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DRAFT FINAL REPORT

# CAPE MAY COUNTY HURRICANE EVACUATION AND ELEVATION STUDY EXTENSION

Submitted to

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THE EDGE IN KNOWLEDGE

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# I SUMMARY

The objective of this research effort was to extend the work completed under the previous study "Analysis and Modeling of Cape May County Roadway Elevations and Evacuation Routes", henceforth referred to as the 'initial study'. The initial study was sponsored by the New Jersey Department of Transportation (NJDOT) to fill the needs of the NJDOT and the New Jersey State Police Office of Emergency Management. The report summarizing this initial effort is available online at http://transportation.njit.edu/nctip/final_report/CapeMayElevEvac.pdf.

This initial study contained two main sections of work, and this study extends both efforts as follows:

- Evacuation Simulation Modeling: Further simulation analysis of evacuations of Cape May County traffic via the NJ 47/347 corridor was conducted. The evacuation analysis consisted of a Paramics-based microsimulation model that determined how long it would take to evacuate Cape May County traffic along the NJ 47/347 corridor. Several more permutations of conditions were tested, many of which tested higher amounts of vehicles evacuating from the NJ 47/347 corridor. Due to the ineffectiveness of the current NJ 47/347 lane reversal plan (as shown in the initial study), a new lane reversal plan was tested that would extend the reversal section further south to the intersection with US 9.
- Roadway Elevation Surveying: Surveying more roadways in the county was conducted to determine elevation and to determine under what category of storm the roadways would be inundated and impassable by either emergency response vehicles or by evacuees. The survey was conducted using GPS instrumentation in survey vehicles that traveled the roadways.

The findings of the research effort are as follows:

- Evacuation Simulation Modeling: The higher evacuation demands for the NJ 47/347 corridor resulted in much higher total evacuation times than the initial scenarios tested in the initial study. The total evacuation times for the corridor now vary from 16 to 89 hours. The ineffectiveness of the current contraflow or lane reversal plan (between NJ 83 and NJ 55) shown in the initial study is reiterated. The extended contraflow scenarios (GSP to NJ 55) show dramatic potential in evacuating the county's population, especially when the higher vehicle per household rates and the maximum routing of vehicles into the NJ 47/347 corridor is assumed. Based on these results, the extension of the lane reversal section to the current planned southern terminus of NJ 83 is highly encouraged. The potential exists to shorten the worst case evacuation scenario from 89 hours to 40 hours.

- Roadway Elevation Surveying: The survey and analysis reveals that while the majority of the surveyed roadways will remain passable during a category 1 hurricane, there were surveyed locations in each of the roadways that would be flooded from a category 1 hurricane strike. The fact that all the surveyed roadways will be at least partially impassable during the peak levels of a storm surge from a category 1 hurricane, indicates the importance of having a evacuation plan in place that allows enough time for evacuation before the maximum storm surge levels are reached.

# II EVACUATION SIMULATIONS

The evacuation analysis was performed using the network and methods developed during the initial study. The simulations were conducted using the Quadstone Paramics software, an advanced microscopic traffic simulation modeling system. Further details about the network development and methods used to perform a multi-day evacuation simulation analysis in Paramics are described in the initial report.

## II.1 Study Area

Figure 1 illustrates the studied evacuation region. The simulated study area, shown in green, begins in Rio Grande, New Jersey in the south (at approximately milepost 5.5 of Route 47) and extends to the north and ends shortly after Route 55 begins. The actual simulation network (shown in Figure 2) includes every public road (state, county, and local jurisdictions) within this primary study area. The secondary study regions, shown in Figure 1 in pink, are areas within Cape May County that were not explicitly included in the simulation network. However, any traffic presumed to feed from the secondary study areas into the Routes 47/347 corridor was included in the simulation. The evacuation routes (Routes 47/347) are highlighted in yellow.

## II.2 Analysis Scenarios

Scenarios are defined by varying the amount of evacuating traffic (demand) and / or the roadway conditions that are provided to allow the traffic to evacuate (network). A single scenario is defined as the combination of one demand condition and one network condition. While network conditions are relatively straight forward and can be described as one parameter, five different parameters are used to define the demand side of the evacuation problem (i.e. when, where, and how many vehicles will be evacuating via the study corridor). The following parameters were considered in the evacuation simulation analysis.

### *II.2.1 Traffic Operations / Network Conditions:*

The network available for the evacuation population to exit the region is defined as a single parameter in the scenarios. Consistent to all the networks is a single zone structure. Origin zones are placed at various vehicle generation locations along the edges of the network (to load traffic entering the network from the secondary study areas) and within the study area (to load traffic residing in the study area). A single destination zone was located at the northern end of the network on Route 55 to receive all evacuating traffic. Variations to the network among the networks

