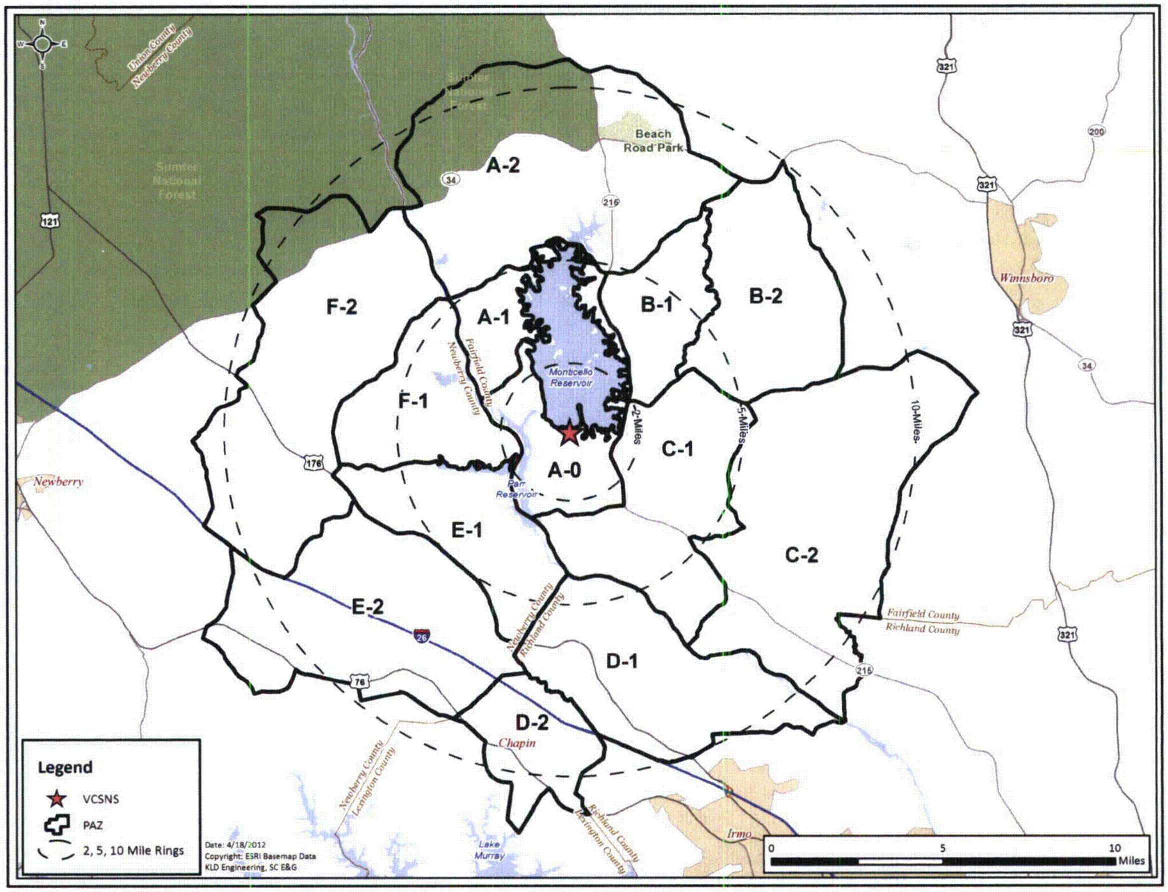
ENGINEERING, P.C.

Virgil C. Summer Nuclear Station

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 Virgil C. Summer Nuclear Station (VCSNS) site located in Fairfield County, South Carolina. ETE are part of the required planning basis and provide VCSNS and state and local governments with site-specific information needed for Protective Action Decisions (PAD).

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.

Overview of Project Activities

This project began in May, 2011 and extended over a period of 8 months. The major activities performed are briefly described in chronological sequence:

- Attended "kick-off" meetings with South Carolina Electric & Gas personnel and emergency management personnel representing state and local 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 VCSNS, 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.
- Reviewed the results of a telephone survey (conducted in December 2006) 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 used for the survey 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 13 Protective Action Zones (PAZ). These PAZs are then grouped within circular areas or "keyhole" configurations (circles plus radial sectors) that define 30 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, Ice). One special scenario, construction of the proposed Units 2 and 3 at VCSNS in 2014 combined with a planned outage at Unit 1, was considered. A roadway impact scenario was considered wherein a single lane was closed on eastbound Interstate-26 in Lexington County for the duration of the evacuation.
- Staged evacuation was considered for those regions where 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 accident at VCSNS that quickly attains the status of General Emergency such that the Advisory to Evacuate is virtually coincident with the siren alert, 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 a 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 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 be evacuated by 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.

Computation of ETE

A total of 420 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 30 Evacuation Regions to evacuate from that Region, under the circumstances defined for one of the 14 Evacuation Scenarios (30 x 14 = 420). 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 radius evacuate immediately, while those beyond 2 miles, but within the EPZ, shelter-in-place. Once 90% of the 2-mile radius is evacuated, those people between 2 and 5 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 has been identified as the value 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.

The use of a public outreach (information) program to emphasize the need for evacuees to minimize the time needed to prepare to evacuate (secure the home, assemble needed clothes, medicines, etc.) should also be considered.

Traffic Management

This study references the comprehensive traffic management plan provided by Fairfield Lexington, Newberry, and Richland Counties *Emergency Operations* Plans, and the *South Carolina Operational Radiological Emergency Response* Plan.

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 VCSNS EPZ showing the layout of the 13 PAZs that comprise, in aggregate, the EPZ.
- Table 3-1 presents the estimates of permanent resident population in each PAZ based on the 2010 Census data.
- Table 6-1 defines each of the 30 Evacuation Regions in terms of their respective groups of PAZ.
- 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. These computed ETE include consideration of mobilization time and of estimated voluntary evacuations from other regions within the EPZ and from the Shadow Region. These tables include results for staged evacuation.
- Tables 7-3 and Table 7-4 presents clearance times for the 2-mile region for un-staged and staged evacuations for the 90th and 100th percentiles, respectively.
- Table 8-7 presents ETE for the schoolchildren in good weather.
- Table 8-11 presents ETE for the transit-dependent population in good weather.
- Figure H-7 presents an example of an Evacuation Region (Region R07) 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 420 unique cases – a combination of 30 unique Evacuation Regions and 14 unique Evacuation Scenarios. Tables 7-1 and 7-2 document these ETE for the 90th and 100th percentiles for both a regular and staged evacuation respectively. These ETE range from 1:35 (hr:min) to 2:25 at the 90th percentile.
- Inspection of Table 7-1 and 7-2 indicates that the ETE for the 100th percentile are significantly longer than those for the 90th percentile. This is the result of the long tail of the evacuation curve caused by those evacuees who take longer to mobilize. See Figures 7-5 through 7-18.
- Inspection of Tables 7-3 and 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 R02, R04 through R11 with Regions R22 through

R30, respectively, in Tables 7-1 and 7-2). See Section 7.6 for additional discussion

- Comparison of Scenarios 6 and 13 in Tables 7-1 and 7-2 indicates that the special event – construction of the proposed Units 2 and 3 at VCSNS in 2014 combined with an outage at Unit 1 – does not materially impact the evacuation time for the VCSNS EPZ.
- Separate ETE were computed for schools, medical facilities, transit-dependent persons, and homebound special needs persons. The average single-wave ETE for schools are within a similar range as the general population ETE at the 90th percentile, while the average ETE for transit-dependent persons exceed the general population ETE at the 90th percentile. See Section 8
- The general population ETE at the 100th percentile closely parallel the trip generation time...further evidence of the long evacuation tail. See Table M-1.
- The general population ETE is relatively insensitive (tripling the shadow evacuation percentage only increases 90th percentile ETE by 20 minutes) to the voluntary evacuation of vehicles in the Shadow Region. See Table M-2.

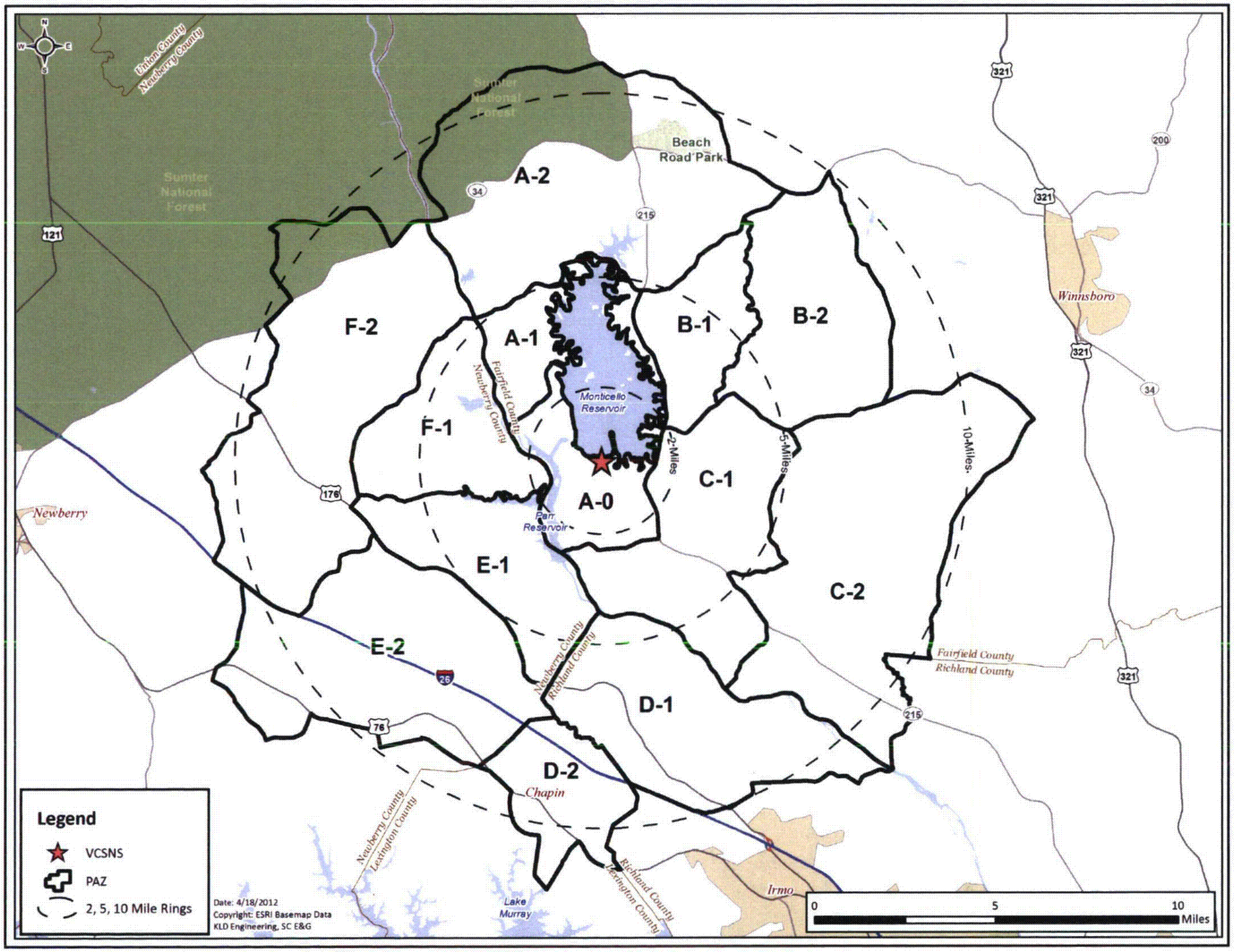


Figure 6-1. VCSNS EPZ Protective Action Zones

Table 3-1. EPZ Permanent Resident Population

PAZ	2000 Census Population	2010 Census Population
A-0	238	220
A-1	372	395
A-2	631	618
B-1	310	341
B-2	414	382
C-1	420	411
C-2	1,451	1,515
D-1	1,765	2,214
D-2	1,648	2,721
E-1	546	536
E-2	1,827	1,997
F-1	228	202
F-2	1,327	1,436
TOTAL	**11,177**	**12,988**
EPZ Population Growth:		**16%**

Table 6-1. Description of Evacuation Regions

Region	Description	Protective Action Zone												
		A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
R01	2-Mile Ring	X												
R02	5-Mile Ring	X	X		X		X				X		X	
R03	Full EPZ	X	X	X	X	X	X	X	X	X	X	X	X	X
Evacuate 2-Mile Radius and Downwind to 5 Miles														
Region	Wind Direction From:	Protective Action Zone												
		A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
R04	S, SSW	X	X		X									
R05	SW, WSW	X	X		X		X							
R06	W	X			X		X							
R07	WNW, NW	X					X							
R08	NNW, N	X					X				X			
R09	NNE, NE	X									X			
R10	ENE, E	X									X		X	
R11	ESE, SE, SSE	X	X										X	
Evacuate 5-Mile Radius and Downwind to the EPZ Boundary														
Region	Wind Direction From:	Protective Action Zone												
		A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
R12	S	X	X	X	X		X				X		X	
R13	SSW, SW	X	X	X	X	X	X				X		X	
R14	WSW, W	X	X		X	X	X	X			X		X	
R15	WNW, NW	X	X		X		X	X	X		X		X	
R16	NNW	X	X		X		X	X	X	X	X		X	
R17	N, NNE	X	X		X		X		X	X	X	X	X	
R18	NE	X	X		X		X			X	X	X	X	X
R19	ENE, E	X	X		X		X				X	X	X	X
R20	ESE	X	X		X		X				X		X	X
R21	SE, SSE	X	X	X	X		X				X		X	X

Table 6-1 (Continued from above)

Staged Evacuation - 2-Mile Radius Evacuates, then Evacuate Downwind to 5 Miles														
Region	**Wind Direction From:**	**Protective Action Zone**												
		A-0	**A-1**	**A-2**	**B-1**	**B-2**	**C-1**	**C-2**	**D-1**	**D-2**	**E-1**	**E-2**	**F-1**	**F-2**
R22	5-Mile Ring	X	X		X		X				X		X	
R23	S, SSW	X	X		X									
R24	SW, WSW	X	X		X		X							
R25	W	X			X		X							
R26	WNW, NW	X					X							
R27	NNW, N	X					X				X			
R28	NNE, NE	X									X			
R29	ENE, E	X									X		X	
R30	ESE, SE, SSE	X	X										X	
Shelter-in-Place until 90% ETE for R01, then Evacuate					PAZ(s) Shelter-in-Place					PAZ(s) Evacuate				

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	Ice	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Ice	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Midweek	Midday	Good	Construction of VCSNS Units 2 and 3
14	Summer	Midweek	Midday	Good	Roadway Impact – Lane Closure on I-26 Eastbound

[1]Winter assumes that school is in session (also applies to Spring and Autumn). Summer assumes 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	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway Impact
Entire 2-Mile Region, 5-Mile Region, and EPZ														
R01	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R02	2:15	2:15	1:40	1:40	1:45	2:15	2:15	2:15	1:40	1:40	1:40	1:45	1:55	2:15
R03	2:25	2:25	2:05	2:10	2:05	2:25	2:25	2:25	2:05	2:10	2:10	2:05	2:10	2:25
2-Mile Ring and Keyhole to 5 Miles														
R04	2:00	2:00	1:35	1:35	1:45	2:00	2:00	2:00	1:35	1:35	1:35	1:45	1:45	2:00
R05	2:10	2:10	1:40	1:40	1:45	2:10	2:10	2:10	1:40	1:40	1:40	1:45	1:50	2:10
R06	2:00	2:05	1:35	1:40	1:45	2:00	2:00	2:05	1:35	1:40	1:40	1:45	1:50	2:00
R07	1:55	1:55	1:35	1:35	1:45	1:55	1:55	1:55	1:35	1:35	1:35	1:45	1:45	1:55
R08	2:05	2:05	1:35	1:40	1:45	2:05	2:05	2:05	1:35	1:40	1:40	1:45	1:50	2:05
R09	1:55	1:55	1:30	1:35	1:40	1:55	1:55	1:55	1:30	1:35	1:35	1:40	1:50	1:55
R10	2:00	2:00	1:35	1:35	1:45	2:00	2:00	2:00	1:35	1:35	1:35	1:45	1:50	2:00
R11	2:00	2:00	1:35	1:35	1:45	1:55	1:55	2:00	1:35	1:35	1:35	1:45	1:45	2:00
5-Mile Ring and Keyhole to EPZ Boundary														
R12	2:20	2:20	1:45	1:45	1:50	2:20	2:20	2:20	1:45	1:45	1:45	1:50	1:55	2:20
R13	2:20	2:20	1:45	1:45	1:50	2:20	2:20	2:20	1:45	1:45	1:45	1:50	1:55	2:20
R14	2:25	2:25	1:50	1:50	1:55	2:25	2:25	2:25	1:50	1:50	1:50	1:55	2:00	2:25
R15	2:25	2:25	1:50	1:50	1:55	2:25	2:25	2:25	1:50	1:50	1:50	1:55	2:05	2:25
R16	2:10	2:10	2:05	2:05	2:05	2:10	2:10	2:15	2:05	2:05	2:10	2:05	2:05	2:15
R17	2:15	2:15	2:05	2:10	2:05	2:10	2:15	2:15	2:05	2:10	2:10	2:05	2:10	2:15
R18	2:10	2:15	2:05	2:10	2:05	2:10	2:15	2:15	2:05	2:10	2:10	2:05	2:10	2:15
R19	2:10	2:10	2:05	2:05	2:05	2:10	2:10	2:15	2:05	2:05	2:10	2:05	2:05	2:10
R20	2:20	2:20	1:45	1:45	1:50	2:20	2:20	2:25	1:45	1:45	1:50	1:50	1:55	2:20
R21	2:25	2:25	1:50	1:50	1:55	2:25	2:25	2:25	1:50	1:50	1:50	1:55	2:00	2:25

