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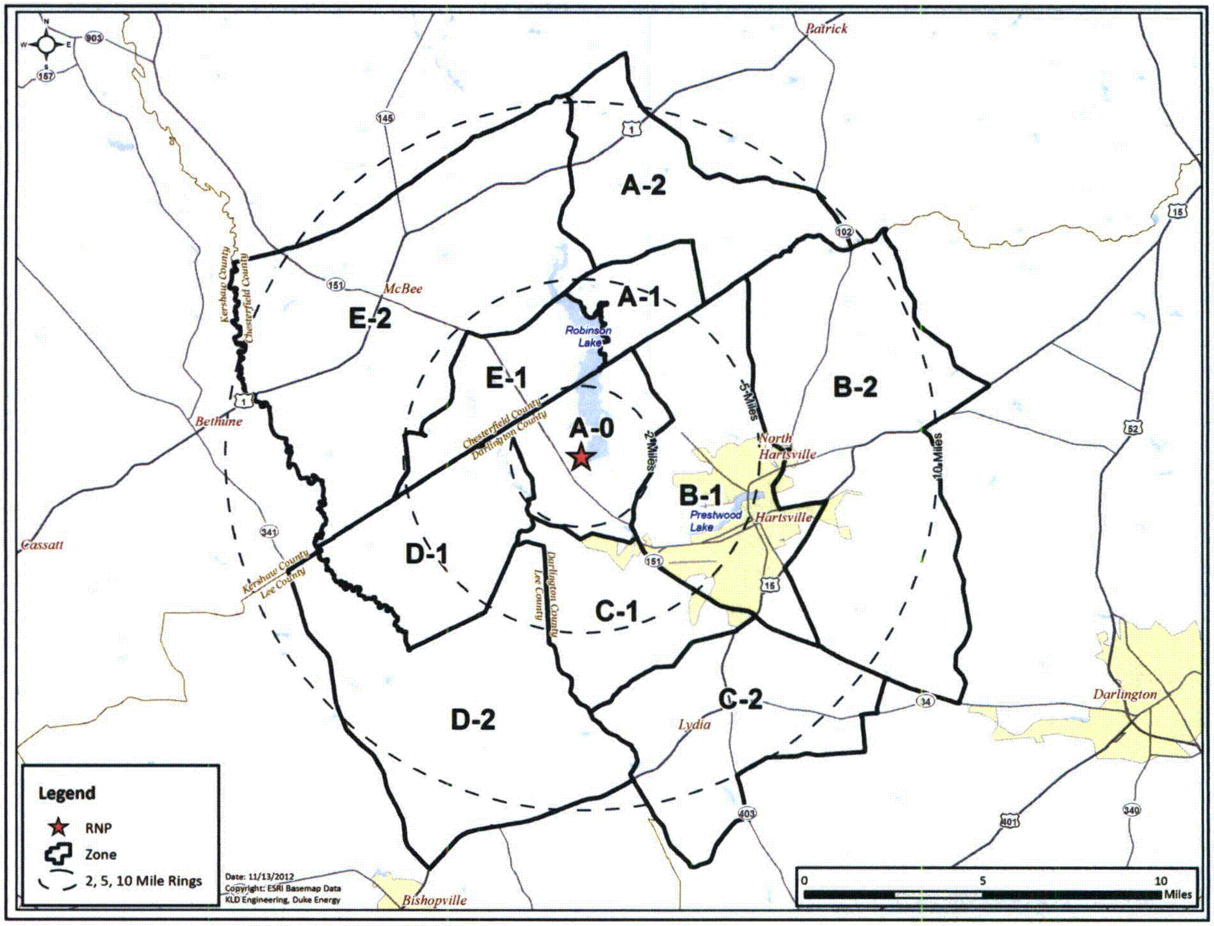
KLD Engineering Report KLD TR-534,
Robinson Nuclear Plant Development
of Evacuation Time Estimates

KLD ENGINEERING, P.C.

Robinson Nuclear Plant

Development of Evacuation Time Estimates



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EXECUTIVE SUMMARY

This report describes the analyses undertaken and the results obtained by a study to develop Evacuation Time Estimates (ETE) for the Robinson Nuclear Plant (RNP) located in Darlington County, South Carolina. ETE provide Progress Energy and State and local governments with site-specific information needed for Protective Action decision-making.

In the performance of this effort, guidance is provided by documents published by Federal Governmental agencies. Most important of these are:

- Criteria for Development of Evacuation Time Estimate Studies, NUREG/CR-7002, November 2011.
- Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG-0654/FEMA-REP-1, Rev. 1, November 1980.
- Development of Evacuation Time Estimates for Nuclear Power Plants, NUREG/CR-6863, January 2005.
- Emergency Planning and Preparedness for Production and Utilization Facilities, 10 CFR 50, Appendix E.

Overview of Project Activities

This project began in April, 2012 and extended over a period of 6 months. The major activities performed are briefly described in chronological sequence:

- Attended "kick-off" meetings with Progress Energy personnel and emergency management personnel representing state and county governments.
- Accessed U.S. Census Bureau data files for the year 2010.
- Studied Geographical Information Systems (GIS) maps of the area in the vicinity of the RNP, then conducted a detailed field survey of the highway network.
- Synthesized this information to create an analysis network representing the highway system topology and capacities within the Emergency Planning Zone (EPZ), plus a Shadow Region covering the region between the EPZ boundary and approximately 15 miles radially from the plant.
- Designed and sponsored a telephone survey of residents within the EPZ to gather focused data needed for this ETE study that were not contained within the census database. The survey instrument was reviewed and modified by the licensee and offsite response organization (ORO) personnel prior to the survey.
- Data collection forms (provided to the OROs at the kickoff meeting) were returned with data pertaining to employment, transients, and special facilities in each county. Telephone calls to specific facilities supplemented the data provided.

- The traffic demand and trip-generation rates of evacuating vehicles were estimated from the gathered data. The trip generation rates reflected the estimated mobilization time (i.e., the time required by evacuees to prepare for the evacuation trip) computed using the results of the telephone survey of EPZ residents.
- Following federal guidelines, the EPZ is subdivided into 11 zones. These zones are then grouped within circular areas or "keyhole" configurations (circles plus radial sectors) that define a total of 32 Evacuation Regions.
- The time-varying external circumstances are represented as Evacuation Scenarios, each described in terms of the following factors: (1) Season (Summer, Winter); (2) Day of Week (Midweek, Weekend); (3) Time of Day (Midday, Evening); and (4) Weather (Good, Rain, Snow). One special event scenario involving a NASCAR race and related activities, at the Darlington Raceway, was considered. One roadway impact scenario was considered wherein a section of SR 151 was closed southbound for the duration of the evacuation.
- Staged evacuation was considered for those regions wherein the 2 mile radius and sectors downwind to 5 miles were evacuated.
- As per NUREG/CR-7002, the Planning Basis for the calculation of ETE is:
  - A rapidly escalating event at the plant wherein evacuation is ordered promptly and no early protective actions have been implemented.
  - While an unlikely accident scenario, this planning basis will yield ETE, measured as the elapsed time from the Advisory to Evacuate until the stated percentage of the population exits the impacted Region, that represent "upper bound" estimates. This conservative Planning Basis is applicable for all initiating events.
- If the emergency occurs while schools are in session, the ETE study assumes that the children will be evacuated by bus directly to reception centers or host schools located outside the EPZ. Parents, relatives, and neighbors are advised to not pick up their children at school prior to the arrival of the buses dispatched for that purpose. The ETE for schoolchildren are calculated separately.
- Evacuees who do not have access to a private vehicle will either ride-share with relatives, friends or neighbors, or be evacuated by buses provided as specified in the county evacuation plans. Those in special facilities will likewise be evacuated with public transit, as needed: bus, van, or ambulance, as required. Separate ETE are calculated for the transit-dependent evacuees, for homebound special needs population, and for those evacuated from special facilities.

<u>Computation of ETE</u>

A total of 448 ETE were computed for the evacuation of the general public. Each ETE quantifies the aggregate evacuation time estimated for the population within one of the 32 Evacuation Regions to evacuate from that Region, under the circumstances defined for one of the 14 Evacuation Scenarios (32 x 14 = 448). Separate ETE are calculated for transit-dependent evacuees, including schoolchildren for applicable scenarios.

Except for Region R03, which is the evacuation of the entire EPZ, only a portion of the people within the EPZ would be advised to evacuate. That is, the Advisory to Evacuate applies only to those people occupying the specified impacted region. It is assumed that 100 percent of the people within the impacted region will evacuate in response to this Advisory. The people occupying the remainder of the EPZ outside the impacted region may be advised to take shelter.

The computation of ETE assumes that 20% of the population within the EPZ but outside the impacted region, will elect to "voluntarily" evacuate. In addition, 20% of the population in the Shadow Region will also elect to evacuate. These voluntary evacuees could impede those who are evacuating from within the impacted region. The impedance that could be caused by voluntary evacuees is considered in the computation of ETE for the impacted region.

Staged evacuation is considered wherein those people within the 2-mile region evacuate immediately, while those beyond 2 miles, but within the EPZ, shelter-in-place. Once 90% of the 2-mile region is evacuated, those people beyond 2 miles begin to evacuate. As per federal guidance, 20% of people beyond 2 miles will evacuate even though they are advised to shelter-in-place.

The computational procedure is outlined as follows:

- A link-node representation of the highway network is coded. Each link represents a unidirectional length of highway; each node usually represents an intersection or merge point. The capacity of each link is estimated based on the field survey observations and on established traffic engineering procedures.
- The evacuation trips are generated at locations called "zonal centroids" located within the EPZ and Shadow Region. The trip generation rates vary over time reflecting the mobilization process, and from one location (centroid) to another depending on population density and on whether a centroid is within, or outside, the impacted area.
- The evacuation model computes the routing patterns for evacuating vehicles that are compliant with federal guidelines (outbound relative to the location of the plant), then simulate the traffic flow movements over space and time. This simulation process estimates the rate that traffic flow exits the impacted region.

The ETE statistics provide the elapsed times for 90 percent and 100 percent, respectively, of the population within the impacted region, to evacuate from within the impacted region. These statistics are presented in tabular and graphical formats. The 90th percentile ETE have been identified as the values that should be considered when making protective action decisions because the 100th percentile ETE are prolonged by those relatively few people who take longer to mobilize. This is referred to as the "evacuation tail" in Section 4.0 of NUREG/CR-7002.

Traffic Management

This study references the comprehensive traffic management plans provided by Darlington, Chesterfield and Lee Counties, and identifies critical intersections. The existing TCPs are well placed and adequate. Two additional locations were evaluated (see Section 9 and Appendix M).

Selected Results

A compilation of selected information is presented on the following pages in the form of Figures and Tables extracted from the body of the report; these are described below.

- Figure 6-1 displays a map of the RNP EPZ showing the layout of the 11 zones that comprise, in aggregate, the EPZ.
- Table 3-1 presents the estimates of permanent resident population in each zone based on the 2010 Census data.
- Table 6-1 defines each of the 32 Evacuation Regions in terms of their respective groups of zones.
- Table 6-2 lists the Evacuation Scenarios.
- Tables 7-1 and 7-2 are compilations of ETE. These data are the times needed to clear the indicated regions of 90 and 100 percent of the population occupying these regions, respectively, for the general population. These computed ETE include consideration of mobilization time and of estimated voluntary evacuations from other regions within the EPZ and from the Shadow Region.
- Tables 7-3 and 7-4 present ETE for the 2-mile region for un-staged and staged evacuations for the 90th and 100th percentiles, respectively.
- Tables 8-7, 8-8, and 8-9 present ETE for the schoolchildren in good weather, rain and snow respectively.
- Tables 8-11, 8-12 and 8-13 present ETE for the transit-dependent population in good weather, rain and snow respectively.
- Figure H-8 presents an example of an Evacuation Region (Region R08) to be evacuated under the circumstances defined in Table 6-1. Maps of all regions are provided in Appendix H.

Conclusions

- General population ETE were computed for 448 unique cases – a combination of 32 unique Evacuation Regions and 14 unique Evacuation Scenarios. Table 7-1 and Table 7-2 document these ETE for the 90th and 100th percentiles. These ETE range from 1:50 (hr:min) to 3:15 at the 90th percentile.
- Inspection of Table 7-1 and Table 7-2 indicates that the ETE for the 100th percentile are significantly longer than those for the 90th percentile. There are two factors that contribute to this large difference. Firstly, the population trip generation curves have a long "tail" due to the fact that a small number of people take a long time to complete all the activities necessary to start their trip. Secondly there is congestion within the EPZ. When the system becomes congested, traffic exits the EPZ at rates somewhat below capacity until some evacuation routes have cleared. As more routes clear, the aggregate rate of egress slows since many vehicles have already left the EPZ. Towards the end of the process, relatively few evacuation routes service the remaining demand. See Figures 7-8 through 7-21.
- Inspection of Table 7-3 and Table 7-4 indicates that a staged evacuation provides no benefits to evacuees from within the 2 mile region and unnecessarily delays the

evacuation of those beyond 2 miles (compare Regions R04 through R10 with R25 through R31 and R02 with R32 in Tables 7-1 and 7-2). See Section 7.6 for additional discussion.

- Comparison of Scenarios 9 (winter, weekend, midday, good weather) and 13 (winter, weekend, midday, good weather, special event) in Table 7-2 indicates that the special event does not materially affect the ETE, although it does create significant and prolonged congestion outside of the EPZ. See Section 7.5 for additional discussion.
- Comparison of Scenarios 1 and 14 in Table 7-1 indicates that the roadway closure – closure of the section of SR 151 southbound between Bethel Road and Faith Road – can increase the 90th percentile ETE by up to 15 minutes for evacuation of the more populous regions. For most regions, however, there is sufficient capacity on neighboring routes to accommodate the evacuating flow.
- Routes out of the EPZ from Hartsville and North Hartsville carry the most traffic, in particular SR 151. The traffic control points on SR 151 are very important, given the demand for that route. The congestion patterns are described in Section 7.3 and shown in Figures 7-3 through 7-7.
- Separate ETE were computed for schools, medical facilities, transit-dependent persons, and homebound special needs persons. The average single-wave ETE for these facilities are within a similar range as the general population ETE at the 90th percentile. See Section 8.
- Table 8-5 indicates that there are enough buses available to evacuate the schools in a single wave; however there are not enough buses to evacuate the schools, daycares and transit dependents in a single wave. See Sections 8.4 and 8.5.
- There are insufficient ambulances available to evacuate the bedridden patients at medical facilities in a single wave. See Table 8-5.
- The general population ETE at the 90th percentile is insensitive to reductions in the base trip generation time of 4 hours 15 minutes due to the traffic congestion within the EPZ. See Table M-1. The 100th percentile ETE is shortened when the trip generation time is reduced.
- The general population ETE is insensitive to the voluntary evacuation of vehicles in the Shadow Region. See Table M-2.
- Population changes of +40 to 50% results in ETE changes that meet the criteria for updating ETE between decennial Censuses in Scenario 6 and Scenario 8. See Section M.3.

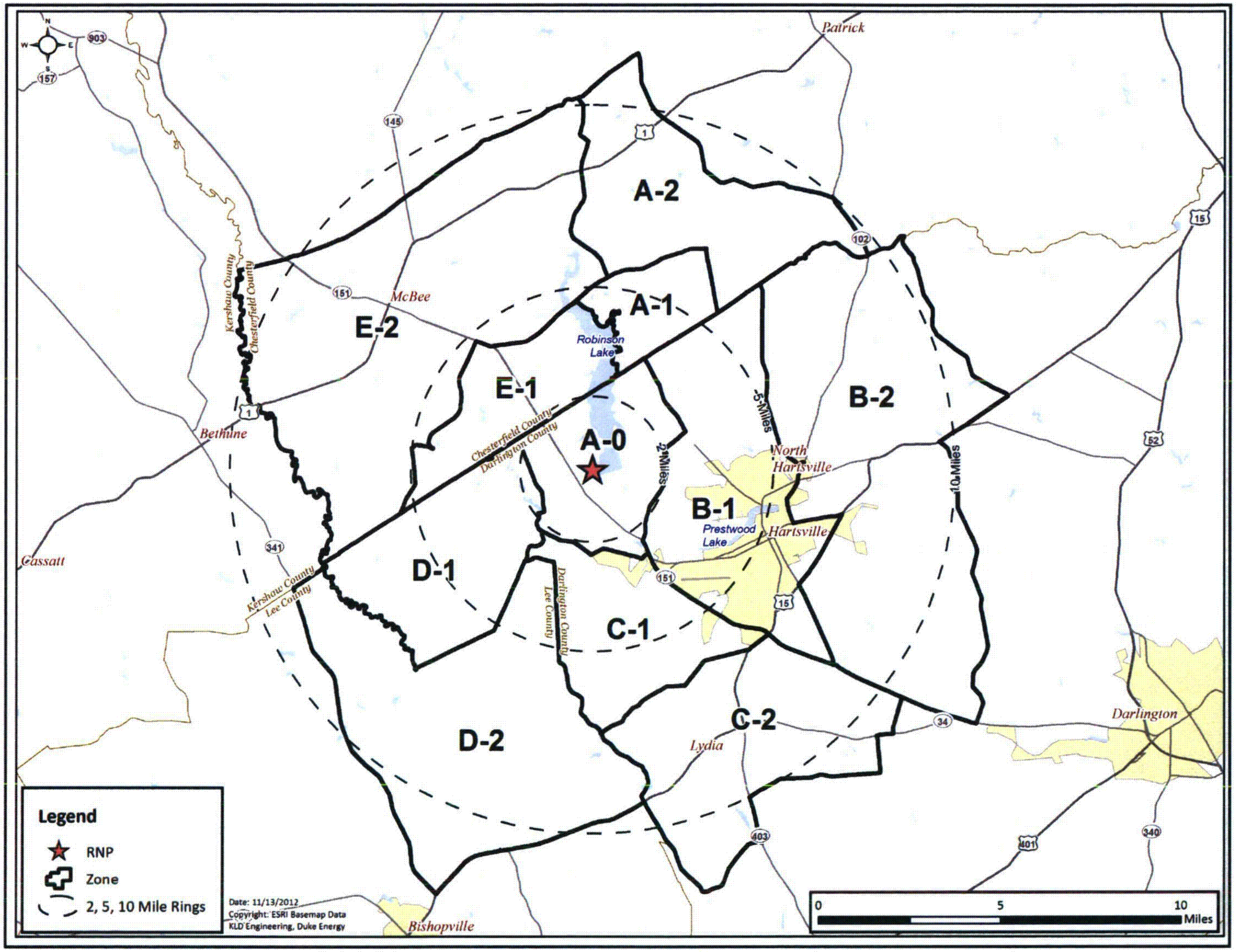

Figure 6-1. RNP Zones

Table 3-1. EPZ Permanent Resident Population

Subarea	2000 Population	2010 Population
A-0	2,161	2,281
A-1	670	669
A-2	852	1,426
B-1	12,721	16,584
B-2	8,998	5,645
C-1	2,555	2,578
C-2	1,903	1,931
D-1	1,039	1,114
D-2	1,409	1,196
E-1	295	396
E-2	1,931	2,106
TOTAL	**34,534**	**35,927**
EPZ Population Growth:		**4.03%**

Table 6-1. Description of Evacuation Regions

Region	Description	Wind Direction From: (Degrees)	Zone										
			A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2
R01	2-Mile Ring	N/A	X										
R02	5-Mile Ring	N/A	X	X		X		X		X		X	
R03	Full EPZ	N/A	X	X	X	X	X	X	X	X	X	X	X
Evacuate 2-Mile Radius and Downwind to 5 Miles													
Region	**Wind Direction From:**	**Wind Direction From: (Degrees)**	**Zone**										
			A-0	**A-1**	**A-2**	**B-1**	**B-2**	**C-1**	**C-2**	**D-1**	**D-2**	**E-1**	**E-2**
R04	North	> 328 - <= 015	X			X		X		X			
R05	Northeast	> 015 - <= 078	X					X		X		X	
R06	East	> 078 - <= 112	X							X		X	
R07	Southeast	> 112 - <=157	X	X						X		X	
R08	South	> 157 - <= 202	X	X		X						X	
(R08)	Southwest	> 202 - <= 247	X	X		X						X	
R09	West	> 247 - <= 292	X	X		X		X					
R10	Northwest	> 292 - <= 328	X			X		X					
Evacuate 2-Mile Radius and Downwind to the EPZ Boundary													
R11	North	> 328 - <= 015	X			X	X	X	X	X	X		
R12	Northeast	> 015 - <= 078	X					X	X	X	X	X	X
R13	East	> 078 - <= 112	X							X	X	X	X
R14	Southeast	> 112 - <=157	X	X	X					X		X	X
R15	South	> 157 - <= 202	X	X	X	X	X					X	X
(R15)	Southwest	> 202 - <= 247	X	X	X	X	X					X	X
R16	West	> 247 - <= 292	X	X	X	X	X	X	X				
R17	Northwest	> 292 - <= 328	X			X	X	X	X		X		
Evacuate 5-Mile Radius and Downwind to the EPZ Boundary													
Region	**Wind Direction From:**	**Wind Direction From: (Degrees)**	**Zone**										
			A-0	**A-1**	**A-2**	**B-1**	**B-2**	**C-1**	**C-2**	**D-1**	**D-2**	**E-1**	**E-2**
R18	North	> 328 - <= 015	X	X		X	X	X	X	X	X	X	
R19	Northeast	> 015 - <= 078	X	X		X		X	X	X	X	X	X
R20	East	> 078 - <= 112	X	X		X		X		X	X	X	X
R21	Southeast	> 112 - <=157	X	X	X	X		X		X		X	X
R22	South	> 157 - <= 202	X	X	X	X	X	X		X		X	X
(R22)	Southwest	> 202 - <= 247	X	X	X	X	X	X		X		X	X
R23	West	> 247 - <= 292	X	X	X	X	X	X	X	X		X	
R24	Northwest	> 292 - <= 328	X	X		X	X	X	X	X	X	X	

Region	Wind Direction From:	Wind Direction From: (Degrees)	Zone										
			A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2
R25	North	> 328 - <= 015	X			X		X		X			
R26	Northeast	> 015 - <= 078	X					X		X		X	
R27	East	> 078 - <= 112	X							X		X	
R28	Southeast	> 112 - <=157	X	X						X		X	
R29	South	> 157 - <= 202	X	X		X						X	
(R29)	Southwest	> 202 - <= 247	X	X		X						X	
R30	West	> 247 - <= 292	X	X		X		X					
R31	Northwest	> 292 - <= 328	X			X		X					
R32	5-Mile Ring	N/A	X	X		X		X		X		X	

Zone(s) Shelter-in-Place until 90% ETE for R01, then Evacuate	Zone(s) Shelter-in-Place	Zone(s) Evacuate

Note: Regions that are repeated for a different wind direction are written in parentheses

Table 6-2. Evacuation Scenario Definitions

Scenario	Season[1]	Day of Week	Time of Day	Weather	Special
1	Summer	Midweek	Midday	Good	None
2	Summer	Midweek	Midday	Rain	None
3	Summer	Weekend	Midday	Good	None
4	Summer	Weekend	Midday	Rain	None
5	Summer	Midweek, Weekend	Evening	Good	None
6	Winter	Midweek	Midday	Good	None
7	Winter	Midweek	Midday	Rain	None
8	Winter	Midweek	Midday	Snow	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Snow	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Weekend	Midday	Good	Darlington NASCAR Race
14	Summer	Midweek	Midday	Good	Roadway Impact – Roadway Closure on SR 151 Southbound

[1] Winter means that school is in session (also applies to spring and autumn). Summer means that school is not in session.

