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National Hurricane Program Metrics Framework

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Abstract

The need for metrics for planning and response measures was identified as key gap to be addressed in the National Hurricane Program's (NHP) Technology Modernization effort. This document proposes a framework for defining a set of metrics for planning and response that will be implemented in the NHP products of hurricane evacuation studies (HES) and post-storm assessments (PSA). To determine the feasibility of this framework, a survey of current HES and PSAs was carried out followed by and then used to determine if the proposed metrics are currently captured. While there is a wide variety in data availability and detail, the implementation of these metrics is not only feasible but presents an opportunity to improve on current practices. The final implementation of this framework shall require the ongoing feedback from local, state, tribal, and federal stakeholders.

ACKNOWLEDGMENTS

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TABLES

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NOMENCLATURE

[Sample list:]

DOE	Department of Energy
FEMA	Federal Emergency Management Agency
HES	Hurricane Evacuation Study
ICCOH	Interagency Coordinating Committee on Hurricanes
NC	North Carolina
NHP	National Hurricane Program
NYC	New York City
SNL	Sandia National Laboratories
TM	Technology Modernization
USACE	United States Army Corps of Engineers

1. INTRODUCTION [Begin Sections on odd pages]

The Federal Emergency Management Agency's (FEMA) National Hurricane Program (NHP) and the Department of Homeland Security (DHS) Science and Technology Directorate (S&T), in conjunction with Massachusetts Institute of Technology Lincoln Laboratory (MIT-LL) and Sandia National Laboratories (SNL), have recently conducted a gap analysis to determine what action items can be carried out to improve the NHP. [1] One outcome from this gap analysis was to highlight the need to "implement a metrics-based improvement process"[1] within the program, specifically in terms of planning and response efforts by NHP. To address these gaps, two sets of proposed approaches to metrics are addressed in this document: 1) a set of metrics to aid in NHP planning for hurricane evacuation studies (HES) and 2) a set of metrics to aid in NHP response to an event. The proposed set of metrics for planning and response address future hurricane evacuation studies and post-storm assessments, respectively.

To determine the proposed metric framework, previously vetted documents and processes, such as the gap analysis, guidance document, and working group discussions. The NHP Planning Metrics section shall outline the proposed metrics and presenting the comparison of existing data to the metrics. An evaluation of current hurricane evacuation studies (HES) was carried out to compare the current proposed metrics framework to current HES practices. The NHP Response Metrics section shall highlight the current post-storm data collection, presenting the proposed metrics, explaining the procedure to gather post-storm information, and presenting the comparison of existing data to the metrics. While the proposed metrics provide a framework for moving forward and guiding future discussions, feedback from key stakeholders, including local, state, tribal, and federal, shall be needed to define a final plan.

2. PLANNING METRICS

Current hurricane evacuation studies (HESs) typically include the following components:

- Hazards analysis
- Vulnerability analysis
- Behavioral analysis
- Shelter analysis
- Transportation analysis

While these standard subject areas are used consistently across different regions and years of HESs, there is merit in suggesting a set of metrics to ensure key details for hurricane planning are always included in HES production. The proposed metric framework was arrived at through evaluation of gap analysis and discussions from stakeholders at NHP TM working group meetings.

2.1. Proposed Planning Metrics

The gap analysis highlighted the importance of formal metrics to enhance the NHP's hurricane planning and response. The listing below represents a proposed set of NHP planning metrics. Definitions and examples are provided for each metric as needed.

Proposed planning metrics for future HESs include:
Hazard Metrics

1. **Number of years since last SLOSH update**
   Definition: Number of years since the last SLOSH updated for the respective basin

Vulnerability Metrics

2. **Evacuation zones**
   Definition: Evacuation zone maps for various affected areas
3. **Number of lives in the evacuation zone**
4. **Population demographics**
   Example: a count of residents, tourists, and mobile homes
5. **Affected critical infrastructure**
   Definition: The amount of critical infrastructure affected by potential storm surge inundation
   Example: adult care facilities, fire stations, group homes, hospitals, nursing homes, police stations, prisons, and major discharge treatment facilities
6. **Affected mobile homes**
   Definition: the number of mobile homes affected by storm surge inundation zones
7. **Potential economic impacts**
   Definition: the cost of expected damage to critical infrastructure