Table 7-1. (Continued from above)

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway Impact
Staged Evacuation - 2-Mile Ring and Keyhole to 5 Miles														
R22	2:15	2:15	2:00	2:00	2:00	2:15	2:15	2:15	2:00	2:00	2:00	2:00	1:55	2:15
R23	2:05	2:05	1:55	1:55	2:00	2:05	2:05	2:05	1:55	1:55	1:55	2:00	1:45	2:05
R24	2:10	2:10	2:00	2:00	2:00	2:10	2:10	2:10	2:00	2:00	2:00	2:00	1:50	2:10
R25	2:05	2:05	1:55	1:55	2:00	2:05	2:05	2:05	1:55	1:55	1:55	2:00	1:50	2:05
R26	2:00	2:00	1:50	1:50	2:00	2:00	2:00	2:00	1:50	1:50	1:55	2:00	1:50	2:00
R27	2:05	2:05	1:55	1:55	2:00	2:05	2:05	2:05	1:55	1:55	2:00	2:00	1:55	2:05
R28	2:00	2:00	1:55	1:55	2:00	2:00	2:00	2:00	1:55	1:55	1:55	2:00	1:50	2:00
R29	2:05	2:05	1:55	1:55	2:00	2:05	2:05	2:05	1:55	1:55	1:55	2:00	1:50	2:05
R30	2:00	2:00	1:55	1:55	2:00	2:00	2:00	2:05	1:55	1:55	1:55	2:00	1:45	2:00

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

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway Impact
Entire 2-Mile Region, 5-Mile Region, and EPZ														
R01	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R02	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R03	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
2-Mile Ring and Keyhole to 5 Miles														
R04	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R05	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R06	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R07	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R08	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R09	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R10	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R11	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
5-Mile Ring and Keyhole to EPZ Boundary														
R12	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R13	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R14	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R15	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R16	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R17	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R18	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R19	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R20	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55
R21	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55	4:55

Table 7-2. (Continued from above)

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway impact
Staged Evacuation - 2-Mile Ring and Keyhole to 5 Miles														
R22	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R23	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R24	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R25	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R26	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R27	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R28	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R29	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50
R30	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50	4:50

Table 7-3. Staged Evacuation Results - _90_ Percent ETE of the 2-Mile Area within the Indicated Region

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway Impact
Unstaged Evacuation - 2-Mile Ring and Keyhole to 5-Miles														
R01	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R02	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R04	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R05	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R06	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R07	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R08	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R09	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R10	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R11	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
Staged Evacuation - 2-Mile Ring and Keyhole to 5-Miles														
R22	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R23	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R24	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R25	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R26	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R27	1:40	1:40	1:30	1:30	1:40	1:40	1:40	1:40	1:30	1:30	1:30	1:40	1:40	1:40
R28	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R29	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35
R30	1:35	1:35	1:30	1:30	1:35	1:35	1:35	1:35	1:30	1:30	1:30	1:35	1:40	1:35

Table 7-4. Staged Evacuation Results – _100_ Percent ETE of the 2-Mile Area within the Indicated Region

	Summer		Summer		Summer	Winter			Winter			Winter	Winter	Summer
	Midweek		Weekend		Midweek Weekend	Midweek			Weekend			Midweek Weekend	Midweek	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	Ice	Good Weather	Rain	Ice	Good Weather	Special Event	Roadway Impact
Unstaged Evacuation - 2-Mile Ring and Keyhole to 5-Miles														
R01	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R02	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R04	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R05	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R06	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R07	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R08	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R09	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R10	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R11	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
Staged Evacuation - 2-Mile Ring and Keyhole to 5-Miles														
R22	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R23	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R24	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R25	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R26	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R27	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R28	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R29	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45
R30	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45	4:45

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

School	Driver Mobilization Time	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 EPZ Bdry to R.C. (min)	ETE to R.C. (hr:min)
Fairfield County, SC Schools									
McCrorey-Liston Elementary School	90	5	8.2	45.0	11	**1:50**	13.57	19	**2:05**
Kelly Miller Elementary School	90	5	1.4	41.0	3	**1:40**	13.62	19	**2:00**
Lexington County, SC Schools									
Abner Montessori School	50	5	4.4	45.0	6	**1:05**	9.75	13	**1:15**
Alternative Academy	50	5	5.1	45.0	7	**1:05**	9.75	13	**1:15**
Chapin Elementary School	50	5	3.4	42.9	5	**1:00**	10.40	14	**1:15**
Chapin High School	50	5	4.4	45.0	6	**1:05**	9.75	13	**1:15**
Chapin Middle School	50	5	2.6	42.9	4	**1:00**	10.40	14	**1:15**
Crooked Creek Park After School Program*	15	5	2.8	43.6	4	**0:25**	10.40	14	**0:40**
Newberry County, SC Schools									
Little Mountain Elementary School	90	5	8.1	45.0	11	**1:50**	5.80	8	**1:55**
Mid-Carolina High School	90	5	5.4	45.0	8	**1:45**	5.80	8	**1:55**
Mid-Carolina Middle School	90	5	5.4	45.0	8	**1:45**	5.80	8	**1:55**
Pomaria-Garmany Elementary School	90	5	4.6	45.0	7	**1:45**	4.97	7	**1:50**
					Maximum for EPZ:	1:50	**Maximum:**		2:05
					Average for EPZ:	1:26	**Average:**		1:37

*Buses remain at the facility while students are at the afterschool program; therefore, a shorter mobilization time is appropriate. ETE is not included in Average for EPZ as this facility is only in use when all other schools are not in session.

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

Route Number	Bus Number	One-Wave						Two-Wave						
		Mobili-zation	Route Length (miles)	Speed (mph)	Route Travel Time (min)	Pickup Time	ETE	Distance to Rec Ctr (miles)	Travel Time to Rec. Ctr	Unload	Driver Rest	Route Travel Time (min)	Pickup Time	ETE
11	1	120	36.2	45	48	30	**3:20**	11.3	15	5	10	63	30	**5:25**
	2	140	36.2	45	48	30	**3:40**	11.3	15	5	10	63	30	**5:45**
12	1	120	15.5	45	21	30	**2:55**	13.6	18	5	10	39	30	**4:35**
	2	140	15.5	45	21	30	**3:15**	13.6	18	5	10	39	30	**4:55**
13	1	120	3.7	45	5	30	**2:35**	10.8	14	5	10	19	30	**3:55**
	2	140	3.7	45	5	30	**2:55**	10.8	14	5	10	19	30	**4:15**
14	1	60	11.2	45	15	30	**1:45**	5.0	7	5	10	22	30	**3:00**
	2	80	11.2	45	15	30	**2:05**	5.0	7	5	10	22	30	**3:20**
15	1	60	15.5	45	21	30	**1:55**	10.9	15	5	10	35	30	**3:30**
						Maximum ETE:	**3:40**						**Maximum ETE:**	**5:45**
						Average ETE:	**2:42**						**Average ETE:**	**4:17**

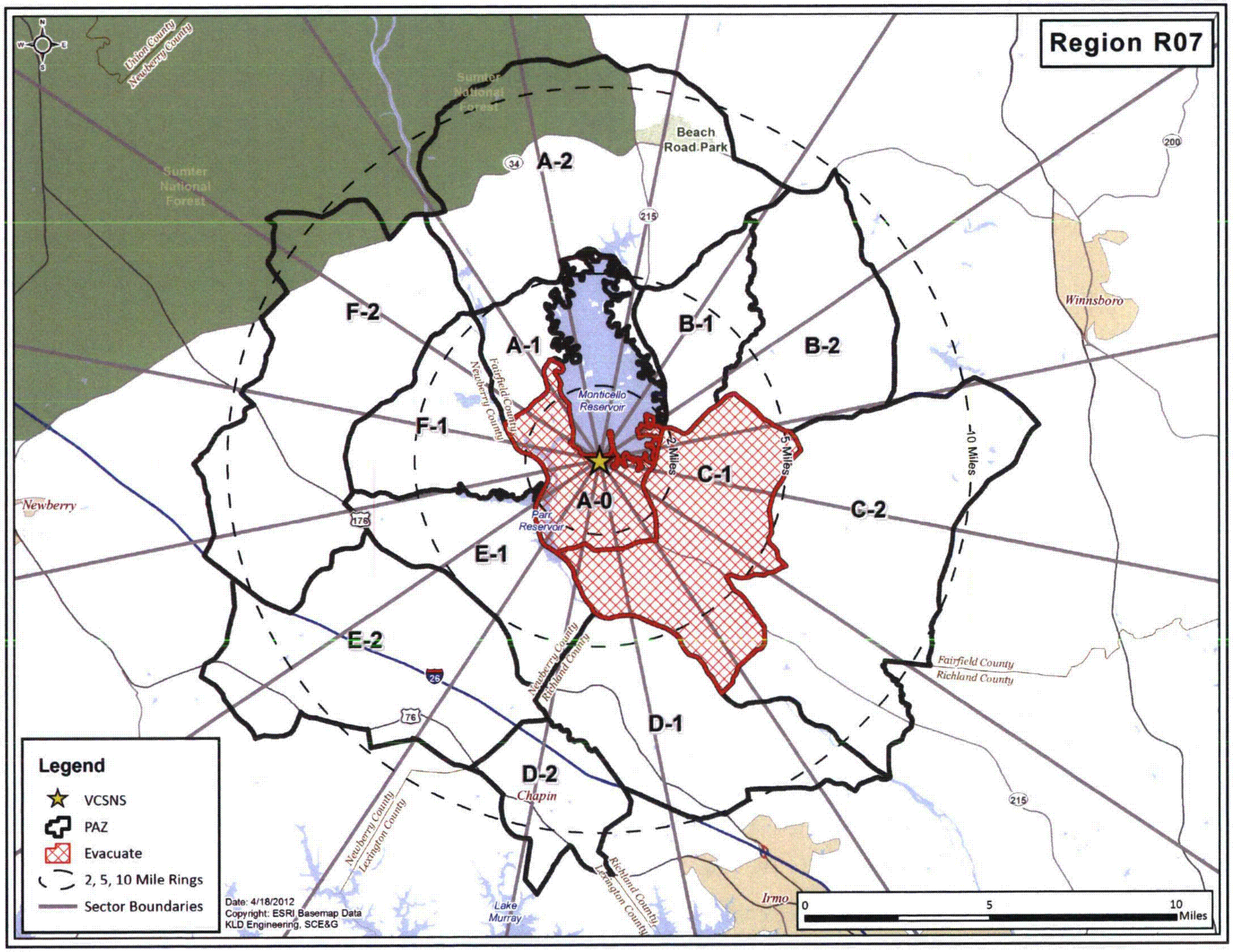


Figure H-7. Region R07

1 INTRODUCTION

This report describes the analyses undertaken and the results obtained by a study to develop Evacuation Time Estimates (ETE) for the Virgil C. Summer Nuclear Station (VCSNS), located in Fairfield County, South Carolina. ETE provide state and local governments with site-specific information needed for Protective Action Decisions (PAD).

In the performance of this effort, guidance is provided by documents published by Federal Government 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.
- Analysis of Techniques for Estimating Evacuation Times for Emergency Planning Zones, NUREG/CR 1745, November 1980.
- Development of Evacuation Time Estimates for Nuclear Power Plants, NUREG/CR-6863, January 2005.

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
South Carolina Electric and Gas emergency management personnel	Meetings to define data requirements and set up contacts with local government agencies
Fairfield County Emergency Management Office Lexington County Emergency Management Office Newberry County Emergency Management Office Richland County Emergency Management Office	Meetings to define data requirements and set up contacts with local government agencies. Obtain local emergency plans, special facility data, major employment data
Local Sheriff's Departments, SC State Department of Public Safety (SC Highway Patrol)	Review the traffic management plans
Fairfield School District Lexington-Richland School District Newberry School District	Review school evacuation procedures, enrollment and staffing data, transportation needs
South Carolina Emergency Management Division	South Carolina Operational Radiological Emergency Response Plan (SCORERP) integration
Newberry and Lexington County Day Care Centers Lexington County Health Facility	Enrollment (patient) and staffing data, transportation needs

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 South Carolina Electric & Gas (SCE&G).
   b. Attended meetings with emergency planners from four EPZ counties, South Carolina State government and state and local police agencies 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) and Shadow Region.
   d. Reviewed existing county and state Emergency Operation Plans.
   e. Obtained demographic data from census, state, and local agencies.
   f. Reviewed an existing random sample telephone survey of EPZ residents.
   g. 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. In addition, a "special event" scenario, which represents a typical mid-week, midday with peak construction workers on-site at Units 2 and 3 at the time of an emergency during an outage at Unit 1, was considered.
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 (TCP) located within the EPZ.
5. Used existing Protective Action Zones (PAZ) to define Evacuation Regions. The EPZ is partitioned into 13 PAZs along jurisdictional and geographic boundaries. "Regions" are groups of contiguous PAZs 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.

7. Prepared the input streams for the DYNEV II system.
   a. Estimated the evacuation traffic demand, based on the available information derived from 2010 Census data, and from data provided by local and state agencies, SCE&G and from the telephone survey.
   b. Applied the procedures specified in the 2010 Highway Capacity Manual (HCM[1]) 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 plant.
8. Executed the DYNEV II system to provide the estimates of evacuation routing and 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 special facilities (schools, medical facilities, etc.), for the transit-dependent population and for homebound special needs population.

1.2 The Virgil C. Summer Nuclear Station (VCSNS) Location

The Virgil C. Summer Nuclear Station is located in Fairfield County, South Carolina, about 17 miles west-south-west of Winnsboro, 18 miles east of Newberry, and 25 miles northwest of Columbia, the state Capitol. The Emergency Planning Zone (EPZ) consists of parts of four counties: Fairfield County, Lexington County, Newberry County, and Richland County. The area surrounding VCSNS is shown in Figure 1-1. This map identifies the communities in the area and the major roads.

The EPZ, which approximates an area of 10-mile radius surrounding the site, is predominantly rural in nature, with a permanent population of about 13,000 people. It is characterized by gently rolling terrain and has good primary and secondary paved roads. There are no major concentrations of population within the EPZ. The only significant recreational area within the EPZ is Lake Monticello; VCSNS is located on its southern shoreline.

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

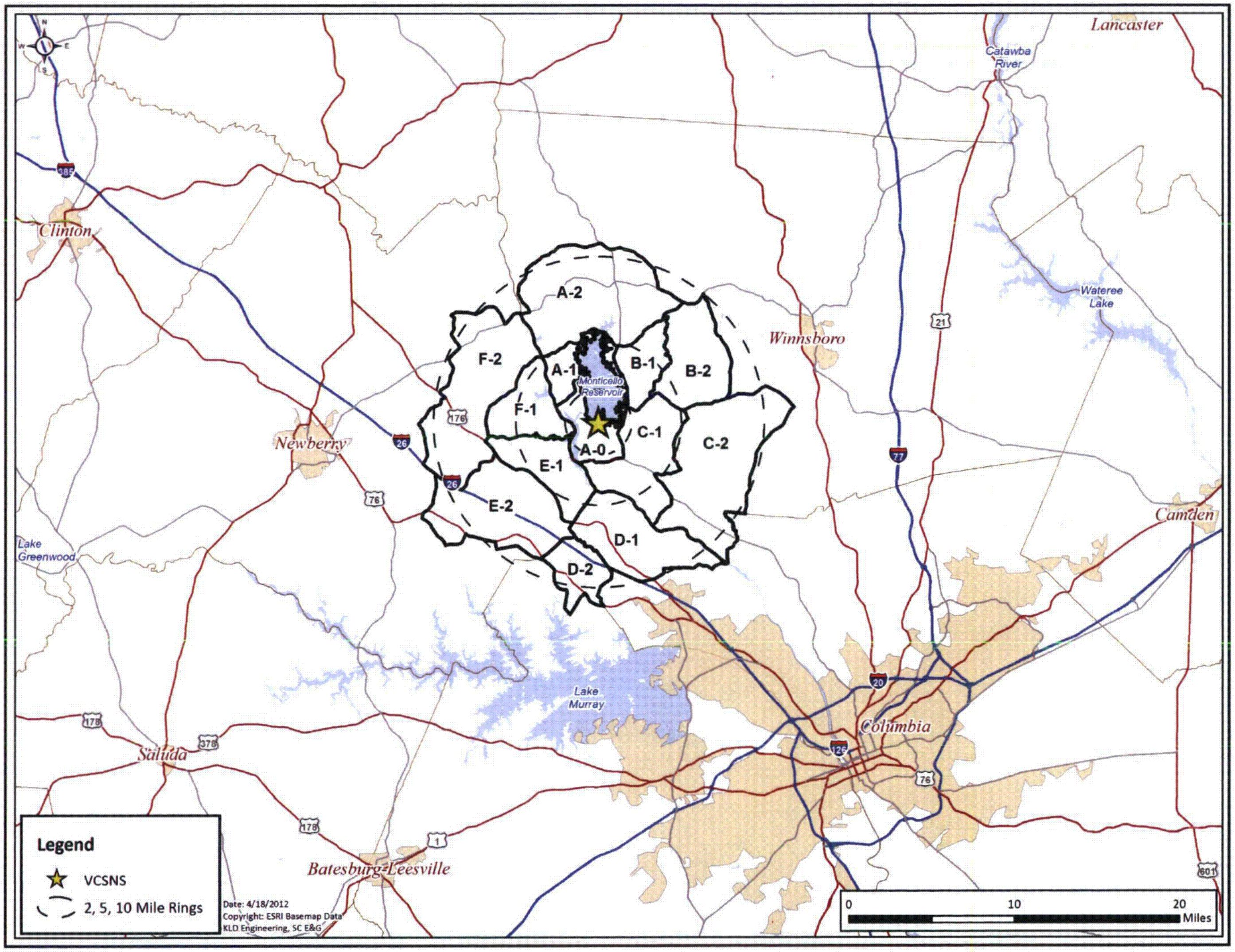


Figure 1-1. VC Summer Nuclear Station Site Location

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
- Pavement width
- Shoulder type & width
- Intersection configuration
- Lane channelization
- Geometrics: curves, grades
- Posted speed
- Actual free speed
- Abutting land use
- Control devices
- Interchange geometries
- Traffic signal type
- Unusual characteristics: Narrow bridges, sharp curves, poor pavement, flood warning signs, inadequate delineations, 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 which computes the

ETE. 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.