Table 7-1. Time to Clear the Indicated Area of *90* Percent of the Affected Population

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Region	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
Entire 2-Mile Region, 5-Mile Region, and EPZ														
R01	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:10	2:00	2:05	2:10	1:55	2:00	2:05
R02	2:10	2:15	1:55	2:00	1:50	2:10	2:15	2:35	1:55	2:00	2:20	1:50	1:55	2:10
R03	2:30	2:45	2:25	2:30	2:15	2:35	2:45	3:10	2:30	2:30	2:50	2:15	2:35	2:45
2-Mile Region and Keyhole to 5 Miles														
R04	2:10	2:15	1:55	2:00	1:50	2:10	2:15	2:35	1:55	2:00	2:20	1:50	1:55	2:10
R05	2:05	2:05	2:00	2:00	1:50	2:05	2:05	2:15	2:00	2:00	2:10	1:50	2:00	2:05
R06	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:15	2:00	2:05	2:10	1:55	2:00	2:05
R07	2:05	2:05	2:00	2:00	1:50	2:05	2:05	2:15	2:00	2:00	2:10	1:50	2:00	2:05
R08	2:10	2:15	2:00	2:00	1:50	2:10	2:15	2:35	2:00	2:00	2:20	1:50	2:00	2:10
R09	2:10	2:15	1:55	2:00	1:50	2:10	2:15	2:35	1:55	2:00	2:20	1:50	1:55	2:10
R10	2:05	2:15	1:55	2:00	1:50	2:10	2:15	2:35	1:55	2:00	2:20	1:50	1:55	2:05
2-Mile Region and Keyhole to EPZ Boundary (10 miles)														
R11	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:10	2:25	2:30	2:55	2:15	2:35	2:45
R12	2:10	2:10	2:05	2:05	1:55	2:10	2:10	2:25	2:05	2:05	2:20	1:55	2:05	2:20
R13	2:10	2:10	2:05	2:05	2:00	2:10	2:10	2:20	2:05	2:05	2:20	2:00	2:05	2:15
R14	2:05	2:10	2:00	2:05	1:55	2:05	2:10	2:20	2:00	2:05	2:15	1:55	2:00	2:05
R15	2:30	2:40	2:20	2:25	2:10	2:30	2:40	3:05	2:20	2:25	2:45	2:10	2:55	2:40
R16	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:10	2:25	2:30	2:50	2:10	2:30	2:45
R17	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:15	2:25	2:30	2:55	2:15	2:35	2:45
5-Mile Region and Keyhole to EPZ Boundary (10 miles)														
R18	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:10	2:25	2:30	2:55	2:10	2:30	2:45
R19	2:10	2:20	2:00	2:05	1:50	2:15	2:20	2:40	2:00	2:05	2:25	1:50	2:00	2:30
R20	2:10	2:15	2:05	2:05	1:55	2:10	2:20	2:35	2:05	2:05	2:30	1:55	2:05	2:20
R21	2:10	2:15	2:05	2:10	2:00	2:10	2:20	2:35	2:05	2:05	2:25	2:00	2:05	2:15
R22	2:30	2:40	2:20	2:25	2:10	2:30	2:40	3:05	2:20	2:25	2:45	2:10	2:45	2:40

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
Region	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
R23	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:10	2:25	2:30	2:50	2:10	2:30	2:45
R24	2:35	2:45	2:25	2:30	2:10	2:35	2:45	3:10	2:25	2:30	2:55	2:10	2:30	2:45
Staged Evacuation - 2-Mile Region and Keyhole to 5 Miles														
R25	2:45	2:50	2:50	2:50	2:45	2:45	2:50	3:15	2:45	2:50	3:15	2:45	2:45	2:45
R26	2:20	2:20	2:20	2:20	2:20	2:20	2:20	2:45	2:20	2:20	2:40	2:20	2:20	2:20
R27	2:15	2:15	2:15	2:15	2:20	2:15	2:15	2:35	2:15	2:15	2:35	2:20	2:15	2:15
R28	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:40	2:15	2:15	2:40	2:15	2:15	2:15
R29	2:45	2:50	2:45	2:50	2:45	2:45	2:50	3:10	2:45	2:50	3:10	2:45	2:45	2:45
R30	2:45	2:50	2:50	2:50	2:45	2:50	2:50	3:15	2:50	2:50	3:15	2:45	2:50	2:45
R31	2:45	2:50	2:50	2:50	2:45	2:45	2:55	3:15	2:50	2:50	3:15	2:45	2:50	2:45
R32	2:40	2:45	2:45	2:45	2:45	2:40	2:45	3:00	2:45	2:45	3:00	2:45	2:45	2:40

Table 7-2. Time to Clear the Indicated Area of *100* Percent of the Affected Population

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
Region	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
Entire 2-Mile Region, 5-Mile Region, and EPZ														
R01	4:15	4:15	4:15	4:15	4:15	4:15	4:15	5:15	4:15	4:15	5:15	4:15	4:15	4:15
R02	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R03	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:35	4:50
2-Mile Region and Keyhole to 5 Miles														
R04	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R05	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R06	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R07	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R08	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R09	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R10	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
2-Mile Region and Keyhole to EPZ Boundary (10 miles)														
R11	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:45
R12	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R13	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R14	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R15	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:35	4:30
R16	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:50
R17	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:50
5-Mile Region and Keyhole to EPZ Boundary (10 miles)														
R18	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:50
R19	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R20	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R21	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25
R22	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:25

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Region	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
R23	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:45
R24	4:25	4:25	4:25	4:25	4:25	4:25	4:25	5:25	4:25	4:25	5:25	4:25	4:25	4:50
Staged Evacuation - 2-Mile Region and Keyhole to 5 Miles														
R25	4:25	4:30	4:20	4:20	4:20	4:25	4:25	5:20	4:20	4:20	5:20	4:20	4:20	4:25
R26	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R27	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R28	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R29	4:25	4:30	4:20	4:20	4:20	4:30	4:30	5:20	4:20	4:20	5:20	4:20	4:20	4:25
R30	4:30	4:30	4:20	4:20	4:20	4:30	4:30	5:20	4:20	4:20	5:20	4:20	4:20	4:30
R31	4:30	4:30	4:20	4:20	4:20	4:30	4:30	5:20	4:20	4:20	5:20	4:20	4:20	4:30
R32	4:30	4:30	4:20	4:20	4:20	4:30	4:30	5:20	4:20	4:20	5:20	4:20	4:20	4:30

Table 7-3. Time to Clear 90 Percent of the 2-Mile Region within the Indicated Region

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Region	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
Unstaged Evacuation - 2-Mile Region 5-Mile Region														
R01	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:10	2:00	2:05	2:10	1:55	2:00	2:05
R02	2:05	2:05	2:00	2:00	1:55	2:05	2:05	2:10	2:00	2:00	2:10	1:55	1:55	2:05
Unstaged Evacuation - 2-Mile Region and Keyhole to 5-Miles														
R04	2:05	2:05	2:00	2:00	1:55	2:05	2:05	2:10	2:00	2:00	2:10	1:55	1:55	2:05
R05	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:10	2:00	2:05	2:10	1:55	2:00	2:05
R06	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:10	2:00	2:05	2:10	1:55	2:00	2:05
R07	2:05	2:05	2:00	2:05	1:55	2:05	2:05	2:10	2:00	2:05	2:10	1:55	2:00	2:05
R08	2:05	2:05	2:00	2:00	1:55	2:05	2:05	2:10	2:00	2:00	2:10	1:55	1:55	2:05
R09	2:05	2:05	2:00	2:00	1:55	2:05	2:05	2:10	2:00	2:00	2:10	1:55	1:55	2:05
R10	2:05	2:05	2:00	2:00	1:55	2:05	2:05	2:10	2:00	2:00	2:10	1:55	1:55	2:05
Staged Evacuation - 2-Mile Region and Keyhole to 5-Miles														
R25	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:30	2:15	2:15	2:30	2:15	2:10	2:15
R26	2:05	2:10	2:05	2:05	2:05	2:05	2:10	2:15	2:05	2:05	2:15	2:05	2:00	2:05
R27	2:05	2:10	2:05	2:05	2:05	2:05	2:10	2:15	2:05	2:05	2:15	2:05	2:00	2:05
R28	2:05	2:10	2:05	2:05	2:05	2:05	2:10	2:15	2:05	2:05	2:15	2:05	2:00	2:05
R29	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:30	2:15	2:15	2:30	2:15	2:10	2:15
R30	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:30	2:15	2:15	2:30	2:15	2:10	2:15
R31	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:30	2:15	2:15	2:30	2:15	2:10	2:15
R32	2:15	2:15	2:15	2:15	2:15	2:15	2:15	2:30	2:15	2:15	2:30	2:15	2:10	2:15

Table 7-4. Time to Clear 100 Percent of the 2-Mile Region within the Indicated Region

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Weekend	Midweek
Scenario:	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
Region	Midday		Midday		Evening	Midday			Midday			Evening	Midday	Midday
	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Snow	Good Weather	Rain	Snow	Good Weather	Special Event	Roadway Impact
Unstaged Evacuation - 2-Mile Region 5-Mile Region														
R01	4:15	4:15	4:15	4:15	4:15	4:15	4:15	5:15	4:15	4:15	5:15	4:15	4:15	4:15
R02	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
Unstaged Evacuation - 2-Mile Region and Keyhole to 5-Miles														
R04	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R05	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R06	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R07	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:15	4:20	4:20	5:20	4:20	4:20	4:20
R08	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R09	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R10	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
Staged Evacuation - 2-Mile Region and Keyhole to 5-Miles														
R25	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R26	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R27	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R28	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R29	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R30	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R31	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20
R32	4:20	4:20	4:20	4:20	4:20	4:20	4:20	5:20	4:20	4:20	5:20	4:20	4:20	4:20

Table 8-7. School Evacuation Time Estimates – Good Weather

School	Driver Mobilization Time (min)	Loading Time (min)	Dist. To EPZ Bdry (mi)	Average Speed (mph)	Travel Time to EPZ Bdry (min)	ETE (hr:min)	Dist. EPZ Bdry to R.C. (mi.)	Travel Time from EPZ Bdry to H.S. (min)	ETE to R.C. (hr:min)
Chesterfield Schools									
McBee Elementary School	90	15	3.9	45.0	5	**1:50**	19.2	26	**2:20**
McBee High School	90	15	3.4	45.0	5	**1:50**	19.2	26	**2:20**
McBee Headstart	90	15	7.4	45.0	10	**1:55**	19.2	26	**2:25**
Darlington Schools									
Lakeview Baptist Church School	90	15	15.5	39.5	24	**2:10**	18.2	24	**2:35**
Carolina Elementary School	90	15	9.9	39.2	15	**2:00**	18.2	24	**2:25**
North Hartsville Elementary School	90	15	10.2	39.0	16	**2:05**	18.2	24	**2:30**
First Presbyterian Church School	90	15	9.2	38.2	14	**2:00**	18.2	24	**2:25**
Hartsville Middle School	90	15	9.5	38.2	15	**2:00**	18.2	24	**2:25**
Hartsville Senior High School	90	15	9.3	38.6	14	**2:00**	18.2	24	**2:25**
Washington Street Elementary School	90	15	8.5	38.6	13	**2:00**	18.2	24	**2:25**
Southside Early Childhood Center	90	15	7.0	15.5	27	**2:15**	18.2	24	**2:40**
1st Baptist Church Preschool	90	15	9.1	37.9	14	**2:00**	18.2	24	**2:25**
Coker College	90	15	9.4	41.1	14	**2:00**	18.2	24	**2:25**
Thornwell School for the Arts	90	15	11.4	42.1	16	**2:05**	18.2	24	**2:30**
Governor's School for Science & Math	90	15	9.5	40.3	14	**2:00**	18.2	24	**2:25**
Eastside Christian Academy	90	15	11.1	42.1	16	**2:05**	18.2	24	**2:30**
Emmanuel Christian School	90	15	11.5	42.0	16	**2:05**	18.2	24	**2:30**
Calvary Christian School	90	15	1.9	45.0	3	**1:50**	14.7	20	**2:10**
Forest Hills Academy	90	15	10.2	43.2	14	**2:00**	18.2	24	**2:25**
West Hartsville Elementary School	90	15	10.8	43.2	15	**2:00**	18.2	24	**2:25**
Thomas Hart Academy	90	15	5.1	43.2	7	**1:55**	18.2	24	**2:20**
					Maximum for EPZ:	**2:15**		**Maximum:**	**2:40**
					Average for EPZ:	**2:00**		**Average:**	**2:25**

Table 8-8. School Evacuation Time Estimates - Rain

School	Driver Mobilization Time (min)	Loading Time (min)	Dist. To EPZ Bdry (mi)	Average Speed (mph)	Travel Time to EPZ Bdry (min)	ETE (hr:min)	Dist. EPZ Bdry to R.C. (mi.)	Travel Time from EPZ Bdry to H.S. (min)	ETE to R.C. (hr:min)
Chesterfield Schools									
McBee Elementary School	100	20	3.9	40.0	6	**2:10**	19.2	29	**2:40**
McBee High School	100	20	3.4	40.0	5	**2:05**	19.2	29	**2:35**
McBee Headstart	100	20	7.4	40.0	11	**2:15**	19.2	29	**2:45**
Darlington Schools									
Lakeview Baptist Church School	100	20	15.5	36.0	26	**2:30**	18.2	27	**3:00**
Carolina Elementary School	100	20	9.9	34.8	17	**2:20**	18.2	27	**2:50**
North Hartsville Elementary School	100	20	10.2	34.9	18	**2:20**	18.2	27	**2:50**
First Presbyterian Church School	100	20	9.2	35.1	16	**2:20**	18.2	27	**2:50**
Hartsville Middle School	100	20	9.5	35.1	16	**2:20**	18.2	27	**2:50**
Hartsville Senior High School	100	20	9.3	35.4	16	**2:20**	18.2	27	**2:50**
Washington Street Elementary School	100	20	8.5	34.2	15	**2:15**	18.2	27	**2:45**
Southside Early Childhood Center	100	20	7.0	12.8	33	**2:35**	18.2	27	**3:05**
1st Baptist Church Preschool	100	20	9.1	34.9	16	**2:20**	18.2	27	**2:50**
Coker College	100	20	9.4	38.0	15	**2:15**	18.2	27	**2:45**
Thornwell School for the Arts	100	20	11.4	38.5	18	**2:20**	18.2	27	**2:50**
Governor's School for Science & Math	100	20	9.5	38.0	15	**2:15**	18.2	27	**2:45**
Eastside Christian Academy	100	20	11.1	38.5	17	**2:20**	18.2	27	**2:50**
Emmanuel Christian School	100	20	11.5	38.3	18	**2:20**	18.2	27	**2:50**
Calvary Christian School	100	20	1.9	40.0	3	**2:05**	14.7	22	**2:30**
Forest Hills Academy	100	20	10.2	40.0	15	**2:15**	18.2	27	**2:45**
West Hartsville Elementary School	100	20	10.8	40.0	16	**2:20**	18.2	27	**2:50**
Thomas Hart Academy	100	20	5.1	40.0	8	**2:10**	18.2	27	**2:40**
					Maximum for EPZ:	**2:35**		**Maximum:**	**3:05**
					Average for EPZ:	**2:20**		**Average:**	**2:50**

Table 8-9. School Evacuation Time Estimates - Snow

School	Driver Mobilization Time (min)	Loading Time (min)	Dist. To EPZ Bdry (mi)	Average Speed (mph)	Travel Time to EPZ Bdry (min)	ETE (hr:min)	Dist. EPZ Bdry to R.C. (mi.)	Travel Time from EPZ Bdry to H.S. (min)	ETE to R.C. (hr:min)
Chesterfield Schools									
McBee Elementary School	110	25	3.9	33.1	7	**2:25**	19.2	33	**3:00**
McBee High School	110	25	3.4	33.1	6	**2:25**	19.2	33	**3:00**
McBee Headstart	110	25	7.4	31.7	14	**2:30**	19.2	33	**3:05**
Darlington Schools									
Lakeview Baptist Church School	110	25	15.5	32.7	28	**2:45**	18.2	31	**3:20**
Carolina Elementary School	110	25	9.9	31.5	19	**2:35**	18.2	31	**3:10**
North Hartsville Elementary School	110	25	10.2	31.6	19	**2:35**	18.2	31	**3:10**
First Presbyterian Church School	110	25	9.2	31.6	17	**2:35**	18.2	31	**3:10**
Hartsville Middle School	110	25	9.5	31.6	18	**2:35**	18.2	31	**3:10**
Hartsville Senior High School	110	25	9.3	31.8	18	**2:35**	18.2	31	**3:10**
Washington Street Elementary School	110	25	8.5	31.8	16	**2:35**	18.2	31	**3:10**
Southside Early Childhood Center	110	25	7.0	10.9	38	**2:55**	18.2	31	**3:30**
1st Baptist Church Preschool	110	25	9.1	31.5	17	**2:35**	18.2	31	**3:10**
Coker College	110	25	9.4	33.4	17	**2:35**	18.2	31	**3:10**
Thornwell School for the Arts	110	25	11.4	33.7	20	**2:35**	18.2	31	**3:10**
Governor's School for Science & Math	110	25	9.5	33.3	17	**2:35**	18.2	31	**3:10**
Eastside Christian Academy	110	25	11.1	33.4	20	**2:35**	18.2	31	**3:10**
Emmanuel Christian School	110	25	11.5	33.5	21	**2:40**	18.2	31	**3:15**
Calvary Christian School	110	25	1.9	35.0	3	**2:20**	14.7	25	**2:45**
Forest Hills Academy	110	25	10.2	34.9	18	**2:35**	18.2	31	**3:10**
West Hartsville Elementary School	110	25	10.8	34.9	19	**2:35**	18.2	31	**3:10**
Thomas Hart Academy	110	25	5.1	35.0	9	**2:25**	18.2	31	**3:00**
					Maximum for EPZ:	**2:55**		**Maximum:**	**3:30**
					Average for EPZ:	**2:35**		**Average:**	**3:10**

Table 8-11. Transit-Dependent Evacuation Time Estimates – Good Weather

		One-Wave							Two-Wave					
Route Number	Bus Number	Mobilization (min)	Route Length (miles)	Speed (mph)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)	Distance to R. C. (miles)	Travel Time to R. C. (min)	Unload (min)	Driver Rest (min)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)
1	4	90	10.4	17.4	36	30	2:40	14.7	20	5	10	49	30	4:35
	3	105	10.4	18.1	34	30	2:50	14.7	20	5	10	49	30	4:45
2	3	90	13.7	16.7	49	30	2:50	14.7	20	5	10	58	30	4:55
	2	105	13.7	17.6	47	30	3:05	14.7	20	5	10	58	30	5:10
3	2	90	12.8	17.7	43	30	2:45	14.7	20	5	10	56	30	4:50
	1	105	12.8	18.4	42	30	3:00	14.7	20	5	10	56	30	5:05
4	2	90	5.5	40.0	8	30	2:10	14.7	20	5	10	35	30	3:50
	1	105	5.5	40.0	8	30	2:25	14.7	20	5	10	35	30	4:05
5	1	90	6.5	40.0	10	30	2:10	14.7	20	5	10	38	30	3:55
	1	105	6.5	40.0	10	30	2:25	14.7	20	5	10	38	30	4:10
6	2	90	7.2	40.0	11	30	2:15	14.7	20	5	10	40	30	4:00
	1	105	7.2	40.0	11	30	2:30	14.7	20	5	10	41	30	4:20
7	1	90	4.3	5.8	44	30	2:45	14.3	19	5	10	31	30	4:25
	1	105	4.3	7.5	34	30	2:50	14.3	19	5	10	31	30	4:30
8	1	90	7.9	9.8	49	30	2:50	14.3	19	5	10	41	30	4:40
9	3	90	13.0	20.0	39	30	2:40	14.7	20	5	10	56	30	4:45
	2	105	13.0	20.9	37	30	2:55	14.7	20	5	10	56	30	5:00
10	4	90	14.3	15.8	54	30	2:55	14.7	20	5	10	60	30	5:00
	3	105	14.3	16.2	53	30	3:10	14.7	20	5	10	60	30	5:15
11	3	90	5.8	20.4	17	30	2:20	14.7	20	5	10	36	30	4:05
	2	105	5.8	23.2	15	30	2:30	14.7	20	5	10	36	30	4:15
						Maximum ETE:	3:10						Maximum ETE:	5:15
						Average ETE:	2:40						Average ETE:	4:35

Table 8-12. Transit-Dependent Evacuation Time Estimates - Rain

		One-Wave							Two-Wave					
Route Number	Bus Number	Mobilization (min)	Route Length (miles)	Speed (mph)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)	Distance to R. C. (miles)	Travel Time to R. C. (min)	Unload (min)	Driver Rest (min)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)
1	4	100	10.4	14.5	43	40	**3:05**	14.7	22	5	10	52	40	**5:15**
	3	115	10.4	14.8	42	40	**3:20**	14.7	22	5	10	52	40	**5:30**
2	3	100	13.7	13.9	59	40	**3:20**	14.7	22	5	10	62	40	**5:40**
	2	115	13.7	14.6	56	40	**3:35**	14.7	22	5	10	62	40	**5:55**
3	2	100	12.8	14.7	52	40	**3:15**	14.7	22	5	10	58	40	**5:35**
	1	115	12.8	15.0	51	40	**3:30**	14.7	22	5	10	58	40	**5:50**
4	2	100	5.5	40.0	8	40	**2:30**	14.7	22	5	10	38	40	**4:30**
	1	115	5.5	40.0	8	40	**2:45**	14.7	22	5	10	38	40	**4:45**
5	1	100	6.5	39.5	10	40	**2:30**	14.7	22	5	10	41	40	**4:30**
	1	115	6.5	40.0	10	40	**2:45**	14.7	22	5	10	41	40	**4:45**
6	2	100	7.2	40.0	11	40	**2:35**	14.7	22	5	10	43	40	**4:40**
	1	115	7.2	40.0	11	40	**2:50**	14.7	22	5	10	42	40	**4:50**
7	1	100	4.3	6.8	38	40	**3:00**	14.3	21	5	10	34	40	**4:55**
	1	115	4.3	9.3	28	40	**3:05**	14.3	21	5	10	34	40	**5:00**
8	1	100	7.9	12.0	39	40	**3:00**	14.3	21	5	10	44	40	**5:05**
9	3	100	13.0	16.7	47	40	**3:10**	14.7	22	5	10	59	40	**5:30**
	2	115	13.0	17.3	45	40	**3:20**	14.7	22	5	10	59	40	**5:40**
10	4	100	14.3	13.3	64	40	**3:25**	14.7	22	5	10	66	40	**5:50**
	3	115	14.3	14.0	61	40	**3:40**	14.7	22	5	10	66	40	**6:05**
11	3	100	5.8	22.2	16	40	**2:40**	14.7	22	5	10	38	40	**4:40**
	2	115	5.8	34.7	10	40	**2:45**	14.7	22	5	10	38	40	**4:45**
						Maximum ETE:	**3:40**						**Maximum ETE:**	**6:05**
						Average ETE:	**3:05**						**Average ETE:**	**5:15**

Table 8-13. Transit Dependent Evacuation Time Estimates - Snow

		One-Wave						Two-Wave						
Route Number	Bus Number	Mobilization (min)	Route Length (miles)	Speed (mph)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)	Distance to R. C. (miles)	Travel Time to R. C. (min)	Unload (min)	Driver Rest (min)	Route Travel Time (min)	Pickup Time (min)	ETE (hr:min)
1	4	110	10.4	12.4	50	50	**3:30**	14.7	25	5	10	57	50	**6:00**
	3	125	10.4	12.6	49	50	**3:45**	14.7	25	5	10	57	50	**6:15**
2	3	110	13.7	12.5	66	50	**3:50**	14.7	25	5	10	67	50	**6:30**
	2	125	13.7	13.0	63	50	**4:00**	14.7	25	5	10	68	50	**6:40**
3	2	110	12.8	12.7	61	50	**3:45**	14.7	25	5	10	64	50	**6:20**
	1	125	12.8	13.2	58	50	**3:55**	14.7	25	5	10	64	50	**6:30**
4	2	110	5.5	35.0	9	50	**2:50**	14.7	25	5	10	42	50	**5:05**
	1	125	5.5	35.0	9	50	**3:05**	14.7	25	5	10	42	50	**5:20**
5	1	110	6.5	35.0	11	50	**2:55**	14.7	25	5	10	45	50	**5:15**
	1	125	6.5	35.0	11	50	**3:10**	14.7	25	5	10	46	50	**5:30**
6	2	110	7.2	35.0	12	50	**2:55**	14.7	25	5	10	47	50	**5:15**
	1	125	7.2	34.7	12	50	**3:10**	14.7	25	5	10	47	50	**5:30**
7	1	110	4.3	8.7	30	50	**3:10**	14.3	25	5	10	38	50	**5:20**
	1	125	4.3	14.5	18	50	**3:15**	14.3	25	5	10	38	50	**5:25**
8	1	110	7.9	14.2	33	50	**3:15**	14.3	25	5	10	49	50	**5:35**
9	3	110	13.0	14.3	55	50	**3:35**	14.7	25	5	10	65	50	**6:15**
	2	125	13.0	14.7	53	50	**3:50**	14.7	25	5	10	65	50	**6:30**
10	4	110	14.3	11.9	72	50	**3:55**	14.7	25	5	10	71	50	**6:40**
	3	125	14.3	12.4	69	50	**4:05**	14.7	25	5	10	72	50	**6:50**
11	3	110	5.8	35.0	10	50	**2:50**	14.7	25	5	10	43	50	**5:05**
	2	125	5.8	35.0	10	50	**3:05**	14.7	25	5	10	43	50	**5:20**
						Maximum ETE:	**4:05**						**Maximum ETE:**	**6:50**
						Average ETE:	**3:25**						**Average ETE:**	**5:55**

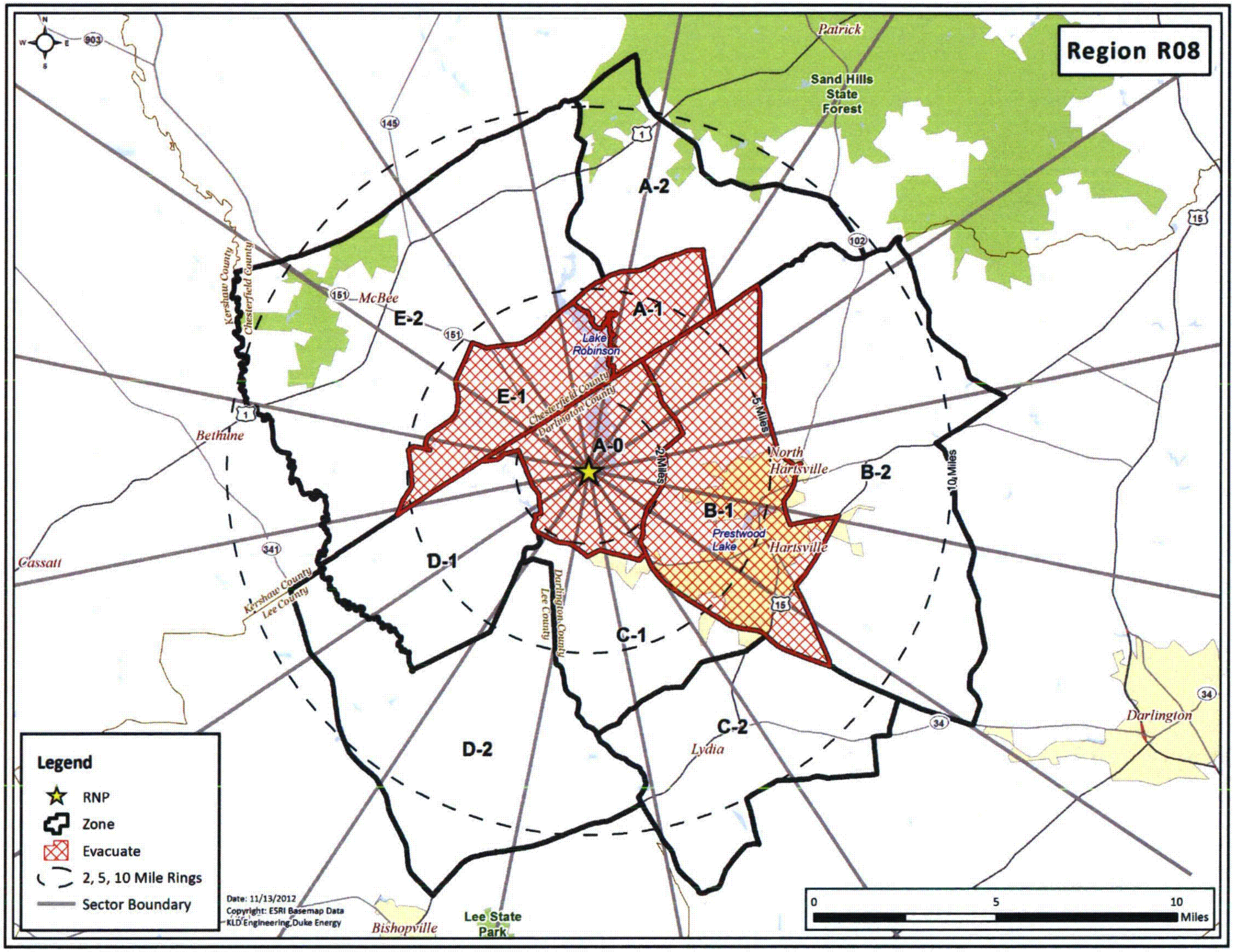

Figure H-8. Region R08

1 INTRODUCTION

This report describes the analyses undertaken and the results obtained by a study to develop Evacuation Time Estimates (ETE) for the Robinson Nuclear Plant (RNP), also known as the H. B. Robinson Steam Electric Plant, Unit No. 2, located in Darlington County, South Carolina. ETE provide Progress Energy and State and local governments with site-specific information needed for Protective Action decision-making.

