Calvert Cliffs Nuclear Power Plant

Development of Evacuation Time Estimates

Prepared for:

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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 Calvert Cliffs Nuclear Power Plant (CCNPP) located in Lusby, Maryland. Evacuation time estimates are part of the required planning basis and provide CCNPP and State and local governments with site-specific information needed for Protective Action decision-making.

In the performance of this effort, all available prior documentation relevant to Evacuation Time Estimates was reviewed. Other guidance is provided by documents published by Federal Government agencies. Most important of these are:

- 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.

Overview of Project Activities

This project began in July, 2007 and extended over a period of 9 months. The major activities performed are briefly described in chronological sequence:

- Attended "kick-off" meetings with Constellation Energy personnel and emergency management personnel representing state and local governments.
- Reviewed prior ETE reports prepared for CCNPP and accessed U.S. Census Bureau data files for the year 2000. Studied Geographical Information Systems (GIS) maps of the area in the vicinity of CCNPP, 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" area extending 15 miles radially from the plant.
- Designed and sponsored a telephone survey of residents within the EPZ to gather focused data needed for this ETE study that were not contained within the census database. The survey instrument was reviewed and modified by State and county personnel prior to the survey.
- 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 8 Zones. These Zones are then grouped within circular areas or "keyhole" configurations (circles plus radial sectors) that define a total of 14 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 and Rain). One special scenario involving construction of a new unit at the CCNPP and one special scenario involving the Air Show at the Patuxent Naval Airbase were considered.

- The Planning Basis for the calculation of ETE is:

  - A rapidly escalating accident at CCNPP that quickly assumes the status of General Emergency such that the Advisory to Evacuate is virtually coincident with the siren alert.

  - While an unlikely accident scenario, this planning basis will yield ETE, measured as the elapsed time from the Advisory to Evacuate until the last vehicle 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 specified host schools 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 school children are calculated separately.

- Evacuees who do not have access to a private vehicle will either ride-share with relatives, friends or neighbors, or be evacuated by buses provided as specified in the county evacuation plans. Those in special facilities will likewise be evacuated with public transit, as needed: bus, van, or ambulance, as required. Separate ETE are calculated for the transit-dependent evacuees and for those evacuated from special facilities.

Computation of ETE

A total of 168 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 14 Evacuation Regions to completely evacuate from that Region, under the circumstances defined for one of the 12 Evacuation Scenarios (14 x 12 = 168). Separate ETE are calculated for transit-dependent evacuees, including school children 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 a portion of the population within the EPZ but outside the impacted region, will elect to "voluntarily" evacuate. In addition, a portion of the population in the "Shadow" region beyond the EPZ that extends a distance of 15 miles from CCNPP, 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.

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 procedures.
- The evacuation trips are generated at locations called "zonal centroids" located within the EPZ. 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 computer models compute the routing patterns for evacuating vehicles that are compliant with federal guidelines (in general, outbound relative to the location of CCNPP), 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 50 percent, 90 percent, 95 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.

Traffic Management

This study includes the development of a comprehensive traffic management plan designed to expedite the evacuation of people from within an impacted region. This plan, which will be reviewed with State and local law enforcement personnel, is also designed to control access into the EPZ after returning commuters have rejoined their families.

The plan is documented in the form of detailed schematics specifying: (1) the directions of evacuation travel to be facilitated, and other traffic movements to be discouraged; (2) the traffic control personnel and equipment needed (cones, barricades) and their deployment; (3) the locations of these "Traffic Control Points" (TCP); (4) the priority assigned to each traffic control point indicating its relative importance and how soon it should be manned relative to others; and (5) the number of traffic control personnel required.

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 3-1 displays a map of the CCNPP site showing the layout of the 8 Zones that comprise, in aggregate, the Emergency Planning Zone (EPZ).
- Table 3-1 presents the estimates of permanent resident population in each Zone based on the 2000 Census data. Extrapolation to the year 2008 reflects population growth rates in each county derived from census data.
- Table 6-1 defines each of the 14 Evacuation Regions in terms of their respective groups of zones.
- Table 6-2 lists the 12 Evacuation Scenarios.
- Table 7-1D is a compilation of ETE. These data are the times needed to *clear the indicated regions* of 100 percent of the population occupying these regions. These computed ETE include consideration of mobilization time and of estimated voluntary evacuations from other regions within the EPZ and from the shadow region.
- Table 8-5A presents ETE for the schoolchildren in good weather.
- Table 8-7A presents ETE for the transit-dependent population in good weather.

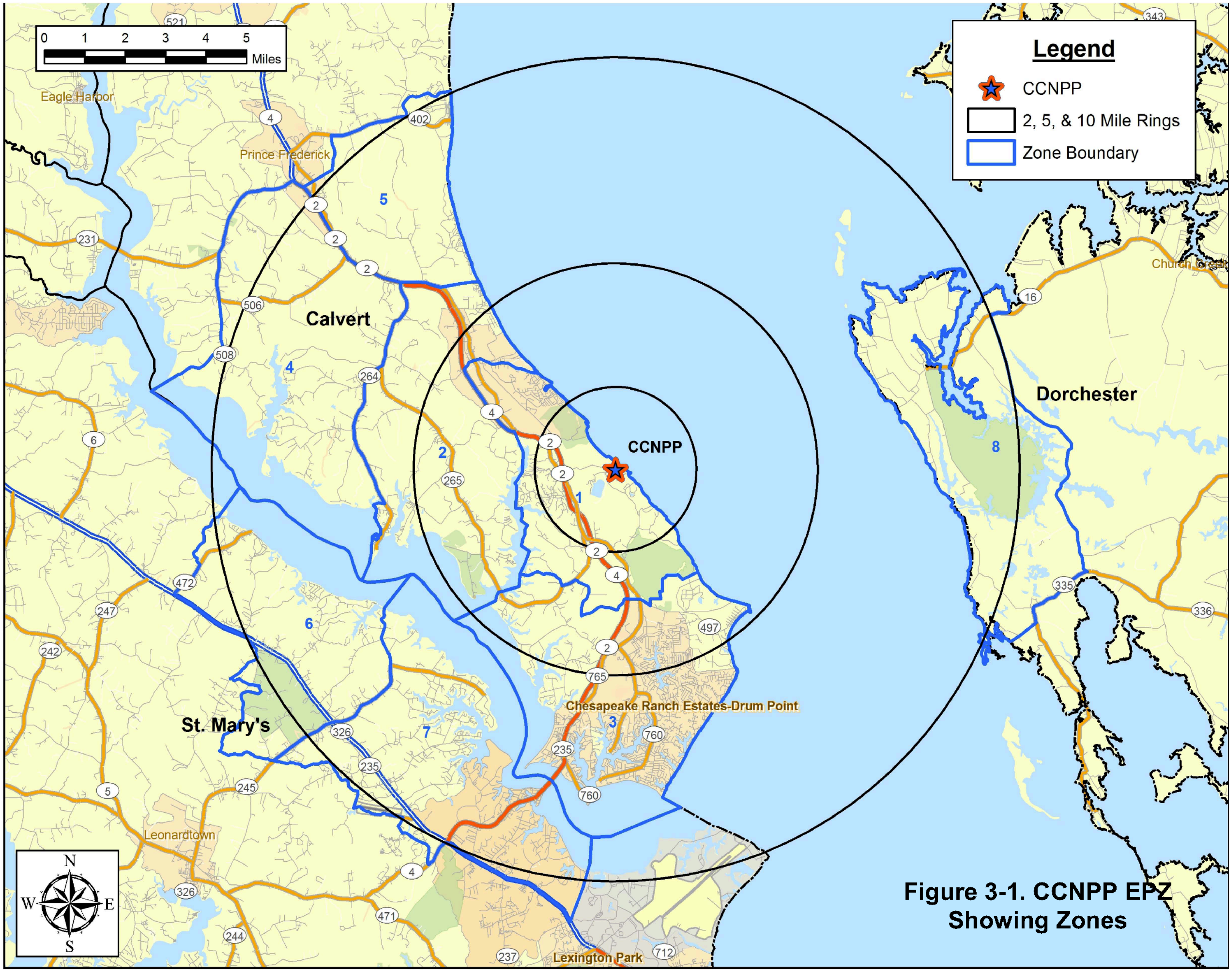

Figure 3-1. CCNPP EPZ Showing Zones

Table 3-1. EPZ Permanent Resident Population			
Zone	**County**	**2000 Population**	**2008 Population**
1	Calvert	5,250	6,484
2	Calvert	4,081	5,040
3	Calvert	17,069	21,080
4	Calvert	4,139	5,112
5	Calvert	2,283	2,820
6	St. Mary's	4,246	5,074
7	St. Mary's	7,770	9,284
8	Dorchester	295	311
TOTAL:		**45,133**	**55,205**
Population Growth:			**22.3%**

Table 6-1. Description of Evacuation Regions									
Region	Description	ZONE							
		1	2	3	4	5	6	7	8
R01	2-Mile Ring	X							
R02	5-Mile Ring	X	X	X					
R03	Full EPZ	X	X	X	X	X	X	X	X
Evacuate 2-Mile Ring and 5 Miles Downwind									
Region	**Wind Direction Towards:**	**ZONE**							
		1	2	3	4	5	6	7	8
	N, NNE, NE, ENE, E	**See Region 1**							
R04	ESE, SE, SSE, S	X		X					
	SSW, SW, WSW	**See Region 2**							
R05	W, WNW, NW, NNW	X	X						
Evacuate 5-Mile Ring and Downwind to EPZ Boundary									
Region	**Wind Direction Towards:**	**ZONE**							
		1	2	3	4	5	6	7	8
	NNE	**See Region 2**							
R06	NE, ENE, E, ESE, SE	X	X	X					X
R07	SSE, S	X	X	X				X	
R08	SSW, SW	X	X	X			X	X	
R09	WSW	X	X	X	X		X	X	
R10	W	X	X	X	X		X		
R11	WNW	X	X	X	X	X	X		
R12	NW, NNW	X	X	X	X	X			
R13	N	X	X	X		X			
R14	*	X							X

*This Region was added at Constellation Energy's request. It is an evacuation of the 2-Mile Ring and downwind (Towards Dorchester County) to the EPZ Boundary.

Table 6-2 Evacuation Scenario Definitions

Scenarios	Season	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	Weekend	Midday	Good	None
9	Winter	Weekend	Midday	Rain	None
10	Winter	Midweek, Weekend	Evening	Good	None
11	Summer	Midweek	Midday	Good	New Plant Construction
12	Summer	Weekend	Midday	Good	Air Show at the Naval Base

Note: Schools are assumed to be in session for the Winter season (midweek, midday).

Table 7-1D. Time To Clear The Indicated Area of 100 Percent of the Affected Population

Season		Summer		Summer		Summer	Winter		Winter		Winter	Summer	Summer	Season
Day of Week		Midweek		Weekend		All	Midweek		Weekend		All	Midweek	Weekend	Day of Week
Scenario:		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario
Time of Day		Midday		Midday		Evening	Midday		Midday		Evening	Midday	Midday	Time of Day
Zone	Region Wind Direction	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Good Weather	Rain	Good Weather	New Plant Construction	Air Show at Base	Region Wind Direction Towards
Entire 2-Mile Region, 5-Mile Region, and EPZ														
1	R01 2-mile ring	4:10	4:10	4:00	4:00	4:00	4:10	4:10	4:00	4:00	4:00	4:30	3:50	R01 2-mile ring
1,2,3	R02 5-mile ring	5:50	6:20	5:50	6:20	5:50	6:00	6:30	5:50	6:20	5:50	6:10	4:20	R02 5-mile ring
1,2,3,4,5, 6,7,8	R03 Entire EPZ	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R03 Entire EPZ
2-Mile Ring and Downwind to 5 Miles														
1	N, NNE, NE, ENE, E	Refer Region 1												N, NNE, NE, ENE, E
1,3	R04 ESE, SE, SSE, S	5:50	6:20	5:50	6:20	5:40	5:50	6:30	5:50	6:20	5:40	6:10	4:20	R04 ESE, SE, SSE, S
1,2,3	SSW, SW, WSW	Refer Region 2												SSW, SW, WSW
1,2	R05 W, WNW, NW, NNW	4:10	4:10	4:10	4:10	4:10	4:10	4:20	4:10	4:10	4:00	4:40	4:00	R05 W, WNW, NW, NNW
5-Mile Ring and Downwind to EPZ Boundary														
1,2,3	NNE	Refer Region 2												NNE
1,2,3,8	R06 NE, ENE, E, ESE, SE	5:50	6:20	5:50	6:20	5:50	6:00	6:30	5:50	6:20	5:50	6:10	4:20	R06 NE, ENE, E, ESE, SE
1,2,3,7	R07 SSE, S	6:00	6:30	6:00	6:30	5:50	6:00	6:40	6:00	6:30	5:50	6:20	13:00	R07 SSE, S
1,2,3,6,7	R08 SSW, SW	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R08 SSW, SW
1,2,3,4,6, 7	R09 WSW	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R09 WSW
1,2,3,4,6	R10 W	6:00	6:40	6:00	6:30	6:00	6:10	6:40	6:00	6:30	6:00	6:20	12:50	R10 W
1,2,3,4,5, 6	R11 WNW	6:00	6:40	6:00	6:30	6:00	6:10	6:40	6:00	6:30	6:00	6:20	12:50	R11 WNW
1,2,3,4,5	R12 NW, NNW	6:00	6:30	6:00	6:30	5:50	6:00	6:40	5:50	6:30	5:50	6:20	4:20	R12 NW, NNW
1,2,3,5	R13 N	6:00	6:30	5:50	6:20	5:50	6:00	6:40	5:50	6:20	5:50	6:20	4:30	R13 N
1,8	R14	4:10	4:10	4:00	4:00	4:00	4:10	4:10	4:00	4:00	4:00	4:30	4:00	R14

Table 8-5A. School Evacuation Time Estimates - Good Weather

School	Driver Mobilization Time(min)	Loading Time (min)	Dist. to EPZ Boundary (mi.)	Travel Time to EPZ Boundary (min)	ETE (hr:min)	Dist. EPZ Boundary to Host School (mi.)	Travel Time EPZ Boundary to Host School (min)	ETE to Host School (hr:min)
Calvert County Schools								
Appeal Elementary School	90	5	8.0	25	**2:00**	40.9	62	**3:05**
Dowell Elementary School	90	5	6.6	21	**2:00**	36.7	56	**2:55**
Mill Creek Middle School	90	5	6.4	20	**1:55**	41.3	62	**3:00**
Mutual Elementary School	90	5	5.9	19	**1:55**	2.0	3	**2:00**
Our Lady Star of the Sea School	60	5	8.9	19	**1:25**	49.2	74	**2:40**
Patuxent Elementary School	90	5	8.0	25	**2:00**	42.8	65	**3:05**
Patuxent High School	90	5	8.8	27	**2:05**	48.7	74	**3:20**
Southern Middle School	60	5	10.2	22	**1:30**	48.7	74	**2:45**
St. Leonard Elementary School	90	5	7.0	22	**2:00**	14.6	22	**2:20**
St. Mary's County Schools								
Esperanza Middle School	60	5	0.0	0	**1:05**	8.9	14	**1:20**
Green Holly Elementary School	60	5	0.2	1	**1:10**	6.5	10	**1:20**
Hollywood Elementary School	60	5	6.1	13	**1:20**	5.8	9	**1:30**
St. John's Elementary School	60	5	0.7	2	**1:10**	5.9	9	**1:20**
Town Creek Elementary School	60	5	0.7	2	**1:10**	15.8	24	**1:35**
				Average for EPZ:	**1:37**		**Average:**	**2:18**

Table 8-7A. Transit Dependent Evacuation Time Estimates - Good Weather

Buses	Single Wave					Second Wave				
	Mobilization	Route Travel Time	Pickup Time	ETE	Mobilization	Unload Time	Driver Rest Time	Route travel Time	Pickup Time	ETE
Batch 1	90	178	30	5:00	135	5	10	178	30	6:00
Batch 2	120	218	30	6:10	165	5	10	218	30	7:10

1. INTRODUCTION

This report describes the analyses undertaken and the results obtained by a study to update the existing Evacuation Time Estimates (ETE) for the Calvert Cliffs Nuclear Power Plant (CCNPP), located in Calvert County, Maryland. Evacuation time estimates are part of the required planning basis and provide State and local governments with site-specific information needed for Protective Action decision-making.

In the performance of this effort, all available prior documentation relevant to Evacuation Time Estimates was reviewed.

Other guidance is provided by documents published by Federal Government agencies. Most important of these are:

- 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.

We wish to express our appreciation to all the directors and staff members of the Calvert County, St. Mary's County and Dorchester County emergency management agencies and local and state law enforcement and planning agencies, who provided valued guidance and contributed information contained in this report.

1.1 Overview of the ETE Update Process

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

1. Information Gathering:
    - Defined the scope of work in discussion with representatives of Constellation Energy.
    - Reviewed existing reports describing past evacuation studies.
    - Attended meetings with emergency planners from the three Evacuation Planning Zone (EPZ) Counties to identify issues to be addressed.

- Conducted a detailed field survey of the EPZ highway system and of area traffic conditions.
- Obtained demographic data from census and state agencies.
- Conducted a random sample telephone survey of EPZ residents.
- Conducted a data collection effort to identify and describe schools, special facilities, major employers, transportation providers, and other important sources of 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, trip generation distribution and in highway capacities, associated with different seasons, day of week, time of day and weather conditions.
4. Defined a traffic management strategy. Traffic control is applied at specified Traffic Control Points (TCP) located within the Emergency Planning Zone (EPZ), and at Access Control Points (ACP) located on the periphery of the EPZ. Local and state police personnel should review all traffic control plans.
5. Defined Evacuation Areas or Regions. The EPZ is partitioned into Protective Action Zones (Zones) which serve as a basis for the ETE analysis presented herein. Evacuation "Regions" are comprised of contiguous Zones for which ETE are calculated. The configuration of these Regions reflects the fact that the wind can take any direction and that the radial extent of the impacted area depends on accident-related circumstances. Each Region, other than those that approximate circular areas, approximates a "key-hole" configuration within the EPZ as required by NUREG/CR-6863.
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 IDYNEV system.
   - Estimated the traffic demand, based on the available information derived from Census data, from prior studies, from data provided by local and state agencies and from the telephone survey.
   - Applied the procedures specified in the 2000 Highway Capacity Manual (HCM) to the data acquired during the field survey, to estimate the capacity of all highway segments comprising the evacuation routes.

- Developed the link-node representation of the evacuation network, which is used as the basis for the computer analysis that calculates the ETE.
- Calculated the evacuating traffic demands for each Region and for each Evacuation Scenario. Considered the effects on demand of "voluntary evacuation" and of "shadow evacuation".
- Represented the traffic management strategy.
- Specified the candidate destinations of evacuation travel consistent with outbound movement relative to the location of the CCNPP.
- Prepared the input stream for the IDYNEV System.
- Executed the IDYNEV models to provide the estimates of evacuation routing and ETE.

8. Generated a complete set of ETE for all specified Evacuation Regions and Scenarios.
9. Documented ETE in formats responsive to the cited NUREG reports.
10. Calculated the ETE for all transit activities including those for special facilities (schools, health-related facilities, etc.) and for the transit-dependent.

Steps 4, 7 and 8 are iterated as described in Appendix D.

1.2 The Calvert Cliffs Nuclear Plant Site Location

The Calvert Cliffs Nuclear Power Plant is located in Lusby, MD approximately 50 miles southeast of Washington, DC. The EPZ consists of parts of three counties: Calvert County, St. Mary's County and Dorchester County. Figure 1-1 displays the area surrounding the CCNNP. This map identifies the communities in the area and the major roads.

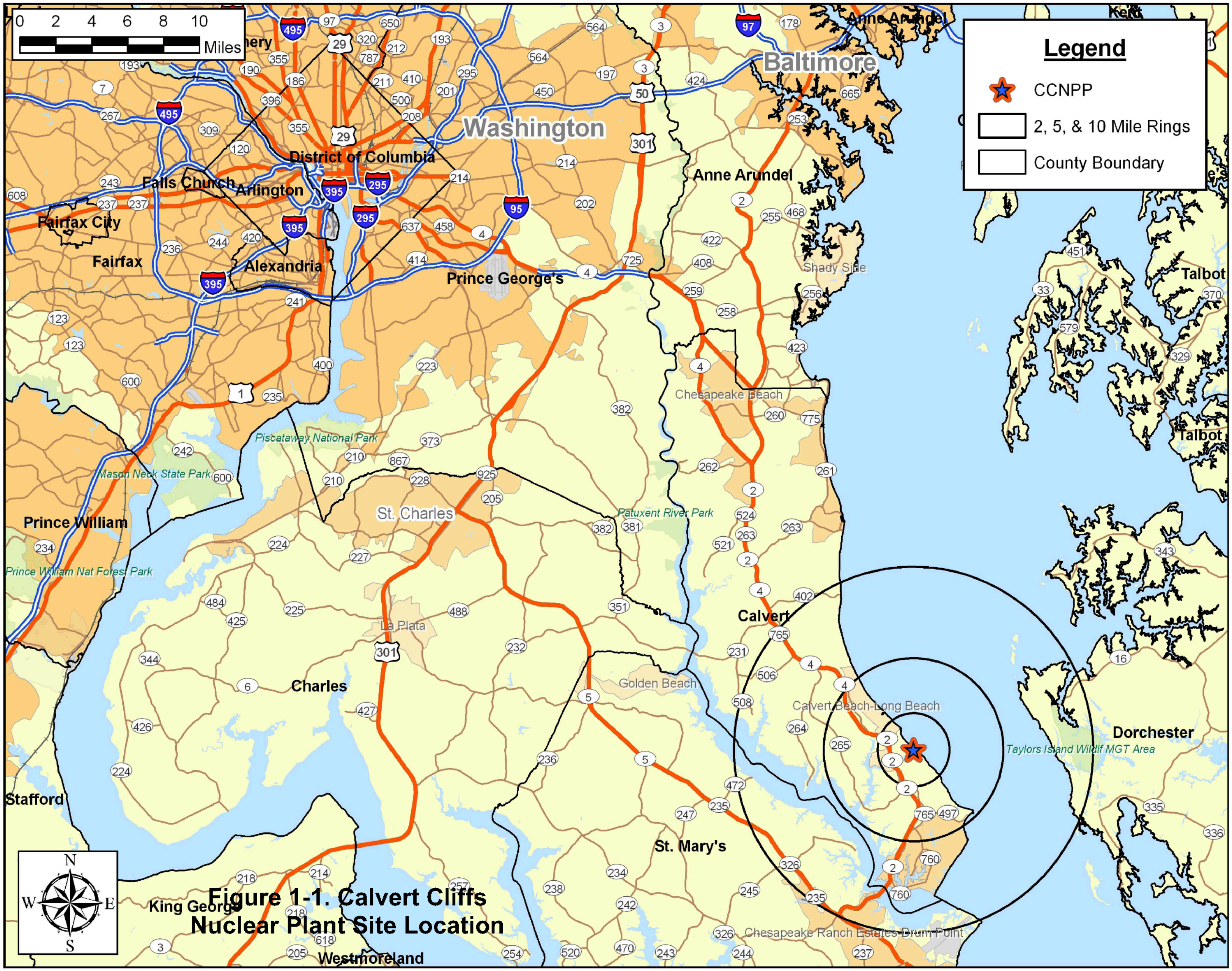

Figure 1-1. Calvert Cliffs Nuclear Plant Site Location

1.3 Preliminary Activities

Since this plan constitutes an update of an existing document, it was necessary to review the prior process and findings. These activities are described below.

Literature Review

KLD Associates was provided with copies of documents describing past studies and analyses leading to the development of emergency plans and of the ETE. We also obtained supporting documents from a variety of sources, which contained information needed to form the database used for conducting evacuation analyses.

Field Surveys of the Highway Network

KLD personnel drove the entire highway system within the EPZ and for some distance outside. The characteristics of each section of highway were recorded. These characteristics include:

• Number of lanes	• Posted speed
• Pavement Width	• Actual free speed
• Shoulder type & width	• Abutting land use
• Intersection configuration	• Control devices
• Lane channelization	• Interchange geometries
• Geometrics: Curves, grades	• Street parking
• Unusual characteristics: Narrow bridges, sharp curves, poor pavement, flood warning signs, inadequate delineations, etc.	

The data were then transcribed; this information was referenced while preparing the input stream for the IDYNEV System. Key highway locations were video archived. A tablet personal computer equipped with Global Positioning Satellite (GPS) and Geographical Information Systems (GIS) technologies was used to record observations during the field survey.

Telephone Survey

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

These data were utilized to develop estimates of vehicle occupancy 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.

Highway capacity was estimated for each highway segment based on the field surveys and on the principles specified in the 2000 Highway Capacity Manual (HCM[1]). The link-node representation of the physical highway network was developed using GIS mapping software and the observations obtained from the field survey. This network representation of "links" and "nodes" is shown in Figure 1-2.

Analytical Tools

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

I-DYNEV consists of three submodels:

- A macroscopic traffic simulation model (for details, see Appendix C).
- An intersection capacity model (for details, see Highway Research Record No. 772, Transportation Research Board, 1980, papers by Lieberman and McShane & Lieberman).
- A dynamic, node-centric routing model that adjusts the "base" routing in the event of an imbalance in the levels of congestion on the outbound links.

Another model of the IDYNEV System is the TRAD (TRaffic Assignment and Distribution) model. This model integrates an equilibrium assignment model with a trip distribution algorithm to compute origin-destination volumes and paths of travel designed to minimize travel time. For details, see Appendix B.

Still another software product developed by KLD, named UNITES (UNIfied Transportation Engineering System) was used to expedite data entry.

The procedure for applying the IDYNEV System within the framework of developing an update to an ETE is outlined in Appendix D. Appendix A is a glossary of terms.

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[1] Highway Capacity Manual (HCM2000), Transportation Research Board, National Research Council, 2000.

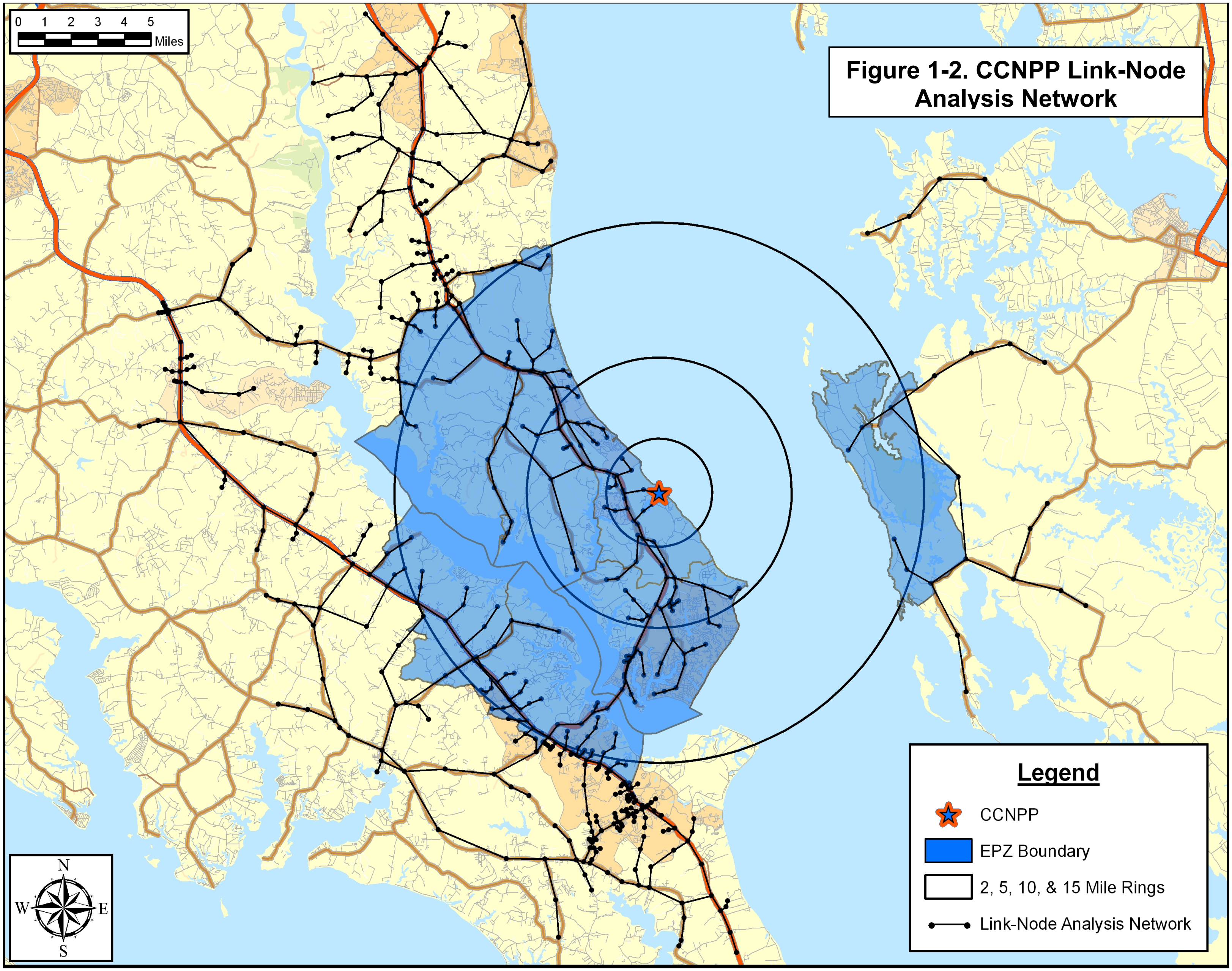
Figure 1-2. CCNPP Link-Node Analysis Network
0 1 2 3 4 5
Miles
N
W
E
S
Legend
CCNPP
EPZ Boundary
2, 5, 10, & 15 Mile Rings
Link-Node Analysis Network

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 CCNPP 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 CCNPP.

A set of candidate destination nodes on the periphery of the EPZ is specified for each traffic origin (or centroid) within the EPZ. The TRAD model produces output that identifies the "best" traffic routing, subject to the design conditions outlined above. In addition to this information, rough estimates of travel time are provided, together with turn-movement data required by the PC-DYNEV simulation model. The evacuation routing used in the model is presented in Section 10 and also in the congestion diagrams in Section 7.

The simulation model is then executed to provide 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 expedite the movement of vehicles. The outputs of this model are the volume of traffic, expressed as vehicles/hour, that exit the Evacuation Region along the various highways (links) that cross the Region boundaries. These outputs are exported into a spreadsheet, which is used to generate the ETE. Section 7 presents a further description of this process along with the ETE Tables.

As outlined in Appendix D, this procedure consists of an iterative design-analysis-redesign sequence of activities. If properly done, this procedure converges to yield an evacuation plan which best services the evacuating public.

1.4 Comparison with Prior ETE Study

Table 1-1 presents a comparison of the present ETE study with the study performed in 2002. 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:

- An increase in permanent resident population.
- Vehicle occupancy and Trip-generation rates are based on the results of a telephone survey of EPZ residents.
- Voluntary and shadow evacuations are considered.
- The highway representation is more detailed.
- Many more evacuation cases considered, responsive to NUREG/CR-6863.
- Traffic management plan included.