Telephone Survey

A telephone survey was undertaken to gather information needed for the evacuation study in December 2006. Since the population and demographics in the EPZ have not changed significantly over the last 5 years, the survey and its results are still valid. 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.

Developing the Evacuation Time Estimates

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.

Analytical Tools

The DYNEV II System that was employed for this study is comprised of several integrated computer models. One of these is the DYNEV (DYnamic Network EVacuation) macroscopic simulation model, a new version of the I-DYNEV model that was developed by KLD under contract with the Federal Emergency Management Agency (FEMA).

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. 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 Level of Service (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 VCSNS site.

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 2009 ETE study (Rev. 3) performed for the VCSNS Unites 2 & 3 COLA. The major factors contributing to the differences between the ETE values obtained in this study and those of the previous study can be summarized as follows:

- A slight increase in permanent resident population.
- The use of 20 percent shadow evacuation as required by NUREG/CR-7002
- Staged evacuation is considered
- The highway representation is updated to reflect current conditions.
- The EPZ boundary considered is the boundary currently in place as part of the county and state RERP plans
- Trip generation distributions were recomputed using a new methodology. The new methodology resulted in a 45 minute longer trip generation for residents with commuters. Transient and employee trip generation distributions were decreased by 30 minutes, and residents without commuters trip generation distributions were decreased by an hour from the prior ETE study.
- The new system, DYNEV II, includes a Dynamic Traffic Assignment (DTRAD) model which represents the ability of evacuees to change routes over time in response to congested conditions.
- The 100th percentile ETE is 45 minutes longer than for the prior ETE study: 4:55 vs. 4:10. The new value reflects the new computed estimates of mobilization (trip-generation) distributions for residents with commuters, which exhibit a very long "tail". The 100th-percentile ETE are determined solely by the mobilization time distributions. Therefore an increase in trip mobilization for any group will result in a longer ETE.
- The 90th percentile ETE is 15 minutes shorter than for the prior ETE study: 2:25 vs. 2:40. The new value reflects the shorter estimates (based on new computation) of mobilization (trip-generation) distributions, specifically for transients, employees, and residents without commuters. Additionally, this study uses a smaller percentage of voluntary shadow evacuation (20%) versus the 2009 study (ranges from 30% to 50%) resulting in less evacuating vehicles and shorter ETE.

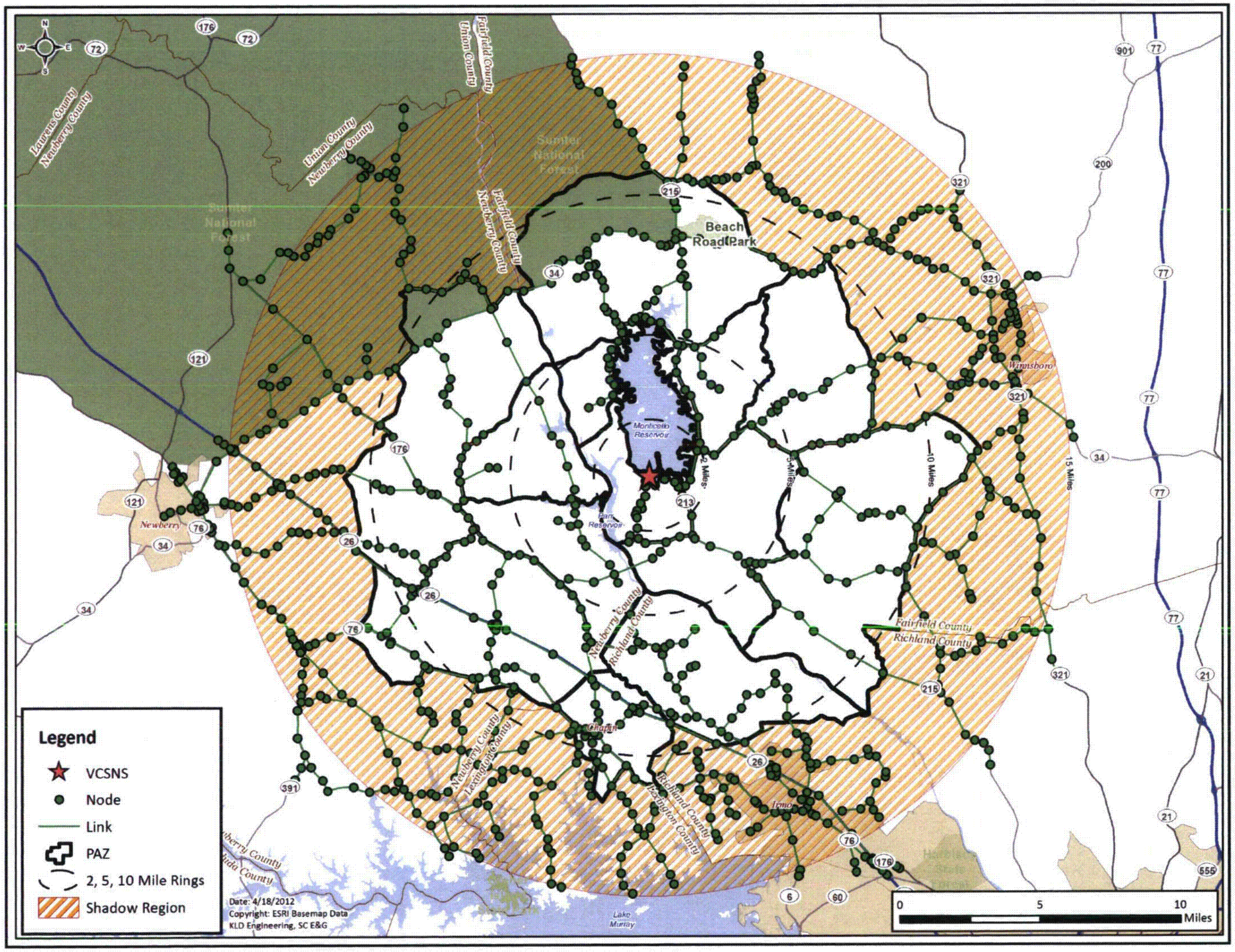


Figure 1-2. VCSNS Link-Node Analysis Network

Table 1-3. ETE Study Comparisons

Topic	Previous ETE Study	Current ETE Study
ResidentPopulation Basis	ArcGIS Software using 2000 US Census blocks; area ratio method used; population extrapolated to 2010. Population = 12,850	ArcGIS Software using 2010 US Census blocks; area ratio method used; Population = 12,988
Resident Population Vehicle Occupancy	2.68 persons/household, 1.49 evacuating vehicles/household yielding: 1.80 persons/vehicle	2.68 persons/household, 1.49 evacuating vehicles/household yielding: 1.80 persons/vehicle
Employee Population	Employees treated as separate population group. Employee estimates based on information provided by county emergency management offices about major employers in EPZ. An estimate of 1.01 employees/vehicleis based on phone survey results.	Employees treated as separate population group. Employee estimates based on information provided by county emergency management offices about major employers in EPZ. 1.01 employees/vehicleis estimated based on phone survey results.
Shadow evacuation from within the EPZ in areas outside region to be evacuated and in the shadow region outside of the EPZ boundary	50 percent of population within the circular portion of the region; 35 percent, in annular ring between the circle and the EPZ boundary.	20 percent of population within all areas of the EPZ not advised to evacuate; 20 percent of population in the Shadow Region in the annular ring between the EPZ boundary and the 15 mile circle (see Figure 2-1)
Network Size	1,181 Links; 840 Nodes.	1,295 Links; 944 Nodes.
Roadway Geometric Data	Field surveys conducted in 2006. Major intersections were video archived. GIS shape-files of signal locations and roadway characteristics created during road survey. Road capacities based on 2000 HCM.	Field surveys conducted in May 2011. Major intersections were video archived. GIS shape-files of signal locations and roadway characteristics created during road survey. Road capacities based on HCM 2010.
School Evacuation	Direct evacuation to designated Reception Center/Host School.	Direct evacuation to designated Reception Center/Host School.

Topic	Previous ETE Study	Current ETE Study
Transit Dependent Population	Defined as households with 0 vehicles + households with 1 vehicle with commuters who do not return home + households with 2 vehicles with commuters who do not return home. Telephone surveys results used to estimate transit dependent population.	Defined as households with 0 vehicles + households with 1 vehicle with commuters who do not return home + households with 2 vehicles with commuters who do not return home. Telephone surveys results used to estimate transit dependent population (See Table 8-1).
Ridesharing	50 percent of transit-dependent persons will ride out with a neighbor or friend.	50 percent of transit-dependent persons will ride out with a neighbor or friend.
Trip Generation for Evacuation	Based on residential telephone survey of specific pre-trip mobilization activities: Residents with commuters returning leave between 45 and 240 minutes. Residents without commuters returning leave between 15 and 240 minutes. Employees and transients leave between 15 and 150 minutes. All times measured from the Advisory to Evacuate.	Based on residential telephone survey of specific pre-trip mobilization activities: Residents with commuters returning leave between 45 and 285 minutes. Residents without commuters returning leave between 15 and 180 minutes. Employees and transients leave between 15 and 120 minutes. All times measured from the Advisory to Evacuate.
Weather	Normal, Rain, or Ice. The capacity and free flow speed of all links in the network are reduced by 10% in the event of rain and 20% for ice.	Normal, Rain, or Ice. The capacity and free flow speed of all links in the network are reduced by 10% in the event of rain and 20% for ice.
Modeling	IDYNEV System: TRAD and PC-DYNEV (version 1.0.0.1).	DYNEV II (version 4.0.0.0).
Special Events	One considered – new plant construction workforce.	One considered – new plant construction workforce during peak construction year with an outage at Unit 1.
Evacuation Cases	21 Regions (central sector wind direction and each adjacent sector technique used) and 13 Scenarios producing 273 unique cases	30 Regions (central sector wind direction and each adjacent sector technique used) and 14 Scenarios producing 420 unique cases

Topic	Previous ETE Study	Current ETE Study
Staged Evacuation	Not Considered	Evacuation of 2 mile region with sheltering of 2-5 mile region followed by 2-5 mile evacuation when 2 mile region evacuation is 90% complete
Evacuation Time Estimates Reporting	ETE reported for 50th, 90th, 95th, and 100th percentile population. Results presented by Region and Scenario.	ETE reported for 90th and 100th percentile population. Results presented by Region and Scenario.
Evacuation Time Estimates for the entire EPZ	Summer Midweek Midday Good weather (100%) = 4:10 Summer Midweek Midday Good weather (90%) = 2:40	Summer Midweek Midday Good weather (100%) = 4:55 Summer Midweek Midday Good weather (90%) = 2:25

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. 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 employment data obtained from county emergency management officials.
3. Population estimates at special facilities are based on available data from individual facilities identified by county emergency management officials. Estimates of transient population were likewise obtained from local officials and from parking area capacities.
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 2.68 persons per household and 1.49 evacuating vehicles per household are used. The relationship between persons and vehicles for special facilities is as follows:
    a. Employees: 1.01 employees per vehicle (telephone survey results) for all major employers.
    b. Parks and Golf Courses: 2.68 people per vehicle (average household size obtained from the telephone survey results, assuming 1 vehicle per family);
    c. Special Events: Plant (VCSNS Units 2 and 3) construction employment, shift, and peak year characteristics supplied by SCE&G

2.2 Study Methodology

1. ETE are presented for the evacuation of the 90th and 100th 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 Protective Action Zones (PAZ) 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. The ETE are computed and presented in tabular format and graphically, in a format compliant with NUREG/CR-7002.
3. 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.
4. 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 included PAZ.
5. 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, but not within the impacted keyhole, will voluntarily evacuate. 20% of those people with 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).
6. 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.
7. Scenario 14 considers the closure of a single lane eastbound on Interstate-26 in Lexington County. The lane closure starts at exit 91 at Columbia Ave and extends for one mile to the EPZ boundary.
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[1]). The models have continuously been refined and extended since those hearings and have been 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.

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

Table 2-1. Evacuation Scenario Definitions

Scenario	Season[2]	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	Ice	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Ice	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Midweek	Midday	Good	Construction of VCSNS Units 2 and 3
14	Summer	Midweek	Midday	Good	Roadway Impact – Lane Closure on I-26 Eastbound

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

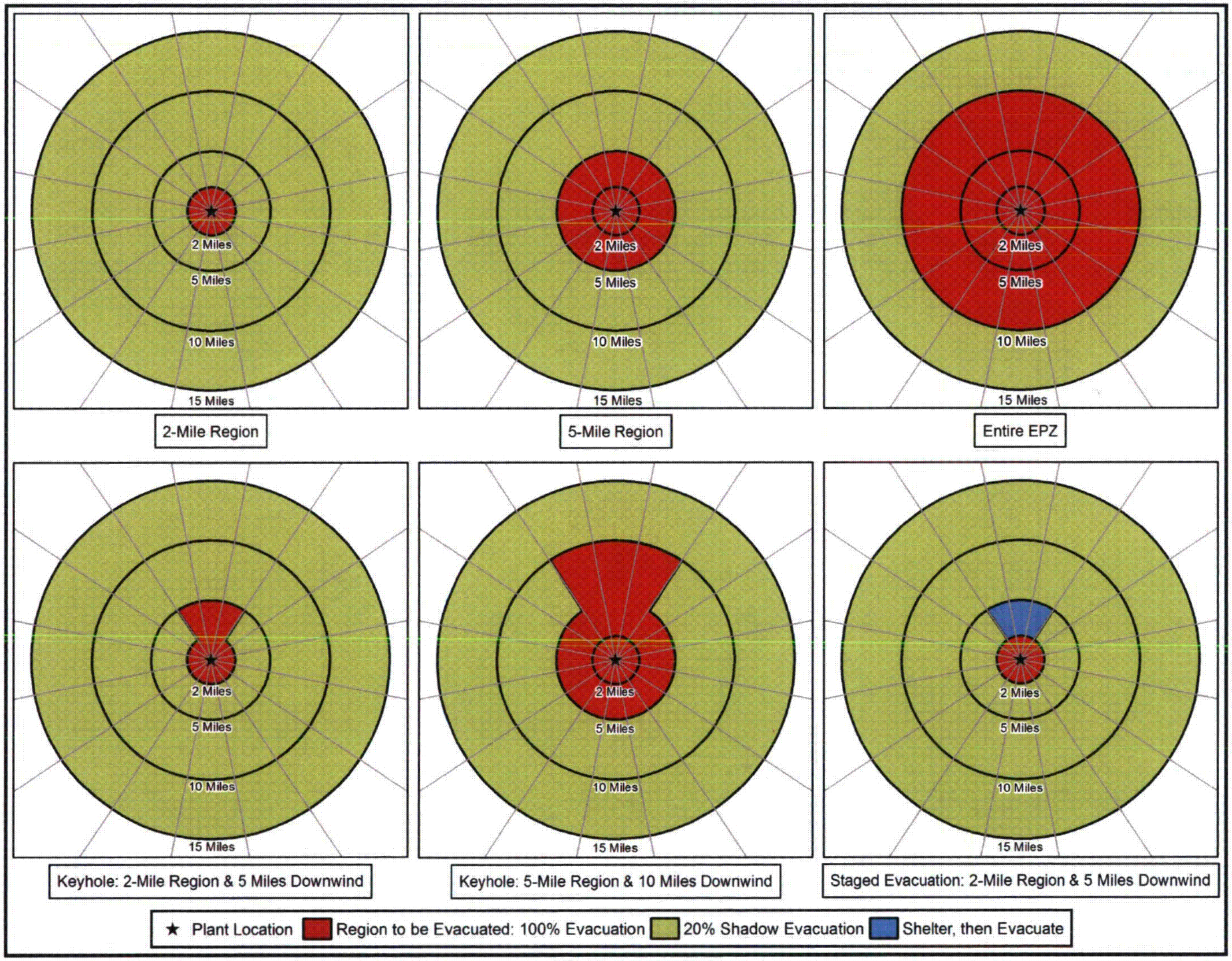


Figure 2-1. Shadow Evacuation Methodology

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 PAZs forming a Region that is issued an Advisory to Evacuate will, in fact, respond and evacuate in general accord with the planned routes.
3. It is assumed for a staged evacuation that within the group of PAZs advised to shelter before beginning to evacuate, all transients and employees will choose not to shelter and begin the evacuation as soon as they are mobilized. Of the households present in the PAZs advised to shelter, 20 percent of them would disregard the shelter advisory and begin to evacuate as soon as they are mobilized.
4. 67 percent of the households in the EPZ have at least 1 commuter; 78 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 52 percent (67% x 78% = 52%) of EPZ households will await the return of a commuter, prior to beginning their evacuation trip.
5. 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.
6. Access Control Points (ACP) will be staffed within approximately 2 hours 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 traffic will enter the EPZ after this 2 hour time period.
7. 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 and reasonably, travel in directions identified in the plan, and obey all control devices and traffic guides.