In the performance of this effort, guidance is provided by documents published by Federal Governmental agencies. Most important of these are:

- Criteria for Development of Evacuation Time Estimate Studies, NUREG/CR-7002, November 2011.
- Criteria for Preparation and Evaluation of Radiological Emergency Response Plans and Preparedness in Support of Nuclear Power Plants, NUREG 0654/FEMA REP 1, Rev. 1, November 1980.
- Development of Evacuation Time Estimates for Nuclear Power Plants, NUREG/CR-6863, January 2005.
- Emergency Planning and Preparedness for Production and Utilization Facilities, 10 CFR 50, Appendix E.

The work effort reported herein was supported and guided by local stakeholders who contributed suggestions, critiques, and the local knowledge base required. Table 1-1 presents a summary of stakeholders and interactions.

Table 1-1. Stakeholder Interaction

Stakeholder	Nature of Stakeholder Interaction
Progress Energy emergency planning personnel	Kick-off meeting to define data requirements and set up contacts with local government agencies. Progress Energy acted as point of contact for data collection and reviewed and approved study assumptions. Final meeting to present results and solicit comments. Comments provided were addressed.
Chesterfield, Darlington, Florence and Lee County Emergency Management Divisions	Kick-off meeting to define data requirements. Counties reviewed and approved study assumptions. Final meeting to present results and solicit comments. Comments provided were addressed.
SC Emergency Management Division, SC Department of Health and Environmental Control	Kick-off meeting to define data requirements. Final meeting to present results and solicit comments. Comments provided were addressed.
Other agencies (e.g. GIS departments)	Communication to define data requirements

1.1 Overview of the ETE Process

The following outline presents a brief description of the work effort in chronological sequence:

1. Information Gathering:
   a. Defined the scope of work in discussions with representatives from Progress Energy.
   b. Attended meetings with emergency planners from Darlington, Chesterfield, Lee and Florence County Emergency Management Divisions as well as SC EMD and South Carolina Department of Health and Environmental Control (SC DHEC) to identify issues to be addressed and resources available.
   c. Conducted a detailed field survey of the highway system and of area traffic conditions within the Emergency Planning Zone (EPZ[1]) and Shadow Region.
   d. Obtained demographic data from the 2010 census and Chesterfield, Darlington and Lee County agencies.
   e. Conducted a random sample telephone survey of EPZ residents.
   f. Conducted a data collection effort to identify and describe schools, special facilities, major employers, transportation providers, and other important information.
2. Estimated distributions of Trip Generation times representing the time required by various population groups (permanent residents, employees, and transients) to prepare (mobilize) for the evacuation trip. These estimates are primarily based upon the random sample telephone survey.
3. Defined Evacuation Scenarios. These scenarios reflect the variation in demand, in trip generation distribution and in highway capacities, associated with different seasons, day of week, time of day and weather conditions.
4. Reviewed the existing traffic management plan to be implemented by local and state police in the event of an incident at the plant. Traffic control is applied at specified Traffic Control Points (TCPs) located within the EPZ.
5. Used existing Zones to define Evacuation Regions. The EPZ is partitioned into 11 Zones along jurisdictional and geographic boundaries. "Regions" are groups of contiguous Zones for which ETE are calculated. The configurations of these Regions reflect wind direction and the radial extent of the impacted area. Each Region, other than those that approximate circular areas, approximates a "key-hole section" within the EPZ as recommended by NUREG/CR-7002.
6. Estimated demand for transit services for persons at "Special Facilities" and for transit-dependent persons at home.

[1] All references to EPZ refer to the plume exposure pathway EPZ.

7. Prepared the input streams for the DYNEV II system which computes the ETE (see Appendices B and C).
    a. Estimated the evacuation traffic demand, based on the available information derived from Census data, and from data provided by local and state agencies, Progress Energy and from the telephone survey.
    b. Applied the procedures specified in the 2010 Highway Capacity Manual (HCM[2]) to the data acquired during the field survey, to estimate the capacity of all highway segments comprising the evacuation routes.
    c. Developed the link-node representation of the evacuation network, which is used as the basis for the computer analysis that calculates the ETE.
    d. Calculated the evacuating traffic demand for each Region and for each Scenario.
    e. Specified selected candidate destinations for each "origin" (location of each "source" where evacuation trips are generated over the mobilization time) to support evacuation travel consistent with outbound movement relative to the location of the Robinson Nuclear Plant.
8. Executed the DYNEV II model to determine optimal evacuation routing and compute ETE for all residents, transients and employees ("general population") with access to private vehicles. Generated a complete set of ETE for all specified Regions and Scenarios.
9. Documented ETE in formats in accordance with NUREG/CR-7002.
10. Calculated the ETE for all transit activities including those for schools and special facilities, for the transit-dependent population and for homebound special needs population.

1.2 The Robinson Nuclear Power Plant Location

Robinson Nuclear Plant (RNP) is located in northeastern South Carolina, approximately five miles west-northwest of Hartsville. The nearest large city is Columbia, South Carolina, approximately 55 miles southwest. The site is approximately 30 miles south of the North Carolina border and 90 miles from the Atlantic Ocean. Figure 1-1 displays the area surrounding the RNP. This map identifies the major cities and communities in the area as well as the major roads.

[2] Highway Capacity Manual (HCM 2010), Transportation Research Board, National Research Council, 2010.

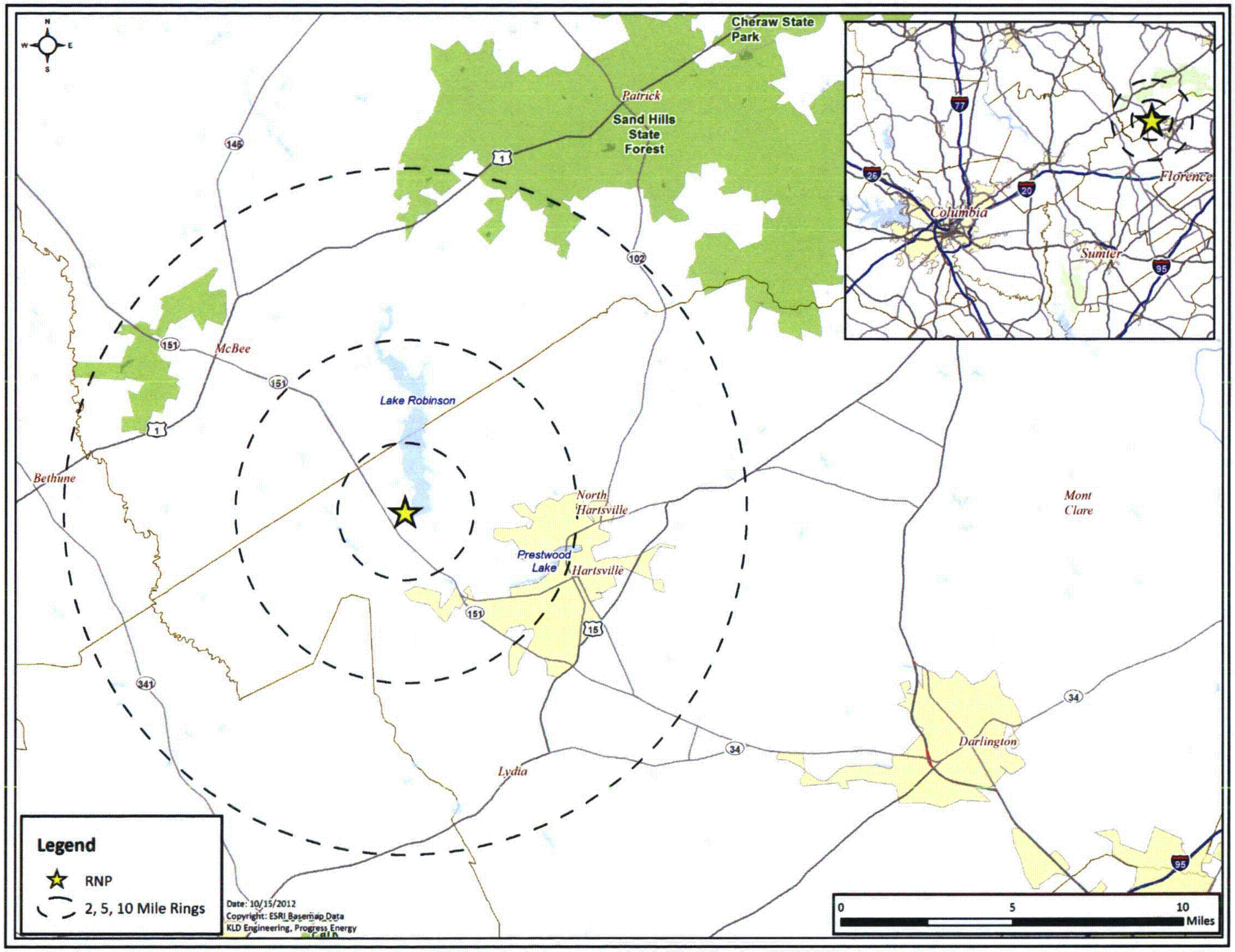

Figure 1-1. RNP Location

1.3 Preliminary Activities

These activities are described below.

Field Surveys of the Highway Network

KLD personnel drove the entire highway system within the EPZ and the Shadow Region which consists of the area between the EPZ boundary and approximately 15 miles radially from the plant. The characteristics of each section of highway were recorded. These characteristics are shown in Table 1-2:

Table 1-2. Highway Characteristics

- Number of lanes
- Lane width
- Shoulder type & width
- Interchange geometries
- Lane channelization & queuing capacity (including turn bays/lanes)
- Geometrics: curves, grades (>4%)
- Posted speed
- Actual free speed
- Abutting land use
- Control devices
- Intersection configuration (including roundabouts where applicable)
- Traffic signal type
- Unusual characteristics: Narrow bridges, sharp curves, poor pavement, flood warning signs, inadequate delineations, toll booths, etc.

Video and audio recording equipment were used to capture a permanent record of the highway infrastructure. No attempt was made to meticulously measure such attributes as lane width and shoulder width; estimates of these measures based on visual observation and recorded images were considered appropriate for the purpose of estimating the capacity of highway sections. For example, Exhibit 15-7 in the HCM indicates that a reduction in lane width from 12 feet (the "base" value) to 10 feet can reduce free flow speed (FFS) by 1.1 mph – not a material difference – for two-lane highways. Exhibit 15-30 in the HCM shows little sensitivity for the estimates of Service Volumes at Level of Service (LOS) E (near capacity), with respect to FFS, for two-lane highways.

The data from the audio and video recordings were used to create detailed geographical information systems (GIS) shapefiles and databases of the roadway characteristics and of the traffic control devices observed during the road survey; this information was referenced while preparing the input stream for the DYNEV II system.

As documented on page 15-5 of the HCM 2010, the capacity of a two-lane highway is 1700 passenger cars per hour in one direction. For freeway sections, a value of 2250 vehicles per hour per lane is assigned, as per Exhibit 11-17 of the HCM 2010. The road survey has identified several segments which are characterized by adverse geometrics on two-lane highways which are reflected in reduced values for both capacity and speed. These estimates are consistent with the service volumes for LOS E presented in HCM Exhibit 15-30. These links may be identified by reviewing Appendix K. Link capacity is an input to DYNEV II. Further discussion of roadway capacity is provided in Section 4 of this report.

Traffic signals are either pre-timed (signal timings are fixed over time and do not change with the traffic volume on competing approaches), or are actuated (signal timings vary over time based on the changing traffic volumes on competing approaches). Actuated signals require detectors to provide the traffic data used by the signal controller to adjust the signal timings. These detectors are typically magnetic loops in the roadway, or video cameras mounted on the signal masts and pointed toward the intersection approaches. If detectors were observed on the approaches to a signalized intersection during the road survey, detailed signal timings were not collected as the timings vary with traffic volume. TCPs at locations which have control devices are represented as actuated signals in the DYNEV II system.

If no detectors were observed, the signal control at the intersection was considered pre-timed, and detailed signal timings were gathered for several signal cycles. These signal timings were input to the DYNEV II system used to compute ETE, as per NUREG/CR-7002 guidance.

Figure 1-2 presents the link-node analysis network that was constructed to model the evacuation roadway network in the EPZ and Shadow Region. The directional arrows on the links and the node numbers have been removed from Figure 1-2 to clarify the figure. The detailed figures provided in Appendix K depict the analysis network with directional arrows shown and node numbers provided. The observations made during the field survey were used to calibrate the analysis network.

<u>Telephone Survey</u>

A telephone survey was undertaken to gather information needed for the evacuation study. Appendix F presents the survey instrument, the procedures used and tabulations of data compiled from the survey returns.

These data were utilized to develop estimates of vehicle occupancy to estimate the number of evacuating vehicles during an evacuation and to estimate elements of the mobilization process. This database was also referenced to estimate the number of transit-dependent residents.

<u>Computing the Evacuation Time Estimates</u>

The overall study procedure is outlined in Appendix D. Demographic data were obtained from several sources, as detailed later in this report. These data were analyzed and converted into vehicle demand data. The vehicle demand was loaded onto appropriate "source" links of the analysis network using GIS mapping software. The DYNEV II system was then used to compute ETE for all Regions and Scenarios.

<u>Analytical Tools</u>

The DYNEV II System that was employed for this study is comprised of several integrated computer models. One of these is the DYNEV (<u>DY</u>namic <u>N</u>etwork <u>EV</u>acuation) macroscopic simulation model, a new version of the IDYNEV model that was developed by KLD under contract with the Federal Emergency Management Agency (FEMA).

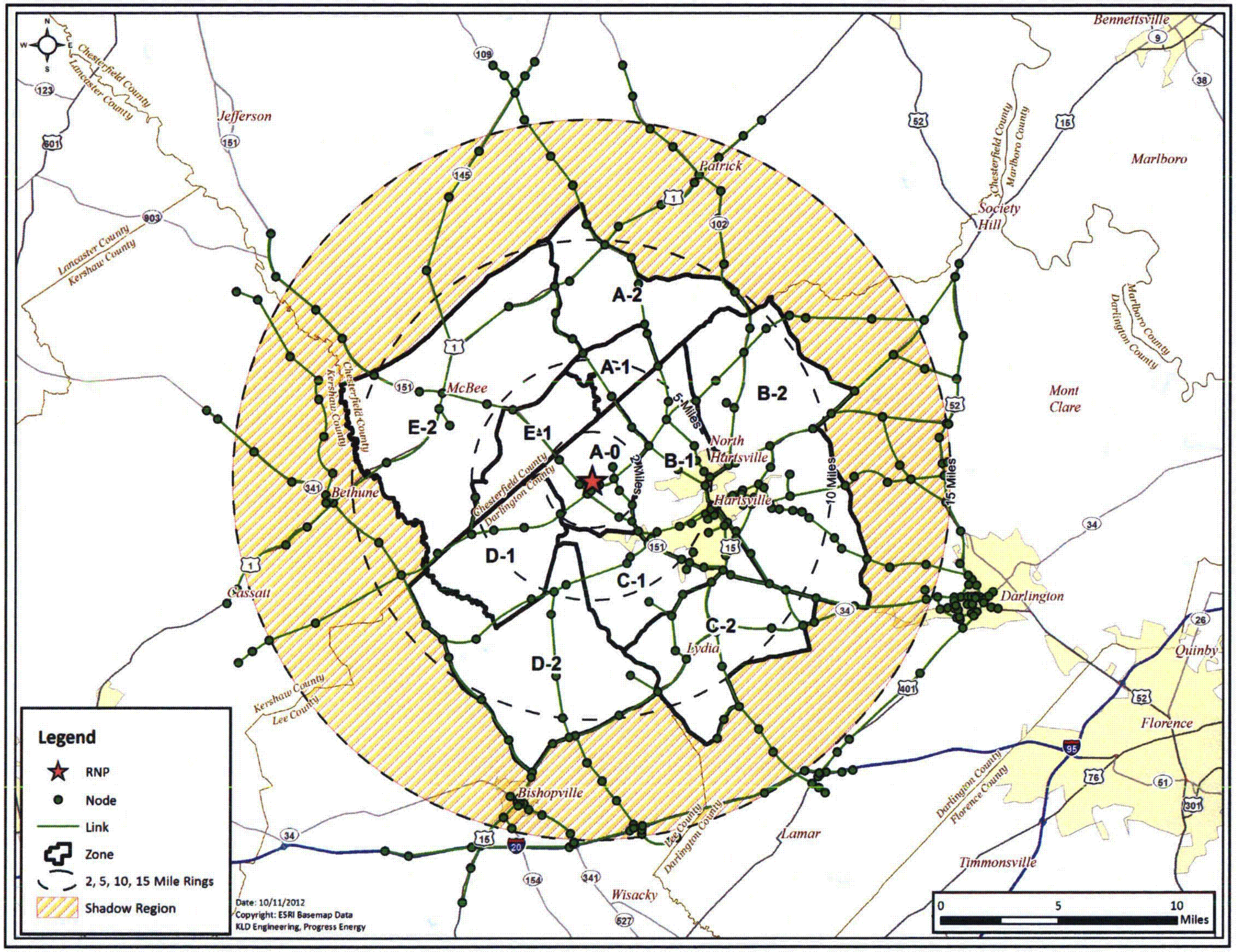

Figure 1-2. RNP Link-Node Analysis Network

DYNEV II consists of four sub-models:

- A macroscopic traffic simulation model (for details, see Appendix C).
- A Trip Distribution (TD) model that assigns a set of candidate destination (D) nodes for each "origin" (O) located within the analysis network, where evacuation trips are "generated" over time. This establishes a set of O-D tables.
- A Dynamic Traffic Assignment (DTA) model which assigns trips to paths of travel (routes) which satisfy the O-D tables, over time. The TD and DTA models are integrated to form the DTRAD (Dynamic Traffic Assignment and Distribution) model, as described in Appendix B.
- A Myopic Traffic Diversion model which diverts traffic to avoid intense, local congestion, if possible.

Another software product developed by KLD, named UNITES (UNIfied Transportation Engineering System) was used to expedite data entry and to automate the production of output tables.

The dynamics of traffic flow over the network are graphically animated using the software product, EVAN (EVacuation ANimator), developed by KLD. EVAN is GIS based, and displays statistics such as LOS, vehicles discharged, average speed, and percent of vehicles evacuated, output by the DYNEV II System. The use of a GIS framework enables the user to zoom in on areas of congestion and query road name, town name and other geographical information.

The procedure for applying the DYNEV II System within the framework of developing ETE is outlined in Appendix D. Appendix A is a glossary of terms.

For the reader interested in an evaluation of the original model, I-DYNEV, the following references are suggested:

- NUREG/CR-4873 – Benchmark Study of the I-DYNEV Evacuation Time Estimate Computer Code
- NUREG/CR-4874 – The Sensitivity of Evacuation Time Estimates to Changes in Input Parameters for the I-DYNEV Computer Code

The evacuation analysis procedures are based upon the need to:

- Route traffic along paths of travel that will expedite their travel from their respective points of origin to points outside the EPZ.
- Restrict movement toward the plant to the extent practicable, and disperse traffic demand so as to avoid focusing demand on a limited number of highways.
- Move traffic in directions that are generally outbound, relative to the location of the RNP.

DYNEV II provides a detailed description of traffic operations on the evacuation network. This description enables the analyst to identify bottlenecks and to develop countermeasures that are designed to represent the behavioral responses of evacuees. The effects of these countermeasures may then be tested with the model.

1.4 Comparison with Prior ETE Study

Table 1-3 presents a comparison of the present ETE study with the 2006 study. The factors contributing to the differences between the ETE values obtained in this study and those of the previous study can be summarized as follows:

- Changes which cause an increase in the ETE
    - Transit-dependent households assigned one vehicle per household in the 2006 study; evacuated on buses in this study.
    - Decrease in the resident vehicle occupancy of approximately 25%.
    - A small increase in permanent resident population.
    - Voluntary and shadow evacuations are considered.
    - Longer 100% mobilization time.
- Changes which cause a decrease in the ETE
    - Bad weather (rain and snow) reductions in free-flow speed and roadway capacity higher for the 2006 study.
    - DYNEV II is a dynamic evacuation model and it therefore supports dynamic route selection.
    - Decrease in the number of vehicles loaded to evacuate transit dependents.
    - Lower transient population estimate.
    - Double-counting of residents is minimized in this study by only counting employees and transients who are non-EPZ residents.
    - County and State TCPs that are listed in the emergency plans are modeled in this study. This improves the performance of those key intersections.

Table 1-3. ETE Study Comparisons

Topic	Previous ETE Study	Current ETE Study
Resident Population Basis	Population data from Synergos Technologies Population = 35,588 (est. for 2010)	ArcGIS Software using 2010 US Census blocks; area ratio method used. Population = 35,927
Resident Population Vehicle Occupancy	2.5 persons/household, 1 vehicle /household yielding 2.5 persons/vehicle	2.27 persons/household, 1.20 evacuating vehicles/household yielding: 1.89 persons/vehicle.

Topic	Previous ETE Study	Current ETE Study
Employee Population	From 2006, first-quarter population estimates obtained from Synergos Technologies, Inc. Employees =3,680	Employee estimates based on information provided about major employers in EPZ, supplemented by telephone calls to individual employers. 1.05 employees per vehicle based on telephone survey results. Employees = 2,918
Transit-Dependent Population	Estimated 11% of households have no vehicle. One vehicle per transit-dependent household is added to the model to represent the use of a friend's or family member's car or a public evacuation vehicle.	Estimates based upon U.S. Census data and the results of the telephone survey. A total of 1,130 people who do not have access to a vehicle, requiring at least 38 buses to evacuate. An additional 59 homebound special needs persons needed special transportation to evacuate (51 require a bus, 8 require an ambulance).
Transient Population	Transient estimates based on discussions with Progress Energy, local emergency managers and information on Carolina Sandhills National Wildlife Refuge and supplemented by previous report. Transients = 18,715	Transient estimates based upon information provided about transient attractions in EPZ, observations of the facilities during the road survey, tourist information and internet searches. See Section 3 for details. Transients = 380
Special Facilities Population	Special facility population based on information provided by each county within the EPZ. Special Facility Population = 1,438 (includes staff) Patients: 25 / vehicle Staff: 1 / vehicle	Special facility population based on information provided by each county within the EPZ. Current census = 454 Buses Required = 9 Wheelchair Vans Required = 31 (capacity 4 per bus) Ambulances Required = 70
School Population	Local school data was obtained from commercially available geographic information system (GIS) data and through contact with individual facilities. School enrollment = 8,531, 52 students per bus. College 1.5 students per vehicle	School population based on information provided by each county within the EPZ. Includes Coker College and Daycares. School enrollment = 8,918 Buses required = 173 Commuter college students 1.05 per vehicle, on average.

Topic	Previous ETE Study	Current ETE Study
Voluntary evacuation from within EPZ in areas outside region to be evacuated	Not considered	20 percent of the population within the EPZ, but not within the Evacuation Region (see Figure 2-1)
Shadow Evacuation	Not considered	20% of people outside of the EPZ within the Shadow Region (see Figure 7-2)
Network Size	1,873 links	487 links; 332 nodes
Roadway Geometric Data	Geometric data from NAVTEQ street network data and validated by field surveys conducted in 2006. Road capacities based on 2000 HCM.	Field surveys conducted in April 2012. Roads and intersections were video archived. Road capacities based on 2010 HCM.
School Evacuation	Direct evacuation to designated Relocation Center.	Direct evacuation to designated Relocation Center.
Ridesharing	Not applicable -- one vehicle added per household with no vehicles of their own.	50 percent of transit-dependent persons will evacuate with a neighbor or friend.
Trip Generation for Evacuation	Notification complete within 90 minutes. Trip Generation curves adapted from data collected during evacuations in response to chemical spills. One mobilization curve for all population groups. Trip generation between 5 and 140 minutes.	Notification complete within 45 minutes Trip generation time based on residential telephone survey of specific pre-trip mobilization activities: Residents with commuters returning leave between 20 and 255 minutes. Residents without commuters returning leave between 10 and 165 minutes. Employees and transients leave between 5 and 120 minutes. All times measured from the Advisory to Evacuate.
Weather	Good weather and adverse weather conditions. The capacity and free flow speed of all links in the network are reduced by 25% and 40% respectively for adverse weather.	Normal, Rain, or Snow. The capacity and free flow speed of all links in the network are reduced by 10% in the event of rain and 20% for snow.
Modeling	PTV Vision VISUM and VISSIM simulation models	DYNEV II System – Version 4.0.15.0

Topic	Previous ETE Study	Current ETE Study
Special Events	None considered	Darlington NASCAR race Peak Special Event Population = 60,000 (including residents) Peak number transients = 15,000 transient vehicles
Evacuation Cases	13 Regions and 16 Scenarios producing 204 unique cases for 2006 population and 104 for 2010 population estimate.	32 Regions (central sector wind direction and each adjacent sector technique used) and 14 Scenarios producing 448 unique cases.
Evacuation Time Estimates Reporting	ETE results presented by Evacuation Area and Scenario.	ETE reported for 90th and 100th percentile population. Results presented by Region and Scenario.
Evacuation Time Estimates for the entire EPZ	2010, Winter, Weekday, Midday, Good Weather: 12:05 2010, Summer Weekend, Midday, Good Weather: 8:55 (Report does not state whether 90th or 100th percentile ETE)	**90th percentile**: Winter Weekday Midday, Good Weather: 2:35 Summer Weekend, Midday, Good Weather: 2:25 **100th percentile:** Winter Weekday Midday, Good Weather: 4:25 Summer Weekend, Midday, Good Weather: 4:25

2 STUDY ESTIMATES AND ASSUMPTIONS

This section presents the estimates and assumptions utilized in the development of the evacuation time estimates.