Table 1-1. ETE Study Comparisons		
Topic	**Treatment**	
	Previous ETE Study	**Current ETE Study**
Resident Population Basis	Maryland Department of Planning Estimate for population in 2000. Population = 50,058	ArcGIS Software using 2000 US Census blocks; block centroid method used; population extrapolated to 2008. Population = 55,205
Resident Population Vehicle Occupancy	Average household size varies by County. Assumed, 1 vehicle/evacuating HH resulting in an average vehicle occupancy of : Calvert County = 2.91, St. Mary's County = 2.72, Dorchester County = 2.36 persons/vehicle	Based on telephone survey, Average household size within EPZ = 2.80 person/household and 1.46 vehicles/evacuating household, resulting in average vehicle occupancy of 1.92 person/vehicle
Employee Population	Employee estimates based on information provided about major employers in EPZ. 1 employee/vehicle.	Employee estimates based on information provided about major employers in EPZ and on data provided by Census Journey-to-Work questionnaires. 1.03 employees/vehicle based on phone survey results.
Voluntary evacuation from within EPZ in areas outside region to be evacuated	Not considered	50 percent of population within the radius being evacuated; 35 percent, in annular ring between the radius being evacuated and the EPZ boundary (See Figure 2-1).
Shadow Evacuation	Not considered.	30% of people outside of the EPZ within the shadow area (See Figure 7-2).
Network Size	204 links, 144 nodes	709 Links; 409 Nodes.

Table 1-1. ETE Study Comparisons (continued)		
Roadway Geometric Data	Field surveys conducted in 2001.	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.
School Evacuation	Direct evacuation to designated Host School.	Direct evacuation to designated Host School.
Transit Dependent Population	Not considered explicitly. Local emergency plans will provide buses for transit dependents.	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 survey results used to estimate transit dependent population.
Ridesharing	100 percent of transit dependents will ride out with a friend.	50 percent of transit dependent persons will ride out with a neighbor of friend.
Trip Generation for Evacuation	Trip Generation curves created based on discussions with county emergency management officials.	Based on residential telephone survey of specific pre-trip mobilization activities: Residents with commuters returning leave between 30 and 240 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.

Table 1-1. ETE Study Comparisons (continued)		
Traffic and Access Control	List of Traffic control points identified.	Traffic and access control points identified and detailed schematics provided.
Weather	Normal or Adverse. The capacity of each link in the network is reduced by 30% for adverse weather.	Normal or Rain. The capacity and free flow speed of all links in the network are reduced by 10% in the event of rain.
Modeling	NETVAC2	IDYNEV System: TRAD and PC-DYNEV.
Special Events	None considered. Only a sensitivity analysis of the closure of the Thomas Johnson Bridge for the Full EPZ.	2 Special Events – New Plant Construction, Air Show at the Naval Base.
Evacuation Cases	8 Regions, 2 seasons, 2 time of day, and 2 weather conditions producing 64 unique cases	14 Regions (central sector wind direction and each adjacent sector technique used) and 12 Scenarios producing 168 unique cases
Evacuation Time Estimates Reporting	ETE reported for 100th percentile population. Results presented by Region and Scenario.	ETE reported for the 50th, 90th, 95th and 100th percentile population. Results presented by Region and Scenario.
Evacuation Time Estimates for the entire EPZ, 100th percentile.	Full EPZ – Summer Daytime: Good weather = 5:50 Full EPZ – Summer Nightime: Good weather = 5:10 Full EPZ – Winter Daytime: Good weather = 6:10 Full EPZ – Winter Nightime: Good weather = 5:50	Summer Weekday Midday Good weather = 6:10 Summer Evening Good weather = 6:00 Winter Weekday Midday Good weather = 6:10 Winter Evening Good weather = 6:00

2. STUDY ESTIMATES AND ASSUMPTIONS

This section presents the estimates and assumptions utilized in the development of the Evacuation Time Estimates (ETE).

2.1 Data Estimates

1. Population estimates are based upon Census 2000 data, projected to year 2008. County-specific projections are based upon the estimates of the average annual growth rate for years between 2000 and 2010 provided by the Maryland Department of Planning, Planning Data Services. Estimates of employees who commute into the EPZ to work are based upon employment data obtained from county emergency management officials, company websites, the 2002 ETE Study Report, telephone calls to employers within the EPZ and the state Journey-to-Work census data.
2. Population estimates at special facilities are based on available data from county emergency management offices, related websites, and the 2002 ETE Study Report.
3. Roadway capacity estimates are based on field surveys and the application of Highway Capacity Manual 2000[1].
4. Population mobilization times are based on a statistical analysis of data acquired from the telephone survey.
5. The relationship between resident population and evacuating vehicles is developed from the telephone survey. The average values of 2.80 persons per household and 1.46 evacuating vehicles per household are used.
6. The relationship between persons and vehicles for special facilities is as follows:
    a. Parks/Recreational: 1 vehicle per family
    b. Employees: 1.03 employees per vehicle (telephone survey results),
7. ETE are presented for the evacuation of the 100th percentile of population for each Region and for each Scenario, and for the 2-mile, 5-mile and 10-mile distances. ETEs are presented in tabular format and graphically, showing the values of ETE associated with the 50th, 90th and 95th percentiles of population. An Evacuation Region is defined as a group of Zones that is issued the Advisory to Evacuate.

[1] Highway Capacity Manual (HCM2000), Transportation Research Board, National Research Council, 2000.

2.2 Study Methodological Assumptions

1. The Evacuation Time is defined as the elapsed time from the Advisory to Evacuate issued to persons within a specific Region of the EPZ, and the time that Region is clear of the indicated percentile of people.
2. The ETE are computed and presented in a format compliant with the guidance in the cited NUREG documentation. The ETE for each evacuation area ("Region" comprised of included Zones) is presented in both statistical and graphical formats.
3. Evacuation movements (paths of travel) are generally outbound relative to the power plant to the extent permitted by the highway network, as computed by the computer models. All available evacuation routes are used in the analysis.
4. Regions are defined by the underlying "keyhole" or circular configurations as specified in NUREG/CR-6863. These Regions, as defined, display irregular boundaries reflecting the geography of the Zones included within these underlying configurations.
5. Voluntary evacuation is considered as indicated in the accompanying Figure 2-1. Within the circle defined by the distance to be evacuated but outside the Evacuation Region, 50 percent of the people not advised to evacuate are assumed to evacuate within the same time-frame. In the outer annular area between the circle defined by the extent of the Evacuation Region and the EPZ boundary, it is assumed that 35 percent of people will voluntarily evacuate. In the area between the EPZ boundary and a 15-mile circular area centered at the plant (the "shadow region"), it will be assumed that 30 percent of the people will evacuate voluntarily. Sensitivity studies explored the effect on ETE, of increasing the percentage of voluntary evacuees in this area (Appendix I). The basis for our assumptions on voluntary evacuation is testimony proffered by Dennis Miletti, a professor at Colorado State University, and one of the nations top disaster response experts, at Atomic Safety and Licensing Board (ASLB) hearings, which were deemed acceptable. There are limited data pertaining to nuclear evacuations in the United States. The numbers we use are Professor Miletti's best estimates based on his years of experience in evacuation planning and emergency preparedness.
6. A total of 12 "Scenarios" representing different seasons, time of day, day of week and weather are considered. Two special event scenarios are studied: the peak construction period of a new unit at the CCNPP site, and the Airshow at the Patuxent Naval Air Base These Scenarios are tabulated below:

Scenario	Season	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	Weekend	Midday	Good	None
9	Winter	Weekend	Midday	Rain	None
10	Winter	Midweek, Weekend	Evening	Good	None
11	Summer	Midweek	Midday	Good	New Plant Construction
12	Summer	Weekend	Midday	Good	Airshow at Base

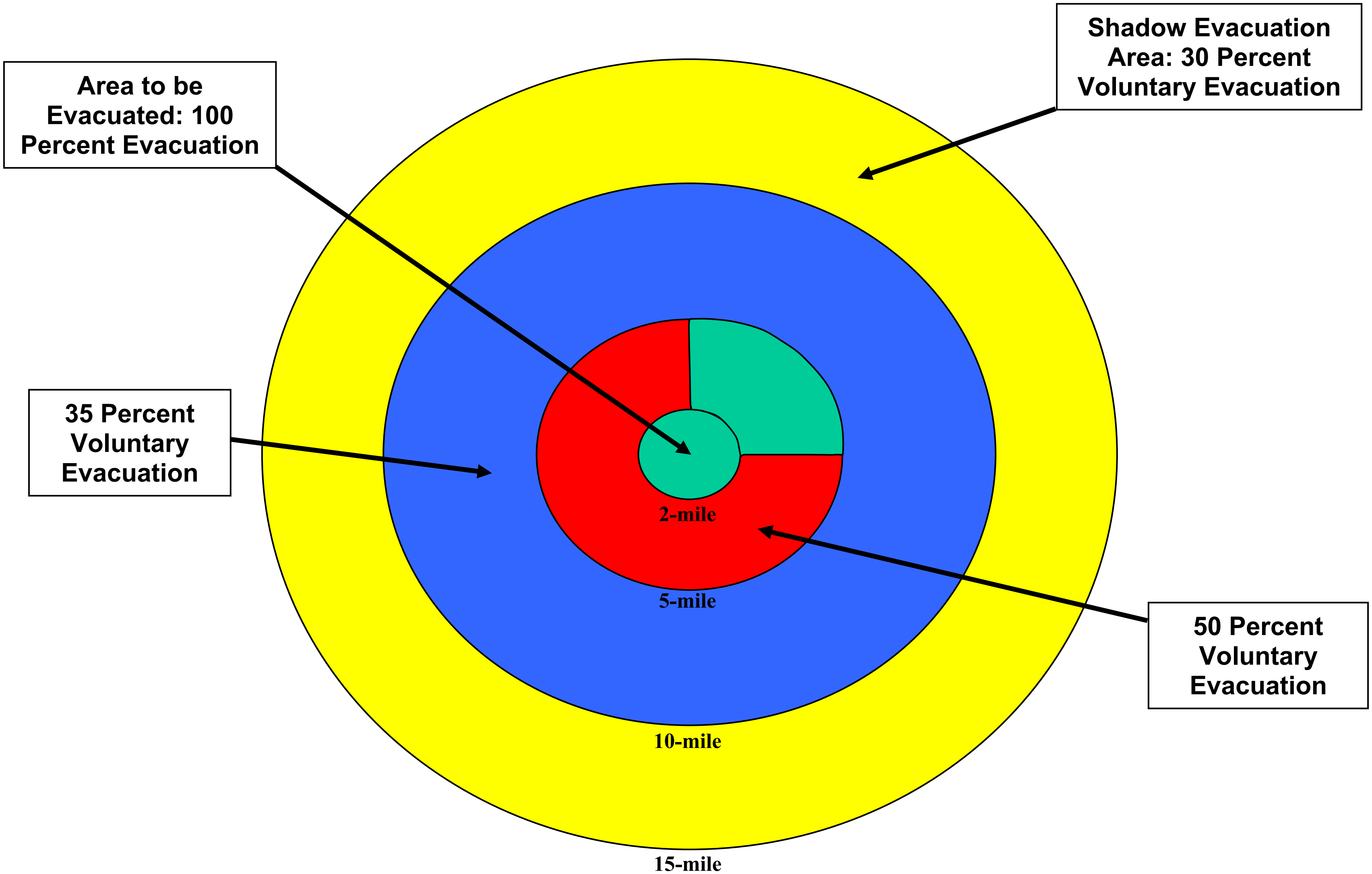

Figure 2-1. Voluntary Evacuation Methodology

7. The models of the IDYNEV System represent the state of the art, and have been recognized as such by the Atomic Safety and Licensing Board (ASLB) in past hearings. (Sources: Atomic Safety & Licensing Board Hearings on Seabrook and Shoreham; Urbanik[2]).

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 10 minutes after the Advisory to Evacuate.
   c. ETE are measured relative to the Advisory to Evacuate.
2. It is assumed that everyone within the group of Zones forming a Region that is issued an Advisory to Evacuate will, in fact, respond in general accord with the planned routes.
3. It is further assumed that:
   a. Schools may be evacuated prior to notification of the general public, if possible.
   b. 65 percent of households in the EPZ have at least one commuter, 58 percent of which will await the return of a commuter before beginning their evacuation trip, based on the telephone survey results.
4. The ETE will also include consideration of "through" (External-External) trips during the time that such traffic is permitted to enter the evacuated Region. "Normal" traffic flow is assumed to be present within the EPZ at the start of the emergency.
5. Access Control Points (ACP) will be staffed approximately 90 minutes after 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 vehicles will enter the EPZ after this 90 minute mobilization time period.
6. Traffic Control Points (TCP) within the EPZ will be staffed over time, beginning at the Advisory to Evacuate. Their number and location will depend on the Region to be evacuated and the personnel resources available. It is assumed that drivers will act rationally, travel in the directions identified in the plan (as documented in the public information material), and obey all control devices and traffic guides.

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

7. 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 assigned host schools.
    b. School children, if school is in session, are given priority in assigning transit vehicles.
    c. Bus mobilization time is considered in ETE calculations.
    d. Analysis of the number of required “waves” of transit vehicles used for evacuation is presented.
8. It is reasonable to assume that some of the transit-dependent 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] which cites previous evacuation experience. The remaining transit-dependent portion of the general population will be evacuated to reception centers by bus.
9. One type of adverse weather scenario is considered. Rain may occur for either winter or summer scenarios. In the case of rain, it is assumed that the rain begins prior to, or at about the same time as the evacuation advisory is issued. No weather-related reduction in the number of transients who may be present in the EPZ is assumed. Adverse weather scenarios affect roadway capacity and free flow highway speeds. The factors assumed for the ETE study are:

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

10. School buses used to transport students are assumed to have the capacity to transport 70 children per bus for elementary schools, and 50 children per bus for middle and high schools. Transit buses used to transport the transit-dependent general population are assumed to transport an average of 30 people per bus.

[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).

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 2000 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. It is clearly wrong to estimate counts of vehicles by simply adding up the capacities of different types of parking facilities, without considering such factors.

Analysis of the population characteristics of the Calvert Cliffs Nuclear Power Plant (CCNPP) 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 (e.g., boating, camping) and then leave the area.

- Commuter-Employees - people who reside outside 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 Zone and by polar coordinate representation (population rose). The CCNPP EPZ has been subdivided into 8 Zones as shown in Figure 3-1.

Permanent Residents

The primary source for estimating permanent population is the latest U.S. Census data. The average household size (2.80 persons/household) and the number of evacuating vehicles per household (1.46 vehicles/household) were adapted from the telephone survey results.

The rate of population change was found for each County in the EPZ and applied to project population to 2008. The estimated growth rates between 2000 and 2008 for the counties are as follows: Calvert County – 23.5%, St. Mary's County – 19.5%, and Dorchester County – 5.3%; this data was provided by the Maryland Department of Planning website, last updated in October of 2007. The data in Table 3-1 show that the EPZ population has increased by 22.3% over the last 8 years.

Permanent resident population and vehicle estimates for 2008 are presented in Table 3-2. Figures 3-2 and 3-3 present the permanent resident population and permanent resident vehicle estimates by sector and distance from the CCNPP. This "rose" was constructed using GIS software.

Construction

A "special event" scenario (Scenario 11) which represents a typical summer, mid-week, midday with good weather and with construction workers on-site during Shift 1 (7:30 AM to 4:00 PM) at the time of the emergency, is considered. This event is assumed to coincide with an outage at one of the two existing units. The peak construction period – based on discussions with Unistar Nuclear – would be in the year 2013, with workforce estimates of 3,940 workers, working in 3 shifts with 70%, 25%, and 5% of workers in each shift, respectively. An average vehicle occupancy of 1.3 workers per vehicle was used to convert workers to vehicles for Shift 1– 2,122 total vehicles. Additionally, 363 new employees (66% during max shift, 1.05 workers per vehicle, yielding 228 vehicles) related to the new unit and 750 employees (66% during max shift, 1.05 workers per vehicle, yielding 471 vehicles) present during the outage were considered. These employees combined with the construction staff resulted in a total of 2,821 additional vehicles. The existing roadway system is used for the construction scenario; no roadway improvements are considered; however, a new traffic signal at the entrance to the construction site along Nursery Road and Maryland Route 2/4 is used. Permanent resident population and shadow population are extrapolated to 2013 for this scenario.

Airshow at the Naval Air Base

Another special event considered (Scenario 12) is the Airshow at the Patuxent Naval Air Base. Based on information provided by the St. Mary’s County Department of Public Safety, this event occurs every other year. The event lasts about 3 days and is normally during a summer weekend (May or June). The expected attendance is approximately 100,000 people for the Blue Angels performance. It is expected that nearly all the attendees will drive into the base and park their cars in the grass fields. An average occupancy of 2.3 people per vehicle is assumed based on a study conducted for a similar event in Seabrook, NH. Overall, this special event will result in a loading of 43,480 vehicles along Cedar Point Road at the intersection with Three Notch Road (Maryland Route 235).

Given the large number of transients and the close proximity of the event to the EPZ boundary, those people evacuating in an emergency will be affected by the large vehicle influx from this event as they will use the same exit route (Maryland Route 235). Thus, it is important to consider this special event, even though it takes place outside of the EPZ.

It is assumed that approximately three-quarters of the residents within the EPZ and the shadow area will attend this special event. In order to avoid double counting of the residents, the residents who attend the event are loaded at the base and only the remaining 25% are loaded within the EPZ and shadow area.

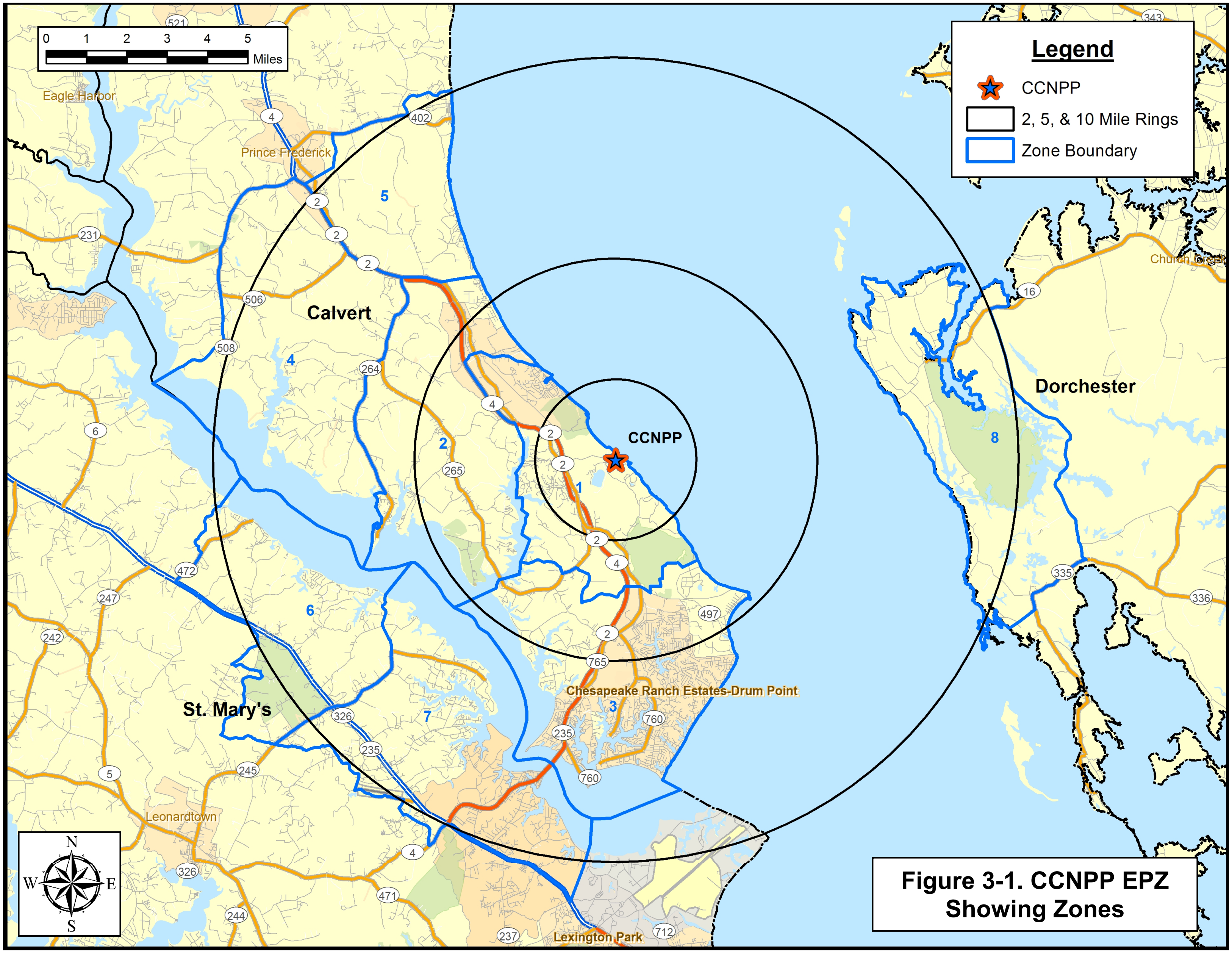
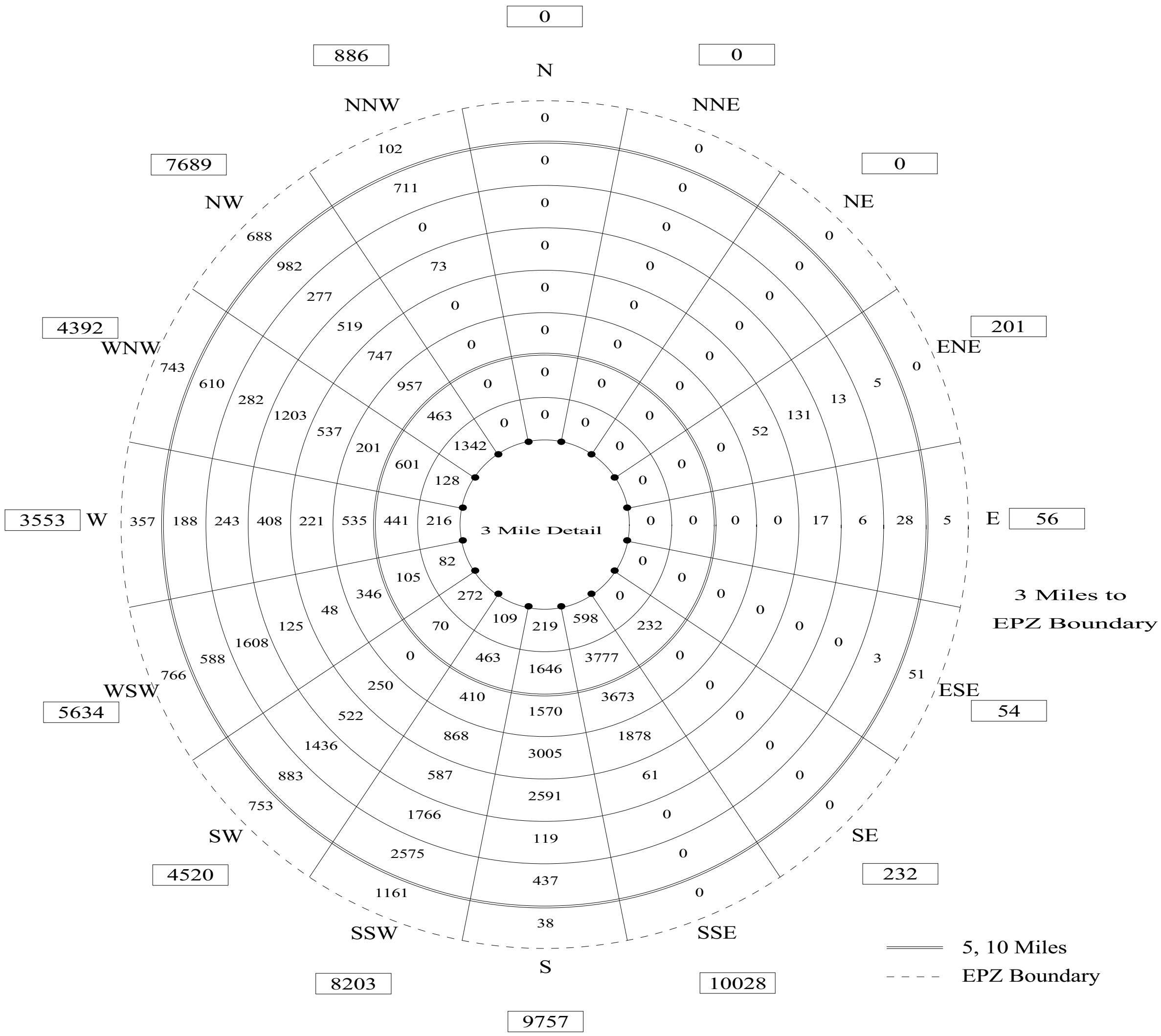


Figure 3-1. CCNPP EPZ Showing Zones

Table 3-1. EPZ Permanent Resident Population			
Zone	**County**	**2000 Population**	**2008 Population**
1	Calvert	5,250	6,484
2	Calvert	4,081	5,040
3	Calvert	17,069	21,080
4	Calvert	4,139	5,112
5	Calvert	2,283	2,820
6	St. Mary's	4,246	5,074
7	St. Mary's	7,770	9,284
8	Dorchester	295	311
TOTAL:		**45,133**	**55,205**
Population Growth:			**22.3%**

Table 3-2. Permanent Resident Population and Vehicles by Zone			
Zone	**County**	**2008 Population**	**2008 Vehicles**
1	Calvert	6,484	3,385
2	Calvert	5,040	2,637
3	Calvert	21,080	11,001
4	Calvert	5,112	2,669
5	Calvert	2,820	1,475
6	St. Mary's	5,074	2,648
7	St. Mary's	9,284	4,852
8	Dorchester	311	164
TOTAL:		**55,205**	**28,831**



Resident Population			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	2771	0-2	2771
2-3	2711	0-3	5482
3-4	2966	0-4	8448
4-5	7798	0-5	16246
5-6	7692	0-6	23938
6-7	7606	0-7	31544
7-8	6237	0-8	37781
8-9	5750	0-9	43531
9-10	7010	0-10	50541
10-EPZ	4664	0-EPZ	55205

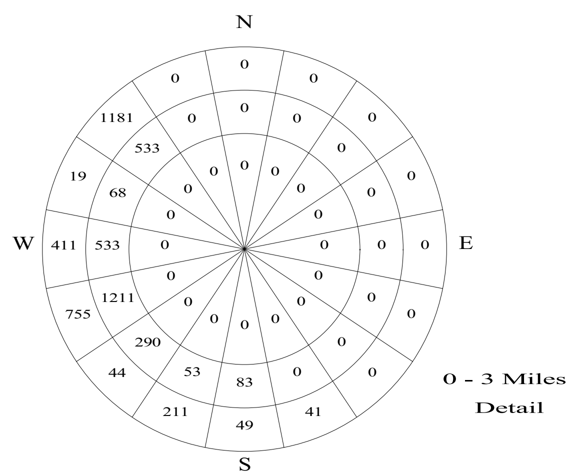
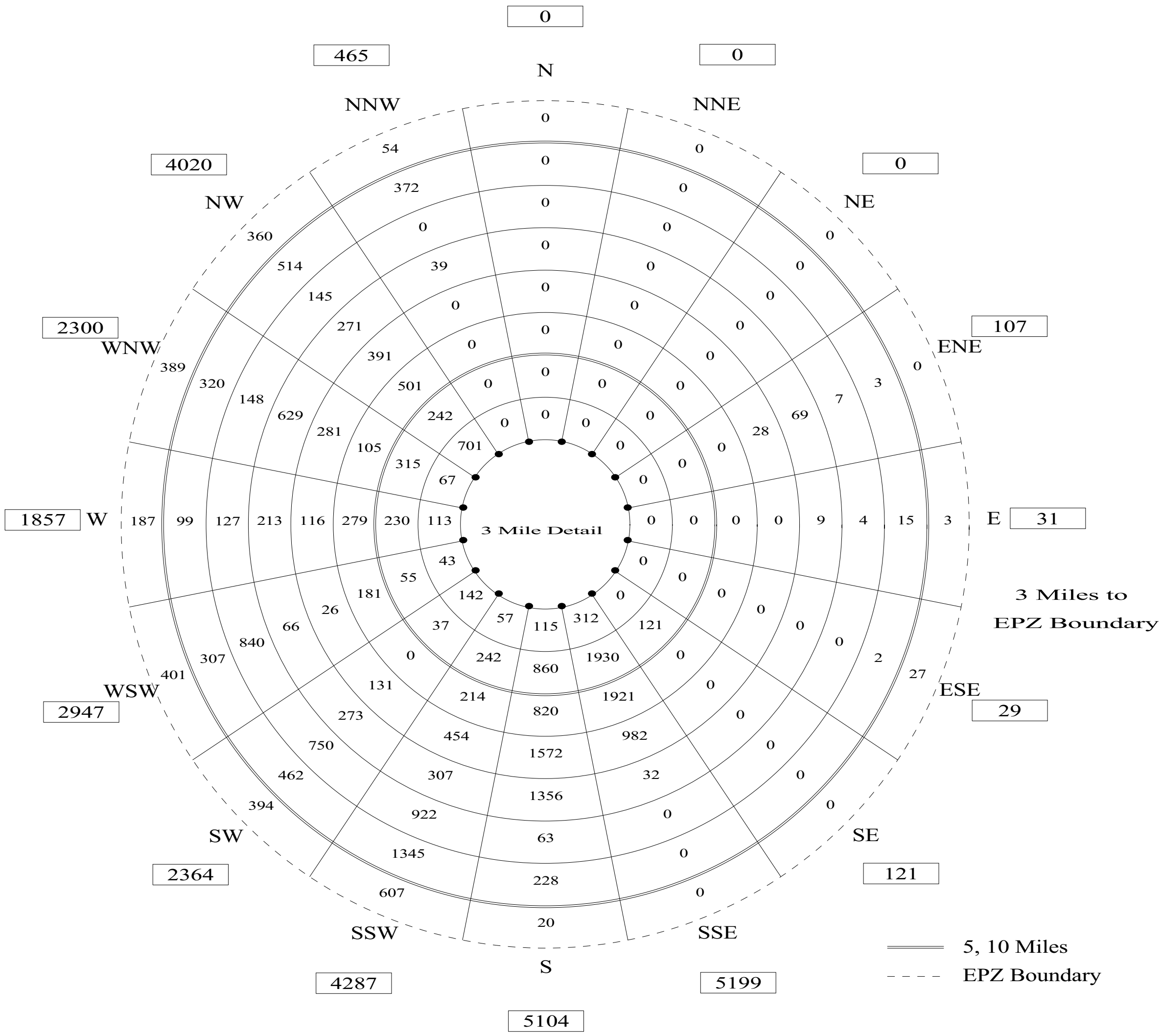


Figure 3-2. Permanent Residents by Sector



Resident Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	1449	0-2	1449
2-3	1419	0-3	2868
3-4	1550	0-4	4418
4-5	4032	0-5	8450
5-6	4021	0-6	12471
6-7	3981	0-7	16452
7-8	3264	0-8	19716
8-9	3006	0-9	22722
9-10	3667	0-10	26389
10-EPZ	2442	0-EPZ	28831

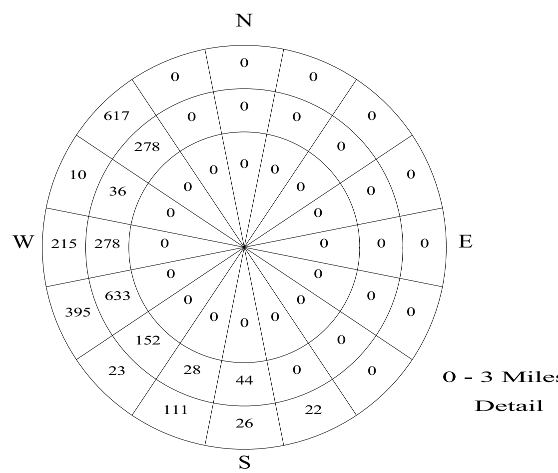


Figure 3-3. Permanent Resident Vehicles by Sector

Transient Population

Transients are defined as those people who are not permanent residents and who enter the EPZ for a specific purpose (shopping, recreation). Transients may spend less than one day or stay overnight or longer at rented apartments, camping facilities, hotels and motels.

