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Improving the Display of River and Flash Flood Predictions

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EXECUTIVE SUMMARY

The National Weather Service (NWS) is responsible for alerting the public about potential flood events. To fulfill this responsibility, NWS uses computer models that simulate river flow, rainfall, and other factors to generate predictions. When necessary, they generate warnings to recipients, who represent many communities of interest, including emergency services, water management organizations, commercial broadcast agencies, and the general public. Two challenges face the NWS in communicating flood predictions to such a broad audience: (1) information needs and knowledge levels vary greatly across audiences; and (2) the process of predicting hydrological phenomena is inherently filled with uncertainty, which may be difficult to communicate.

The Aptima solution to these challenges features three components: (1) formulation of a theory of uncertainty as it pertains to flood events; (2) design of visualization techniques to maximize the comprehension and utility of flood information to a broad range of users; and (3) development of a prototype system with which to demonstrate our design concepts.

The solution presented will increase both the usability and value of NWS flood prediction services, and will enable various communities of interest to carry out their respective missions more effectively in the future.

INTRODUCTION

The ultimate objective of this effort is to provide recommendations that would help improve ratings that emergency managers (EMs) give to NOAA's National Weather Service (NWS), by helping better organize and communicate the information that is most salient to the EMs and their mission. Consequently, this effort is concerned with the utility to the EMs of the information presented at the NWS website (http://www.weather.gov). We also seek to devise ways for better communicating probabilistic information to users with non-engineering backgrounds (making sure that the meaning and implications of the presented information are well understood).

To achieve the above objectives, we devise a qualitative model of the EM's information needs and associated uncertainties, some of which the information at the NWS website seeks to reduce. We then explicitly model (a) *the overlap* and (b) *the mismatch* between the information at the NWS website and the EM's information needs, and assess the likely impact (or lack of impact) of the information presented at the NWS website on the uncertainty reduction from the EM's perspective. We also examine whether it is possible to achieve further reduction in uncertainty faced by EMs, given our understanding of the available information and the process by which EMs access and use the NWS website data (Figure 1).