2.1 Data Estimates

1. Permanent resident population estimates are based upon Census 2010 data.
2. Estimates of employees who reside outside the EPZ and commute to work within the EPZ are based upon data obtained from the U.S. Census Bureau, Center for Economic Studies and surveys of major employers in the EPZ.
3. Population estimates at special facilities are based on available data from county emergency management offices and from phone calls to specific facilities.
4. Roadway capacity estimates are based on field surveys and the application of the Highway Capacity Manual 2010.
5. Population mobilization times are based on a statistical analysis of data acquired from a random sample telephone survey of EPZ residents (see Section 5 and Appendix F).
6. The relationship between resident population and evacuating vehicles is developed from the telephone survey. Average values of 2.27 persons per household and 1.20 evacuating vehicles per household are used. The relationship between persons and vehicles for transients and employees is as follows:
    a. Employees: 1.05 employees per vehicle (telephone survey results) for all major employers.
    b. Special Events: Data for transients attending a race weekend at the Darlington Raceway was provided by track officials, averaging at 4 persons per vehicle.
    c. Transient attractions: 2 transients per vehicle for golf courses, based on information from individual facilities. A total of 173 transients in 113 vehicles are assigned to lodging facilities in the EPZ.

2.2 Study Methodological Assumptions

1. ETE are presented for the evacuation of the 90^{th} and 100^{th} percentiles of population for each Region and for each Scenario. The percentile ETE is defined as the elapsed time from the Advisory to Evacuate issued to a specific Region of the EPZ, to the time that Region is clear of the indicated percentile of evacuees. A Region is defined as a group of zones that is issued an Advisory to Evacuate. A scenario is a combination of circumstances, including time of day, day of week, season, and weather conditions.
2. Evacuation movements (paths of travel) are generally outbound relative to the plant to the extent permitted by the highway network. All major evacuation routes are used in the analysis.
3. Regions are defined by the underlying "keyhole" or circular configurations as specified in Section 1.4 of NUREG/CR-7002. These Regions, as defined, display irregular boundaries reflecting the geography of the zones included within these underlying configurations.

4. As indicated in Figure 2-2 of NUREG/CR-7002, 100% of people within the impacted "keyhole" evacuate. 20% of those people within the EPZ, not within the impacted keyhole, will voluntarily evacuate. 20% of those people within the Shadow Region will voluntarily evacuate. See Figure 2-1 for a graphical representation of these evacuation percentages. Sensitivity studies explore the effect on ETE of increasing the percentage of voluntary evacuees in the Shadow Region (see Appendix M).
5. A total of 14 "Scenarios" representing different temporal variations (season, time of day, day of week) and weather conditions are considered. These Scenarios are outlined in Table 2-1. The two seasons used are winter and summer; winter is when schools are in session and summer is when schools are not in session.
6. Scenario 14 considers the closure of section of SR 151 southbound located directly south of the intersection with S. 5th Street in Hartsville.

Table 2-1. Evacuation Scenario Definitions

Scenario	Season[1]	Day of Week	Time of Day	Weather	Special
1	Summer	Midweek	Midday	Good	None
2	Summer	Midweek	Midday	Rain	None
3	Summer	Weekend	Midday	Good	None
4	Summer	Weekend	Midday	Rain	None
5	Summer	Midweek, Weekend	Evening	Good	None
6	Winter	Midweek	Midday	Good	None
7	Winter	Midweek	Midday	Rain	None
8	Winter	Midweek	Midday	Snow	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Snow	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Weekend	Midday	Good	Darlington NASCAR Race
14	Summer	Midweek	Midday	Good	Roadway Impact – Roadway Closure on SR 151 Southbound

[1] Winter assumes that school is in session (also applies to spring and autumn). Summer assumes that school is not in session.

Figure 2-1. Voluntary Evacuation Methodology

2.3 Study Assumptions

1. The Planning Basis Assumption for the calculation of ETE is a rapidly escalating accident that requires evacuation, and includes the following:
    a. Advisory to Evacuate is announced coincident with the siren notification.
    b. Mobilization of the general population will commence within 15 minutes after siren notification.
    c. ETE are measured relative to the Advisory to Evacuate.
2. It is assumed that everyone within the group of zones forming a Region that is issued an Advisory to Evacuate will, in fact, respond and evacuate in general accord with the planned routes.
3. 48 percent of the households in the EPZ have at least 1 commuter; 55 percent of those households with commuters will await the return of a commuter before beginning their evacuation trip, based on the telephone survey results. Therefore 26 percent (48% x 55% = 26%) of EPZ households will await the return of a commuter, prior to beginning their evacuation trip. It is assumed that the responses to the telephone survey regarding the return of commuters prior to evacuating are applicable for this study
4. The ETE will also include consideration of "through" (External-External) trips during the time that such traffic is permitted to enter the evacuated Region. "Normal" traffic flow is assumed to be present within the EPZ at the start of the emergency.
5. Access Control Points (ACP) will be staffed within approximately 120 minutes following the siren notifications, to divert traffic attempting to enter the EPZ. Earlier activation of ACP locations could delay returning commuters. It is assumed that no through traffic will enter the EPZ after this 120 minute time period.
6. Traffic Control Points (TCP) within the EPZ will be staffed over time, beginning at the Advisory to Evacuate. Their number and location will depend on the Region to be evacuated and resources available. The objectives of these TCP are:
    a. Facilitate the movements of all (mostly evacuating) vehicles at the location.
    b. Discourage inadvertent vehicle movements towards the plant.
    c. Provide assurance and guidance to any traveler who is unsure of the appropriate actions or routing.
    d. Act as local surveillance and communications center.
    e. Provide information to the emergency operations center (EOC) as needed, based on direct observation or on information provided by travelers.

    In calculating ETE, it is assumed that evacuees will drive safely, travel in directions identified in the plan, and obey all control devices and traffic guides.
7. Buses, vans, wheelchair vans and ambulances will be used to transport those without access to private vehicles (t is assumed that drivers are available for these vehicles):
    a. If schools are in session, transport (buses) will evacuate students directly to the designated relocation centers.
    b. Based on information provided, for most daycares parents will pick up children prior to evacuation; those daycares that do evacuate their students will provide transportation.

c. Buses, wheelchair vans and ambulances will evacuate patients at medical facilities and at any senior facilities within the EPZ, as needed.
d. Transit-dependent general population will be evacuated to relocation centers.
e. Schoolchildren, if school is in session, are given priority in assigning transit vehicles.
f. Bus mobilization time is considered in ETE calculations.
g. Analysis of the number of required round-trips ("waves") of evacuating transit vehicles is presented.
h. Transport of transit-dependent evacuees from relocation centers to congregate care centers is not considered in this study.

8. Provisions are made for evacuating the transit-dependent portion of the general population to relocation centers by bus, based on the assumption that some of these people will ride-share with family, neighbors, and friends, thus reducing the demand for buses. We assume that the percentage of people who rideshare is 50 percent. This assumption is based upon reported experience for other emergencies[2], and on guidance in Section 2.2 of NUREG/CR-7002.
9. Two types of adverse weather scenarios are considered. Rain may occur for either winter or summer scenarios; snow occurs in winter scenarios only. It is assumed that the rain or snow begins earlier or at about the same time the evacuation advisory is issued. No weather-related reduction in the number of transients who may be present in the EPZ is assumed. It is assumed that roads are passable and that the appropriate agencies are plowing the roads as they would normally when snowing.

   Adverse weather scenarios affect roadway capacity and the free flow highway speeds. The factors applied for the ETE study are based on recent research on the effects of weather on roadway operations[3]; the factors are shown in Table 2-2.

7. The ETE are computed and presented in tabular format and graphically, in a format compliant with NUREG/CR-7002.
8. The models of the I-DYNEV System were recognized as state of the art by the Atomic Safety & Licensing Board (ASLB) in past hearings. (Sources: Atomic Safety & Licensing Board Hearings on Seabrook and Shoreham; Urbanik[4]). The models have continuously been refined and extended since those hearings and were independently validated by a consultant retained by the NRC. The new DYNEV II model incorporates the latest technology in traffic simulation and in dynamic traffic assignment.

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[2] Institute for Environmental Studies, University of Toronto, THE MISSISSAUGA EVACUATION FINAL REPORT, June 1981. The report indicates that 6,600 people of a transit-dependent population of 8,600 people shared rides with other residents; a ride share rate of 76% (Page 5-10).

[3] Agarwal, M. et. al. Impacts of Weather on Urban Freeway Traffic Flow Characteristics and Facility Capacity, Proceedings of the 2005 Mid-Continent Transportation Research Symposium, August, 2005. The results of this paper are included as Exhibit 10-15 in the HCM 2010.

[4] Urbanik, T., et. al. Benchmark Study of the I-DYNEV Evacuation Time Estimate Computer Code, NUREG/CR-4873, Nuclear Regulatory Commission, June, 1988.

10. School buses used to transport students are assumed to transport 70 students per bus for elementary schools and 50 students per bus for middle and high schools, based on discussions with county offices of emergency management. Transit buses used to transport the transit-dependent general population are assumed to transport 30 people per bus.
11. School bus speeds are capped at 45 mph in the calculation of ETE, in order to ensure compliance with South Carolina state laws.

Table 2-2. Model Adjustment for Adverse Weather

Scenario	Highway Capacity*	Free Flow Speed*	Mobilization Time for General Population
Rain	90%	90%	No Effect
Snow	80%	80%	Clear driveway before leaving home (See Figure F-13)
*Adverse weather capacity and speed values are given as a percentage of good weather conditions. Roads are assumed to be passable.			

3 DEMAND ESTIMATION

The estimates of demand, expressed in terms of people and vehicles, constitute a critical element in developing an evacuation plan. These estimates consist of three components:

1. An estimate of population within the EPZ, stratified into groups (resident, employee, transient).
2. An estimate, for each population group, of mean occupancy per evacuating vehicle. This estimate is used to determine the number of evacuating vehicles.
3. An estimate of potential double-counting of people and vehicles.

Appendix E presents much of the source material for the population estimates. Our primary source of population data, the 2010 Census, however, is not adequate for directly estimating some transient groups.

Throughout the year, vacationers and tourists enter the EPZ. These non-residents may dwell within the EPZ for a short period (e.g. a few days or one or two weeks), or may enter and leave within one day. Estimates of the size of these population components must be obtained, so that the associated number of evacuating vehicles can be ascertained.

The potential for double-counting people and vehicles must be addressed. For example:

- A resident who works and shops within the EPZ could be counted as a resident, again as an employee and once again as a shopper.
- A visitor who stays at a hotel and spends time at a park, then goes shopping could be counted three times.

Furthermore, the number of vehicles at a location depends on time of day. For example, motel parking lots may be full at dawn and empty at noon. Similarly, parking lots at area parks, which are full at noon, may be almost empty at dawn. Estimating counts of vehicles by simply adding up the capacities of different types of parking facilities will tend to overestimate the number of transients and can lead to ETE that are too conservative.

Analysis of the general population characteristics of the Robinson Nuclear Plant EPZ indicates the need to identify three distinct groups:

- Permanent residents - people who are year round residents of the EPZ.
- Transients - people who reside outside of the EPZ who enter the area for a specific purpose (shopping, recreation) and then leave the area.
- Employees - people who reside outside of the EPZ and commute to work within the EPZ on a daily basis.

For this study, employees and transients have different scenario percentages (see Table 6-3). For example, employees peak during the winter, weekday, midday scenarios while transients peak during summer evenings. For this reason, employees were treated separately from transients.

Estimates of the population and number of evacuating vehicles for each of the population groups are presented for each zone and by polar coordinate representation (population distribution figures). The RNP EPZ is subdivided into 11 zones. The EPZ is shown in Figure 3-1.

3.1 Permanent Residents

The primary source for estimating permanent population is the latest U.S. Census data. The average household size (2.27 persons/household – See Figure F-1) and the number of evacuating vehicles per household (1.20 vehicles/household – See Figure F-8) were adapted from the telephone survey results.

Population estimates are based upon Census 2010 data. The estimates are created by cutting the census block polygons by the zone and EPZ boundaries. A ratio of the original area of each census block and the updated area (after cutting) is multiplied by the total block population to estimate the population within the EPZ. This methodology assumes that the population is evenly distributed across a census block. Table 3-1 provides the permanent resident population within the EPZ, by zone based on this methodology.

The year 2010 permanent resident population is divided by the average household size and then multiplied by the average number of evacuating vehicles per household in order to estimate number of vehicles. Permanent resident population and vehicle estimates are presented in Table 3-2. Figure 3-2 and Figure 3-3 present the permanent resident population and permanent resident vehicle estimates by sector and distance from the Robinson Nuclear Plant. The population distribution figures were constructed using GIS software.

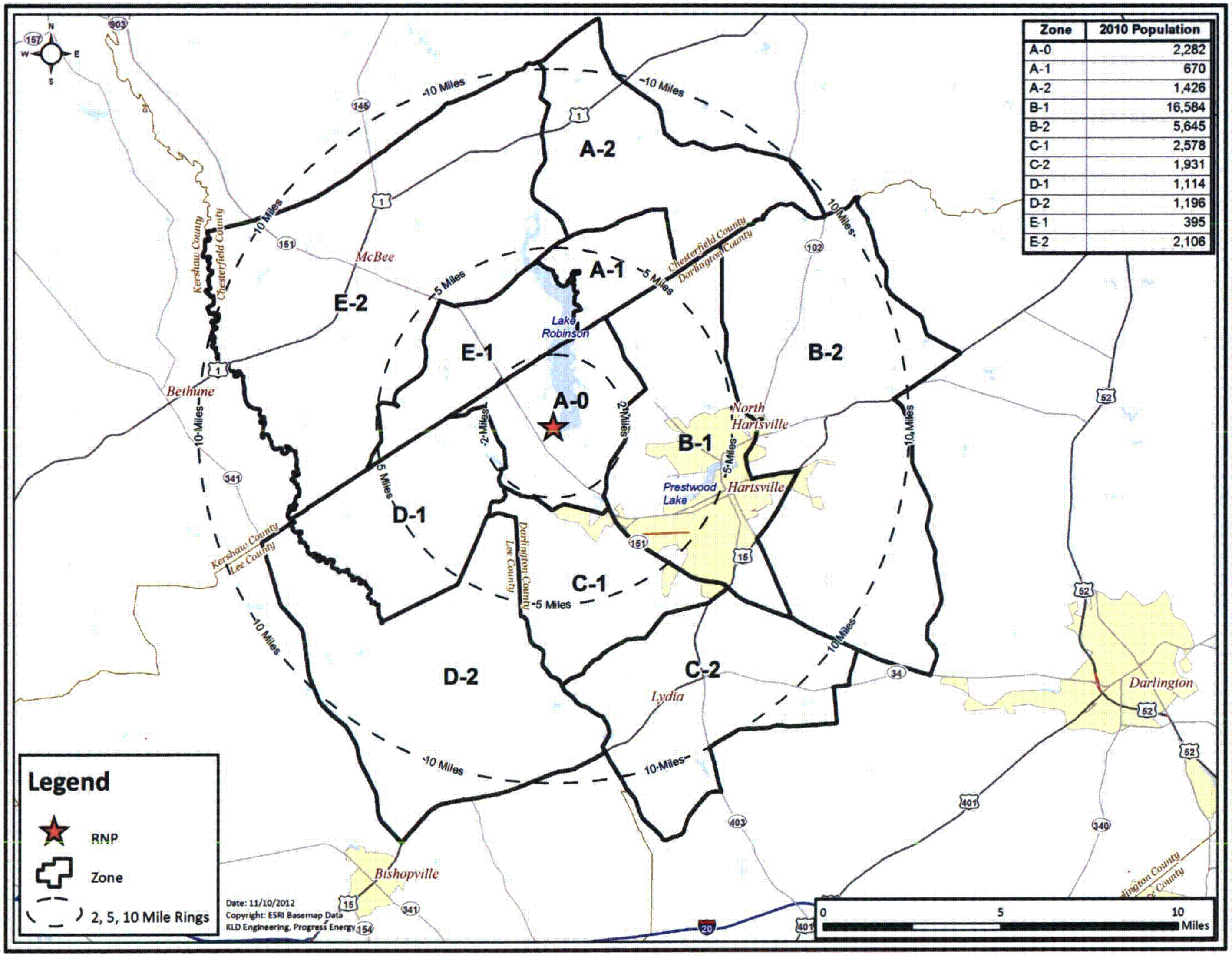


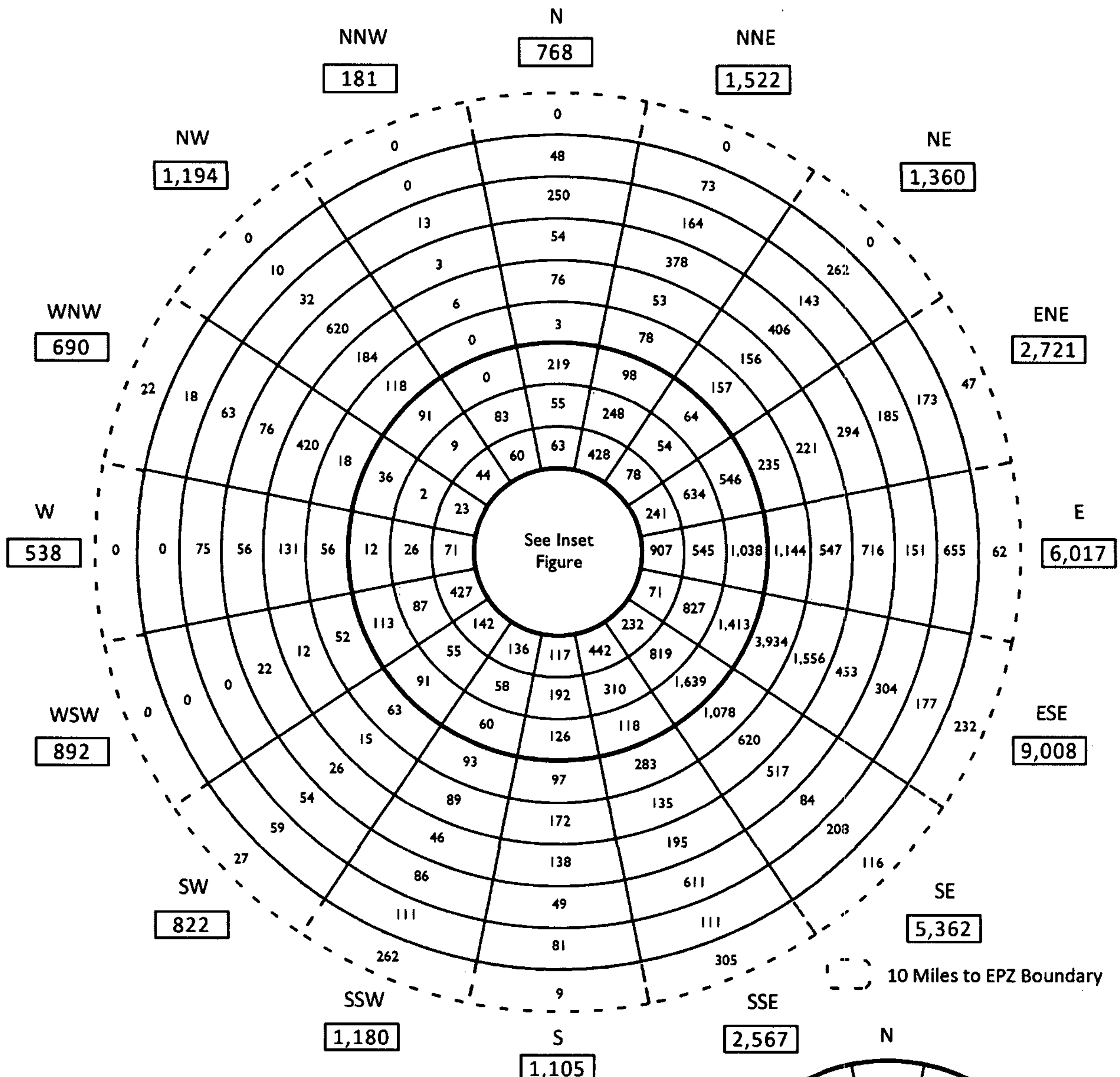
Figure 3-1. RNP EPZ

Table 3-1. EPZ Permanent Resident Population

Zone	2000 Population	2010 Population
A-0	2,161	2,282
A-1	670	670
A-2	852	1,426
B-1	12,721	16,584
B-2	8,998	5,645
C-1	2,555	2,578
C-2	1,903	1,931
D-1	1,039	1,114
D-2	1,409	1,196
E-1	295	395
E-2	1,931	2,106
TOTAL	**34,534**	**35,927**
EPZ Population Growth:		**4.03%**

Table 3-2. Permanent Resident Population and Vehicles by Zone

Zone	2010 Population	2010 Resident Vehicles
A-0	2,282	1,210
A-1	670	353
A-2	1,426	759
B-1	16,584	8,927
B-2	5,645	2,992
C-1	2,578	1,366
C-2	1,931	1,023
D-1	1,114	591
D-2	1,196	642
E-1	395	208
E-2	2,106	1,118
TOTAL	**35,927**	**19,189**



Resident Population

Miles	Subtotal by Ring	Cumulative Total
0 - 1	572	572
1 - 2	1,071	1,643
2 - 3	3,482	5,125
3 - 4	4,004	9,129
4 - 5	5,664	14,793
5 - 6	7,409	22,202
6 - 7	4,393	26,595
7 - 8	4,000	30,595
8 - 9	2,264	32,859
9 - 10	1,986	34,845
10 - EPZ	1,082	35,927
	Total:	35,927

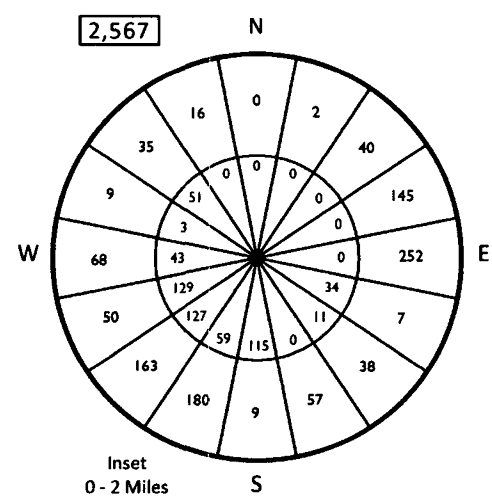
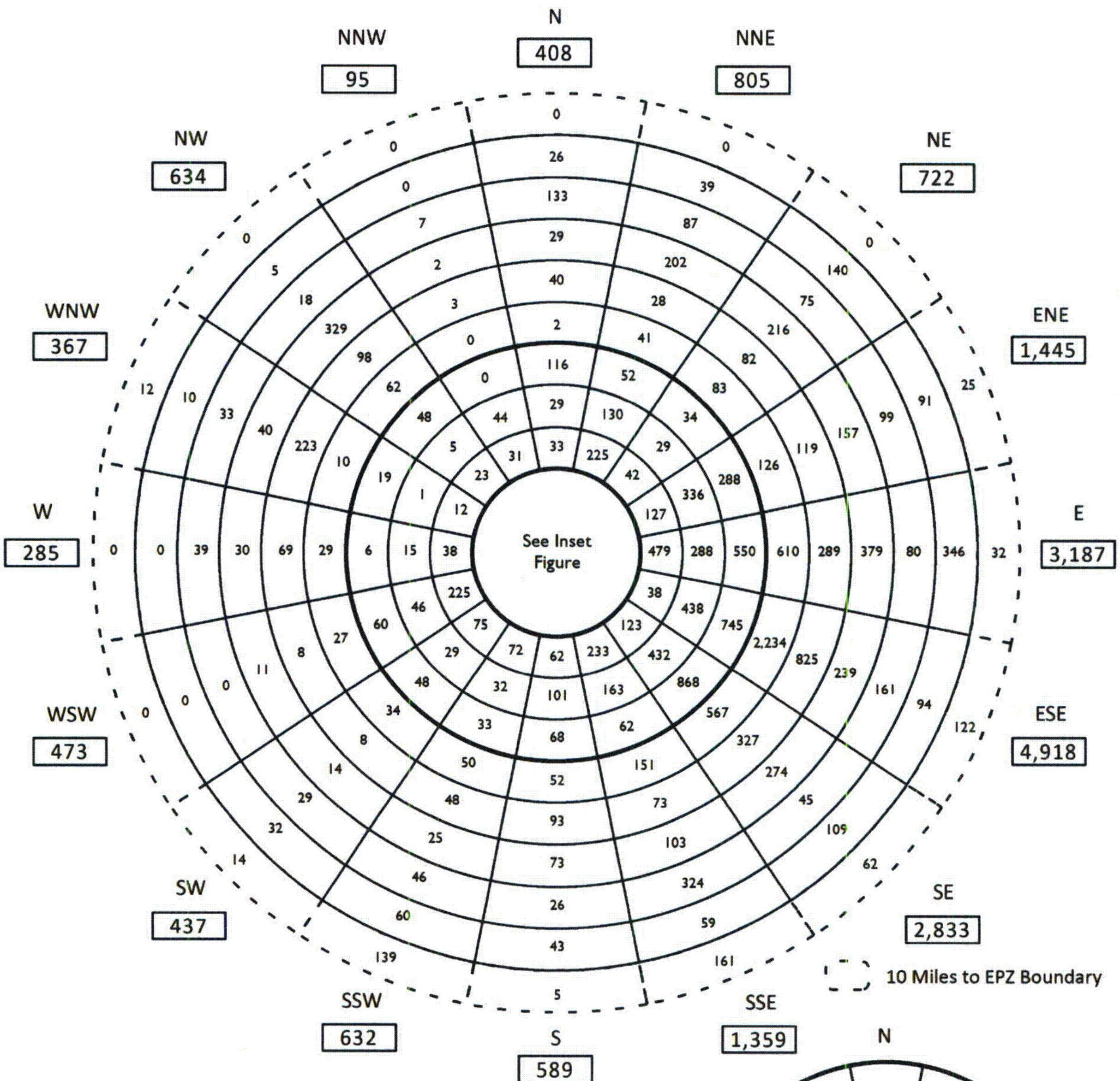


