Technical Memorandum

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Subject: Maximum Sustainable Evacuation Traffic Flow Rates for Hurricane Evacuation Analysis Purposes

Date: June 17, 2010

This technical memorandum has been prepared to document the process and results of an effort to develop a series of maximum sustainable traffic flow rates that can be used to conduct simulation modeling of US-1 within the Florida Keys during an evacuation of this area. The need for this information became apparent after numerous efforts to develop macroscopic models to estimate the evacuation clearance time for the Keys over the past decade. Because macro-level modeling typically relies on aggregate relationships between the level of travel demand and the roadway's ability to service it, the expected roadway capacity is a key factor in estimating key performance measures such as operating speeds, travel time, and delay. While not the actual "capacity" of the road, the flow rates presented here represent the practical rates that are likely to be realistically sustainable over an extended period (8 or more hours) of a mass evacuation.

Over the past ten years, discussions among various stakeholders and agencies charged with the civil protection of residents and visitors in the Keys and those with the authority to develop policies governing the growth and development of these areas have suggested a range of different values that should be used when assigning road capacities. Some of these have been based on Highway Capacity Manual (HCM) procedures while others have been based on professional experience and judgment. Few if any, however, have been based on direct observation during prior evacuation events.

A history of research and observation shows that the maximum amount of traffic flow that can be accommodated by a segment of roadway can be significantly impacted by factors such as the behaviors of the drivers and vehicles using it. The complex interaction of these variables and the nature of development conditions within the Keys combined with the variable nature of hurricanes and evacuee responses make it difficult to predict a maximum flow rate using traditional means.

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Over the past 10 years, however, a considerable amount of new data and studies have become available that have increased the understanding of evacuation traffic flow conditions. These recent developments include the collection of traffic data under actual mass evacuation conditions on different functional roadway classifications and design configurations. Data also include observations from several different states from a number of different hurricane evacuation events. Some of this information has been published in government reports and technical papers, several of which are referenced in this memo.

A key point in this memo is also the development and use of the term "maximum sustainable evacuation traffic flow rate." This term differs from prior discussions and modeling efforts which utilized the term "capacity." It is based on years of field observation which consistently suggest that the maximum flow rates that can be sustained during an evacuation are often considerably lower than those observed during routine (non-emergency) conditions such as daily rush-hours. Explanations of why this drop occurs are varied, with some of them discussed later in this memo.

Background

In mid-2009, based on previous analysis and recommendation by Dr. Brian Wolshon, a nationally recognized expert in hurricane evacuation matters, the Florida Department of Transportation (FDOT) initiated a site-specific maximum sustainable traffic flow rate study[1] in the Key Largo area. The purpose of this report was to assess traffic flow rates under a variety of conditions and to confirm the appropriateness of the roadway capacity values used in the 2001 Florida Keys Hurricane Evacuation Study (2001 Study) established by the 2001 Study Project Steering Committee (PSC). The 2001 Study PSC included representatives from the U.S. Army Corps of Engineers (USACOE), Florida Division of Emergency Management (DEM), Monroe County Board of County Commissioners, Monroe County Emergency Management, Florida International University (FIU), and FDOT staff and consultants, Vanasse-Hangen-Brustlin and Miller Consulting, Inc.

The site-specific capacity study was prepared for the FDOT by Dr. Brian Wolshon and Traf Tech Engineering, Inc. The analyses were conducted using CORSIM, a micro-scale simulation system (e.g., an agent-based model). As such, the model is influenced by locally prevailing traffic control and geometric design features such as intersections, turn lanes, and median crossovers in addition to individual driver and vehicle characteristics that govern gap-acceptance and lane-changing behaviors.

To further enhance the validity of the analyses conducted in this effort and the results gained from them, a series of base-line simulation models were developed and then calibrated to a set of field observed traffic volumes recorded over a recent event-weekend in the Keys. The results obtained from the site-specific capacity study indicate that the capacities used in the 2001 Study within the Key Largo area are appropriate for hurricane evacuation purposes. That is, the 900 vehicles per hour per lane (vphpl) maximum sustainable evacuation traffic flow rate assigned to US 1 within Key Largo is considered appropriate given the type of road and development conditions that exist in this area as well as the life-threatening nature of hurricanes.

This report includes new data available from the 10-year period since the original 2001 Study. It also includes observational studies and simulation systems that have improved our understanding of traffic operations under mass evacuation demand conditions.

Recently observed flow rates include those associated with Hurricanes Floyd in Florida and South Carolina (FEMA 2000) and Hurricane Katrina in Louisiana (Wolshon & McArdle 2008, and Wolshon, Catarella-Michel & Lambert 2006). These observations show that many of the highest observed flow rates cannot be sustained for periods lasting several hours because of inevitable disruptions to the smooth flow of traffic as well as flow restrictions that may exist far downstream of a particular point of measurement. Under capacity-level demand conditions, even slight disruptions in traffic streams can result in the formation and propagation of traffic shockwaves that move both quickly and widely through a network. It is for these reasons that experts in the field of evacuation transportation refer to "practical" maximum sustainable evacuation flow rates. Prior study has shown that these practical rates are 10 to 20 percent below maximum flow rates that are observed at the same location during normal daily peak periods and below rates that would be suggested under the ideal condition capacity values discussed in the HCM.

Recent Hurricane Evacuation Traffic Flow Rates

To illustrate and describe the concept of practical maximum sustainable evacuation flow rates, it is helpful to review observations made in recent hurricane evacuations. Because of the high level of storm activity and related need to carry out major mass evacuations, the State of Louisiana has been one of the most studied areas of the United States for evacuation traffic movement. Over the past six years, the southeast region of the state including metropolitan New Orleans has been evacuated four times (Ivan '04, Katrina '05, Rita '05, and Gustav '08). These events have afforded the opportunity to collect and analyze traffic patterns as well as to make incremental changes to the regional evacuation plans.

In recent studies at Louisiana State University's Gulf Coast Research Center for Evacuation and Transportation Resiliency, the flow rates recorded by the Louisiana Department of Transportation and Development (LA DOTD) on roads throughout the state during the Hurricane Katrina evacuation were used to determine practical maximum sustainable evacuation flow rates for a variety of roadway and area types (Wolshon 2008). It was suggested that these volumes could be used when performing future clearance time estimate studies in Louisiana and elsewhere.

The studies focused on four different facility types including freeways, freeways flowing under contraflow, four-lane divided highways, and two-lane highways within urbanized and non-urbanized regions. Although none of the roads and areas that were studied was exactly like US-1 through the Florida Keys, several segments were similar enough to give a reasonable approximation of the conditions. Results of the analyses from two of the most relevant of these facilities, four-lane divided highways and two-lane highways are discussed in the following sections.

Four-lane Divided Highways

The roads that were likely the most analogous to the four-lane divided segments of US-1 in the Upper Keys were segments of the four-lane divided highways of US-61 and LA-1 moving into the "semi-suburban" areas within the region between New Orleans and Baton Rouge. The locations of the count stations on these roads could generally be described as fringe suburban communities in which traffic moved from uninterrupted flow segments into more developed areas that include at-grade signalized intersections, similar to what occurs as traffic moves north into the upper Keys areas approaching Key Largo. These sites are also relevant to the US-1 discussion because during the evacuation they were loaded with traffic volume far-above routine peak-hour levels and the demand was sustained over two full back-to-back daylight periods. This gives an illustration of what could occur during a full evacuation of the Keys when traffic demand is expected to be sustained at such levels for about 24 hours.

On US-61 in the vicinity of LaPlace, Louisiana, represented graphically in Figure 1, the maximum hourly flow during the Katrina evacuation reached 1,881 vehicles per hour (vph) (958 vph in Lane 1 and 923 vph in Lane 2) on Day 2 (Sunday) of the event. Similarly, the maximum hourly flow on LA-1 in the vicinity of Plaquemine, Louisiana, represented graphically in Figure 2, was observed to rise to 1,740 vph (858 vph in Lane 1 and 882 vph in Lane 2) during the second day of the evacuation. Also apparent in these figures is that these flow rates were generally able to be sustained at levels of 1,650 vph to 1,720 vph in both lanes (somewhat below the peak) for about *10* continuous hours during both days of the evacuation. These flows suggest the maximum sustainable limits of these two roads without breaking down into a no-flow "gridlock" condition.

