3.50	$3.50	$3.50	$1.75	$1.75	$1.75	$1.75

SOUNDTRANSIT

MEMO

August 1, 2002

TO: Eric Pihl

FROM: Don Billen

SUBJECT: Updated Treatment of Bus Speeds in the Sound Transit Model

This memorandum describes the updated procedures for treating bus speeds in Sound Transit's incremental ridership forecasting process. This is in response to your request that Sound Transit rely on output from the PSRC multi-modal model to estimate changes in bus speeds over time.

Sound Transit Incremental Ridership Model

Sound Transit uses an incremental model to forecast transit ridership consisting of three stages:

- Stage 1: Changes in demographics
- Stage 2: External changes in highway travel time (congestion) and costs (including parking costs), transit fares, and household income are taken into consideration.
- Stage 3: Incremental changes in the transit level-of-service (i.e. access, wait, and ride travel times) are taken into consideration.

The third stage of the forecasting process is where the effects of changes in bus speeds are captured. Base year link speeds in combination with transit travel time functions are used so that they result in network bus travel times equal to observed bus travel times. Individual transit routes are coded with transit travel time functions that account for acceleration/deceleration time, with bus speeds equal to the base year link speed for express portions of a route. Dwell time is similarly coded for individual transit routes, with zero dwell time for express portions of a route.

Future year link bus speeds are degraded relative to base year link speeds and according to the procedures described below. The transit travel time functions which account for acceleration/deceleration time are the same in the base year and future year. Dwell time similarly remains the same in the base and future year.

Since the model's development in the early 1990's by the Regional Transit Project, future year link speeds have been estimated using a constant degradation rate of seven to nine percent per decade. This degradation rate is consistent with historic trends in bus speeds. However, FTA staff have expressed concern about extrapolating historical trends into the future and suggested relating future bus speeds to road speeds in the PSRC multi-modal model.

Updated Procedure for Estimating Future Bus Speeds

Sound Transit and its ridership consultant have investigated several methods for relating road speeds in the PSRC model to bus speeds in the Sound Transit model. After reviewing these methods with Puget Sound Regional Council and City of Seattle modeling staff, we have arrived at the following procedure.

For arterial bus speeds, weighted average auto travel time within the PSRC model is calculated at an intra 26-district level for the base year and forecast year in the PM peak and off-peak. The ratio between the base year and forecast year intra-district times is calculated. This change in intra-district auto travel times is used to estimate the change in bus speeds and is applied to the base year link speed values in the ST model for each geographic district. Table 1 shows the resulting PM peak bus degradation rates for each of the 26 districts for the period of 1998-2020.

Table 1: PM Peak Arterial Degradation Rates

Comparative Analysis of 1998 to 2020 Weighted Average Intra-District Travel Times

District		1998	2020	2020/1998 Ratio	Change Per Decade
North Everett	1	6.13	6.80	1.11	4.8%
South Everett	2	8.24	9.28	1.13	5.6%
Lynnwood	3	8.04	9.95	1.24	10.2%
North Creek	4	10.13	11.17	1.10	4.5%
Shorelin	5	6.47	6.79	1.05	2.2%
Ballard	6	6.32	6.79	1.07	3.3%
North Seattle	7	6.64	7.29	1.10	4.3%
University District	8	4.55	5.52	1.21	9.2%
Queen Anne	9	6.44	6.94	1.08	3.5%
Capitol Hill	10	4.86	5.07	1.04	1.9%
Seattle CBD	11	2.48	2.63	1.06	2.6%
W Seattle	12	7.28	8.63	1.19	8.1%
Rainier	13	9.17	9.92	1.08	3.6%
Sea-Tac	14	8.01	8.81	1.10	4.4%
Renton	15	10.00	11.58	1.16	6.9%
Federal Way	16	8.26	9.50	1.15	6.5%
Kent	17	9.99	11.16	1.12	5.2%
Kirkland	18	8.75	10.10	1.15	6.7%
Redmond	19	8.60	11.42	1.33	13.8%
West Bellevue	20	5.51	5.68	1.03	1.4%
Bellevue	21	8.85	9.69	1.10	4.3%
Issaquah	22	8.62	10.33	1.20	8.6%
North Tacoma	23	8.48	10.58	1.25	10.6%
South Tacoma	24	6.16	6.78	1.10	4.4%
Lakewood	25	8.30	9.72	1.17	7.4%
Puyallup	26	10.51	11.46	1.09	4.0%
External	27	16.97	19.70	1.16	7.0%
Destination Totals		19.33	22.34	1.16	6.8%

For freeway bus speeds, zone to zone travel times between major entry and exit points for buses along regional freeways are calculated for the base year and future year. As with arterial times, the ratio between the base year and forecast year times is calculated. This change in freeway auto travel times is used to estimate the change in bus speeds and is applied to the base year link speed in the ST model for each freeway segment. Table 2 shows the resulting bus degradation rates on two freeway segments in the light rail study area.