Figure 3-2. Permanent Resident Population by Sector



Resident Vehicles

Miles	Subtotal by Ring	Cumulative Total
0 - 1	305	305
1 - 2	569	874
2 - 3	1,838	2,712
3 - 4	2,118	4,830
4 - 5	2,997	7,827
5 - 6	4,078	11,905
6 - 7	2,333	14,238
7 - 8	2,123	16,361
8 - 9	1,202	17,563
9 - 10	1,054	18,617
10 - EPZ	572	19,189
	Total:	19,189

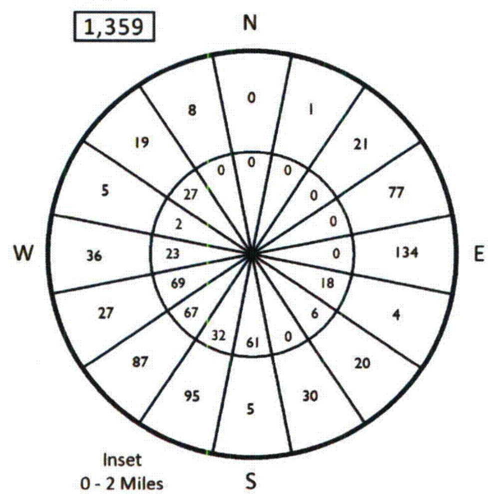


Figure 3-3. Permanent Resident Vehicles by Sector

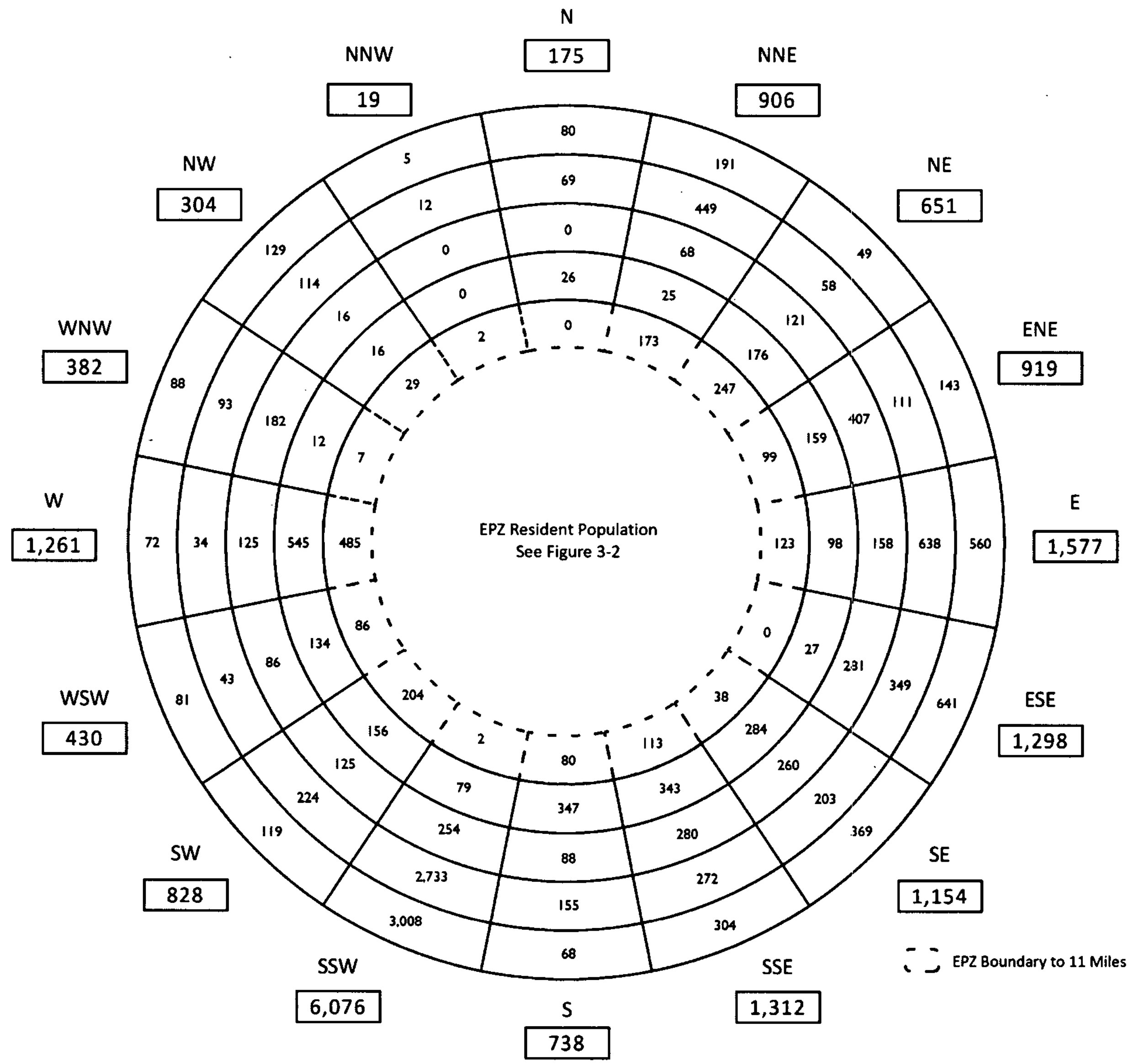
3.2 Shadow Population

A portion of the population living outside the evacuation area extending to 15 miles radially from the RNP (in the Shadow Region) may elect to evacuate without having been instructed to do so. Based upon NUREG/CR-7002 guidance, it is assumed that 20 percent of the permanent resident population, based on U.S. Census Bureau data, in this Shadow Region will elect to evacuate.

Shadow population characteristics (household size, evacuating vehicles per household, mobilization time) are assumed to be the same as those for the EPZ permanent resident population. Table 3-3, Figure 3-4, and Figure 3-5 present estimates of the shadow population and vehicles, by sector.

Table 3-3. Shadow Population and Vehicles by Sector

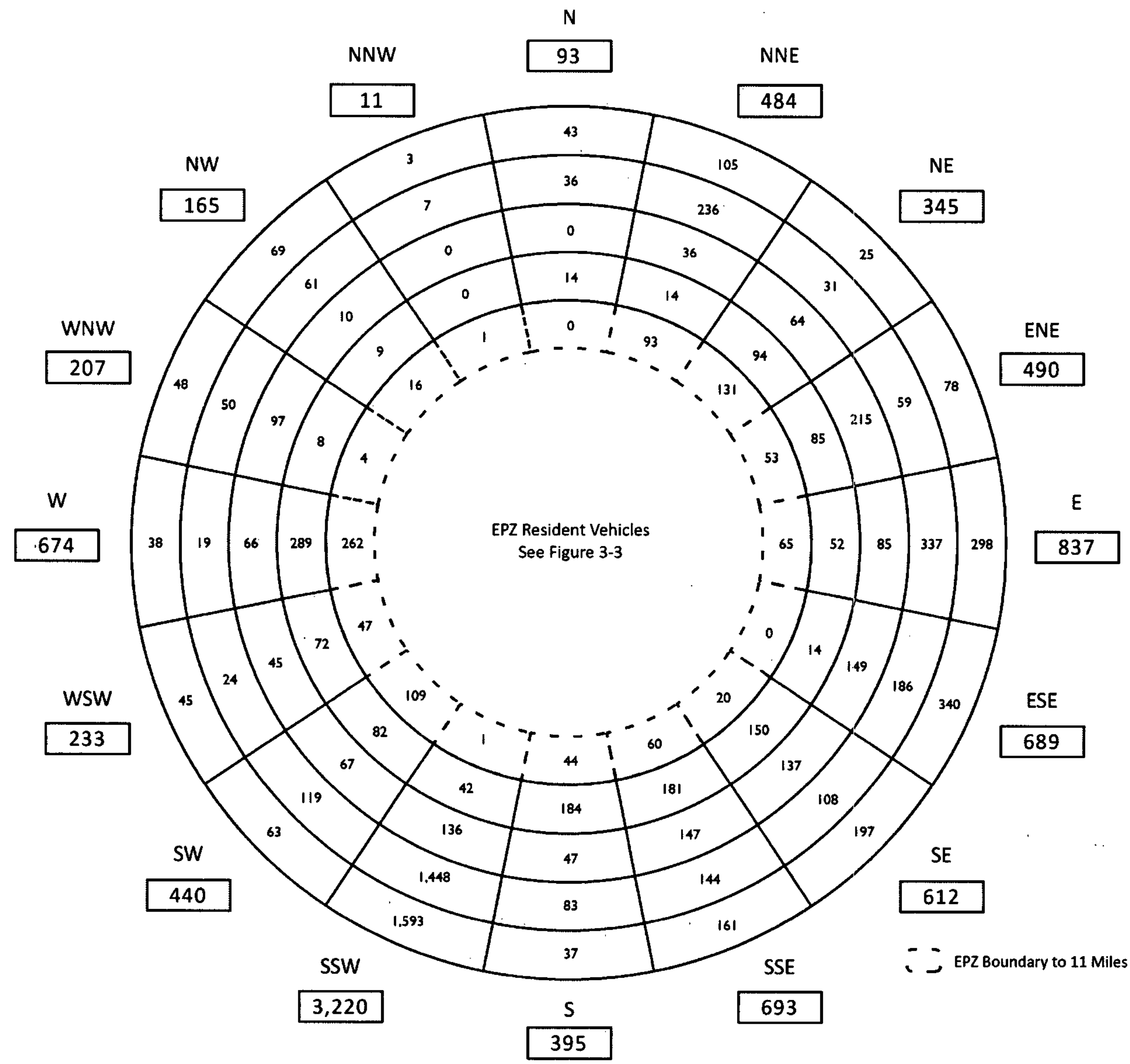
Sector	Population	Evacuating Vehicles
N	175	93
NNE	906	484
NE	651	345
ENE	919	490
E	1,577	837
ESE	1,298	689
SE	1,154	612
SSE	1,312	693
S	738	395
SSW	6,076	3,220
SW	828	440
WSW	430	233
W	1,261	674
WNW	382	207
NW	304	165
NNW	19	11
TOTAL	**18,030**	**9,588**



Shadow Population

Miles	Subtotal by Ring	Cumulative Total
EPZ - 11	1,688	1,688
11 - 12	2,427	4,115
12 - 13	2,451	6,566
13 - 14	5,557	12,123
14 - 15	5,907	18,030
	Total:	18,030

Figure 3-4. Shadow Population by Sector



Shadow Vehicles

Miles	Subtotal by Ring	Cumulative Total
EPZ - 11	906	906
11 - 12	1,290	2,196
12 - 13	1,301	3,497
13 - 14	2,948	6,445
14 - 15	3,143	9,588
	Total:	9,588

Figure 3-5. Shadow Vehicles by Sector

3.3 Transient Population

Transient population groups are defined as those people (who are not permanent residents, nor commuting employees) who enter the EPZ for a specific purpose (shopping, recreation). Transients may spend less than one day or stay overnight at hotels and motels. The RNP EPZ includes the following types of facilities that attract transients:

- Lodging Facilities
- Golf Courses
- Coker College

Surveys of lodging facilities within the EPZ were conducted to determine the number of rooms, percentage of occupied rooms at peak times, and the number of people and vehicles per room for each facility. These data were used to estimate the number of transients and evacuating vehicles at each of these facilities. A total of 173 transients in 113 vehicles are assigned to lodging facilities in the EPZ.

Two golf courses within the EPZ were located. One golf course, Hartsville Country Club was determined to be predominantly local usage and no transients were assigned. The second golf course, Fox Golf Club was contacted to determine the number of golfers and vehicles at each facility on a typical peak day, and the number of golfers that travels from outside the area. A total of 20 transients and 10 vehicles are assigned to golf courses within the EPZ.

Coker College provided student enrollment numbers as of August 2012 which is 1,100 students, 875 of which attend the campus within the EPZ. The remainder of those students attend the three satellite campuses outside the EPZ. Students who reside on campus, out of the 875 EPZ students, were reported at 525, with 425 vehicles. These students have been included as a part of the permanent population in Table 3-2. There are 100 students (included in the 525 total) without personal vehicles. Assuming 50% ride share with friends, 50 students have been assigned to the campus as transit dependent. 1 bus has been assigned to Coker College for these students. Commuting students for the campus were reported at 350 students. Using the same percentages estimated for the employees as travel habits mimic those of employees, 53.5% of these students are assumed to live within the EPZ, 187 students in 178 vehicles which have been included in the transient populations.

The Darlington County emergency plans included sites for three boat landings within the EPZ. No transients were assigned to the landings as they were also determined to be predominantly for local usage.

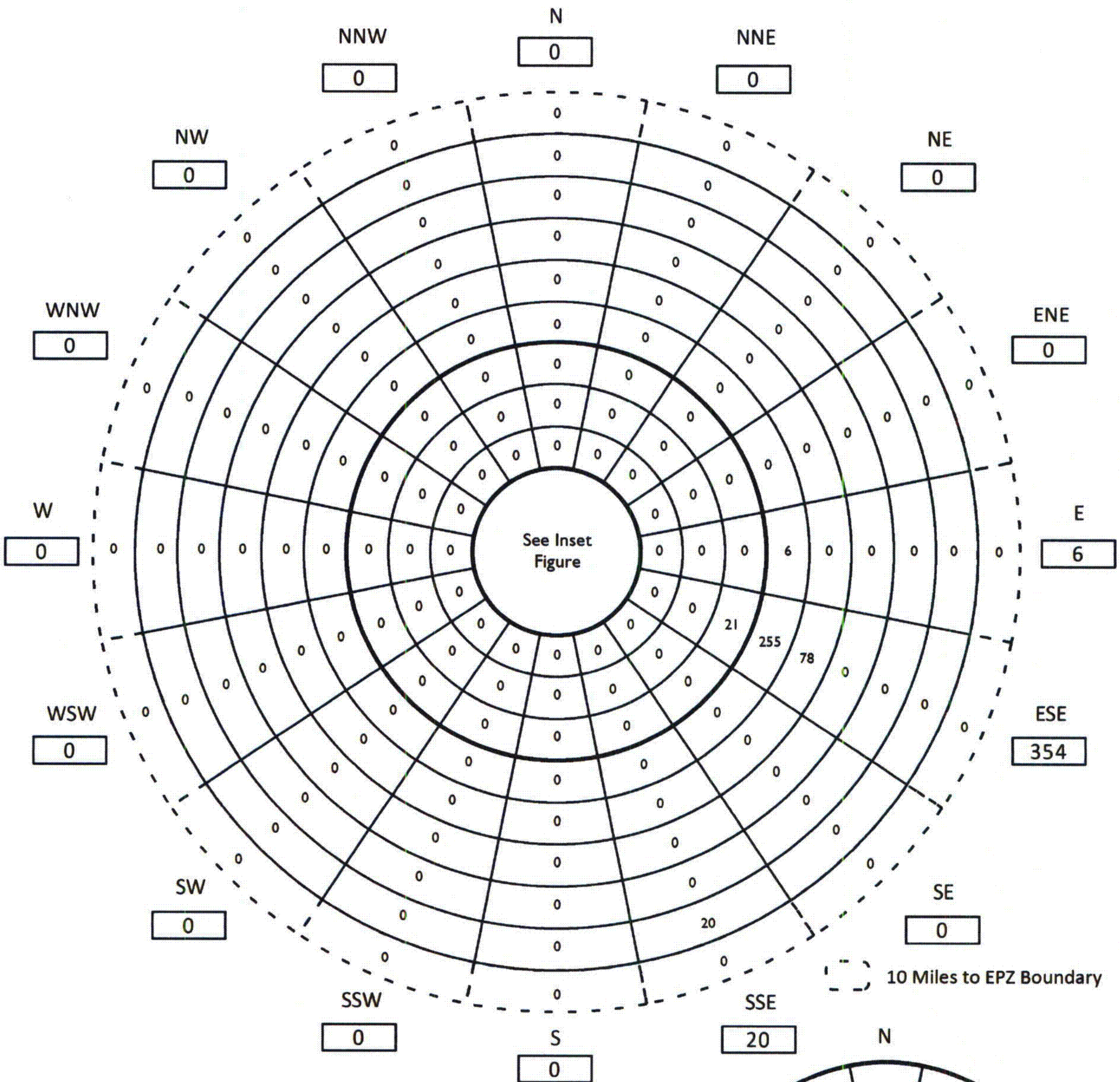
The previous ETE Report included estimates of transients within the Robinson EPZ at approximately 18,000 people. This number includes employees, motel guests and transient estimates from 2006. The previous report also estimated transients at the Sandhills State Forest and Wildlife Refuge but the majority of the park is located outside the EPZ. No transients were assigned to this facility as the major attractions, hunting, camping and hiking, take place outside the EPZ. Local authorities and RNP confirmed that such a high number of transients could not be substantiated.

Appendix E summarizes the transient data that was estimated for the EPZ. Table E-5 presents the number of transients visiting recreational areas and the transient students. Also included in this table are the lodging facilities. The number of transients and transient vehicles listed is the result of peak usage details while subtracting out the local population.

Table 3-4 presents transient population and transient vehicle estimates by Zone. Figure 3-6 and Figure 3-7 present these data by sector and distance from the plant.

Table 3-4. Summary of Transients and Transient Vehicles

Zone	Transients	Transient Vehicles
A-0	-	-
A-1	-	-
A-2	-	-
B-1	282	252
B-2	78	39
C-1	-	-
C-2	20	10
D-1	-	-
D-2	-	-
E-1	-	-
E-2	-	-
TOTAL	**380**	**301**



Transients

Miles	Subtotal by Ring	Cumulative Total
0 - 1	0	0
1 - 2	0	0
2 - 3	0	0
3 - 4	0	0
4 - 5	21	21
5 - 6	261	282
6 - 7	78	360
7 - 8	0	360
8 - 9	0	360
9 - 10	20	380
10 - EPZ	0	380
	Total:	380

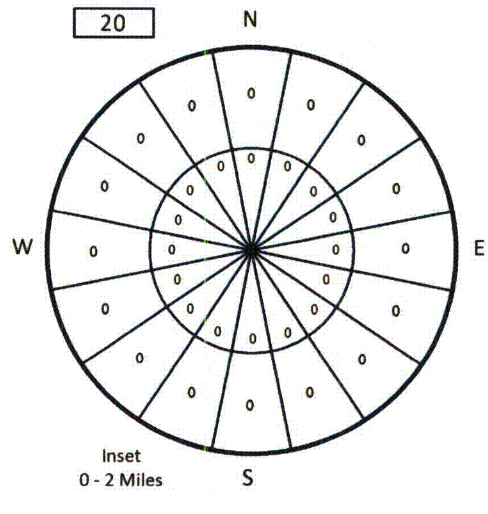
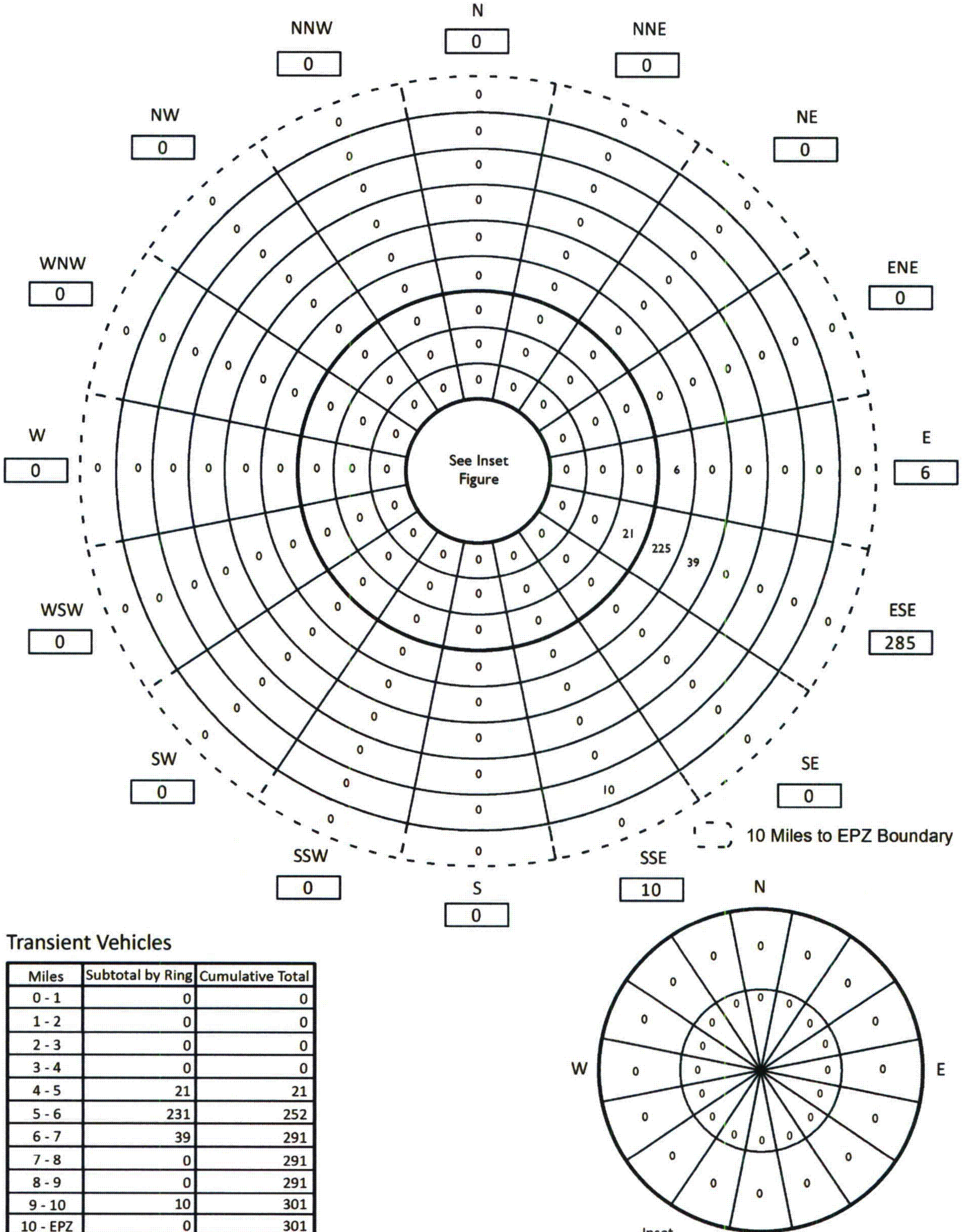


Figure 3-6. Transient Population by Sector



Transient Vehicles

Miles	Subtotal by Ring	Cumulative Total
0 - 1	0	0
1 - 2	0	0
2 - 3	0	0
3 - 4	0	0
4 - 5	21	21
5 - 6	231	252
6 - 7	39	291
7 - 8	0	291
8 - 9	0	291
9 - 10	10	301
10 - EPZ	0	301
	Total:	301

Figure 3-7. Transient Vehicles by Sector

3.4 Employees

Employees who work within the EPZ fall into two categories:

- Those who live and work in the EPZ
- Those who live outside of the EPZ and commute to jobs within the EPZ.

Those of the first category are already counted as part of the permanent resident population. To avoid double counting, we focus only on those employees commuting from outside the EPZ who will evacuate along with the permanent resident population.

Data provided by Darlington and Chesterfield counties and the previous ETE report were used to estimate the number of employees commuting into the EPZ for those employers who did not provide data or were not able to provide information from phone calls made to facilities.

In Table E-4, the Employees (Max/Shift) is multiplied by the percent Non-EPZ factor to determine the number of employees who are not residents of the EPZ. A vehicle occupancy of 1.05 employees per vehicle obtained from the telephone survey (See Figure F-7) was used to determine the number of evacuating employee vehicles for all major employers. For employers that did not provide percentage of non-EPZ employers, 53.5% was used. This was based on data provided by the U.S. Census Bureau's Longitudinal Employer-Household Dynamics interactive website[1] which is able to calculate the average inflow/outflow of employees within a specified area.

Table 3-5 presents non-EPZ Resident employee and vehicle estimates by Zone. Figure 3-8 and Figure 3-9 present these data by sector.