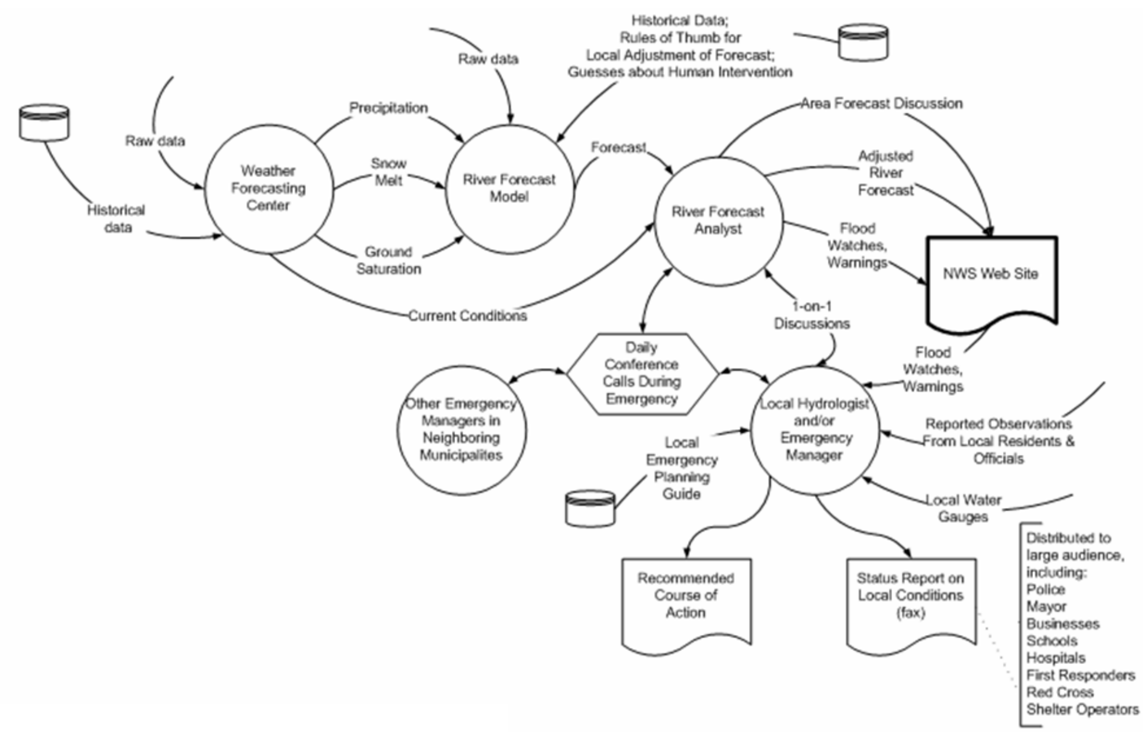

Figure 1. Information flow the NWS to the EMs.

Our modeling process begins with defining the EM's mission, continues by mapping out the associated information requirements, and analyzes the concomitant uncertainties from the EM's perspective. Then, we contrast the information needs of the EMs with the information at the NWS website, analyze the information pathways, and examine the uncertainties associated with the NWS river flood forecasts (e.g., the horizon of forecast predictability; the envelop of alternative scenarios; the timeliness and intensity of the flooding events; and so on).

Our model prescribes the entities and relationships that underlie the EM's decision-making process and planning; the model then examines the availability and ease of access to, and use of, the information that contextualizes and helps assess the state of the key objects and events of interest to the EMs. Table 1 lists some of the attributes of our model.

Table 1. Elements of the EM's mission and of the NWS information space.

Stakeholders (EMs): - Mission tasks (e.g., decide on when to issue warnings; recommend COA) - Outputs: Decisions, COA - Triggers: Contingency events - Precursors: weather events, patterns - Information flow (sources and pieces of information) - Fusion process, resources, and timeliness - Values (inferred and hypothesized)	***Environment***: - Rivers, dams, gauges - Roads - Special facilities - Upstream areas - …	***NWS information***: - Weather events - Gauge readings - Gauge predictions - …	***NWS pathways*** (e.g., ...): - Geographic map -> Specific region -> Forecasts -> Text summary -> Historical data - Warnings -> Region-specific predictions - Forecast models -> Numerical models -> Statistical models - … [We manually analyze the primary pathways; in the future, this analysis can be semi-automated]
Objective function: - Value captured, opportunity lost - Completeness, correctness, clarity - Ease of use, etc. - Salience			

From the quality of service standpoint, our model is concerned with the completeness, correctness, clarity, relevance, usefulness, and ease of use of the information, which we translate into the following criteria that we use to assess the NWS website and to develop and evaluate our recommendations:

- *Value captured* – i.e., the value to the EMs of all the information presented at the NWS website;
- *Opportunity cost or loss* – i.e., the value of the available (or easily extractable) information not presented at the NWS website;
- Website *navigation overhead* – i.e., overhead of dealing with information that potentially obscures navigation to more useful information;
- *Salience* of the information – i.e., relevance of the information presented at the NWS website to the EM's mission;
- *Compactness* of the information representation – i.e., conciseness of representation and associated cognitive load (for reviewing, analyzing, and memorizing the information);
- *Clarity* – i.e., the ease of detecting and understanding the key triggers (e.g., events) and their implications from the information presented.

We thus aim at: (a) explicitly identifying what available (or easily extractable) information of value to the EM is not presented at the NWS site (and suggesting how and where to present this information in the context of the NWS information presentation scheme); (b) discovering what information presented at the NWS site is not of value to the EMs but potentially obscures navigation to the useful information (and suggesting changes to the current NWS information presentation scheme to streamline navigation to the more useful information); and (3) suggesting better ways of displaying information (and inherent uncertainty).