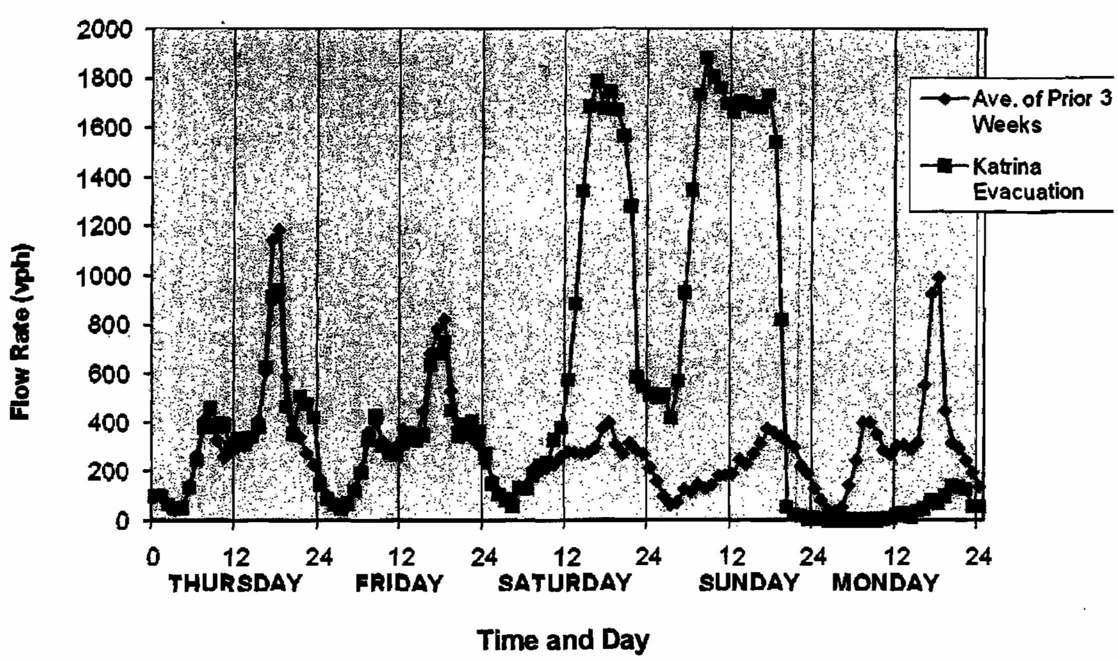


Figure 1. Hourly Northbound Evacuation (2-lane) Traffic Volume - US-61 LaPlace Louisiana, Hurricane Katrina

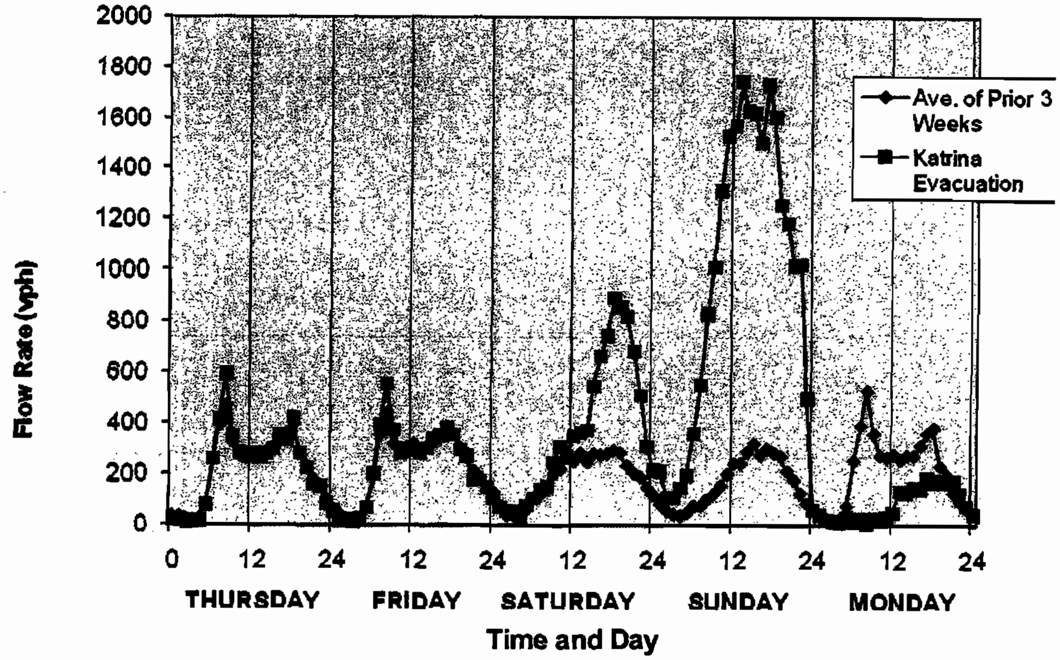


Figure 2. Hourly Northbound Evacuation (2-lane) Traffic Volume - LA-1 Plaquemines Louisiana, Hurricane Katrina

For comparison, two other four-lane divided highway locations are also included. These included two separate sections of US-190 in the vicinity of Baton Rouge, Louisiana. Baton Rouge is a key location for evacuees seeking to move to westerly destinations during evacuations of southeastern Louisiana because it includes two of the four Mississippi River bridge crossings within the 100 mile segment between New Orleans and Natchez, Mississippi. While these are four-lane divided highway segments, they are thought to be significantly different from US-1 and the segments of US-61 and LA-1 discussed previously because they are within areas of generally uninterrupted flow for several miles up and downstream of data recording stations. Although there are minor at-grade intersections, none of them are signalized and access to/from major routes is accomplished using grade separated interchanges.

At the outflow point of the US-190 bridge over the Mississippi River, illustrated graphically in Figure 3, maximum hourly flow reached 2,337 vehicles per hour (vph) (1,094 vph in Lane 1 and 1,283 vph in Lane 2) during the second day of the Hurricane Katrina evacuation. At a location several miles downstream of the bridge, illustrated graphically in Figure 4, a maximum flow of 1,937 vehicles per hour (vph) (560 vph in Lane 1 and 1,377 vph in Lane 2) was observed on US-190. Also relevant to the discussion of the US-1 evacuation flow rates is that even these elevated maximum flows were sustained for periods of about three hours before dropping to rates of 1,700 to 2,000 vph for the remaining 8 to 10 hours of Day 2 of the evacuation. Even with the benefit of grade separations and uninterrupted flow conditions, these flows are not significantly different from the previously discussed four-lane divided segments of US-60 and LA-1.

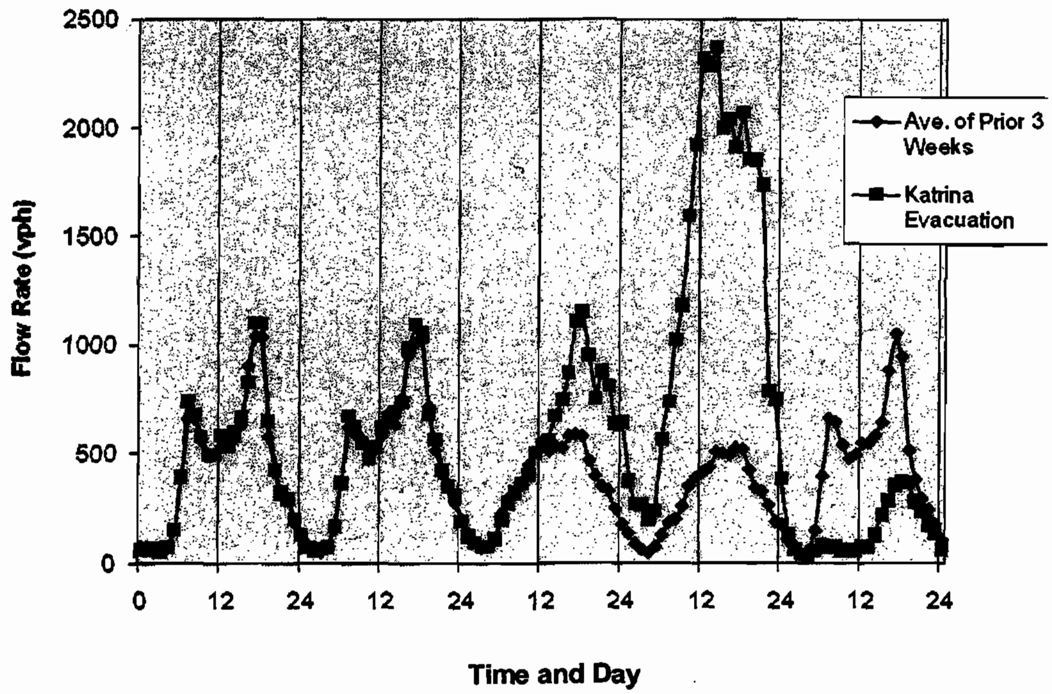


Figure 3. Hourly Westbound Evacuation (2-lane) Traffic Volume - US-190 (Mississippi River Bridge departure) Port Allen Louisiana, Hurricane Katrina