Behavioral Metrics

8. **Updated behavioral study**
   Definition: Has the behavioral information been updated since the last HES

Shelter Metrics

9. **Number and capacity of available shelters**

Definition: Number and capacity of available shelters outside of the storm surge inundation zone

10. **Number of inundated shelters**
    Definition: Number of shelters affected by storm surge inundation

Transportation Metrics

11. **Defined decision time**
    Definition: The time when public officials should issue an evacuation order
    Example: "Therefore, the proposed decision time for determining when the evacuation must be given is 12 hours more than the proposed clearance time"
12. **Predicted clearance time**
    Definition: amount of time needed to for the last vehicle to leave the evacuation zone
13. **Actual vs. Predicted clearance time**
    Definition: A comparison of historical clearance times (from previous hurricanes) to predicted clearance times
14. **Evacuation choke points**
    Definition: a list or map of locations in roadway segments that will experience congestion during an evacuation

Additional Suggested Metrics:

15. **Training performance**
    Definition: The number of emergency managers participating in FEMA training each year and the level of that training
16. **Number of updates per year**
    Definition: A list of the number and type of HES component updates per year
    Example: Updated transportation analysis to reflect the opening of a new highway
17. **Number of years since last HES update**
18. **Public education**
    Definition: Plan for educating the public on key outcomes of the HES

2.2. Analysis of Current HESs

To determine how the proposed metrics can be incorporated into the current HES process, previous HES documented were examined. The following five HESs were examined:

- Lower Southeast Florida: Broward County (1991) [2]
- Lower Southeast Florida: Monroe County (1991) [3]
- North Carolina (2000) [4]
- Mississippi (2002) [5]
- New York City (2009) [6]

While most of the proposed metrics were found to be currently captured, the absence of certain metrics supports the need for a formal metric system. The complete comparison is listed below in Table 1.

Table 1. Metrics captured by existing hurricane evacuation studies

An "X" denotes that the metric is accounted for in the HES, "-" denotes that the metric has been alluded to but not explicitly measured, and a blank space indicates that the HES does not mention the metric.

	Lower Southeast Florida (1991) Broward	Lower Southeast Florida (1991) Monroe	North Carolina (2000)	Mississippi (2002)	New York City (2009)
Hazard					
Number of years since last SLOSH updated	X	X	X	X	X
Behavioral					
Updated behavioral survey	X	X	X	X	X
Vulnerability					
Evacuation zones	X		X	X	X
Number of lives in the evacuation zone	X		X	X	X
Population demographics	X		X	X	X
Affected critical infrastructure	X		X	X	X
Affected mobile homes			-	X	X
Potential economic impacts					
Shelter					
Number and capacity of available shelters	X	X	X	X	X
Number of inundated shelters	X	X	X		X
Transportation					
Defined decision time	-				-
Predicted clearance time	X	X	X	X	X
Actual vs. predicted clearance time					
Evacuation choke points			X	X	X

Of the proposed planning metrics for HES, it appears that HESs are consistently capturing the same metrics. However, metrics that were consistently not recorded were: potential economic impacts, defined decision time, and actual vs. predicted clearance time.

For those proposed planning metrics that were being captured, the detail of these metrics was not always constant between HESs. For example in Vulnerability Metrics, the Broward HES listed institutional and medical facilities as critical infrastructure [2] while the NYC HES considered a larger scope of critical infrastructure, such as adult care, fire stations, group homes, hospitals, nursing homes, police stations, prisons, and major discharge treatment [6]. The Vulnerability portion of the Monroe HES was minimal with only a map depicting areas affected by storm tide flooding [3]. Interestingly, the Broward HES and the Monroe HES were prepared by the same organizations during the same time period, yet Vulnerability Metrics differ greatly.