8. Buses will be used to transport those without access to private vehicles:
    a. If schools are in session, transport (buses) will evacuate students directly to the designated host schools.
    b. It is assumed parents will pick up children at day care centers prior to evacuation.
    c. Buses, wheelchair vans, and ambulances will evacuate patients at medical facilities and residents at senior facilities within the EPZ, as needed.
    d. Transit-dependent general population will be evacuated to reception 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 reception centers to congregate care centers is not considered in this study.
9. Provisions are made for evacuating the transit-dependent portion of the general population to reception 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[3], and on guidance in Section 2.2 of NUREG/CR-7002.
10. Two types of adverse weather scenarios are considered. Rain may occur for either winter or summer scenarios; ice occurs in winter scenarios only. It is assumed that the rain or icy conditions begins earlier or at about the same time the evacuation advisory is issued. Transient populations are assumed to be unaffected by weather conditions. It is assumed that roads are passable and that the appropriate agencies are servicing the roads as they would normally when icy conditions are present.

[3] 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).

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[4]; the factors are shown in Table 2-2.

11. 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 state offices of emergency management. Transit buses used to transport the transit-dependent general population are assumed to transport 30 people per bus.

Table 2-2. Model Adjustment for Adverse Weather

Scenario	Highway Capacity*	Free Flow Speed*	Mobilization Time for General Population
Rain	90%	90%	No Effect
Ice	80%	80%	No Effect
*Adverse weather capacity and speed values are given as a percentage of good weather conditions. Roads are assumed to be passable.			

[4]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.

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 Emergency Planning Zone (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 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 population characteristics of the VC Summer Nuclear Station (VCSNS) 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 businesses within the EPZ on a daily basis.

Estimates of the population and number of evacuating vehicles for each of the population groups are presented for each Protective Action Zone (PAZ) and by polar coordinate representation (population rose). The VCSNS EPZ has been subdivided into 13 PAZ. 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 (2.68 persons/household – See Figure F-1) and the number of evacuating vehicles per household (1.49 vehicles/household – See Figure F-7) were adapted from the telephone survey results.

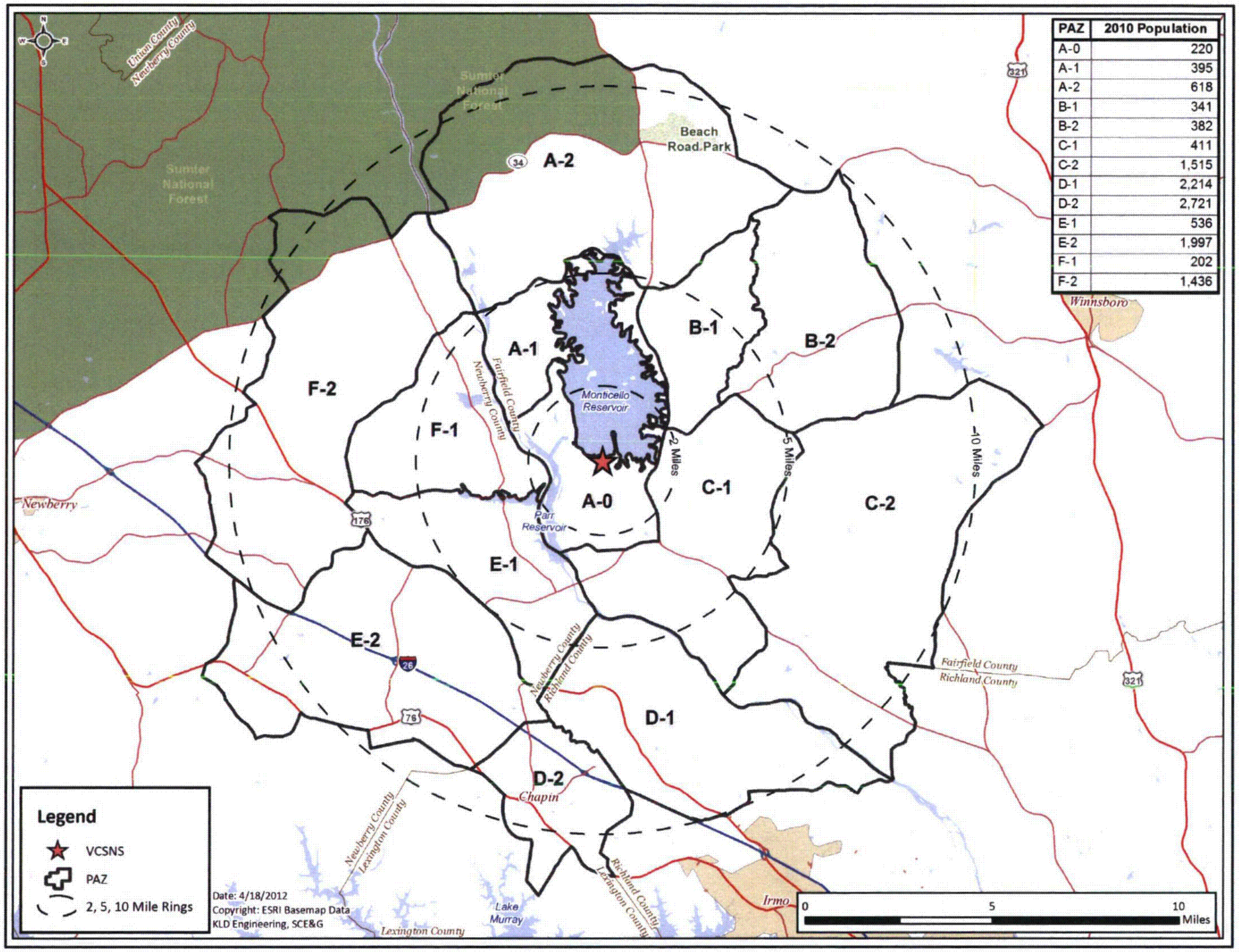
Population estimates are based upon Census 2010 data, Table 3-1 provides the permanent resident population within the EPZ, by PAZ.

The year 2010 permanent resident population is divided by the average household size obtained from the telephone survey and then multiplied by the average number of evacuating vehicles per household determined by the telephone survey 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 VCSNS Site. This "rose" was constructed using GIS software.

It can be argued that this estimate of permanent residents overstates, somewhat, the number of evacuating vehicles, especially during the summer. It is certainly reasonable to assert that some portion of the population would be on vacation during the summer and would travel elsewhere. A rough estimate of this reduction can be obtained as follows:

- Assume 50 percent of all households vacation for a two-week period over the summer.
- Assume these vacations, in aggregate, are uniformly dispersed over 10 weeks, i.e. 10 percent of the population is on vacation during each two-week interval.
- Assume half of these vacationers leave the area.

On this basis, the permanent resident population would be reduced by 5 percent in the summer and by a lesser amount in the off-season. Given the uncertainty in this estimate, we elected to apply no reductions in permanent resident population for the summer scenarios to account for residents who may be out of the area.



PAZ	2010 Population
A-0	220
A-1	395
A-2	618
B-1	341
B-2	382
C-1	411
C-2	1,515
D-1	2,214
D-2	2,721
E-1	536
E-2	1,997
F-1	202
F-2	1,436

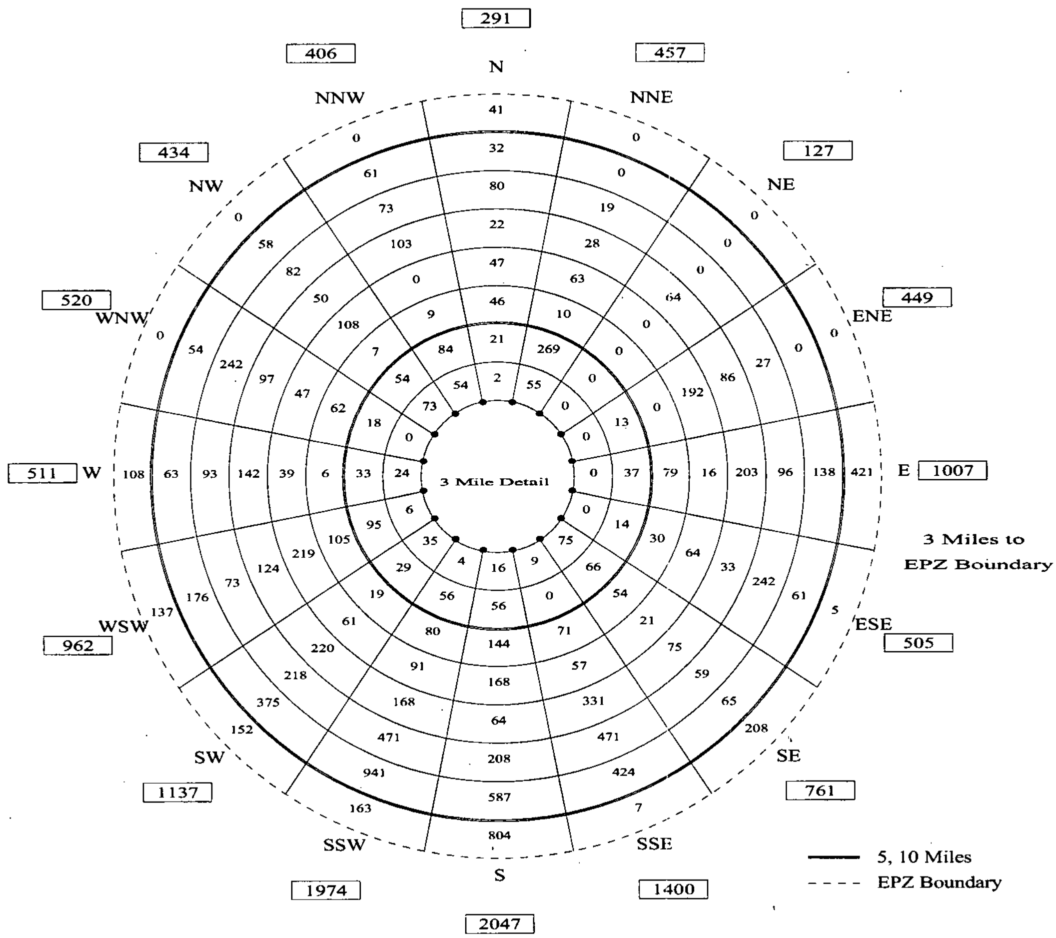
Figure 3-1. VCSNS EPZ

Table 3-1. EPZ Permanent Resident Population

PAZ	2000 Census Population	2010 Census Population
A-0	238	220
A-1	372	395
A-2	631	618
B-1	310	341
B-2	414	382
C-1	420	411
C-2	1,451	1,515
D-1	1,765	2,214
D-2	1,648	2,721
E-1	546	536
E-2	1,827	1,997
F-1	228	202
F-2	1,327	1,436
TOTAL	**11,177**	**12,988**
EPZ Population Growth:		**16%**

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

PAZ	2010 Census Population	Evacuating Vehicles
A-0	220	123
A-1	395	219
A-2	618	346
B-1	341	190
B-2	382	213
C-1	411	232
C-2	1,515	848
D-1	2,214	1,233
D-2	2,721	1,514
E-1	536	297
E-2	1,997	1,111
F-1	202	111
F-2	1,436	798
TOTAL	**12,988**	**7,235**



Resident Population			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	28	0-1	28
1-2	218	0-2	246
2-3	284	0-3	530
3-4	353	0-4	883
4-5	845	0-5	1728
5-6	722	0-6	2450
6-7	1193	0-7	3643
7-8	1810	0-8	5453
8-9	2454	0-9	7907
9-10	3035	0-10	10942
10-EPZ	2046	0-EPZ	12988

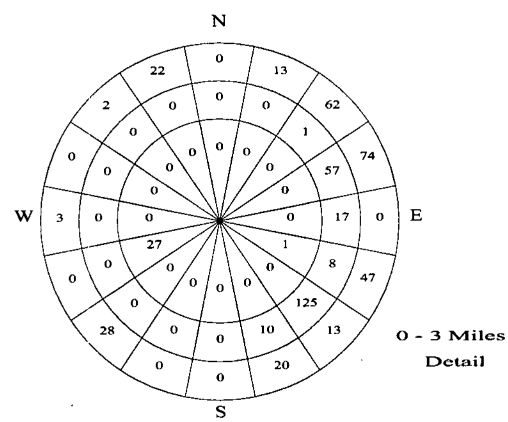
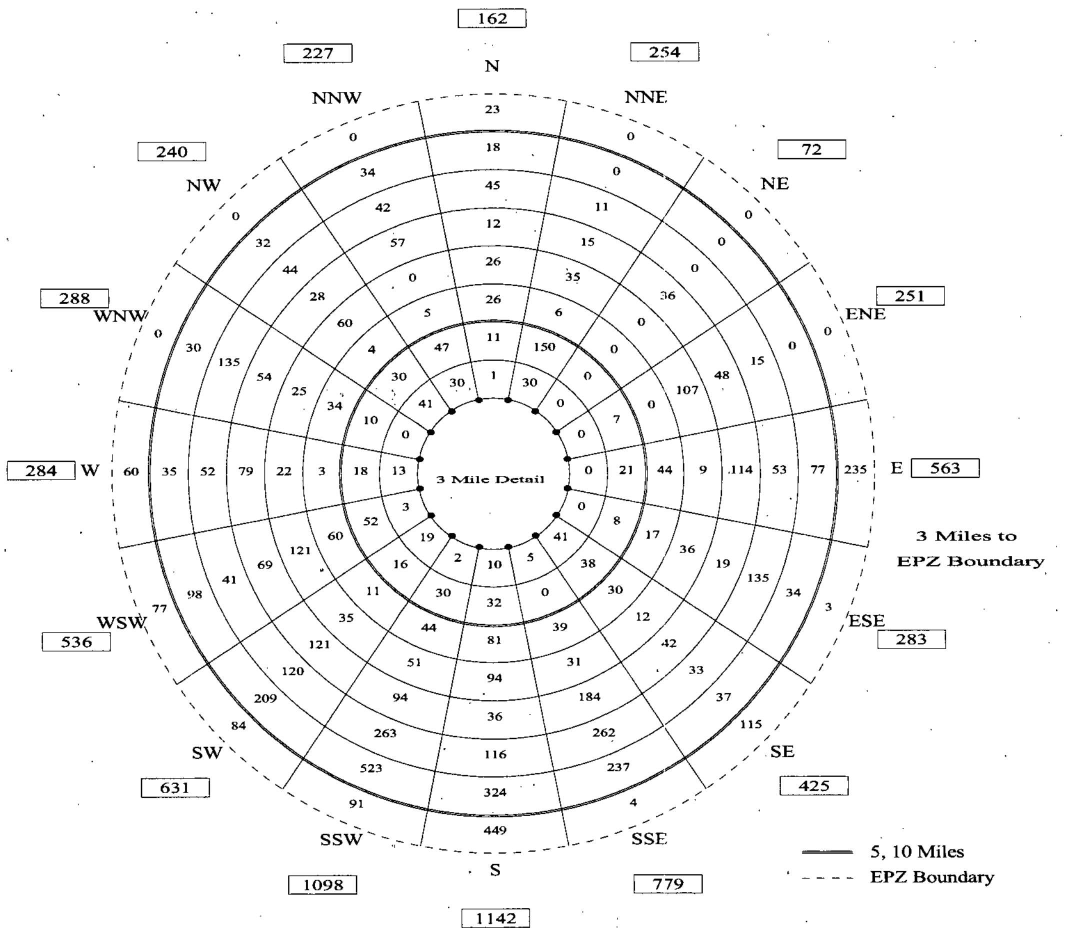


Figure 3-2. Permanent Resident Population by Sector



Resident Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	16	0-1	16
1-2	123	0-2	139
2-3	159	0-3	298
3-4	195	0-4	493
4-5	470	0-5	963
5-6	404	0-6	1367
6-7	664	0-7	2031
7-8	1008	0-8	3039
8-9	1367	0-9	4406
9-10	1688	0-10	6094
10-EPZ	1141	0-EPZ	7235

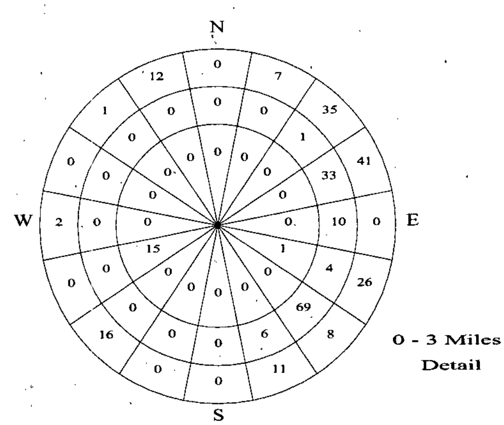


Figure 3-3. Permanent Resident Vehicles by Sector

3.2 Shadow Population

A proportion of the population living in the Shadow Region, which is outside the Emergency Planning Zone (EPZ) and extends to 15 miles radially from VCSNS, 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, evacuation vehicles per household, mobilization time) are assumed to be the same as those for the EPZ permanent resident population. Table 3-3 presents estimates of the total shadow population and vehicles.

Table 3-3. Shadow Population and Vehicles by Sector

Sector	Population	Evacuating Vehicles
N	261	146
NNE	84	46
NE	987	550
ENE	7,022	3,905
E	1,274	710
ESE	996	553
SE	4,991	2,777
SSE	16,484	9,163
S	7,758	4,313
SSW	5,851	3,250
SW	1,443	804
WSW	2,344	1,305
W	2,186	1,213
WNW	937	521
NW	117	66
NNW	116	66
TOTAL	**52,851**	**29,388**

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 camping facilities.