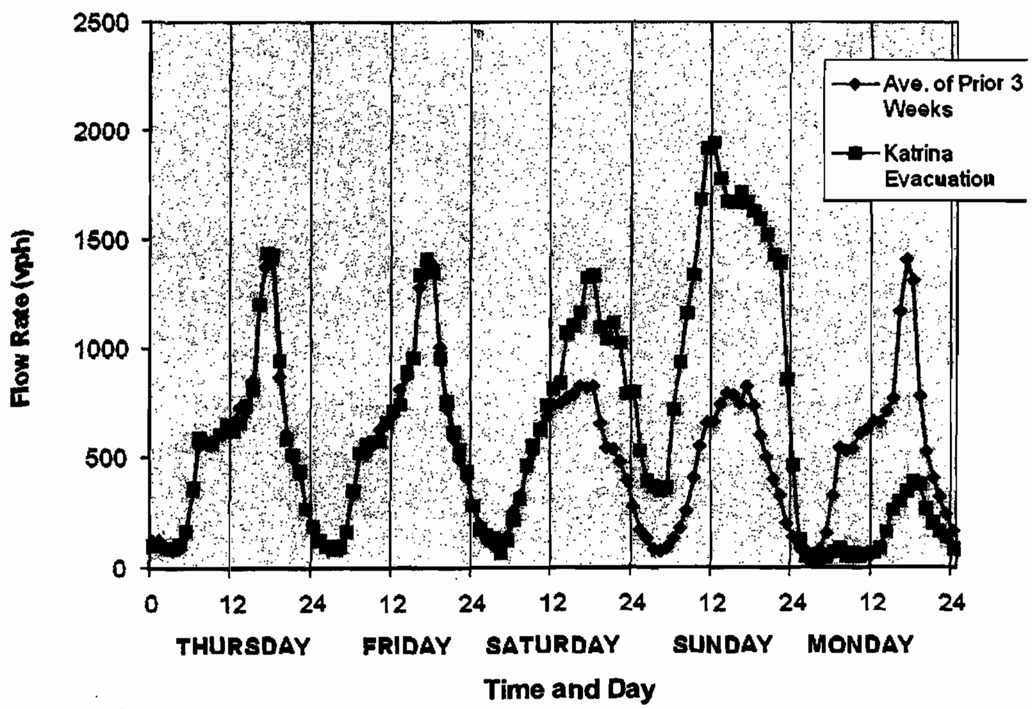


Figure 4. Hourly Westbound Evacuation (2-lane) Traffic Volume - US-190 Port Allen Louisiana, Hurricane Katrina

Combined, these observations suggest that the practical maximum sustainable evacuation flow rates on four-lane divided highways in relatively developed areas are likely to be about 900 to 1,000 vehicles per hour per lane (vphpl). In areas where the evacuation traffic stream is subjected to intersections with signal control or periodic interruptions from traffic enforcement police, it is further suggested that the practical maximums will be at the low end of this estimate and perhaps still lower if nighttime and/or adverse weather conditions are present. Since the Keys are required to evacuate over a period of near, or in excess of 24 hours, at least half of this evacuation process will occur in low light to total darkness conditions.

Two-lane Highways

The LSU research also included analyses of two-lane Louisiana state highways. The data collected for the Hurricane Katrina evacuation studies included roads throughout the state in areas impacted both directly and indirectly by the evacuation traffic. This research will be published in an upcoming issue of the American Society of Civil Engineer's *Natural Hazards Review* (Wolshon & McArdle 2010).

The research showed that although the highest traffic was observed on routes servicing highly populated areas nearest to the coast and closest to the projected path of the storm, two-lane roads providing access to freeway routes or serving as alternate paths to congested freeways also carried heavy traffic loads. The highest volumes observed on two-lane routes in Louisiana during the Hurricane Katrina were recorded on LA-21 near Bogalusa, Louisiana (north of New Orleans) and on US-190 near Basile, Louisiana (north of Lafayette). These are represented graphically in Figures 5 and 6.

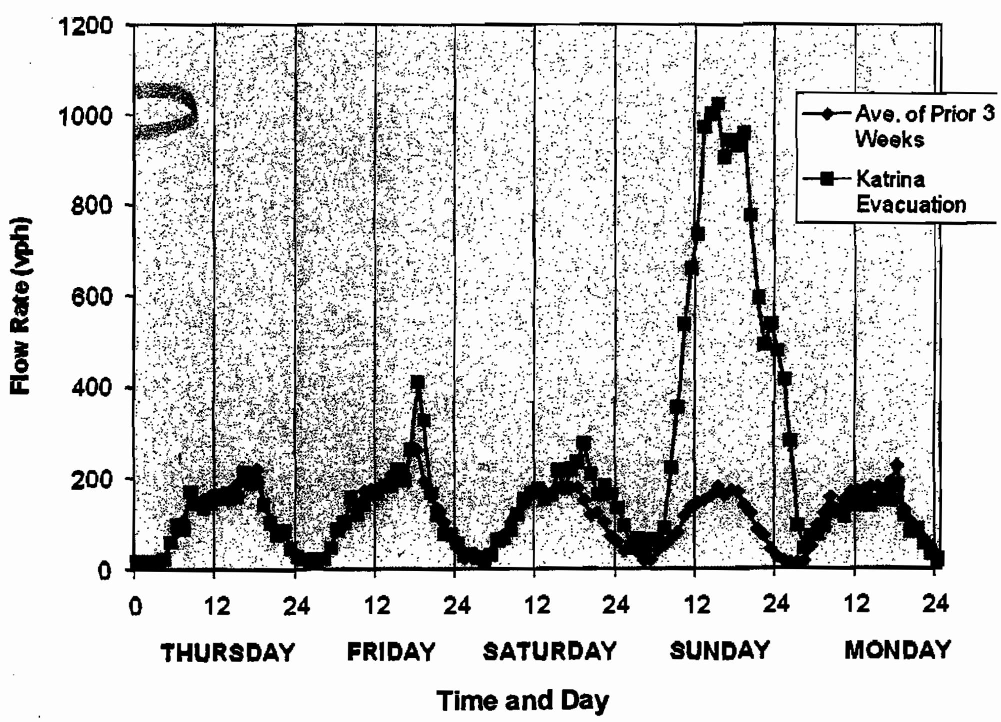


Figure 5. Hourly Westbound Evacuation Traffic Volume - US-190 Basile Louisiana, Hurricane Katrina

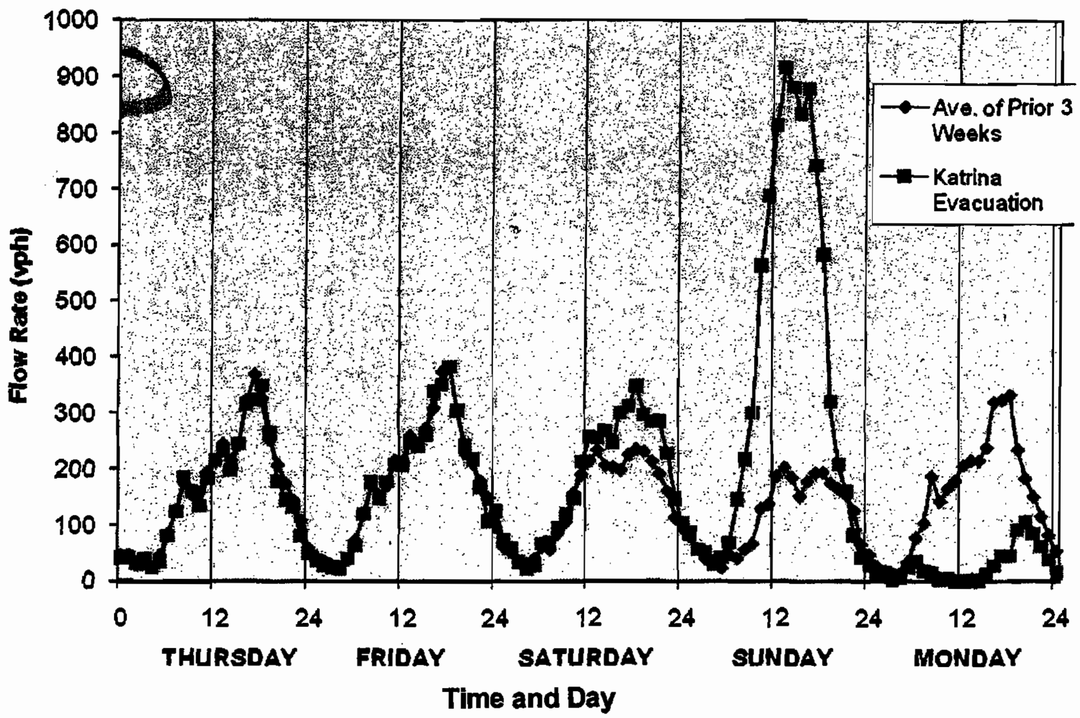


Figure 6. Hourly Northbound Evacuation Traffic Volume - LA-21 Bogalusa Louisiana, Hurricane Katrina

The research also suggested that the orientation and relative proximity to Interstate freeways made them likely alternatives to the more heavily traveled (and congested) freeway routes. Data from both of these routes were also collected in predominantly rural areas of the state, with relatively low populations, and within areas of few traffic signals such as might be similar to many of the two lane segments of US-1 in the Florida Keys.