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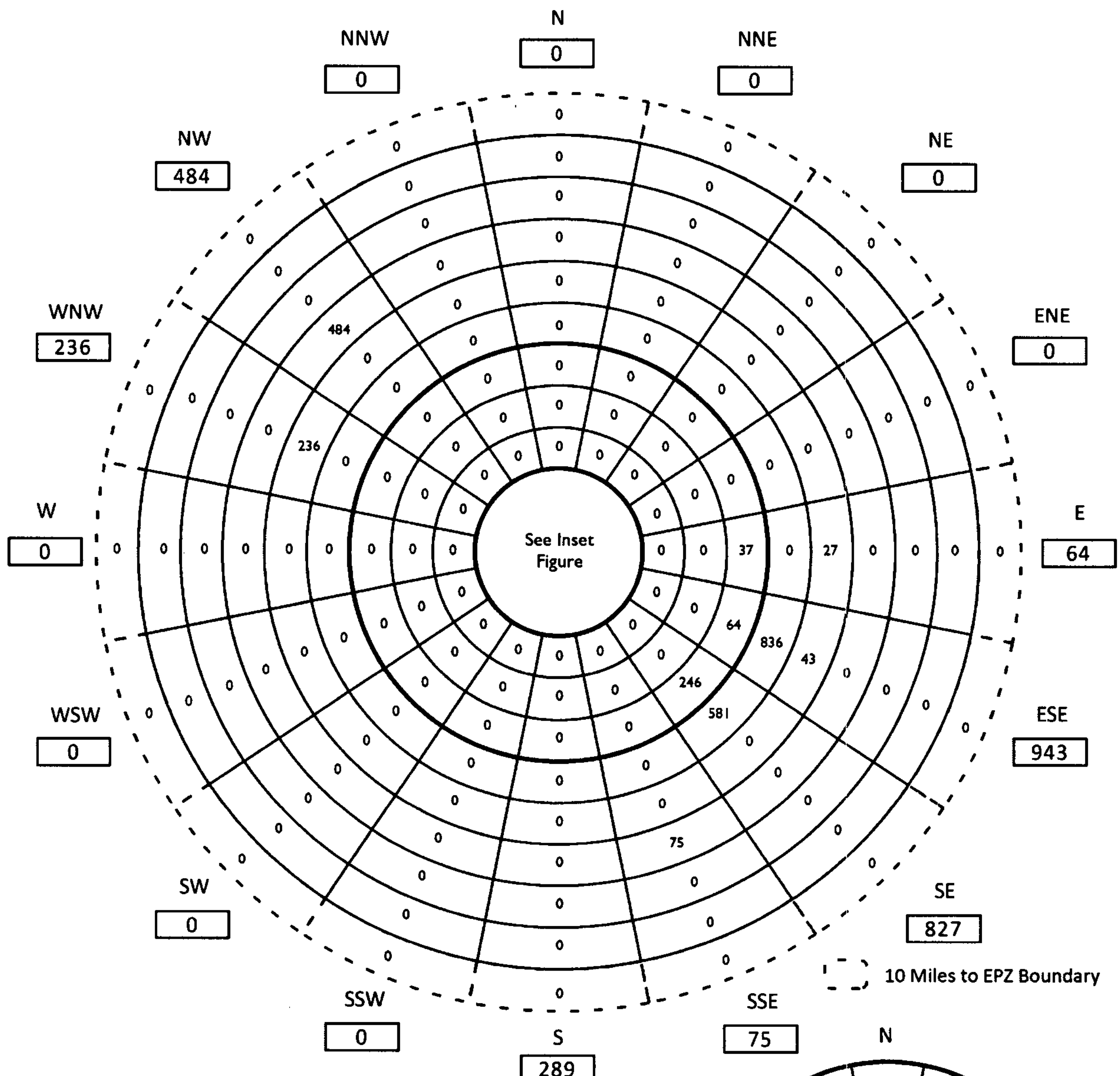
http://lehdmap.did.census.gov/

Table 3-5. Summary of Non-EPZ Resident Employees and Employee Vehicles

Zone	Employees	Employee Vehicles
A-0	289	275
A-1	-	-
A-2	-	-
B-1	1,719	1,638
B-2	70	67
C-1	45	43
C-2	75	71
D-1	-	-
D-2	-	-
E-1	-	-
E-2	720	685
TOTAL	**2,918**	**2,779**



Employees

Miles	Subtotal by Ring	Cumulative Total
0 - 1	289	289
1 - 2	0	289
2 - 3	0	289
3 - 4	0	289
4 - 5	347	636
5 - 6	1,417	2,053
6 - 7	306	2,359
7 - 8	559	2,918
8 - 9	0	2,918
9 - 10	0	2,918
10 - EPZ	0	2,918
Total:		2,918

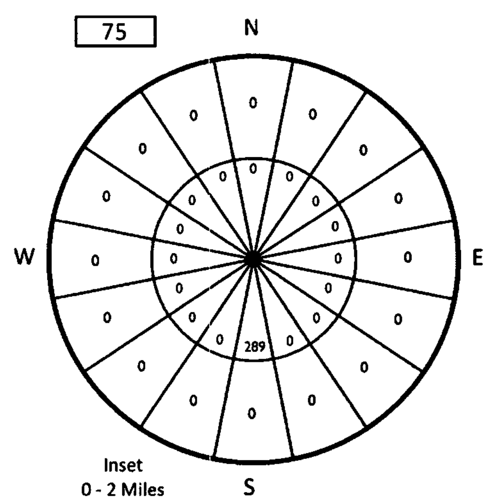
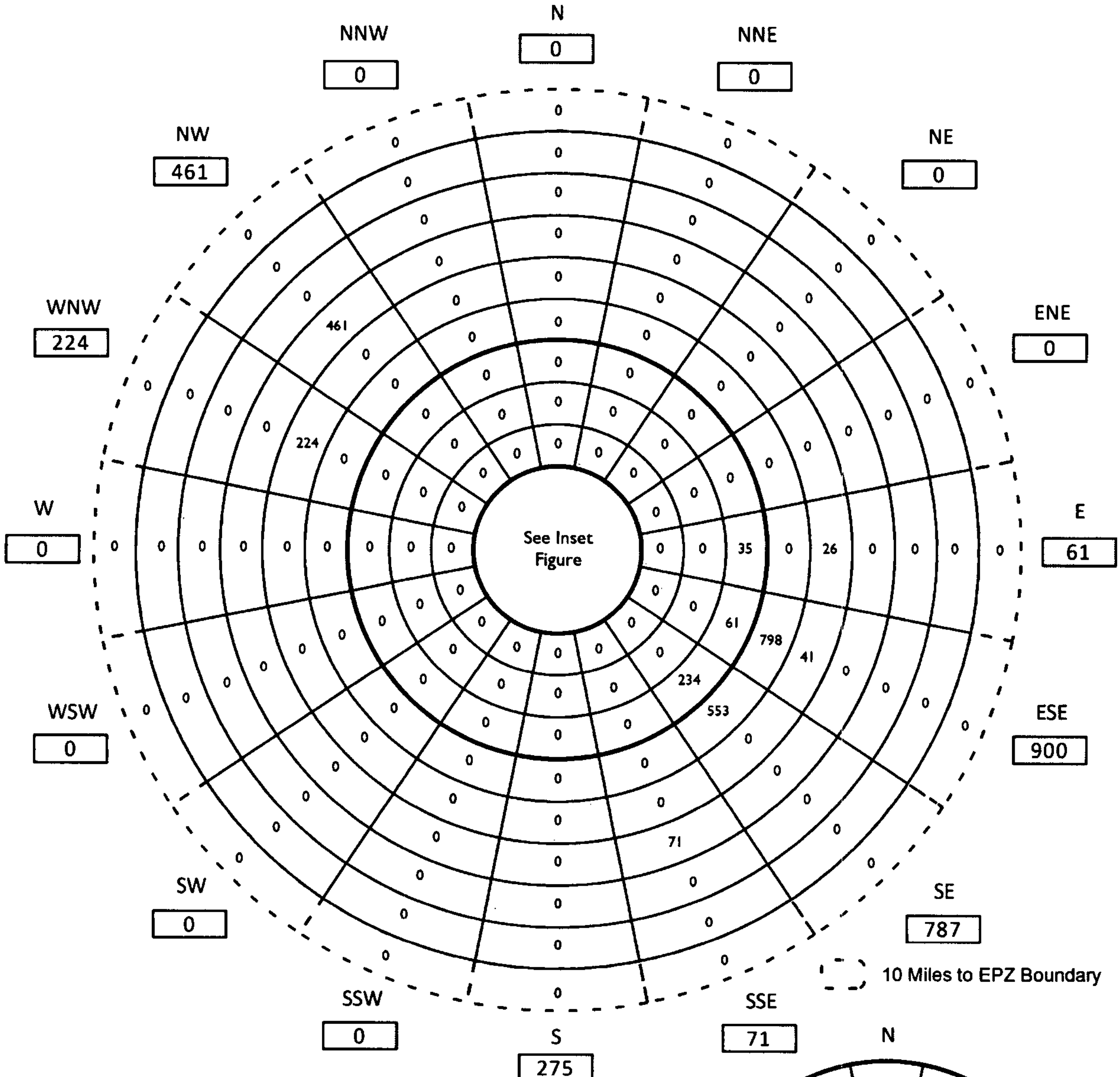


Figure 3-8. Non-EPZ Employee Population by Sector



Employee Vehicles

Miles	Subtotal by Ring	Cumulative Total
0 - 1	275	275
1 - 2	0	275
2 - 3	0	275
3 - 4	0	275
4 - 5	330	605
5 - 6	1,351	1,956
6 - 7	291	2,247
7 - 8	532	2,779
8 - 9	0	2,779
9 - 10	0	2,779
10 - EPZ	0	2,779
Total:		2,779

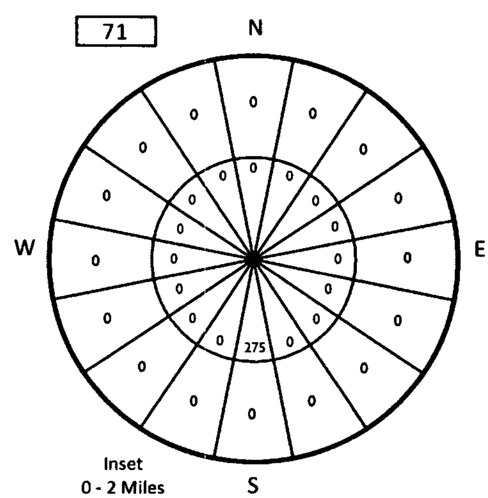


Figure 3-9. Non-EPZ Employee Vehicles by Sector

3.5 Medical Facilities

Data were provided by the counties for each of the medical facilities within the EPZ. Table E-3 in Appendix E summarizes the data gathered. Section 8 details the evacuation of medical facilities and their patients. The number and type of evacuating vehicles that need to be provided depend on the patients' state of health. It is estimated that buses can transport up to 30 people; wheelchair vans, up to 4 people; and ambulances, up to 1 person for critical care and 2 for non-critical.

3.6 Total Demand in Addition to Permanent Population

Vehicles will be traveling through the EPZ (external-external trips) at the time of an emergency event. After the Advisory to Evacuate is announced, these through-travelers will also evacuate. These through vehicles are assumed to travel on the major routes traversing the EPZ – US 1, US 15, I-120 and SR 151. It is assumed that this traffic will continue to enter the EPZ during the first 120 minutes following the Advisory to Evacuate.

Average Annual Daily Traffic (AADT) data was obtained from Federal Highway Administration to estimate the number of vehicles per hour on the aforementioned routes. The AADT was multiplied by the K-Factor, which is the proportion of the AADT on a roadway segment or link during the design hour, resulting in the design hour volume (DHV). The design hour is usually the 30th highest hourly traffic volume of the year, measured in vehicles per hour (vph). The DHV is then multiplied by the D-Factor, which is the proportion of the DHV occurring in the peak direction of travel (also known as the directional split). The resulting values are the directional design hourly volumes (DDHV), and are presented in Table 3-6, for each of the routes considered. The DDHV is then multiplied by 2 hours (access control points – ACP – are assumed to be activated at 120 minutes after the advisory to evacuate) to estimate the total number of external vehicles loaded on the analysis network. As indicated, there are 11,216 vehicles entering the EPZ as external-external trips prior to the activation of the ACP and the diversion of this traffic. This number is reduced by 60% for evening scenarios (Scenarios 5 and 12) as discussed in Section 6.

3.7 Special Event

One special event (Scenario 13) is considered for the ETE study – a NASCAR race at Darlington Raceway. This is by far the special event in the area and is considered by local emergency management personnel to be the most likely to impede an evacuation. The largest event occurs on the second weekend in May. Data was obtained from Darlington County and the raceway. Transient attendance is reported at approximately 60,000 people in 15,000 vehicles. The website http://www.darlingtonraceway.com/ also provided information for events held at the raceway and traffic patterns.

Public transportation is not provided for this event and was not considered in the special event analysis.

Table 3-6. RNP EPZ External Traffic

Up Node	Dn Node	Road Name	Direction	HPMS[1] AADT	K-Factor[2]	D-Factor[2]	Hourly Volume	External Traffic
8018	18	SR 151	SB	12,698	0.116	0.5	736	1,472
8206	344	SR 151	NB	12,698	0.116	0.5	736	1,472
8087	87	US 1	EB	4,732	0.136	0.5	322	644
8101	101	US 1	WB	4,732	0.136	0.5	322	644
8168	168	I-20	EB	25,569	0.107	0.5	1,368	2,736
8184	184	I-20	WB	25,569	0.107	0.5	1,368	2,736
8074	74	US 15	WB	6,400	0.118	0.5	378	756
8061	61	US 15	EB	6,400	0.118	0.5	378	756
							TOTAL	**11,216**

[1]Highway Performance Monitoring System (HPMS), Federal Highway Administration (FHWA), Washington, D.C., 2011
[2]HCM 2010

3.8 Summary of Demand

A summary of population and vehicle demand is provided in Table 3-7 and Table 3-8, respectively. This summary includes all population groups described in this section and Section 8. Additional population groups – transit-dependent, special facility and school population – are described in greater detail in Section 8. A total of 53,146 people and 35,954 vehicles are considered in this study.

Table 3-7. Summary of Population Demand

Zone	Residents	Transit-Dependent	Transients	Employees	Special Facilities	Schools	Coker College*	Shadow Population	External Traffic	Total
A-0	2,282	72	-	289	-	-	-	-	-	2,643
A-1	670	21	-	-	-	-	-	-	-	691
A-2	1,426	45	-	-	-	-	-	-	-	1,471
B-1	16,584	522	95	1,719	300	6,797	187	-	-	26,204
B-2	5,645	178	78	70	154	431	-	-	-	6,556
C-1	2,578	81	-	45	-	214	-	-	-	2,918
C-2	1,931	61	20	75	-	400	-	-	-	2,487
D-1	1,114	35	-	-	-	13	-	-	-	1,162
D-2	1,196	38	-	-	-	0	-	-	-	1,234
E-1	395	-	-	-	-	0	-	-	-	395
E-2	2,106	77	-	720	-	876	-	-	-	3,779
Shadow	-	-	-	-	-	-	-	3,606	-	3,606
Total	**35,927**	**1,130**	**193**	**2,918**	**454**	**8,731**	**187**	**3,606**	**0**	**53,146**

NOTE: Shadow Population has been reduced to 20%. Refer to Figure 2-1 for additional information.

NOTE: Special Facilities include both medical facilities.

NOTE: Transient students only for Coker College are listed separately. The remaining students are all included in the school enrollment numbers.

Table 3-8. Summary of Vehicle Demand

Zone	Residents	Transit-Dependent	Transients	Employees	Special Facilities	Schools	Coker College*	Shadow Population	External Traffic	Total
A-0	1,210	6	-	275	-	-	-	-	-	1,491
A-1	353	2	-	-	-	-	-	-	-	355
A-2	759	4	-	-	-	-	-	-	-	763
B-1	8,927	36	70	1,638	84	248	178	-	-	11,181
B-2	2,992	12	43	67	35	24	-	-	-	3,173
C-1	1,366	6	-	43	-	18	-	-	-	1,433
C-2	1,023	6	10	71	-	20	-	-	-	1,130
D-1	591	4	-	-	-	2	-	-	-	597
D-2	642	4	-	-	-	-	-	-	-	646
E-1	208	-	-	-	-	-	-	-	-	208
E-2	1,118	6	-	685	-	34	-	-	-	1,843
Shadow	-	-	-	-	-	-	-	1,918	11,216	13,134
Total	**19,189**	**86**	**123**	**2,779**	**119**	**346**	**178**	**1,918**	**11,216**	**35,954**

NOTE: Buses represented as two passenger vehicles. Refer to Section 8 for additional information.

NOTE: Transient students only for Coker College are listed separately. The remaining students are all included in the school enrollment numbers.

4 ESTIMATION OF HIGHWAY CAPACITY

The ability of the road network to service vehicle demand is a major factor in determining how rapidly an evacuation can be completed. The capacity of a road is defined as the maximum hourly rate at which persons or vehicles can reasonably be expected to traverse a point or uniform section of a lane of roadway during a given time period under prevailing roadway, traffic and control conditions, as stated in the 2010 Highway Capacity Manual (HCM 2010).

In discussing capacity, different operating conditions have been assigned alphabetical designations, A through F, to reflect the range of traffic operational characteristics. These designations have been termed "Levels of Service" (LOS). For example, LOS A connotes free-flow and high-speed operating conditions; LOS F represents a forced flow condition. LOS E describes traffic operating at or near capacity.

Another concept, closely associated with capacity, is “Service Volume” (SV). Service volume is defined as “The maximum hourly rate at which vehicles, bicycles or persons reasonably can be expected to traverse a point or uniform section of a roadway during an hour under specific assumed conditions while maintaining a designated level of service.” This definition is similar to that for capacity. The major distinction is that values of SV vary from one LOS to another, while capacity is the service volume at the upper bound of LOS E, only.

This distinction is illustrated in Exhibit 11-17 of the HCM 2010. As indicated there, the SV varies with Free Flow Speed (FFS), and LOS. The SV is calculated by the DYNEV II simulation model, based on the specified link attributes, FFS, capacity, control device and traffic demand.

Other factors also influence capacity. These include, but are not limited to:

- Lane width
- Shoulder width
- Pavement condition
- Horizontal and vertical alignment (curvature and grade)
- Percent truck traffic
- Control device (and timing, if it is a signal)
- Weather conditions (rain, snow, fog, wind speed, ice)

These factors are considered during the road survey and in the capacity estimation process; some factors have greater influence on capacity than others. For example, lane and shoulder width have only a limited influence on Base Free Flow Speed (BFFS[1]) according to Exhibit 15-7 of the HCM. Consequently, lane and shoulder widths at the narrowest points were observed during the road survey and these observations were recorded, but no detailed measurements of lane or shoulder width were taken. Horizontal and vertical alignment can influence both FFS and capacity. The estimated FFS were measured using the survey vehicle’s speedometer and observing local traffic, under free flow conditions. Capacity is estimated from the procedures of

[1] A very rough estimate of BFFS might be taken as the posted speed limit plus 10 mph (HCM 2010 Page 15-15)

the 2010 HCM. For example, HCM Exhibit 7-1(b) shows the sensitivity of Service Volume at the upper bound of LOS D to grade (capacity is the Service Volume at the upper bound of LOS E).

As discussed in Section 2.3, it is necessary to adjust capacity figures to represent the prevailing conditions during inclement weather. Based on limited empirical data, weather conditions such as rain reduce the values of free speed and of highway capacity by approximately 10 percent. Over the last decade new studies have been made on the effects of rain on traffic capacity. These studies indicate a range of effects between 5 and 20 percent depending on wind speed and precipitation rates. As indicated in Section 2.3, we employ a reduction in free speed and in highway capacity of 10 percent and 20 percent for rain and snow, respectively.

Since congestion arising from evacuation may be significant, estimates of roadway capacity must be determined with great care. Because of its importance, a brief discussion of the major factors that influence highway capacity is presented in this section.

Rural highways generally consist of: (1) one or more uniform sections with limited access (driveways, parking areas) characterized by "uninterrupted" flow; and (2) approaches to at-grade intersections where flow can be "interrupted" by a control device or by turning or crossing traffic at the intersection. Due to these differences, separate estimates of capacity must be made for each section. Often, the approach to the intersection is widened by the addition of one or more lanes (turn pockets or turn bays), to compensate for the lower capacity of the approach due to the factors there that can interrupt the flow of traffic. These additional lanes are recorded during the field survey and later entered as input to the DYNEV II system.

4.1 Capacity Estimations on Approaches to Intersections

At-grade intersections are apt to become the first bottleneck locations under local heavy traffic volume conditions. This characteristic reflects the need to allocate access time to the respective competing traffic streams by exerting some form of control. During evacuation, control at critical intersections will often be provided by traffic control personnel assigned for that purpose, whose directions may supersede traffic control devices. The existing traffic management plans documented in the county emergency plans are extensive and were adopted without change.

The per-lane capacity of an approach to a signalized intersection can be expressed (simplistically) in the following form:

$$Q_{cap,m} = \left(\frac{3600}{h_m}\right) \times \left(\frac{G-L}{C}\right)_m = \left(\frac{3600}{h_m}\right) \times P_m$$

where:

$Q_{cap,m}$ = Capacity of a single lane of traffic on an approach, which executes

		movement, *m*, upon entering the intersection; vehicles per hour (vph)
h_m	=	Mean queue discharge headway of vehicles on this lane that are executing movement, *m*; seconds per vehicle
G	=	Mean duration of GREEN time servicing vehicles that are executing movement, *m*, for each signal cycle; seconds
L	=	Mean "lost time" for each signal phase servicing movement, *m*; seconds
C	=	Duration of each signal cycle; seconds
P_m	=	Proportion of GREEN time allocated for vehicles executing movement, *m*, from this lane. This value is specified as part of the control treatment.
m	=	The movement executed by vehicles after they enter the intersection: through, left-turn, right-turn, and diagonal.

The turn-movement-specific mean discharge headway h_m, depends in a complex way upon many factors: roadway geometrics, turn percentages, the extent of conflicting traffic streams, the control treatment, and others. A primary factor is the value of "saturation queue discharge headway", h_{sat}, which applies to through vehicles that are not impeded by other conflicting traffic streams. This value, itself, depends upon many factors including motorist behavior. Formally, we can write,

$$h_m = f_m(h_{sat}, F_1, F_2, \ldots)$$

where:

h_{sat}	=	Saturation discharge headway for through vehicles; seconds per vehicle
F_1, F_2	=	The various known factors influencing h_m
$f_m(\,)$	=	Complex function relating h_m to the known (or estimated) values of h_{sat}, F_1, F_2, ...

The estimation of h_m for specified values of h_{sat}, F_1, F_2, ... is undertaken within the DYNEV II simulation model by a mathematical model[2]. The resulting values for h_m always satisfy the condition:

$$h_m \geq h_{sat}$$

[2]Lieberman, E., "Determining Lateral Deployment of Traffic on an Approach to an Intersection", McShane, W. & Lieberman, E., "Service Rates of Mixed Traffic on the far Left Lane of an Approach". Both papers appear in Transportation Research Record 772, 1980. Lieberman, E., Xin, W., "Macroscopic Traffic Modeling For Large-Scale Evacuation Planning", presented at the TRB 2012 Annual Meeting, January 22-26, 2012

That is, the turn-movement-specific discharge headways are always greater than, or equal to the saturation discharge headway for through vehicles. These headways (or its inverse equivalent, "saturation flow rate"), may be determined by observation or using the procedures of the HCM 2010.

The above discussion is necessarily brief given the scope of this ETE report and the complexity of the subject of intersection capacity. In fact, Chapters 18, 19 and 20 in the HCM 2010 address this topic. The factors, F1, F2,..., influencing saturation flow rate are identified in equation (18-5) of the HCM 2010.

The traffic signals within the EPZ and Shadow Region are modeled using representative phasing plans and phase durations obtained as part of the field data collection. Traffic responsive signal installations allow the proportion of green time allocated (P_m) for each approach to each intersection to be determined by the expected traffic volumes on each approach during evacuation circumstances. The amount of green time (G) allocated is subject to maximum and minimum phase duration constraints; 2 seconds of yellow time are indicated for each signal phase and 1 second of all-red time is assigned between signal phases, typically. If a signal is pre-timed, the yellow and all-red times observed during the road survey are used. A lost time (L) of 2.0 seconds is used for each signal phase in the analysis.

4.2 Capacity Estimation along Sections of Highway

The capacity of highway sections -- as distinct from approaches to intersections -- is a function of roadway geometrics, traffic composition (e.g. percent heavy trucks and buses in the traffic stream) and, of course, motorist behavior. There is a fundamental relationship which relates service volume (i.e. the number of vehicles serviced within a uniform highway section in a given time period) to traffic density. The top curve in Figure 4-1 illustrates this relationship.

As indicated, there are two flow regimes: (1) Free Flow (left side of curve); and (2) Forced Flow (right side). In the Free Flow regime, the traffic demand is fully serviced; the service volume increases as demand volume and density increase, until the service volume attains its maximum value, which is the capacity of the highway section. As traffic demand and the resulting highway density increase beyond this "critical" value, the rate at which traffic can be serviced (i.e. the service volume) can actually decline below capacity ("capacity drop"). Therefore, in order to realistically represent traffic performance during congested conditions (i.e. when demand exceeds capacity), it is necessary to estimate the service volume, V_F, under congested conditions.

The value of V_F can be expressed as:

$$V_F = R \times Capacity$$

where:

R	=	Reduction factor which is less than unity

We have employed a value of R=0.90. The advisability of such a capacity reduction factor is based upon empirical studies that identified a fall-off in the service flow rate when congestion occurs at "bottlenecks" or "choke points" on a freeway system. Zhang and Levinson[3] describe a research program that collected data from a computer-based surveillance system (loop detectors) installed on the Interstate Highway System, at 27 active bottlenecks in the twin cities metro area in Minnesota over a 7-week period. When flow breakdown occurs, queues are formed which discharge at lower flow rates than the maximum capacity prior to observed breakdown. These queue discharge flow (QDF) rates vary from one location to the next and also vary by day of week and time of day based upon local circumstances. The cited reference presents a mean QDF of 2,016 passenger cars per hour per lane (pcphpl). This figure compares with the nominal capacity estimate of 2,250 pcphpl estimated for the ETE and indicated in Appendix K for freeway links. The ratio of these two numbers is 0.896 which translates into a capacity reduction factor of 0.90.

Since the principal objective of evacuation time estimate analyses is to develop a "realistic" estimate of evacuation times, use of the representative value for this capacity reduction factor (R=0.90) is justified. This factor is applied only when flow breaks down, as determined by the simulation model.

Rural roads, like freeways, are classified as "uninterrupted flow" facilities. (This is in contrast with urban street systems which have closely spaced signalized intersections and are classified as "interrupted flow" facilities.) As such, traffic flow along rural roads is subject to the same effects as freeways in the event traffic demand exceeds the nominal capacity, resulting in queuing and lower QDF rates. As a practical matter, rural roads rarely break down at locations away from intersections. Any breakdowns on rural roads are generally experienced at intersections where other model logic applies, or at lane drops which reduce capacity there. Therefore, the application of a factor of 0.90 is appropriate on rural roads, but rarely, if ever, activated.

The estimated value of capacity is based primarily upon the type of facility and on roadway geometrics. Sections of roadway with adverse geometrics are characterized by lower free-flow speeds and lane capacity. Exhibit 15-30 in the Highway Capacity Manual was referenced to estimate saturation flow rates. The impact of narrow lanes and shoulders on free-flow speed and on capacity is not material, particularly when flow is predominantly in one direction as is the case during an evacuation.