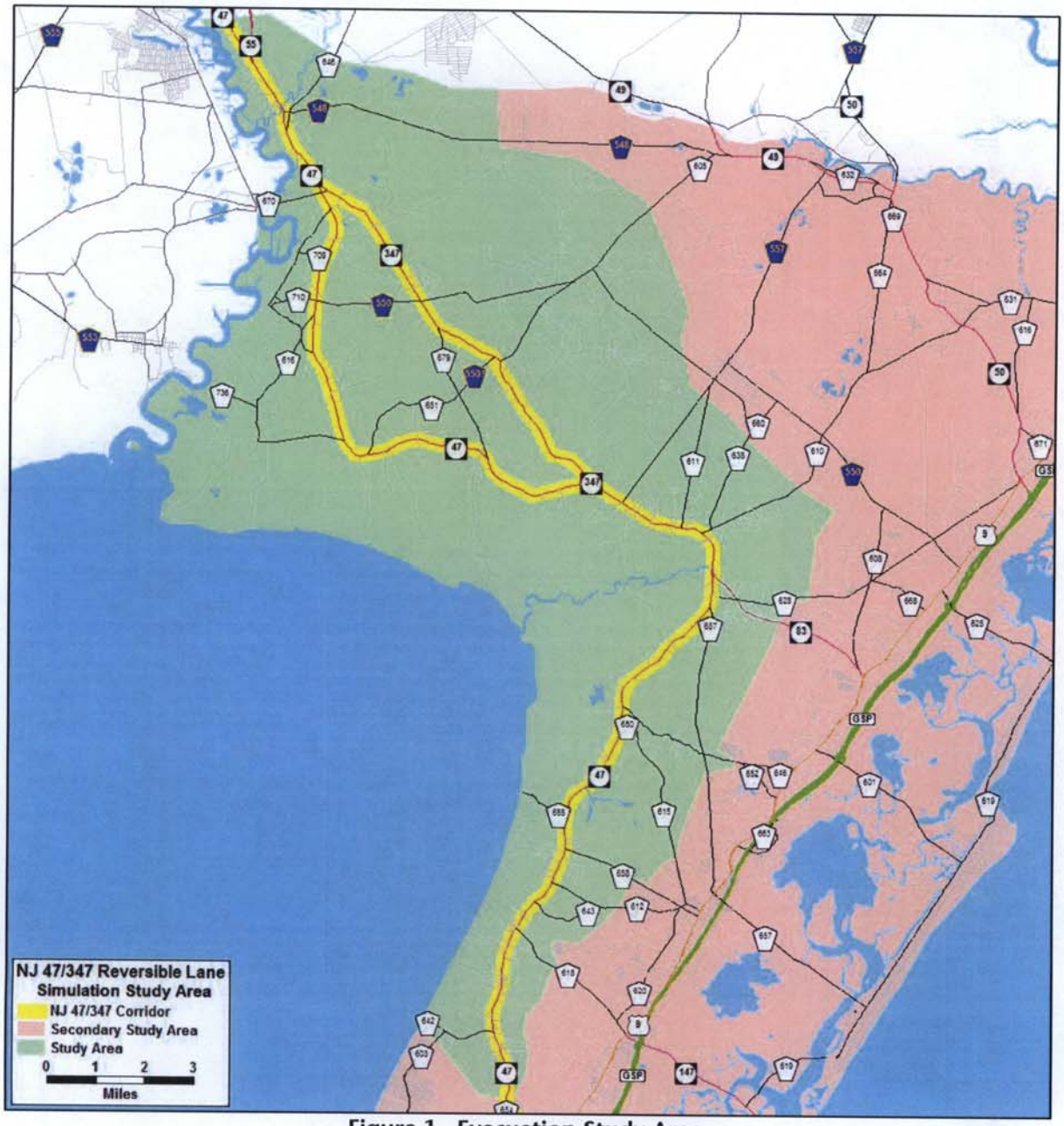


Figure 1. Evacuation Study Area

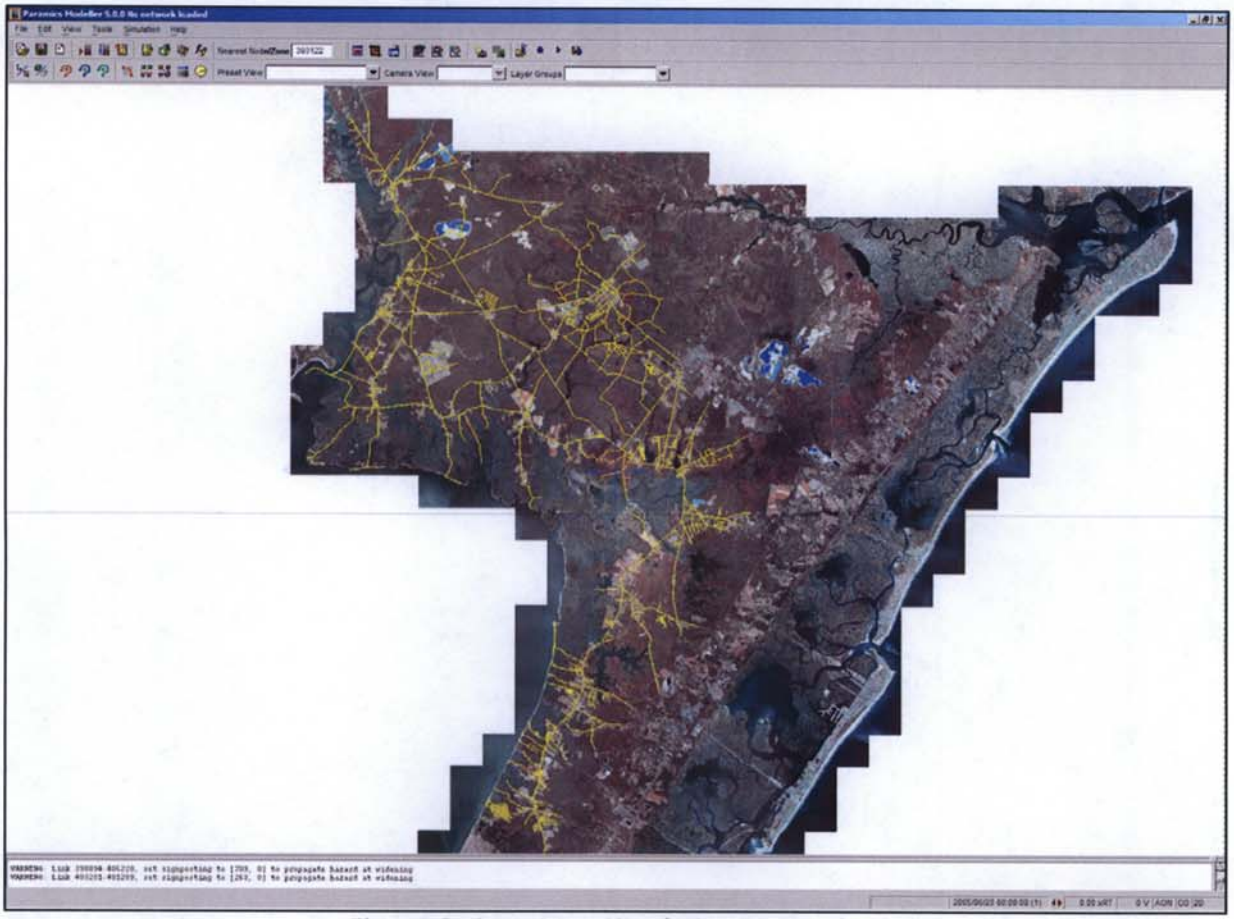

**Figure 2. Cape May Simulation Network**

include variations in the reversed lane or contraflow operations that are implemented in the corridor. The three study options for the network include:

1. No Lane Reversal:

   This scenario assumes normal lane usage in the NJ 47/347 corridor (predominantly one travel lane in each direction), but assumes police are directing traffic at key intersections to allow side street traffic which is normally stop controlled to enter the evacuation corridor.

2. Current Lane Reversal Plan:

   This scenario assumes the operation of Routes 47/347 under contraflow conditions between the junctions of Route 83 in the south to Route 55 in the north. This alternative follows the instructions specified in the State Police Routes 47/347 Reverse Lane Plan.

3. Extended Lane Reversal Plan

This scenario assumes that contraflow operations are extended to the south along NJ 47 to the Garden State Parkway. This scenarios results in 2 lanes available for northbound evacuating traffic along the NJ 47/347 corridor from the Garden State Parkway in the south and feeding into NJ 55 in the north. Intersection controls for the extended contraflow sections operate in a similar fashion to the current plan (e.g. police control directing intersections, forced detours or barricades channel evacuating traffic onto the northbound evacuation route).