During the second day of the Hurricane Katrina evacuation on the two-lane segment of US-190 near Basile, the maximum one hour flow reached 1,021 vph. These evacuation flows were sustained throughout the day with flows of above 900 vph for about eight consecutive hours. At the LA-21 station in Bogalusa, a maximum flow of 915 vph was observed on the same day. The elevated volume of greater than 800 vph extended over a period of about five hours. However, it appears that the demand at this location was not sufficient to maintain the maximum flow for a longer period.

Although it is not clear that these study areas are representative of the conditions along rural stretches of US-1 through the Middle and Lower Keys, overall, these data suggest that it is possible to maintain sustained maximum flow rates at and above 900 to 1,000 vph during an evacuation.

Florida Keys Evacuation Flow Rates

Although the flow conditions associated with evacuations in the Florida Keys have not been studied in the level of scientific detail as those in Louisiana, the fact that this area has regularly been threatened by hurricanes over the past 10 years has meant that several evacuations of the Keys have been carried out at varying levels of urgency and rates of participation. These events have also permitted the FDOT to record traffic volumes under evacuation conditions.

A review of recent history shows that in 2004 and 2005 a total of six hurricanes required some level of evacuation in the Keys. After a two-year lull in activity, two more tropical systems required evacuations in 2008. In August 2004, Hurricane Charley passed about 70 miles west of Key West, bringing tropical storm winds to the Lower Keys and requiring a mandatory evacuation of the visitor population. The Lower Keys were also evacuated in advance of the expected arrival of Hurricane Ivan in September 2004 and Hurricane Dennis in July 2005, although neither storm came close enough to cause significant damage in these areas. In 2005, Hurricane Rita grew from a tropical storm to a Category 2 hurricane as it moved westward from the Bahamas, ultimately passing south of Key West and causing serious damage and surge flooding as far north as Key Largo. In October 2005, Hurricane Wilma became the most devastating hurricane to hit the Keys in decades when it passed just northwest of Key West. The low-lying parts of the city were left under 3 to 6 feet of water from the storm surge, and major flooding was reported throughout the Keys up to Key Largo (Kasper 2005).

In 2008, Tropical Storms Fay and Ike also resulted in orders to evacuate various resident and non-resident populations. Table 1 lists the evacuation orders that were issued for these events. The table also includes the dates and times of the orders and the areas which they covered.

Although the level of threat and corresponding evacuation requirements varied for each of these events, the most relevant point to the development of the maximum sustainable evacuation flow rates is that several of these evacuations generated traffic demand at levels that were significantly above normal, resulting in traffic congestion and/or queuing along various segments of US-1 in the Keys. The occurrence of congestion and queuing is important to this discussion because it demonstrates that the demand generated by the evacuation was sufficient to exceed the available capacity of the roadway for some duration of time. As such, the hourly volumes that were recorded are assumed to reflect the maximum traffic that could be carried by US-1 at those locations during those periods.

The volumes recorded during each of these events are also included in Attachment B of this report. The data included in Attachment B comes from three stations that are part of the FDOT statewide permanent traffic data monitoring system. The first of these, Station 900165, is located on a four-lane segment of US-1 at Mile Marker (MM) 4.32 on Stock Island near Key West. The second, Station 900227, is on a two-lane section of US-1 at MM 29.6 on Big Pine Key and the third, Station 900164, from a four-lane section of US-1 at MM 106.3 on Key Largo near its intersection with County Road 905. In addition to the traffic volumes recorded during the evacuation period, each of the figures from the South Florida Regional Planning Council (SFRPC) (SFRPC 2007) also includes the:

- annual average hourly volume trends for same time period,
- average hourly volume trends for same time period for the two months preceding the evacuation, and
- the times at which orders for specific populations were issued, including:

- permanent residents
- visitors
- partial resident/visitor
- residents driving in or towing mobile homes, RVs, or boats

The graphs from Tropical Storms Fay and Ike were prepared separately and include the:

- hourly volume trends recorded during each day of the evacuation period, and
- average hourly volume trends for same time period for June, July, August, and September of 2008.

Storm	Date	Time	Location	Evacuation Ordered
2004				
Hurricane Charlie	08/11/04	11:00am	Key West to Craig Key (MM 72)	Limited visitor
	08/12/04	5:00am	Entire Florida Keys	Visitors
Hurricane Frances	09/02/04	8:00am	-	Visitors
Hurricane Ivan	09/09/04	8:00am	-	Visitors
	09/09/04	5:00pm	-	Mobile homes, RV, boat residents
	09/10/04	5:00am	-	Residents
2005				
Hurricane Dennis	07/07/05	12:00pm	-	Visitors
	07/07/05	4:00pm	West of 7 Mile Bridge to Key West	Limited Resident
Hurricane Rita	09/19/05	6:00am	-	Visitors
	09/19/05	8:00am	-	Residents
Hurricane Wilma	10/19/05	12:00pm	-	Visitors
	10/22/05	12:00pm	-	Residents
2008				
Tropical Storm Fay	08/17/08	8:00am	-	Visitors
	08/17/08	7:00pm	-	Mobile homes, RV, boat residents
Tropical Storm Ike	09/06/08	9:00am	-	Visitors
	09/07/08	8:00am	-	Residents

Table 1. Monroe County Evacuation Orders 2004-2005 and 2008 (SFRPC 2007)

Although each of the stations reveals somewhat different information, the two that are perhaps the most relevant to the discussion here are Stations 900227 and 900164. Station 900227 (Big Pine Key) is important because it is the only two-lane segment location for which traffic data was available in the Keys for these six events. Station 900164 (Key Largo) is important because it represents as near to a complete data set of out-of-county traffic movements as can be counted in the Keys since nearly all vehicles passing this point will be traveling out of Monroe County.

Station 900227 (Big Pine Key)
At Station 900227 it is interesting to note that the northbound direction did not always exceed the corresponding annual average hourly volumes for the same time period. In fact, this appears to have only occurred in four of the six storm events. This suggests that the forecasted conditions of Hurricanes Wilma and Frances were not sufficient to induce a major movement of evacuees. The highest traffic volumes at this location were associated with the evacuations for Rita, Dennis, and Charley. For each of these events the maximum hourly flows in the single outbound lane of this segment were in the range of 1,000 to 1,150 vph. Although this high volume lasted only an hour or two for the Hurricane Rita evacuation, elevated traffic volumes at or greater than 1,000 vph lasted for periods of four to five hours.

During the two tropical storm events of 2008, a maximum flow of 1,030 vph was recorded between 11:00am and noon on Sunday, August 17th. Flows of 909 vph and 944 vph were recorded during the preceding and following one hour periods, respectively.

Although it cannot be known with absolute certainty that these flow volumes were the absolute maximum that this segment of road could carry nor whether the demand generated by the 2004 and 2005 evacuations was sufficient to fully feed this section, the fact that the elevated volumes were significantly above any of the annual hourly average north or southbound observations and that they were maintained above these levels for several consecutive hours, suggests that they are likely the maximum evacuation traffic volumes that can be sustained at this location during such an event. It is also worth noting that these observations are also in the same range as the volumes recorded on similar functionally classified roadways in Louisiana during Hurricane Katrina in 2005.

Station 900164 (Key Largo)
At Station 900164 evacuating volumes significantly exceeded the annual average hourly rates during five of the seven events for which data was available (data was not recorded during the 2005 Hurricane Rita evacuation). The highest observed volumes at this location were recorded during the evacuations for Tropical Storm Fay, Hurricanes Dennis and Charley, and to a lesser extent Hurricane Ivan. During Hurricanes Dennis and Charley, the maximum hourly flows were in the range of 1,400 to 1,450 vph (for two lanes). Although there was some variation, this elevated volume lasted at these levels for periods of six to eight hours.

Similar to Station 900227, elevated volumes were apparent during the Tropical Storm Fay evacuation, but not for Tropical Storm Ike. Maximum evacuation traffic flow rates of about 1,600 vph to 1,750 vph (for two lanes) were sustained for about six to seven hours on Sunday, August 17, 2008.

Also of note on these graphs were two other trends. The first was that the elevated evacuation volumes existed over two days and for periods in excess of 30 hours. The second observation was the significant drop of the traffic volume during the overnight hours of the two-day evacuation period. Although the hourly traffic volumes were notably higher than the annual hourly average, it was clear that, similar to numerous observations in other areas of the country for other hurricanes, evacuation travel demand tends to ebb during late night hours.

Similar to the observations at the other FDOT traffic data recording stations in the Keys, the fact that the elevated volumes were significantly above any of the north or southbound observations and that they were maintained above these levels for several consecutive hours suggests that these are likely close to the maximum evacuation traffic volumes which can be sustained at this location during such an event.

A comparison of the Keys volumes to those observed in Louisiana during Hurricane Katrina are also noteworthy because the volumes recorded on this section of US-1 were, as expected, somewhat lower than in Louisiana. This is because, as discussed earlier, the segments of four-lane divided highways in Louisiana were in areas where the amount of driveway openings, adjacent development and at-grade intersections was less than in this area of Key Largo. As such, the earlier suggestion that the practical maximum sustainable evacuation flow rates on four-lane divided highways in relatively developed areas will likely to be in the neighborhood of approximately 900 to 1,000 vphpl continues to be appropriate.