The recreational areas in the CCNPP EPZ include parks, museums, recreation centers, campgrounds, a sports complex and a historical site. Appendix E details the recreational data provided by the 2002 ETE Study Report, by county websites, and by websites for recreational facilities. The peak attendance at the recreational areas is estimated as 2,421 people evacuating in 831 vehicles.

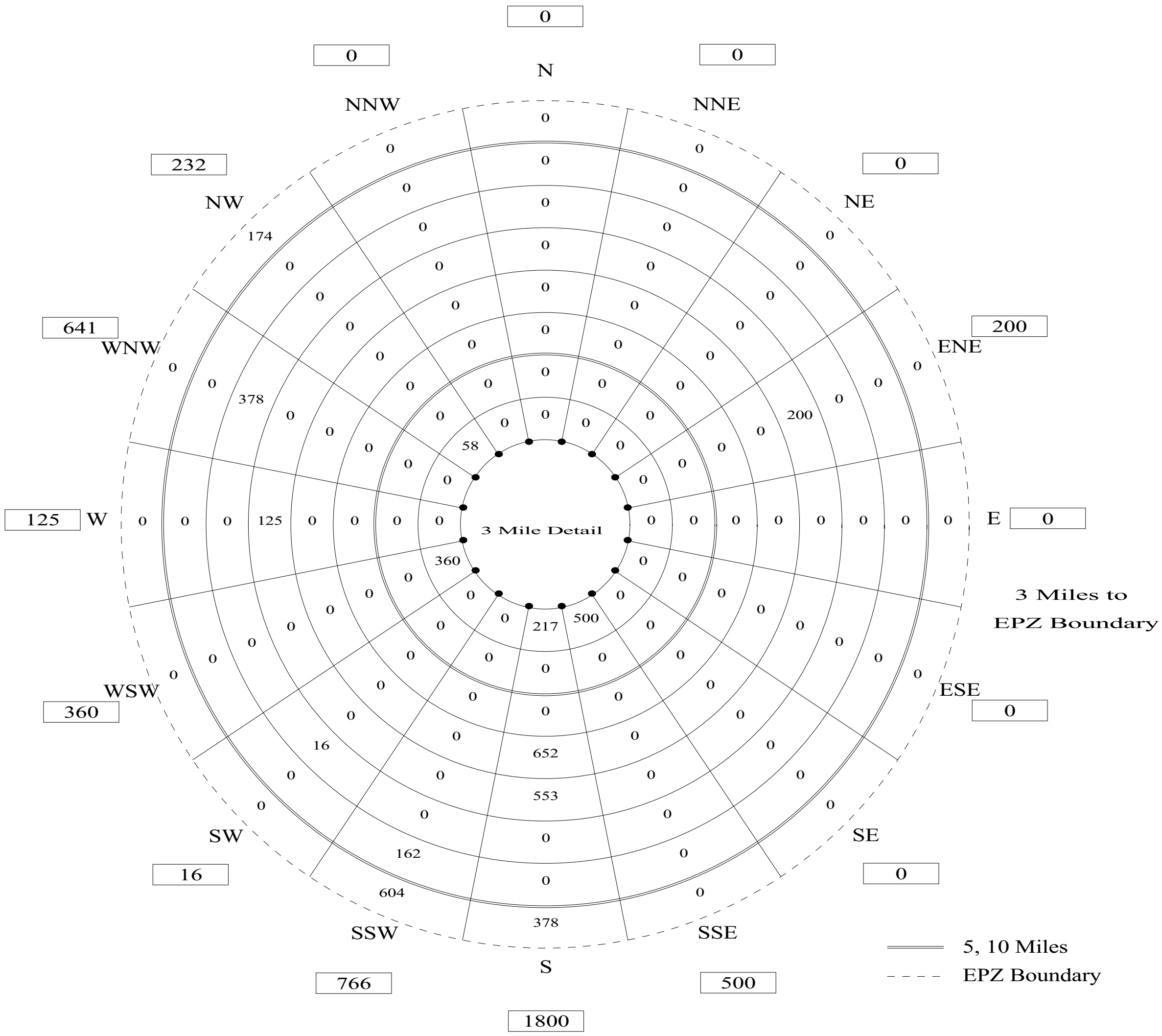
Hotels and Motels

There are 10 major hotels (50 or more rooms), six bed and breakfast lodgings and one cabin facility in the EPZ. Appendix E details the hotel data provided by county tourism websites as well as websites for the lodging facilities. At the hotels, motels and bed and breakfasts, we assume two people per room. The peak attendance at the hotels and motels is estimated as 2,219 people evacuating in 1,087 vehicles.

Table 3-3 summarizes the transient population and vehicles within the EPZ. This includes the major recreational facilities and lodging facilities.

Table 3-3. Summary of Transients by Zone

Zone	Transients	Transient Vehicles
1	480	183
2	418	128
3	1,705	705
4	677	255
5	**No Transients**	
6	16	8
7	1,144	572
8	200	67
TOTAL	**4,640**	**1,918**



Transient Population			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	263	0-2	263
2-3	0	0-3	263
3-4	1135	0-4	1398
4-5	0	0-5	1398
5-6	0	0-6	1398
6-7	652	0-7	2050
7-8	878	0-8	2928
8-9	394	0-9	3322
9-10	162	0-10	3484
10-EPZ	1156	0-EPZ	4640

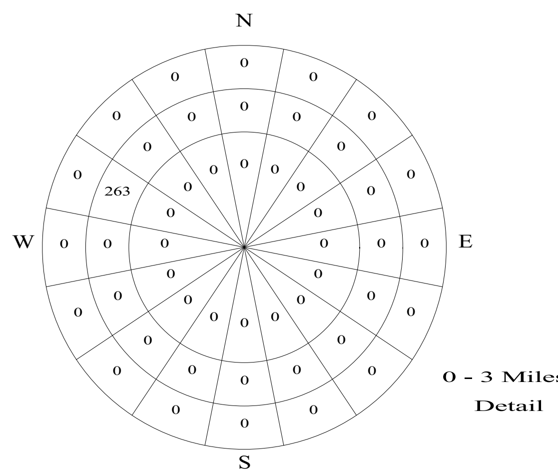
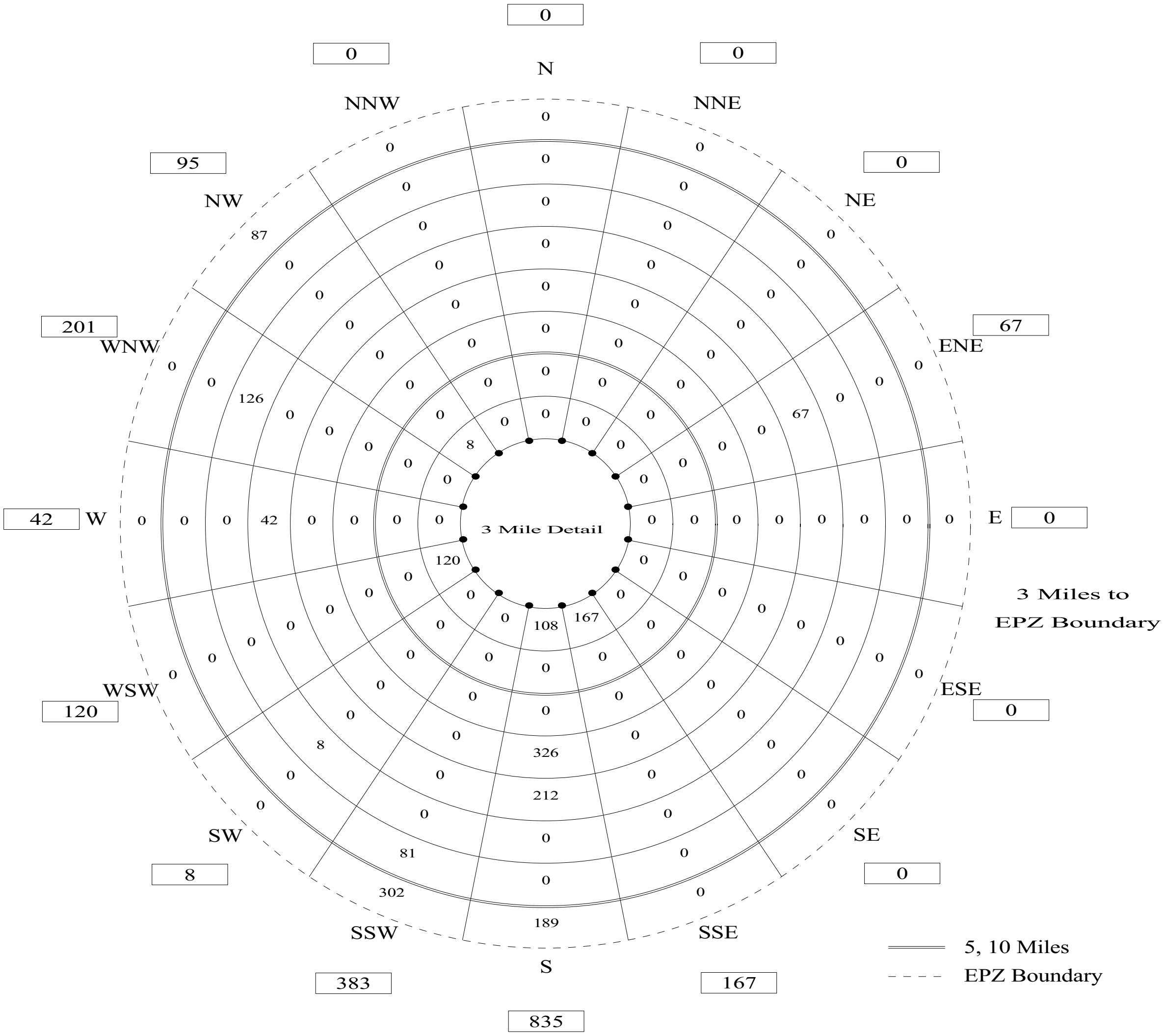


Figure 3-4. Transient Population by Sector



Transient Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	0	0-1	0
1-2	75	0-2	75
2-3	0	0-3	75
3-4	403	0-4	478
4-5	0	0-5	478
5-6	0	0-6	478
6-7	326	0-7	804
7-8	321	0-8	1125
8-9	134	0-9	1259
9-10	81	0-10	1340
10-EPZ	578	0-EPZ	1918

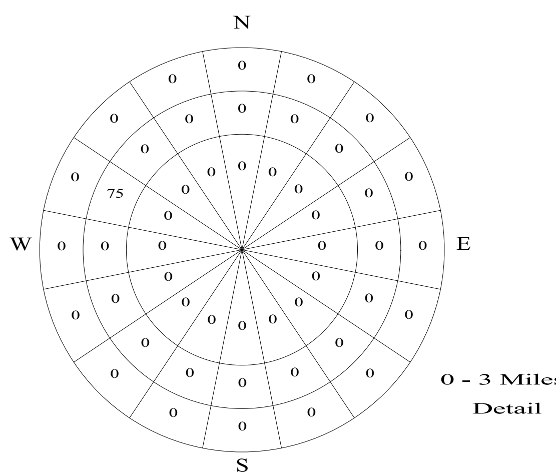


Figure 3-5. Transient Vehicles by Sector

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 on those commuting employees who will evacuate along with the permanent resident population.

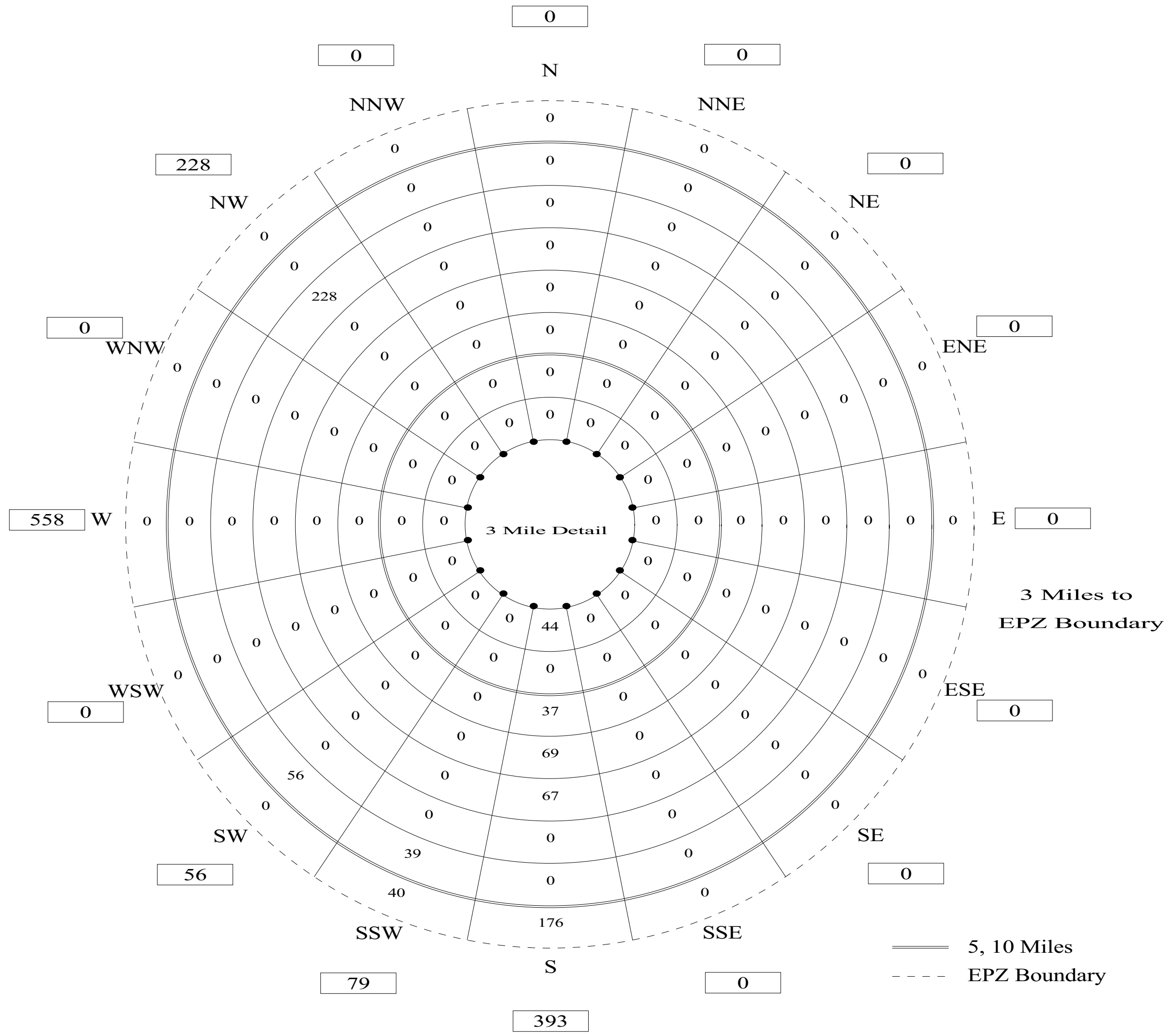
Data for major employers (more than 50 total employees) in the EPZ was provided by the county offices of emergency management, county websites, and individual employer websites. The locations of these facilities were mapped using GIS software. The GIS map was overlaid with the evacuation analysis network and employees were loaded onto appropriate links. The map of major employers in the EPZ can be seen in Appendix E.

Journey to Work data provided by the Census indicates that, on average, 25% of the employees in the Calvert County portion of the EPZ and 20% of the employees in the St. Mary's County portion of the EPZ travel to work from outside the EPZ. These percentages were applied to estimate the total number of people commuting into the EPZ to work.

An occupancy of 1.03 persons per employee-vehicle obtained from the telephone survey is used to determine the number of evacuating employee vehicles.

Table 3-4 presents non-EPZ Resident employee and vehicle estimates by zone. Figures 3-6 and 3-7 present these data by sector.

Table 3-4. Summary of Non-EPZ Employees by Zone		
Zone	**Total Non-EPZ Employees**	**Employee Vehicles**
1	558	542
2	**No employment**	
3	217	212
4	77	75
5	151	148
6	56	54
7	255	250
8	**No employment**	
TOTAL:	**1,314**	**1,281**



Employees			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	558	0-1	558
1-2	0	0-2	558
2-3	0	0-3	558
3-4	44	0-4	602
4-5	0	0-5	602
5-6	37	0-6	639
6-7	69	0-7	708
7-8	67	0-8	775
8-9	228	0-9	1003
9-10	95	0-10	1098
10-EPZ	216	0-EPZ	1314

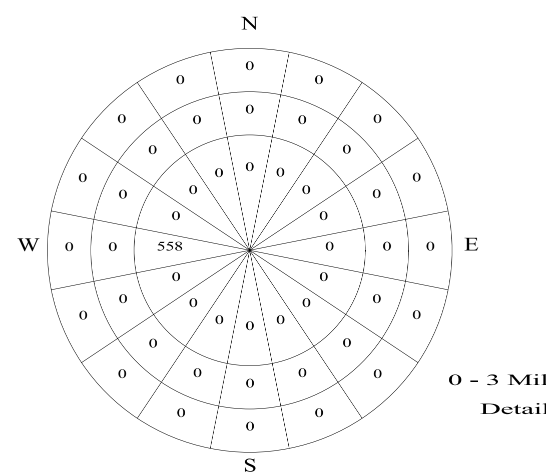
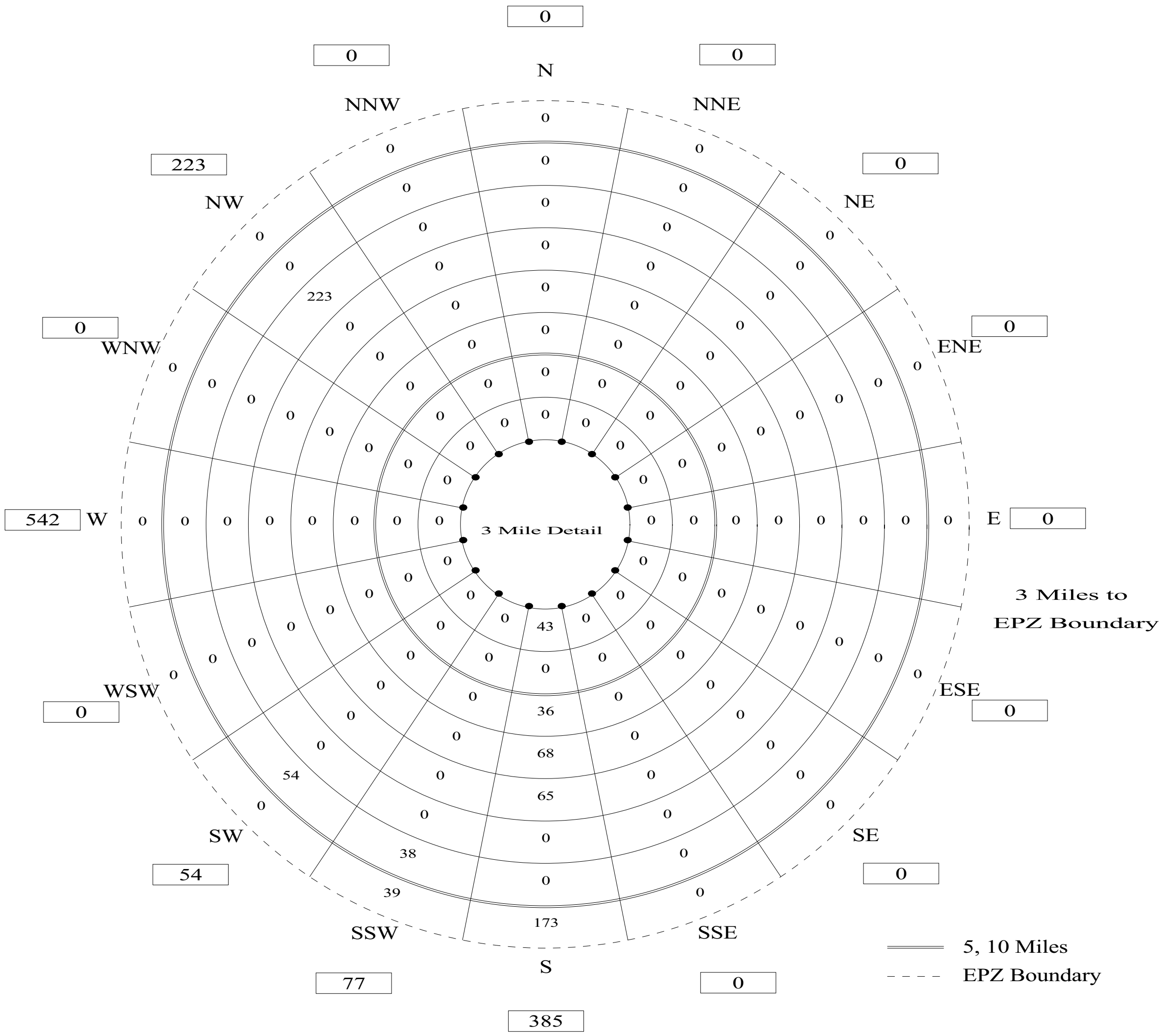


Figure 3-6. Employee Population by Sector



Employee Vehicles			
Miles	Ring Subtotal	Total Miles	Cumulative Total
0-1	542	0-1	542
1-2	0	0-2	542
2-3	0	0-3	542
3-4	43	0-4	585
4-5	0	0-5	585
5-6	36	0-6	621
6-7	68	0-7	689
7-8	65	0-8	754
8-9	223	0-9	977
9-10	92	0-10	1069
10-EPZ	212	0-EPZ	1281

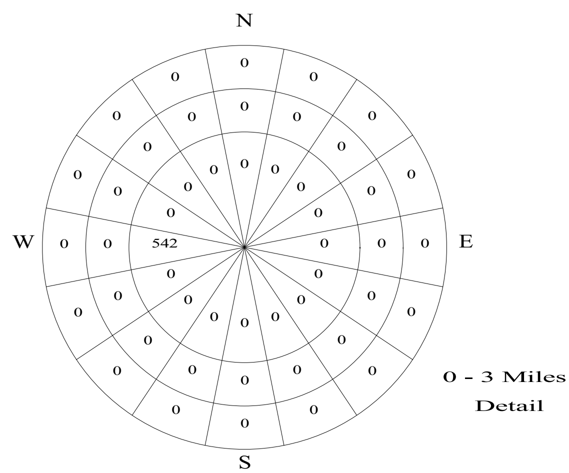


Figure 3-7. Employee Vehicles by Sector

Medical Facilities

There are no hospitals within the Calvert Cliffs EPZ; however, there are nursing homes and senior centers. Data for these facilities obtained from nursing home websites and from the 2002 ETE Study Report.

Pass-Through Demand

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 through the EPZ (e.g. Maryland Route 2/4 and Maryland Route 235). It is assumed that this traffic will continue to enter the EPZ during the first 90 minutes following the Advisory to Evacuate. We estimate approximately 300 vehicles per lane as the pass through demand; with 8 lanes entering the EPZ, a total of 2,400 vehicles enter the EPZ as external-external trips during this period.

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 (from the 2000 Highway Capacity Manual).

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.

Because of the effect of weather on the capacity of a roadway, it is necessary to adjust capacity figures to represent the prevailing conditions during inclement weather. Based on limited empirical data, weather conditions such as heavy 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.

Given the population density within the EPZ and the limited availability of major evacuation routes (only two major thoroughfares - Route 235 and Route 2/4), congestion is expected to occur within the EPZ and especially in/around the Thomas Johnson Bridge. As such, 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.

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 Traffic Management Plan identifies these locations (called Traffic Control Points, TCP) and the management procedures applied.

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

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

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	=	The mean duration of GREEN time servicing vehicles that are executing movement, *m*, for each signal cycle; seconds
L	=	The mean "lost time" for each signal phase servicing movement, *m*; seconds
C	=	The duration of each signal cycle; seconds
P_m	=	The 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, 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,

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

where:

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

The estimation of h_m for specified values of h_{sat}, F_1, F_2, ... is undertaken within the PC-DYNEV simulation model and within the TRAD model by a mathematical model[1]. The resulting values for h_m always satisfy the condition:

$$h_m \geq h_{sat}$$

1 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.

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

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. Figure 4-1 describes this relationship.

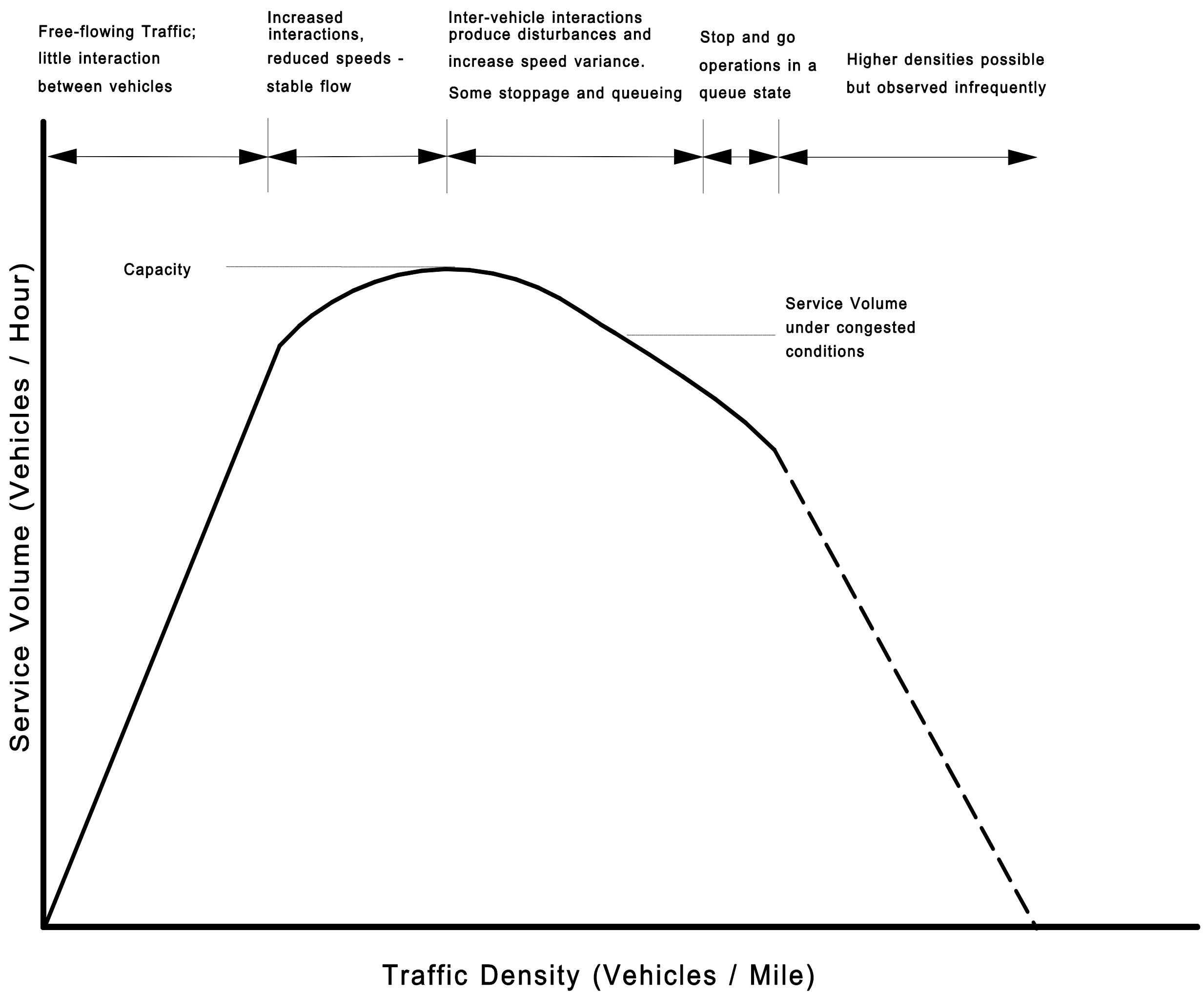


Figure 4-1. Fundamental Relationship Between Volume and Density

As indicated, there are two flow regimes: (1) Free Flow (left side of curve); and (2) Forced Flow (right side of curve). In the Free Flow regime, the traffic demand is fully serviced; this 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. 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:

$$V_F = R \times \text{Capacity}$$

where R = Reduction factor which is less than unity.

Based on empirical data collected on freeways, we have employed a value of R=0.85. It is important to mention that some investigators, on analyzing data collected on freeways, conclude that little reduction in capacity occurs even when traffic is operating at Level of Service, *F*. While there is conflicting evidence on this subject, we adopt a conservative approach and use a value of capacity, V_F, that is applied during LOS F conditions; V_F, is lower than the specified capacity.

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.

The procedure used here was to estimate "section" capacity, V_E, based on observations made traveling over each section of the evacuation network, by the posted speed limits and travel behavior of other motorists and by reference to the 2000 Highway Capacity Manual. It was then determined 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.

Application to the Calvert Cliffs Nuclear Power Plant EPZ

As part of the development of the Calvert Cliffs Nuclear Power Plant (CCNPP) EPZ traffic network, an estimate of roadway capacity is required. The source material for the capacity estimates presented herein is contained in:

2000 Highway Capacity Manual (HCM)
Transportation Research Board
National Research Council
Washington, D.C.

The highway system in the CCNPP EPZ consists primarily of two categories of roads and, of course, intersections:

- Two-lane roads: Local, State Routes
- Multi-lane Highways (at-grade)

Each of these classifications will be discussed.

Two-Lane Roads

Ref: HCM Chapter 20

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 evacuation 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 city limits.

Multi-Lane Highway

Ref: HCM Chapter 21

Exhibit 21-23 (in the HCM) presents a set of curves that indicates a per-lane capacity of approximately 2100 pc/h, for free-speeds of 55-60 mph. Based on observation, the multi-lane highways outside of urban areas within the EPZ, service traffic with free-speeds in this range. The actual time-varying speeds computed by the simulation model reflect the demand:capacity relationship and the impact of control at intersections.

Intersections

Ref: HCM Chapters 16, 17

Procedures for estimating capacity and LOS for approaches to intersections are presented in Chapters 16 (signalized intersections) and 17 (un-signalized intersections). These are the two longest chapters in the HCM 2000, reflecting the complexity of these procedures. The simulation logic is likewise complex, but different; as stated on page 31-21 of the HCM2000: “Assumptions and complex theories are used in the simulation model to represent the real-world dynamic traffic environment.”