Table 2: PM Peak Freeway Degradation Rates

Comparative Analysis of 1998 to 2020 Freeway Travel Times					
Freeway Segment		1998	2020	2020/1998 Ratio	Change Per Decade
I-5: Seattle CBD to Northgate		15.50	18.07	1.17	7.2%
SR 520: Seattle to Overlake		22.15	25.12	1.13	5.9%

The resulting rates of degradation for both arterials and highways are somewhat lower than historic changes in bus speeds in the Central Puget Sound Region, so may underestimate actual degradation rates. However, the updated method offers the advantage of being sensitive to varying congestion rates over time and across geographic areas and to changes in these rates with alternative land use or highway network scenarios.

Alternate Method Investigated

Our ridership forecasting consultant originally proposed to simply average PSRC link speeds within a cross-classification of geography and facility type for a base and future year to estimate changes in bus speeds. (see Parsons Brinkerhoff memo of 12-2-01 from Youssef Dehghani to Don Billen).

Investigation of this method between 1998 and 2020 yielded results that varied greatly between geographic areas and on the aggregate showed changes in road times much lower than other analyses of PSRC model output. The average decline in speeds across all facilities was 1% per decade between 1998 and 2020 compared to previous analysis of zone-zone road skims that showed an average decline of 8% per decade (see Parsons Brinkerhoff memo of 11-19-01 from Youssef Dehghani to Don Billen). Furthermore, the change in arterial speeds in different geographic areas varied by factors as high as 16 to 23 times. For instance, major arterial speed degradation in the Eastside of King County was 17 times as high as in Snohomish County, even though both are high growth areas with very limited road expansion currently funded. (Table 3)

Upon review of these results with PSRC and City of Seattle modeling staff, we concluded that simple averaging of link speeds is inaccurate and that it would be better to rely on zone-zone skim times than link level times. The simple averaging of link speeds results in too much influence from low volume roadways and too little influence from highway volume roadways. Also, using link level rather than zone-zone travel time skims created the possibility for the results to be influenced by the density of road networks coded in a geographic area.

Table 3

Analysis of PM Peak Speed Degradation in PSRC Model By Facility Type and Area Type

(average change per decade from 1998 to 2020)

		Area Type							
		All	**Seattle CBD**	**Seattle**	**Eastside**	**Rest of King County**	**Snohomish County**	**Pierce County**	**Kitsap County**
Facility Type	**All**	1.5%	0.9%	0.7%	5.6%	3.0%	0.8%	1.8%	0.2%
↓	**Freeway GP Lanes**	6.3%	4.48%		8.8%	3.1%	14.4%	4.0%	6.1%
	Freeway HOV Lanes	1.2%	1.95%		4.2%	5.56%			
	Major Arterials	1.4%	3.4%	0.8%	6.8%	3.0%	0.4%	1.9%	0.2%
	Minor Arterials	1.8%	0.1%	0.2%	3.1%	2.7%	2.1%	0.3%	0.0%

Notes :- The data shown above represents the percentage speed degradation over a period of 22 years from 1998 to 2020.
- The percentage degradation in speed was obtained from the "slope" of the regression equation obtained from a linear regression analysis of PM peak link travel times for a particular facility type and area type.
- The regression analysis showed an R^2 of greater 0.9 for all the categories.
- Major arterials include all those arterials in the PSRC model that have a speed greater than 25 mph, e.g., MLK way, Rainier Avenue, NE 8th (in Bellevue etc.). Minor arterials are arterials with a speed less than 25 mph.

These concerns led PSRC and City of Seattle modeling staff to recommend the use of weighted average auto travel times from zone-zone travel time skims and to Sound Transit's development of the procedures described at the beginning of this memo.