In areas like the Upper Keys and Key Largo where the evacuation traffic stream is expected to be subjected to potential periodic interruptions from traffic law enforcement and where approximately 20 percent of the total Keys evacuation traffic demand is expected to be generated and enter onto US-1, it is further suggested that the practical maximums will be at the low end of this estimate and perhaps still lower if nighttime and/or adverse weather conditions are present.

Conclusion

Based on the data collected on US-1 during recent evacuations in the Keys, evacuation flow rates collected in other locations, and the specific design, control, and land development characteristics that currently exist along US-1, the table of maximum sustainable evacuation traffic flow rates shown in Attachment A are suggested for hurricane evacuation analysis purposes. Although the data recorded during prior evacuations in the Keys do not reflect the "near-worst case scenario" conditions that are currently being studied, they represent a reasonable estimate of what should realistically be sustainable, given the absence of such data. Perhaps most important is that they represent estimates that, although close to being reached, have never been exceeded during any past evacuation event for which traffic data has been available.

As noted on the table, these values also represent the anticipated maximum sustainable flow rates per "functional evacuation lane," where a functional evacuation lane is defined as any through travel lane or continuous paved shoulder with a width of at least 10 feet. Because of the possibility that some of the existing (and potential future) suitable shoulder areas could be used as an additional outbound "lane" to carry evacuation traffic on some segments of US-1 during an emergency, these values can also be used for planning models of these temporary outbound travel areas. Since shoulders have never, to our knowledge, been used in the Florida Keys as functional evacuation lanes on a formal basis or been systematically studied to assess their operational characteristics, their exact carrying capacity in not known at this time. However, prior analysis conducted for FDOT (ATEC 2008) has concluded that continuous paved shoulders of ten feet or greater in width will permit traffic operations that are effectively the same as an adjacent standard travel lane during an evacuation. This finding is based largely on the opinion that, although traffic flow conditions will vary during an evacuation, travel speeds during the main part of the evacuation are likely to be less than the free flow rate and with the likely high densities of the traffic stream the typical benefits of wide lanes may be negligible.

The values in Attachment A also represent the most relevant and applicable data currently available as well as the decades of study, experience and professional judgment of the authors. However, as in all traffic estimates and forecasts of future conditions it must be recognized that traffic conditions can vary at any specific time or location on a day-to-day or even hour-to-hour basis. Such variations result from infinite combinations of uncertain driver, environmental (nighttime, rain, flooding, etc.), traffic control, and vehicle-mix conditions. These specific conditions may bring traffic flow to a crawl for significant periods or even permit flows to be marginally higher for short periods during an evacuation. As more data become available in the future and the understanding of the specifics of traffic operations during evacuations improves, it is also possible that the flow rates shown in Attachment A may need further refinement. It is highly recommended that similar analyses be conducted periodically in the future as new hurricane evacuation traffic flow data becomes available.

References

Espino, E., 2008. "Capacity of Shoulder lane vs center lane during hurricane evacuation event on SR 5/Overseas Highway" – Technical Memorandum, FDOT, District Six, PLEMO.

Federal Emergency Management Agency (FEMA), 2000. "Reverse Lane Standards and ITS Strategies Southeast United States Hurricane Study – Technical Memorandum 3", Final Report, Post, Buckley, Schuh & Jernigan, Inc. Tallahassee, FL.

Kasper, K., 2005. "Hurricane Wilma in the Florida Keys, National Oceanic and Atmospheric Administration (NOAA)/National Weather Service (NWS) Weather Forecast Office (WFO) Key West, Florida. [Available at: http://www.srh.noaa.gov/media/key/Research/wilma.pdf, accessed May 28, 2010]

South Florida Regional Planning Council (SFRPC), 2007. "2006 South Florida Regional Hurricane Evacuation Traffic Study Technical Support Document," prepared for the Florida Department of Community Affairs, Tallahassee, FL. [Available at: http://www.sfrpc.org/data/RHEMTecSupportFinal.pdf, accessed May 28, 2010]

Wolshon B. and B. McArdle, 2008. "Temporospatial Analysis of Hurricane Katrina Regional Evacuation Traffic Patterns," ASCE Journal of Infrastructure Systems – Special Infrastructure Planning, Design, and Management for Big Events Issues, March 2009, Vol. 15, No. 1, pp.12-20.

Wolshon B., 2008. "Empirical Characterization of Mass Evacuation Traffic Flow," Transportation Research Record 2041 - The Journal of Transportation Research Board, pp. 38-48.

Wolshon B. and B. McArdle, 2010. "Traffic Impacts and Dispersal Patterns on Secondary and Low Volume Roadways During Regional Evacuations," currently in press for publication in the American Society of Civil Engineer's *Natural Hazards Review.*

Wolshon B., A. Catarella-Michel, and L. Lambert, 2006. "Louisiana Highway Evacuation Plan for Hurricane Katrina: Proactive Management of Regional Evacuations," ASCE Journal of Transportation Engineering, Volume 132, Issue 1, pp. 1-10.

ATTACHMENT A
Maximum Sustainable Evacuation Traffic Flow Rates for the Florida Keys During Hurricane Evacuations

TABLE 2A

Roadway Configuration on US Highway 1 (Overseas Highway) and CR 905/Card Sound Road in the Florida Keys, Monroe County, Florida

Area	Milemarkers		Location/Description	Year 2010 Configuration
	From	To		
Lower Keys	2.0	4.0	Key West to Stock Island	4L
Lower Keys	4.0	9.0	Stock Island to Big Coppitt Key	4LD
Lower Keys	9.0	17.0	Big Coppitt Key to Sugarloaf Key	2L
Lower Keys	17.0	22.0	Sugarloaf Key to Cudjoe Key	2L
Lower Keys	22.0	24.0	Cudjoe Key to Summerland Key Cove Airport	2L
Lower Keys	24.0	25.0	Summerland Key Cove Airport to Summerland Key	3L
Lower Keys	25.0	30.0	Summerland Key to Big Pine Key	2L
Lower Keys	30.0	34.0	Big Pine Key to West Summerland Keys	2L
Lower Keys	34.0	35.2	West Summerland Keys to Spanish Harbor Keys	2L
Lower Keys	35.2	36.5	Spanish Harbor Keys to Bahia Honda Bridge	4LD
Lower Keys	36.5	37.5	Bahia Honda Bridge to Bahia Honda Key	2L
Middle Keys	37.5	47.0	Bahia Honda Key to Hog Key	2L
Middle Keys	47.0	48.0	Hog Key to Boot Key	2L
Middle Keys	48.0	50.2	Boot Key to Marathon	4L
Middle Keys	50.2	50.8	Marathon to Marathon Shores	5L
Middle Keys	50.8	54.0	Marathon Shores to Key Colonial Beach	4LD
Middle Keys	54.0	54.5	Key Colonial Beach to Deer Key	4LD
Middle Keys	54.5	58.0	Deer Key to Grassy Key	2L
Upper Keys	58.0	74.0	Grassy Key to Matecumbe Harbor	2L
Upper Keys	74.0	80.0	Matecumbe Harbor to Teatable Key	2L
Upper Keys	80.0	83.5	Teatable Key to Islamorada	3L
Upper Keys	83.5	85.6	Islamorada to Windley Key	2L
Upper Keys	85.6	90.0	Windley Key to Plantation Key	2L
Upper Keys	90.0	100.0	Tavernier Key to Newport Key	4LD
Upper Keys	100.0	105.0	Newport Key to Sexton Cove	4LD
Upper Keys	105.0	106.3	Sexton Cove to Rattlesnake Key	4LD
Upper Keys	106.3	126.5	Rattlesnake Key to Card Sound Rd	2L/4L
South Dade	126.5	HEFT	Card Sound Rd to HEFT	4LD
Upper Keys	106.3	Int CR 905 / CR 905 A	Lake Surprise to Crocodile Lake	2L
Upper Keys	Ocean Reef	Int CR 905 / CR 905 A	Tanglefish Key to Crocodile Lake	2L
Upper Keys	Int CR 905 / CR 905 A	US 1	Crocodile Lake to South Miami-Dade	2L

LEGEND

- 2L Two-lane facility
- 2L/4L Two lanes with short four-lane sections for passing purposes
- 3L Three-lane facility (center lane is a two-way left-turn lane)
- 4L Four-lane undivided facility
- 4LD Four-lane divided facility
- 5L Five-lane facility (center lane is a two-way left-turn lane)