5. ESTIMATION OF TRIP GENERATION TIME

Federal Government guidelines (see NUREG 0654, Appendix 4) specify that the planner estimate the distributions of elapsed times associated with mobilization activities undertaken by the public to prepare for the evacuation trip. The elapsed time associated with each activity is represented as a statistical distribution reflecting differences between members of the public. The quantification of these activity-based distributions relies largely on the results of the telephone survey (Appendix F). We define the sum of these distributions of elapsed times as the Trip Generation Time Distribution.

Background

In general, an accident at a nuclear power plant is characterized by the following Emergency Action Classification 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 accord with Federal Regulations, that a rapidly escalating accident will be considered in calculating the Trip Generation Time. We will assume:

a. The Advisory to Evacuate will be announced coincident with the emergency notification.
b. Mobilization of the general population will commence up to 10 minutes after the alert notification.
c. Evacuation Time Estimates (ETEs) are measured relative to the Advisory to Evacuate.
d. Schools will be evacuated prior to the Advisory to Evacuate; if circumstances permit.

We emphasize that the adoption of this planning basis is not a representation that these events will occur at the Calvert Cliffs Nuclear Power Plant (CCNPP) within the indicated time frame. Rather, these assumptions are necessary in order to:

- Establish a temporal framework for estimating the Trip Generation distribution as recommended in Appendix 4 of NUREG 0654.
- Identify temporal points of reference that uniquely define "Clear Time" and ETE.

It is more likely that a longer time will elapse between the various classes of an emergency at CCNPP and that the Advisory to Evacuate is announced somewhat later than the siren alert.

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, resulting in a lower number of people evacuating within the Emergency Planning Zone (EPZ) when the Advisory to Evacuate is announced. Thus, the time needed to evacuate the EPZ, after the Advisory to Evacuate will be less than the estimates presented in this report, since this study assumes no time lapse between the sirens and the Advisory to Evacuate.

The notification process consists of two events:

- <u>Transmitting</u> information (e.g. using sirens, EAS broadcasts, etc.).
- <u>Receiving</u> and correctly <u>interpreting</u> the information that is transmitted.

The peak permanent resident population within the EPZ approximates 55,000 persons who are deployed over an area of approximately 182 square miles and 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 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 that the emergency is declared. These people may be commuters, shoppers and other travelers who reside within the EPZ and who will return to join the other household members upon receiving notification of an emergency.

As indicated in NUREG 0654, the estimated elapsed times for the receipt of notification can be expressed as a <u>distribution</u> 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 ETEs may be obtained.

For example, people at home or at work within the EPZ will be notified by siren, and/or TV and/or radio. Those EPZ residents who are 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 also differ from weekdays.

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 activities) 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-accident condition
2	Awareness of accident situation
3	Depart place of work or elsewhere, to return home
4	Arrive (or be at) home
5	Begin evacuation trip to leave the area

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

Event Sequence	Activity	Distribution
1 → 2	Public receives notification information	1
2 → 3	Prepare to leave work	2
2,3 → 4	Travel home*	3
2,4 → 5	Prepare to leave for evacuation trip	4

*If already at home, this is a null (no-time-consumed) activity.

These relationships are shown graphically in Figure 5-1.

An employee who lives outside the EPZ will follow sequence (d) of Figure 5-1; a resident of the EPZ who is at work, and will return home before beginning the evacuation trip will follow sequence (a) of Figure 5-1. Note that event 5, "Leave to evacuate the area," is conditional either on event 2 or on event 4. That is, activity 2 → 5 by a resident at home can be undertaken in parallel with activities 2 → 3, 3 → 4 and 4 → 5 by a commuter returning to that home, as shown in Figure 5-1 (a). Specifically, one adult member of a household can prepare to leave home (i.e. secure the home, pack clothing, etc.), while others are traveling home from work. In this instance, the household members would be able to evacuate sooner than if such trip preparation were deferred until all household members had returned home. For this study, we adopt the conservative posture that all activities will occur in 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.

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 we are operating on distributions – not scalar numbers).

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

It is reasonable to expect that 85 percent of those within the EPZ will be aware of the accident within 30 minutes with the remainder notified within the following 20 minutes. The notification distribution is given below:

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

Elapsed Time (Minutes)	Percent of Population Notified
0	0
5	7
10	13
15	26
20	46
25	65
30	85
35	90
40	95
45	98
50	100

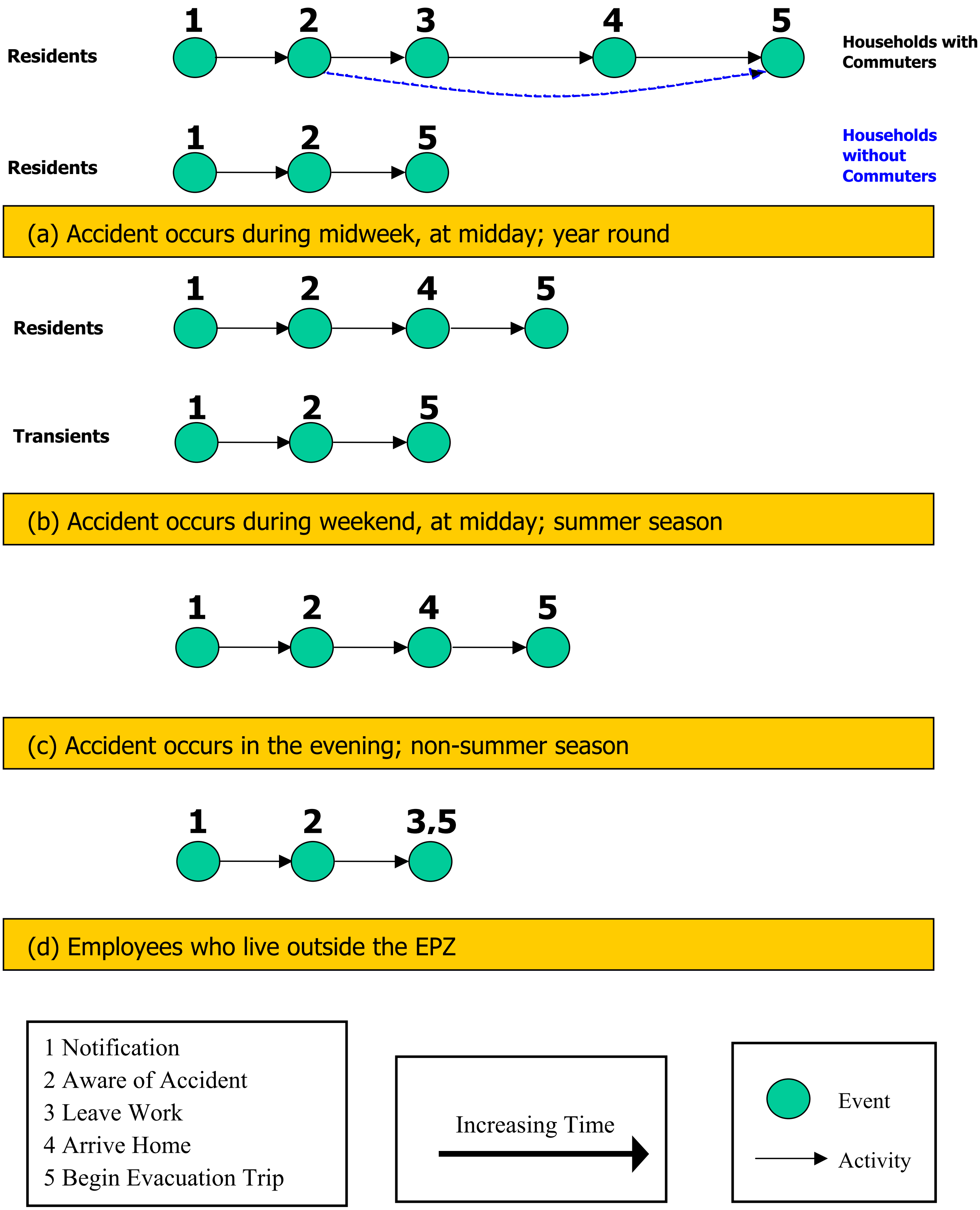


Figure 5-1. Events and Activities Preceding the Evacuation Trip

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

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

Elapsed Time (Minutes)	**Cumulative Percent Employees Leaving Work**
0	0
5	36
10	50
15	60
20	69
25	75
30	78
35	82
40	85
45	88
50	90
55	92
60	95
65	95
70	96
75	97
80	97
85	98
90	98
95	99
100	99
105	99
110	99
115	100

Distribution No. 3, Travel Home: Activity 3 $\rightarrow$ 4

These data are provided directly by the telephone survey. This distribution is plotted in Figure 5-2 and listed below.

Elapsed Time (Minutes)	Cumulative Percent Returning Home
0	0
5	6
10	17
15	32
20	44
25	51
30	64
35	68
40	72
45	76
50	78
55	80
60	84
65	85
70	87
75	89
80	91
85	93
90	95
95	96
100	97
105	98
110	98
115	99
120	100

Distribution No. 4, Prepare to Leave Home: Activity 2, 4 $\rightarrow$ 5

These data are provided directly by the telephone survey. This distribution is plotted in Figure 5-2 and listed below.

Elapsed Time (Minutes)	Cumulative Pct. Ready to Evacuate
0	0
5	10
10	19
15	29
20	41
25	54
30	63
35	68
40	72
45	75
50	79
55	83
60	87
65	90
70	91
75	93
80	93
85	93
90	93
95	93
100	94
105	94
110	94
115	95
120	96
125	96
130	97
135	97
140	98
145	99
150	100

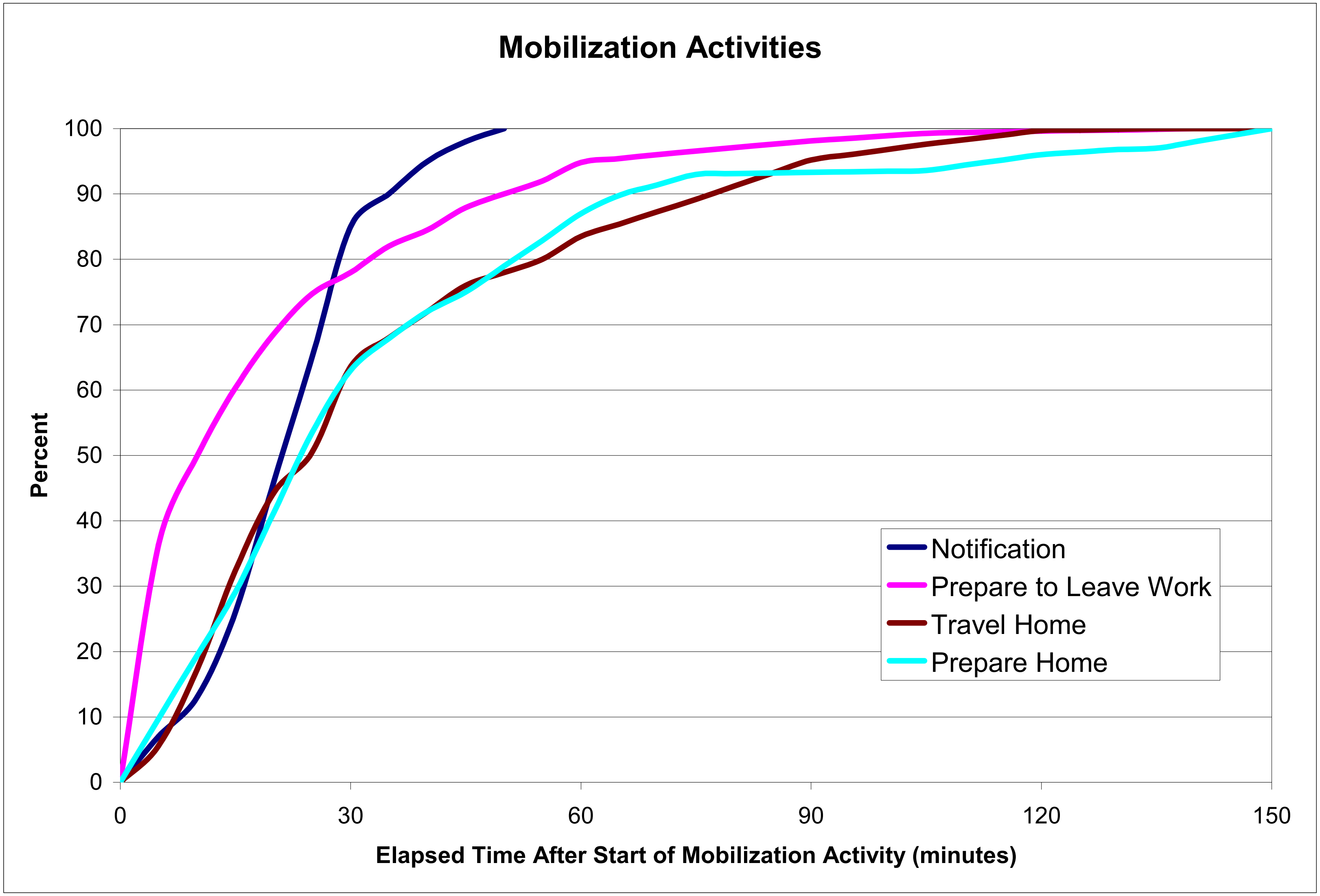


Figure 5-2. Evacuation Mobilization Activities

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. We assume that the stated events take place in sequence such that all preceding events must be completed before the current event can occur. For example, if a household awaits the return of a commuter, the work-to-home trip (Activity 3 → 4) must precede Activity 4 → 5.

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

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

Distributions A through D are described below:

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.
C	Time distribution of residents with commuters leaving home to begin the evacuation trip.
D	Time distribution of residents without commuters returning home to begin the evacuation trip.

Figure 5-3 presents the combined trip generation distributions designated A, C, and D. These distributions are presented on the same time scale. The PC-DYNEV simulation model is designed to accept varying rates of vehicle trip generation for each origin centroid, expressed in the form of histograms. These histograms, which represent Distributions A, C, and D, properly displaced with respect to one another, are tabulated in Table 5-1 (Distribution B, Arrive Home, omitted for clarity).

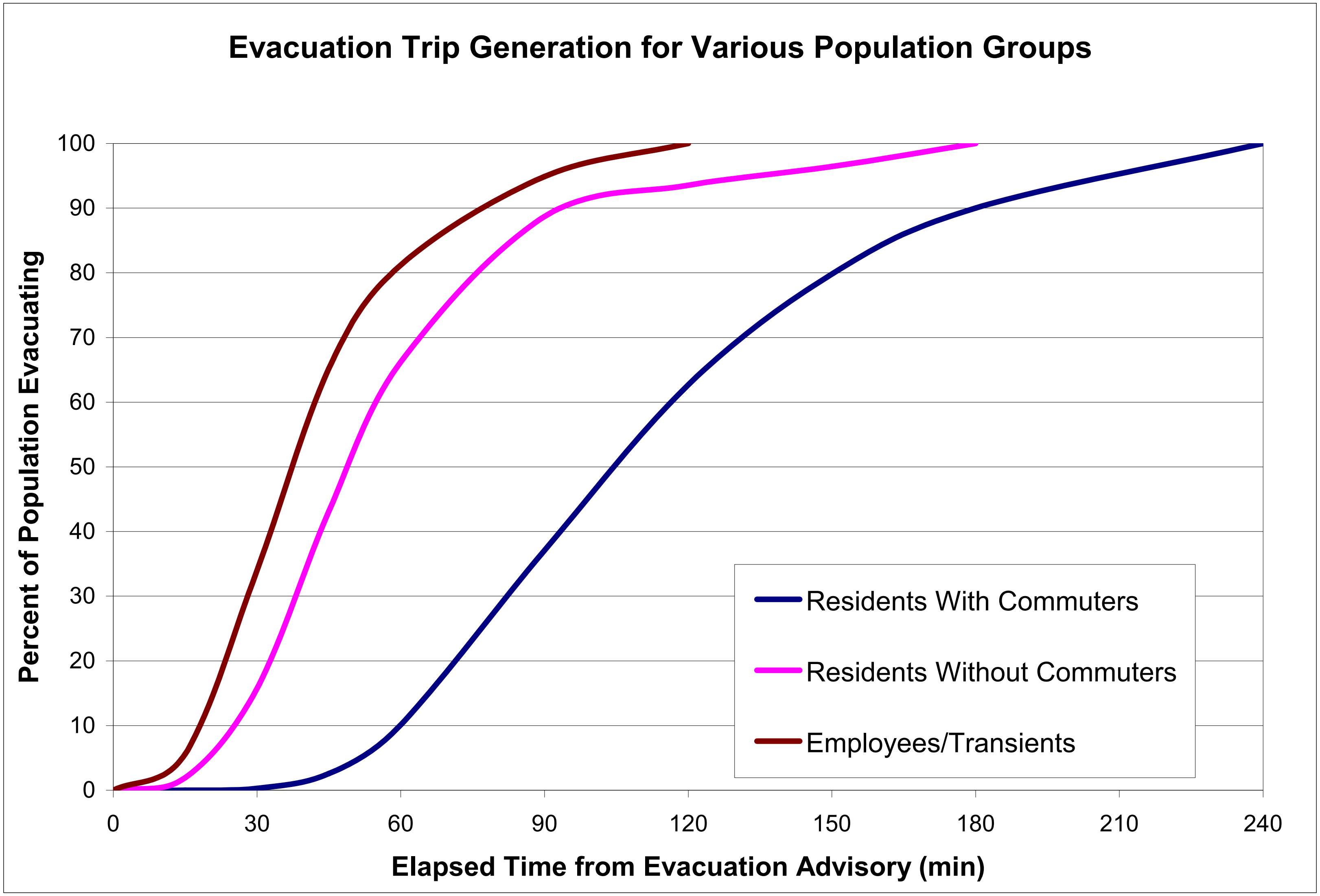


Figure 5-3. Comparison of Trip Generation Distributions

Table 5-1. Trip Generation Time Histograms for the EPZ Population

Time Period	Duration (Min)	Percent of Total Trips Generated Within Indicated Time Period			
		Residents With Commuters (Distribution C)	Residents Without Commuters (Distribution D)	Employees (Distribution A)	Transients (Distribution A)
1	15	0	2	6	6
2	15	0	14	28	28
3	15	2	27	31	31
4	15	8	23	16	16
5	30	27	23	14	14
6	30	26	5	5	5
7	30	17	3	0	0
8	30	10	3	0	0
9	60	10	0	0	0
10	600	0	0	0	0

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 evacuation Zones, 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 14 Regions were defined which encompass all the groupings of Zones considered. These Regions are defined in Table 6-1. The zone configurations are identified in Figure 6-1. Each keyhole sector-based area consists of a circular area centered at the Calvert Cliffs Nuclear Power Plant (CCNPP), and three adjoining sectors, each with a central angle of 22.5 degrees. These sectors extend to a distance of 5 miles from CCNPP (Regions R4 and R5), or to the EPZ boundary (Regions R06 to R14). The azimuth of the center sector defines the orientation of these Regions.

A total of 12 Scenarios were evaluated for all Regions. Thus, there are a total of 14x12=168 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.

Table 6-1. Description of Evacuation Regions									
Region	**Description**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R01	2-Mile Ring	X							
R02	5-Mile Ring	X	X	X					
R03	Full EPZ	X	X	X	X	X	X	X	X
Evacuate 2-Mile Ring and 5 Miles Downwind									
Region	**Wind Direction Towards:**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	N, NNE, NE, ENE, E	**See Region 1**							
R04	ESE, SE, SSE, S	X		X					
	SSW, SW, WSW	**See Region 2**							
R05	W, WNW, NW, NNW	X	X						
Evacuate 5-Mile Ring and Downwind to EPZ Boundary									
Region	**Wind Direction Towards:**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	NNE	**See Region 2**							
R06	NE, ENE, E, ESE, SE	X	X	X					X
R07	SSE, S	X	X	X				X	
R08	SSW, SW	X	X	X			X	X	
R09	WSW	X	X	X	X		X	X	
R10	W	X	X	X	X		X		
R11	WNW	X	X	X	X	X	X		
R12	NW, NNW	X	X	X	X	X			
R13	N	X	X	X		X			
R14	*	X							X

*This Region was added at Constellation Energy's request. It is an evacuation of the 2-Mile Ring and downwind (Towards Dorchester County) to the EPZ Boundary.

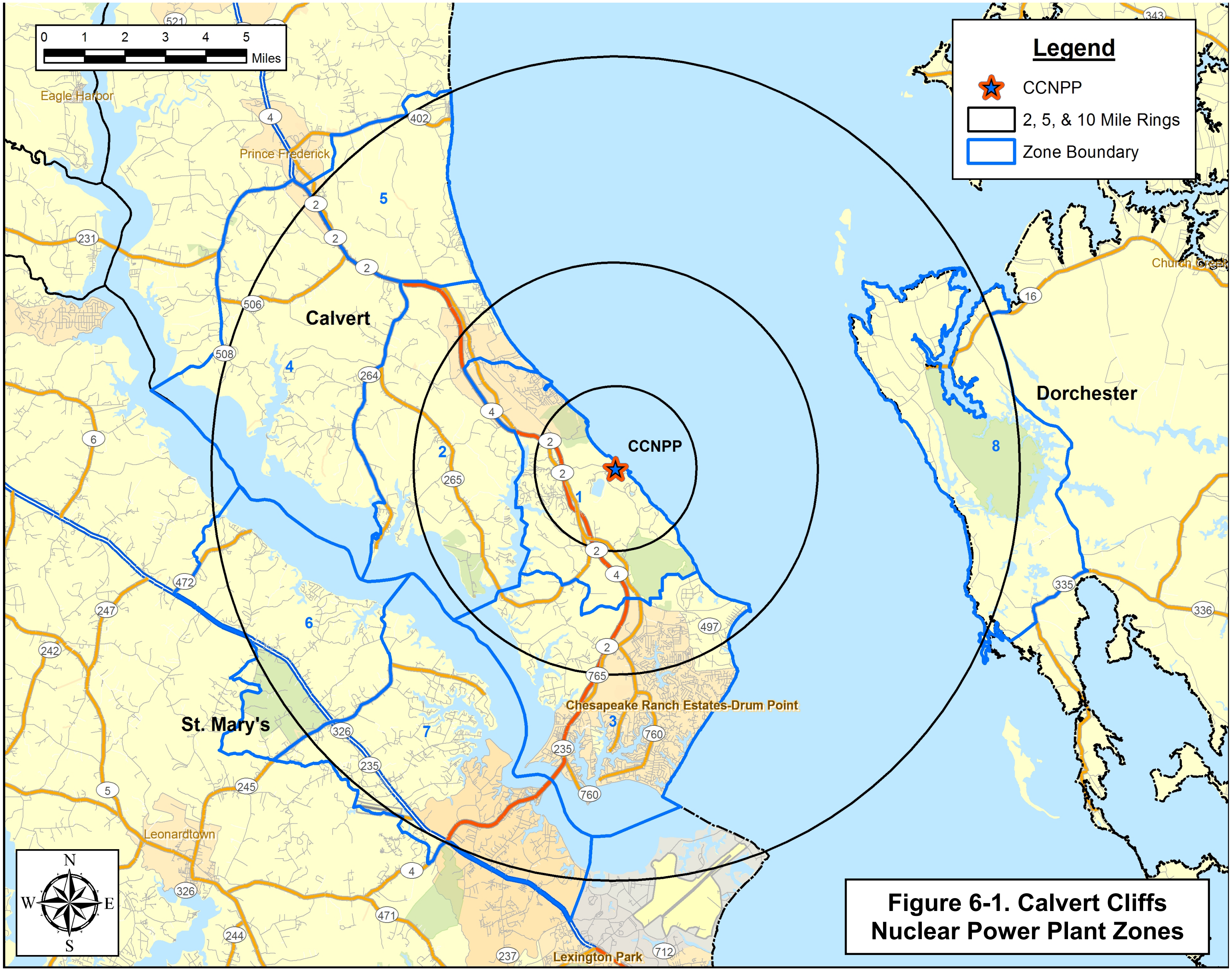


Figure 6-1. Calvert Cliffs Nuclear Power Plant Zones

Table 6-2 Evacuation Scenario Definitions					
Scenarios	**Season**	**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	Weekend	Midday	Good	None
9	Winter	Weekend	Midday	Rain	None
10	Winter	Midweek, Weekend	Evening	Good	None
11	Summer	Midweek	Midday	Good	New Plant Construction
12	Summer	Weekend	Midday	Good	Air Show at the Naval Base

Note: Schools are assumed to be in session for the Winter season (midweek, midday).

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

Scenarios	Residents With Commuters in Household	Residents With No Commuters in Household	Employees	Transients	Shadow	Special Events	School Buses	Transit Buses	External Through Traffic
1	65%	35%	96%	50%	31%	0%	10%	100%	100%
2	65%	35%	96%	50%	31%	0%	10%	100%	100%
3	6%	94%	47%	100%	31%	0%	0%	100%	100%
4	6%	94%	47%	100%	31%	0%	0%	100%	100%
5	6%	94%	10%	25%	30%	0%	0%	100%	60%
6	65%	35%	100%	25%	31%	0%	100%	100%	100%
7	65%	35%	100%	25%	31%	0%	100%	100%	100%
8	6%	94%	47%	40%	31%	0%	0%	100%	100%
9	6%	94%	47%	40%	31%	0%	0%	100%	100%
10	6%	94%	10%	15%	30%	0%	0%	100%	60%
11	65%	35%	96%	50%	31%	100%	10%	100%	100%
12	6%	94%	47%	100%	31%	100%	0%	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 of 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 30% relocation of shadow residents along with a proportional percentage of shadow employees. The percentage of shadow employees is computed using the scenario-specific ratio of EPZ employees to residents.

Special Events .... Additional vehicles in the CCNPP EPZ area during the construction phase of the new unit and the Air Show at the Patuxent Naval Air Base.

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), respectively.

External Through Traffic .... Traffic on local highways and major arterial roads at the start of the evacuation. This traffic is stopped by access control approximately 90 minutes 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	18,665	10,166	1,230	959	9,857	-	30	66	2,400	43,373
2	18,665	10,166	1,230	959	9,857	-	30	66	2,400	43,373
3	1,867	26,965	602	1,918	9,651	-	-	66	2,400	43,469
4	1,867	26,965	602	1,918	9,651	-	-	66	2,400	43,469
5	1,867	26,965	128	480	9,496	-	-	66	1,440	40,442
6	18,665	10,166	1,281	480	9,874	-	294	66	2,400	43,226
7	18,665	10,166	1,281	480	9,874	-	294	66	2,400	43,226
8	1,867	26,965	602	767	9,651	-	-	66	2,400	42,318
9	1,867	26,965	602	767	9,651	-	-	66	2,400	42,318
10	1,867	26,965	128	288	9,496	-	-	66	1,440	40,250
11†	20,040	10,919	1,230	959	10,714	2,821	30	66	2,400	49,179
12*	473	6,775	602	1,918	2,574	43,480	-	66	2,400	58,288

†Permanent Resident population and Shadow population have been extrapolated to the Year 2013, which is when construction workforce will be at its peak.

***Based on an assumption that 75% of the population within the EPZ and Shadow will be attending the Air Show, the loading of the residents within the EPZ and in the shadow area have been adjusted appropriately.**

Populations for all Scenarios except Scenario 11 are projected to the year 2008.

7. GENERAL POPULATION EVACUATION TIME ESTIMATES (ETE)

This section presents the current results of the computer analyses using the IDYNEV System described in Appendices B, C and D. These results cover 14 regions within the CCNPP EPZ and the 12 Evacuation Scenarios discussed in Section 6.

The ETE for all Evacuation Cases are presented in Tables 7-1A through 7-1D. **These tables present the estimated times to clear the indicated population percentages from the Evacuation Regions for all Evacuation Scenarios.** The tabulated values of ETE are obtained from the PC-DYNEV simulation model outputs of vehicles exiting the specified evacuation areas. These data are generated at 10-minute intervals, then interpolated to the nearest 5 minutes.

NRC guidance suggests routing traffic during evacuation away from CCNPP and out of the EPZ to the extent practicable. Zone 3, which is the most populous of all zones within the EPZ is south of CCNPP and has only 1 evacuation route – Maryland Route 2/4. If all the traffic from this Zone were routed away from the plant in the southbound direction, they would have to use the Thomas Johnson Bridge (1-lane in either direction), which presents a significant traffic bottleneck. A sensitivity study was conducted to measure the effect of routing evacuees from Zone 3 northbound on Route 2/4. Balancing the vehicle demand from Zone 3 in the northbound and southbound directions on Route 2/4 results in a significant decrease in ETE (4 hours and 40 minutes less) than routing only southbound (See Appendix I). Although this routing moves some of the evacuees closer to CCNPP, the ETE is significantly reduced, minimizing the risk of exposure. **All the results presented in this section and in Appendix J are based on routing evacuating traffic from Zone 3 northbound and southbound on Route 2/4.**

7.1 Voluntary Evacuation and Shadow Evacuation

We define “voluntary evacuees” as people who are within the EPZ in Zones located outside the Evacuation Region, for which an Advisory to Evacuate *has not* been issued, yet who nevertheless elect to evacuate. We define “shadow evacuation” as the movement of people from areas *outside* the EPZ for whom no protective action recommendation has been issued. Both voluntary and shadow evacuation are assumed to take place over the same time frame as the evacuation from within the impacted Evacuation Region.

The ETE for the CCNPP addresses the issue of voluntary evacuees as discussed in Section 2.2 and displayed in Figure 7-1 (same as Figure 2-1). Figure 7-2 presents the area identified as the Shadow Evacuation Region. This region extends radially from the boundary of the EPZ to a distance of 15 miles from CCNPP.

Traffic generated within this Shadow Evacuation Region, traveling away from the CCNPP location, has the potential for impeding evacuating vehicles from within the Evacuation Region. We assume that the traffic volumes emitted within the Shadow

Evacuation Region correspond to 30 percent of the residents there plus a proportionate number of employees in that region. **All ETE calculations include this shadow traffic movement.**

7.2 Patterns of Traffic Congestion During Evacuation

Figures 7-3 through 7-6 illustrate the patterns of traffic congestion that arise for the case when the entire EPZ (Region R03) is advised to evacuate during the summer, midweek, midday period under good weather conditions (Scenario 1).

Traffic congestion, as the term is used here, is defined as Level of Service (LOS) F. LOS F is defined as follows (2000 HCM):

> Level of Service F is used to define forced or breakdown flow. This condition exists wherever the amount of traffic approaching a point exceeds the amount that can traverse the point. Queues form behind such locations. Operations within the queue are characterized by stop-and-go waves, and they are extremely unstable. Vehicles may progress at reasonable speeds for several hundred feet or more, then be required to stop in a cyclic fashion. Level of Service F is used to describe the operating conditions within the queue, as well as the point of the breakdown. It should be noted, however, that in many cases operating conditions of vehicles or pedestrians discharged from the queue may be quite good. Nevertheless, it is the point at which arrival flow exceeds discharge flow, which causes the queue to form, and Level of Service F is an appropriate designation for such points.

This definition is general and conceptual in nature, and applies primarily to uninterrupted flow. Levels of Service for interrupted flow facilities vary widely in terms of both the user's perception of service quality and the operational variables used to describe them.

All highway "links" which experience LOS F at the indicated times are delineated in these Figures by a red line; all others are lightly indicated. Congestion develops in areas with concentrations of population and at traffic bottlenecks. Congestion develops at one and a half hours after the Advisory to Evacuate (ATE) southbound on Route 2/4 within Zone 3 (south of CCNPP), especially around Rousby Hall Rd (State Route 760) and the Thomas Johnson Bridge. Additionally, sections of Route 2/4 around Broomes Island Road (Route 264) and Prince Frederick are congested (Figure 7-3).