### *II.2.2 Area Population*

The first demand related parameter, the area population parameter, defines how many people are in the region that could potentially need to evacuate. The primary source of determining the at-risk population is an estimate of housing units that are in the region and how many of them would be occupied. An additional source of potential people in the region is the large number of trips that travel into the region only for the day. The size of the day-tripper population is thus not able to be estimated by counting housing units (since they have no need for housing in the region). The assumption under the initial study and carried through to this current study is that no day-trippers would be in the area due to the impending threat of a hurricane strike on the region. This leaves the threaten population to be derived from examining the number of housing units in the county.

All estimates of housing units are taken from the US Army Corp of Engineers estimates of vulnerable housing units, included as part of the Hurricane Evacuation Study (HES). The HES study categorizes all housing units as either permanent, seasonal, or hotel / motel units. A separate estimate of mobile homes is included due to the increased risk to this type of housing unit from a hurricane. The number of housing units are then subcategorized by the evacuation district (subgroups of municipalities) and by the potential for being inundated by different categories of hurricanes. Missing from the HES study was an estimate of campground sites throughout the county. A survey of campgrounds sites conducted during the initial study was added to the HES vulnerable housing unit estimates. Variations in the area population demand parameter include:

1. Peak Season (estimated Labor Day weekend)

This alternative assumes that 100% of permanent resident housing units, seasonal housing units, hotel / motel units, and campgrounds are occupied and will contribute to the potential evacuating population.

2. Off-Peak Season (estimated late September)

This alternative assumes that 100% of permanent resident housing units and 50% of seasonal housing units, hotel / motel units, and campgrounds are occupied and will contribute to the potential evacuating population.

### *II.2.3 Evacuating Vehicles per Household Assumptions*

Since the focus is on vehicle evacuation from the region using the NJ 47/347corridor, the number of housing units is used to derive the number of vehicles that would be evacuating, rather than the evacuating population. In this study, two options existed to determine the number of vehicles that would be evacuating:

1. Census-based Vehicles per household rates

This first option is the assumption made during the initial study. Similar to other hurricane evacuation studies, particularly one study conducted for the Delmarva Peninsula, vehicle per household rates for permanent housing units are based on census data. While the Delmarva Study assumed one vehicle per seasonal housing unit, it was deemed that this was too low for Cape May County. Instead, the initial report used the same vehicle per household rate for seasonal units as for the permanent housing units. The vehicle per household rates from the initial study are as follows:

| Type of Housing Unit | Vehicles per Household Rate (& Source) |
|---|---|
| Permanent | 1.54 (2000 Census for Cape May County) |
| Seasonal | 1.54 (2000 Census for Cape May County)) |
| Hotel / Motel | 1.0 (Assumption) |
| Campgrounds: | 1.0 (Assumption) |

2. Increased Vehicles per Household

Following the initial report, some comments were received that even the increased census-based vehicle rates were too low for the typical vehicles per household conditions seen in Cape May County. As such, a new alternative was tested using the following vehicles rates:

| Type of Housing Unit | Vehicles per Household Rate (& Source) |
|---|---|
| Permanent | 3.0 (Assumption) |
| Seasonal | 3.0 (Assumption) |
| Hotel / Motel | 1.0 (Assumption) |
| Campgrounds: | 1.0 (Assumption) |

### *II.2.4 Routing Assumptions*

Once the number and originating location of the evacuating vehicles is know, there must be an estimate of how many vehicles would be evacuating using the NJ 47/347 corridor. In all cases, the housing unit location was deemed the origin point for the evacuating trip. Adding to the initial study, two options of vehicle usage of the NJ 47/347 corridor are tested here:

1. Balanced NJ 47/347 and Other Corridor Routing:

Used in the initial study, this routing option assumed that traffic exiting from the barrier islands was allowed to use both the study corridor of NJ 47/347 and other routes (including the US 9 / Garden State Parkway corridor and the NJ 50 / NJ 49 corridors) for evacuation. The percentage of vehicles using the NJ 47/347 corridor was based on the originating evacuation location and the total roadway capacity of evacuation roadways from the county. In this assumption, a balance of traffic among all potential evacuation corridors for the region was sought. This requires that the other corridors are operating under acceptable conditions and that they are available for use by some of the evacuees from the barrier islands.

2. Heavy NJ 47/347 Routing:

This alternative assumes that all (100%) barrier island traffic from Avalon and south and all mainland traffic south of NJ 83 will evacuate via the study corridor of NJ 47/347, and none of this traffic will be evacuated via other corridors. Traffic from the barrier islands north of NJ 83 (Sea Isle City and north) are assumed to be evacuated (100%) via other routes as in the previous option. This alternative tests the worst case conditions that would exist if the other evacuation corridors from the region, including the Garden State Parkway, US 9, NJ 49, NJ 50, and the Atlantic City Expressway, were overwhelmed and no additional capacity existed to help evacuate the majority of the Cape May peninsula population.

### *II.2.5 Hurricane Intensity*

The strength of the hurricane striking the region has a significant impact on the percentage of people that will participate in the evacuation versus the percentage that will stay at home and try to ride out the storm. The factors affecting whether or not someone will participate in the evacuation include the type of housing unit and the relative threat of inundation from the storm. People in permanent housing units are much more likely to remain in an attempt to secure and protect their property. Persons occupying seasonal housing units (including seasonal rentals and hotel / motel units) are much more likely to leave for safer ground. Mobile home units, which may be either permanent or seasonal, have different participation rates due to the added threat of hurricane strength winds. All occupied campsites are always assumed to evacuate, regardless of the threat of inundation. Voluntary evacuations will also occur from housing units where the threat of inundation by storm surge is not high, but other dangers from a hurricane still exist. The participation rates used are those that were developed from surveys conducted for the Delmarva Evacuation Study.

1. Category 1 Hurricane:

In this scenario, the evacuation prior to a category 1 hurricane strike is examined. The scenario includes the evacuation of all category 1 inundation areas, plus volunteer evacuees based on the participation rates for a category 1 storm.

| Category 1 Hurricane | | | | |
|---|---|---|---|---|
| Inundation Level | Permanent Units | Mobile Homes | Seasonal Units | Campgrounds Units |
| 1 | 100% | 100% | 100% | 100% |
| 2 | 2% | 70% | 90% | 100% |
| 3 | 1% | 50% | 50% | 100% |
| 4 | 1% | 50% | 50% | 100% |
| No Flood | 1% | 50% | 50% | 100% |

2. Category 2 (and up) Hurricanes:

In this alternative a full scale evacuation of the county is considered. The worst case scenario, this scenario includes the evacuation of all housing units in a category 4 or lower inundation level, plus voluntary evacuations from uplands or dry locations. This results in the application of the category 4 participation rates.

| Category 2 or Higher Hurricane | | | | |
|---|---|---|---|---|
| Inundation Level | Permanent Units | Mobile Homes | Seasonal Units | Campgrounds Units |
| 1 | 100% | 100% | 100% | 100% |
| 2 | 100% | 100% | 100% | 100% |
| 3 | 100% | 100% | 100% | 100% |
| 4 | 100% | 100% | 100% | 100% |
| No Flood | 5% | 100% | 100% | 100% |