TABLE 2B Maximum Sustainable Traffic Flow Rates per Functional Evacuation Lane for Hurricane Evacuation Purposes US Highway 1 (Overseas Highway) and CR 905/Card Sound Road in the Florida Keys, Monroe County, Florida				
Area	Milemarkers		Location/Description	Suggested Maximum Sustainable Flow Rate per Hour per Functional Evacuation Lane
	From	To		
Lower Keys	2.0	4.0	Key West to Stock Island	900
Lower Keys	4.0	9.0	Stock Island to Big Coppitt Key	900
Lower Keys	9.0	17.0	Big Coppitt Key to Sugarloaf Key	1,100
Lower Keys	17.0	22.0	Sugarloaf Key to Cudjoe Key	1,100
Lower Keys	22.0	24.0	Cudjoe Key to Summerland Key Cove Airport	1,100
Lower Keys	24.0	25.0	Summerland Key Cove Airport to Summerland Key	1,100
Lower Keys	25.0	30.0	Summerland Key to Big Pine Key	1,100
Lower Keys	30.0	34.0	Big Pine Key to West Summerland Keys	1,050
Lower Keys	34.0	35.2	West Summerland Keys to Spanish Harbor Keys	1,100
Lower Keys	35.2	36.5	Spanish Harbor Keys to Bahia Honda Bridge	1,100
Lower Keys	36.5	37.5	Bahia Honda Bridge to Bahia Honda Key	1,100
Middle Keys	37.5	47.0	Bahia Honda Key to Hog Key	1,200
Middle Keys	47.0	48.0	Hog Key to Boot Key	1,100
Middle Keys	48.0	50.2	Boot Key to Marathon	900
Middle Keys	50.2	50.8	Marathon to Marathon Shores	900
Middle Keys	50.8	54.0	Marathon Shores to Key Colonial Beach	900
Middle Keys	54.0	54.5	Key Colonial Beach to Deer Key	900
Middle Keys	54.5	58.0	Deer Key to Grassy Key	1,100
Upper Keys	58.0	74.0	Grassy Key to Matecumbe Harbor	1,100
Upper Keys	74.0	80.0	Matecumbe Harbor to Teatable Key	1,100
Upper Keys	80.0	83.5	Teatable Key to Islamorada	1,100
Upper Keys	83.5	85.6	Islamorada to Windley Key	1,100
Upper Keys	85.6	90.0	Windley Key to Plantation Key	1,100
Upper Keys	90.0	100.0	Tavernier Key to Newport Key	900
Upper Keys	100.0	105.0	Newport Key to Sexton Cove	900
Upper Keys	105.0	106.3	Sexton Cove to Rattlesnake Key	900
Upper Keys	106.3	126.5	Rattlesnake Key to Card Sound Rd	1,200
South Dade	126.5	HEFT	Card Sound Rd to HEFT	900
Upper Keys	106.3	Int CR 905 / CR 905 A	Lake Surprise to Crocodile Lake	1,100
Upper Keys	Ocean Reef	Int CR 905 / CR 905 A	Tanglefish Key to Crocodile Lake	1,100
Upper Keys	Int CR 905 / CR 905 A	US 1	Crocodile Lake to South Miami-Dade	1,100

NOTES

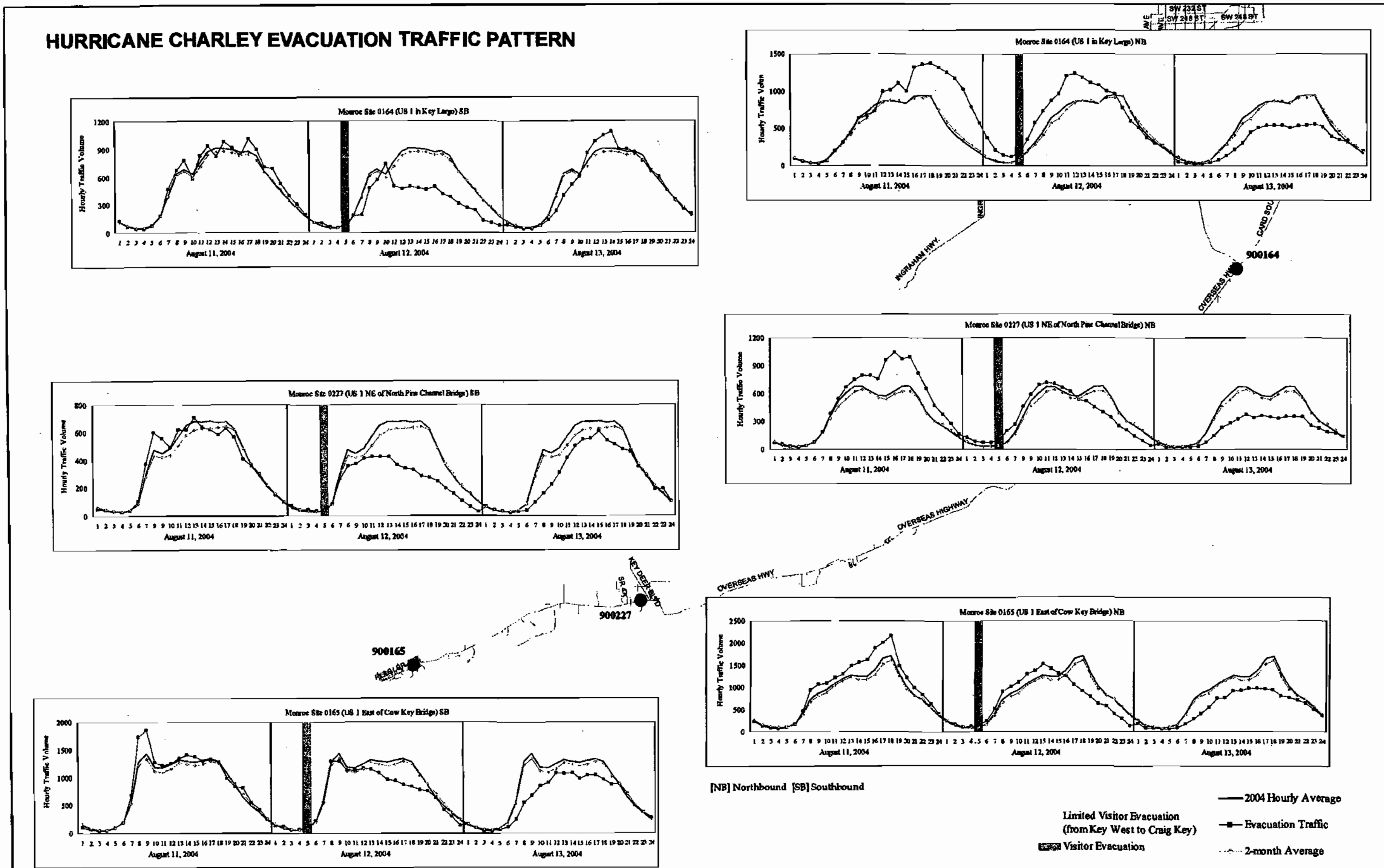
A Functional Evacuation Lane has a pavement width of at least 10 feet

The above flow rates are maximum values that are expected to be sustained for extended periods (more than 8 hours). During night conditions, these flow rates may be lower than the ones shown above.