Figure 7-4 presents the congestion pattern 3 hours after the ATE. Congestion persists in the aforementioned areas within the EPZ and along St. Andrew’s Church Road (Route 4) and Point Lookout Road (Route 5) in the shadow area. By four and a half hours (Figure 7-5), congestion is beginning to dissipate and only persists along Rousby Hall Rd (Route 760), Broomes Island Road (Route 264), St. Andrew’s Church Road (Route 4) and Route 2/4, north of Prince Frederick. After five and a half hours (Figure 7-6), congestion only remains on the Rousby Hall Rd (Route 760) approach to Route

2/4. The absence of congestion on network links (white colored links) implies that traffic demand there has decreased below the roadway capacity for a period of time sufficient to dissipate any traffic queues. It does not necessarily imply that traffic has completely cleared from these roadway sections.

7.3 Evacuation Rates

Evacuation is a continuous process, as implied by Figures 7-3 through 7-6. Another format for displaying the dynamics of evacuation is depicted in Figure 7-7. This plot indicates the rate at which traffic flows out of the indicated areas for the case of an evacuation of the entire EPZ (Region R03) under the indicated conditions. Appendix J presents these plots for all Evacuation Scenarios for Region R03.

As indicated in Figure 7-7, there is typically a long "tail" to these distributions. Vehicles evacuate an area slowly at the beginning, as people respond to the Advisory to Evacuate at different rates. Then traffic demand builds rapidly (slopes of curves increase). When the system becomes congested, traffic exits the EPZ at rates somewhat below capacity until some evacuation routes have cleared. As more routes clear, the aggregate rate of egress slows since many vehicles have already left the EPZ. Towards the end of the process, relatively few evacuation routes service the remaining demand. It is reasonable to expect that some evacuees may delay or lengthen their mobilization activities and evacuate at a later time as a result; these ETE estimates do not (and should not) be distorted to account for these relatively few stragglers.

This decline in aggregate flow rate, towards the end of the process, is characterized by these curves flattening and gradually becoming horizontal. Ideally, it would be desirable to fully saturate all evacuation routes equally so that all will service traffic near capacity levels and all will clear at the same time. For this ideal situation, all curves would retain the same slope until the end -- thus minimizing evacuation time. In the real world, this ideal is generally unattainable reflecting the variation in population density and in highway capacity over the EPZ.

7.4 Guidance on Using ETE Tables

Tables 7-1A through 7-1D present the ETE values for all 14 Evacuation Regions and all 12 Evacuation Scenarios. They are organized as follows:

Table	Contents
7-1A	ETE represents the elapsed time required for 50 percent of the population within a Region, to evacuate from that Region.
7-1B	ETE represents the elapsed time required for 90 percent of the population within a Region, to evacuate from that Region.
7-1C	ETE represents the elapsed time required for 95 percent of the population within a Region, to evacuate from that Region.
7-1D	ETE represents the elapsed time required for 100 percent of the population within a Region, to evacuate from that Region.

The user first determines the percentile of population for which the ETE is sought. The applicable value of ETE within the chosen Table may then be identified using the following procedure:

1. Identify the applicable **Scenario**:
    - The Season
        - Summer (schools not in session)
        - Winter (also Autumn and Spring)
    - The Day of Week
        - Midweek (work-day)
        - Weekend, Holiday
    - The Time of Day
        - Midday (work and commuting hours)
        - Evening
    - Weather Condition
        - Good Weather
        - Rain
    - Special Event
        - New Plant Construction
        - Air show at Naval Air Base

While these Scenarios are designed, in aggregate, to represent conditions throughout the year, some further clarification is warranted:

- The conditions of a summer evening (either midweek or weekend) and rain are not explicitly identified in Tables 7-1A through 7-1D. For these conditions, Scenario (4) provides guidance as an upper bound on ETE.

- The conditions of a winter evening (either midweek or weekend) and rain are not explicitly identified in Tables 7-1A through 7-1D. For these conditions, Scenario (9) provides guidance as an upper bound on ETE.
- The seasons are defined as follows:
  - Summer implies that public schools are *not* in session.
  - Winter, Spring and Autumn imply that public schools *are* in session.
- Time of Day: Midday implies the time over which most commuters are at work.

2. With the Scenario (and column in the Table) identified, now identify the **Evacuation Region**:

- Determine the projected azimuth direction of the plume (coincident with the wind direction). This direction is expressed in terms of compass orientation: *towards* N, NNE, NE, …
- Determine the distance that the Evacuation Region will extend from the CCNPP. The applicable distances and their associated candidate Regions are given below:
  - 2 Miles (Region R01)
  - 5 Miles (Regions R02, R04 and R05)
  - to EPZ Boundary (Regions R03 and R06 through R14)
- Enter Table 7-2 and identify the applicable group of candidate Regions based on the wind direction and on the distance that the selected Region extends from the CCNPP. Select the Evacuation Region identifier in that row from the first column of the Table.

3. Determine the **ETE for the Scenario** identified in Step 1 and the Region identified in Step 2, as follows:
   - The columns of Table 7-1 are labeled with the Scenario numbers. Identify the proper column in the selected Table using the Scenario number determined in Step 1.
   - Identify the row in this table that provides ETE values for the Region identified in Step 2.
   - The unique data cell defined by the column and row so determined contains the desired value of ETE expressed in Hours:Minutes.

<u>Example</u>

It is desired to identify the ETE for the following conditions:

- Sunday, August 10th at 4:00 AM.
- It is raining.
- Wind direction is *towards* the northeast (NE).
- Wind speed is such that the distance to be evacuated is judged to be 10 miles (to EPZ boundary).
- The desired ETE is that value needed to evacuate 95 percent of the population from within the impacted Region.

Table 7-1C is applicable because the 95th-percentile population is desired. Proceed as follows:

1. Identify the Scenario parameters as: *Season*: summer; *Day of Week*: weekend; *Time of Day*: evening (non-work hours); and *Weather*: Rain. Entering Table 7-1C, it is seen that there is no match for these descriptors. However, based on the discussions above (Section 7.4, item 1), Scenario 4 provides guidance as an upper bound on ETE.

2. Enter Table 7-2 and locate the group entitled "Evacuate 5-Mile Ring and Downwind to EPZ Boundary". Under "Wind Direction Towards:", identify the NE (northeast) azimuth and read REGION R06 in the first column of that row.

3. Enter Table 7-1C to locate the data cell containing the value of ETE for Scenario 4 and Region R06. This data cell is in column (4) and in the row for Region R06; it contains the ETE value of **5:20**.

Table 7-1A. Time To Clear The Indicated Area of 50 Percent of the Affected Population

Season		Summer		Summer		Summer	Winter		Winter		Winter	Summer	Summer	Season
Day of Week		Midweek		Weekend		All	Midweek		Weekend		All	Midweek	Weekend	Day of Week
Scenario:		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario
Time of Day		Midday		Midday		Evening	Midday		Midday		Evening	Midday	Midday	Time of Day
Zone	Region Wind Direction Towards	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Good Weather	Rain	Good Weather	New Plant Construction	Air Show at Base	Region Wind Direction Towards
Entire 2-Mile Region, 5-Mile Region, and EPZ														
1	R01 2-mile ring	1:30	1:35	1:20	1:25	1:15	1:30	1:35	1:15	1:25	1:15	1:50	0:60	R01 2-mile ring
1,2,3	R02 5-mile ring	2:25	2:35	2:20	2:35	2:15	2:25	2:35	2:15	2:30	2:10	2:45	1:05	R02 5-mile ring
1,2,3,4,5, 6,7,8	R03 Entire EPZ	2:15	2:35	2:15	2:25	2:05	2:15	2:35	2:05	2:25	2:05	2:35	4:50	R03 Entire EPZ
2-Mile Ring and Downwind to 5 Miles														
1	N, NNE, NE, ENE, E	Refer Region 1												N, NNE, NE, ENE, E
1,3	R04 ESE, SE, SSE, S	2:10	2:25	2:05	2:20	2:00	2:10	2:25	2:05	2:15	2:00	2:35	1:10	R04 ESE, SE, SSE, S
1,2,3	SSW, SW, WSW	Refer Region 2												SSW, SW, WSW
1,2	R05 W, WNW, NW, NNW	1:45	1:60	1:40	1:50	1:35	1:45	1:60	1:40	1:50	1:35	2:10	0:60	R05 W, WNW, NW, NNW
5-Mile Ring and Downwind to EPZ Boundary														
1,2,3	NNE	Refer Region 2												NNE
1,2,3,8	R06 NE, ENE, E, ESE, SE	2:25	2:35	2:20	2:30	2:10	2:25	2:35	2:15	2:30	2:10	2:45	1:05	R06 NE, ENE, E, ESE, SE
1,2,3,7	R07 SSE, S	2:15	2:30	2:10	2:25	2:05	2:15	2:30	2:10	2:20	2:05	2:35	5:10	R07 SSE, S
1,2,3,6,7	R08 SSW, SW	2:15	2:35	2:15	2:25	2:05	2:15	2:35	2:10	2:25	2:05	2:35	5:05	R08 SSW, SW
1,2,3,4,6, 7	R09 WSW	2:20	2:35	2:15	2:25	2:05	2:20	2:35	2:10	2:25	2:05	2:35	4:50	R09 WSW
1,2,3,4,6	R10 W	2:15	2:30	2:10	2:25	2:05	2:20	2:30	2:05	2:20	2:05	2:30	4:25	R10 W
1,2,3,4,5, 6	R11 WNW	2:15	2:30	2:10	2:25	2:05	2:15	2:30	2:10	2:25	2:05	2:30	4:20	R11 WNW
1,2,3,4,5	R12 NW, NNW	2:25	2:35	2:20	2:35	2:15	2:25	2:40	2:15	2:30	2:10	2:45	1:10	R12 NW, NNW
1,2,3,5	R13 N	2:25	2:35	2:20	2:35	2:15	2:25	2:35	2:15	2:30	2:10	2:40	1:15	R13 N
1,8	R14	1:30	1:35	1:20	1:25	1:15	1:30	1:35	1:20	1:25	1:15	1:50	0:60	R14

Table 7-1B. Time To Clear The Indicated Area of 90 Percent of the Affected Population

Season		Summer		Summer		Summer	Winter		Winter		Winter	Summer	Summer	Season
Day of Week		Midweek		Weekend		All	Midweek		Weekend		All	Midweek	Weekend	Day of Week
Scenario:		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario
Time of Day		Midday		Midday		Evening	Midday		Midday		Evening	Midday	Midday	Time of Day
Zone	Region Wind Direction	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Good Weather	Rain	Good Weather	New Plant Construction	Air Show at Base	Region Wind Direction
Entire 2-Mile Region, 5-Mile Region, and EPZ														
1	R01 2-mile ring	2:45	2:50	2:25	2:40	2:25	2:45	2:50	2:20	2:35	2:25	3:20	2:00	R01 2-mile ring
1,2,3	R02 5-mile ring	4:10	4:30	4:05	4:30	4:10	4:10	4:30	4:00	4:30	4:10	4:50	3:10	R02 5-mile ring
1,2,3,4,5, 6,7,8	R03 Entire EPZ	4:20	4:45	4:20	4:45	4:00	4:20	4:45	4:10	4:35	4:00	5:00	11:20	R03 Entire EPZ
2-Mile Ring and Downwind to 5 Miles														
1	N, NNE, NE, ENE, E	Refer Region 1												N, NNE, NE, ENE, E
1,3	R04 ESE, SE, SSE, S	4:20	4:40	4:20	4:40	4:20	4:30	4:50	4:20	4:40	4:20	4:30	3:20	R04 ESE, SE, SSE, S
1,2,3	SSW, SW, WSW	Refer Region 2												SSW, SW, WSW
1,2	R05 W, WNW, NW, NNW	3:05	3:20	2:55	3:15	2:45	3:05	3:20	2:50	3:05	2:45	3:55	2:00	R05 W, WNW, NW, NNW
5-Mile Ring and Downwind to EPZ Boundary														
1,2,3	NNE	Refer Region 2												NNE
1,2,3,8	R06 NE, ENE, E, ESE, SE	4:05	4:30	4:05	4:30	4:00	4:10	4:30	4:00	4:30	4:10	4:50	3:10	R06 NE, ENE, E, ESE, SE
1,2,3,7	R07 SSE, S	4:15	4:40	4:15	4:40	4:00	4:15	4:40	4:10	4:30	4:00	4:50	11:20	R07 SSE, S
1,2,3,6,7	R08 SSW, SW	4:15	4:40	4:15	4:40	4:00	4:15	4:40	4:10	4:30	4:00	4:50	11:25	R08 SSW, SW
1,2,3,4,6, 7	R09 WSW	4:20	4:45	4:20	4:45	4:05	4:20	4:45	4:15	4:35	4:05	4:55	11:20	R09 WSW
1,2,3,4,6	R10 W	4:20	4:45	4:20	4:45	4:20	4:20	4:50	4:20	4:40	4:20	4:55	11:10	R10 W
1,2,3,4,5, 6	R11 WNW	4:20	4:45	4:20	4:45	4:15	4:20	4:45	4:20	4:40	4:15	5:00	11:10	R11 WNW
1,2,3,4,5	R12 NW, NNW	4:20	4:45	4:15	4:40	4:10	4:20	4:45	4:10	4:35	4:10	5:05	3:00	R12 NW, NNW
1,2,3,5	R13 N	4:15	4:40	4:10	4:40	4:10	4:20	4:40	4:10	4:35	4:10	4:55	3:10	R13 N
1,8	R14	2:45	2:50	2:25	2:40	2:25	2:45	2:50	2:20	2:35	2:25	3:25	2:00	R14

Table 7-1C. Time To Clear The Indicated Area of 95 Percent of the Affected Population

Season		Summer		Summer		Summer	Winter		Winter		Winter	Summer	Summer	Season
Day of Week		Midweek		Weekend		All	Midweek		Weekend		All	Midweek	Weekend	Day of Week
Scenario:		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario
Time of Day		Midday		Midday		Evening	Midday		Midday		Evening	Midday	Midday	Time of Day
Zone	Region Wind Direction Towards	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Good Weather	Rain	Good Weather	New Plant Construction	Air Show at Base	Region Wind Direction
Entire 2-Mile Region, 5-Mile Region, and EPZ														
1	R01 2-mile ring	3:00	3:10	2:40	2:50	2:40	3:00	3:10	2:40	2:50	2:40	3:50	2:10	R01 2-mile ring
1,2,3	R02 5-mile ring	4:50	5:20	4:50	5:20	4:50	5:00	5:30	4:50	5:20	4:50	5:10	3:40	R02 5-mile ring
1,2,3,4,5, 6,7,8	R03 Entire EPZ	5:00	5:30	5:00	5:20	4:30	5:00	5:30	4:50	5:20	4:50	5:20	12:10	R03 Entire EPZ
2-Mile Ring and Downwind to 5 Miles														
1	N, NNE, NE, ENE, E	Refer Region 1												N, NNE, NE, ENE, E
1,3	R04 ESE, SE, SSE, S	4:50	5:20	4:50	5:20	4:50	5:00	5:30	4:50	5:20	4:50	5:10	3:50	R04 ESE, SE, SSE, S
1,2,3	SSW, SW, WSW	Refer Region 2												SSW, SW, WSW
1,2	R05 W, WNW, NW, NNW	3:20	3:35	3:05	3:25	3:00	3:20	3:30	3:00	3:20	3:00	4:05	2:10	R05 W, WNW, NW, NNW
5-Mile Ring and Downwind to EPZ Boundary														
1,2,3	NNE	Refer Region 2												NNE
1,2,3,8	R06 NE, ENE, E, ESE, SE	4:50	5:20	4:50	5:20	4:50	5:00	5:30	4:50	5:20	4:50	5:10	3:40	R06 NE, ENE, E, ESE, SE
1,2,3,7	R07 SSE, S	4:50	5:20	4:50	5:20	4:40	5:00	5:30	4:50	5:20	4:50	5:10	12:10	R07 SSE, S
1,2,3,6,7	R08 SSW, SW	4:50	5:20	4:50	5:20	4:40	5:00	5:30	4:50	5:20	4:50	5:10	12:10	R08 SSW, SW
1,2,3,4,6, 7	R09 WSW	4:50	5:20	4:50	5:20	4:40	5:00	5:30	4:50	5:20	4:50	5:20	12:10	R09 WSW
1,2,3,4,6	R10 W	5:00	5:20	4:50	5:20	5:00	5:00	5:30	4:50	5:20	5:00	5:20	12:00	R10 W
1,2,3,4,5, 6	R11 WNW	5:00	5:20	4:50	5:20	5:00	5:00	5:30	4:50	5:20	5:00	5:20	12:00	R11 WNW
1,2,3,4,5	R12 NW, NNW	4:50	5:20	4:50	5:20	4:40	5:00	5:30	4:50	5:20	4:50	5:20	3:40	R12 NW, NNW
1,2,3,5	R13 N	5:00	5:30	5:00	5:20	5:00	5:00	5:30	4:50	5:20	5:00	5:20	3:50	R13 N
1,8	R14	3:00	3:10	2:40	2:50	2:40	3:00	3:10	2:40	2:50	2:40	3:50	2:10	R14

Table 7-1D. Time To Clear The Indicated Area of 100 Percent of the Affected Population

Season		Summer		Summer		Summer	Winter		Winter		Winter	Summer	Summer	Season
Day of Week		Midweek		Weekend		All	Midweek		Weekend		All	Midweek	Weekend	Day of Week
Scenario:		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	Scenario
Time of Day		Midday		Midday		Evening	Midday		Midday		Evening	Midday	Midday	Time of Day
Zone	Region Wind Direction	Good Weather	Rain	Good Weather	Rain	Good Weather	Good Weather	Rain	Good Weather	Rain	Good Weather	New Plant Construction	Air Show at Base	Region Wind Direction Towards
Entire 2-Mile Region, 5-Mile Region, and EPZ														
1	R01 2-mile ring	4:10	4:10	4:00	4:00	4:00	4:10	4:10	4:00	4:00	4:00	4:30	3:50	R01 2-mile ring
1,2,3	R02 5-mile ring	5:50	6:20	5:50	6:20	5:50	6:00	6:30	5:50	6:20	5:50	6:10	4:20	R02 5-mile ring
1,2,3,4,5, 6,7,8	R03 Entire EPZ	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R03 Entire EPZ
2-Mile Ring and Downwind to 5 Miles														
1	N, NNE, NE, ENE, E	Refer Region 1												N, NNE, NE, ENE, E
1,3	R04 ESE, SE, SSE, S	5:50	6:20	5:50	6:20	5:40	5:50	6:30	5:50	6:20	5:40	6:10	4:20	R04 ESE, SE, SSE, S
1,2,3	SSW, SW, WSW	Refer Region 2												SSW, SW, WSW
1,2	R05 W, WNW, NW, NNW	4:10	4:10	4:10	4:10	4:10	4:10	4:20	4:10	4:10	4:00	4:40	4:00	R05 W, WNW, NW, NNW
5-Mile Ring and Downwind to EPZ Boundary														
1,2,3	NNE	Refer Region 2												NNE
1,2,3,8	R06 NE, ENE, E, ESE, SE	5:50	6:20	5:50	6:20	5:50	6:00	6:30	5:50	6:20	5:50	6:10	4:20	R06 NE, ENE, E, ESE, SE
1,2,3,7	R07 SSE, S	6:00	6:30	6:00	6:30	5:50	6:00	6:40	6:00	6:30	5:50	6:20	13:00	R07 SSE, S
1,2,3,6,7	R08 SSW, SW	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R08 SSW, SW
1,2,3,4,6, 7	R09 WSW	6:10	6:40	6:10	6:40	6:00	6:10	6:50	6:00	6:30	6:00	6:30	13:00	R09 WSW
1,2,3,4,6	R10 W	6:00	6:40	6:00	6:30	6:00	6:10	6:40	6:00	6:30	6:00	6:20	12:50	R10 W
1,2,3,4,5, 6	R11 WNW	6:00	6:40	6:00	6:30	6:00	6:10	6:40	6:00	6:30	6:00	6:20	12:50	R11 WNW
1,2,3,4,5	R12 NW, NNW	6:00	6:30	6:00	6:30	5:50	6:00	6:40	5:50	6:30	5:50	6:20	4:20	R12 NW, NNW
1,2,3,5	R13 N	6:00	6:30	5:50	6:20	5:50	6:00	6:40	5:50	6:20	5:50	6:20	4:30	R13 N
1,8	R14	4:10	4:10	4:00	4:00	4:00	4:10	4:10	4:00	4:00	4:00	4:30	4:00	R14

Table 7-2. Description of Evacuation Regions									
Region	**Description**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
R01	2-Mile Ring	**X**							
R02	5-Mile Ring	**X**	**X**	**X**					
R03	Full EPZ	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Evacuate 2-Mile Ring and 5 Miles Downwind									
Region	**Wind Direction Towards:**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	N, NNE, NE, ENE, E	**See Region 1**							
R04	ESE, SE, SSE, S	**X**		**X**					
	SSW, SW, WSW	**See Region 2**							
R05	W, WNW, NW, NNW	**X**	**X**						
Evacuate 5-Mile Ring and Downwind to EPZ Boundary									
Region	**Wind Direction Towards:**	**ZONE**							
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**
	NNE	**See Region 2**							
R06	NE, ENE, E, ESE, SE	**X**	**X**	**X**					**X**
R07	SSE, S	**X**	**X**	**X**				**X**	
R08	SSW, SW	**X**	**X**	**X**			**X**	**X**	
R09	WSW	**X**	**X**	**X**	**X**		**X**	**X**	
R10	W	**X**	**X**	**X**	**X**		**X**		
R11	WNW	**X**	**X**	**X**	**X**	**X**	**X**		
R12	NW, NNW	**X**	**X**	**X**	**X**	**X**			
R13	N	**X**	**X**	**X**		**X**			
R14	*	**X**							**X**

*This Region was added at Constellation Energy's request. It is an evacuation of the 2-Mile Ring and downwind (Towards Dorchester County) to the EPZ Boundary.

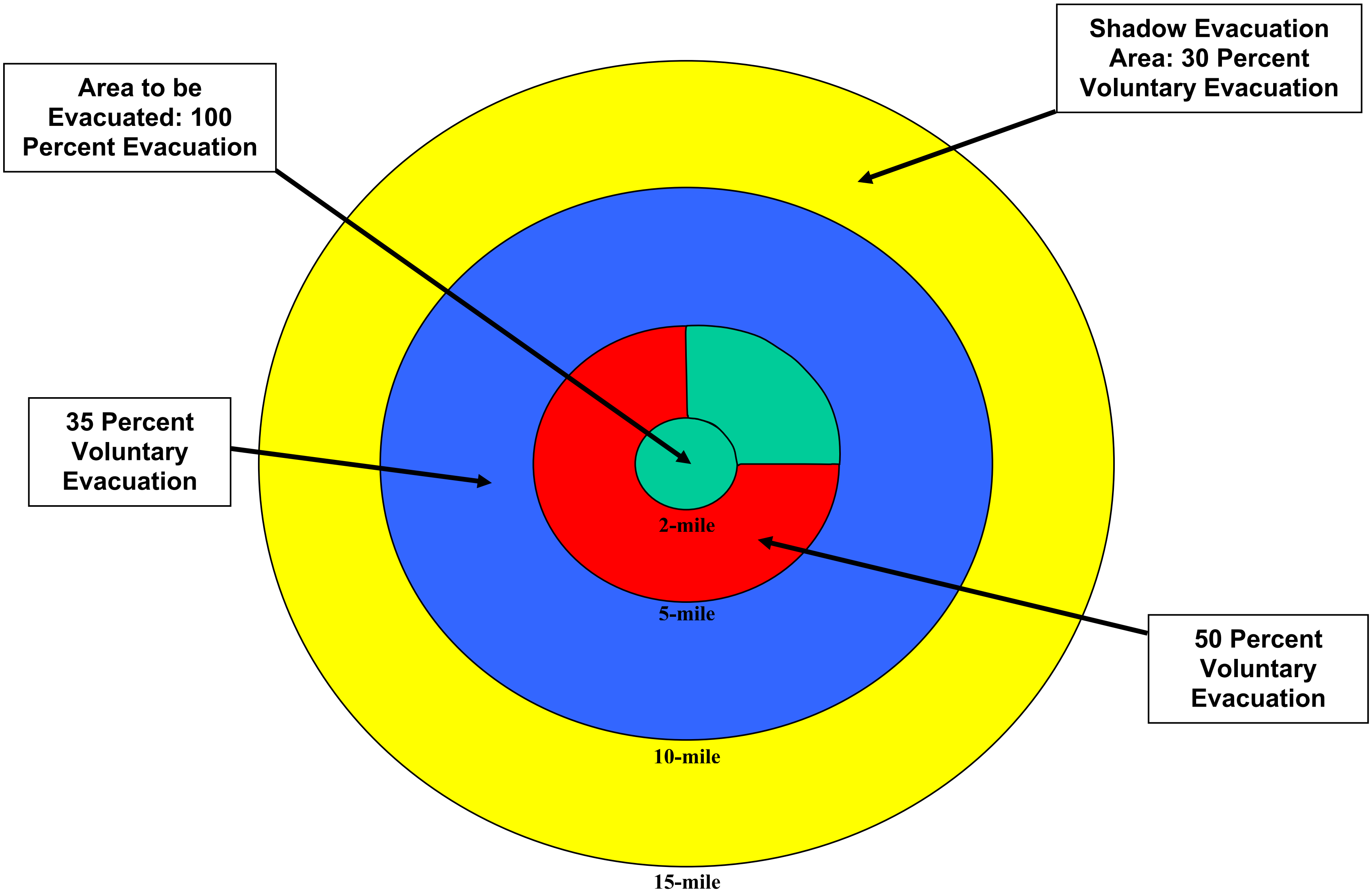


Figure 7-1. Assumed Evacuation Response

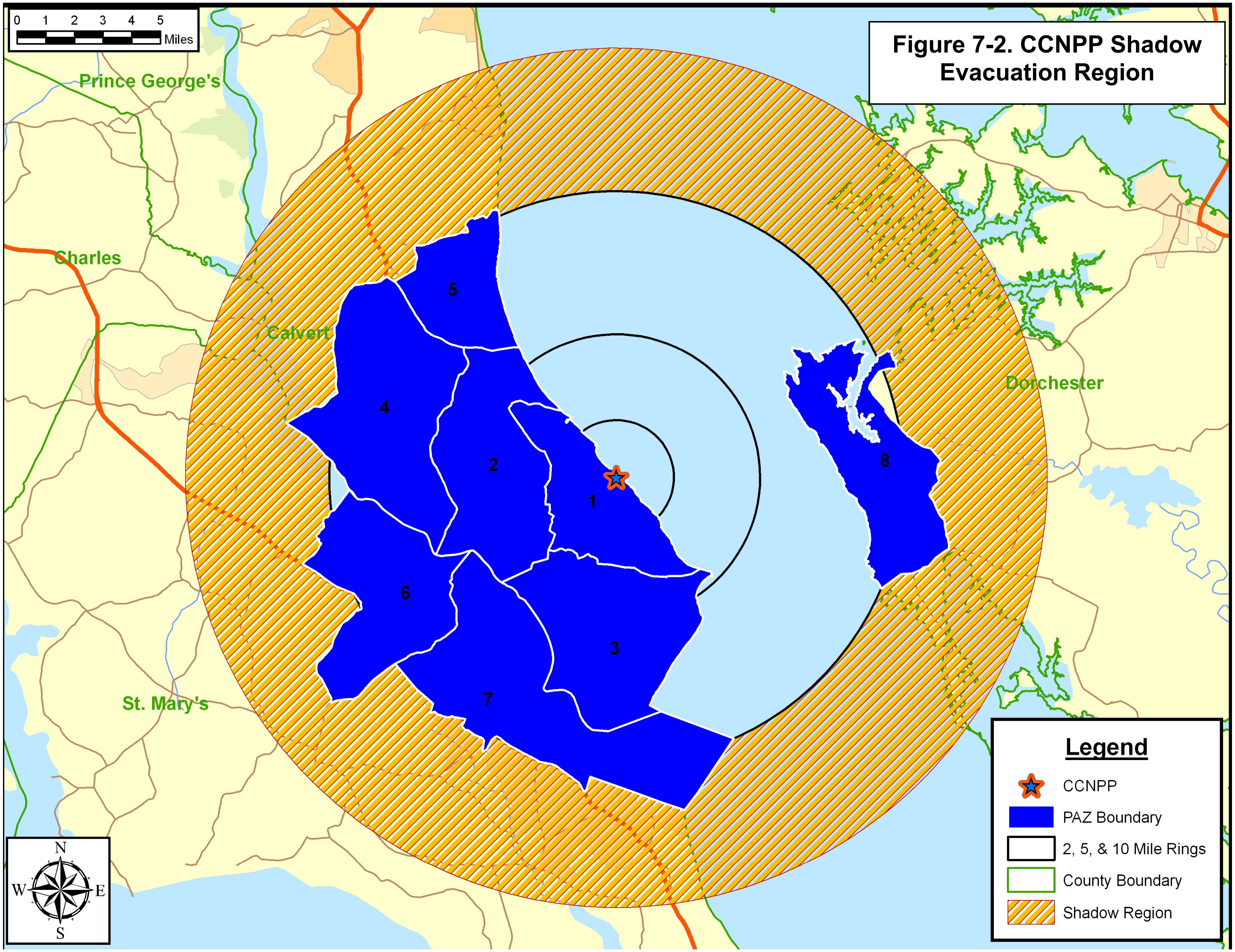


Figure 7-2. CCNPP Shadow Evacuation Region
0 1 2 3 4 5
Miles
Prince George's
Charles
Calvert
St. Mary's
Dorchester
1
2
3
4
5
6
7
8
N
W
E
S
Legend
CCNPP
PAZ Boundary
2, 5, & 10 Mile Rings
County Boundary
Shadow Region