CC: John Witmer, FTA Region X
Larry Blaine, Puget Sound Regional Council
Eric Tweit, City of Seattle
Tracy Reed, Ron Lewis, Mike Williams, Sound Transit

DB <Updated bus speed degradation method.doc>

Table D3a. PM-peak and Off-peak Arterial Speed Degradation Rates

District		2025/2011 Ratio		2035/2011 Ratio	
No.	**Name**	**PM Peak Period**	**Off-Peak Period**	**PM Peak Period**	**Off-Peak Period**
1	North Everett				
2	South Everett				
3	Lynnwood				
4	North Creek				
5	Shoreline				
6	Ballard				
7	North Seattle				
8	University District				
9	Queen Anne				
10	Capitol Hill				
11	Seattle CBD				
12	West Seattle				
13	Rainier				
14	Sea-Tac				
15	Renton				
16	Federal Way				
17	Kent				
18	Kirkland				
19	Redmond				
20	West Bellevue				
21	Bellevue				
22	Issaquah				
23	North Tacoma				
24	South Tacoma				
25	Lakewood				
26	Puyallup				
27	External				

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table D3b: PM-peak and Off-peak Freeway Speed Degradation Rates

	2025/2011 Ratio		2035/2011 Ratio	
Freeway Segment	**PM Peak Period**	**Off-Peak Period**	**PM Peak Period**	**Off-Peak Period**
I-5: Seattle CBD to Northgate				
SR 520 & I-90: Seattle to Bellevue/Redmond/Issaquah				

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Appendix E

- **_FAZ-Level Land Use Forecasts_**
- **_Zonal Parking Costs_**

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
ST AREA									
110	1,910	4,570	1,070				2,430	5,370	2,420
120	4,430	10,640	1,040				5,380	11,960	1,750
135	5,990	14,560	1,770				7,560	17,000	2,910
136	5,000	12,740	3,410				5,380	13,270	4,770
205	5,460	12,700	10,180				5,440	11,770	15,950
206	5,390	12,660	6,080				6,910	15,070	9,750
315	5,500	14,760	7,180				6,590	16,140	12,830
325	8,100	20,480	4,580				9,270	21,760	9,910
405	7,550	20,640	3,800				8,700	21,860	7,700
505	14,100	42,370	4,750				18,230	50,130	9,750
506	7,620	22,810	1,750				13,540	37,010	5,020
605	8,210	22,320	1,970				12,500	31,230	4,770
606	7,490	20,190	2,210				11,130	27,580	5,330
705	7,280	20,130	1,780				12,930	32,820	7,120
706	4,800	13,950	2,340				6,920	18,470	4,560
805	7,000	20,800	2,800				10,400	28,250	5,550
806	8,590	24,750	1,170				15,620	41,200	2,680
900	4,220	10,050	6,880				6,770	14,910	15,810
1000	3,750	9,780	1,230				4,670	11,250	3,100
1115	3,880	10,190	3,050				5,230	12,650	5,370
1116	6,400	15,320	6,910				8,000	17,810	11,380
1120	10,820	28,600	10,160				15,790	38,390	14,480
1130	1,860	3,760	1,670				3,200	6,050	5,660
1200	6,560	16,530	3,100				11,870	27,550	7,350
1310	9,320	25,080	3,860				10,690	26,540	6,550
1320	6,890	18,280	2,940				8,810	21,570	4,250
1330	7,420	22,920	2,850				9,090	25,710	4,500
1410	4,530	11,030	11,690				5,360	12,130	19,830
1420	4,790	12,220	11,600				6,070	14,320	20,650
1505	8,180	19,110	4,240				9,280	20,150	8,840
1506	8,780	21,410	3,100				10,290	23,260	4,490
1605	8,110	17,860	5,910				9,420	19,570	8,520
1606	5,700	12,940	1,440				7,020	14,880	2,820
1710	8,530	21,690	9,690				9,810	23,200	14,540