It was also found that a HES sometimes alluded to a proposed metric, but did not provide specifics that would aid planning. For example, in most transportation analyses, the defined

decision time was either absent or left to the judgment of public officials. The NYC HES states, “Evacuations must be started early enough so that movements are complete before the arrival of sustained tropical storm winds” [6]. Similarly, the Broward HES mentions, “Even though risky, the closer the Emergency Manager can allow the storm to come before making the decision to evacuate, the more accurate the decision on the scope of evacuation” [2]. Though the metric is not given directly, and may be listed in a separate internal document for each region, these HESs highlight the need for one. The Broward HES was the only report to assert that buses evacuate 30 hours in advance of storm hazards.

No metrics were recorded or alluded to for “Additional Suggested Metrics”. This is likely due to their not being associated with a specific HES component. However, given that their importance was specifically highlighted in the gap analysis[1], it suggests that these metrics should be captured in future NHP planning initiatives.

3. RESPONSE METRICS

Currently the process for documenting the decision process and outcomes in response to a tropical cyclone event varies widely. While post-storm assessments (PSA) represents the current gold standard, a set of defined response metrics as a template for future PSAs shall ensure high levels of quality and consistency. An open source search revealed that the detail, quality, and sources of hurricane response data differ greatly depending on storm. The NHP Response Metrics are also suggested to create a standard data collection process to better understand NHP's performance and areas needing improvement.

3.1. Survey of Current Post-Storm Assessments

Data is collected after a storm and compiled into a post-storm assessment (PSA) typically one to two years after a hurricane event resulting in a formal report. The purpose of PSAs are as follows[7]:

- Document the storm's characteristics and effects
- Examine the warnings, responses, and recovery occasioned by the storm
- Evaluate the effectiveness and usefulness of hurricane evacuation study data and products used during the hurricane
- Discover whether previous information collected was accurate
- Help to understand what improvements could still be made

For the purposes of this analysis, documented post-storm data was viewed in three ways: 1) a federal PSA, 2) a non-federal PSA, or 3) non-PSA documentation:

- A federal PSA was any report produced for or by the federal government, such as the USACE or FEMA.
- A non-federal PSA is a report commissioned or produced by an entity not in the federal government, such as a state or city government.
- Non-PSA documentation includes post-storm data from news articles, academic sources, scholarly publications, or emergency manager accounts.

While some federal PSAs are available through the NOAA website, they are not present for all previous storms that achieved landfall. [7] Several other federal post-storm assessments and PSAs produced by non-federal organizations are accessible through open source searching. All PSAs and other references used for the following response metric data analysis can be accessible from an open source search.

3.2. Proposed Response Metrics

The proposed response metrics were identified as a result of the gap analysis outcomes and the storm guideline from the vetted guidance document. While these proposed response metrics come from documents vetted by the TM working group members, they represent a framework to guide future discussions before final implementation. Definitions and examples for each metric are provided as necessary.

The proposed response metrics include:

1. **Training participation**
   Definition: The number of emergency managers who participated in FEMA training
2. **Activation of Emergency Operations Center (EOC): Partial and Full**
   Definition: Point in the timeline when the EOC was partially and then fully activated
   Example: Location of county, time EOC was partially activated, time EOC was fully activated, and what prompted decision to activate?
3. **Supplies prepositioned**
   Definition: Were supplied delivered and prepositioned before onset of hazardous conditions
   Example: "at noon on August 28, Louisiana requested 180,000 liters of water and 109,440 MREs for the Superdome" [8]
4. **Shelters: Activated and Supplied**
   Definition: When and how many shelters were open and were they supplied
5. **Evacuation order given**
   Definition: Time of order, by whom, and for which areas or populations
6. **Evacuation duration**
   Definition: Actual clearance time
7. **Evacuation participation rate**
   Definition: Percentage of people who evacuated from evacuation zones (e.g. mandatory, voluntary, coastal, noncoastal, etc.)
8. **Damages to critical infrastructure**
   Definition: Cost, number of facilities damaged, type of damage
9. **Number of unnecessary evacuations or shadow evacuations (storm dependent)**
   Definition: Percentage of people who evacuated from areas that did not receive evacuation orders
10. **Delay from optimal evacuation time**
    Definition: Time of evacuation order until the arrival of tropical storm winds vs. the clearance time
11. **Communication of evacuation order**
    Definition: How was the order issued, who gave or decided the order

3.3. Analysis of Previous Post-Storm Assessments

A sample of PSAs were analyzed to determine if a metric-based, post-storm collection process can benefit the NHP. The methodology consisted of three steps: 1) selecting hurricanes and collecting post-storm data, 2) finding which of the proposed metrics are accounted for, and 3) documenting the on the level of detail for each of the metrics.