### *II.2.6 Behavior Response*

The final demand related parameter determines when the evacuating traffic will attempt to evacuate in relation to a call for evacuation. The initial study selected the behavioral response curves or S-curves as the model for loading traffic temporally to the simulation model. A response curve (also referred to as a loading curve) portrays the assumed departure time distribution of evacuees. The loading curve is usually represented as the cumulative percentage of evacuees evacuating by time period, and takes on a sigmoid or "S" shape. Three types of responses were simulated; fast, medium, and slow. The response rate signifies how readily the evacuees are expected to respond to an order to evacuate. As illustrated in Figure 3, the time point of zero is when the evacuation order is issued. The graph illustrates that initial values of 8, 5 and 3 percent of the total demand have loaded even six hours prior to the issuance of the evacuation order for the slow, medium and fast responses respectively. This initial evacuation reflects the proportion of the population who left before the order was given (also know as shadow evacuation). In this work, all three behavior loading curves are tested.

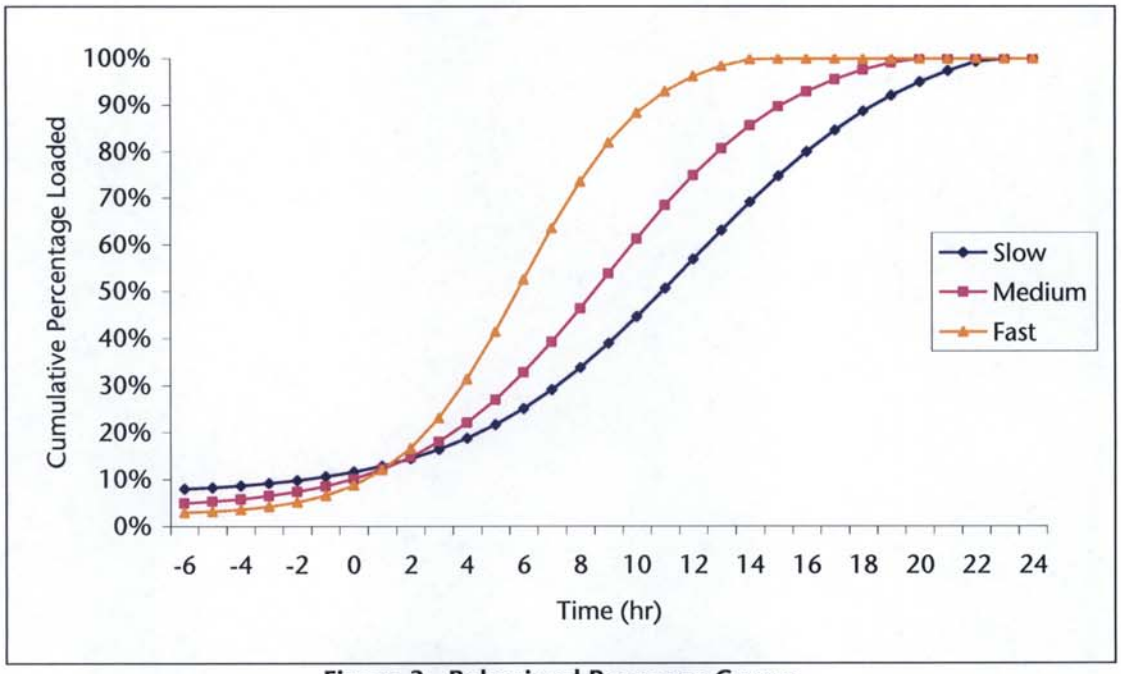


**Figure 3. Behavioral Response Curves**

## II.3 Combined Analysis Scenarios

All combinations of the alternatives were tested. Thus, a total of 144 scenarios were analyzed based on all permutations of the study parameters:

3 Traffic Operations / Network Conditions
x 2 Area Population
x 2 Evacuating Vehicles per Household Assumptions
x 2 Routing Assumptions
x 2 Hurricane Intensity
x 3 Behavior Response Profiles
= 144 Scenarios

In the initial study, 24 scenarios contained within this list were analyzed. This left the remaining 120 scenarios to be tested under this extension effort. In addition, to account for the stochastic nature of traffic simulation analysis, three different simulations using random seeds were conducted for each scenario. The three simulations were then averaged to determine the total evacuation time for the scenarios.

## II.4 Evacuation Results

The higher evacuation demands for the NJ 47/347 corridor resulted in much higher total evacuation times than the initial scenarios tested in the initial study. The total evacuation times for the corridor now vary from 16 to 89 hours. The large degree of variance accounts for the newly tested parameters that have a dramatic increase on the amount of population assumed to evacuate through the NJ 47/347 corridor.

Table 1 summarizes the total evacuation time required under the assumed demand scenarios for all three network configurations for a fast behavior response to the call to evacuate. Similarly, Tables 2 and 3 summarize, respectively, the total evacuation times required for a medium and slow behavior response.

The ineffectiveness of the current contraflow or lane reversal plan (between NJ 83 and NJ 55) is reiterated. The extended contraflow scenarios (GSP to NJ 55) show dramatic potential in evacuating the county's population, especially when the higher vehicle per household rates and the maximum routing of vehicles into the NJ 47/347 corridor is assumed.

Based on these results, the extension of the lane reversal section to the current planned southern terminus of NJ 83 is highly encouraged. The potential exists to shorten the worst case evacuation scenario from 89 hours to 40 hours. Given the speed of which hurricanes often approach the mid-Atlantic region and the resulting notice that could be given of a potential hurricane strike, the difference could mean the lives of tens of thousands.