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
1720	11,110	26,360	5,470				12,510	27,440	7,900
1810	2,030	5,930	11,970				3,470	8,990	22,340
1820	4,420	6,560	19,290				6,760	9,650	31,710
1900	180	950	11,450				610	1,900	21,680
2000	3,380	7,760	12,740				5,850	12,440	26,330
2100	7,080	18,820	1,550				9,390	22,970	3,930
2215	7,080	17,950	4,220				8,860	20,810	7,580
2216	6,960	20,040	2,220				8,300	22,180	4,260
2225	5,520	13,490	3,400				9,250	20,880	7,070
2910	930	2,760	630				1,450	3,930	950
2925	5,730	16,390	790				6,690	17,580	1,490
2926	8,740	25,700	900				11,310	30,490	2,030
2927	2,250	5,790	1,060				3,710	8,800	2,790
2935	3,770	20,400	25,030				3,530	18,040	31,940
2936	2,030	4,950	2,630				4,190	9,430	6,380
2940	4,710	13,890	1,300				6,370	17,480	2,560
3010	14,870	41,280	6,910				16,730	46,920	8,250
3020	9,750	23,830	19,500				11,100	27,810	24,110
3030	11,650	33,610	5,710				14,110	41,040	9,060
3045	10,900	28,120	2,410				11,900	31,170	3,440
3046	9,520	24,480	5,330				10,220	27,260	6,900
3110	3,450	9,750	2,080				5,590	15,920	3,500
3120	9,580	25,310	17,550				11,940	32,040	24,430
3130	7,500	17,100	17,980				9,260	21,710	26,730
3200	8,060	22,410	4,930				12,830	36,000	6,750
3310	5,970	17,310	1,630				8,880	25,910	3,060
3320	10,420	31,260	2,800				15,680	47,270	4,030
3330	4,760	13,310	760				5,690	16,070	1,560
3413	2,750	7,790	540				3,920	11,190	940
3414	8,890	25,780	1,600				9,540	27,950	2,350
3415	8,230	22,980	4,520				11,390	32,090	4,910
3416	8,450	22,700	2,550				10,250	27,840	3,620
3425	6,170	18,110	1,480				10,460	30,890	1,830
3426	6,320	20,210	1,620				10,820	34,660	2,260
3427	7,830	22,670	2,570				11,790	34,390	4,020

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
3505	14,460	35,290	14,570				17,000	42,360	19,770
3600	8,080	18,780	42,390				9,380	22,430	57,810
3705	12,460	32,230	31,550				14,110	37,510	40,450
3706	6,020	14,880	2,820				6,890	17,320	5,350
3815	8,410	19,760	7,890				10,500	25,250	8,310
3816	8,500	23,340	3,050				9,990	27,730	4,940
3825	6,810	17,870	5,370				8,770	23,350	6,980
3900	2,700	5,500	24,800				4,350	9,110	35,430
3905	3,010	7,440	17,560				3,820	9,610	26,590
4005	4,530	11,650	1,610				5,770	15,060	2,940
4110	7,540	18,070	27,400				9,370	22,870	39,580
4120	7,910	18,190	2,840				9,300	21,880	3,850
4130	6,670	14,530	25,780				8,360	18,710	38,760
4210	7,780	19,590	2,560				11,800	30,150	3,710
4225	6,160	16,170	1,720				7,460	19,840	4,150
4226	6,160	15,770	1,540				9,070	23,540	2,980
4230	3,490	9,900	630				4,090	11,740	970
4300	4,660	10,980	9,110				6,130	14,790	12,990
4400	8,920	23,290	7,210				10,250	27,280	7,370
4505	5,780	16,740	580				7,580	22,130	920
4506	6,640	16,460	27,210				8,330	20,990	33,650
4605	8,140	22,800	9,200				10,320	29,240	13,710
4606	8,120	24,140	2,580				10,300	30,820	4,260
4607	6,720	21,140	4,000				10,660	33,660	8,060
4706	5,520	17,450	1,110				5,840	18,500	1,330
4810	4,050	8,980	8,030				5,060	11,500	10,320
4820	3,370	7,080	4,160				4,530	9,770	5,290
4900	4,970	7,580	45,290				12,420	19,600	74,150
5010	8,460	19,030	14,530				9,560	22,130	17,900
5020	9,960	25,060	5,600				10,900	27,900	8,000
5100	2,610	7,070	1,110				2,880	7,890	1,560
5205	5,660	12,290	30,600				9,140	18,180	38,330
5305	11,100	24,690	24,320				12,900	29,540	31,980
5306	10,610	24,030	14,970				12,750	29,690	20,850
5415	6,190	15,500	50,560				9,550	21,570	66,390