Five hurricanes of varying locations, time periods, and intensities were studied. Location refers to the location of the PSA, not the entire area affected by the hurricane. The hurricanes examined are listed in Table 2.

Table 2. Hurricanes Examined for Proposed NHP Response Metrics

Hurricane	Location of PSA	Year	Storm Type

Andrew	Florida	1992	Category 4
Floyd	Florida, Georgia, and the Carolinas	1999	Category 2
Katrina	New Orleans	2005	Category 3
Rita	Texas	2005	Category 3
Sandy	New York City	2012	Post tropical cyclone

For each hurricane, PSAs were investigated for the proposed measures. Data from a federal PSA indicates the proposed response metrics are currently available to the NHP. When data for the proposed response metrics were not located in federal reports, non-federal PSAs were collected. In the absence of the two prior sources, additional open source documentation was utilized such as news articles, academic sources, scholarly publications, and emergency manager accounts. Evaluating non-federal sources establishes that response metrics are measurable and being recorded. Report type and quality of data differed between hurricanes with Table 3 illustrates how disproportionate available post-storm data is between them.

Table 3. Data sources used for proposed response metric analysis

	Andrew	Floyd	Katrina	Rita	Sandy
Federal	2 [9, 10]	1 [11]	2 [8, 12]	-	1 [13]
Non-federal	-	1 [14]	-	-	2 [15, 16]
Other	-	1 [17]	1 [18]	4 [19-22]	5 [23-27]

While the data for the proposed response metrics for some hurricanes could be fulfilled with federal PSAs, it was not consistent across all storms. The analysis approach was to first examine federal documents for the proposed metrics and primarily use this data if present. However, if the metric is not found in federal PSAs, non-federal PSAs were then searched and with additional open source literature used in absence of any government sources. A summary of the analysis for each proposed metric is shown below in Tables 4-6.

Table 4. EOC, Supplies, and Shelter Metrics

*** Documentation from a federal post-storm assessment (e.g. NHP, USACE, FEMA)
** Documentation from a non-federal post-storm assessment (e.g. state or city)
* Documentation from a news article, academic source, scholarly publication, or emergency manager account
A blank cell indicates that no information was found on the metric

EOC, Supplies, and Shelter Metrics					
	Andrew	**Floyd**	**Katrina**	**Rita**	**Sandy**
Activation of EOC	***	***	***		**
Supplies Prepositioned			***		**
Shelters: Time opened	***	***	***		**
Shelters: Number opened	***	***	***		**
Shelter: Number of	***	***	***		**

evacuees					

Hurricanes Andrew, Floyd, and Katrina have comprehensive federal PSAs that contain information on almost all EOC, Supplies, and Shelter Metrics [8, 9, 28]. PSAs for Andrew [9] and Floyd [28] were produced by the same contractor for the USACE. These reports provided extensive detail in a similar style which would allow for comparisons to be made between the two hurricanes. For example, the USACE reports provided information on: Number of Shelters Opened, Number of People Sheltered, Technical Data Report Shelters/Expected Shelter Demand, Time Opened/Duration, and Problems Encountered [9, 11].

Katrina had a wide range of federal PSAs and metrics were easily obtained. Conversely, no PSAs by any organization were available for Hurricane Rita. Metric collection relied on news and journal articles, however, no details of EOC, Supplies, and Shelter Metrics could be found in these sources.

For Hurricane Sandy, no federal PSA were found so data was supplemented from various sources. EOC, Supplies, and Shelter Metrics were found in non-federal reports and New York State OEM presentation on New York City shelters and evacuation. The presentation contained particularly detailed metrics, noting that 147 Red Cross shelters served "approximately 29,364 people" [24].