**Table 1. Total Evacuation Times Assuming a Fast Behavior Response**

| Demand Scenarios | | | | Fast Behavior Response | | | | |
|---|---|---|---|---|---|---|---|---|
| Season | Storm Category | Vehicles Rates | Routing Assumption | No Lane Reversal | Current Contraflow | Extended Contraflow | Current Contraflow Savings | Extended Contraflow Savings |
| Off-Peak | Cat. 1 | Census | Balanced | 16.4 | 16.4 | 16.4 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Assumed | Balanced | 16.5 | 16.5 | 16.5 | 0.0 | -0.1 |
| Off-Peak | Cat. 1 | Census | Max to 47 | 20.2 | 20.0 | 16.5 | 0.2 | 3.6 |
| Off-Peak | Cat. 1 | Assumed | Max to 47 | 37.9 | 37.7 | 19.2 | 0.2 | 18.5 |
| Off-Peak | Cat. 2+ | Census | Balanced | 16.5 | 16.5 | 16.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 2+ | Assumed | Balanced | 24.6 | 24.5 | 16.4 | 0.1 | 8.1 |
| Off-Peak | Cat. 2+ | Census | Max to 47 | 32.4 | 32.1 | 16.8 | 0.3 | 15.3 |
| Off-Peak | Cat. 2+ | Assumed | Max to 47 | 59.9 | 59.0 | 29.3 | 0.9 | 29.7 |
| Peak | Cat. 1 | Census | Balanced | 16.5 | 16.5 | 16.5 | 0.0 | 0.0 |
| Peak | Cat. 1 | Assumed | Balanced | 27.1 | 27.0 | 16.5 | 0.2 | 10.4 |
| Peak | Cat. 1 | Census | Max to 47 | 33.3 | 32.7 | 16.7 | 0.6 | 16.0 |
| Peak | Cat. 1 | Assumed | Max to 47 | 64.5 | 63.4 | 29.4 | 1.1 | 34.1 |
| Peak | Cat. 2+ | Census | Balanced | 20.9 | 20.4 | 16.5 | 0.5 | 3.9 |
| Peak | Cat. 2+ | Assumed | Balanced | 36.5 | 36.2 | 19.0 | 0.3 | 17.2 |
| Peak | Cat. 2+ | Census | Max to 47 | 46.9 | 45.9 | 21.9 | 1.1 | 24.0 |
| Peak | Cat. 2+ | Assumed | Max to 47 | 88.8 | 87.0 | 39.3 | 1.7 | 47.7 |

**Table 2. Total Evacuation Times Assuming a Medium Behavior Response**

| Demand Scenarios | | | | Medium Behavior Response | | | | |
|---|---|---|---|---|---|---|---|---|
| Season | Storm Category | Vehicles Rates | Routing Assumption | No Lane Reversal | Current Contraflow | Extended Contraflow | Current Contraflow Savings | Extended Contraflow Savings |
| Off-Peak | Cat. 1 | Census | Balanced | 21.5 | 21.5 | 21.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Assumed | Balanced | 21.5 | 21.5 | 21.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Census | Max to 47 | 21.5 | 21.5 | 21.6 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Assumed | Max to 47 | 37.4 | 37.4 | 21.6 | 0.1 | 15.8 |
| Off-Peak | Cat. 2+ | Census | Balanced | 21.5 | 21.5 | 21.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 2+ | Assumed | Balanced | 24.7 | 24.5 | 21.5 | 0.3 | 2.9 |
| Off-Peak | Cat. 2+ | Census | Max to 47 | 32.0 | 31.8 | 21.5 | 0.2 | 10.3 |
| Off-Peak | Cat. 2+ | Assumed | Max to 47 | 58.4 | 57.8 | 29.3 | 0.6 | 28.5 |
| Peak | Cat. 1 | Census | Balanced | 21.5 | 21.5 | 21.5 | 0.0 | 0.0 |
| Peak | Cat. 1 | Assumed | Balanced | 28.0 | 27.5 | 21.5 | 0.5 | 5.9 |
| Peak | Cat. 1 | Census | Max to 47 | 32.5 | 32.2 | 21.5 | 0.3 | 10.6 |
| Peak | Cat. 1 | Assumed | Max to 47 | 62.9 | 61.8 | 29.4 | 1.2 | 32.3 |
| Peak | Cat. 2+ | Census | Balanced | 22.4 | 22.3 | 21.6 | 0.1 | 0.7 |
| Peak | Cat. 2+ | Assumed | Balanced | 36.1 | 35.8 | 21.5 | 0.3 | 14.3 |
| Peak | Cat. 2+ | Census | Max to 47 | 46.1 | 45.2 | 22.6 | 0.9 | 22.6 |
| Peak | Cat. 2+ | Assumed | Max to 47 | 86.7 | 84.9 | 39.0 | 1.8 | 45.9 |

**Table 3. Total Evacuation Times Assuming a Slow Behavior Response**

| Demand Scenarios | | | | Slow Behavior Response | | | | |
|---|---|---|---|---|---|---|---|---|
| Season | Storm Category | Vehicles Rates | Routing Assumption | No Lane Reversal | Current Contraflow | Extended Contraflow | Current Contraflow Savings | Extended Contraflow Savings |
| Off-Peak | Cat. 1 | Census | Balanced | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Assumed | Balanced | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Census | Max to 47 | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 1 | Assumed | Max to 47 | 37.6 | 37.5 | 24.6 | 0.0 | 13.0 |
| Off-Peak | Cat. 2+ | Census | Balanced | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Off-Peak | Cat. 2+ | Assumed | Balanced | 26.1 | 26.0 | 24.5 | 0.2 | 1.5 |
| Off-Peak | Cat. 2+ | Census | Max to 47 | 32.6 | 32.4 | 24.5 | 0.2 | 7.9 |
| Off-Peak | Cat. 2+ | Assumed | Max to 47 | 57.6 | 57.2 | 30.1 | 0.4 | 27.1 |
| Peak | Cat. 1 | Census | Balanced | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Peak | Cat. 1 | Assumed | Balanced | 29.3 | 28.8 | 24.5 | 0.5 | 4.3 |
| Peak | Cat. 1 | Census | Max to 47 | 33.1 | 32.6 | 24.5 | 0.5 | 8.1 |
| Peak | Cat. 1 | Assumed | Max to 47 | 62.1 | 61.0 | 30.4 | 1.1 | 30.6 |
| Peak | Cat. 2+ | Census | Balanced | 24.5 | 24.5 | 24.5 | 0.0 | 0.0 |
| Peak | Cat. 2+ | Assumed | Balanced | 36.6 | 36.1 | 24.5 | 0.4 | 11.6 |
| Peak | Cat. 2+ | Census | Max to 47 | 45.9 | 45.0 | 24.6 | 1.0 | 20.4 |
| Peak | Cat. 2+ | Assumed | Max to 47 | 84.6 | 83.1 | 39.2 | 1.5 | 43.9 |