Steps to our solution include:

1. Establish EMs' information needs through knowledge elicitation interview sessions.
2. Assess (potential) value to EMs of information already presented at the NWS website.
3. Establish what additional information of high value to the EMs can be derived (with relative ease) from the information already at the NWS website.
4. Rank-order available information and potential additional information (including the information about uncertainty) based on value to the EMs.
5. Devise suggestions for reorganizing the information presented at the NWS website and the concomitant navigation pathways to maximize value delivered, simplify search, focus attention, improve clarity, and minimize navigation overhead.

The following sections describe our model and analysis findings and resulting recommendations. The second section presents User Interface concepts that illustrate a representative subset of our recommendations and lays the groundwork for producing more detailed recommendations in the future. The final section is a discussion on confidence vs. probability vs. likelihood.

MISSION-DRIVEN INFORMATION NEEDS OF EMERGENCY MANAGERS

EM Mission Summary

Our model focuses on the following three aspects common to the EM's missions:

(a) Making decisions about the likely flooding (i.e., predicting the ***flood events*** and the flood magnitude);

(b) Laying out likely *scenarios* (i.e., identifying key ***contingency events***, such as water blocking some roads; facing competing needs for transportation means; mud slides; etc.) to anchor the flood planning efforts;

(c) Making recommendations to authorities and the public, i.e., suggesting ***courses of action*** **(*COA*)** (such as evacuation / rescue; use of temporary shelters; use of transportation – what, when, where, via which roads) for the above scenarios.

These three aspects then serve as requirements for the development of prototype visualizations. In Figure 2, a visualization of the extent of a flood and the impacted regions for given scenarios is presented. While the visualizations are discussed in greater detail in the UI description section, we provide a brief overview of these concepts to illustrate their explicit link to the developed model. This visualization addresses the three aspects of the model in the following ways:

(a) Decisions about likely flooding, associated with predictions of flood events and flood magnitude, are supported through a presentation of likelihood and confidence scores above the visual depiction of the flood extent.

(b) Contingency events and likely scenarios are shown through a geographic representation of current and possible future flooding scenarios.

(c) The impact of flooding on courses of action is represented by presenting planned evacuation routes and relevant locations of concern within the context of current and predicted flooding.