The VCSNS EPZ has a number of areas and facilities that attract transients, including Monticello Reservoir, Parr Reservoir, and Broad River that offer hunting, fishing, and boating. There is also some camping along the Broad River. Seven recreational areas, all of which offer picnicking and six of which have boat ramps, are located in the EPZ near the Parr and Monticello Reservoirs. There are several larger lakes in areas outside of the EPZ that attract the majority of transients in the area (i.e. Lake Murray in Lexington County). There are no lodging facilities in the EPZ.

Phone calls were made to recreational facilities to determine the number of visitors for each facility. It was determined from these calls that 90% of these visitors are EPZ residents, leaving 10% as transients.

A maximum of 240 people could be golfing in the EPZ (150 at Mid Carolina Club and 90 at Lake Murray Golf Center) at any given time. Therefore, 24 of the total 240 golfers are transients visiting from outside the EPZ.

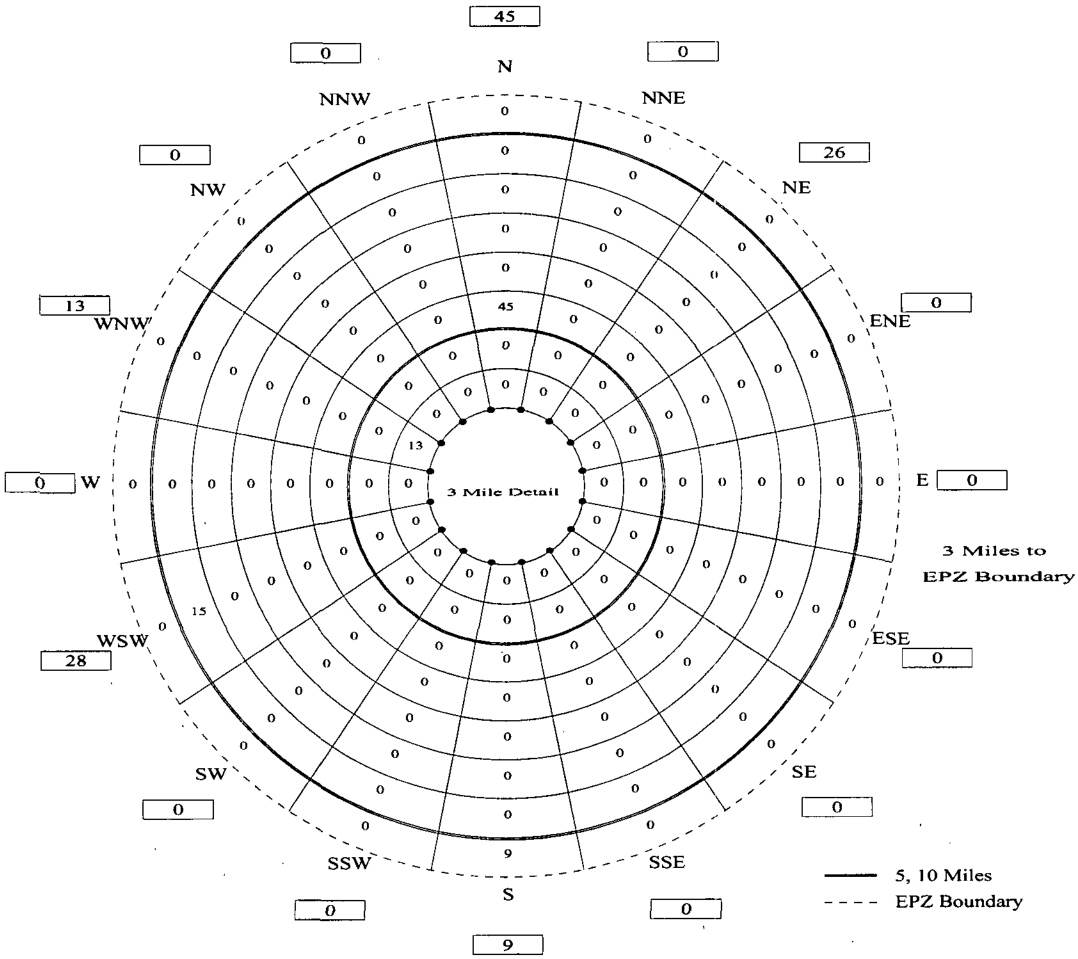
According to road survey data of parking lot capacity at recreational areas, it was estimated that the maximum number of vehicles visiting the seven recreational areas near the Parr and Monticello Reservoirs is 370. Therefore, 37 of the total 370 vehicles are transient vehicles (10% of total visitors). It was assumed that families visited these recreational facilities together. Based on this assumption and using the average household size of 2.68 people obtained from the telephone survey, the total number of transients per site was computed – see table E-4.

A total of 121 transients could be recreating in the EPZ at peak times. The peak season is the summer.

Table 3-4 presents transient population and transient vehicle estimates by PAZ. Figure 3-4 and Figure 3-5 present these data by sector.

Table 3-4. Summary of Transients and Transient Vehicles

PAZ	Transients	Transient Vehicles
A-0	0	0
A-1	44	17
A-2	27	10
B-1	0	0
B-2	0	0
C-1	0	0
C-2	0	0
D-1	0	0
D-2	9	6
E-1	0	0
E-2	15	10
F-1	26	10
F-2	0	0
EPZ TOTAL	**121**	**53**



Transient Population			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	0	0-2	0
2-3	39	0-3	39
3-4	13	0-4	52
4-5	0	0-5	52
5-6	45	0-6	97
6-7	0	0-7	97
7-8	0	0-8	97
8-9	0	0-9	97
9-10	15	0-10	112
10-EPZ	9	0-EPZ	121

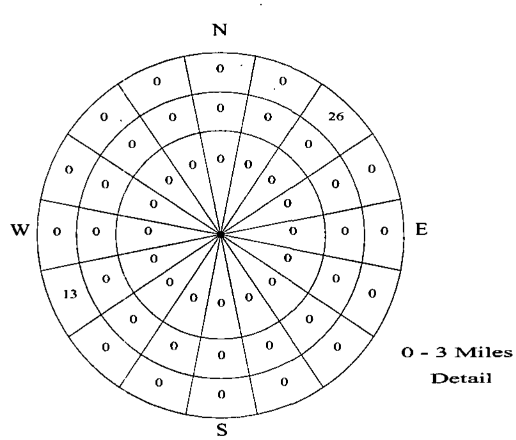
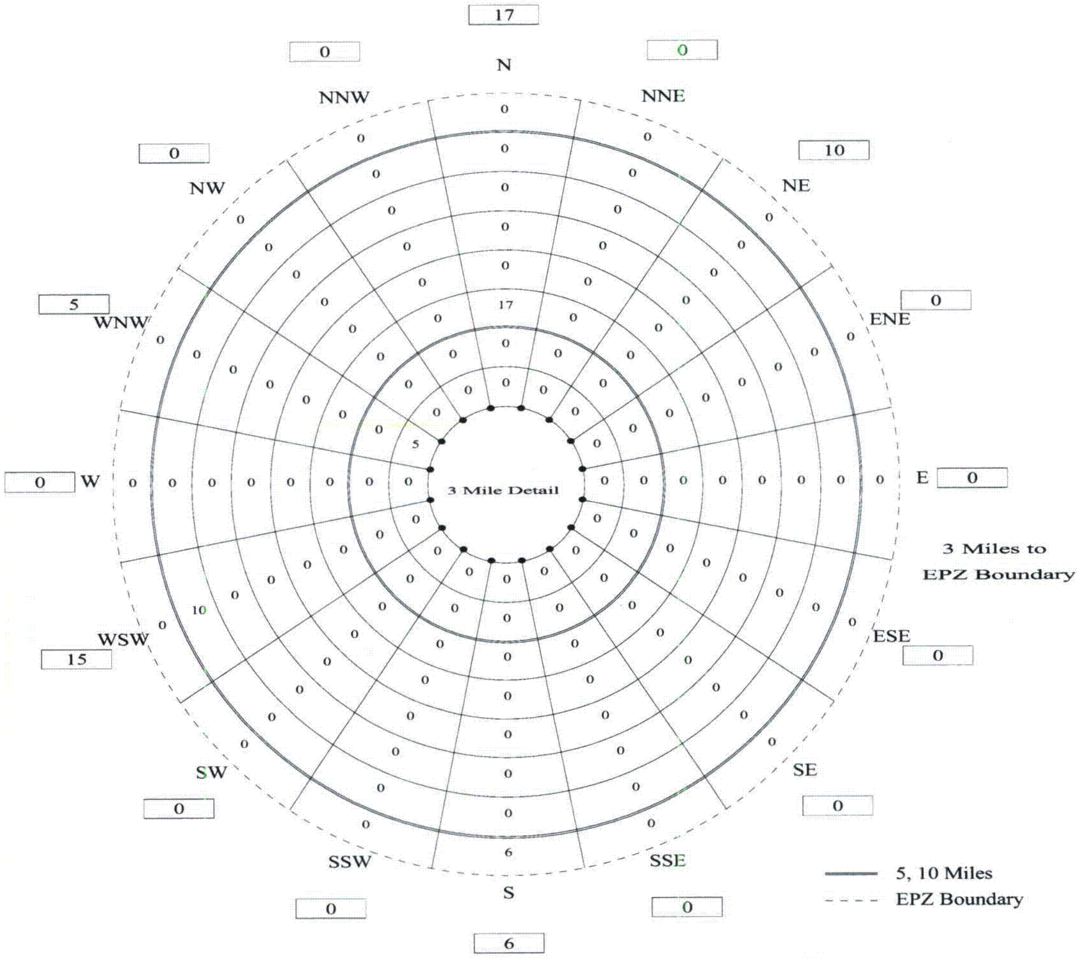


Figure 3-4. Transient Population by Sector



Transient Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	0	0-2	0
2-3	15	0-3	15
3-4	5	0-4	20
4-5	0	0-5	20
5-6	17	0-6	37
6-7	0	0-7	37
7-8	0	0-8	37
8-9	0	0-9	37
9-10	10	0-10	47
10-EPZ	6	0-EPZ	53

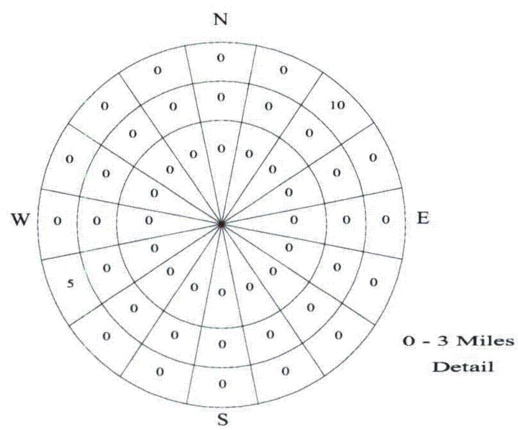


Figure 3-5. Transient Vehicles by Sector

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 for major employers (more than 50 total employees) in the EPZ was provided by the county emergency management offices. The major employers are summarized in Table E-3 and discussed below. The locations of these facilities were mapped using GIS software. The GIS map was overlaid with the evacuation analysis network and employee vehicles were loaded onto appropriate links.

Six major employers were identified for the VCSNS EPZ:

1. The Virgil C. Summer Nuclear Station
   - Total employment of 867 people.
   - Maximum shift employment of 693 people.
   - 90% of employees are non-EPZ residents.
2. Central Label Products
   - Total employment of 105 people.
   - Maximum shift employment of 75 people.
   - 25% of employees are non-EPZ residents.
3. CoreLogic
   - Total employment of 135 people.
   - Maximum shift employment of 135 people.
   - 67% of employees are non-EPZ residents.
4. Ellett Brothers – Sporting Equipment Distributors
   - Total employment of 198 people.
   - Maximum shift employment of 100 people.
   - 68% of employees are non-EPZ residents.
5. General Information Services
   - Total employment of 400 people.
   - Maximum shift employment of 340 people.
   - Average of 78.5% of employees assumed non-EPZ residents.
6. Georgia Pacific Corporation
   - Total employment of 300 people.
   - Maximum shift employment of 100 people.
   - 90% of employees are non-EPZ residents.

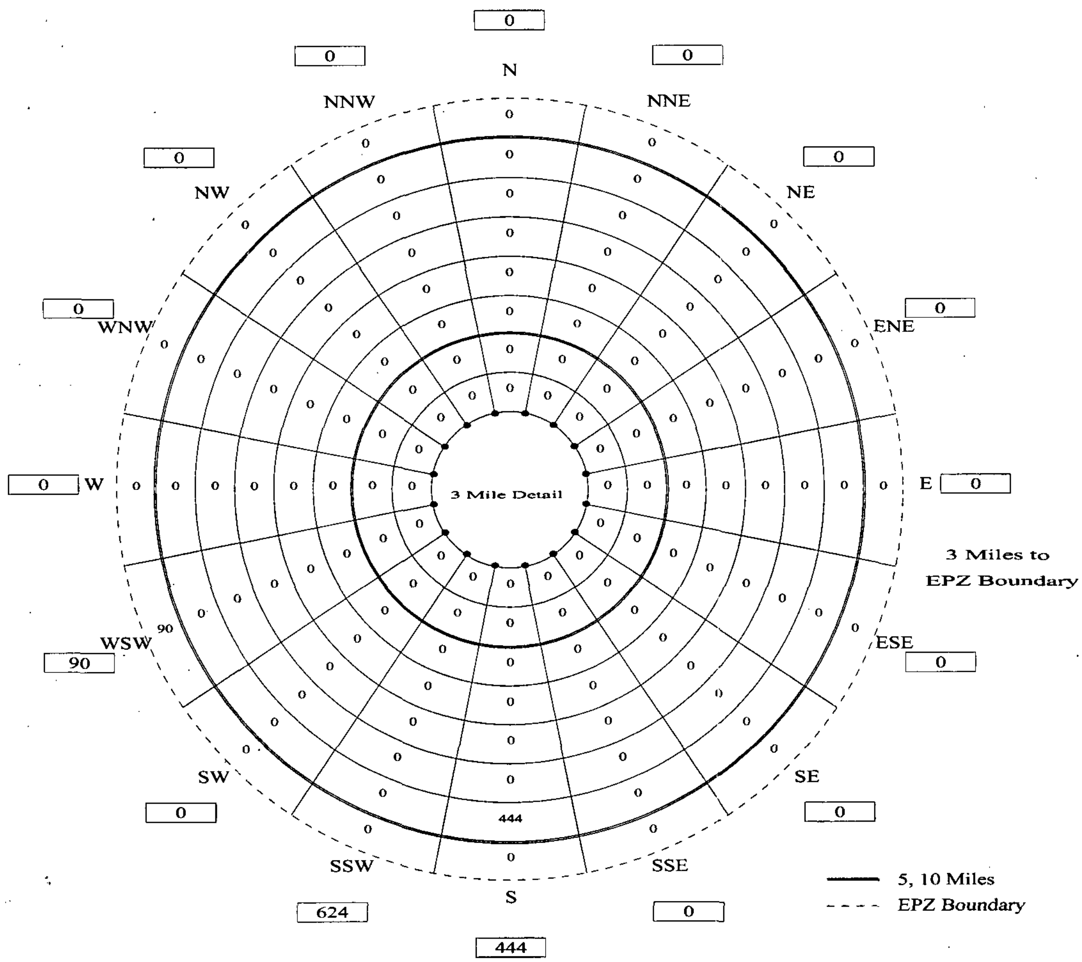
There are likely several smaller employment centers within the EPZ, but employees there are most likely EPZ residents.

Results of the telephone survey indicate an employee-vehicle occupancy rate of 1.01 persons per vehicle, and were used to estimate the number of evacuating employee vehicles.

Table 3-5 presents non-EPZ Resident employee and vehicle estimates by PAZ. Figure 3-6 and Figure 3-7 present these data by sector.