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
5425	16,100	38,230	27,440				22,060	52,140	38,240
5426	7,570	20,980	10,050				8,230	23,040	14,690
5515	9,440	24,600	2,820				11,050	29,250	4,030
5525	5,580	14,250	4,600				8,130	21,050	6,090
5535	8,500	21,640	4,640				10,200	26,400	6,410
5545	4,330	13,340	3,150				6,120	18,900	6,660
5546	5,960	16,920	8,970				7,990	22,870	14,400
5600	5,600	13,660	11,610				7,700	19,130	14,970
5715	7,660	17,150	1,040				7,900	18,150	2,160
5716	8,920	24,160	4,030				9,470	25,990	5,810
5720	17,140	34,790	7,310				17,590	37,130	9,670
5815	1,690	4,580	21,260				1,960	5,400	28,800
5825	1,220	3,180	44,040				1,700	4,610	52,740
5826	2,100	4,340	5,830				2,550	5,420	9,440
5915	6,850	20,210	4,180				8,600	25,610	6,560
5916	12,450	37,990	5,480				13,770	42,560	7,580
5925	10,000	26,440	14,560				11,870	32,020	18,370
6010	7,460	16,400	115,720				13,010	28,170	153,270
6020	10,660	15,710	40,370				20,740	31,700	57,870
6113	19,400	31,390	36,190				23,520	39,980	39,880
6114	15,000	33,210	17,420				16,810	38,560	17,590
6115	10,660	21,140	8,440				10,840	22,280	9,780
6123	10,360	16,760	49,120				20,920	35,170	65,060
6124	13,650	25,830	10,890				14,750	29,020	14,500
6125	4,910	9,530	7,780				5,300	10,930	11,760
6126	5,440	12,330	2,270				5,670	13,180	3,570
6213	9,260	17,270	9,490				10,290	20,030	17,810
6214	230	2,590	24,380				560	3,230	28,280
6215	11,360	28,990	13,990				13,520	34,490	16,840
6216	6,040	14,530	5,960				6,600	16,240	6,530
6223	12,110	26,870	6,480				13,590	30,970	8,890
6224	10,380	21,330	5,140				12,420	26,340	7,530
6225	8,940	18,100	14,820				12,000	25,090	19,990
6226	12,730	29,150	5,510				13,990	32,940	7,550
6316	13,560	26,370	11,980				15,250	30,790	16,510

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
6325	15,500	34,560	5,020				18,440	42,260	7,290
6326	10,680	23,190	8,780				13,240	29,710	10,800
6410	14,420	37,090	11,340				15,010	39,620	12,460
6420	12,510	32,370	5,380				13,220	35,170	6,780
6505	4,590	12,320	1,480				6,130	16,680	2,120
6506	5,650	15,240	3,740				7,380	20,130	5,270
6605	4,120	12,050	1,060				6,420	18,910	1,560
6606	1,980	5,590	780				2,930	8,350	1,310
6900	2,930	8,000	1,540				3,310	9,120	2,420
6910	1,690	4,350	380				2,350	6,120	880
7015	6,510	15,410	2,880				7,600	17,770	4,310
7025	9,010	19,780	6,440				11,180	24,390	9,330
7026	3,850	10,180	350				4,050	10,500	590
7100	8,340	21,030	7,450				9,730	24,150	10,700
7205	5,370	14,140	6,180				6,150	15,970	9,260
7206	7,370	17,620	12,980				9,570	22,610	22,570
7315	6,420	18,130	2,380				9,030	24,870	3,900
7316	7,150	19,590	2,490				9,760	26,130	4,080
7320	11,120	28,890	4,900				16,440	41,880	9,280
7335	13,170	34,200	6,430				18,420	46,910	10,610
7340	9,650	27,660	1,860				12,040	33,680	2,980
7415	3,630	9,550	8,690				5,850	15,090	14,870
7425	8,750	26,800	1,140				12,440	37,040	2,880
7435	2,870	8,370	1,780				3,430	9,750	4,980
7436	2,100	6,130	690				3,080	8,740	1,820
7515	1,750	4,330	6,720				3,390	8,250	13,810
7525	5,590	15,490	1,330				7,420	20,120	3,490
7526	6,110	16,530	5,300				7,720	20,430	9,880
7535	8,310	18,880	3,980				16,110	36,150	9,000
7537	9,290	23,050	11,760				12,270	30,000	20,260
7605	600	1,740	380				760	2,140	740
7606	880	2,300	430				1,380	3,550	840
7700	3,710	9,410	4,170				4,580	11,530	6,710
7805	6,830	20,010	1,320				9,760	27,880	2,750
7806	1,850	5,140	700				2,810	7,610	1,910