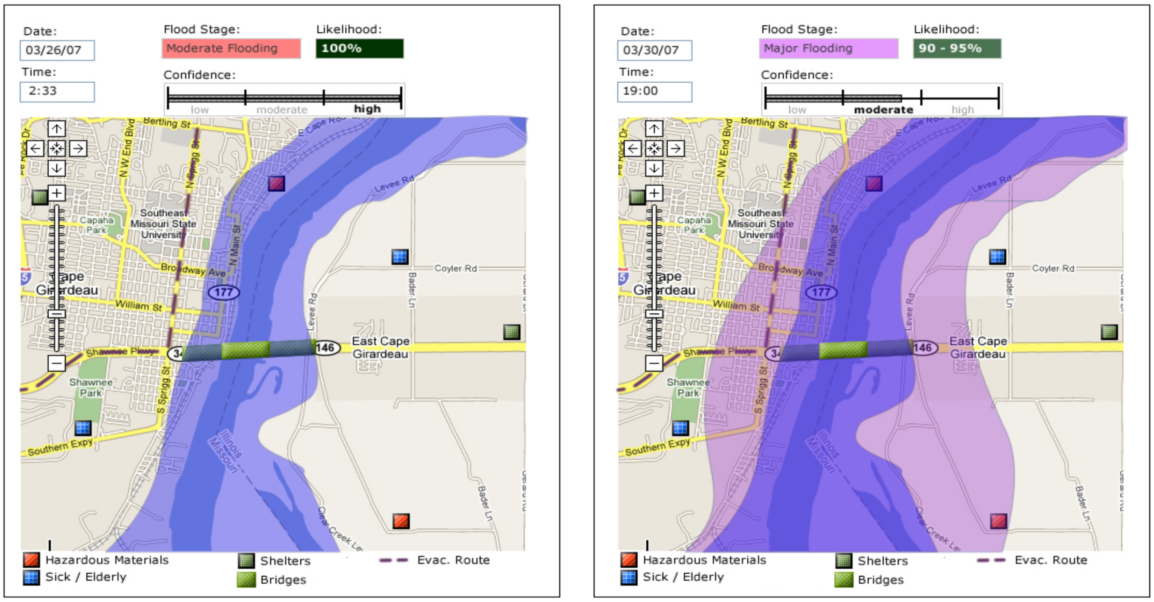

Figure 2. A visualization of the "extent" of flooding and the items impacted at current time (left) and a possible flooding scenario at a future time (right) (refer to *Interactivity of River Height Graph with Extent Map and Measures of Damage* under *User Interface Description*).

Note: We define scenarios as sequences of time-stamped events $\{(e_i, t_i)\}$, where e_i's denote events and t_i's denote their respective times of occurrence. Alternatively, one can think of visualizing scenarios as the time evolution (time-stamped snap-shots; as in Figure 2 above) of the flooding forecasts for a given area (from which the time-stamped events – e.g., flooding at the special facility – may be inferred). Specific scenarios may impact the feasibility of emergency measures and related courses of action (e.g., water rising to block the evacuation pathway). Potential contingency events involve the special structures (such as chemical plants; medical hospitals; bridges; etc.) that require the attention of the EMs.

Note 1: We must note the limitations on the EM's role which is in many cases confined to (1) **monitoring** the flood situations and (2) **suggesting COA** to first responder organizations; rather than (3) enforcing the COA (e.g., by the Commonwealth law, such as in PA, the EMs have no authority over the local government). Hence, we need to consider related time-critical issues, e.g., many government offices close at 4 PM (and are not working on weekends and holidays); therefore, warnings delivered after that time are less likely to be noticed.

Note 2: As a starting point, we have identified four baseline types of the EMs with somewhat different perspectives on how they are likely to use the NWS website information: (i) Eastern-Rural EMs; (ii) Eastern-Urban EMs; (iii) Western-Rural EMs; and (iv) Western-Urban EMs. Our final product will account for the respective differences among these EM groups and will assess how our design recommendations may benefit each of the corresponding EM groups.

EM Information Environment

The EMs use the following ***sources of information***:

- NWS river forecast site
- PENNDOT (Pa Dept of Transportation) road condition site
- IFLOWS -- web site that contains “raw” readings from rain and river gauges. See: http://afws.net/

Note: Some EM operate their own private stream gauges – reported via IFLOWS.

The three streams of information inputs key to the EMs include:

1. NWS weather forecast
2. NWS flood watches, warnings
3. Readings from local gauges

Note: EMs tend to be biased toward a cautious/conservative response – “false alarm is better than a miss”

No comprehensive “big picture” tool for the EMs exists – EMs must mentally integrate lots of small platforms and information pieces.

- E.g., when looking at stream and rain gauge data, EMs look at both the **absolute level** and the **rate of increase**. EMs have thresholds (“caution levels”) at which, for example, they may transmit messages via pager to:
  - Fire chiefs
  - Local emergency management coordinator
  - Police

EM Information Needs

Some of the key information concerns for the EMs include the temporal and geographical aspects of uncertainty (e.g., when, where, how high, and for how long will the flooding occur and what contingency events are then likely to follow and in what sequence). These sources of information provide a *global* view of flooding, which is most helpful to users attempting to gain an understanding of flood patterns across a large region. Only some of the corresponding information items (e.g., weather precursors to flooding) are known to be dealt with by the NWS website.

Other aspects (e.g., road access, infrastructure-specific contingency events) deal with information that is only *locally* available. However, the EMs could benefit from being able to match the predicted conditions to the previously occurred floods (e.g., referenced by the historical data stored at the NWS website), to combine the NWS flood predictions with the locally available data (roads layout, areas, special structures), in order to identify the likely contingency events and time scenarios.