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

PAZ	Employees	Employee Vehicles
A-0	624	616
A-1	0	0
A-2	0	0
B-1	0	0
B-2	0	0
C-1	0	0
C-2	0	0
D-1	0	0
D-2	444	438
E-1	0	0
E-2	90	89
F-1	0	0
F-2	0	0
EPZ TOTAL	**1,158**	**1,143**



Employees			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	624	0-1	624
1-2	0	0-2	624
2-3	0	0-3	624
3-4	0	0-4	624
4-5	0	0-5	624
5-6	0	0-6	624
6-7	0	0-7	624
7-8	0	0-8	624
8-9	0	0-9	624
9-10	444	0-10	1068
10-EPZ	90	0-EPZ	1158

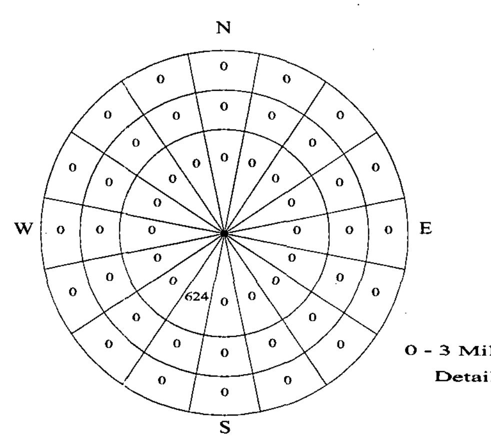
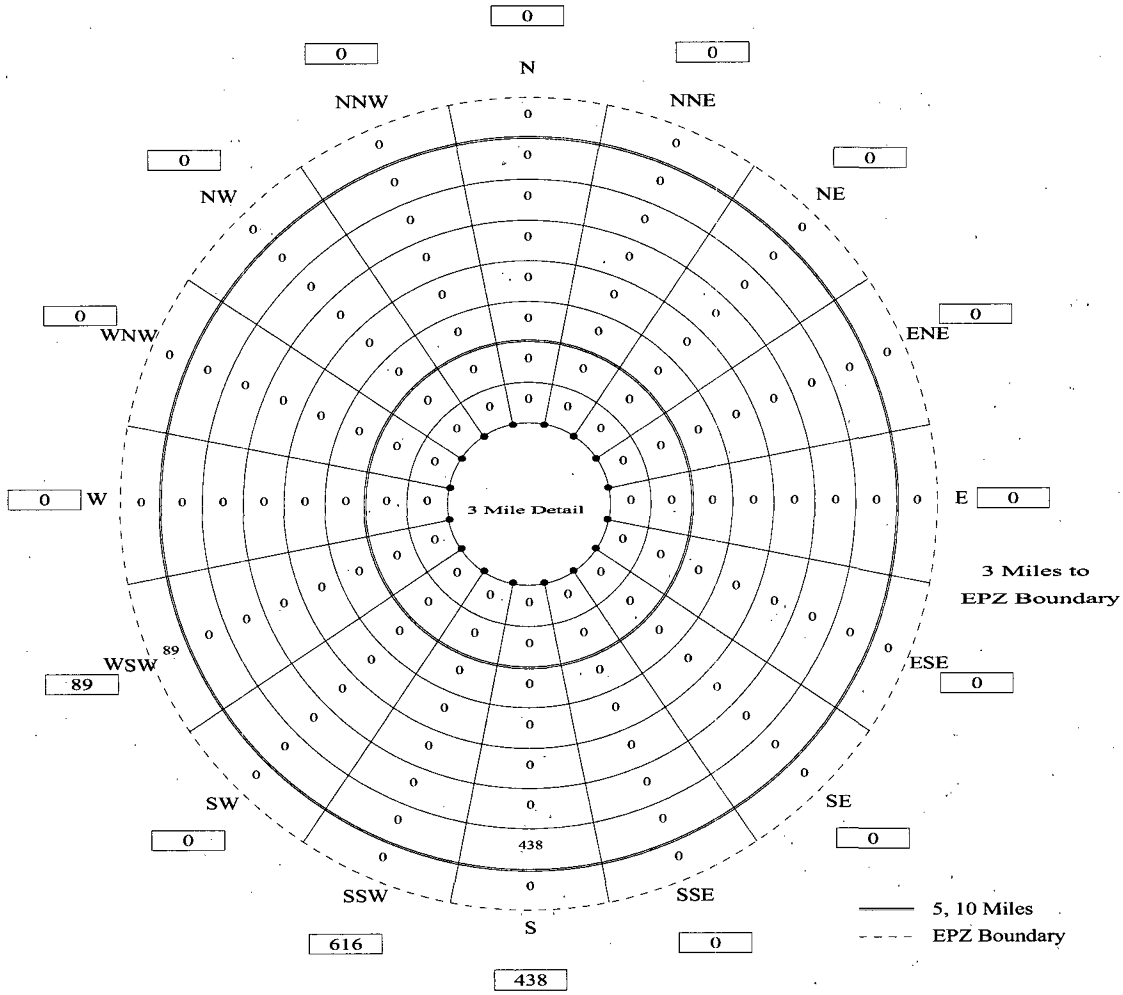


Figure 3-6. Employee Population by Sector



Employee Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	616	0-1	616
1-2	0	0-2	616
2-3	0	0-3	616
3-4	0	0-4	616
4-5	0	0-5	616
5-6	0	0-6	616
6-7	0	0-7	616
7-8	0	0-8	616
8-9	0	0-9	616
9-10	438	0-10	1054
10-EPZ	89	0-EPZ	1143

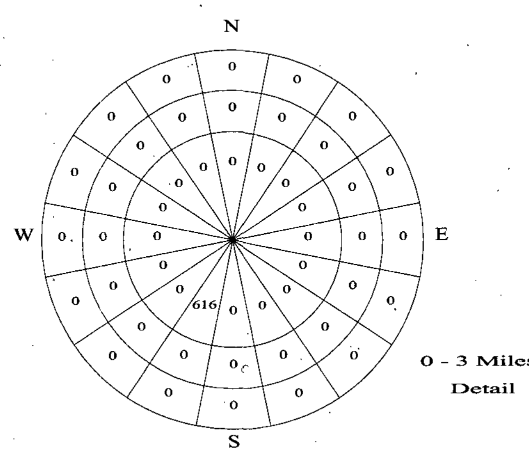


Figure 3-7. Employee Vehicles by Sector

3.5 Medical Facilities

There are two medical facilities in the VCSNS EPZ. Chapter 8 details the evacuation time estimate for the patients of these facilities. The number and type of evacuating vehicles that need to be provided depends on the number of patients and on their state of health. Buses can transport up to 30 people; wheelchair buses, up to 15 people; wheelchair vans, up to 4 people; ambulances, up to 2 people (patients).

3.6 Total Demand in Addition to Permanent Population

Vehicles will be traveling through the EPZ (external-external trips) at the time of an accident. 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 Highways 76, 176, and 321, as well as Interstate 26. 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 the 2010 data supplied by the Federal Highway Administration's Highway Performance Monitoring System. 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 activated at 120 minutes after the advisory to evacuate) to estimate the total source vehicles loaded on the analysis network. As indicated, there are 10,687 vehicles entering the EPZ as external-external trips prior to the activation of the ACP.

3.7 Special Events

The special event considered for this study is the event in which a General Emergency commences during the peak construction year of Units 2 and 3 at the VCSNS site with an outage at Unit 1. During the fourth quarter of the peak construction year, 2014, there is a planned outage. There will be an estimated 3,500 construction workers (3,465 vehicles) at that time at the site. There will also be an additional 700 employees (693 vehicles) at the VCSNS site for the outage. VCSNS personnel have identified that a radiological accident is possible during an outage. Therefore, there would be an additional 4,158 evacuating vehicles from the plant site if a General Emergency occurs during an outage in the peak construction year. A population growth rate was applied to extrapolate the permanent resident population in the EPZ and Shadow Region to realistically represent this scenario. An additional 525 resident vehicles and 110 shadow vehicles were loaded on the network to represent the increased population in 2014.

Table 3-6. VCSNS Site External Traffic

Road Name	Direction	Source Link		AADT[1]	K-Factor[2]	D-Factor[2]	Hourly Volume	Source Vehicles
		UpNode	DnNode					
I-26	Eastbound	8363	363	38,549	0.107	0.5	2,062	4,124
I-26	Westbound	8824	824	38,549	0.107	0.5	2,062	4,124
US-176	Westbound	8827	827	6,300	0.118	0.5	372	743
US-176	Eastbound[3]	8401	401	6,300	0.118	0.25	186	372
US-76	Eastbound	8813	848	6,300	0.118	0.25	186	372
US-321	Northbound	8664	664	3,500	0.136	0.5	238	476
US-321	Southbound	8470	470	3,500	0.136	0.5	238	476
							EPZ Total:	**10,687**

[1] Highway Performance Monitoring System (HPMS), Federal Highway Administration (FHWA), Washington, D.C., 2011
[2] HCM 2010, page 3-10
[3] AADT for US-176 is assumed equal to AADT for US-76

3.8 Summary of Demand

A summary of population and vehicle demand is summarized in Table 3-7 and Table 3-8 respectively. This summary includes all population groups described in this section. Additional population groups – transit-dependent, special facility and school population – are described in greater detail in Section 8. A total of 31,166 people and 25,224 vehicles are considered in this study.

Table 3-7. Summary of Population Demand

ERPA	Residents	Transit-Dependent	Transients	Employees	Special Facilities	Schools	Shadow Population	External Traffic	Total
A-0	220	4	0	624	0	0	0	0	848
A-1	395	7	44	0	0	0	0	0	446
A-2	618	12	27	0	0	219	0	0	876
B-1	341	6	0	0	0	0	0	0	347
B-2	382	7	0	0	0	0	0	0	389
C-1	411	8	0	0	0	0	0	0	419
C-2	1,515	28	0	0	0	270	0	0	1,813
D-1	2,214	41	0	0	0	0	0	0	2,255
D-2	2,721	51	9	444	60	3474	0	0	6,759
E-1	536	10	0	0	0	0	0	0	546
E-2	1,997	37	15	90	0	1672	0	0	3,811
F-1	202	4	26	0	0	0	0	0	232
F-2	1,436	27	0	0	0	392	0	0	1,855
Shadow	0	0	0	0	0	0	10,570	0	10,570
Total	**12,988**	**242**	**121**	**1,158**	**60**	**6,027**	**10,570**	**0**	31,166

Table 3-8. Summary of Vehicle Demand

ERPA	Residents	Transit-Dependent	Transients	Employees	Special Facilities	Schools	Shadow Population	External Traffic	Total
A-0	123	0	0	616	0	0	0	0	739
A-1	219	0	17	0	0	0	0	0	236
A-2	346	0	10	0	0	8	0	0	364
B-1	190	4	0	0	0	0	0	0	194
B-2	213	0	0	0	0	8	0	0	221
C-1	232	0	0	0	0	0	0	0	232
C-2	848	0	0	0	0	0	0	0	848
D-1	1,233	4	0	0	0	0	0	0	1,237
D-2	1,514	4	6	438	6	112	0	0	2,080
E-1	297	2	0	0	0	0	0	0	299
E-2	1,111	4	10	89	0	64	0	0	1,278
F-1	111	0	10	0	0	0	0	0	121
F-2	798	0	0	0	0	12	0	0	810
Shadow	0	0	0	0	0	0	5,878	10,687	16,565
Total	7,235	18	53	1,143	6	204	5,878	10,687	25,224

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
- 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. The estimated FFS were measured using the survey vehicle's speedometer and observing local traffic, under free flow conditions.

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

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

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 ice, 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}, $F_1, F_2, \ldots$

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:

$$h_m \geq h_{sat}$$

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

[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", to be presented at the TRB 2012 Annual Meeting, January 22-26, 2012

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, F_1, F_2,..., 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 is 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.

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

4.3 Application to the VCSNS 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 small towns 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.

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 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.

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.

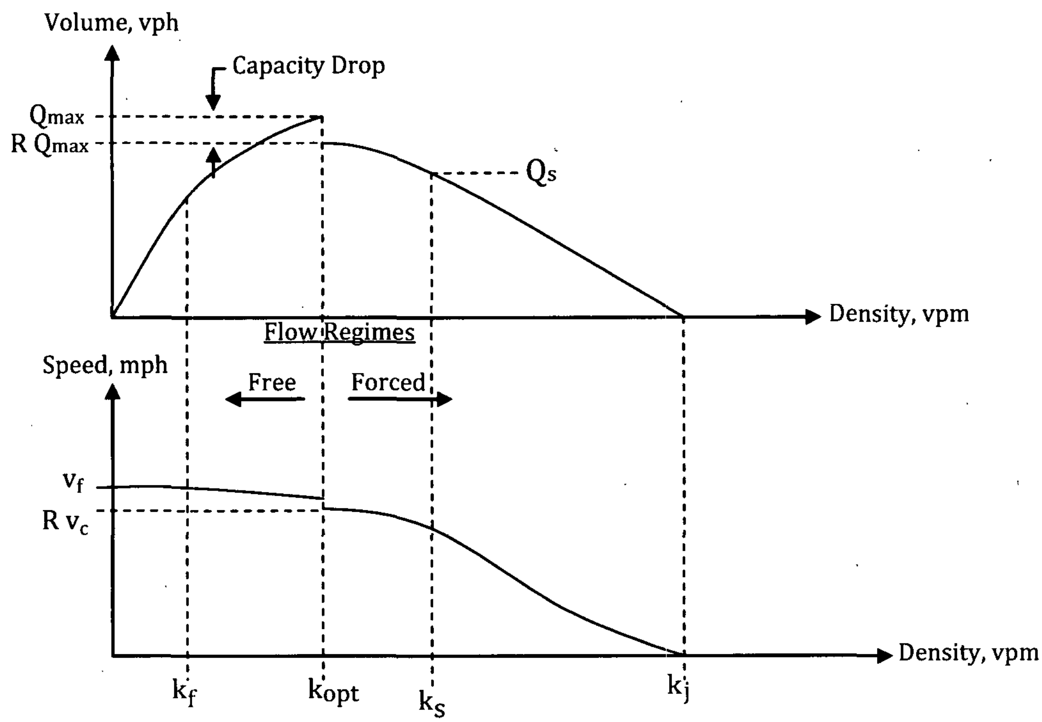


Figure 4-1. Fundamental Diagrams

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 among 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

In general, an accident at a nuclear power station is characterized by the following Emergency Action Levels (see Appendix 1 of NUREG 0654 for details):

1. Unusual Event
2. Alert
3. Site Area Emergency
4. General Emergency

At each level, the Federal guidelines specify a set of Actions to be undertaken by the Licensee, and by state and local offsite authorities. As a Planning Basis, we will adopt a conservative posture, in accordance with Section 1.2 of NUREG/CR-7002, that a rapidly escalating accident will be considered in calculating the Trip Generation Time. We will assume:

1. The Advisory to Evacuate will be announced coincident with the emergency notification.
2. Mobilization of the general population will commence up to 10 minutes after the initial notification.
3. ETE are measured relative to the Advisory to Evacuate.

We emphasize 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.

It is likely that a longer time will elapse between the various classes of an emergency.

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 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 systems available within the EPZ (e.g. using sirens, EAS broadcasts, loud speakers).
2. Receiving and correctly interpreting the information that is transmitted.

The general population within the EPZ is dispersed over an area of approximately 314 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 accident.

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 may 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 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 2006 as part of the VCSNS COL Application. Use of this survey for the 2010 ETE effort is justified by the fact that the demographics of the area have not significantly changed in the last five years; the average household size computed from the survey results differs from the 2010 Census value by about 3 percent. 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)

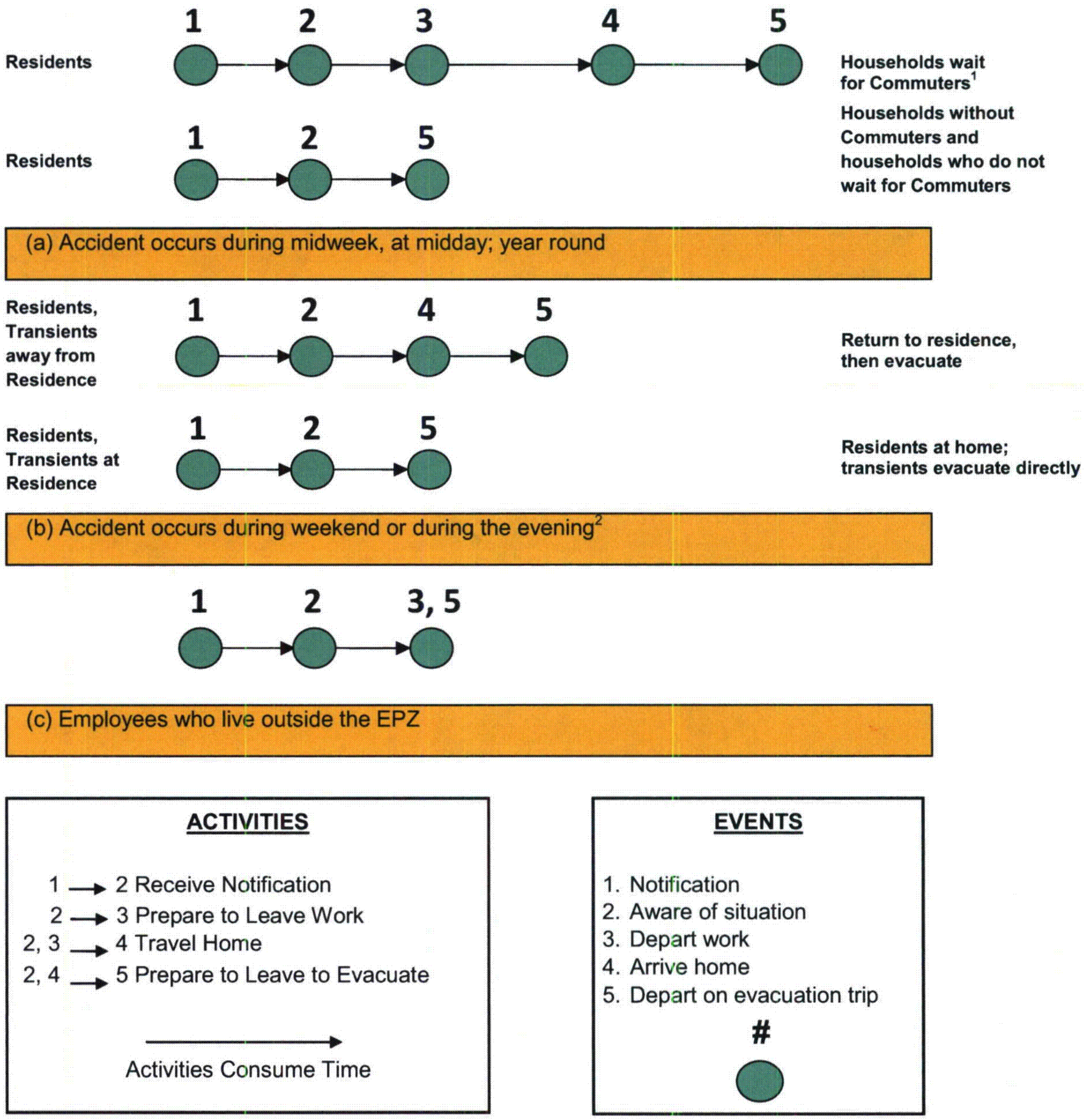
As such, a completed Activity changes the 'state' of an individual (e.g., the activity, 'travel home' changes the state from 'depart work' to 'arrive home'). Therefore, an Activity can be described as an 'Event Sequence'; the elapsed times to perform an event sequence vary from one person to the next 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 sequential (for instance, commuter returning home before beginning 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

It is assumed (based on the presence of sirens within the EPZ) that 85 percent of those within the EPZ will be aware of the accident 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	85%
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 could 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 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%	50	86%
5	29%	55	86%
10	40%	60	96%
15	53%	65	97%
20	60%	70	98%
25	61%	75	98%
30	75%	80	99%
35	76%	85	99%
40	80%	90	100%
45	85%		

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%	40	85%
5	12%	45	94%
10	24%	50	96%
15	35%	55	96%
20	52%	60	98%
25	59%	65	99%
30	77%	75	99%
35	80%	90	100%

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 below.