Table 5. Evacuation Metrics

*** Documentation from a federal post-storm assessment (e.g. NHP, USACE, FEMA)
** Documentation from a non-federal post-storm assessment (e.g. state or city)
* Documentation from a news article, academic source, scholarly publication, or emergency manager account
A blank cell indicates that no information was found on the metric

Evacuation Metrics					
	Andrew	**Floyd**	**Katrina**	**Rita**	**Sandy**
Evacuation order given	***	***	***	*	*
Communication of evacuation order	***	***	***	*	*
Evacuation duration	***	***			
Evacuation participation rate	***	***	***	*	*
Unnecessary or shadow evacuations		***	N/A	*	N/A

Similar to EOC, Supplies, and Shelter Metrics, federal PSAs for Evacuation Metrics best populates the metrics. The metric data was also collected from the USACE reports for Hurricanes Andrew and Floyd. For both hurricanes, evacuation data was provided on: Time EOC was Activated, What Prompted Decision to Activate, What Study Products/Decision Aids Were Used in Decision Making, Time of Evacuation Order/Number Evacuated, and How Well Study Products Worked. This quality can allow the NHP to deeply understand response and bridge understanding between hurricane evacuation studies [9, 11].

Hurricane Katrina's federal PSAs provided dense details of the metrics through explaining events unfolding chronologically. The following is an example of the high level of detail in the Katrina PSAs:

> "Local governments across the northern Gulf Coast issued evacuation orders throughout Saturday. Voluntary evacuations for areas in Louisiana outside the levee protection district began in the morning. Lafourche, Plaquemines, St. Charles, and parts of St. Tammany Parishes ordered mandatory evacuations for their citizens during the day. Mandatory evacuation orders were also issued for parts of Jefferson Parish. In New Orleans, Mayor Ray Nagin hosted a press conference that afternoon, during which he recommended evacuations of Algiers, the Lower Ninth Ward, and low-lying areas of the City. Later, at 5:00 PM CDT, he formally called for voluntary evacuations of the City. He also declared a state of emergency for New Orleans, which advised residents to undertake several precautionary measures such as stocking up on bottled water, batteries, and non-perishable food." [12]

Contrary to Andrew, Floyd, and Katrina, the metrics in Rita were sparse and undetailed. Because a majority of data came from news articles, the metrics were incomplete or unavailable. For example, instead of detailed evacuation behavioral surveys (e.g. participation rate by surge zone, main reason for evacuating, heard officials say evacuate, evacuation by perceived safety, etc.) as in Andrew or Floyd, "Evacuation participation rate" was collected from a Wall Street Journal articles that stated, "Officials estimated at least 90% of Jefferson County, Texas, residents had heeded warnings." [21]

Similar to Rita, Hurricane Sandy's Evacuation Metrics were gathered from non-federal sources, such as journal articles, news reports, and an emergency manager account. Hurricane Sandy's evacuation order was not found in an official document, but located in a Wall Street Journal article[21]. Other search for the time of the order resulted in the timestamp of a Twitter evacuation posting from the NYC Mayor's Office. Notably, because federal PSAs were not available, specific metrics of interest, such as Evacuation Duration, Activation of the EOC, or Evacuation Order Given, were either unavailable or contained limited information. For example, Hurricane Andrew's EOC was fully activated at 2:00AM on 8/22/1992 for Monroe County and the evacuation order for Monroe was given at 6:00AM on 8/22/1992 [9]. Hurricane Rita did not have EOC information available and the evacuation order was found in a news article, "Sept. 23 - At 9:30 a.m. on Wednesday, with Hurricane Rita gathering strength and aimed at Texas, Mayor Bill White of Houston ordered mandatory evacuations from low-lying sections of the city while urging voluntary evacuations from flood-prone neighborhoods and mobile homes"[20]. The article leaves vague the specific areas this evacuation order would apply to.