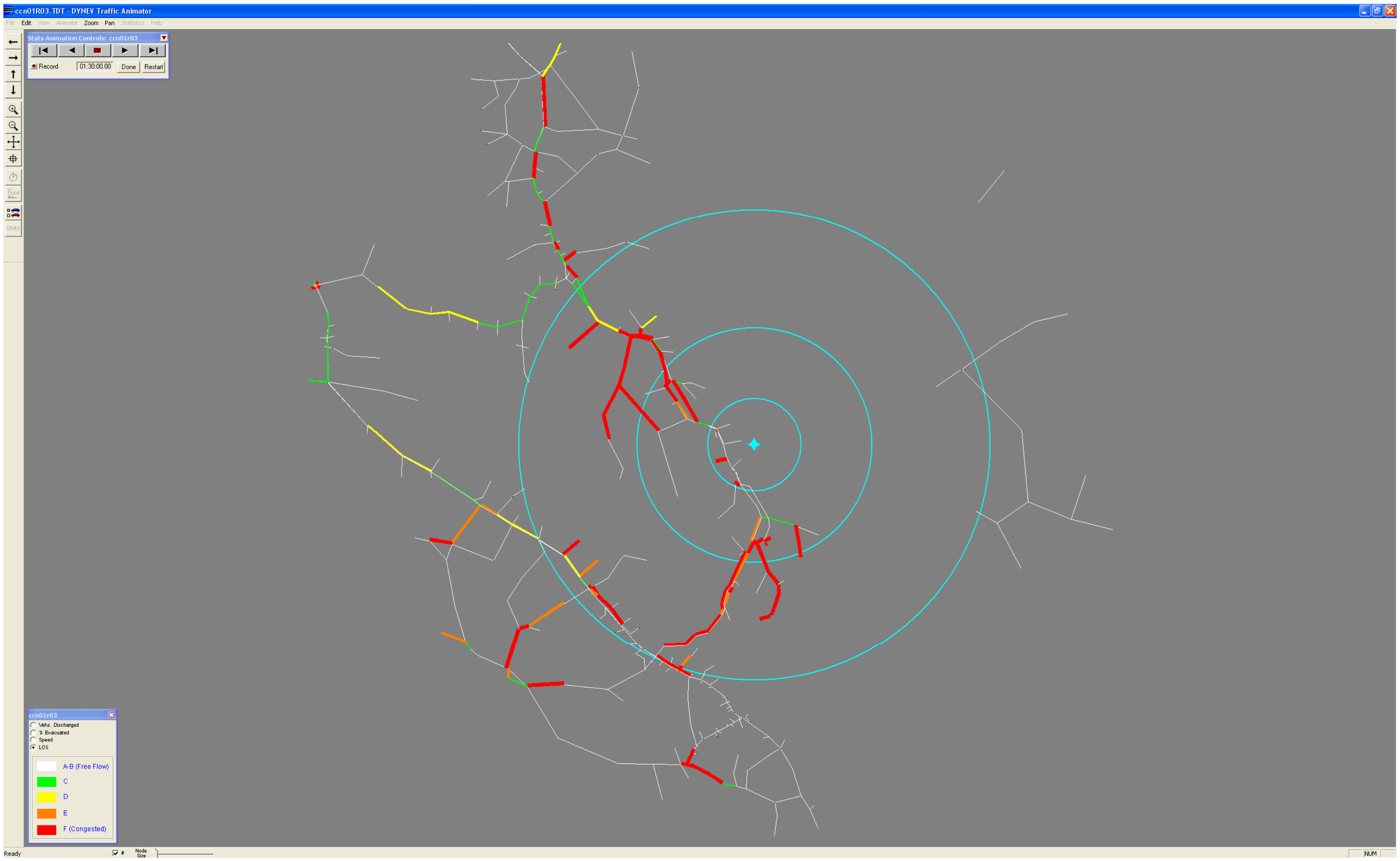


Figure 7-3. Congestion Patterns at 1½ Hours after the Evacuation Advisory – Scenario 1, Full EPZ

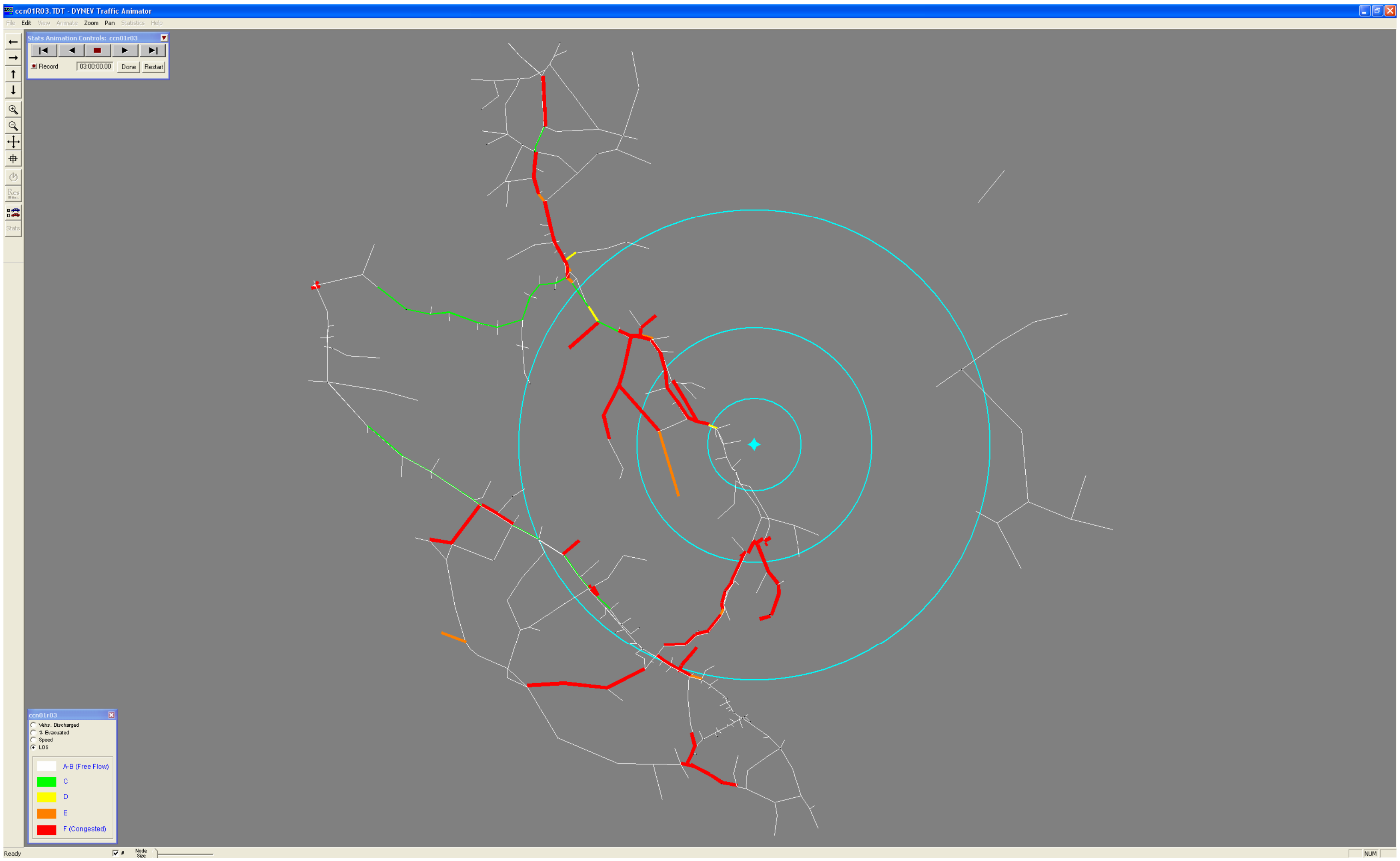


Figure 7-4 Congestion Patterns at 3 Hours after the Evacuation Advisory – Scenario 1, Full EPZ

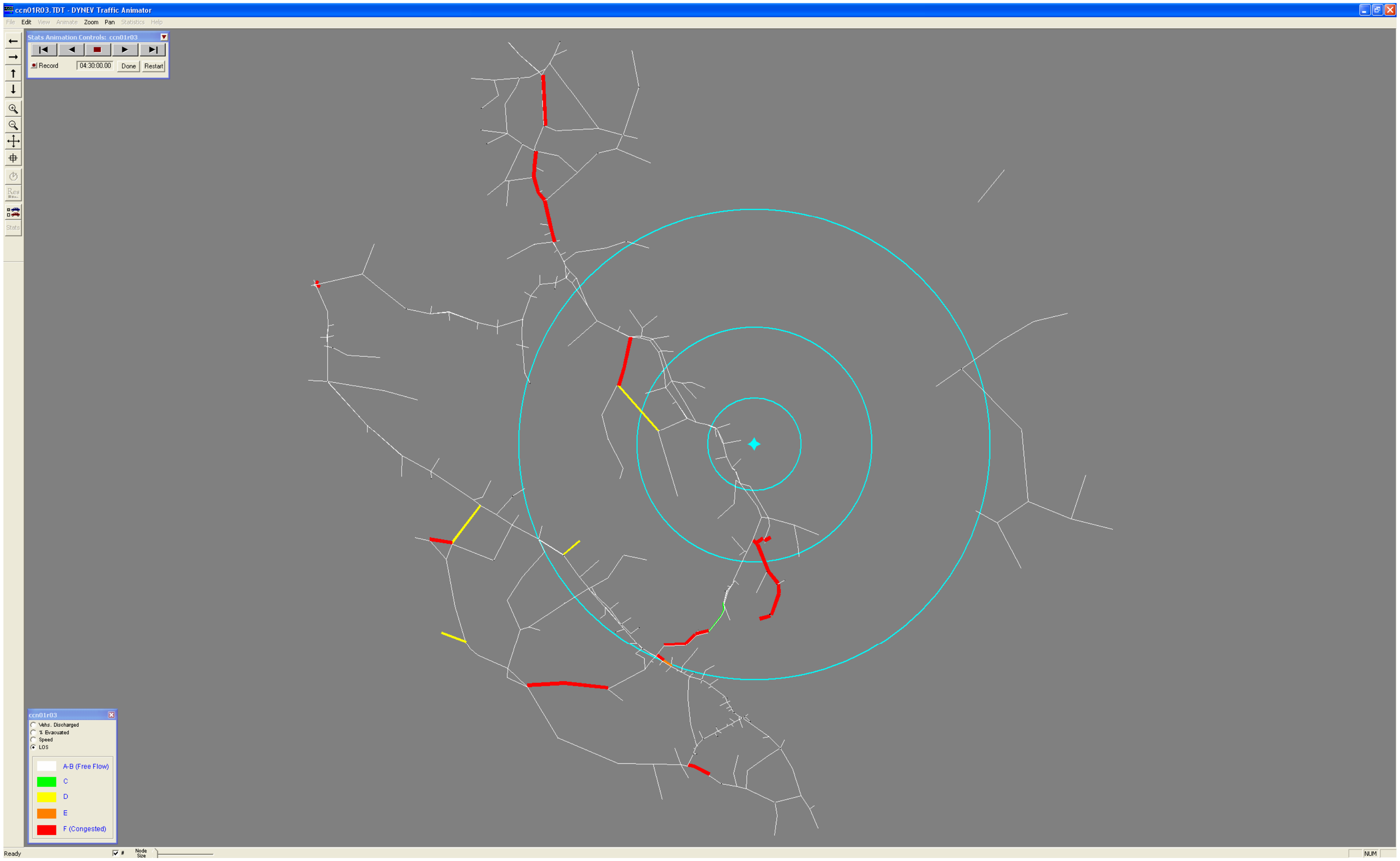


Figure 7-5 Congestion Patterns at 4½ Hours after the Evacuation Advisory– Scenario 1, Full EPZ

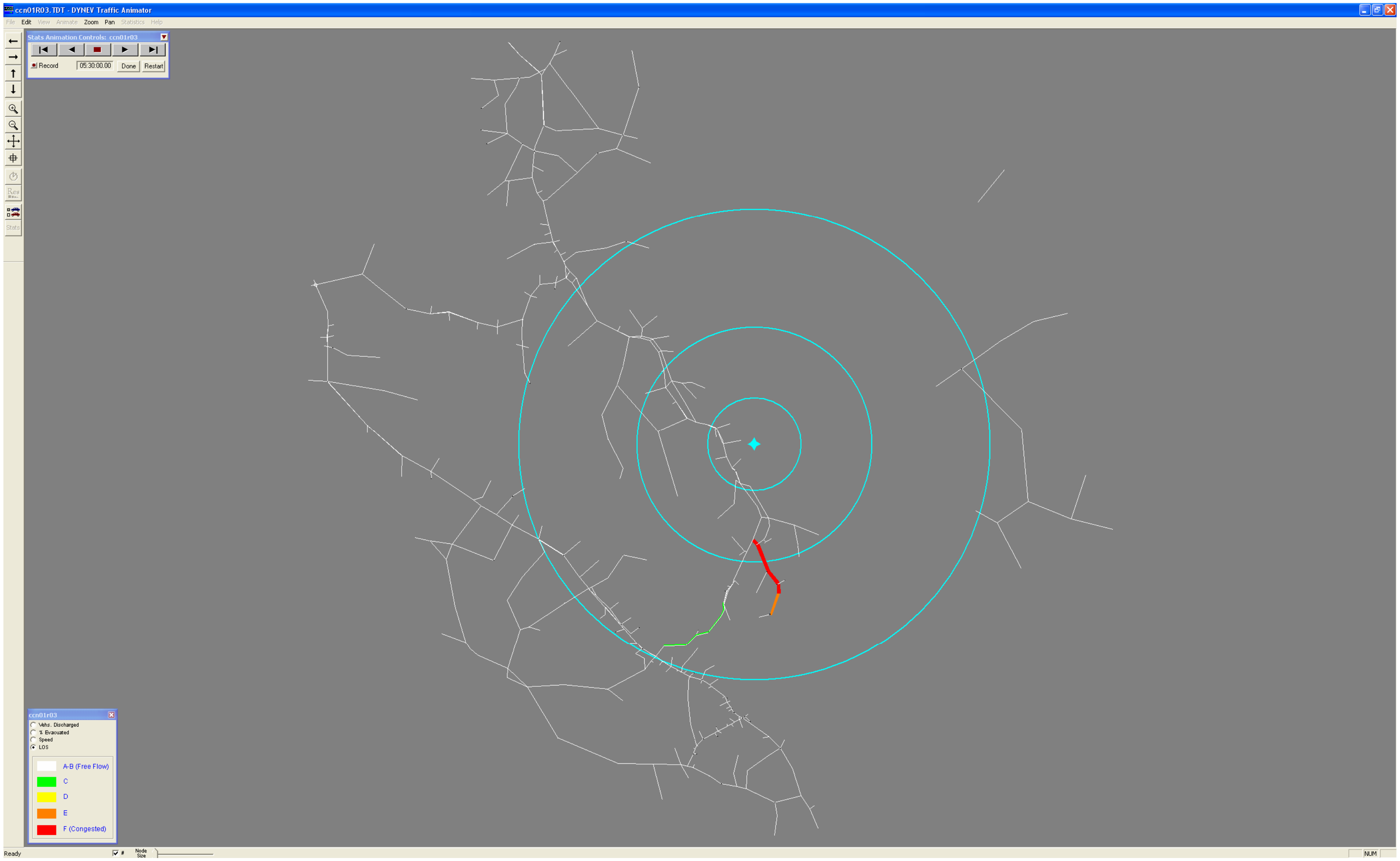


Figure 7-6 Congestion Patterns at 5½ Hours after the Evacuation Advisory – Scenario 1, Full EPZ

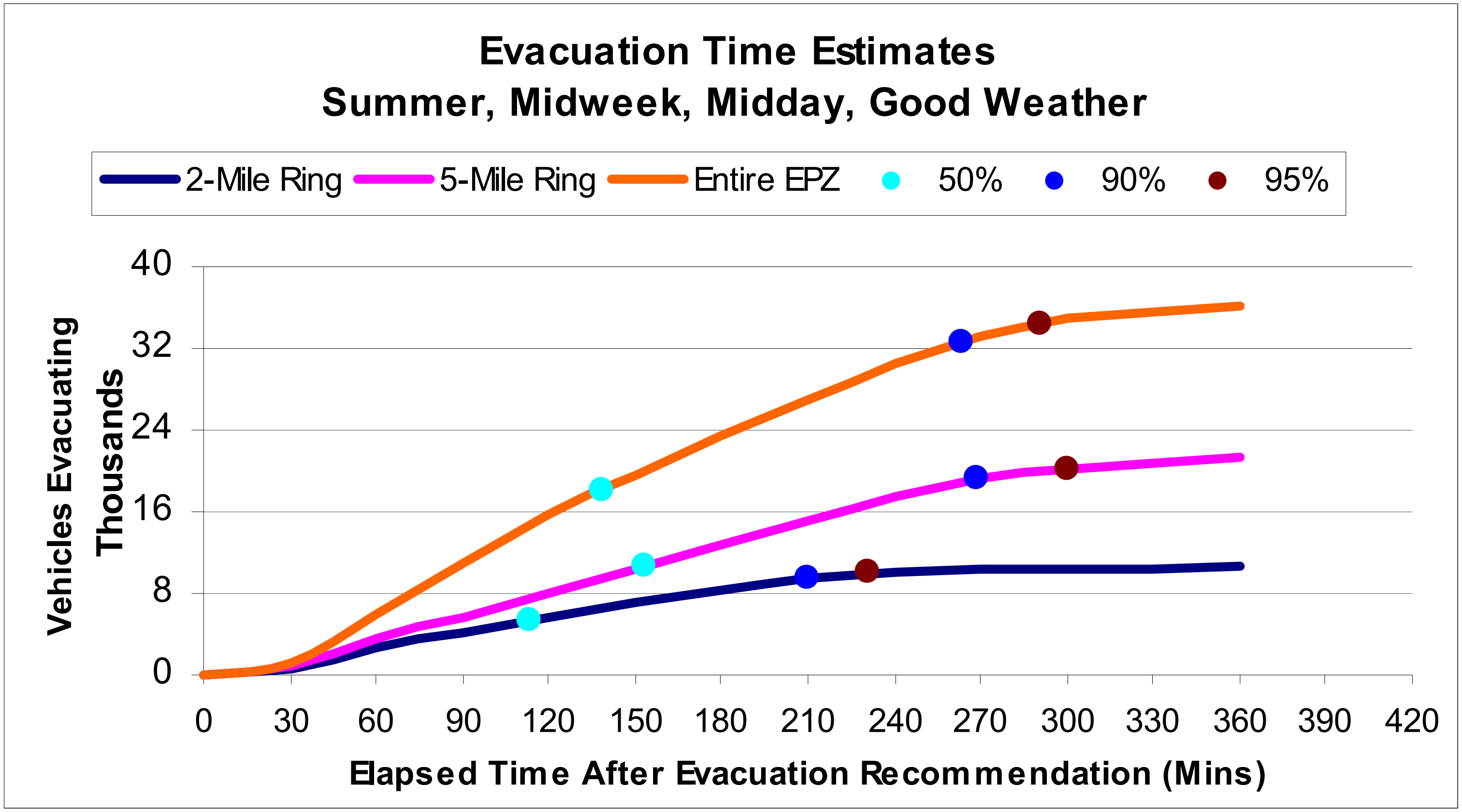


Figure 7-7. Evacuation Time Estimates for CCNPP Summer, Midweek, Midday, Good Weather Evacuation of Region R03 (Entire EPZ)

8. TRANSIT-DEPENDENT AND SPECIAL FACILITY EVACUATION TIME ESTIMATES

This section details the analyses applied and the results obtained in the form of evacuation time estimates for transit vehicles (buses). The demand for transit service reflects the needs of two population groups: (1) residents, employees and transients with no vehicles available; and (2) residents of special facilities such as schools, health-support facilities, institutions and child-care facilities.

These transit vehicles merge into and become a part of the general evacuation traffic environment that is comprised mostly of "passenger cars" (pc's). The presence of each transit vehicle in the evacuating traffic stream is represented within the modeling paradigm described in Appendix D as equivalent to two pc's. This equivalence factor represents the larger size and more sluggish operating characteristics of a transit vehicle relative to those of a pc.

Transit vehicles must be mobilized in preparation for their respective evacuation missions. Specifically:

- Bus drivers must be alerted
- They must travel to the bus depot
- They must be briefed there and assigned to a route or facility

These activities consume time. Based on data provided by the emergency staff for the EPZ counties, it is estimated that bus mobilization time will average between 60 and 90 minutes extending from the Advisory to Evacuate to the time when buses arrive at their respective assignments.

During this mobilization period, other mobilization activities are taking place. One of these is the action taken by parents, neighbors, relatives and friends to pick up children from school prior to the arrival of buses, so that they may join their families. Virtually all studies of evacuations have concluded that this "bonding" process of uniting family members is universally prevalent during emergencies and should be anticipated in the planning process. Many emergency plans, however, call for parents to pick up children at the host schools to speed the evacuation of the school children in the event that buses need to return to the EPZ and evacuate transit dependents. We provide estimates of buses under the assumption that no children will be picked up at school by their parents as an upper bound estimate of the transit vehicles needed.

The procedure is:

- Estimate demand for transit service
- Estimate time to perform all transit functions
- Estimate route travel times to the EPZ boundary and to the host schools.

8.1 Transit-Dependent People - Demand Estimate

The telephone survey (see Appendix F) results were used to estimate the portion of the population requiring transit service:

- Those persons in households that do not have a vehicle available.
- Those persons in households that do have vehicle(s) that would not be available at the time the evacuation is advised.

In the latter group, the vehicle(s) may be used by a commuter(s) who does not return (or is not expected to return) home to evacuate the household.

Table 8-1 presents estimates of transit-dependent people. Note:

- Estimates of persons requiring transit vehicles include school children. For those evacuation scenarios where children are at school when an evacuation is advised, separate transportation is provided for the school children. The actual need for transit vehicles by residents is thereby less than the given estimates. However, we will not reduce our estimates of transit vehicles since it would add to the complexity of the implementation procedures.
- It is reasonable and appropriate to consider that many transit-dependent persons will evacuate by ride-sharing with neighbors, friends or family. For example, nearly 80 percent of those who evacuated from Mississauga, Ontario[1] who did not use their own cars, shared a ride with neighbors or friends. Other documents report that approximately 70 percent of transit-dependent persons were evacuated via ride-sharing. **We will adopt a conservative estimate that 50 percent of transit-dependent persons will ride-share.**

The estimated number of bus trips needed to service transit-dependent persons is based on an estimate of average bus occupancy of 30 persons at the conclusion of the bus run. Transit vehicle seating capacities typically equal or exceed 60 children (equivalent to 40 adults). If transit vehicle evacuees are two-thirds adults and one-third children, then the number of "adult seats" taken by 30 persons is 20 + (2/3 x10) = 27. On this basis, the average load factor anticipated is (27/40) x 100 = 68 percent. Thus, if the actual demand for service exceeds the estimates of Table 8-1 by 50 percent, the demand for service can still be accommodated by the available bus seating capacity.

Table 8-1 indicates that transportation must be provided for 980 people. Therefore, a total of 33 bus runs are required to transport this population to reception centers.

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[1] The Mississauga Evacuation – Final Report, The Institute for Environmental Studies, University of Toronto, June 1981

To illustrate this estimation procedure, we calculate the number of persons, P, requiring public transit or ride-share, and the number of buses, B, required for the CCNPP EPZ:

$$P = 19{,}715 \times (0.025 \times 1.50 + 0.222 \times (1.64 - 1) \times 0.645 \times 0.42 + 0.393 \times (2.81 - 2) \times (0.645 \times 0.42)^2)$$
$$P = 19{,}715 * (0.09935) = 1{,}960$$
$$B = (0.5 \times P) \div 30 = 33$$

These calculations are explained as follows:

- All members (1.5 avg.) of households (HH) with no vehicles (2.5%) will evacuate by public transit or ride-share. The term 19,715 (number of households) x 0.025 x 1.5, accounts for these people.
- The members of HH with 1 vehicle away (22.2%), who are at home, equal (1.64-1). The number of HH where the commuter will not return home is equal to (19,715 x 0.222 x 0.645 x 0.42), as 64.5% of EPZ households have a commuter, 42% of which would not return home in the event of an emergency. The number of persons who will evacuate by public transit or ride-share is equal to the product of these two terms.
- The members of HH with 2 vehicles that are away (39.3%), who are at home, equal (2.81 – 2). The number of HH where neither commuter will return home is equal to 19,715 x 0.393 x $(0.645 \times 0.42)^2$. The number of persons who will evacuate by public transit or ride-share is equal to the product of these two terms.
- Households with 3 or more vehicles are assumed to have no need for transit vehicles.
- The total number of persons requiring public transit is the sum of such people in HH with no vehicles, or with 1 or 2 vehicles that are away from home.

8.2 School Population – Transit Demand

Table 8-2 presents the school population and transportation requirements for the direct evacuation of all schools within the EPZ. The column in Table 8-2 entitled "Bus Runs Required" specifies the number of buses required for each school under the following set of assumptions and estimates:

- No students will be picked up by their parents prior to the arrival of the buses.
- Bus capacity, expressed in students per bus, is set to 70 for primary schools and 50 for middle and high schools.
- Those staff members who do not accompany the students will evacuate in their private vehicles.

- No allowance is made for student absenteeism which is in the neighborhood of 3 percent, daily.

We recommend that the Counties introduce procedures whereby the schools are contacted prior to the dispatch of buses from the depot (approximately one hour after the Advisory to Evacuate), to ascertain the current estimate of students to be evacuated. In this way, the number of buses dispatched to the schools will reflect the actual number needed. Some parents will likely pick up their children at school, although they are asked to pick children up at the host schools. Those buses originally allocated to evacuate school children that are not needed due to children being picked up by their parents, can be gainfully assigned to service other facilities or those persons who do not have access to private vehicles or to ride-sharing.

Table 8-3 presents a list of the host schools for each school in the EPZ; Figure 8-3 maps all of the EPZ schools and their host schools. Those students not picked up by their parents prior to the arrival of the buses, will be transported to these host schools where they will be subsequently retrieved by their respective families.

8.3 Special Facility Demand

Table 8-4 presents the current census for special facilities obtained through phone calls to the facilities and through Internet searches. Approximately 103 people have been identified as living in, or being treated in, these facilities. This data also indicates the number of wheelchair-bound people. The transportation requirements for those people residing in special facilities are also presented. The number of bus runs estimated assumes 30 ambulatory patients per trip. Wheelchair buses can transport 15 patients while vans can transport 4 patients. There are 2 senior centers listed with a total of 59 seniors at the facilities during the day; there are no overnight accommodations at these facilities. Based on discussions with representatives from these facilities, most of the seniors drive to the facility each day. Some of the seniors, however, will require transportation. We have conservatively included all of the visitors to the senior centers as transit dependent people. In total, we estimate that 5 buses and 2 wheelchair vans are required to meet the special facility demand.

8.4 Evacuation Time Estimates for Transit-Dependent People

County bus resources are assigned to evacuating school children as the first priority in the event of an emergency. In the event that the allocation of buses dispatched from the depots to the various facilities and to the bus routes is somewhat “inefficient”, or if there is a shortfall of available drivers, then there may be a need for some buses to return to the EPZ from the host school after completing their first evacuation trip, to complete a “second wave” of providing transport service to evacuees. Based on discussions with the EPZ counties, there are sufficient bus resources to evacuate the schools in a single wave. There are not, however, sufficient bus resources to evacuate the transit-dependent population in a single wave, as most of the buses in the counties will be allocated for the evacuation of school children. For this reason, the ETE will be calculated for both a one wave transit-dependent evacuation and for two waves (Table 8-7). Of course, if the impacted Evacuation Region is other than R03 (the entire EPZ), then there will likely be ample transit resources relative to demand in the impacted Region and this discussion of a second wave would likely not apply.

When school evacuation needs are satisfied, subsequent assignments of buses (if available) to service the transit-dependent should be sensitive to their mobilization time. Clearly, the buses should be dispatched after people have completed their mobilization activities and are in a position to board the buses when they arrive at the pick-up points.

Evacuation Time Estimates for Transit Trips were developed using both good weather and adverse weather conditions. Figure 8-1 presents the chronology of events relevant to transit operations. The elapsed time for each activity will now be discussed with reference to Figure 8-1.

<u>Activity: Mobilize Drivers (A→B→C)</u>

Mobilization is the elapsed time from the Advisory to Evacuate until the time the buses arrive at the facility to be evacuated. Based on data provided by the counties, for a rapidly escalating radiological emergency with no observable indication before the fact, drivers would likely require between 60 and 90 minutes (depending on the facility to be evacuated) to be contacted, to travel to the depot, be briefed, and to travel to the transit-dependent facilities. Mobilization time is extended by 10 minutes when raining to account for slower travel times.

<u>Activity: Board Passengers (C→D)</u>

Studies have shown that passengers can board a bus at headways of 2-4 seconds (Ref. HCM2000 Page 27-27). Therefore, the total dwell time to service passengers boarding a bus to capacity at a single stop (e.g., at a school) is about 5 minutes. A loading time of 10 minutes will be used for rain scenarios. For multiple stops along a pick-up route we must allow for the additional delay associated with stopping and starting at each pick-up point. This additional delay to service passengers expands this estimate of boarding time to 30 minutes in good weather, and 35 minutes in rain.

<u>Activity: Travel to EPZ Boundary (D→E)</u>

<u>School Evacuation</u>

The distance from a school to the EPZ boundary is measured using Geographical Information Systems (GIS) software along the most likely route out of the EPZ. The travel times to the EPZ boundary are based on evacuation speeds output by the model (PC-DYNEV). The average speed for an evacuation of the full EPZ under Scenario 6 (winter [school in session], good weather) and Scenario 7 (with rain) at 60 minutes is 28.3 mph and 24.2 mph, respectively, and at 90 minutes is 19.6 mph and 16.7 mph, respectively. The travel time from the EPZ boundary to the Host School is computed assuming average speeds of 40 mph and 35 mph for good weather and rain, respectively. These speeds are assumed outside of the EPZ as congestion will likely be less pronounced and travel speeds will be faster.

Tables 8-5A (good weather) and 8-5B (rain) present the following evacuation time estimates (rounded up to the nearest 5 minutes) for schools in the EPZ: (1) The elapsed time from the Advisory to Evacuate until the bus exits the EPZ; and (2) The elapsed time until the bus reaches the Host School. The evacuation time out of the EPZ can be computed as the sum of travel times associated with Activities A→B→C, C→D, and D→E (For example: 90 min. + 5 + 27 = 2:05, rounded to the nearest 5 minutes, for Patuxent High School, with good weather). The evacuation time to the Host School is determined by adding the time associated with Activity E→F (discussed below), to this EPZ evacuation time. **Note: the evacuation routes used for some of the schools within Calvert County that are south of CCNPP travel through St. Mary's County along Three Notch Road (State Route 235), Hallowing Point Road (State Route 231) and State Route 2/4. The buses are not routed northbound along Route 2/4 because this would take the school buses directly towards the CCNPP. This results in longer routes and longer travel times than expected from the EPZ boundary to the Host Schools.**

<u>Evacuation of Transit-Dependent Population</u>

The buses dispatched from the depots to service the transit-dependent evacuees will be scheduled so that they arrive at their respective routes after their passengers have completed their mobilization. As indicated in Section 5, about 90 percent of the evacuees will complete their mobilization when the first buses will begin their routes, 90 minutes after the Advisory to Evacuate.

Those buses servicing the transit-dependent evacuees will first travel along their pick-up routes, then proceed out of the EPZ. Table 8-7 presents the transit-dependent population evacuation time estimates for each route obtained using the procedures outlined above.

<u>Activity: Travel to Reception Center/Host School (E→F)</u>

The distances from the EPZ boundary to the host schools are measured using GIS software along the most likely route from the EPZ to the host school. For a one-wave evacuation, this travel time outside the EPZ does not contribute to the ETE. For a two-wave evacuation, the ETE for buses must be considered separately, since it could exceed the ETE for the general public.

<u>Activity: Passengers Leave Bus (F→G)</u>

Passengers can de-board within 5 minutes. The bus driver takes a 10 minute break.

Activity: Bus Returns to Route for Second Wave Evacuation (G→C)

The buses assigned to return to the EPZ to perform a "second wave" evacuation of transit-dependent evacuees will be those buses that evacuated the school children as they will likely be the first resources available. Most of the host schools are in close proximity to the transit bus route identified below, thus the travel time to the start of the bus route is assumed to be negligible. The bus travels its route and picks up transit-dependent evacuees along the route.