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

Elapsed Time (Minutes)	Cumulative Percent Ready to Evacuate	Elapsed Time (Minutes)	Cumulative Percent Ready to Evacuate
0	0%	70	88%
5	10%	75	91%
10	19%	80	91%
15	29%	85	92%
20	39%	90	93%
25	50%	95	93%
30	60%	100	93%
35	63%	105	93%
40	66%	110	94%
45	69%	115	95%
50	74%	120	96%
55	79%	125	98%
60	84%	130	99%
65	86%	135	100%

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

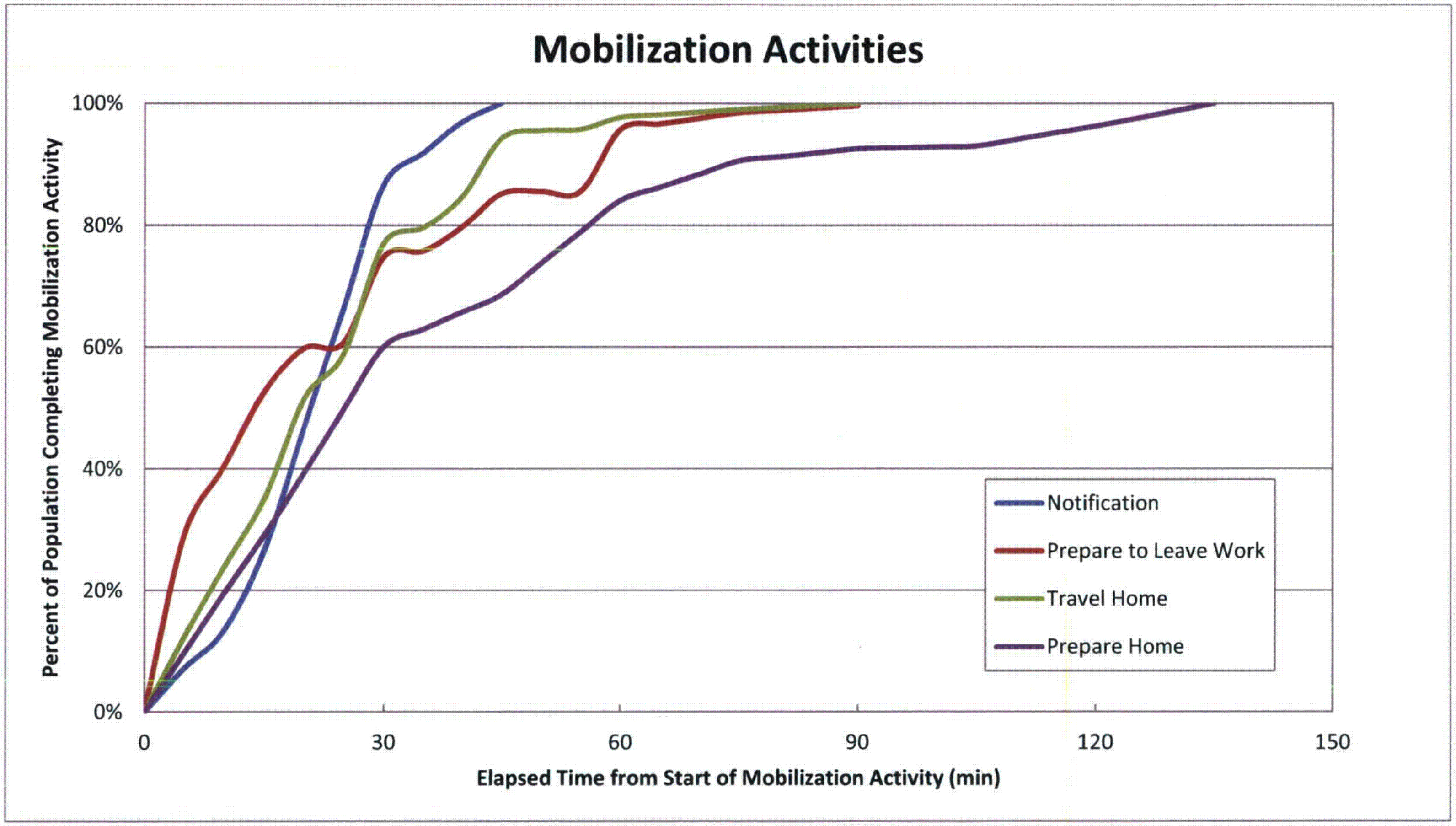


Figure 5-2. Evacuation Mobilization Activities

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 $\rightarrow$ 4) must precede Activity 4 $\rightarrow$ 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 5-6 presents the summing procedure to arrive at each designated distribution.

Table 5-6. 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

Table 5-7 presents a description of each of the final trip generation distributions achieved after the summing process is completed.

Table 5-7. 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).

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 540 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 singlularly or in groups, much of which assumes the data is normally distributed and some of which uses non-parametric methods to avoid that assumption. The literature cites that limited work has been done directly on outliers in sample survey responses.

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

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

2) The individual mobilization <u>activities</u> (prepare to leave work, travel home, prepare home) are reviewed for outliers, and <u>then</u> the overall trip generation distributions are created (see Figure 5-4 , Table 5-6 ,Table 5-7)

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

4) To eliminate outliers, use all of the following:
   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
   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 "e" 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 .

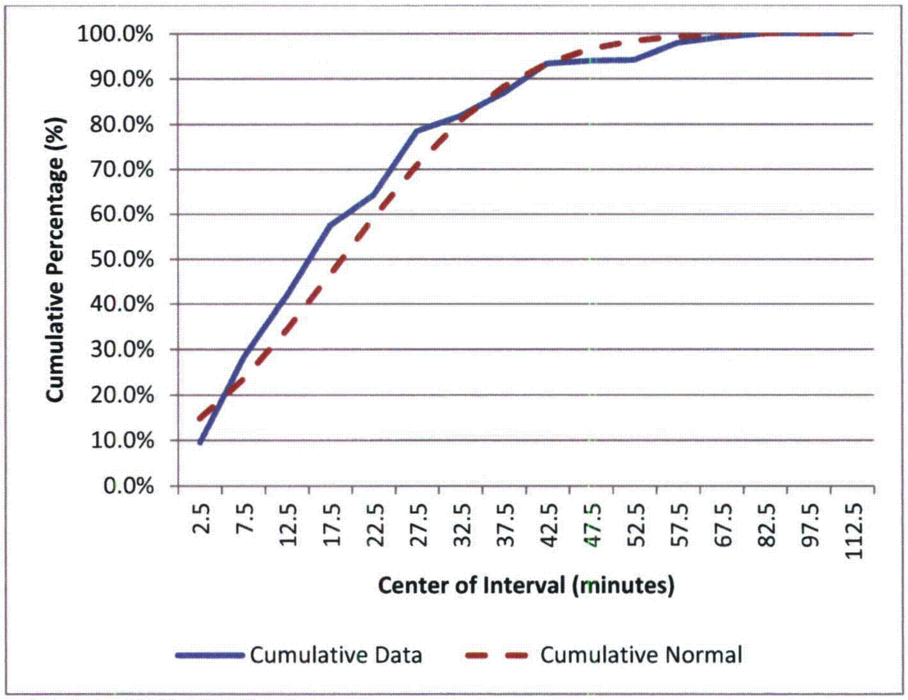


Figure 5-3. Comparison of Data Distribution and Normal Distribution

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 some 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, not 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). 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, and D. 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.)

Once the mobilization distributions are computed, they are reviewed so that when the cumulative distribution reaches a level that further vehicle generation from any source node is less than one vehicle, the cumulative distribution is adjusted as follows: (a) Assuming the maximum generation from any source is 2,000 vehicles, the generation becomes less than one vehicle when the cumulative probability is greater than 0.9995 [that is, $F(t) \geq 0.9995$]; (b) when this is attained, the cumulative distribution is rescaled so that it attains 1.0000 at that point. In this way, by rescaling the curve, the full number of vehicles are generated.

The number of 2,000 for any one source is used as the default condition. The sum of generated vehicles over all sources can of course exceed 100,000 or more. In the rare case that a single source generates more than 2,000 vehicles, the software models it as multiple concurrent sources, each below 2,000 vehicles.

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 System 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, and D, properly displaced with respect to one another, are tabulated in Table 5-8Table 5-8 (Distribution B, Arrive Home, omitted for clarity).

The final time period (13) 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. PAZs comprising the 2 mile region are advised to evacuate immediately
2. PAZs comprising regions extending from 2 to 5 miles downwind are advised to shelter in-place while the two mile region is cleared
3. As vehicles evacuate the 2 mile region, people who are sheltering 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 people 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 PAZs 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 other venues. Also, notifying the transient population of a staged evacuation would prove difficult.
4. Employees will also be assumed to evacuate without staging

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 PAZs comprising the two mile region. This value, T_{Scen}^*, obtained from simulation results is scenario-specific. 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 similar for many scenarios (see Table 7-1A) and consequently a single [representative] value is used for all staged evacuation cases.

3. Staged trip generation distributions are created for the following population groups:
   a. Residents with returning commuters
   b. Residents without returning commuters

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 95 minutes, on average. At the 90th percentile evacuation time (T_{Scen}^*), approximately 9 percent of the households with returning commuters and 18 percent of the households without returning commuters who were advised to shelter have nevertheless departed the area; these are the people who 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 for the 2-mile Region occurs before the end of the trip generation period, 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 5-9 provides the trip generation for staged evacuation.

5.4.3 Trip Generation for Waterways and Recreational Areas

Part 3-1-2 of the South Carolina Operational Radiological Emergency Response Plan (August 2009) states that the South Carolina Department of Natural Resources (SCDNR) will alert persons boating or fishing on Lake Monticello along portions of the Broad River. SCDNR officers will initiate alert and clearing efforts on the lake and river as needed.

As indicated in Table 5-2, this study assumes 100% notification in 45 minutes. Table 5-8 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.

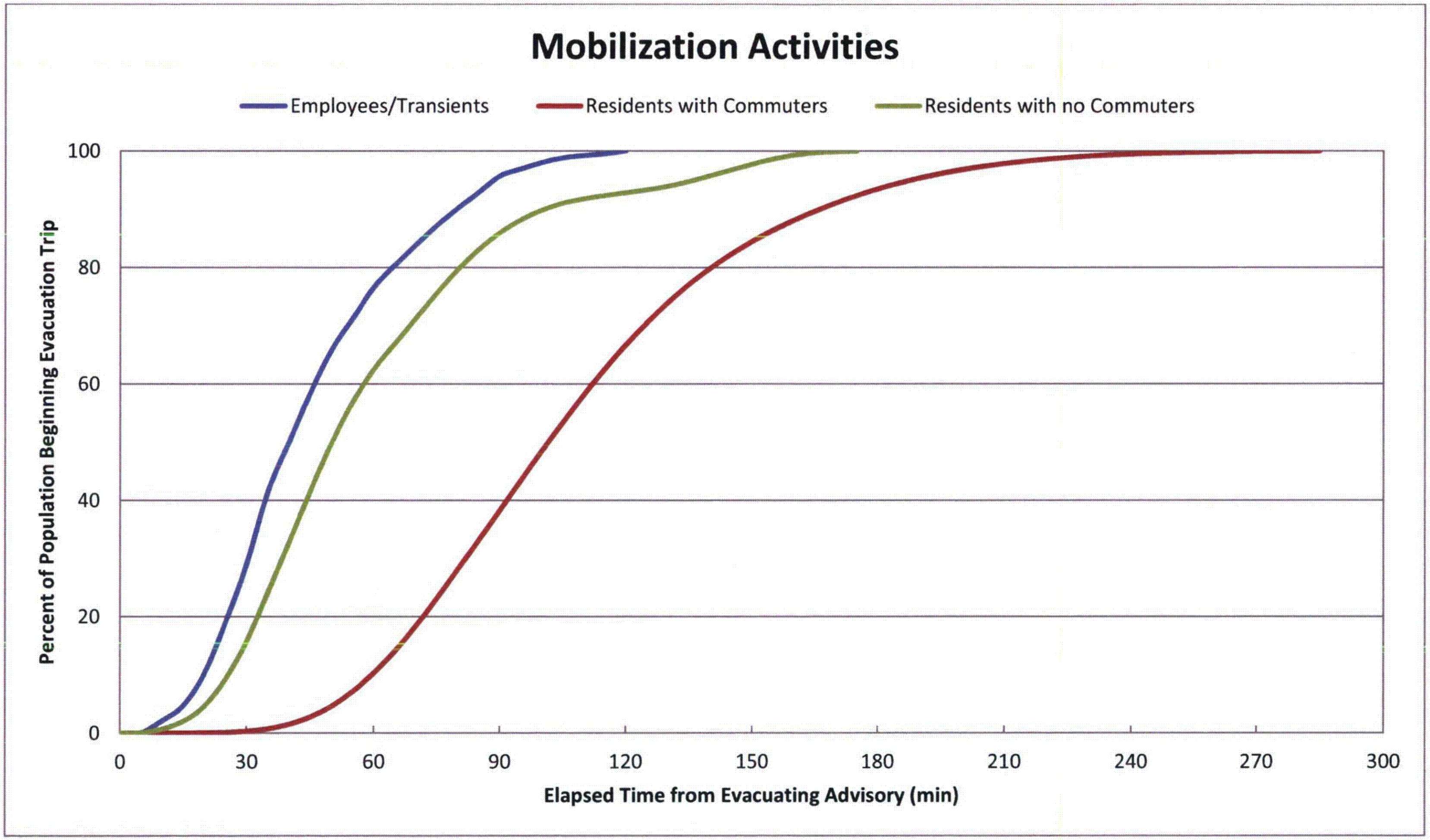


Figure 5-4. Comparison of Trip Generation Distributions

Table 5-8. Trip Generation Histograms for the EPZ Population

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)
1	15	5	5	0	2
2	15	24	24	0	14
3	15	30	30	3	26
4	15	18	18	7	21
5	15	10	10	13	13
6	15	9	9	15	10
7	15	3	3	15	5
8	15	1	1	14	2
9	30	0	0	17	5
10	30	0	0	9	2
11	60	0	0	6	0
12	45	0	0	1	0
13	600	0	0	0	0

Notes:

- Shadow vehicles are loaded onto the analysis network (Figure 1-2) using Distribution C
- Special event vehicles are loaded using Distribution A.

Table 5-9. Trip Generation Histograms for the EPZ Population in the 2-5 Mile Region for a Staged Evacuation

Time Period	Duration (Min)	Percent of Total Trips Generated Within Indicated Time Period in the 2-5 Mile Region for a Staged Evacuation			
		Employees (Distribution A)	Transients (Distribution A)	Residents with Commuters (Distribution C)	Residents Without Commuters (Distribution D)
1	15	5	5	0	0
2	15	24	24	0	3
3	15	30	30	1	5
4	15	18	18	1	5
5	15	10	10	3	2
6	15	9	9	3	2
7	15	3	3	34	50
8	15	1	1	25	26
9	30	0	0	17	5
10	30	0	0	9	2
11	60	0	0	6	0
12	45	0	0	1	0
13	600	0	0	0	0

*Trip Generation for Employees and Transients (see Table 5-8) is the same for Unstaged and Staged Evacuation.