For the candidate information items to potentially add value to the EMs, our model looks at the information directly linked to the flooding forecast (i.e., to the predicted water levels) at both a global and local level. We examine the potential value added from conveying the direct causes of the flooding events (and/or the patterns of causes) for better predicting how the flooding scenario will unfold, as well as for matching the future flooding with the past flooding. For example, the upper panel of Figure 3 displays gauge readings for a specific region, providing a global view of current flooding in an area. The lower panel of Figure 3 highlights the upstream gauge readings that may directly influence the flooding forecast at a given site, providing a more localized view of the surrounding areas of concern that will directly impact a specific location. In the future, these closely coupled readings can serve as quantitative metrics characterizing the prospective flooding, to help match it with past floods from the history archives. Our model also looks at the direct effects (post-flood events) that may present triggers for specific emergency measures.

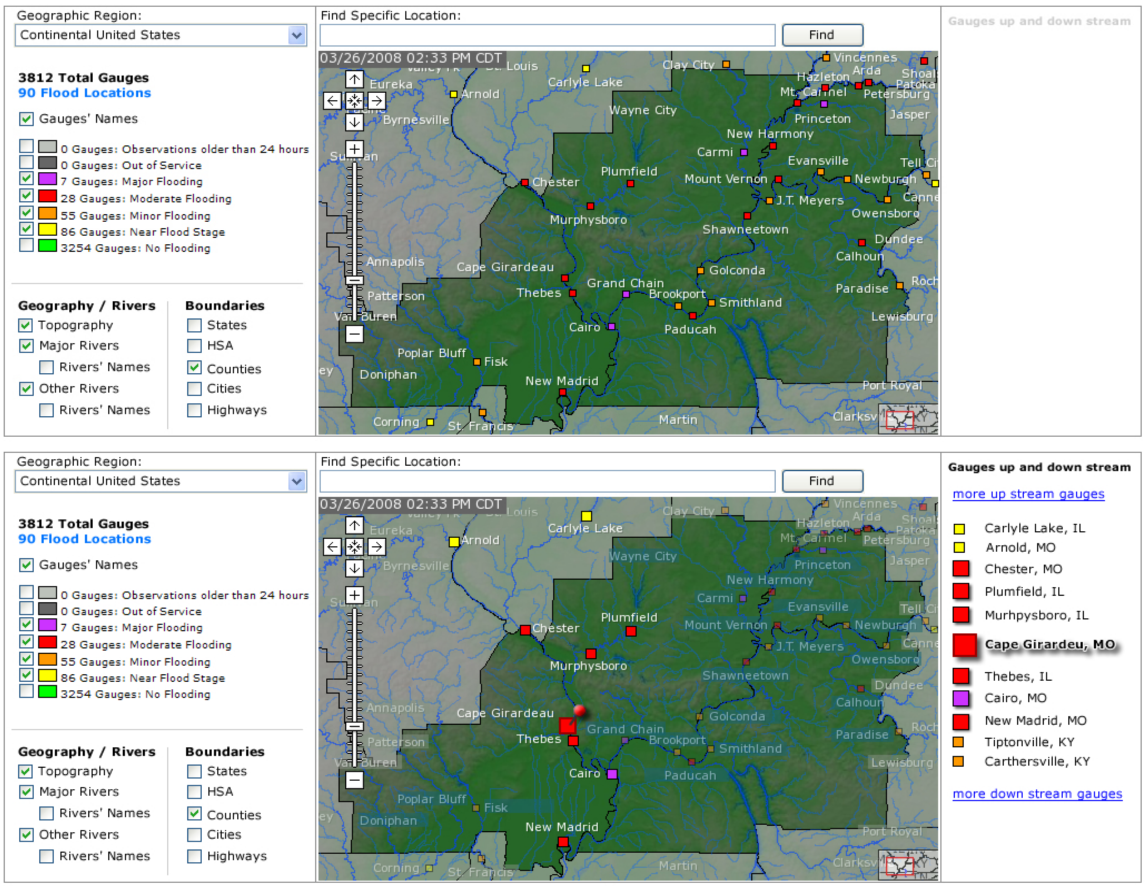

Figure 3. A visual depiction of up and down stream gauges' relationship to a selected gauge. (refer to *Landmark Map* under *User Interface Description*).