Analysis of Bus Route Operations

Based on the highway network within the EPZ, the suggested route for bus operations to service the transit dependent population within the EPZ is shown in Figure 8-2. A single loop that traverses Three Notch Road (State Route 235), Hallowing Point Road (State Route 231) and State Route 2/4 would best service the transit dependent residents. These buses would be dispatched in 2 batches – one at 90 minutes after the Advisory to Evacuate and the second batch at 120 minutes. These buses would traverse this main route and circulate within the higher population areas in the EPZ. These passengers would be dropped off at the reception centers along the bus route. The mobilization times (135 minutes for good weather, 160 minutes for rain) for a second-wave evacuation are the average ETE for schools to arrive at the Host Schools, as these buses will return to the EPZ to service the transit dependent. The second batch of buses (if needed) will be delayed by 30 minutes in the second-wave also.

The ETE for good weather for each batch of buses is given in Table 8-7A. Table 8-7B provides the ETE for rain. The route length is approximately 58 miles; the average travel speeds output by PC-DYNEV are used to estimate route travel times. The average speed for an evacuation of the full EPZ under Scenario 6 (winter, good weather) and Scenario 7 (with rain) at 90 minutes is 19.6 mph and 16.7 mph, respectively, and at 120 minutes is 16.0 mph and 13.3 mph, respectively.

The ETE for a single wave transit-dependent evacuation does not exceed the general population ETE; however, a two-wave evacuation would exceed the general population ETE.

Evacuation of Ambulatory Persons from Special Facilities

The bus operations for this group are similar to those for school evacuation except:

- Buses are assigned on the basis of 25-30 patients to allow for staff to accompany the patients.
- The passenger loading time will be longer at approximately one minute per patient to account for the time to move patients from inside the facility to the vehicles.

It is estimated that mobilization time averages 90 minutes. In the event there is a shortfall of transit vehicles for a “first-wave” evacuation, then buses used to evacuate schools will have to return to evacuate the special facilities in addition to evacuating the other transit-dependents.

The school ETE to Host Schools is 2:20 on average, and about 15 minutes of additional inbound travel time to the special facility from the host school would be required. It follows, therefore, that about one hour and 5 minutes (difference of 140 minute average ETE to host school plus 15 minute inbound travel time and assumed 90 minute mobilization time) would have to be added to the calculated ETE for special facilities, in the event they are evacuated as a “second wave.”

The average distance of the medical facilities within the EPZ to the EPZ boundary is approximately 5 miles. Thus, buses will have to travel 5 miles, on average, to leave the EPZ. The average speed output by the model at 90 minutes for Region 3, Scenario 6 is 19.6 mph; thus, travel time out of the EPZ is 15 minutes.

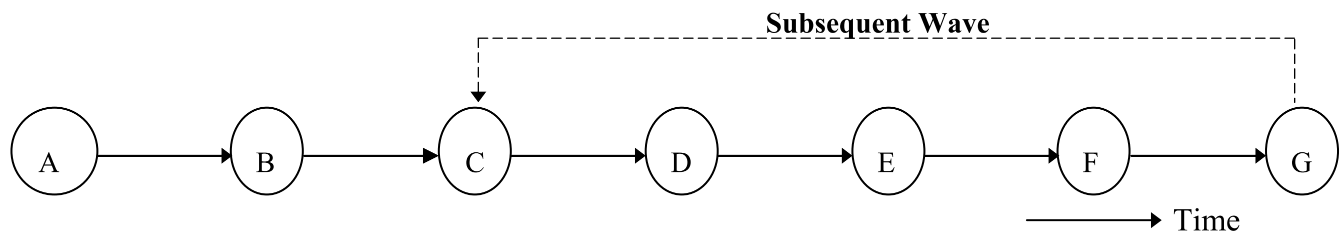
The ETE for each medical facility is the sum of the mobilization time, loading time, and travel time out of the EPZ. For example, the calculation of ETE for the bus servicing the Southern Pines Senior Center with a census of 30 is:

ETE: 90 + 30 x 1 + 15 = 135 min. or 2:15. 3:20 for “second wave”.

Table 8-4 indicates that 2 wheelchair van runs are needed for the entire EPZ. Loading times are estimated at 5 minutes per wheelchair bound person as staff will have to assist them in boarding the van. The ETE for the wheelchair-bound patients is calculated in the same way as the ETE for the ambulatory patients. For example, the ETE for the wheelchair bound at Solomon’s Nursing Center is:

ETE: 90 + 7 x 5 + 15 = 140 min. or 2:20.

Thus, the ETE for special facilities do not exceed the general population ETE.



Event

A	Advisory to Evacuate
B	Bus Dispatched from Depot
C	Bus Arrives at Facility/Pick-up Route
D	Bus Departs for Reception Center/Host School
E	Bus Exits Region
F	Bus Arrives at Reception Center/Host School
G	Bus Available for “Second Wave” Evacuation Service

Activity

A→B	Driver Mobilization
B→C	Travel to Facility or to Pick-up Route
C→D	Passengers Board the Bus
D→E	Bus Travels Towards Region Boundary
E→F	Bus Travels Towards Reception Center/Host School Outside the EPZ.
F→G	Passengers Leave Bus; Driver Takes a Break

Figure 8-1. Chronology of Transit Evacuation Operations

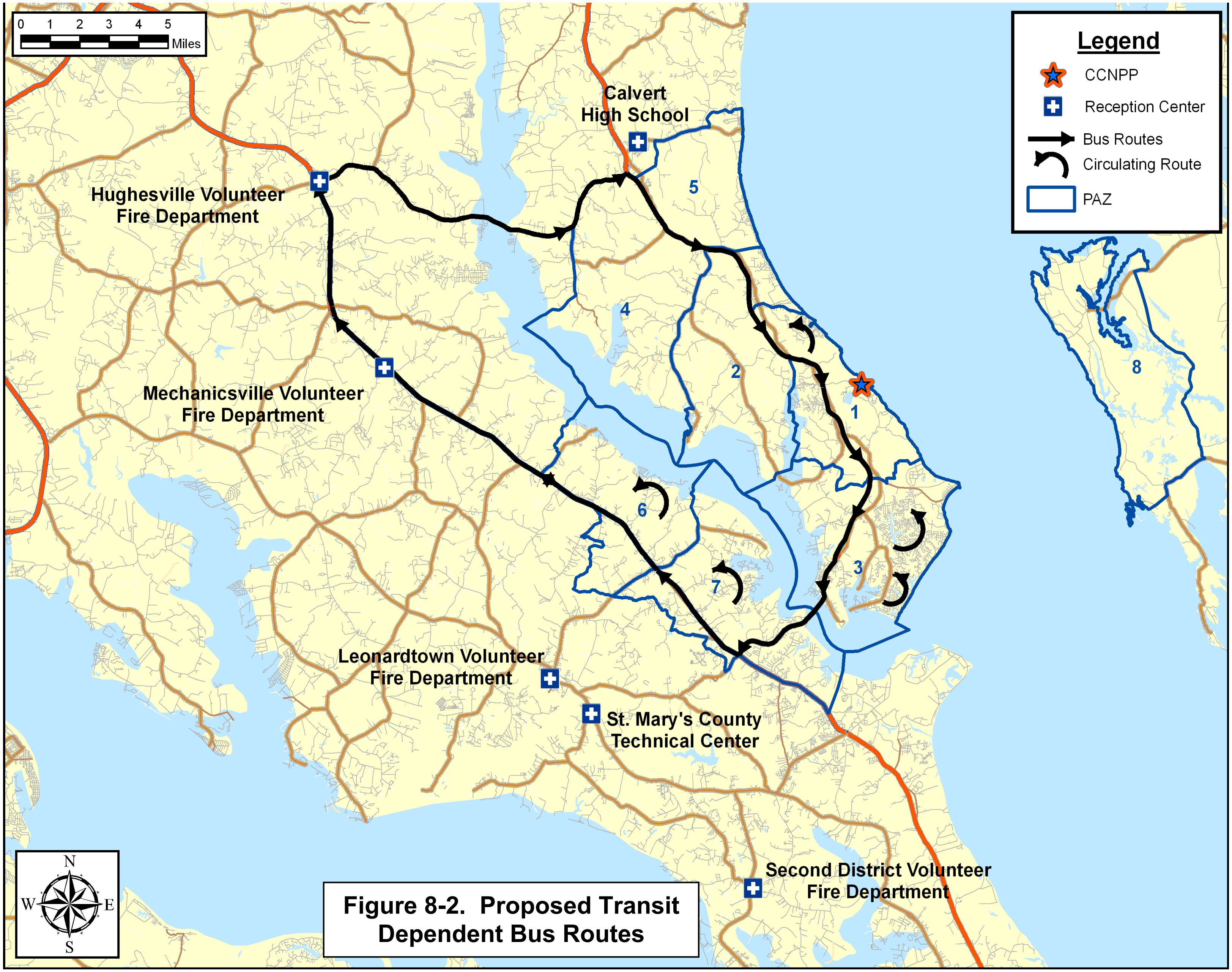


Figure 8-2. Proposed Transit Dependent Bus Routes

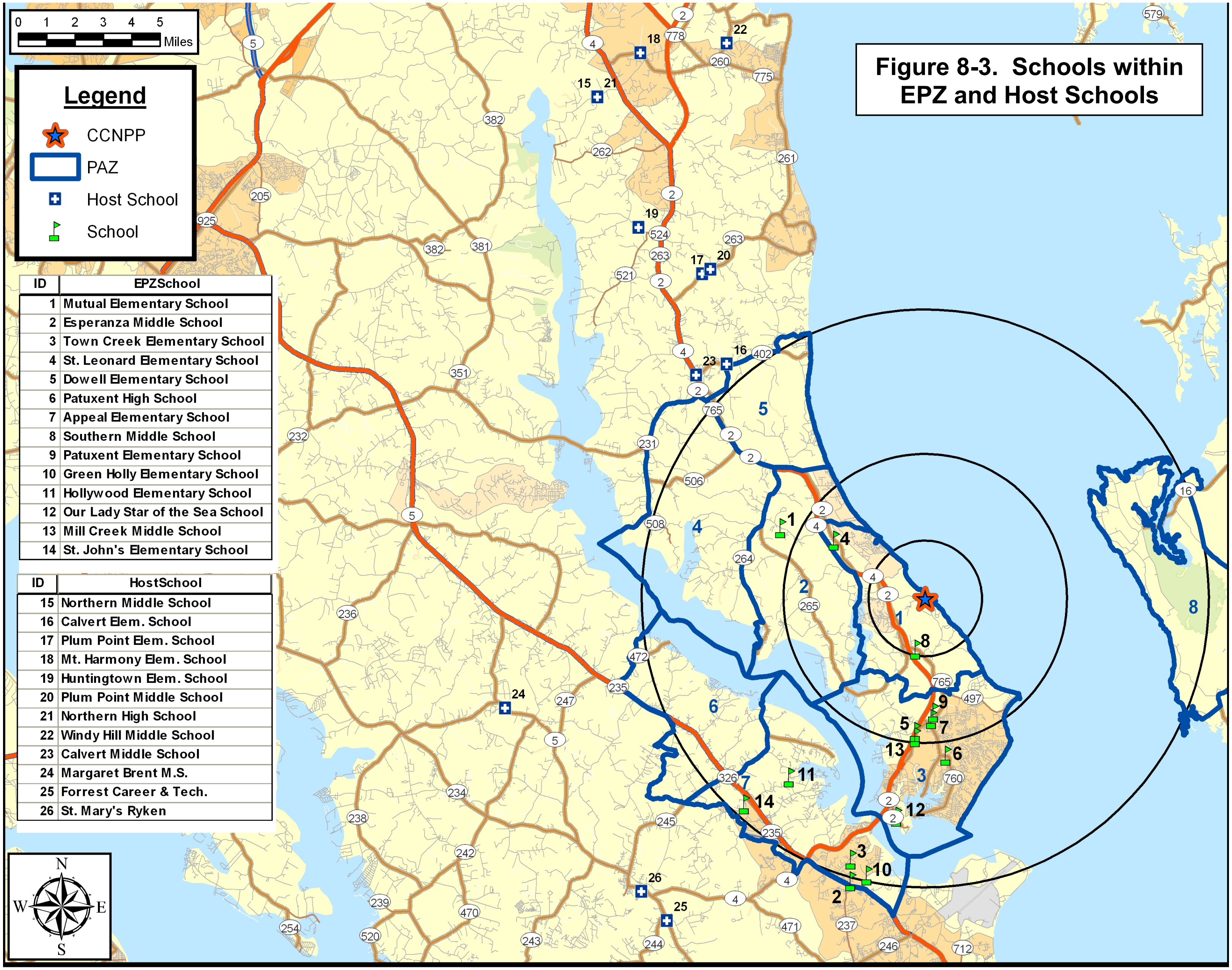


Figure 8-3. Schools within EPZ and Host Schools
0 1 2 3 4 5 Miles
Legend
CCNPP
PAZ
Host School
School

ID	EPZSchool
1	Mutual Elementary School
2	Esperanza Middle School
3	Town Creek Elementary School
4	St. Leonard Elementary School
5	Dowell Elementary School
6	Patuxent High School
7	Appeal Elementary School
8	Southern Middle School
9	Patuxent Elementary School
10	Green Holly Elementary School
11	Hollywood Elementary School
12	Our Lady Star of the Sea School
13	Mill Creek Middle School
14	St. John's Elementary School

ID	HostSchool
15	Northern Middle School
16	Calvert Elem. School
17	Plum Point Elem. School
18	Mt. Harmony Elem. School
19	Huntingtown Elem. School
20	Plum Point Middle School
21	Northern High School
22	Windy Hill Middle School
23	Calvert Middle School
24	Margaret Brent M.S.
25	Forrest Career & Tech.
26	St. Mary's Ryken

N
E
S
W

Table 8-1. Transit Dependent Population Estimates

Facility Name	2007 EPZ Population	Survey Average Household Size With Indicated No. of Vehicles			Estimated Number of Households	Survey Percent Households With			Survey Percent Households With Commuters	Survey Percent Households With Non-Returning Commuters	Total People Requiring Transport	Estimated Ridesharing Percentage	People Requiring Public Transit	Percent of Population Requiring Public Transit
		0	1	2		0 Veh-icle	1 Veh-icle	2 Veh-icle						
Calvert Cliffs Nuclear Power Plant	55,205	1.5	1.64	2.81	19,715	2.5%	22.2%	39.3%	64.5%	42%	1,960	50%	980	1.8%

*See Section 8.1 for detailed calculation.

Table 8-2. School Population Demand Estimates

PAZ	Distance (miles)	Dir-ection	School Name	Municipality	Enroll-ment	Staff	Bus Runs Required
Calvert County							
1	1.8	S	Southern Middle School	Lusby	632	91	13
1	3.8	WNW	St. Leonard Elementary School	St. Leonard	739	40	11
2	5.6	WNW	Mutual Elementary School	Pt. Republic	628	82	9
3	4.0	S	Patuxent Elementary School	Lusby	503	44	8
3	4.2	S	Appeal Elementary School	Lusby	431	52	7
3	4.6	S	Dowell Elementary School	Lusby	695	79	10
3	4.8	S	Mill Creek Middle School	Lusby	631	87	13
3	5.5	S	Patuxent High School	Lusby	1,366	103	28
3	7.6	S	Our Lady Star of the Sea School	Solomons	194	25	3
				Calvert County Total:	5,819	603	102
St. Mary's County							
7	7.8	SW	Hollywood Elementary School	Hollywood	641	66	10
7	9.4	SSW	Town Creek Elementary School	Lexington Park	272	37	4
7	9.8	SSW	Green Holly Elementary School	Lexington Park	620	96	9
7	9.9	SW	St. John's Elementary School	Hollywood	221	21	4
7	10.1	SSW	Esperanza Middle School	Lexington Park	880	93	18
				St. Mary's County Total:	2,634	313	45
				EPZ Total:	**8,453**	**916**	**147**

Table 8-3. Host Schools		
School	**PAZ**	**Host School**
High Schools		
Patuxent High School	3	Northern High School
Middle Schools		
Southern Middle School	1	Northern Middle School
Mill Creek Middle School	3	Plum Point Middle School
Esperanza Middle School	7	Forrest Career and Technology Center
Elementary Schools		
St. Leonard Elementary School	1	Windy Hill Middle School
Mutual Elementary School	2	Calvert Elementary School
Appeal Elementary School	3	Plum Point Elementary School
Dowell Elementary School	3	Calvert Middle School
Our Lady Star of the Sea School	3	Mt. Harmony Elementary School
Patuxent Elementary School	3	Huntingtown Elementary School
Green Holly Elementary School	7	Forrest Career and Technology Center
Hollywood Elementary School	7	Margaret Brent Middle School
St. John's Elementary School	7	St. Mary’s Ryken
Town Creek Elementary School	7	Margaret Brent Middle School

Table 8-4. Special Facility Transit Demand

PAZ	Facility Name	Municipality	Cap-acity	Current Census	Ambu-latory	Wheel-chair Bound	Bed-ridden	Ambu-lance Runs	Wheel-chair Bus Runs	Wheel-chair Van Runs	Bus Runs
CALVERT COUNTY											
3	Asbury at Solomon's Island	Solomons	6	5	5	0	0	0	0	0	1
3	Solomon's Nursing Center	Solomons	40	39	32	7	0	0	0	2	2
3	Southern Pines (Senior Center)	Lusby	30	30	30	0	0	0	0	0	1
ST.MARYS COUNTY											
7	Vivian Ripple Center (Senior Center)	Hollywood	29	29	29	0	0	0	0	0	1
		Total:	**105**	**103**	**96**	**7**	**0**	**0**	**0**	**2**	**5**

Table 8-5A. School Evacuation Time Estimates - Good Weather

School	Driver Mobilization Time(min)	Loading Time (min)	Dist. to EPZ Boundary (mi.)	Travel Time to EPZ Boundary (min)	ETE (hr:min)	Dist. EPZ Boundary to Host School (mi.)	Travel Time EPZ Boundary to Host School (min)	ETE to Host School (hr:min)
Calvert County Schools								
Appeal Elementary School	90	5	8.0	25	**2:00**	40.9	62	**3:05**
Dowell Elementary School	90	5	6.6	21	**2:00**	36.7	56	**2:55**
Mill Creek Middle School	90	5	6.4	20	**1:55**	41.3	62	**3:00**
Mutual Elementary School	90	5	5.9	19	**1:55**	2.0	3	**2:00**
Our Lady Star of the Sea School	60	5	8.9	19	**1:25**	49.2	74	**2:40**
Patuxent Elementary School	90	5	8.0	25	**2:00**	42.8	65	**3:05**
Patuxent High School	90	5	8.8	27	**2:05**	48.7	74	**3:20**
Southern Middle School	60	5	10.2	22	**1:30**	48.7	74	**2:45**
St. Leonard Elementary School	90	5	7.0	22	**2:00**	14.6	22	**2:20**
St. Mary's County Schools								
Esperanza Middle School	60	5	0.0	0	**1:05**	8.9	14	**1:20**
Green Holly Elementary School	60	5	0.2	1	**1:10**	6.5	10	**1:20**
Hollywood Elementary School	60	5	6.1	13	**1:20**	5.8	9	**1:30**
St. John's Elementary School	60	5	0.7	2	**1:10**	5.9	9	**1:20**
Town Creek Elementary School	60	5	0.7	2	**1:10**	15.8	24	**1:35**
				Average for EPZ:	**1:37**		**Average:**	**2:18**

Table 8-5B. School Evacuation Time Estimates - Rain

School	Driver Mobilization Time(min)	Loading Time (min)	Dist. to EPZ Boundary (mi.)	Travel Time to EPZ Boundary (min)	ETE (hr:min)	Dist. EPZ Boundary to Host School (mi.)	Travel Time EPZ Boundary to Host School (min)	ETE to Host School (hr:min)
Calvert County Schools								
Appeal Elementary School	100	10	8.0	29	**2:20**	40.9	71	**3:30**
Dowell Elementary School	100	10	6.6	24	**2:15**	36.7	63	**3:20**
Mill Creek Middle School	100	10	6.4	23	**2:15**	41.3	71	**3:25**
Mutual Elementary School	100	10	5.9	22	**2:15**	2.0	4	**2:20**
Our Lady Star of the Sea School	70	10	8.9	23	**1:45**	49.2	85	**3:10**
Patuxent Elementary School	100	10	8.0	29	**2:20**	42.8	74	**3:35**
Patuxent High School	100	10	8.8	32	**2:25**	48.7	84	**3:50**
Southern Middle School	70	10	10.2	26	**1:50**	48.7	84	**3:10**
St. Leonard Elementary School	100	10	7.0	26	**2:20**	14.6	26	**2:45**
St. Mary's County Schools								
Esperanza Middle School	70	10	0.0	0	**1:20**	8.9	16	**1:40**
Green Holly Elementary School	70	10	0.2	1	**1:25**	6.5	12	**1:35**
Hollywood Elementary School	70	10	6.1	16	**1:40**	5.8	10	**1:50**
St. John's Elementary School	70	10	0.7	2	**1:25**	5.9	11	**1:35**
Town Creek Elementary School	70	10	0.7	2	**1:25**	15.8	28	**1:50**
				Average for EPZ:	**1:55**		**Average:**	**2:41**

Table 8-6. Summary of Transit Dependent Bus Routes

Route Number	Number of Buses	Route Description
1	Batch 1 – 20 buses – after 90 minutes	Loop – State Route 235, State Route 2/4 and State Route 231
1	Batch 2 – 20 buses – after 120 minutes	Loop – State Route 235, State Route 2/4 and State Route 231

Table 8-7A. Transit Dependent Evacuation Time Estimate - Good Weather

	Single Wave				Second Wave					
Buses	Mobilization	Route Travel Time	Pickup Time	ETE	Mobilization	Unload Time	Driver Rest Time	Route travel Time	Pickup Time	ETE
Batch 1	90	178	30	5:00	135	5	10	178	30	6:00
Batch 2	120	218	30	6:10	165	5	10	218	30	7:10

Table 8-7B. Transit Dependent Evacuation Time Estimate - Rain

	Single Wave				Second Wave					
Buses	Mobilization	Route Travel Time	Pickup Time	ETE	Mobilization	Unload Time	Driver Rest Time	Route travel Time	Pickup Time	ETE
Batch 1	90	209	35	5:35	160	5	10	209	35	7:00
Batch 2	120	262	35	7:00	190	5	10	262	35	8:25

9. TRAFFIC MANAGEMENT STRATEGY

This section presents the current traffic control and management strategy that is designed to expedite the movement of evacuating traffic. The resources required to implement this strategy include:

- Personnel with the capabilities of performing the planned control functions of traffic guides (preferably, not necessarily, law enforcement officers).
- Traffic Control Devices to assist these personnel in the performance of their tasks. These devices should comply with the guidance of the Manual of Uniform Traffic Control Devices (MUTCD) published by the Federal Highway Administration (FHWA) of the U.S.D.O.T. All state and most county transportation agencies have access to the MUTCD (also available online). Applicable devices include, with reference to the MUTCD:
    - Traffic Barriers: Chapter 6F, section 6F.61, 62 and Figure 6F-4.
    - Traffic Cones: Chapter 3F and section 6F.56.
    - Signs: Chapter 2I
- A plan that defines all necessary details and is documented in a format that is readily understood by those assigned to perform traffic control.

The functions to be performed in the field are:

1. Facilitate evacuating traffic movements that serve to expedite travel out of the EPZ along routes that the analysis has found to be most effective.
2. Discourage traffic movements that permit evacuating vehicles to travel in a direction which takes them significantly closer to the power plant, or which interferes with the efficient flow of other evacuees.

We employ the terms "facilitate" and "discourage" rather than "enforce" and "prohibit" to indicate the need for flexibility in performing the traffic control function. There are always legitimate reasons for a driver to prefer a direction other than that indicated. For example:

- A driver may be traveling home from work or from another location, to join other family members preliminary to evacuating.
- An evacuating driver may be taking a detour from the evacuation route in order to pick up a relative, or other evacuees.
- The driver may be an emergency worker en route to perform an important activity.

The implementation of a plan must also be flexible enough for the application of sound judgment by the traffic guide.

The traffic management strategy is the outcome of the following process:

1. A field survey of these critical locations.
   The schematics describing traffic control, which are presented in Appendix G, are based on data collected during field surveys, upon large-scale maps, and on overhead photos.
2. Computer analysis of the evacuation traffic flow environment.
   This analysis identifies the best routing and those locations that experience pronounced congestion.
3. Consultation with emergency management and enforcement personnel.
   Trained personnel who are experienced in controlling traffic and are aware of the likely evacuation traffic patterns have extensively reviewed these control tactics.
4. Prioritization of TCPs.
   Application of traffic control at some TCPs will have a more pronounced influence on expediting traffic movements than at other TCPs. For example, TCPs controlling traffic originating from areas in close proximity to the power plant could have a more beneficial effect on minimizing potential exposure to radioactivity than those TCPs located far from the power plant. Thus, during the mobilization of personnel to respond to the emergency situation, those TCPs which are assigned a higher priority, should be manned earlier. These priorities have been developed in conjunction with county emergency management representatives and law enforcement personnel.

The control tactic at each TCP is presented in each schematic that appears in Appendix G.

The use of Intelligent Transportation Systems (ITS) technologies can reduce manpower and equipment needs, while still facilitating the evacuation process. Dynamic Message Signs (DMS) can be placed within the EPZ to provide information to travelers regarding traffic conditions, route selection, and reception center information. DMS can also be placed outside of the EPZ to warn motorists to avoid using routes that may conflict with the flow of evacuees away from the nuclear power station. Highway Advisory Radio (HAR) can be used to broadcast information to evacuees en route through their vehicle stereo systems. Automated Traveler Information Systems (ATIS) can also be used to provide evacuees with information. Internet websites can provide traffic and evacuation route information before the evacuee begins his trip, while on board navigation systems (GPS units), cell phones, and pagers can be used to provide information en route. These are only several examples of how ITS technologies can benefit the evacuation process.

Chapter 2I of the MUTCD presents guidance on Emergency Management signing. Specifically, the Evacuation Route sign, EM-1 on page 2I-3, with the word “Hurricane” removed, could be installed selectively within the EPZ, if considered advisable by local and state authorities. Similar comments apply to sign EM-3 which identifies TCP locations.

10. EVACUATION ROUTES

Evacuation routes are composed of two distinct components:

- Routing from a Protective Action Zone (PAZ) being evacuated to the boundary of the Evacuation Region and thence out of the Emergency Planning Zone (EPZ).
- Routing of evacuees from the EPZ boundary to the reception centers.

Evacuees should be routed within the EPZ in such a way as to *minimize their exposure to risk*. This primary requirement is met by routing traffic to move *away* from the location of the Calvert Cliffs Nuclear Power Plant, to the extent practicable, and by delineating evacuation routes that expedite the movement of evacuating vehicles. This latter objective is addressed by developing evacuation routes to achieve a balancing of traffic demand relative to the available highway capacity to the extent possible, subject to satisfying the primary requirement noted above. This is achieved by carefully specifying candidate destinations for all origin centroids where evacuation trips are generated, and applying the TRAD model effectively. See Appendices A-D for further discussion.

The routing of evacuees from the EPZ boundary to the reception centers should be responsive to several considerations:

- Minimize the amount of travel outside the EPZ, from the points where these routes cross the EPZ boundary, to the reception centers.
- Relate the anticipated volume of traffic destined to the reception center, to the capacity of the reception center facility.

Figure 10-1 presents a map showing the general population reception centers. The major evacuation routes for the three counties within the EPZ are presented in Figures 10-2 through 10-4.