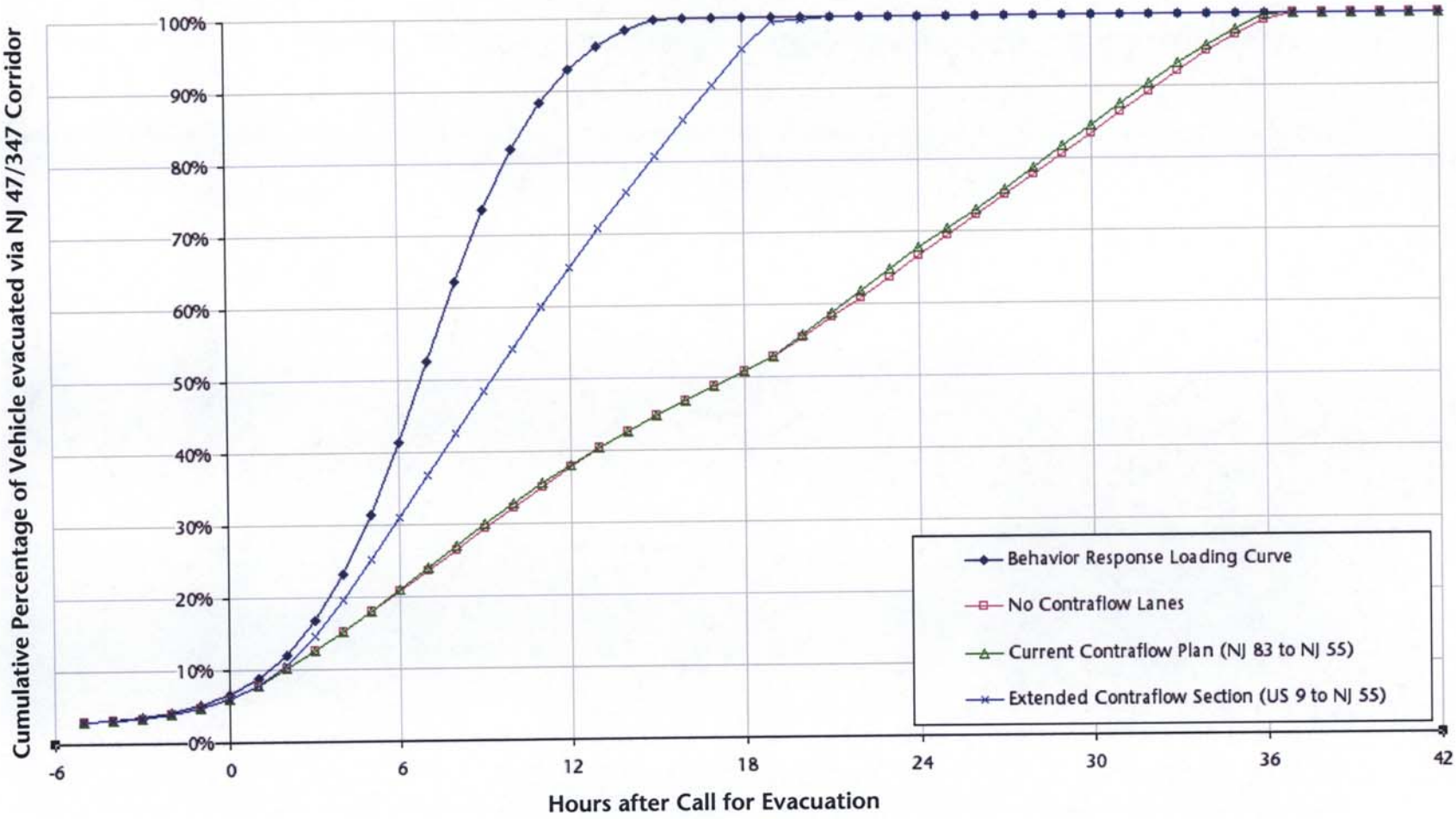


**Figure 4. Cumulative Percentage Evacuated by Hour for a Category 2+ Peak Season Hurricane Strike Assuming a High Vehicle per Household Rates and a Balanced Routing between NJ 47/347 and Other Routes**

# III Elevation Survey

As Cape May County has such a low topography, the potential for inundation from hurricane storm surges is great. This greatly complicates evacuation issues, as a critical issue in any evacuation plan is to determine which roadways would be available to carry out the evacuation plan, including providing access for both evacuees and for emergency vehicle access. The initial study determined the elevations and degree of inundation for the NJ 47/347 corridor. The survey work completed under this work effort does the same for the key feeder roadways into the NJ 47/347 evacuation corridor. The analysis of both sets of survey results follows.

## III.1 Selection of Roadways

The following roadways were selected by examining the official evacuation routes that pass through low-lying areas, as well as non-evacuation routes that could be prove useful for persons evacuating via the NJ 47/347 Corridor.

Cape May County Route 657: Dennisville Rd (Est. Length: 3.0 Miles)
From CO 646 (Swainton-Goshen Rd) to NJ 47 (Delsea Rd)

Cape May County Route 603: Bayshore Rd (Est. Length: 3.0 Miles)
From CO 654 (Fulling Mill Rd) to NJ 47 (Delsea Rd)

Cape May County Route 615: Goshen Rd (Est. Length: 4.3 Miles)
From CO ~~654~~ 615 (Mechanic St) to NJ 47 (Delsea Rd)

Cape May County Route 618: Indian Trail Rd (Est. Length: 3.2 Miles)
From US 9 (Shore Rd) to NJ 47 (Delsea Rd)

Cape May County Route 658: Hand Ave (Est. Length: 3.0 Miles)
From ~~CO 654 (Fulling Mill Rd)~~ US Route 9 (Shore Road) to NJ 47 (Delsea Rd)

The total length of roadway covered by the above sections is approximately 16.5 miles. The survey roadways are illustrated highlighted in yellow in the following Figure 5, which overlays the estimated inundation zones of different categories of hurricane strikes.