The procedure used here was to estimate "section" capacity, V_E, based on observations made traveling over each section of the evacuation network, based on the posted speed limits and travel behavior of other motorists and by reference to the 2010 HCM. The DYNEV II simulation model determines for each highway section, represented as a network link, whether its capacity would be limited by the "section-specific" service volume, V_E, or by the intersection-specific capacity. For each link, the model selects the lower value of capacity.

[3]Lei Zhang and David Levinson, "Some Properties of Flows at Freeway Bottlenecks," Transportation Research Record 1883, 2004.

4.3 Application to the RNP Study Area

As part of the development of the link-node analysis network for the study area, an estimate of roadway capacity is required. The source material for the capacity estimates presented herein is contained in:

> 2010 Highway Capacity Manual (HCM)
> Transportation Research Board
> National Research Council
> Washington, D.C.

The highway system in the study area consists primarily of three categories of roads and, of course, intersections:

- Two-Lane roads: Local, State
- Multi-Lane Highways (at-grade)
- Freeways

Each of these classifications will be discussed.

4.3.1 Two-Lane Roads

Ref: HCM Chapter 15

Two lane roads comprise the majority of highways within the EPZ. The per-lane capacity of a two-lane highway is estimated at 1700 passenger cars per hour (pc/h). This estimate is essentially independent of the directional distribution of traffic volume except that, for extended distances, the two-way capacity will not exceed 3200 pc/h. The HCM procedures then estimate Level of Service (LOS) and Average Travel Speed. The DYNEV II simulation model accepts the specified value of capacity as input and computes average speed based on the time-varying demand: capacity relations.

Based on the field survey and on expected traffic operations associated with evacuation scenarios:

- Most sections of two-lane roads within the EPZ are classified as "Class I", with "level terrain"; some are "rolling terrain".
- "Class II" highways are mostly those within urban and suburban centers.

4.3.2 Multi-Lane Highway

Ref: HCM Chapter 14

Exhibit 14-2 of the HCM 2010 presents a set of curves that indicate a per-lane capacity ranging from approximately 1900 to 2200 pc/h, for free-speeds of 45 to 60 mph, respectively. Based on observation, the multi-lane highways outside of urban areas within the EPZ service traffic with free-speeds in this range. The actual time-varying speeds computed by the simulation model reflect the demand: capacity relationship and the impact of control at intersections. A conservative estimate of per-lane capacity of 1900 pc/h is adopted for this study for multi-lane highways outside of urban areas, as shown in Appendix K.

4.3.3 Freeways

Ref: HCM Chapters 10, 11, 12, 13

Chapter 10 of the HCM 2010 describes a procedure for integrating the results obtained in Chapters 11, 12 and 13, which compute capacity and LOS for freeway components. Chapter 10 also presents a discussion of simulation models. The DYNEV II simulation model automatically performs this integration process.

Chapter 11 of the HCM 2010 presents procedures for estimating capacity and LOS for "Basic Freeway Segments". Exhibit 11-17 of the HCM 2010 presents capacity vs. free speed estimates, which are provided below.

Free Speed (mph):	55	60	65	70+
Per-Lane Capacity (pc/h):	2250	2300	2350	2400

The inputs to the simulation model are highway geometrics, free-speeds and capacity based on field observations. The simulation logic calculates actual time-varying speeds based on demand: capacity relationships. A conservative estimate of per-lane capacity of 2250 pc/h is adopted for this study for freeways, as shown in Appendix K.

Chapter 12 of the HCM 2010 presents procedures for estimating capacity, speed, density and LOS for freeway weaving sections. The simulation model contains logic that relates speed to demand volume: capacity ratio. The value of capacity obtained from the computational procedures detailed in Chapter 12 depends on the "Type" and geometrics of the weaving segment and on the "Volume Ratio" (ratio of weaving volume to total volume).

Chapter 13 of the HCM 2010 presents procedures for estimating capacities of ramps and of "merge" areas. There are three significant factors to the determination of capacity of a ramp-freeway junction: The capacity of the freeway immediately downstream of an on-ramp or immediately upstream of an off-ramp; the capacity of the ramp roadway; and the maximum flow rate entering the ramp influence area. In most cases, the freeway capacity is the controlling factor. Values of this merge area capacity are presented in Exhibit 13-8 of the HCM 2010, and depend on the number of freeway lanes and on the freeway free speed. Ramp capacity is presented in Exhibit 13-10 and is a function of the ramp free flow speed. The DYNEV II simulation model logic simulates the merging operations of the ramp and freeway traffic in accord with the procedures in Chapter 13 of the HCM 2010. If congestion results from an excess of demand relative to capacity, then the model allocates service appropriately to the two entering traffic streams and produces LOS F conditions (The HCM does not address LOS F explicitly).

4.3.4 Intersections

Ref: HCM Chapters 18, 19, 20, 21

Procedures for estimating capacity and LOS for approaches to intersections are presented in Chapter 18 (signalized intersections), Chapters 19, 20 (un-signalized intersections) and Chapter 21 (roundabouts). The complexity of these computations is indicated by the aggregate length of these chapters. The DYNEV II simulation logic is likewise complex.

The simulation model explicitly models intersections: Stop/yield controlled intersections (both 2-way and all-way) and traffic signal controlled intersections. Where intersections are controlled by fixed time controllers, traffic signal timings are set to reflect average (non-evacuation) traffic conditions. Actuated traffic signal settings respond to the time-varying demands of evacuation traffic to adjust the relative capacities of the competing intersection approaches.

The model is also capable of modeling the presence of manned traffic control. At specific locations where it is advisable or where existing plans call for overriding existing traffic control to implement manned control, the model will use actuated signal timings that reflect the presence of traffic guides. At locations where a special traffic control strategy (continuous left-turns, contra-flow lanes) is used, the strategy is modeled explicitly. Where applicable, the location and type of traffic control for nodes in the evacuation network are noted in Appendix K. The characteristics of the ten highest volume signalized intersections are detailed in Appendix J.

4.4 Simulation and Capacity Estimation

Chapter 6 of the HCM is entitled, "HCM and Alternative Analysis Tools." The chapter discusses the use of alternative tools such as simulation modeling to evaluate the operational performance of highway networks. Among the reasons cited in Chapter 6 to consider using simulation as an alternative analysis tool is:

> *"The system under study involves a group of different facilities or travel modes with mutual interactions invoking several procedural chapters of the HCM. Alternative tools are able to analyze these facilities as a single system."*

This statement succinctly describes the analyses required to determine traffic operations across an area encompassing an EPZ operating under evacuation conditions. The model utilized for this study, DYNEV II, is further described in Appendix C. It is essential to recognize that simulation models do not replicate the methodology and procedures of the HCM – they *replace* these procedures by describing the complex interactions of traffic flow and computing Measures of Effectiveness (MOE) detailing the operational performance of traffic over time and by location. The DYNEV II simulation model includes some HCM 2010 procedures only for the purpose of estimating capacity.

All simulation models must be calibrated properly with field observations that quantify the performance parameters applicable to the analysis network. Two of the most important of these are: (1) Free flow speed (FFS); and (2) saturation headway, h_{sat}. The first of these is estimated by direct observation during the road survey; the second is estimated using the concepts of the HCM 2010, as described earlier. These parameters are listed in Appendix K, for each network link.

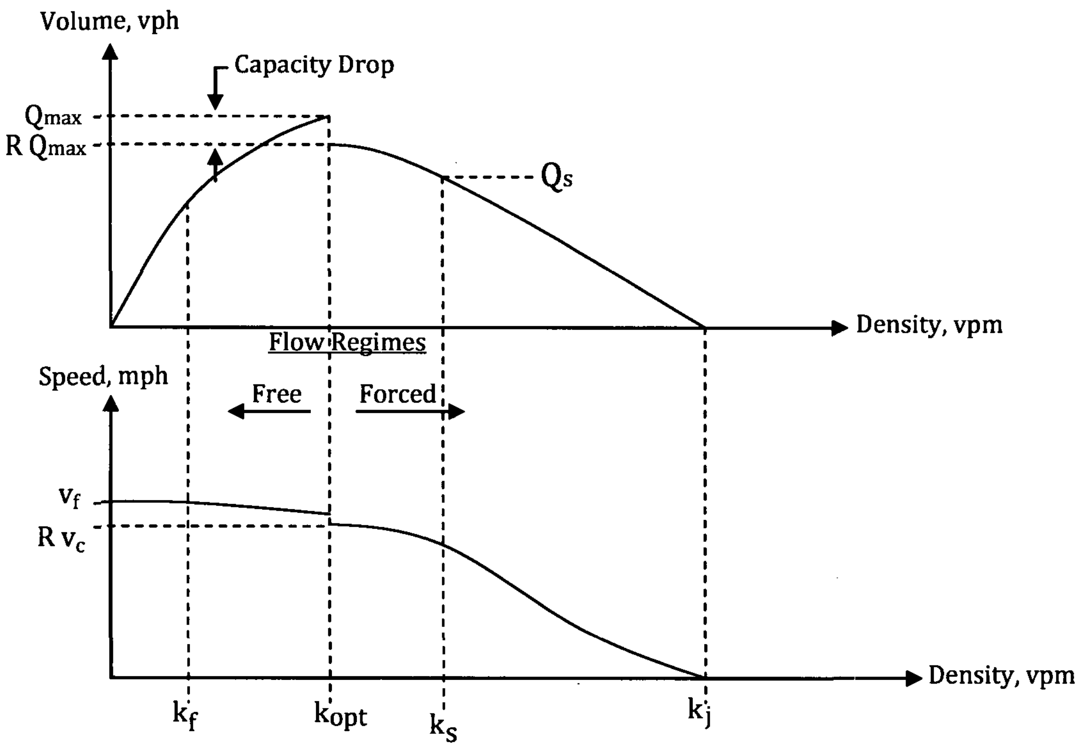


Figure 4-1. Fundamental Diagrams

5 ESTIMATION OF TRIP GENERATION TIME

Federal Government guidelines (see NUREG/CR-7002) specify that the planner estimate the distributions of elapsed times associated with mobilization activities undertaken by the public to prepare for the evacuation trip. The elapsed time associated with each activity is represented as a statistical distribution reflecting differences between members of the public. The quantification of these activity-based distributions relies largely on the results of the telephone survey. We define the sum of these distributions of elapsed times as the Trip Generation Time Distribution.

5.1 Background

As a Planning Basis, we will adopt a conservative posture, in accordance with Section 1.2 of NUREG/CR-7002, that a rapidly escalating event will be considered in calculating the Trip Generation Time assuming that:

1. The Advisory to Evacuate will be announced coincident with the siren notification.
2. Mobilization of the general population will commence within 15 minutes after the siren notification.
3. ETE are measured relative to the Advisory to Evacuate.

It is emphasized that the adoption of this planning basis is not a representation that these events will occur within the indicated time frame. Rather, these assumptions are necessary in order to:

1. Establish a temporal framework for estimating the Trip Generation distribution in the format recommended in Section 2.13 of NUREG/CR-6863.
2. Identify temporal points of reference that uniquely define "Clear Time" and ETE.

For example, suppose one hour elapses from the siren alert to the Advisory to Evacuate. In this case, it is reasonable to expect some degree of spontaneous evacuation by the public during this one-hour period. As a result, the population within the EPZ will be lower when the Advisory to Evacuate is announced, than at the time of the siren alert. In addition, many will engage in preparation activities to evacuate, in anticipation that an Advisory will be broadcast. Thus, the time needed to complete the mobilization activities and the number of people remaining to evacuate the EPZ after the Advisory to Evacuate, will both be somewhat less than the estimates presented in this report. Consequently, the ETE presented in this report are likely to be higher than the actual evacuation time, if this hypothetical situation were to take place.

The notification process consists of two events:

1. Transmitting information using the alert notification system available within the EPZ (e.g. sirens, tone alerts, EAS broadcasts, loud speakers).
2. Receiving and correctly interpreting the information that is transmitted.

The population within the EPZ is dispersed over an area of approximately 320 square miles and is engaged in a wide variety of activities. It must be anticipated that some time will elapse between the transmission and receipt of the information advising the public of an emergency event.

The amount of elapsed time will vary from one individual to the next depending on where that person is, what that person is doing, and related factors. Furthermore, some persons who will be directly involved with the evacuation process may be outside the EPZ at the time the emergency is declared. These people may be commuters, shoppers and other travelers who reside within the EPZ and who will return to join the other household members upon receiving notification of an emergency.

As indicated in Section 2.13 of NUREG/CR-6863, the estimated elapsed times for the receipt of notification can be expressed as a distribution reflecting the different notification times for different people within, and outside, the EPZ. By using time distributions, it is also possible to distinguish between different population groups and different day-of-week and time-of-day scenarios, so that accurate ETE may be computed.

For example, people at home or at work within the EPZ will be notified by siren, and/or tone alert and/or radio (if available). Those well outside the EPZ will be notified by telephone, radio, TV and word-of-mouth, with potentially longer time lags. Furthermore, the spatial distribution of the EPZ population will differ with time of day - families will be united in the evenings, but dispersed during the day. In this respect, weekends will differ from weekdays.

As indicated in Section 4.1 of NUREG/CR-7002, the information required to compute trip generation times is typically obtained from a telephone survey of EPZ residents. Such a survey was conducted in support of this ETE study. Appendix F presents the survey sampling plan, survey instrument, and raw survey results. It is important to note that the shape and duration of the evacuation trip mobilization distribution is important at sites where traffic congestion is not expected to cause the evacuation time estimate to extend in time well beyond the trip generation period. The remaining discussion will focus on the application of the trip generation data obtained from the telephone survey to the development of the ETE documented in this report.

5.2 Fundamental Considerations

The environment leading up to the time that people begin their evacuation trips consists of a sequence of events and activities. Each event (other than the first) occurs at an instant in time and is the outcome of an activity.

Activities are undertaken over a period of time. Activities may be in "series" (i.e. to undertake an activity implies the completion of all preceding events) or may be in parallel (two or more activities may take place over the same period of time). Activities conducted in series are functionally dependent on the completion of prior activities; activities conducted in parallel are functionally independent of one another. The relevant events associated with the public's preparation for evacuation are:

Event Number	Event Description
1	Notification
2	Awareness of Situation
3	Depart Work
4	Arrive Home
5	Depart on Evacuation Trip

Associated with each sequence of events are one or more activities, as outlined below:

Table 5-1. Event Sequence for Evacuation Activities

Event Sequence	Activity	Distribution
1 → 2	Receive Notification	1
2 → 3	Prepare to Leave Work	2
2,3 → 4	Travel Home	3
2,4 → 5	Prepare to Leave to Evacuate	4
N/A	Snow Clearance	5

These relationships are shown graphically in Figure 5-1.

- An Event is a 'state' that exists at a point in time (e.g., depart work, arrive home)
- An Activity is a 'process' that takes place over some elapsed time (e.g., prepare to leave work, travel home)

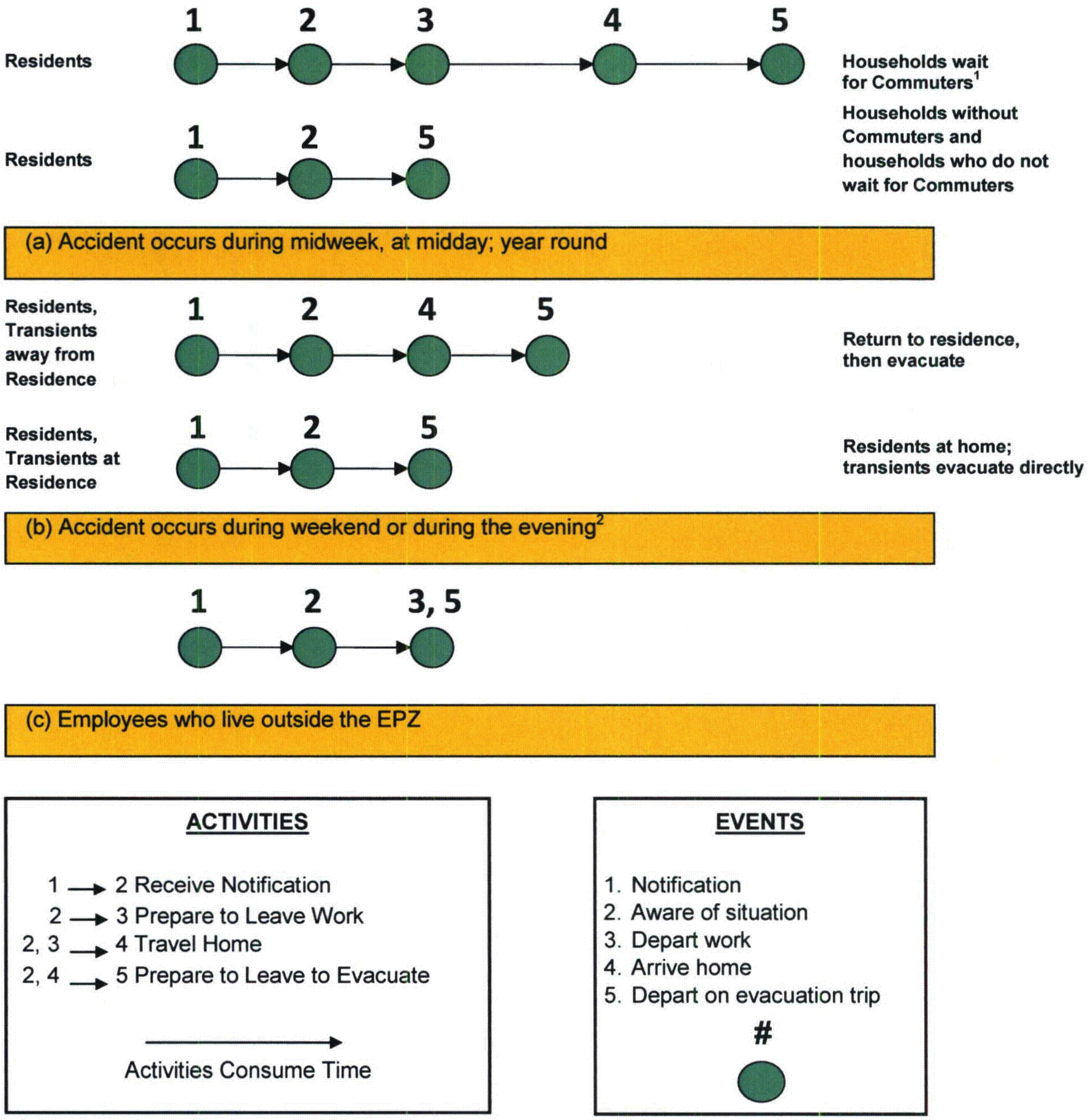
As such, a completed Activity changes the 'state' of an individual (e.g. the activity, 'travel home' changes the state from 'depart work' to 'arrive home'). Therefore, an Activity can be described as an 'Event Sequence'; the elapsed times to perform an event sequence vary from one person to the next and are described as statistical distributions on the following pages.

An employee who lives outside the EPZ will follow sequence (c) of Figure 5-1. A household within the EPZ that has one or more commuters at work, and will await their return before beginning the evacuation trip will follow the first sequence of Figure 5-1(a). A household within the EPZ that has no commuters at work, or that will not await the return of any commuters, will follow the second sequence of Figure 5-1(a), regardless of day of week or time of day.

Households with no commuters on weekends or in the evening/night-time, will follow the applicable sequence in Figure 5-1(b). Transients will always follow one of the sequences of Figure 5-1(b). Some transients away from their residence could elect to evacuate immediately without returning to the residence, as indicated in the second sequence.

It is seen from Figure 5-1, that the Trip Generation time (i.e. the total elapsed time from Event 1 to Event 5) depends on the scenario and will vary from one household to the next. Furthermore, Event 5 depends, in a complicated way, on the time distributions of all activities preceding that event. That is, to estimate the time distribution of Event 5, we must obtain estimates of the time distributions of all preceding events. For this study, we adopt the conservative posture that all activities will occur in sequence.

In some cases, assuming certain events occur strictly sequentially (for instance, commuter returning home before beginning preparation to leave, or removing snow only after the preparation to leave) can result in rather *conservative* (that is, longer) estimates of mobilization times. It is reasonable to expect that at least some parts of these events will overlap for many households, but that assumption is not made in this study.



[1] Applies for evening and weekends also if commuters are at work.

[2] Applies throughout the year for transients.

Figure 5-1. Events and Activities Preceding the Evacuation Trip

5.3 Estimated Time Distributions of Activities Preceding Event 5

The time distribution of an event is obtained by "summing" the time distributions of all prior contributing activities. (This "summing" process is quite different than an algebraic sum since it is performed on distributions – not scalar numbers).

Time Distribution No. 1, Notification Process: Activity 1 → 2

In accordance with the 2012 Federal Emergency Management Agency (FEMA) Radiological Emergency Preparedness Program Manual, 100% of the population is notified within 45 minutes. It is assumed (based on the presence of sirens within the EPZ) that 87 percent of those within the EPZ will be aware of the event within 30 minutes with the remainder notified within the following 15 minutes. The notification distribution is given below:

Table 5-2. Time Distribution for Notifying the Public

Elapsed Time (Minutes)	Percent of Population Notified
0	0%
5	7%
10	13%
15	27%
20	47%
25	66%
30	87%
35	92%
40	97%
45	100%

Distribution No. 2, Prepare to Leave Work: Activity 2 → 3

It is reasonable to expect that the vast majority of business enterprises within the EPZ will elect to shut down following notification and most employees would leave work quickly. Commuters, who work outside the EPZ could, in all probability, also leave quickly since facilities outside the EPZ would remain open and other personnel would remain. Personnel or farmers responsible for equipment/livestock would require additional time to secure their facility. The distribution of Activity 2 → 3 shown in Table 5-3 reflects data obtained by the telephone survey. This distribution is also applicable for residents who need time to leave stores, restaurants, parks and other locations within the EPZ. This distribution is plotted in Figure 5-2.

Table 5-3. Time Distribution for Employees to Prepare to Leave Work

Elapsed Time (Minutes)	Cumulative Percent Employees Leaving Work	Elapsed Time (Minutes)	Cumulative Percent Employees Leaving Work
0	0%	45	92.9%
5	15.7%	50	94.0%
10	37.6%	55	94.0%
15	52.5%	60	98.4%
20	64.8%	75	99.2%
25	69.2%	90	100.0%
30	82.1%		
35	83.5%		
40	85.7%		

NOTE: The survey data was normalized to distribute the "Don't know" response. That is, the sample was reduced in size to include only those households who responded to this question. The underlying assumption is that the distribution of this activity for the "Don't know" responders, if the event takes place, would be the same as those responders who provided estimates.

Distribution No. 3, Travel Home: Activity 3 → 4

These data are provided directly by those households which responded to the telephone survey. This distribution is plotted in Figure 5-2 and listed in Table 5-4.

Table 5-4. Time Distribution for Commuters to Travel Home

Elapsed Time (Minutes)	Cumulative Percent Returning Home	Elapsed Time (Minutes)	Cumulative Percent Returning Home
0	0	45	86.7%
5	29.1%	50	87.3%
10	44.6%	55	87.6%
15	55.9%	60	96.0%
20	61.3%	75	96.6%
25	63.0%	90	98.0%
30	80.8%	105	98.6%
35	81.6%	120	100.0%
40	82.5%		

NOTE: The survey data was normalized to distribute the "Don't know" response

Distribution No. 4, Prepare to Leave Home: Activity 2, 4 → 5

These data are provided directly by those households which responded to the telephone survey. This distribution is plotted in Figure 5-2 and listed in Table 5-5.

Table 5-5. Time Distribution for Population to Prepare to Evacuate

Elapsed Time (Minutes)	Cumulative Percent Ready to Evacuate
0	0%
15	26.6%
30	65.7%
45	73.1%
60	91.9%
75	94.1%
90	95.5%
105	95.7%
120	98.2%
135	100.0%

NOTE: The survey data was normalized to distribute the "Don't know" response

Distribution No. 5, Snow Clearance Time Distribution

Inclement weather scenarios involving snowfall must address the time lags associated with snow clearance. It is assumed that snow equipment is mobilized and deployed during the snowfall to maintain passable roads. The general consensus is that the snow-plowing efforts are generally successful for all but the most extreme blizzards when the rate of snow accumulation exceeds that of snow clearance over a period of many hours.

Consequently, it is reasonable to assume that the highway system will remain passable – albeit at a lower capacity – under the vast majority of snow conditions. Nevertheless, for the vehicles to gain access to the highway system, it may be necessary for driveways and employee parking lots to be cleared to the extent needed to permit vehicles to gain access to the roadways. These clearance activities take time; this time must be incorporated into the trip generation time distributions. These data are provided by those households which responded to the telephone survey. This distribution is plotted in Figure 5-2 and listed in Table 5-6.

Note that those respondents (70%) who answered that they would not take time to clear their driveway were assumed to be ready immediately at the start of this activity. Essentially they would drive through the snow on the driveway to access the roadway and begin their evacuation trip.