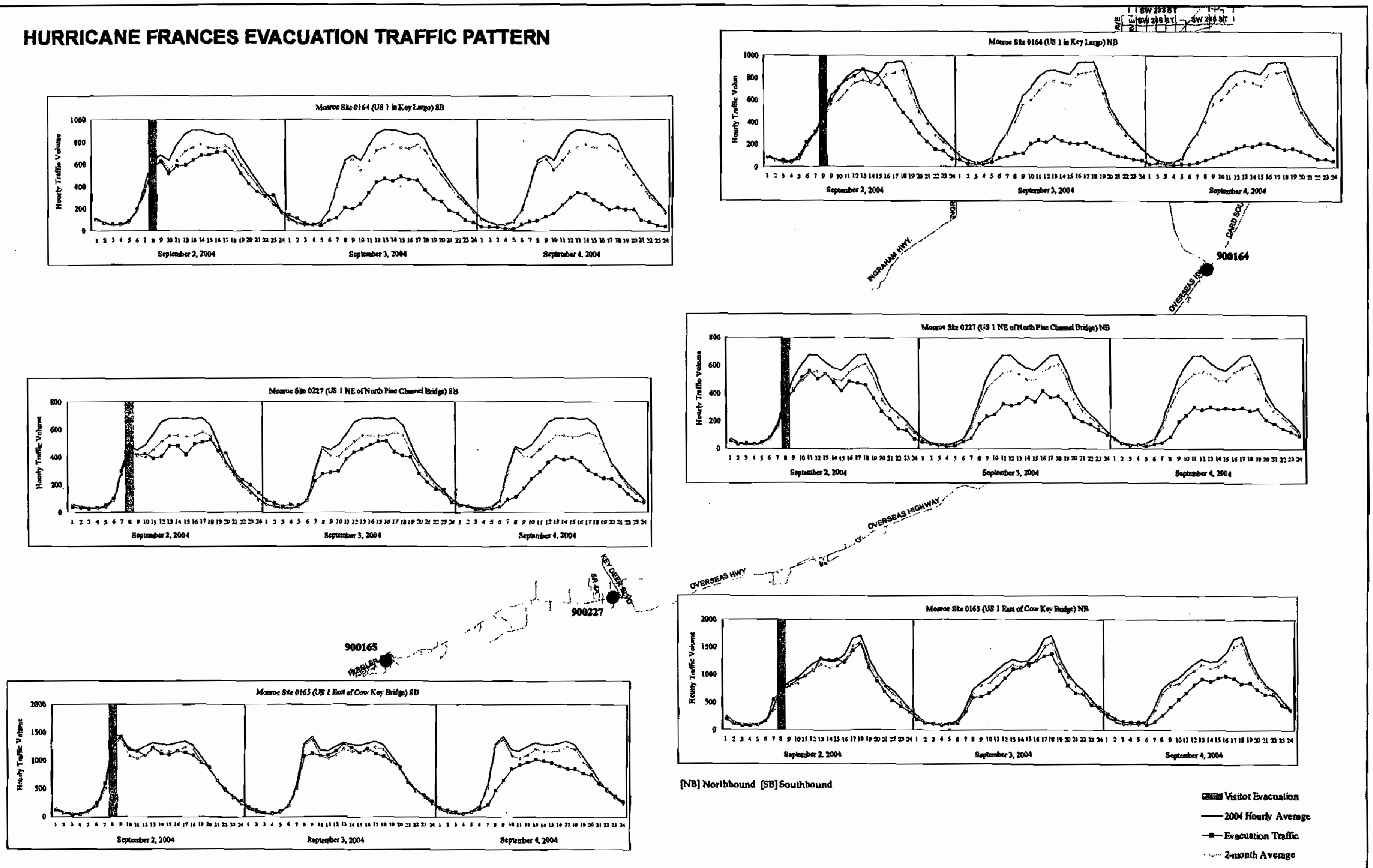
ATTACHMENT B

Hurricane Evacuation Traffic Volumes Florida Keys 2004-2005 and 2008

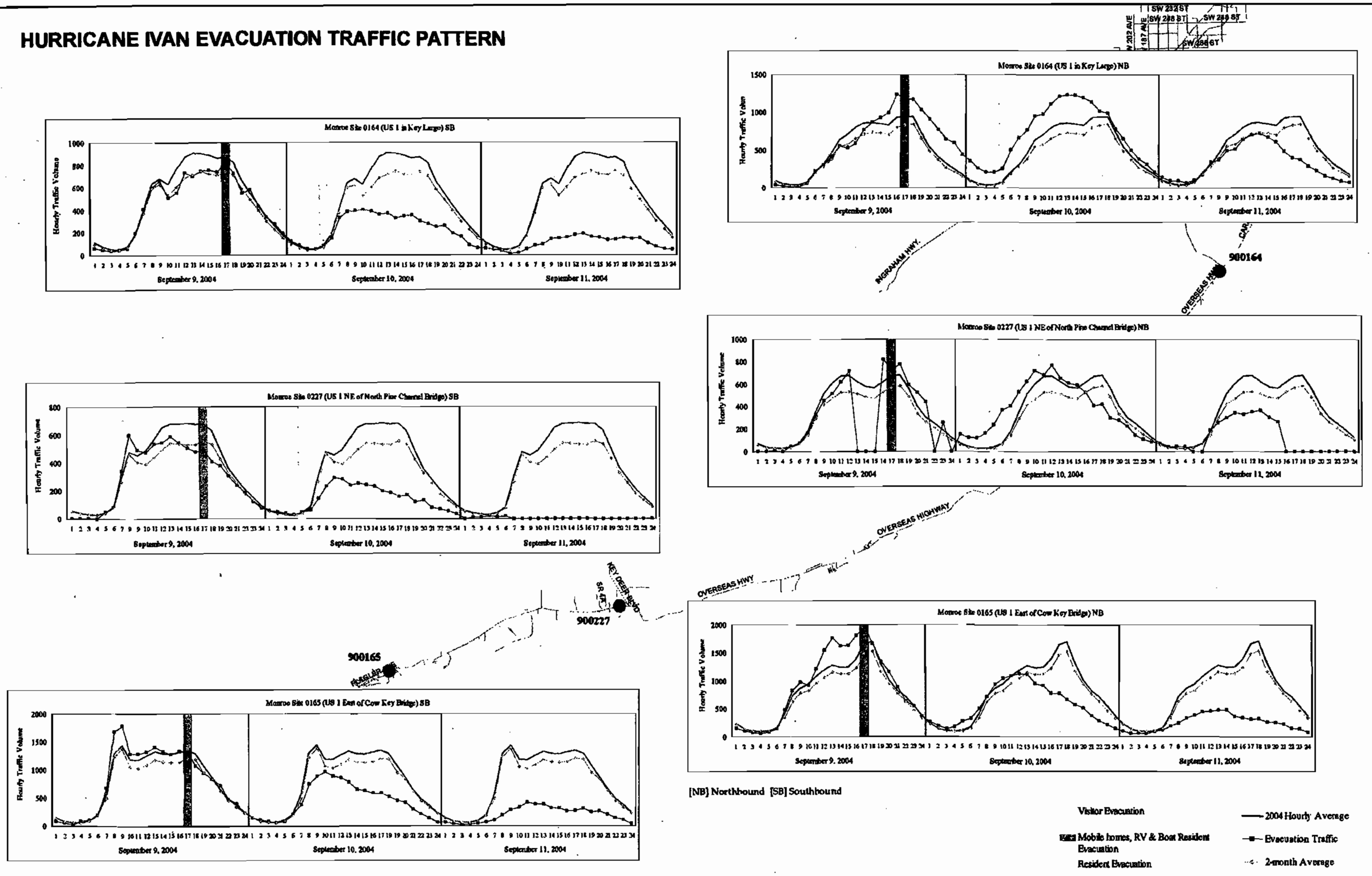
HURRICANE CHARLEY EVACUATION TRAFFIC PATTERN



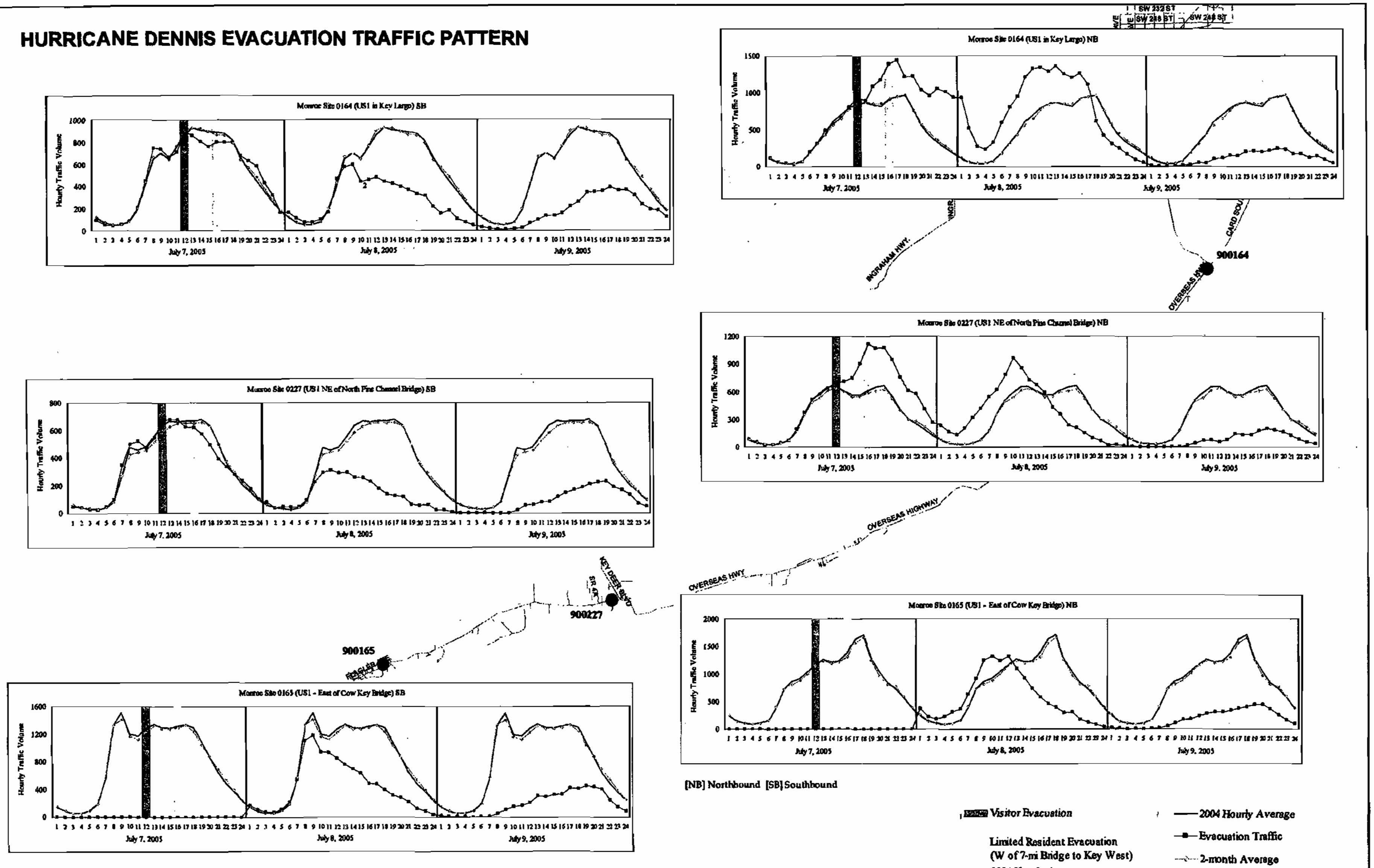
HURRICANE FRANCES EVACUATION TRAFFIC PATTERN