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
7905	6,870	19,520	3,220				11,390	31,580	5,970
8000	5,230	13,620	27,900				6,740	17,220	38,460
8115	11,980	28,590	8,330				15,170	35,720	14,160
8125	6,400	15,980	4,430				7,600	18,700	6,150
8126	4,840	11,980	6,430				6,010	14,720	10,310
8210	4,210	9,790	16,180				5,860	13,550	27,470
8220	7,240	19,270	16,100				8,130	21,120	25,470
8310	11,550	30,100	7,080				15,950	40,810	10,520
8320	4,470	13,530	4,640				6,520	19,220	9,060
8405	4,770	14,710	200				8,490	25,430	590
8406	830	2,310	40				1,470	3,980	230
8500	7,080	18,910	8,850				9,980	26,120	15,010
8600	5,950	19,190	7,980				9,100	28,360	12,230
8905	2,670	7,740	220				3,680	10,370	460
8906	2,860	8,320	400				3,610	10,250	960
8910	5,640	15,130	1,220				8,320	21,830	1,990
8925	5,100	14,370	1,060				7,000	19,290	2,050
8926	4,660	12,850	810				6,540	17,620	1,570
8927	2,010	5,620	80				2,420	6,630	280
8935	3,960	11,020	3,350				6,450	17,530	5,920
8936	6,000	16,330	1,150				8,620	22,990	2,230
8937	3,670	10,090	3,820				5,530	14,820	7,160
ST Area Total	**1,352,900**	**3,428,900**	**1,662,300**				**1,758,400**	**4,395,500**	**2,433,800**

Table E1: Total Households, Population, and Employment Interim Forecasts for 2011, 2025 and 2035 (continued)

PSRC FAZ #	Base Year 2011			Year 2025			Year 2035		
	Households	Population	Employment	Households	Population	Employment	Households	Population	Employment
Rest of the Region									
6930	4,500	10,850	2,150				5,260	12,940	2,790
9002	9,200	23,850	6,230				12,550	31,270	8,100
9004	6,320	17,120	2,200				10,690	27,490	4,620
9005	2,130	5,660	100				3,900	9,830	250
9006	3,720	10,240	690				5,710	14,900	1,360
9009	1,950	5,030	800				3,060	7,500	1,210
9011	3,760	8,650	5,190				6,160	13,580	7,510
9015	5,300	14,050	790				7,690	19,370	1,500
9016	4,040	11,200	950				6,000	15,800	1,710
9017	1,370	3,380	230				2,070	4,890	490
9018	6,470	16,540	8,680				10,090	24,610	13,790
9019	6,140	15,550	1,880				10,330	24,930	3,540
9020	5,770	14,350	1,690				10,220	24,250	3,290
9900	3,090	6,970	1,360				4,450	9,670	2,430
9901	2,680	7,240	2,630				3,880	9,960	4,890
9902	9,280	22,510	25,140				13,060	29,890	33,860
9904	4,670	9,870	5,090				6,970	14,210	6,360
9908	1,300	7,400	5,770				1,620	9,230	6,300
9909	1,580	4,350	720				2,440	6,370	1,350
9913	2,990	6,220	3,090				4,490	9,020	4,190
9914	6,140	16,080	1,710				9,430	23,510	3,400
9915	5,440	14,580	1,840				6,640	16,930	2,900
9916	3,840	10,320	1,570				5,770	14,710	2,970
Sub-total	**101,700**	**262,000**	**80,500**				**152,500**	**374,900**	**118,800**
PSRC Four-County Total	**1,454,600**	**3,690,900**	**1,742,800**				**1,910,900**	**4,770,400**	**2,552,600**

Note: This table will be updated after the adoption of land-use forecasts by PSRC.

Table E2: Zonal Parking Costs for 2011, 2025, and 2035 (in 2011 constant dollars)