Table 6. Damage Metrics

*** Documentation from a federal post-storm assessment (e.g. NHP, USACE, FEMA)
** Documentation from a non-federal post-storm assessment (e.g. state or city)
* Documentation from a news article, academic source, scholarly publication, or emergency manager account
A blank cell indicates that no information was found on the metric

Damages Metrics					
	Andrew	**Floyd**	**Katrina**	**Rita**	**Sandy**
Damage Cost	***		***		***

Buildings/homes damaged	***		***		**
Critical infrastructure damaged			***		**

The quality and depth of the Damage Metrics varied between reports and hurricanes. Hurricane Andrew's USACE report mentioned the magnitude of damages during the report's introduction, however, Hurricane Floyd's USACE report did not make note of any damage statistics. [9, 28] Hurricane Katrina's federal reports provided comprehensive detail of damages. [8] One reason for this may be the extensive amount of damage and large interest by the federal government to understand what occurred during Hurricane Katrina. Due to lack of reporting, no damage statistics were found for Hurricane Rita. This may be due to the timing of Hurricane Rita immediately after Hurricane Katrina. Hurricane Sandy had a mixture of damage statistics from a National Hurricane Center report, city planning report, and a journal article. The various sources needed to be compiled to have a full view of storm damage.

4. CONCLUSIONS AND RECOMMEDNATIONS

3.1. Conclusions

This document provides a proposed set of metrics for planning and response purposes based off of current practices and feedback from key stakeholders. The proposed planning and response metrics shall have utility in the future HES and PSA process, respectively. To support these proposed metrics and their future impacts, an analysis was carried out on current HES and PSA documents. Analysis of HESs show that these reports are consistently capturing the proposed metrics. However, some proposed metrics are not consistently captured or explicitly listed and the detail of data differs between studies. The analysis also discovered that a subset of the proposed metrics, the "Additional Suggested Metrics", are consistently not accounted for. This was not considered unusual as these proposed metrics do not fall under a traditional HES analysis component. However, capturing this data in the future, such as Training Performance and Public Education plan, may result in an improved HES plan.

Analysis of current PSAs show data collection and documentation in post-storm assessments (PSAs) lack uniformity. Unbalanced data collection across the sample of five hurricanes highlight the need for response metrics and Table 3 highlights a lack of availability of federal data for some hurricanes, such as Rita and Sandy. The USACE reports for Andrew and Floyd provide insight into the merit of unified metrics. Across all hurricanes in this study, metric-related data was not found for training participation and delay from optimal evacuation time. Identifying a set of metrics based on the vetted storm timeline provides a suggestion for a unified system of post-storm data collection. Collecting data according to a prescribed set of metrics can help understand what occurred during the hurricane, allow the NHP to make comparisons between storms, and evaluate their response. These proposed response metrics are a formal method of data collection and can be applied to any hurricane with repeatability.

3.2. Limitations

Applying any set of formal metrics presents a variety of challenges due to the uniqueness of each basin and locality. This includes the approach each state and/or county may have towards emergency management of tropical cyclone events and planning. To account for these differences, feedback from key stakeholders at the local, state, tribal, and federal level will be required before final implementation of any set of metrics. The uniqueness of their approach may also account for the differences seen in the data collected in the HES and PSAs sampled in this analysis. For post-storm assessments, the uniqueness of each storm could inhibit meaningful comparisons to be made between the metrics of different hurricanes. Ideally a broader study of PSAs would be carried out to include a wider range in storms but this may not be feasible due to the lack of data. There are also limitations in comparing the response to storms over a large time period due to changes in technology and approaches to emergency management.

3.3. Recommendations

While the proposed planning and response metrics were derived from vetted documents, the process of surveying available data to support these metrics showed a wide variety in that data. A

formal metric-based approach may provide the NHP the opportunity a consistent process for evaluating their products. To ensure buy-in from key stakeholders, this proposed framework for metrics should be presented to those key stakeholders to test against their current process. It is the process of following a set of metrics that can make one realize the previous inconsistencies. Highlighting these inconsistences will show where there are opportunities for improvement and where resources should be allocated. Best practices for capturing these metrics can then be shared across different organizations. This analysis also illustrated the variety in data sources that can be used in the PSA process. Reaching out to and utilizing these additional sources can foster a better body of knowledge among federal, state, tribal, and local emergency managers. However, decisions may need to be made on who may be responsible for generating and collecting data to support certain levels of metrics. Once the general framework is adopted, further consensus will be needed to determine the appropriate range for each metric, such as how many HES updates should be carried out over a certain time period and what should be considered critical infrastructure? These proposed metrics may not be universally adopted by each locality due to its unique needs, but their implementation represents an important step in the TM process.

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