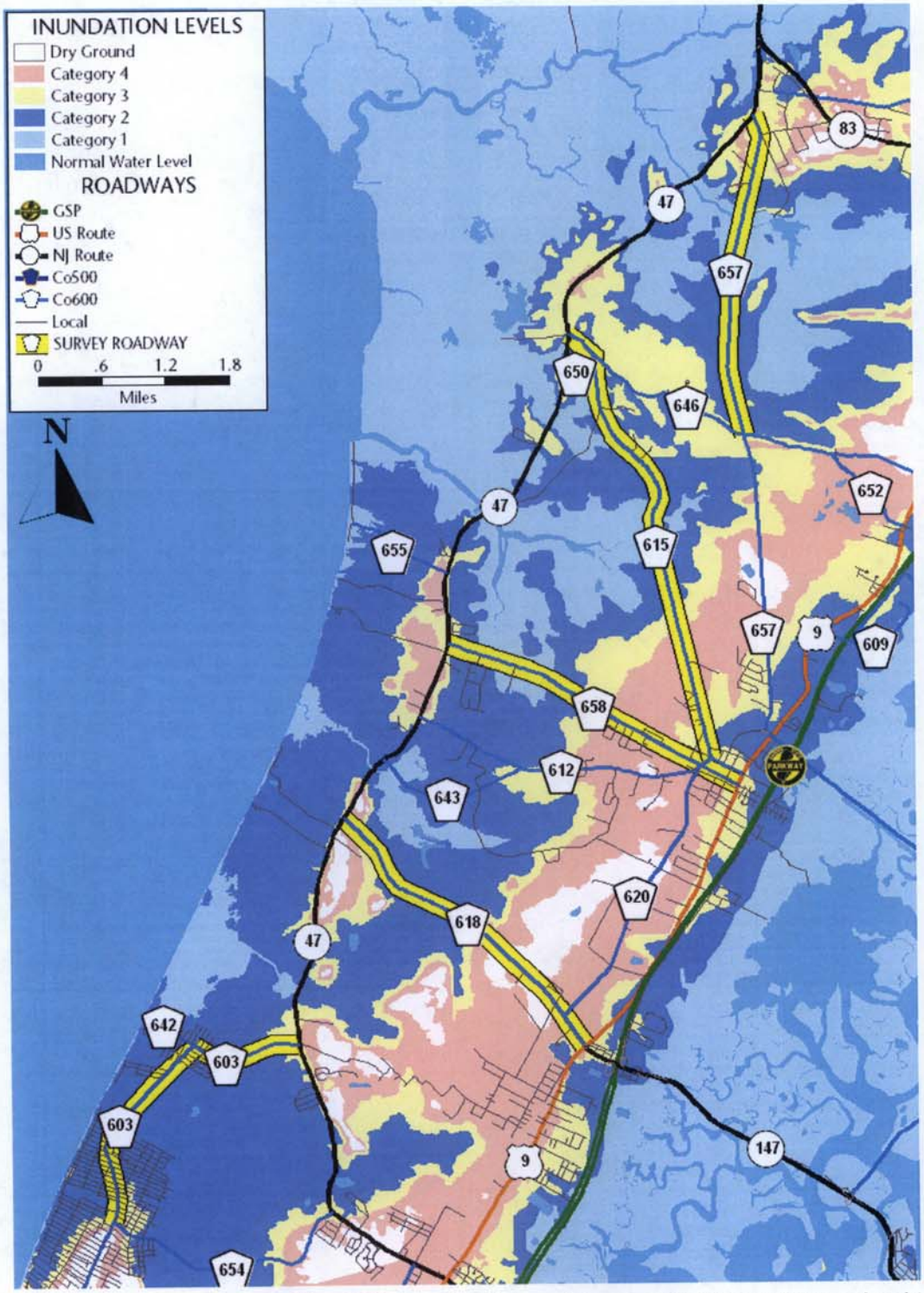


Figure 5: Roadways Selected for GPS Elevation Survey (shown with HES inundation levels)

## III.2 Methodology

### *III.2.1 Kinematic GPS Survey*

The kinematic GPS survey mode provides the ability to establish positions and elevations of new points while a GPS receiver is in motion. A second stationary GPS receiver at a nearby benchmark location (with known horizontal positions/coordinates and elevation) that provides accuracy control for other newly established points. The survey was completed on June 11, 2007. During the initial study, the needed level of accuracy was found to be achievable even when the vehicle was moving at reasonable speeds along the roadway. As such, the survey conducted for this work effort was completed without a safety escort vehicle. The surveyed elevation points were combined with those surveyed from the initial study to produce the maps and analysis that follows. An electronic copy of the survey points and the accompanying analysis of each survey point is available and was delivered along with this report.

### *III.2.2 Storm Surge Elevations*

The storm surge elevations for different hurricane categories were obtained from the Hurricane Evacuation Study or HES map (June 2006 version) produced by the Philadelphia District of the U.S. Army Corps of Engineers (USACE). The map shows storm surge elevations at selected points around Cape May County and the areas that are predicted to be inundated by the anticipated storm surge from different categories of hurricanes. The HES maps list elevations in the NGVD'29 (National Geodetic Vertical Datum of 1929) datum rather than in NAVD'88 (North American Vertical Datum of 1988) datum which is the vertical datum currently used by NJDOT. The difference between these vertical (elevation) datums is more than one foot in the Cape May area. Given the general characteristics of the area (very flat topography), an elevation error of one foot could have a significant impact on whether the roadways are passable or not. Therefore, a datum conversion from NAVD'88 to NGVD'29 was performed for the GPS surveyed elevations in order to ensure compatibility with the information provided by the USACE.

## III.3 Survey Results

In order to determine what category of hurricane would cause storm surges to inundate the surveyed roadways, the storm surge predictions (reported at various points around the region on the HES maps) were transcribed to the surveyed elevations. For each of the surveyed points, the nearest of these 'surge points' was selected. For survey points east of the high point 'ridgeline' that runs down the middle of the peninsula, surge points from the bayside of the barrier islands were used. For the survey points west of the highest point on the peninsula, surge points from the

bayside of the peninsula were used. The resulting mapping of the HES storm surge prediction points to the surveyed roadway elevation points is shown in Figure 6.