Table 5-6. Time Distribution for Population to Clear 2-3" of Snow

Elapsed Time (Minutes)	Cumulative Percent Completing Snow Removal
0	70%
15	76.7%
30	87.0%
45	89.7%
60	94.8%
75	95.2%
90	95.7%
105	95.9%
120	97.5%
135	97.9%
150	97.9%
165	97.9%
180	100.0%

NOTE: The survey data was normalized to distribute the "Don't know" response

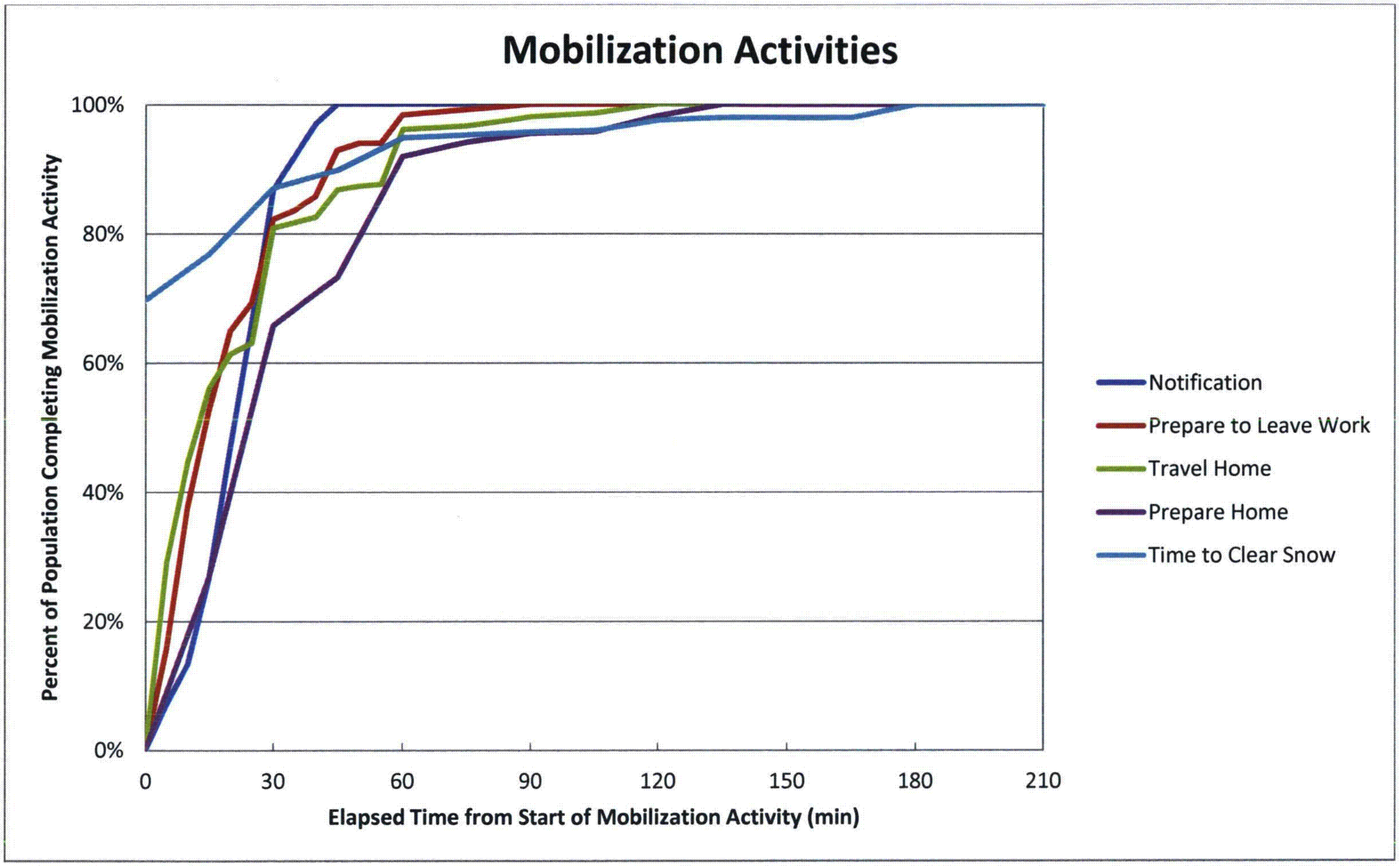


Figure 5-2. Evacuation Mobilization Activities

5.4 Calculation of Trip Generation Time Distribution

The time distributions for each of the mobilization activities presented herein must be combined to form the appropriate Trip Generation Distributions. As discussed above, this study assumes that the stated events take place in sequence such that all preceding events must be completed before the current event can occur. For example, if a household awaits the return of a commuter, the work-to-home trip (Activity 3 → 4) must precede Activity 4 → 5.

To calculate the time distribution of an event that is dependent on two sequential activities, it is necessary to "sum" the distributions associated with these prior activities. The distribution summing algorithm is applied repeatedly as shown to form the required distribution. As an outcome of this procedure, new time distributions are formed; we assign "letter" designations to these intermediate distributions to describe the procedure. Table 5-7 presents the summing procedure to arrive at each designated distribution.

Table 5-7. Mapping Distributions to Events

Apply "Summing" Algorithm To:	Distribution Obtained	Event Defined
Distributions 1 and 2	Distribution A	Event 3
Distributions A and 3	Distribution B	Event 4
Distributions B and 4	Distribution C	Event 5
Distributions 1 and 4	Distribution D	Event 5
Distributions C and 5	Distribution E	Event 5
Distributions D and 5	Distribution F	Event 5

Table 5-8 presents a description of each of the final trip generation distributions achieved after the summing process is completed.

Table 5-8. Description of the Distributions

Distribution	Description
A	Time distribution of commuters departing place of work (Event 3). Also applies to employees who work within the EPZ who live outside, and to Transients within the EPZ.
B	Time distribution of commuters arriving home (Event 4).
C	Time distribution of residents with commuters who return home, leaving home to begin the evacuation trip (Event 5).
D	Time distribution of residents without commuters returning home, leaving home to begin the evacuation trip (Event 5).
E	Time distribution of residents with commuters who return home, leaving home to begin the evacuation trip, after snow clearance activities (Event 5).
F	Time distribution of residents with no commuters returning home, leaving to begin the evacuation trip, after snow clearance activities (Event 5).

5.4.1 Statistical Outliers

As already mentioned, some portion of the survey respondents answer "don't know" to some questions or choose to not respond to a question. The mobilization activity distributions are based upon actual responses. But, it is the nature of surveys that a few numeric responses are inconsistent with the overall pattern of results. An example would be a case in which for 500 responses, almost all of them estimate less than two hours for a given answer, but 3 say "four hours" and 4 say "six or more hours".

These "outliers" must be considered: are they valid responses, or so atypical that they should be dropped from the sample?

In assessing outliers, there are three alternates to consider:

1) Some responses with very long times may be valid, but reflect the reality that the respondent really needs to be classified in a different population subgroup, based upon special needs;

2) Other responses may be unrealistic (6 hours to return home from commuting distance, or 2 days to prepare the home for departure);

3) Some high values are representative and plausible, and one must not cut them as part of the consideration of outliers.

The issue of course is how to make the decision that a given response or set of responses are to be considered "outliers" for the component mobilization activities, using a method that objectively quantifies the process.

There is considerable statistical literature on the identification and treatment of outliers singly or in groups, much of which assumes the data is normally distributed and some of which uses nonparametric methods to avoid that assumption. The literature cites that limited work has been done directly on outliers in sample survey responses.

In establishing the overall mobilization time/trip generation distributions, the following principles are used:

1) It is recognized that the overall trip generation distributions are conservative estimates, because they assume a household will do the mobilization activities sequentially, with no overlap of activities;

2) The individual mobilization activities (prepare to leave work, travel home, prepare home, clear snow) are reviewed for outliers, and then the overall trip generation distributions are created (see Figure 5-1, Table 5-7, Table 5-8);

3) Outliers can be eliminated either because the response reflects a special population (e.g. special needs, transit dependent) or lack of realism, because the purpose is to estimate trip generation patterns for personal vehicles;

4) To eliminate outliers,
    a) the mean and standard deviation of the specific activity are estimated from the responses,
    b) the median of the same data is estimated, with its position relative to the mean noted,
    c) the histogram of the data is inspected, and
    d) all values greater than 3.5 standard deviations are flagged for attention, taking special note of whether there are gaps (categories with zero entries) in the histogram display.

   In general, only flagged values more than 4 standard deviations from the mean are allowed to be considered outliers, with gaps in the histogram expected.

   When flagged values are classified as outliers and dropped, steps "a" to "d" are repeated.

5) As a practical matter, even with outliers eliminated by the above, the resultant histogram, viewed as a cumulative distribution, is not a normal distribution. A typical situation that results is shown below in Figure 5-3.

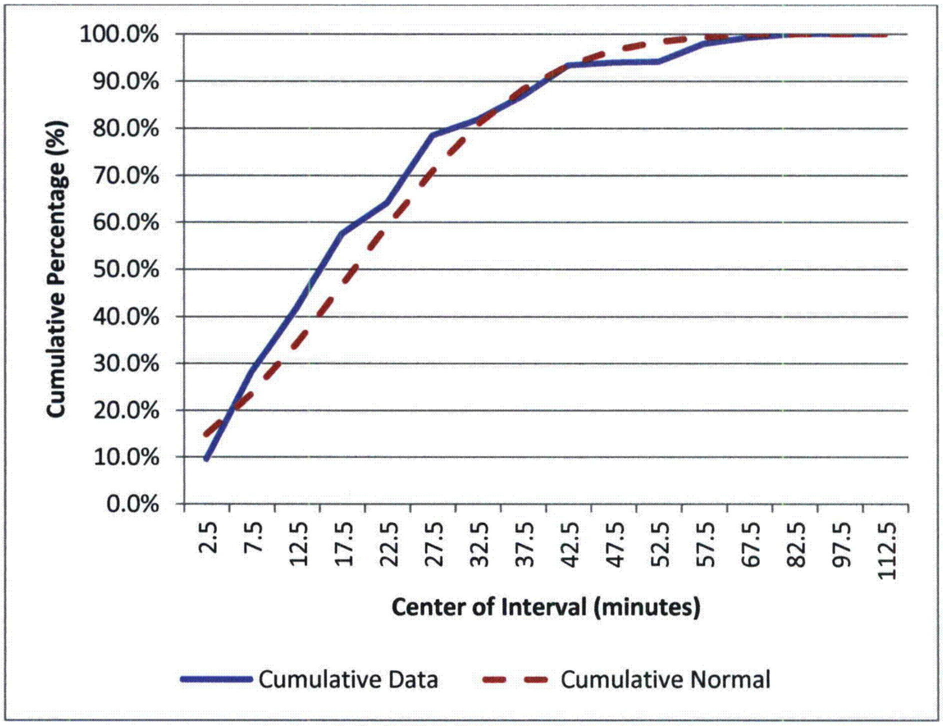


Figure 5-3. Comparison of Data Distribution and Normal Distribution

6) In particular, the cumulative distribution differs from the normal distribution in two key aspects, both very important in loading a network to estimate evacuation times:

- Most of the real data is to the left of the "normal" curve above, indicating that the network loads faster for the first 80-85% of the vehicles, potentially causing more (and earlier) congestion than otherwise modeled;
- The last 10-15% of the real data "tails off" slower than the comparable "normal" curve, indicating that there is significant traffic still loading at later times.

Because these two features are important to preserve, it is the histogram of the data that is used to describe the mobilization activities, <u>not</u> a "normal" curve fit to the data. One could consider other distributions, but using the shape of the *actual* data curve is unambiguous and preserves these important features;

7) With the mobilization activities each modeled according to Steps 1-6, including preserving the features cited in Step 6, the overall (or total) mobilization times are constructed.

This is done by using the data sets and distributions under different scenarios (e.g. commuter returning, no commuter returning, no snow or snow in each). In general, these are additive, using weighting based upon the probability distributions of each element; Figure 5-4 presents the combined trip generation distributions designated A, C, D, E and F. These distributions are presented on the same time scale. (As discussed earlier, the use of strictly additive activities is a conservative approach, because it makes all activities sequential – preparation for departure follows the return of the commuter; snow clearance follows the preparation for departure, and so forth. In practice, it is reasonable that some of these activities are done in parallel, at least to some extent – for instance, preparation to depart begins by a household member at home while the commuter is still on the road.)

The mobilization distributions that result are used in their tabular/graphical form as direct inputs to later computations that lead to the ETE.

The DYNEV II simulation model is designed to accept varying rates of vehicle trip generation for each origin centroid, expressed in the form of histograms. These histograms, which represent Distributions A, C, D, E and F, properly displaced with respect to one another, are tabulated in Table 5-9 (Distribution B, Arrive Home, omitted for clarity).

The final time period (15) is 600 minutes long. This time period is added to allow the analysis network to clear, in the event congestion persists beyond the trip generation period. Note that there are no trips generated during this final time period.

5.4.2 Staged Evacuation Trip Generation

As defined in NUREG/CR-7002, staged evacuation consists of the following:

1. Zones comprising the 2 mile region are advised to evacuate immediately
2. Zones comprising regions extending from 2 to 5 miles downwind are advised to shelter in-place while the 2 mile region is cleared
3. As vehicles evacuate the 2 mile region, sheltered people from 2 to 5 miles downwind continue preparation for evacuation
4. The population sheltering in the 2 to 5 mile region are advised to begin evacuating when approximately 90% of those originally within the 2 mile region evacuate across the 2 mile region boundary
5. Non-compliance with the shelter recommendation is the same as the shadow evacuation percentage of 20%

Assumptions

1. The EPZ population in zones beyond 5 miles will react as does the population in the 2 to 5 mile region; that is they will first shelter, then evacuate after the 90th percentile ETE for the 2 mile region
2. The population in the shadow region beyond the EPZ boundary, extending to approximately 15 miles radially from the plant, will react as they do for all non-staged evacuation scenarios. That is 20% of these households will elect to evacuate with no shelter delay.

3. The transient population will not be expected to stage their evacuation because of the limited sheltering options available to people who may be at parks, on a beach, or at other venues. Also, notifying the transient population of a staged evacuation would prove difficult.
4. Employees will also be assumed to evacuate without first sheltering.

Procedure

1. Trip generation for population groups in the 2 mile region will be as computed based upon the results of the telephone survey and analysis.
2. Trip generation for the population subject to staged evacuation will be formulated as follows:
    a. Identify the 90th percentile evacuation time for the zones comprising the two mile region. This value, T_{Scen}^*, is obtained from simulation results. It will become the time at which the region being sheltered will be told to evacuate for each scenario.
    b. The resultant trip generation curves for staging are then formed as follows:
        i. The non-shelter trip generation curve is followed until a maximum of 20% of the total trips are generated (to account for shelter non-compliance).
        ii. No additional trips are generated until time T_{Scen}^*
        iii. Following time T_{Scen}^*, the balance of trips are generated:
            1. by stepping up and then following the non-shelter trip generation curve (if T_{Scen}^* is $\leq$ max trip generation time) or
            2. by stepping up to 100% (if T_{Scen}^* is > max trip generation time)
    c. Note: This procedure implies that there may be different staged trip generation distributions for different scenarios. NUREG/CR-7002 uses the statement "approximately 90th percentile" as the time to end staging and begin evacuating. The value of T_{Scen}^* is 2:00 for non-snow scenarios and 2:15 for snow scenarios.
3. Staged trip generation distributions are created for the following population groups:
    a. Residents with returning commuters
    b. Residents without returning commuters
    c. Residents with returning commuters and snow conditions
    d. Residents without returning commuters and snow conditions

Figure 5-5 presents the staged trip generation distributions for both residents with and without returning commuters; the 90th percentile two-mile evacuation time is 120 minutes for good weather or rain and 135 minutes for snow scenarios. At the 90th percentile evacuation time, 20% of the population (who normally would have completed their mobilization activities for an un-staged evacuation) advised to shelter has nevertheless departed the area. These people do not comply with the shelter advisory. Also included on the plot are the trip generation distributions for these groups as applied to the regions advised to evacuate immediately.

Since the 90th percentile evacuation time occurs before the end of the trip generation time, after the sheltered region is advised to evacuate, the shelter trip generation distribution rises to meet the balance of the non-staged trip generation distribution. Following time T_{Scen}^*, the balance of staged evacuation trips that are ready to depart are released within 15 minutes. After T_{Scen}^{*}+15, the remainder of evacuation trips are generated in accordance with the unstaged trip generation distribution.

Table 5-10 provides the trip generation histograms for staged evacuation.

5.4.3 Trip Generation for Waterways and Recreational Areas

Annex 1 of the South Carolina Operational Radiological Emergency Response Plan states that South Carolina Department of Natural Resources will alert persons boating or fishing on Lake Robinson.

As indicated in Table 5-2, this study assumes 100% notification in 45 minutes (which is also in accordance with Darlington County RERP (Appendix A) and the 2012 Federal Emergency Management Agency (FEMA) Radiological Emergency Preparedness Program Manual). Table 5-9 indicates that all transients will have mobilized within 2 hours. It is assumed that this 2 hour timeframe is sufficient time for boaters, campers and other transients to return to their vehicles and begin their evacuation trip.

Table 5-9. Trip Generation Histograms for the EPZ Population for Unstaged Evacuation

Time Period	Duration (Min)	Percent of Total Trips Generated Within Indicated Time Period					
		Employees (Distribution A)	Transients (Distribution A)	Residents with Commuters (Distribution C)	Residents Without Commuters (Distribution D)	Residents With Commuters Snow (Distribution E)	Residents Without Commuters Snow (Distribution F)
1	15	4%	4%	0%	2%	0%	1%
2	15	23%	23%	0%	13%	0%	10%
3	15	35%	35%	4%	28%	3%	21%
4	15	22%	22%	10%	24%	7%	21%
5	15	10%	10%	15%	14%	13%	15%
6	15	4%	4%	17%	10%	14%	12%
7	15	1%	1%	16%	4%	14%	6%
8	15	1%	1%	12%	1%	13%	3%
9	15	0%	0%	9%	1%	9%	3%
10	30	0%	0%	10%	3%	13%	4%
11	30	0%	0%	5%	0%	7%	1%
12	30	0%	0%	1%	0%	3%	2%
13	30	0%	0%	1%	0%	2%	1%
14	60	0%	0%	0%	0%	2%	0%
15	600	0%	0%	0%	0%	0%	0%

NOTE:

- Shadow vehicles are loaded onto the analysis network (Figure 1-2) using Distributions C and E for good weather and snow, respectively.
- Special event vehicles are loaded using Distribution A.

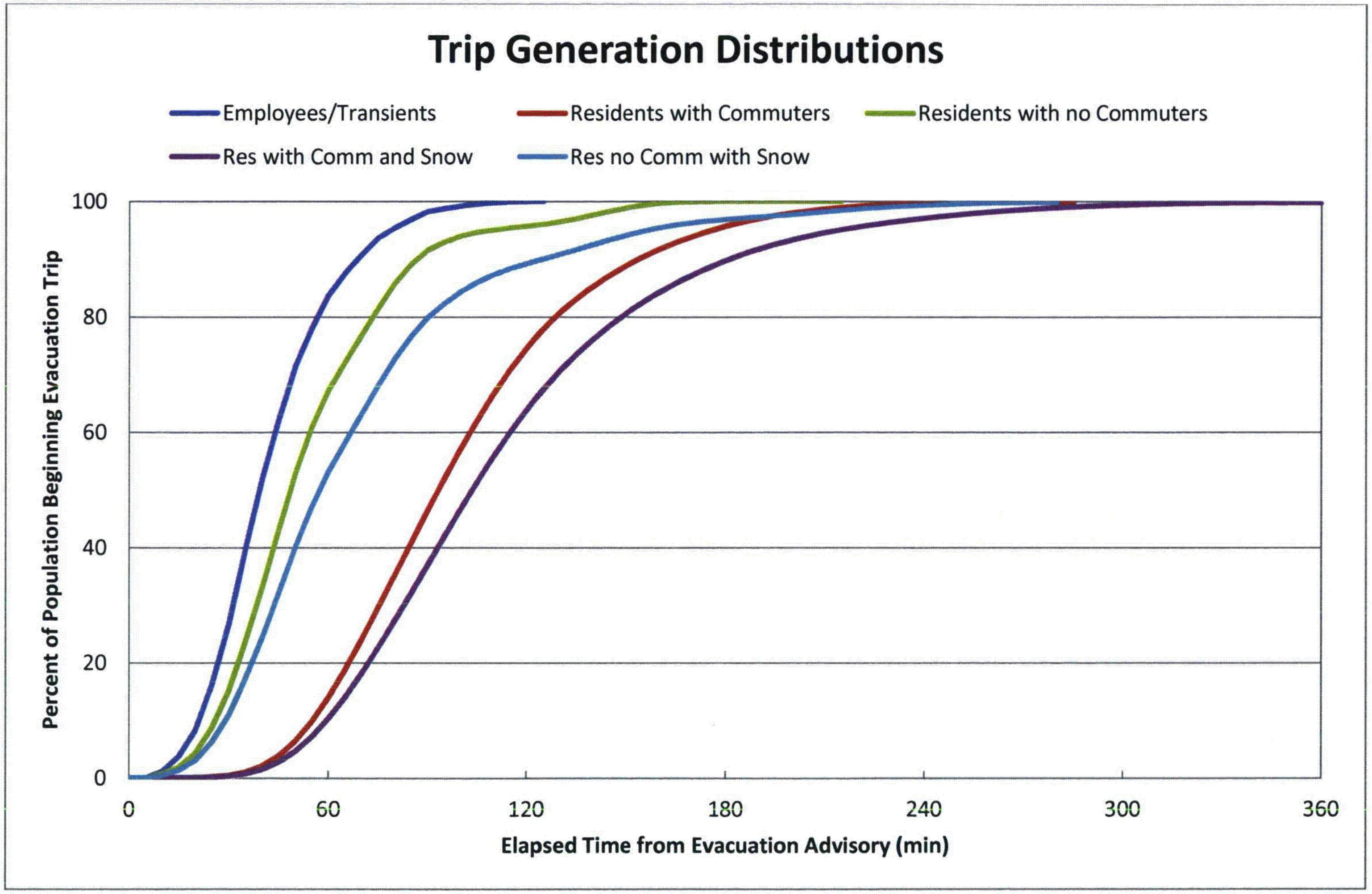


Figure 5-4. Comparison of Trip Generation Distributions

Table 5-10. Trip Generation Histograms for the EPZ Population for Staged Evacuation

Time Period	Duration (Min)	Percent of Total Trips Generated Within Indicated Time Period*			
		Residents with Commuters (Distribution C)	Residents Without Commuters (Distribution D)	Residents With Commuters Snow (Distribution E)	Residents Without Commuters Snow (Distribution F)
1	15	0%	0%	0%	0%
2	15	0%	3%	0%	2%
3	15	1%	6%	1%	4%
4	15	2%	4%	1%	5%
5	15	3%	3%	3%	3%
6	15	3%	2%	2%	2%
7	15	3%	1%	3%	1%
8	15	3%	0%	3%	1%
9	15	68%	78%	2%	0%
10	30	10%	3%	71%	78%
11	30	5%	0%	7%	1%
12	30	1%	0%	3%	2%
13	30	1%	0%	2%	1%
14	60	0%	0%	2%	0%
15	600	0%	0%	0%	0%

*Trip Generation for Employees and Transients (see Table 5-9) is the same for Unstaged and Staged Evacuation.

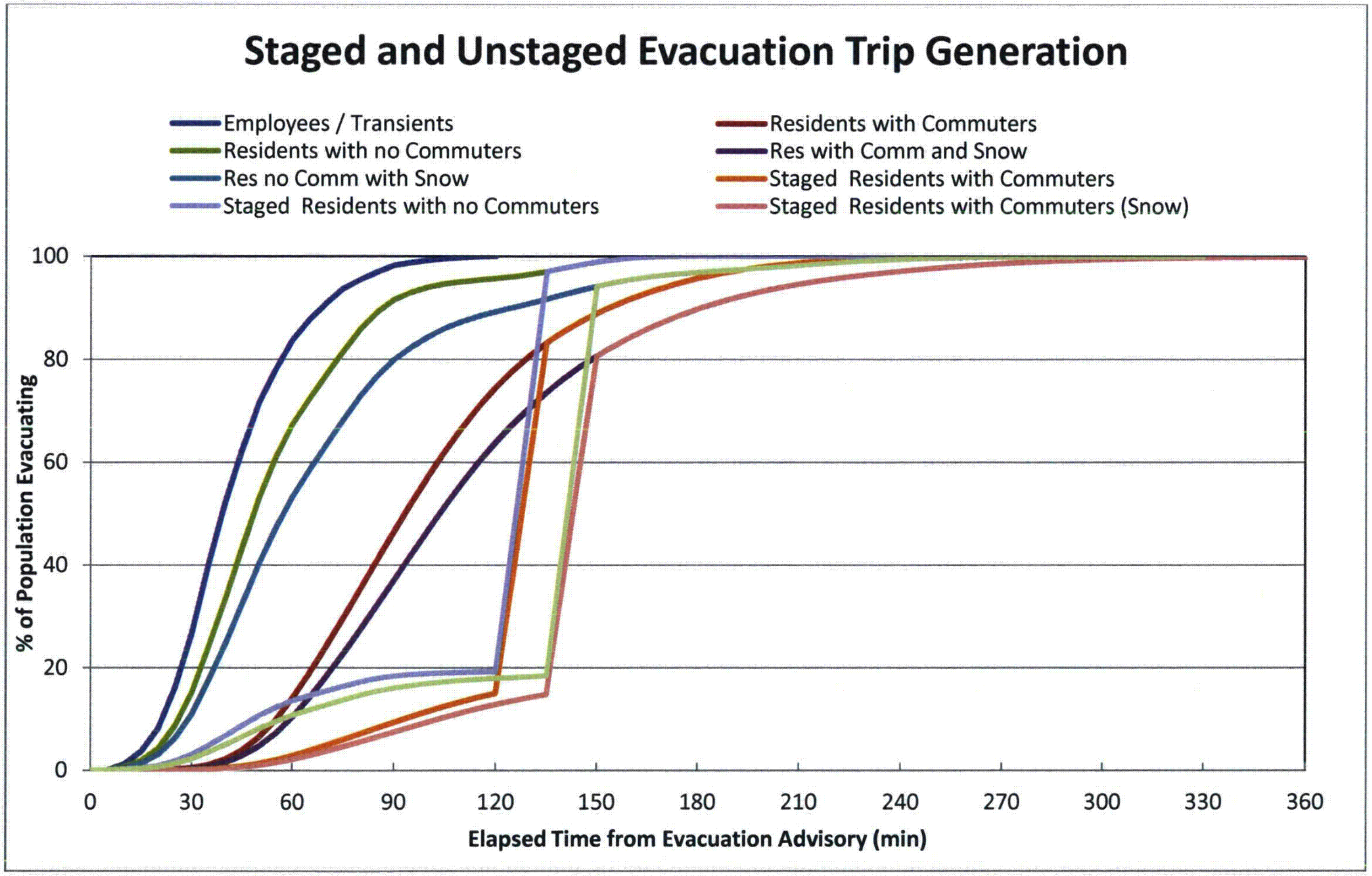


Figure 5-5. Comparison of Staged and Unstaged Trip Generation Distributions in the 2 to 5 Mile Region