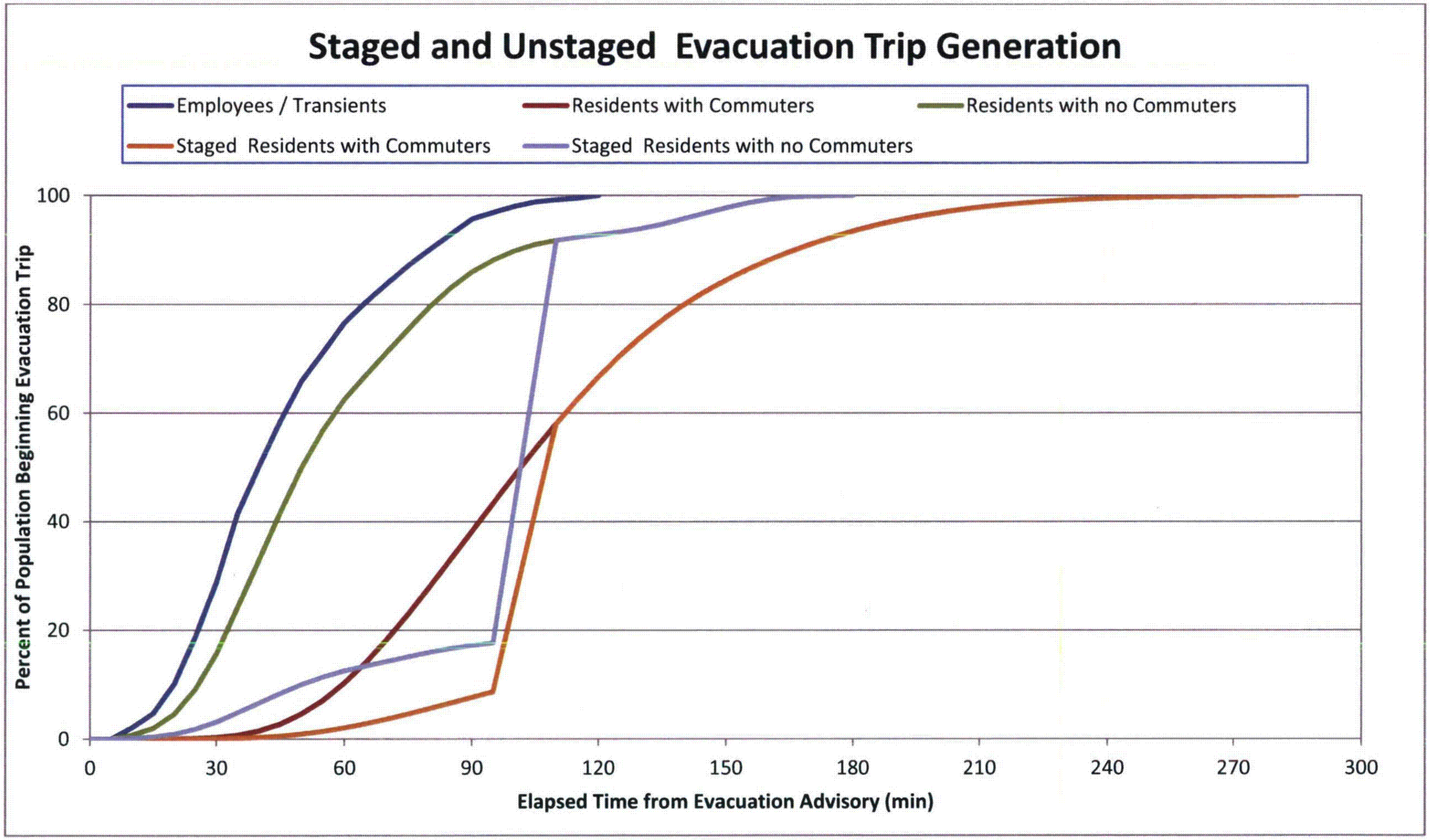


Figure 5-5. Comparison of Staged and Unstaged Trip Generation Distributions in the 2-5 Mile Region

6 DEMAND ESTIMATION FOR EVACUATION SCENARIOS

An evacuation "case" defines a combination of Evacuation Region and Evacuation Scenario. The definitions of "Region" and "Scenario" are as follows:

Region A grouping of contiguous Protective Action Zones (PAZ), that forms either a "keyhole" sector-based area, or a circular area within the EPZ, that must be evacuated in response to a radiological emergency.

Scenario A combination of circumstances, including time of day, day of week, season, and weather conditions. Scenarios define the number of people in each of the affected population groups and their respective mobilization time distributions.

A total of 30 Regions were defined which encompass all the groupings of PAZs considered. These Regions are defined in Table 6-1. The PAZ configurations are identified in Figure 6-1. Each keyhole sector-based area consists of a central circle centered at the VCSNS Site, and three adjoining sectors, each with a central angle of 22.5 degrees, as per NUREG/CR-7002 guidance. The central sector coincides with the wind direction. These sectors extend to 5 miles downwind (Regions R04 through R11) or to the EPZ boundary (Regions R12 through R21) from the VCSNS Site. Regions R01, R02, and R03 represent evacuations of the 2-mile region, 5-mile region, and the entire EPZ, respectively. Regions R22 through R30 are geographically identical to Regions R02 and Regions R04 through R11, respectively; however, those subareas between 2 miles and 5 miles are staged until 90% of the 2-mile region (Region R01) has evacuated.

A total of 14 Scenarios were evaluated for all Regions. Thus, there are a total of 14x30=420 evacuation cases. Table 6-2 is a description of all Scenarios.

Each combination of region and scenario implies a specific population to be evacuated. Table 6-3 presents the percentage of each population group assumed to evacuate for each scenario. Table 6-4 presents the vehicle counts for each scenario for an evacuation of Region R03 – the entire EPZ.

The vehicle estimates presented in Section 3 are "peak values". These peak values are adjusted depending on the scenario and region being considered using the scenario-specific percentages presented in Table 6-3 and the regional percentages provided in Table H-1.

The percentages presented in Table 6-3 were determined as follows:

The number of residents with commuters during the week (when workforce is at its peak) is equal to the product of 67% (the number of households with at least one commuter) and 78% (the number of households with a commuter who would await the return of the commuter prior to evacuating). See assumption 4 in Section 2.3. It is assumed for weekend and evening scenarios that 10% of households with commuters will have a commuter at work during those times.

Employment is assumed to be at its peak during the winter, midweek, midday scenarios.

Employment is reduced slightly (96%) for summer, midweek, midday scenarios. This is based on the assumption that 50% of the employees commuting into the EPZ will be on vacation for a week during the approximate 12 weeks of summer. It is further assumed that those taking vacation will be uniformly dispersed throughout the summer with approximately 4% of employees vacationing each week. Based on discussions with VCSNS personnel, the evening and weekend employment at the existing VCSNS Site is approximately 10% and 75% of the weekday employment, respectively. As shown in Table E-3, SCE&G is the largest employer in the EPZ; therefore the value of 10% of employment in evenings and 75% of employment on weekends has been applied to the EPZ as a whole.

Transient activity is assumed to be at its peak (100%) during summer weekends and less (25%) during the week. Transient activity is assumed to be low during evening hours – 10% for summer and 3% for winter. Transient activity on winter weekends is assumed to be 25%. Transient activity during winter weekdays is assumed to be 25% of the transient activity on summer weekends (25%), which equates to approximately 6%.

As noted in the shadow footnote to Table 6-3, the shadow percentages are computed using a base of 20% (see assumption 5 in Section 2.2) voluntary evacuation multiplied by a scenario-specific proportion of employees to permanent residents in the shadow region. For example, using the values provided in Table 6-3 for Scenario 1, the shadow percentage is computed as follows:

$$20\% \times \left(1 + \frac{1,097}{3,739 + 3,496}\right) = 23\%$$

One special event was considered: the construction of Units 2 and 3 at the VCSNS Site coincident with an outage at Unit 1. Thus, the special event traffic is 100% of the additional construction and contract outage workers on site evacuated for Scenario 13 and 0% for all other scenarios.

The roadway impact scenario (Scenario 14) assumes that the available capacity along a section of the eastbound I-26 interstate highway traversing the EPZ through Lexington County would be reduced by closing a single lane. Thus, the percentages for this scenario are the same as for Scenario 1.

It is assumed that summer school enrollment is approximately 10% of enrollment during the regular school year for summer, midweek, midday scenarios. School is not in session during weekends and evening, thus no buses to evacuate schoolchildren are needed under those circumstances. As discussed in Section 7, schools are assumed to be in session during the winter season, midweek, midday and 100% of buses will be needed under those circumstances. Transit buses for the transit-dependent population are set to 100% for all scenarios as it is assumed that the transit-dependent population is present in the EPZ for all scenarios.

External-external traffic is assumed to be reduced to 40% during the evening scenarios and is 100% for all other scenarios.

Table 6-1. Description of Evacuation Regions

Region	Description	Protective Action Zone												
		A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
R01	2-Mile Ring	X												
R02	5-Mile Ring	X	X		X		X				X		X	
R03	Full EPZ	X	X	X	X	X	X	X	X	X	X	X	X	X
Evacuate 2-Mile Radius and Downwind to 5 Miles														
Region	**Wind Direction From**	**Protective Action Zone**												
		A-0	**A-1**	**A-2**	**B-1**	**B-2**	**C-1**	**C-2**	**D-1**	**D-2**	**E-1**	**E-2**	**F-1**	**F-2**
R04	S, SSW	X	X		X									
R05	SW, WSW	X	X		X		X							
R06	W	X			X		X							
R07	WNW, NW	X					X							
R08	NNW, N	X					X				X			
R09	NNE, NE	X									X			
R10	ENE, E	X									X		X	
R11	ESE, SE, SSE	X	X										X	
Evacuate 5-Mile Radius and Downwind to the EPZ Boundary														
Region	**Wind Direction From:**	**Protective Action Zone**												
		A-0	**A-1**	**A-2**	**B-1**	**B-2**	**C-1**	**C-2**	**D-1**	**D-2**	**E-1**	**E-2**	**F-1**	**F-2**
R12	S	X	X	X	X		X				X		X	
R13	SSW, SW	X	X	X	X	X	X				X		X	
R14	WSW, W	X	X		X	X	X	X			X		X	
R15	WNW, NW	X	X		X		X	X	X		X		X	
R16	NNW	X	X		X		X	X	X	X	X		X	
R17	N, NNE	X	X		X		X		X	X	X	X	X	
R18	NE	X	X		X		X			X	X	X	X	X
R19	ENE, E	X	X		X		X				X	X	X	X
R20	ESE	X	X		X		X				X		X	X
R21	SE, SSE	X	X	X	X		X				X		X	X

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

Table 6-1 (Continued from above)

Staged Evacuation - 2-Mile Radius Evacuates, then Evacuate Downwind to 5 Miles														
Region	Wind Direction From:	Protective Action Zone												
		A-0	A-1	A-2	B-1	B-2	C-1	C-2	D-1	D-2	E-1	E-2	F-1	F-2
R22	5-Mile Ring	X	X		X		X				X		X	
R23	S, SSW	X	X		X									
R24	SW, WSW	X	X		X		X							
R25	W	X			X		X							
R26	WNW, NW	X					X							
R27	NNW, N	X					X				X			
R28	NNE, NE	X									X			
R29	ENE, E	X									X		X	
R30	ESE, SE, SSE	X	X										X	
Shelter-in-Place until 90% ETE for R01, then Evacuate					PAZ(s) Shelter-in-Place				PAZ(s) Evacuate					

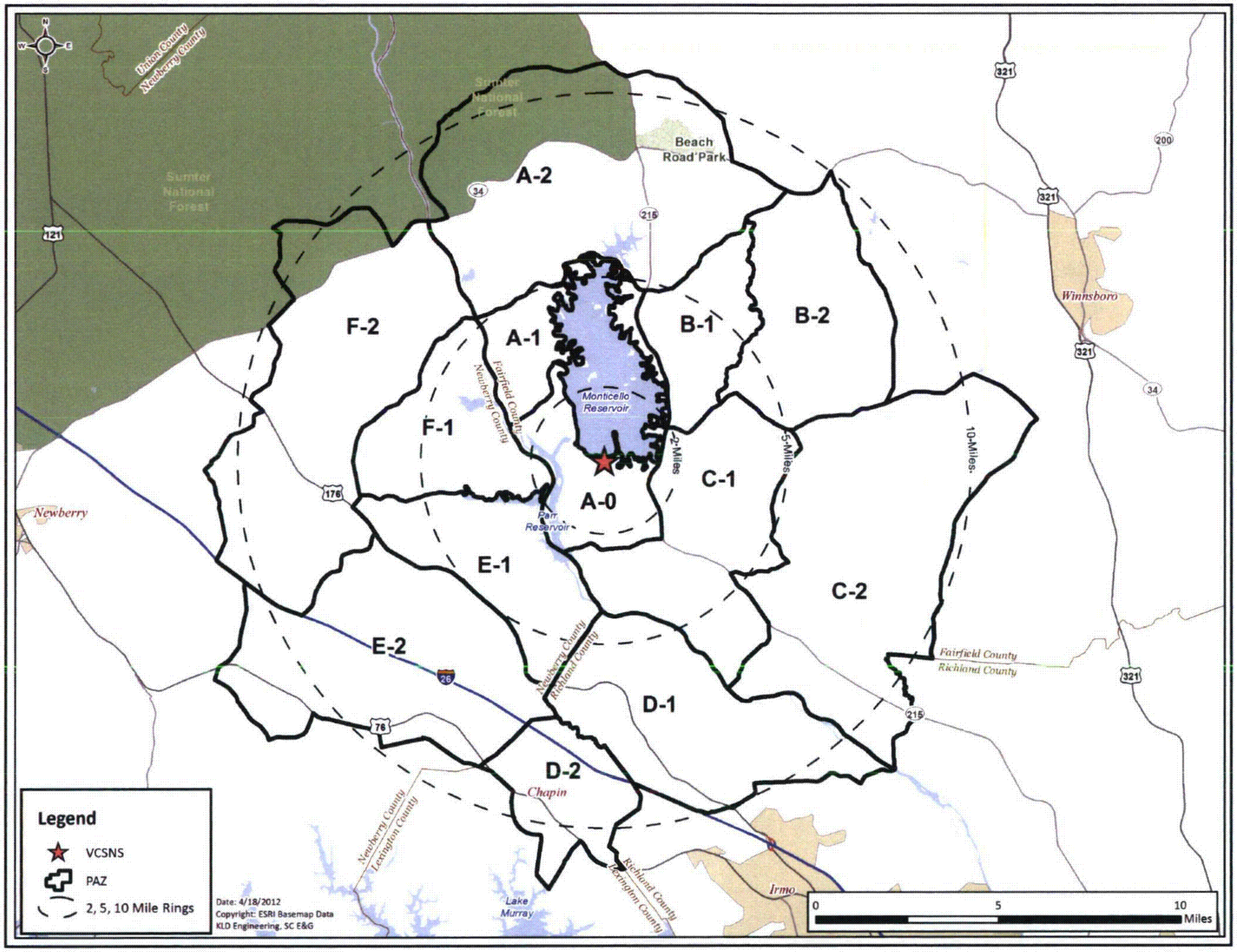


Figure 6-1. VCSNS EPZ Protective Action Zones

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	Ice	None
9	Winter	Weekend	Midday	Good	None
10	Winter	Weekend	Midday	Rain	None
11	Winter	Weekend	Midday	Ice	None
12	Winter	Midweek, Weekend	Evening	Good	None
13	Winter	Midweek	Midday	Good	Construction of VCSNS Units 2 and 3
14	Summer	Midweek	Midday	Good	Roadway Impact – Lane Closure on I-26 Eastbound

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

Table 6-3. Percent of Population Groups Evacuating for Various Scenarios

Scenario	Households With Returning Commuters	Households Without Returning Commuters	Employees	Transients	Shadow	Special Events	School Buses	Transit Buses	External Through Traffic
1	52%	48%	96%	25%	23%	0%	10%	100%	100%
2	52%	48%	96%	25%	23%	0%	10%	100%	100%
3	10%	90%	75%	100%	22%	0%	0%	100%	100%
4	10%	90%	75%	100%	22%	0%	0%	100%	100%
5	10%	90%	10%	10%	20%	0%	0%	100%	40%
6	52%	48%	100%	6%	23%	0%	100%	100%	100%
7	52%	48%	100%	6%	23%	0%	100%	100%	100%
8	52%	48%	100%	6%	23%	0%	100%	100%	100%
9	10%	90%	75%	25%	22%	0%	0%	100%	100%
10	10%	90%	75%	25%	22%	0%	0%	100%	100%
11	10%	90%	75%	25%	22%	0%	0%	100%	100%
12	10%	90%	10%	3%	20%	0%	0%	100%	40%
13	52%	48%	100%	6%	23%	100%	100%	100%	100%
14	52%	48%	96%	25%	23%	0%	10%	100%	100%

Resident Households with Commuters ....Households of EPZ residents who await the return of commuters prior to beginning the evacuation trip.
Resident Households with No Commuters ..Households of EPZ residents who do not have commuters or will not await the return of commuters prior to beginning the evacuation trip.
Employees...EPZ employees who live outside the EPZ
Transients ....People who are in the EPZ at the time of an accident for recreational or other (non-employment) purposes.
Shadow..Residents and employees in the shadow region (outside of the EPZ) who will spontaneously decide to relocate during the evacuation. The basis for the values shown is a 20% relocation of shadow residents along with a proportional percentage of shadow employees.
Special Events ....Additional vehicles in the EPZ due to the identified special event.
School and Transit Buses ....Vehicle-equivalents present on the road during evacuation servicing schools and transit-dependent people (1 bus is equivalent to 2 passenger vehicles).
External Through Traffic ....Traffic on interstates/freeways and major arterial roads at the start of the evacuation. This traffic is stopped by access control approximately 2 hours after the evacuation begins.

Table 6-4. Vehicle Estimates by Scenario

Scenarios	Residents with Commuters	Residents without Commuters	Employees	Transients	Shadow	Special Events	School Buses	Transit Buses	External Traffic	Total Scenario Vehicles
1	3,739	3,496	1,097	13	6,769	-	20	18	10,687	25,839
2	3,739	3,496	1,097	13	6,769	-	20	18	10,687	25,839
3	374	6,861	857	53	6,574	-	-	18	10,687	25,424
4	374	6,861	857	53	6,574	-	-	18	10,687	25,424
5	374	6,861	114	5	5,970	-	-	18	4,275	17,617
6	3,739	3,496	1,143	3	6,806	-	204	18	10,687	26,096
7	3,739	3,496	1,143	3	6,806	-	204	18	10,687	26,096
8	3,739	3,496	1,143	3	6,806	-	204	18	10,687	26,096
9	374	6,861	857	13	6,574	-	-	18	10,687	25,384
10	374	6,861	857	13	6,574	-	-	18	10,687	25,384
11	374	6,861	857	13	6,574	-	-	18	10,687	25,384
12	374	6,861	114	1	5,970	-	-	18	4,275	17,613
13	4,014	3,746	1,143	3	6,916	4,158	204	18	10,687	30,889
14	3,739	3,496	1,097	13	6,769	-	20	18	10,687	25,839

Notes: Vehicle estimates are for an evacuation of the entire EPZ (Region R03)
Scenario 13 takes place in the fourth quarter of 2014. Population growth rates have been applied to extrapolate permanent resident and shadow vehicles for this scenario - See Section 3.7 for additional information.