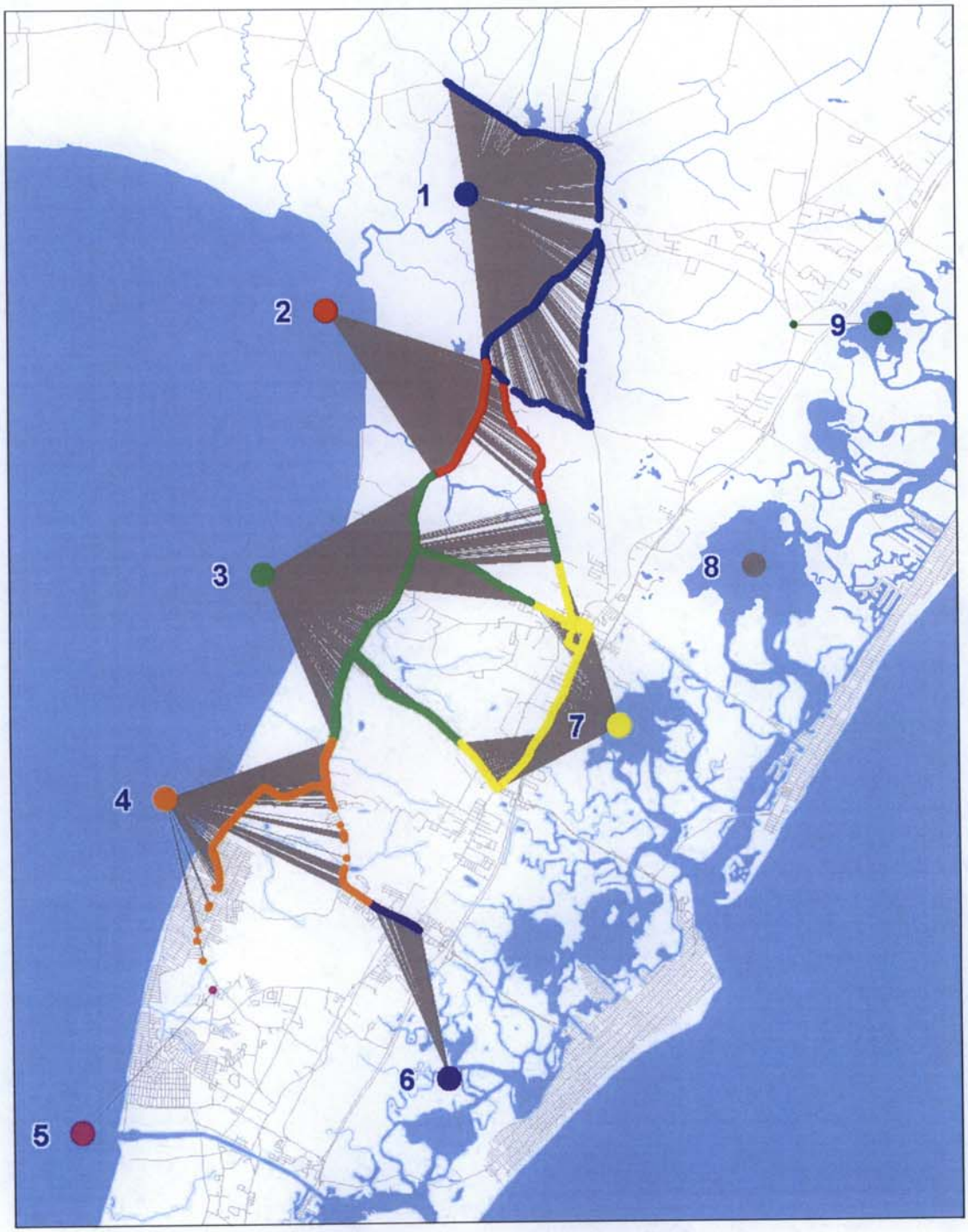


**Figure 6: Mapping the HES Storm Surge Prediction Points to the Surveyed Roadway Elevation Points**

After determining the level of storm surge that would be experienced for the surveyed roadways, the GPS elevation points were classified as being always dry or always inundated at a given hurricane category. For example, if the HES map showed storm surge elevations of 4, 6, 8 and 10 feet for hurricane categories 1, 2, 3 and 4, respectively, and the GPS point was at elevation 11.25 feet, this point was deemed to remain dry under any conditions. If, however, the GPS point was at elevation 6.48 feet, it was classified as a point that will be inundated in the event of a hurricane of level 3. The results of the classification of the GPS surveyed points into various hurricane categories are shown in Figure 7. Within this figure, the color of the survey point along the roadways indicates the lowest category of hurricane for which the storm surge would inundate the roadway.

The survey and analysis reveals that the majority of the surveyed roadways will remain passable during a category 1 hurricane, however, there were surveyed locations in each of the roadways that would be flooded from a category 1 hurricane strike. These locations correspond with the low points predicted by the HES maps. This reiterates the findings from the initial study that the HES maps are a good tool in predicting the category of hurricane that would inundate the regions roadways.

However, for a roadway to be used as an evacuation route, the entire length must be passable. The fact that all the surveyed roadways will be at least partially impassable during the peak levels of a storm surge from a category 1 hurricane, indicates the importance of having a evacuation plan in place that allows enough time for evacuation before the maximum storm surge levels are reached.

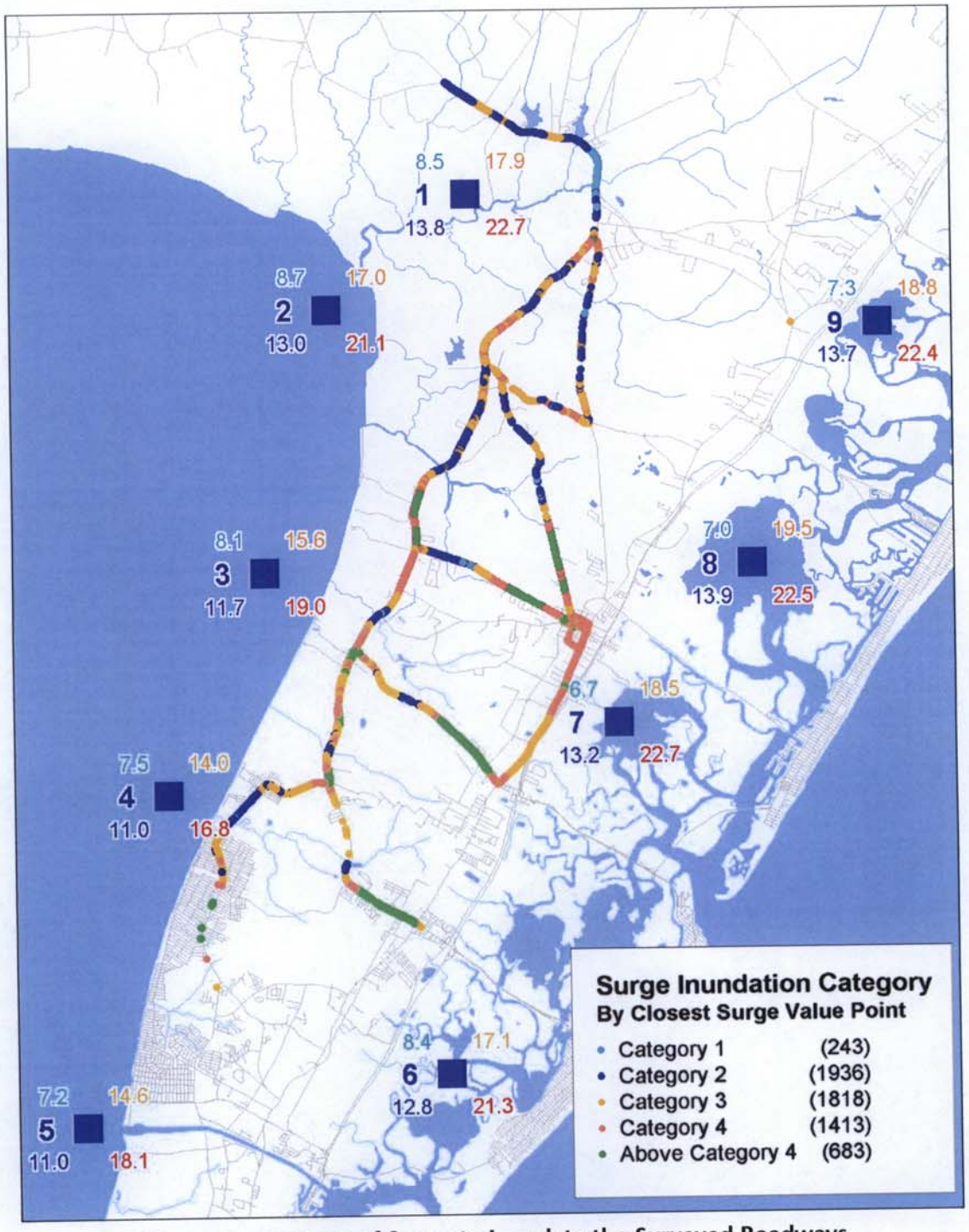


**Figure 7: Category of Storm to Inundate the Surveyed Roadways**

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