Thus, our model specifies the generic information items of potential value to the EMs as follows:

I. *Flood precursor signatures* – (time-stamped) patterns of events and conditions likely to cause the flooding:

→ [Functionality and value]: Event categories, influence relationships, and time placement signatures *quantify* the flood precursor signatures and allow for *proximity distance metrics* and thus for mathematical algorithms to search for similar past floodings.

- *Causes* – i.e., weather and climate conditions, e.g., precipitation, snow melting, upstream water inflow, etc.;

- *Conditions thresholds* – threshold values of each essential cause attributes (i.e., the "tip-points" from no flooding to flooding).

II. *Worst case envelop* – (sets of) adverse events with sufficiently high likelihood of occurrence:

→ [Functionality and value]: Key planning points for emergency measures and for assessing feasibility of the concomitant courses of action.

- *Effects* – e.g., roads under water;
- *Threats* – e.g., mudslides;
- *Triggers* – e.g., flooding at the key special facilities (hospitals, chemical plants, residential areas, etc.);

III. *Uncertainty* – NWS forecast model's attributes (e.g., standard deviation as a function of future time) for how far into the future the confidence of predictions extends and how many deviations of the flooding scenario are likely (and should be accounted for in emergency planning):

→ [Functionality and value]: Helps scope the prospective emergency planning efforts.

- *Horizon of predictability* – into-the-future time interval of high-confidence predictions (during which prediction confidence metrics is above the threshold);
- *Spread of envelop* – e.g., high and low water level predictions, the maximal predicted time for water to subside.

Table 2 lists examples of the several *specific* information items of value to the EMs.

Table 2. Information items of value to EM.

Item	EM Process	Benefit / Use	Source / Is on NWS river forecast website (Y/N)
Water level predictions	Making decisions about the likely flooding	High absolute level and/or rate of increase signal likely flooding events	(primarily) from NWS river forecast site / Yes
Weather events – predicted precursors to flooding	Laying out likely scenarios	Coupled with historical local knowledge, this can lead to better predicting the contingency scenarios	NWS weather forecast / No – but they must be readily available, as they are likely used by the NWS river forecast model
Risks - predicted **contingency events** (e.g., predicted mud slides, road conditions) – occurrence (what) and time (when)	Choosing the emergency measures and concomitant courses of action (COA)	Helps assess adequacy and feasibility of emergency measures	Can be derived from **historical data** about past flood events / No

We thus note that the EM's mission is concerned with the specific flooding and contingency ***events*** and with associated ***time scenarios***. This poses special requirements for packaging and representing the NWS forecast data (e.g., the time-spaced semi-transparent snapshots of progressing flood conditions, superimposed with the local special facility maps, can be used to determine the likely and worst-case flood scenarios, and thus to facilitate and focus planning of the emergency measures).

The EMs must pay special attention to the adverse effects of prospective flooding and to the infrastructure-specific predictions. The key challenge that EMs face is the need to integrate NWS flooding forecasts with ***local information*** that the NWS does not deal with. The NWS website information can potentially be tailored to assist this need. Some of the information that the NWS generates (e.g., weather precursors to flooding and forecasts for the border upstream/downstream areas) can assist the EMs in predicting contingency events or local flood mini-scenarios, and must be displayed/accessible alongside the flooding forecasts. Ideally, the NWS can help identify the likely future flood scenarios by pinpointing the *most similar* past flood scenarios extracted from the previously stored historical data. Also, the NWS can package its data feeds to be consumed by the EMs who operate their own websites which store local information and are equipped with additional functionality (e.g., for making the infrastructure specific predictions; for extracting the summaries about previous floodings; for projecting contingency scenarios; and for choosing the emergency measures and specific courses of action).

Note: Recently initiated formal EM's After Action Review (AAR)/ Lessons Learned program can be used to record contingency events and map them both to the flood conditions and weather precursors, on the one hand, and to effective courses of action for emergency measures (as well as to potential risks), on the other hand.