	Daily			Hourly		
AAZ	2011	2025	2035	2011	2025	2035
15	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
16	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
43	$3.47	$4.21	$4.84	$1.04	$1.26	$1.45
44	$3.47	$4.21	$4.84	$1.04	$1.26	$1.45
47	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
58	$3.59	$4.37	$5.02	$1.08	$1.31	$1.51
59	$3.59	$4.37	$5.02	$1.08	$1.31	$1.51
60	$3.66	$4.45	$5.11	$1.10	$1.33	$1.53
62	$3.47	$4.21	$4.84	$1.04	$1.26	$1.45
64	$4.44	$5.39	$6.19	$1.33	$1.62	$1.86
65	$4.44	$5.39	$6.19	$1.33	$1.62	$1.86
69	$5.56	$6.75	$7.76	$1.67	$2.03	$2.33
70	$5.69	$6.91	$7.94	$1.71	$2.07	$2.38
71	$8.65	$10.51	$12.08	$2.59	$3.15	$3.62
72	$9.22	$11.21	$12.88	$2.77	$3.36	$3.86
73	$11.51	$13.98	$16.07	$3.45	$4.19	$4.82
94	$11.56	$14.05	$16.14	$3.47	$4.21	$4.84
95	$6.17	$7.49	$8.61	$1.85	$2.25	$2.58
96	$4.44	$5.39	$6.19	$1.33	$1.62	$1.86
98	$6.95	$8.44	$9.70	$2.09	$2.53	$2.91
99	$9.31	$11.31	$13.00	$2.79	$3.39	$3.90
100	$11.20	$13.61	$15.64	$3.36	$4.08	$4.69
101	$6.97	$8.47	$9.74	$2.09	$2.54	$2.92
102	$13.19	$16.02	$18.41	$3.96	$4.81	$5.52
103	$8.73	$10.60	$12.18	$2.62	$3.18	$3.65
104	$8.03	$9.76	$11.22	$2.41	$2.93	$3.36
105	$8.73	$10.60	$12.18	$2.62	$3.18	$3.65
106	$9.13	$11.09	$12.74	$2.74	$3.33	$3.82
107	$6.28	$7.63	$8.76	$1.88	$2.29	$2.63
108	$6.60	$8.01	$9.21	$1.98	$2.40	$2.76
109	$6.77	$8.23	$9.46	$2.03	$2.47	$2.84
114	$4.01	$4.87	$5.60	$1.20	$1.46	$1.68
115	$4.12	$5.00	$5.75	$1.24	$1.50	$1.72
116	$9.66	$11.73	$13.48	$2.90	$3.52	$4.05

Table E2: Zonal Parking Costs for 2011, 2025, and 2035 (in 2011 constant dollars) (continued)

AAZ	Daily			Hourly		
	2011	2025	2035	2011	2025	2035
117	$13.51	$16.41	$18.86	$4.05	$4.92	$5.66
118	$6.39	$7.76	$8.92	$1.92	$2.33	$2.68
119	$9.01	$10.94	$12.57	$2.70	$3.28	$3.77
120	$14.11	$17.14	$19.70	$4.23	$5.14	$5.91
121	$18.03	$21.91	$25.18	$5.41	$6.57	$7.55
122	$17.13	$20.81	$23.92	$5.14	$6.24	$7.17
123	$10.14	$12.32	$14.16	$3.04	$3.70	$4.25
124	$13.19	$16.02	$18.41	$3.96	$4.81	$5.52
125	$14.35	$17.44	$20.04	$4.31	$5.23	$6.01
126	$18.03	$21.91	$25.18	$5.41	$6.57	$7.55
127	$12.93	$15.71	$18.05	$3.88	$4.71	$5.41
128	$12.27	$14.90	$17.13	$3.68	$4.47	$5.14
129	$18.34	$22.28	$25.60	$5.50	$6.68	$7.68
130	$18.34	$22.28	$25.60	$5.50	$6.68	$7.68
131	$12.03	$14.61	$16.79	$3.61	$4.38	$5.04
132	$18.12	$22.02	$25.30	$5.44	$6.61	$7.59
133	$21.76	$26.43	$30.37	$6.53	$7.93	$9.11
134	$16.17	$19.64	$22.57	$4.85	$5.89	$6.77
135	$17.23	$20.93	$24.06	$5.17	$6.28	$7.22
136	$14.40	$17.50	$20.11	$4.32	$5.25	$6.03
137	$7.29	$8.86	$10.18	$2.19	$2.66	$3.05
138	$14.33	$17.40	$20.00	$4.30	$5.22	$6.00
139	$10.60	$12.87	$14.79	$3.18	$3.86	$4.44
140	$10.94	$13.29	$15.28	$3.28	$3.99	$4.58
141	$10.87	$13.21	$15.18	$3.26	$3.96	$4.55
142	$10.60	$12.88	$14.80	$3.18	$3.86	$4.44
143	$13.93	$16.92	$19.44	$4.18	$5.08	$5.83
144	$7.02	$8.53	$9.81	$2.11	$2.56	$2.94
145	$14.64	$17.79	$20.44	$4.39	$5.34	$6.13
146	$5.02	$6.09	$7.00	$1.50	$1.83	$2.10
147	$3.95	$4.80	$5.52	$1.19	$1.44	$1.66
148	$3.95	$4.80	$5.52	$1.19	$1.44	$1.66
153	$6.01	$7.30	$8.39	$1.80	$2.19	$2.52
154	$4.72	$5.73	$6.59	$1.42	$1.72	$1.98
155	$16.05	$19.50	$22.41	$4.82	$5.85	$6.72