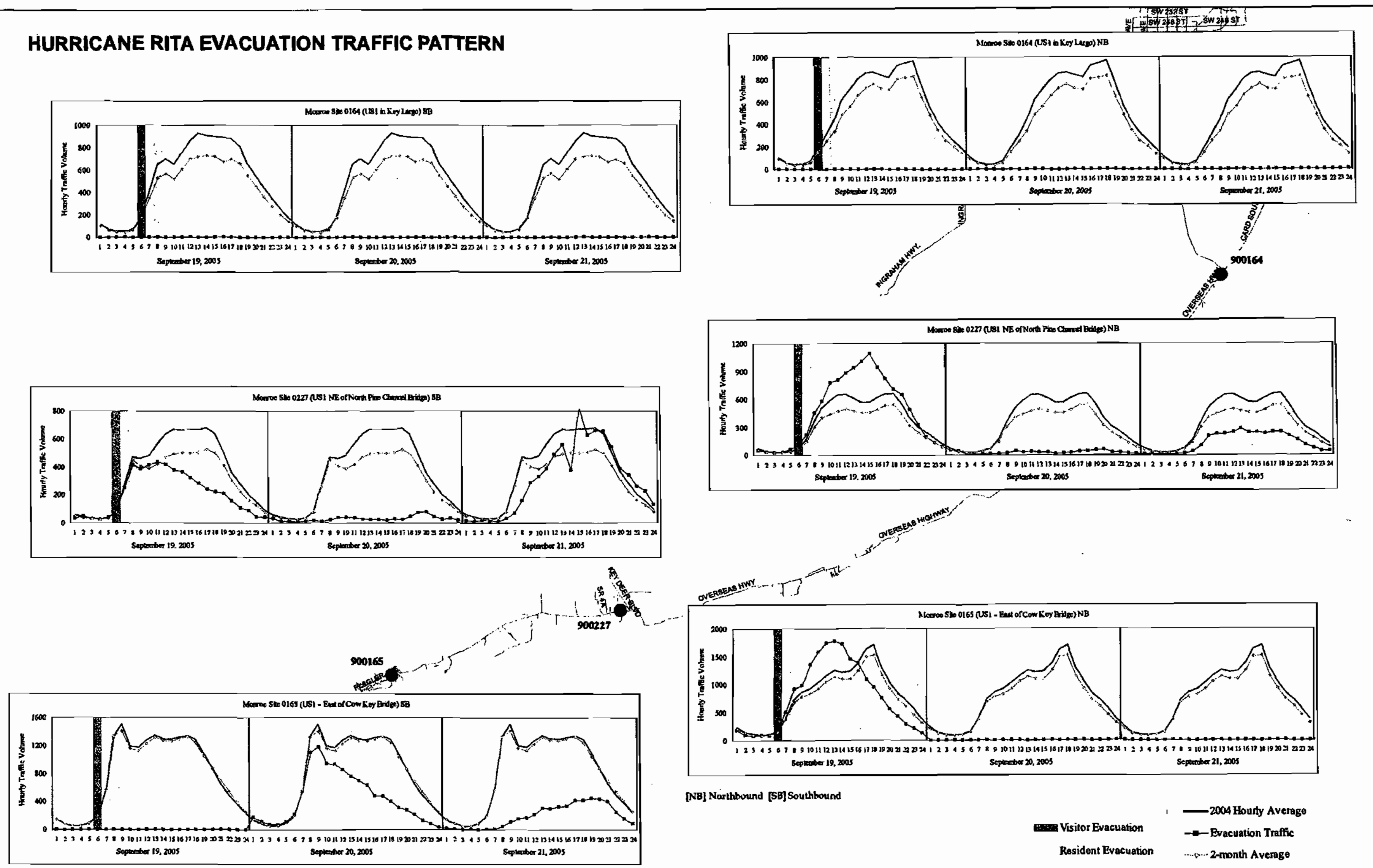
HURRICANE IVAN EVACUATION TRAFFIC PATTERN



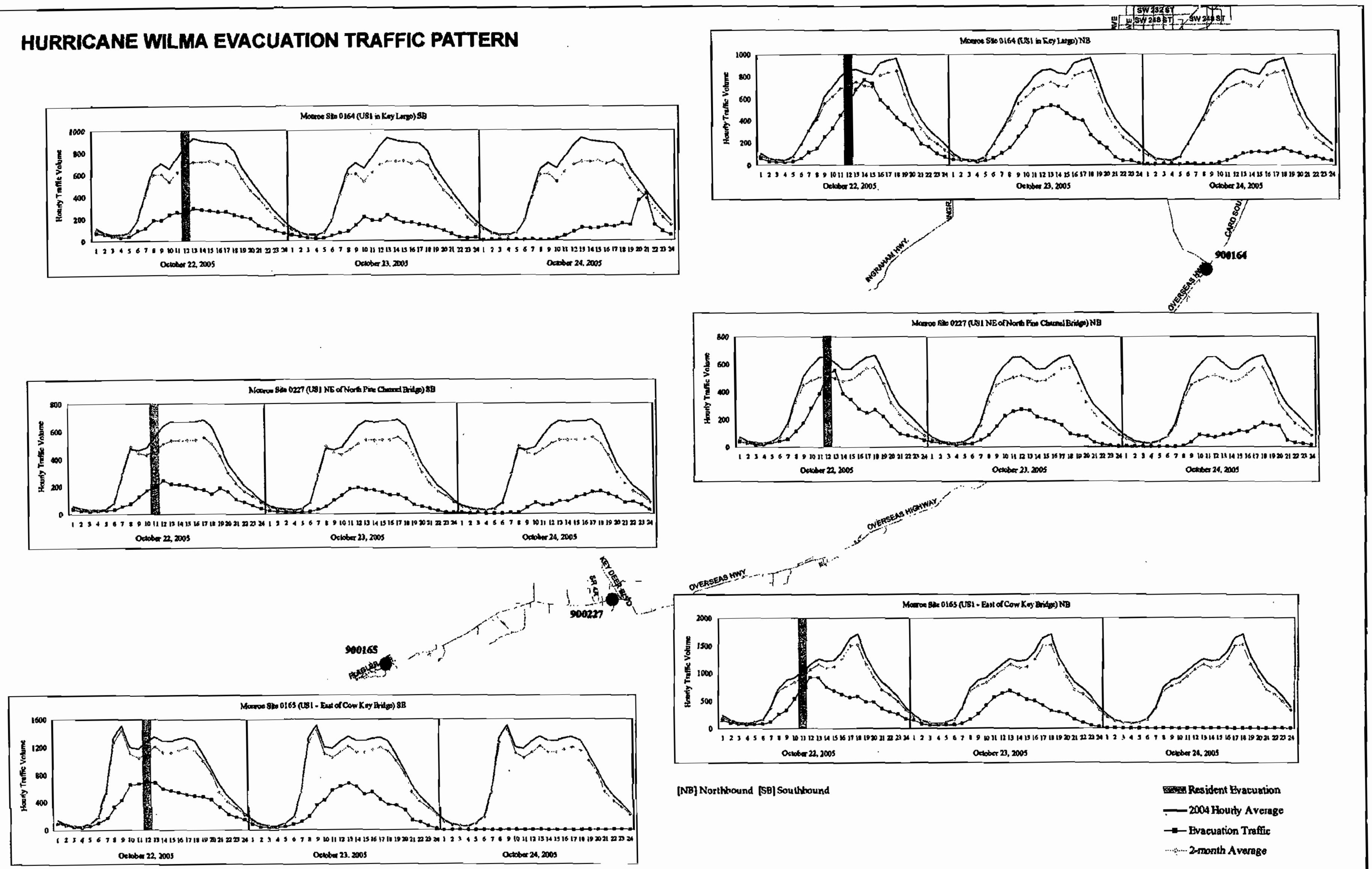
HURRICANE DENNIS EVACUATION TRAFFIC PATTERN



HURRICANE RITA EVACUATION TRAFFIC PATTERN



HURRICANE WILMA EVACUATION TRAFFIC PATTERN



TROPICAL STORMS FAY EVACUATION TRAFFIC PATTERN