Present Information Organization and Opportunities

Information at NWS website – summary

NOAA's NWS website contains a variety of weather related data products that include climate data and weather forecasts with detailed uncertainty estimates and weather observations (past weather conditions and long-term averages) from stations around the United States. The website features numerous data categories and representations, as well as associated links (e.g., the daily weather summaries and the month's weather to date at the Local Climatological Data or F-6 form; prediction maps; historical weather data; etc.). The NWS website also contains the description of the underlying Forecast Models, including Numerical Models and Statistical Models.

Table 3 lists several prominent links to data categories available at the NWS website.

Table 3. (A subset of) the data links at the NWS website.

Warnings	**Observations**	**Forecasts**	**Forecast Models**	**Climate**
Current By State/County... UV Alerts	Radar Satellite Snow Cover Surface Weather Observed Precip	Local Graphical Aviation Marine Hurricanes Severe Weather Fire Weather	Numerical Models Statistical Models...	Past Weather Predictions **Weather Safety** Weather Radio Hazard Assmt... StormReady / TsunamiReady

From the EM's mission perspective, the main challenge is to orchestrate the weather emergency and flood related NWS data representations to:

(i) Provide compact summaries of likely prospective weather scenarios;
(ii) Visualize how the probable dynamics of weather scenarios relate to the local geography;
(iii) Enable time-specific predictions of threats to appropriately focus the attention of the EMs and their emergency planning efforts;
(iv) Link the likely prospective weather scenarios to the similar past scenarios (automate the function of finding the most similar scenarios);
(v) Summarize the associated uncertainties to pace the weather monitoring and emergency planning efforts.

Currently, the EMs obtain the following information from the NWS website:

(a) Active warnings, including flood warnings per geographic areas (Major, Moderate, Minor, Near Flood Stage, No Flooding)
(b) Gauge level per location (~water levels)
(c) Daily forecast of river levels (e.g., 3 or 5 day)
(d) Current weather data
(e) Weather map
(f) Data over time (graphical)
(g) Data over time (tabular)
(h) Statistics (historical data)
(i) Interactive state radar map.

Existing data items and additional opportunities

The following data items of value to the EM are available from the NWS river forecast website:

1. Anticipated **flood magnitude**, predictions with range data.

   Note: This main concern of emergency managers is to predict the dynamics and magnitude of these events and their impacts. Time-spaced snapshots may help the EMs visualize the prospective flood scenarios – such representations can be obtained in two different ways: (1) as automatically generated predictions by the underlying NWS models; and (2) as images of the similar flooding scenarios from the past. Within the proposed visualization approach, these two representations are captured through graphical predictions of flood magnitude and resulting events, as shown in Figures 2 and 5.

2. **Potentially threatening conditions** at boundary areas.

   Note: These events are available from the NWS website; however the navigation and summaries can be better linked to the local flood forecasts to reduce the cognitive load associated with extracting this information. Some of the associated quantitative signatures are needed primarily to identify the most similar past emergency scenarios (i.e., their on-demand display can help reduce the data overload, while still providing access). We provide this local flooding impact information through visualizations shown in Figure 2.

3. **Historical data** about past flood scenarios.

   Note: This information is not currently captured in the developed visualizations, but is used to drive the predictions captured within the developed visualizations.

The following data items of (potential) value to the EMs are not handily linked to the EM's information items / pathways at the NWS river forecast website:

1. Anticipated **weather events** – predicted precursors to floods.

   Note: These events should be available from the underlying NWS flooding forecast models. This seems to be the "low hanging fruit". This information is not currently captured in the developed visualizations, but is used to drive the presented predictions. Future visualizations may explore the inclusion of this information.