Table E2: Zonal Parking Costs for 2011, 2025, and 2035 (in 2011 constant dollars) (continued)

AAZ	Daily			Hourly		
	2011	2025	2035	2011	2025	2035
156	$3.10	$3.77	$4.33	$0.93	$1.13	$1.30
157	$3.10	$3.77	$4.33	$0.93	$1.13	$1.30
158	$3.10	$3.77	$4.33	$0.93	$1.13	$1.30
159	$3.10	$3.77	$4.33	$0.93	$1.13	$1.30
162	$9.83	$11.94	$13.72	$2.95	$3.58	$4.12
163	$3.10	$3.77	$4.33	$0.93	$1.13	$1.30
240	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
255	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
262	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
263	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
264	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
280	$4.00	$17.00	$19.53	$1.20	$5.10	$5.86
281	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
283	$21.85	$26.55	$30.51	$6.56	$7.96	$9.15
284	$23.60	$28.67	$32.95	$7.08	$8.60	$9.88
309	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
310	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
325	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
351	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
355	$14.70	$17.86	$20.53	$4.41	$5.36	$6.16
356	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
357	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
361	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
362	$0.00	$7.90	$9.08	$0.00	$2.37	$2.72
363	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
364	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
392	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
398	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
418	$4.76	$5.78	$6.64	$1.43	$1.73	$1.99
423	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
430	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
436	$0.00	$8.51	$9.78	$0.00	$2.55	$2.93
448	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
466	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
467	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74

Table E2: Zonal Parking Costs for 2011, 2025, and 2035 (in 2011 constant dollars) (continued)

AAZ	Daily			Hourly		
	2011	2025	2035	2011	2025	2035
468	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
475	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
476	$0.00	$7.13	$8.20	$0.00	$2.14	$2.46
484	$16.34	$19.85	$22.82	$4.90	$5.96	$6.84
485	$15.13	$18.39	$21.13	$4.54	$5.52	$6.34
487	$14.70	$17.86	$20.53	$4.41	$5.36	$6.16
488	$0.00	$7.13	$8.20	$0.00	$2.14	$2.46
501	$0.00	$8.51	$9.78	$0.00	$2.55	$2.93
503	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
504	$0.00	$7.13	$8.20	$0.00	$2.14	$2.46
505	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
511	$0.00	$4.46	$5.12	$0.00	$1.34	$1.54
512	$3.25	$3.94	$4.53	$0.97	$1.18	$1.36
513	$3.25	$3.94	$4.53	$0.97	$1.18	$1.36
522	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
535	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
537	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
561	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
586	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
587	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
598	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
603	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
609	$1.00	$4.25	$4.88	$0.30	$1.27	$1.46
610	$1.27	$1.55	$1.78	$0.38	$0.46	$0.53
629	$1.27	$1.55	$1.78	$0.38	$0.46	$0.53
630	$1.27	$1.55	$1.78	$0.38	$0.46	$0.53
631	$1.31	$1.59	$1.83	$0.39	$0.48	$0.55
632	$6.47	$7.86	$9.03	$1.94	$2.36	$2.71
633	$3.87	$4.70	$5.40	$1.16	$1.41	$1.62
634	$3.87	$4.70	$5.40	$1.16	$1.41	$1.62
635	$7.12	$8.64	$9.93	$2.13	$2.59	$2.98
636	$7.12	$8.64	$9.93	$2.13	$2.59	$2.98
637	$7.12	$8.64	$9.93	$2.13	$2.59	$2.98
638	$7.12	$8.64	$9.93	$2.13	$2.59	$2.98
639	$0.00	$1.05	$1.20	$0.00	$0.31	$0.36

Table E2: Zonal Parking Costs for 2011, 2025, and 2035 (in 2011 constant dollars) (continued)

	Daily			Hourly		
AAZ	2011	2025	2035	2011	2025	2035
657	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
672	$0.00	$6.36	$7.31	$0.00	$1.91	$2.19
673	$0.00	$6.36	$7.31	$0.00	$1.91	$2.19
713	$0.00	$4.45	$5.11	$0.00	$1.33	$1.53
734	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
735	$0.00	$2.14	$2.45	$0.00	$0.64	$0.74
737	$0.00	$4.25	$4.88	$0.00	$1.27	$1.46
777	$1.00	$7.90	$9.08	$0.30	$2.37	$2.72
778	$1.00	$2.14	$2.45	$0.30	$0.64	$0.74