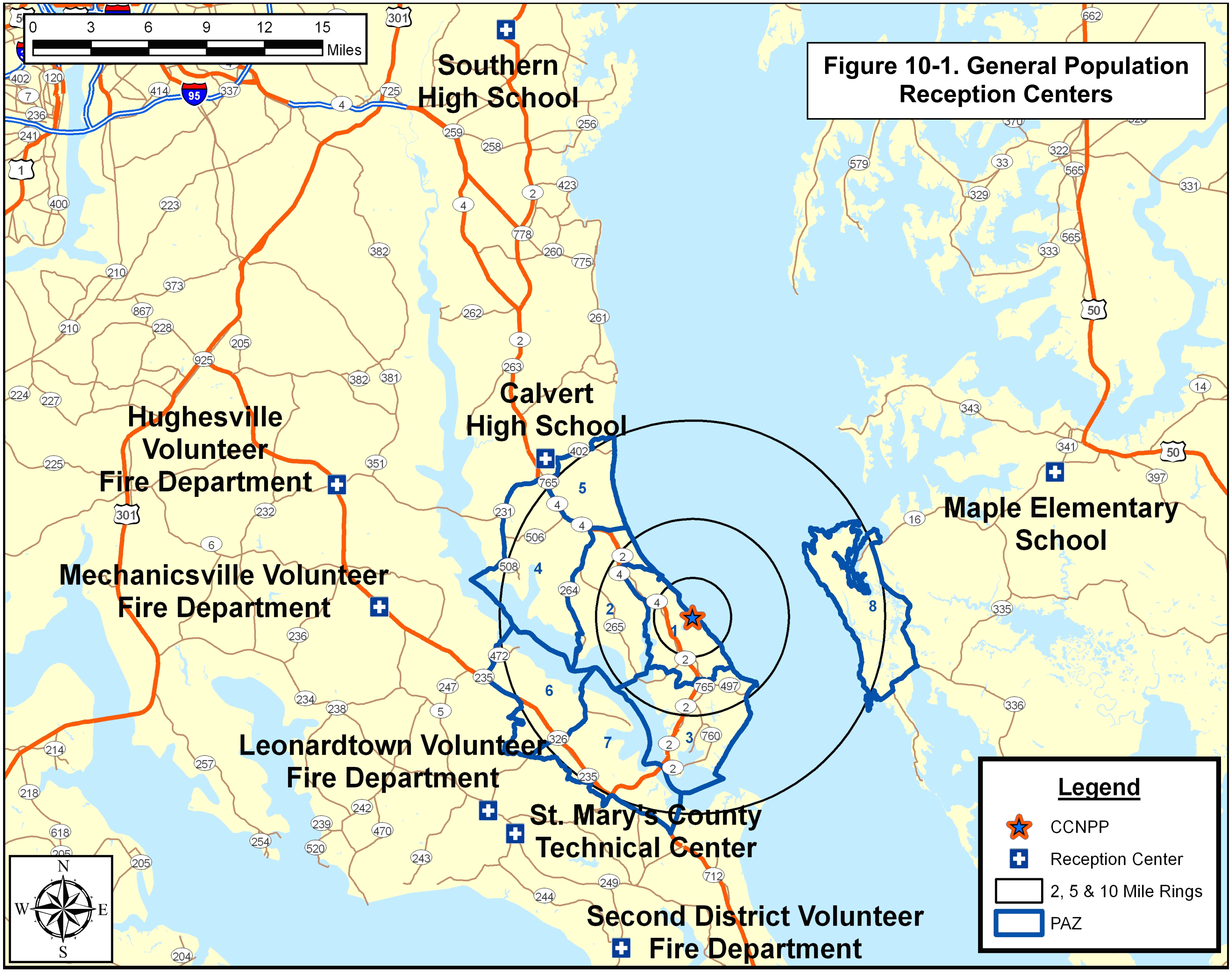


Figure 10-1. General Population Reception Centers
Southern High School
Calvert High School
Hughesville Volunteer Fire Department
Mechanicsville Volunteer Fire Department
Leonardtown Volunteer Fire Department
St. Mary's County Technical Center
Second District Volunteer Fire Department
Maple Elementary School
0 3 6 9 12 15 Miles
Legend
CCNPP
Reception Center
2, 5 & 10 Mile Rings
PAZ
N
S
E
W

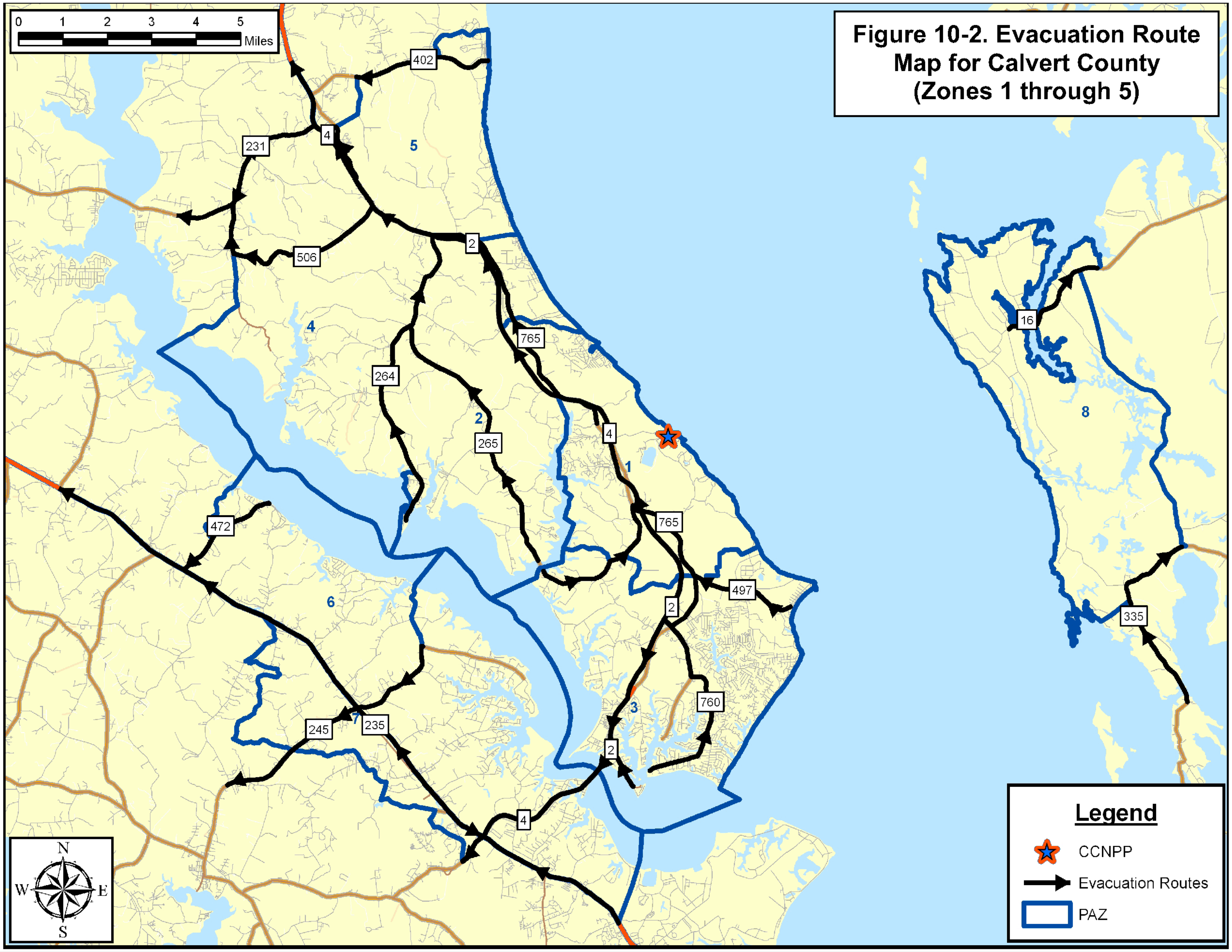


Figure 10-2. Evacuation Route Map for Calvert County (Zones 1 through 5)
0 1 2 3 4 5 Miles
N
W
E
S
402
231
4
2
506
5
4
765
264
2
265
4
1
765
472
497
6
2
335
16
8
760
3
245
235
7
2
4
Legend
CCNPP
Evacuation Routes
PAZ

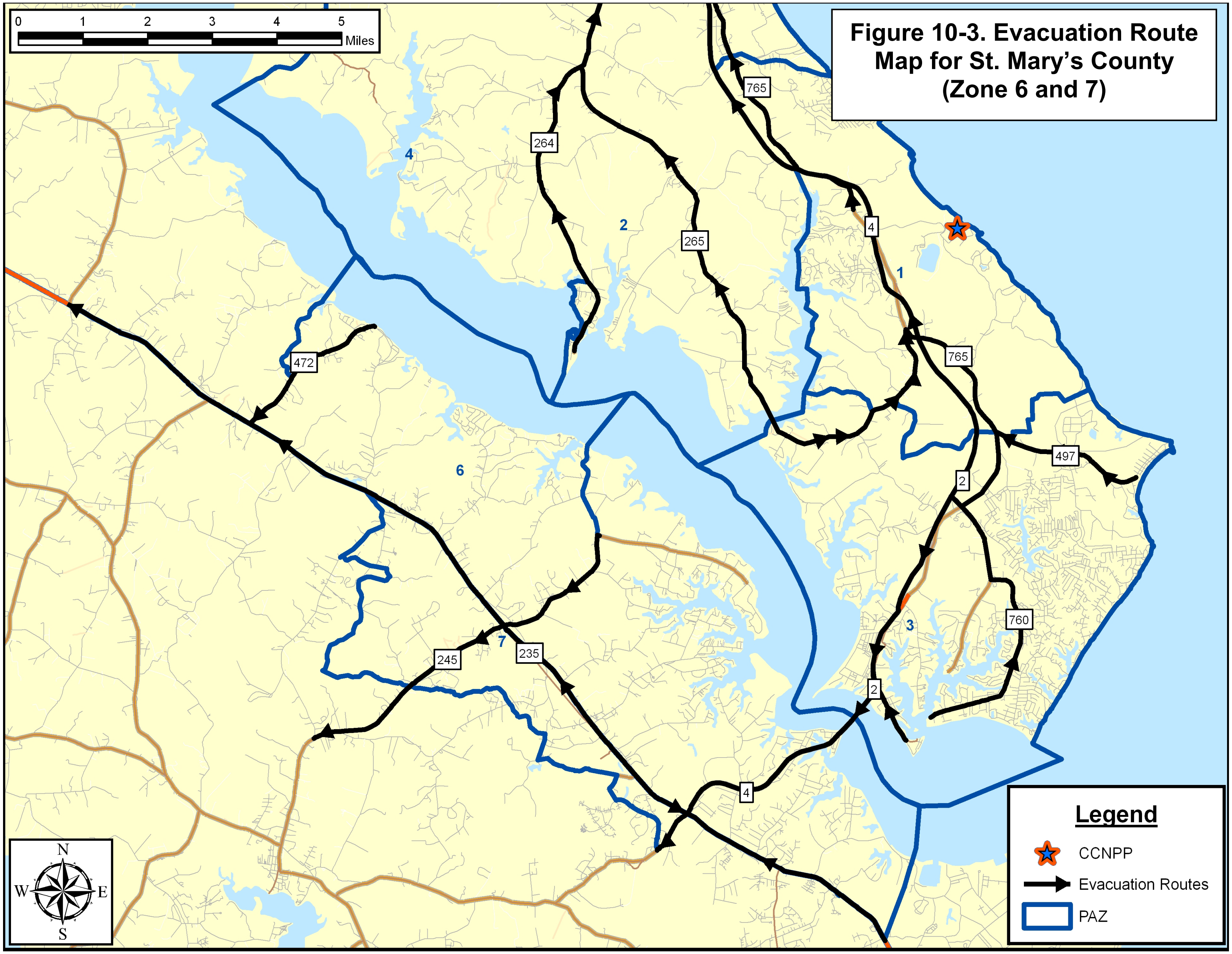


Figure 10-3. Evacuation Route
Map for St. Mary's County
(Zone 6 and 7)
0
1
2
3
4
5
Miles
Legend
CCNPP
Evacuation Routes
PAZ
N
S
W
E
765
264
265
4
765
472
497
2
760
245
235
2
4
1
2
3
4
6
7

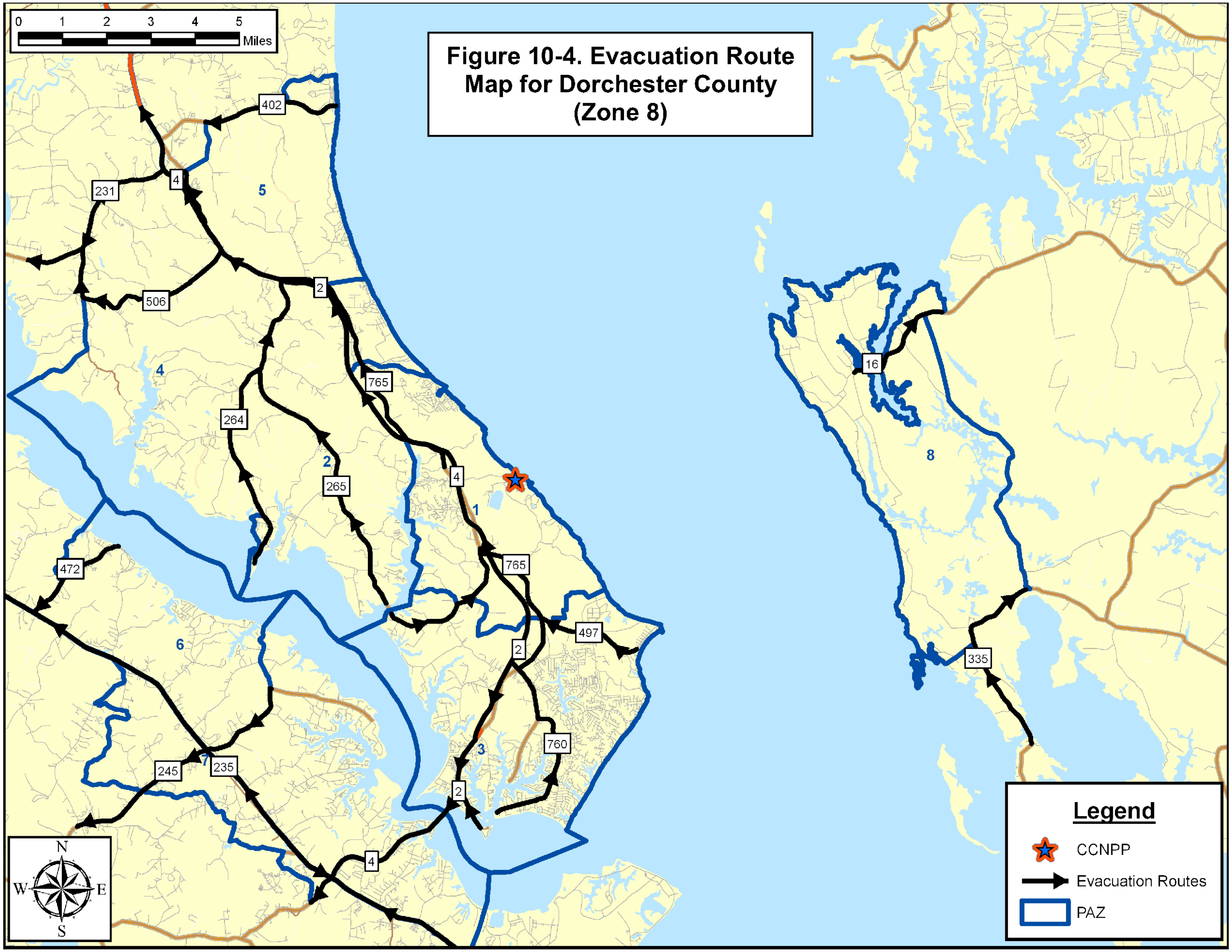


Figure 10-4. Evacuation Route Map for Dorchester County (Zone 8)
0 1 2 3 4 5
Miles
402
231
4
5
506
2
4
765
264
2
265
4
1
765
472
497
6
2
245
7
235
3
760
2
4
16
8
335
N
W
E
S
Legend
CCNPP
Evacuation Routes
PAZ

11. SURVEILLANCE OF EVACUATION OPERATIONS

There is a need for surveillance of traffic operations during the evacuation. There is also a need to clear any blockage of roadways arising from accidents or vehicle disablement. Surveillance can take several forms.

1. Traffic control personnel, located at Traffic Control and Access Control points, provide fixed-point surveillance.
2. Ground patrols may be undertaken along well-defined paths to ensure coverage of those highways that serve as major evacuation routes.
3. Aerial surveillance of evacuation operations may also be conducted using helicopter or fixed-wing aircraft.
4. Cellular phone calls (if cellular coverage exists) from motorists may also provide direct field reports of road blockages.

These concurrent surveillance procedures are designed to provide coverage of the entire EPZ as well as the area around its periphery. It is the responsibility of the Counties to support an emergency response system that can receive messages from the field and be in a position to respond to any reported problems in a timely manner. This coverage should quickly identify, and expedite the response to any blockage caused by a disabled vehicle.

Tow Vehicles

In a low-speed traffic environment, any vehicle disablement is likely to arise due to a low-speed collision, mechanical failure or the exhaustion of its fuel supply. In any case, the disabled vehicle can be pushed onto the shoulder, thereby restoring traffic flow. Past experience in other emergencies indicates that evacuees who are leaving an area often perform activities such as pushing a disabled vehicle to the side of the road without prompting.

While the need for tow vehicles is expected to be low under the circumstances described above, it is still prudent to be prepared for such a need. Tow trucks with a supply of gasoline may be deployed at strategic locations within, or just outside, the EPZ. These locations should be selected so that:

- They permit access to key, heavily loaded, evacuation routes.
- Responding tow trucks would most likely travel counter-flow relative to evacuating traffic.

12. CONFIRMATION TIME

It is necessary to confirm that the evacuation process is effective in the sense that the public is complying with the advisory to evacuate. Although Calvert, St. Mary's and Dorchester Counties may use their own procedures for confirmation, we suggest an alternative or complementary approach.

The procedure we suggest employs a stratified random sample and a telephone survey. The size of the sample is dependent on the expected number of households that do not comply with the advisory to evacuate. We believe it is reasonable to assume, for the purpose of estimating sample size that at least 80 percent of the population within the EPZ will comply with the advisory to evacuate. On this basis, an analysis could be undertaken (see Table 12-1) to yield an estimated sample size of approximately 300.

The confirmation process should start at about 3 hours after the advisory to evacuate, which is when 90 percent of evacuees have completed their mobilization activities. At this time, virtually all evacuees will have departed on their respective trips and the local telephone system will be largely free of traffic.

As indicated in Table 12-1, approximately 7-1/2 person hours are needed to complete the telephone survey. If six people are assigned to this task, each dialing a different set of telephone exchanges (e.g., each person can be assigned a different set of Zones), then the confirmation process will extend over a time frame of about 75 minutes. Thus, the confirmation should be completed well before the evacuated area is cleared. Of course, fewer people would be needed for this survey if the Evacuation Region were only a portion of the EPZ. Use of modern automated computer controlled dialing equipment can significantly reduce the manpower requirements and the time required to undertake this type of confirmation survey.

Should the number of telephone responses (i.e., people still at home) exceed 20 percent, then the telephone survey should be repeated after an hour's interval until the confirmation process is completed.

TABLE 12-1
ESTIMATED NUMBER OF TELEPHONE CALLS REQUIRED FOR CONFIRMATION OF EVACUATION

Problem Definition

Estimate number of phone calls, n, needed to ascertain the proportion, F of households that have not evacuated.

Reference: Burstein, H., Attribute Sampling, McGraw Hill, 1971

Given:

No. of households plus other facilities, N, within the EPZ (est.) = 19,715
Est. proportion, F, of households that have not evacuated = 0.20
Allowable error margin, e: 0.05
Confidence level, α: 0.95 (implies A = 1.96)

Applying Table 10 of cited reference,

$$p = F + e = 0.25; \; q = 1 - p = 0.75$$

$$n = \frac{A^2 pq + e}{e^2} = 308$$

Finite population correction:

$$n_F = \frac{nN}{n + N - 1} = 303$$

Thus, some 300 telephone calls will confirm that approximately 20 percent of the population has not evacuated. If only 10 percent of the population does not comply with the advisory to evacuate, then the required sample size, n_F = 214.

Est. Person Hours to complete 300 telephone calls

Assume: Time to dial using touch-tone (random selection of listed numbers): 30 seconds
Time for 6 rings (no answer): 36 seconds
Time for 4 rings plus short conversation: 60 sec.
Interval between calls: 20 sec.

Person Hours: 300[30+20+0.8(36)+0.2(60)]/3600 = 7.6

13. RECOMMENDATIONS

The following recommendations are offered:

1. The traffic management plan should be reviewed by state and county emergency planners with local and state law enforcement agencies (See Section 9 and Appendix G). Specifically…
   - The number and locations of Traffic Control Points (TCP) and Access Control Points (ACP) should be reviewed in detail.
   - The indicated resource requirements (personnel, traffic control devices) should be reconciled with current assets.
2. Intelligent Transportation Systems (ITS) such as Dynamic Message Signs (DMS), Highway Advisory Radio (HAR), Automated Traveler Information Systems (ATIS), etc. should be used to facilitate the evacuation process (See Section 9). The placement of additional signage should consider evacuation needs.
3. Counties should implement procedures whereby schools are contacted prior to dispatch of buses from the depots to obtain an accurate count of students needing transportation and the number of buses required (See Section 8).
4. Counties should work with the Department of Transportation to have equipment needed for traffic control duties mobilized in a timely manner should an evacuation be advised (See Section 9).
5. Counties should establish strategic locations to position tow trucks in the event of a disabled vehicle during the evacuation process (See Section 11) and should encourage gas stations to remain open during the evacuation.
6. Counties should establish a system to confirm that the Advisory to Evacuate is being adhered to (see the approach suggested by KLD in Section 12).
7. A sensitivity study was performed to measure the effect of routing some evacuees from Zone 3 (the most populated Zone within the EPZ) northbound on State Route 2/4 even though it brings evacuees closer to CCNPP. The ETE is 4 hours and 40 minutes shorter when allowing Zone 3 evacuees to travel northbound and southbound on State Route 2/4. **It is recommended that evacuees from Zone 3 be advised to travel northbound or southbound on State Route 2/4 in order to evacuate the impacted area as quickly as possible.**
8. The ETE for an evacuation of the full EPZ exceeds the mobilization time (about 4 hours) by 2 hours, on average. This indicates that there is congestion within the EPZ during evacuation which prolongs the ETE. The efficient use of traffic control personnel and equipment is highly recommended to facilitate the evacuation process (See Recommendations 1 and 2).
9. Counties should implement procedures to accurately estimate the number of transit-dependent people within the EPZ and to develop bus routes to service those transit-dependent people (See the suggestions in Section 8).

APPENDIX A

Glossary of Traffic Engineering Terms

APPENDIX A: GLOSSARY OF TRAFFIC ENGINEERING TERMS

Term	Definition
Link	A network link represents a specific, one-directional section of roadway. A link has both physical (length, number of lanes, topology, etc.) and operational (turn movement percentages, service rate, free-flow speed) characteristics.
Measures of Effectiveness	Statistics describing traffic operations on a roadway network.
Node	A network node generally represents an intersection of network links. A node has control characteristics, i.e., the allocation of service time to each approach link.
Origin	A location attached to a network link, within the EPZ or shadow area, where trips are generated at a specified rate in vehicles per hour (vph). These trips enter the roadway system to travel to their respective destinations.
Network	A graphical representation of the geometric topology of a physical roadway system, which is comprised of directional links and nodes.
Prevailing roadway and traffic conditions	Relates to the physical features of the roadway, the nature (e.g., composition) of traffic on the roadway and the ambient conditions (weather, visibility, pavement conditions, etc.).
Service Rate	Maximum rate at which vehicles, executing a specific turn maneuver, can be discharged from a section of roadway at the prevailing conditions, expressed in vehicles per second (vps) or vehicles per hour (vph).
Service Volume	Maximum number of vehicles which can pass over a section of roadway in one direction during a specified time period with operating conditions at a specified Level of Service. The Service Volume at the upper bound of Level of Service, E, equals Capacity. Service Volume is usually expressed as vehicles per hour (vph).
Signal Cycle Length	The total elapsed time to display all signal indications, in sequence. The cycle length is expressed in seconds.
Signal Interval	A single combination of signal indications. The interval duration is expressed in seconds. A signal phase is comprised of a sequence of signal intervals.
Signal Phase	A set of signal indications (and intervals) which services a particular combination of traffic movements on selected approaches to the intersection. The phase duration is expressed in seconds.

Term	Definition
Traffic (Trip) Assignment	A process of assigning traffic to paths of travel in such a way as to satisfy all trip objectives (i.e., the desire of each vehicle to travel from a specified origin in the network to a specified destination) and to optimize some stated objective or combination of objectives. In general, the objective is stated in terms of minimizing a generalized "cost". For example, "cost" may be expressed in terms of travel time.
Traffic Density	The number of vehicles that occupy one lane of a roadway section of specified length at a point of time, expressed as vehicles per mile (vpm).
Traffic (Trip) Distribution	A process for determining the destinations of all traffic generated at the origins. The result often takes the form of a Trip Table, which is a matrix of origin-destination traffic volumes.
Traffic Simulation	A computer model designed to replicate the real-world operation of vehicles on a roadway network, so as to provide statistics describing traffic performance. These statistics are called Measures of Effectiveness.
Traffic Volume	The number of vehicles that pass over a section of roadway in one direction, expressed in vehicles per hour (vph). Where applicable, traffic volume may be stratified by turn movement.
Travel Mode	Distinguishes between private auto, bus, rail, pedestrian and air travel modes.
Trip Table or Origin-Destination Matrix	A rectangular matrix or table, whose entries contain the number of trips generated at each specified origin, during a specified time period, that are attracted to (and travel toward) each of its specified destinations. These values are expressed in vehicles per hour (vph) or in vehicles.
Turning Capacity	The capacity associated with that component of the traffic stream which executes a specified turn maneuver from an approach at an intersection.

APPENDIX B

Traffic Assignment and Distribution Model

APPENDIX B: TRAFFIC ASSIGNMENT AND DISTRIBUTION MODEL

This section describes the integrated trip assignment and distribution model named TRAD that is expressly designed for use in analyzing evacuation scenarios. This model employs equilibrium traffic assignment principles and is one of the models of the I-DYNEV System.

To apply TRAD, the analyst must specify the highway network, link capacity information, the volume of traffic generated at all origin centroids, a set of accessible candidate destination nodes on the periphery of the EPZ for each origin, and the approach capacity to each destination node. TRAD calculates the optimal trip distribution and the optimal trip assignment (i.e., routing) of the traffic generated at each origin node, traveling to the associated set of candidate destination nodes, so as to minimize evacuee travel times.

Overview of Integrated Assignment and Distribution Model

The underlying premise is that the selection of destinations and routes is intrinsically coupled in an evacuation scenario. That is, people in vehicles seek to travel out of an area of potential risk as rapidly as possible by selecting the "best" route. The model is designed to identify these "best" routes in a manner that distributes vehicles from origins to destinations and routes them over the highway network, in a consistent and optimal manner.

The approach we adopt is to extend the basic equilibrium assignment methodology to embrace the distribution process, as well. That is, the selection of destination nodes by travelers from each origin node, and the selection of the connecting paths of travel, are both determined by the integrated model. This determination is subject to specified capacity constraints, so as to satisfy the stated objective function. This objective function is the statement of the User Optimization Principle by Wardrop.

To accomplish this integration, we leave the equilibrium assignment model intact, changing only the form of the objective function. It will also be necessary to create a "fictional" augmentation of the highway network. This augmentation will consist of Pseudo-Links and Pseudo-Nodes, so configured as to embed an equilibrium Distribution Model within the fabric of the Assignment Model.

Specification of TRAD Model Inputs

The user must specify, for each origin node, the average hourly traffic volume generated, as well as a set of candidate accessible destinations. A destination is "accessible" to traffic originating at an origin node if there is at least one path connecting the origin to the destination node. There must be at least one destination node specified for each origin centroid. The number of trips generated at the origin node, which are distributed to each specified, accessible destination node within this set, is determined by the model in a way as to satisfy the network-wide objective function (Wardrop's Principle).

The user must also specify the total number of trips which can be accommodated by each destination node. This value reflects the capacities of the road(s) immediately servicing the destination node. Clearly, we require that the total number of trips traveling to a destination, j, from all origin nodes, i, should not exceed the capacities of the approaches to destination node, j. By summing over all destination nodes, this constraint also states that the total trips generated at all origin nodes should not exceed the total capacity to accommodate these trips at all of the specified destinations.

In summary, the user must specify the total trips generated at each of the origin nodes, the maximum number of trips that can be accommodated by each of the specified destination nodes and the highway network attributes which include the traffic control tactics. The TRAD model includes a function which expresses travel time on each network link in terms of traffic volume and link capacity. This function drives the underlying trip distribution and trip assignment decision-making process. Thus, the TRAD model satisfies the objectives of evacuees to select destination nodes and travel paths to minimize evacuation travel time. As such, this integrated model is classified as a behavioral model.

At the outset, it may appear that we have an intractable problem:

- If TRAD retains the basic assignment algorithm, it must be provided a Trip Table as input.
- On the other hand, if the distribution model is embedded within the assignment model, rather than preceding it, a Trip Table is not available as input.

The resolution of this problem is as follows:

1. The software constructs an "augmentation" network that allows the user to specify the volume for each origin node and a set of candidate destinations on the periphery of the EPZ. The allocation of trips from the origin node to each candidate destination node is not specified and is determined internally by the model.
2. Each [real] link of the highway network is calibrated by relating speed to the volume:capacity (v/c) ratio.
3. The software constructs pseudo-links which service the assigned volumes, A_j, traveling to the destination nodes, j, in the augmented network.

This analysis network is comprised of three sub-networks:

1. The real highway sub-network, which consists of "Class I" Links and Nodes.
2. A sub-network of "Class II" Pseudo-Links which acts as an interface between the highway sub-network and the network augmentation.
3. The sub-network of "Class III" Pseudo-Links and Nodes which comprises the network augmentation described above.

The need for these Class II links will become clear later. The classifications are described below:

Class I Links and Nodes

These links and nodes represent the physical highway network: sections of highway and intersections. Trips generated at each Origin [Centroid] Node are assigned to a specified Class I link via a "connector" link. These connector links are transparent to the user and offer no impedance to the traveler; they represent the aggregation of local streets which service the centroidal generated trips and feed them onto the highway network. The real-world destination nodes are part of this network. The immediate approaches to these destination nodes are Class I links.

Class II Links

These pseudo-links are constructed so as to connect each specified destination node with its Class III Pseudo-Node (P-N) counterpart on a one-to-one basis. The capacities of these Class II links are set equal to the capacities at their respective destination nodes.

Class III Links and Nodes

Class III links and nodes form the augmentation to the basic network. These Pseudo-Links provide paths from the Class II links servicing traffic traveling from the specified [real] destination nodes, to the Super-Nodes which represent the user-specified set of destination nodes associated with each origin node.

Each Class of links provides a different function:

- Class I links represent the physical highway network. As such, each link has a finite capacity, a finite length and an estimated travel time for free-flowing vehicles. The nodes generally represent intersections, interchanges and, possibly, changes in link geometry. The topology of the Class I network represents that of the physical highway system.
- The Class II links represent the interface between the real highway sub-network and the augmentation sub-network. These pseudo-links are needed

to represent the specified maximum number of vehicles that can be accommodated by each destination node. Instead of explicitly assigning a capacity limitation to the destination nodes, we assign the capacity limitation of the Class II Pseudo-Links. This approach is much more suitable, computationally.

- The topology of the network augmentation (i.e., Class III Links and Nodes) is designed so that all traffic from an origin node can only travel to the single "Super-Node" by flowing through its set of real destination nodes, thence along the links of the augmented network.

The Class II Pseudo-Links and the network augmentation of Class III Pseudo-Nodes and Links represent logical constructs of fictitious links created internally by the model that allows the user to specify the identity of all destination nodes in each origin-based set, without specifying the distribution of traffic volumes from the origin to each destination node in that set.

Calculation of Capacities and Impedances

Each class of links exhibits different properties. Specifically, the relationship between travel impedance (which is expressed in terms of travel time) and both volume and capacity will differ:

- For Class I links, the capacity represents the physical limitation of the highway sections. Travel impedance is functionally expressed by relating travel time with respect to the traffic volume-link capacity relationship.
- For Class II links, link capacity represents the maximum number of vehicles that can be accommodated at the [real] destination nodes that form the upstream nodes of each Class II link. Since Class II links are Pseudo-Links, there should be virtually no difference in impedance to traffic along Class II links when the assigned traffic volume on these links is below their respective capacities. That is, the assignment of traffic should not be influenced by differences in travel impedance on those Class II links where the assigned volumes do not exceed their respective capacities.
- For Class III links, both capacity and impedance have no meaning. Since the Class II links limit the number of vehicles entering the Class III sub-network at all entry points (i.e., at the Class II Pseudo-Nodes) and since all these links are Pseudo-Links, it follows that the Class III network is, by definition, an un-capacitated network.

Specification of the Objective Function

It is computationally convenient to be able to specify a single impedance (or "cost") function relating the travel time on a link, to its capacity and assigned traffic volume, for all classes of links. To achieve this, we will adopt the following form based on the original "BPR Formula":

$$T = T_o\{\alpha[1 + a_1(\frac{v}{c})^{b_1}] + \beta[1 + a_2(\frac{v}{c})^{b_2}]\} + I$$

Where, as for the present traffic assignment model in TRAD,

T	=	Link travel time, sec.
T_o	=	Unimpeded link travel time, sec.
V	=	Traffic volume on the link, veh/hr
C	=	Link capacity, veh/hr
a_i, b_i	=	Calibration parameters
α, ß	=	Coefficients defined below
I	=	Impedance term, expressed in seconds, which could represent turning penalties or any other factor which is justified in the user's opinion

The assignment of coefficients varies according to the Class in which a link belongs:

Class	α	ß	T_o
I	1	0	L/U_f
II	0	1	W
III	0	0	1

Here, L is a highway link length and U_f is the free-flow speed of traffic on a highway link. The values of a_1 and b_1, which are applicable only for Class I links, are based on experimental data:

$a_1 = 0.8$ $b_1 = 5.0$

The values of a_2 and b_2, which are applicable for each Class II link, are based upon the absolute requirement that the upstream destination node can service no more traffic than the user-specified value of the maximum destination node “capacity.” In addition, these parameters must be chosen so that these Pseudo-Links all offer the same impedance to traffic when their assigned volumes are less than their respective specified maximum attractions. The weighting factor, W, is computed internally by the software.

Of course, it is still possible for the assignment algorithm within TRAD to distribute more traffic to a destination node than that node can accommodate. For emergency planning purposes, this is a desirable model feature. Such a result will be flagged by the model to alert the user to the fact that some factor is strongly motivating travelers to move to that destination node, despite its capacity limitations. This factor can take many forms: inadequate highway capacity to other destinations, improper specification of candidate destinations for some of the origins, or some other design inadequacy. The planner can respond by modifying the control tactics, changing the origin-destination distribution pattern, providing more capacity at the overloaded destinations, etc.