2. Potential **scenarios** – resulting **contingency events** (time-stamped and linked to geography).

   Note: The NWS website can provide access to the *most similar* flooding snapshots (both local and from geographically similar locations) from its past historical data (via links to its historical data flood snapshot archives). The EMs can then look up the corresponding local data if available at their local websites. With the current After Action Reviews, the historical local archives of data (identifying contingency events and concomitant emergency management strategies for specific floods) can be built over time, if not already available. By appropriately indexing the flood attributes, our model can help define the *distance metrics* and concomitant nearest- and close neighbor- algorithms to help select the similar past floodings from historical data for this and other geographically similar locations. These data are used in driving the model's predictions, which are captured within the proposed visualizations shown in Figure 5.

3. **Infrastructure specific predictions** that impact COA needs and feasibility.

   Note: As noted above, this information is captured in the visualizations shown in Figure 2. This information is further augmented through a damage estimate visualization component, shown in Figure 4.

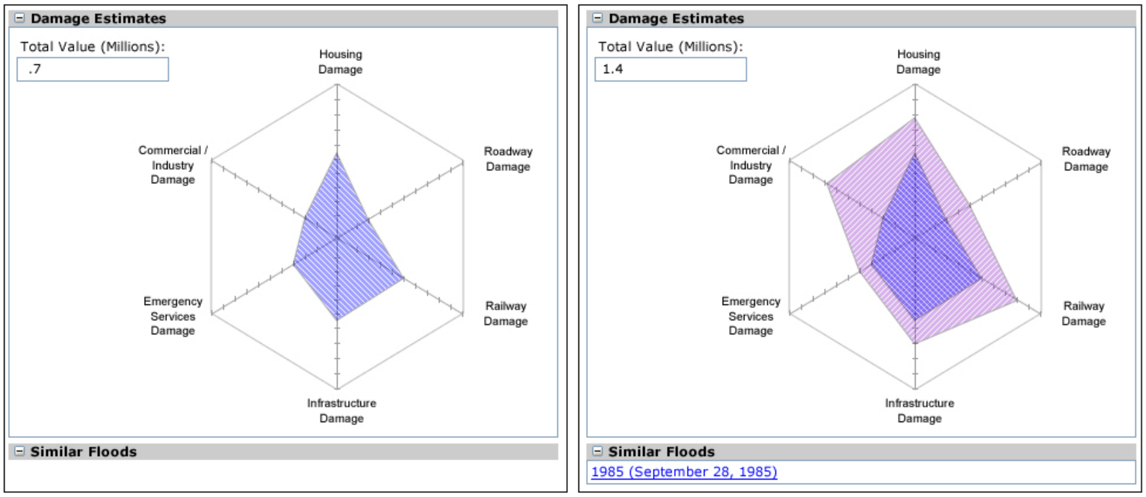

Figure 4. Predicted impact estimates along measured dimensions of damage at the current time (left – region highlighted in blue) and the possible damage for a given flood scenario in the future (right – region highlighted in purple) (refer to *Interactivity of River Height Graph with Extent Map and Measures of Damage* under *User Interface Description*).

4. **Likely adverse effects** that require special attention of EMs.

   Note: Items 6 and 7 are likely to include information that is local to the EMs. However, the NWS can provide the information about similar past floodings, and some corresponding past map imaging data, that would facilitate the process of identifying local adverse events and infrastructure specific predictions. Although explicit visualizations have not yet been developed to address these requirements, they represent an area of planned expansion, as highlighted in the "Similar Floods" section in Figure 4.

The different Forecast Models presented at the NWS website, including Numerical Models and Statistical Models, can be contrasted to assess the forecast confidence and the scenario evolution envelope. For different localities, different models may be historically better at generating more reliable predictions. Also, the EMs may operate their own prediction models, and may want to contrast their predictions versus those produced by the NWS models (as well as contrast past predictions versus actually observed readings), especially when seeking to establish the worst-case scenarios for the upcoming threatening climate and weather conditions (the worst of the two or more predictions could be assigned as the baseline worst-case scenario). Figure 5 illustrates how the developed visualization components address these specific needs. In the upper panels of the figure, the user is presented with predicted flooding in the context of a cone of uncertainty surrounding the predictions. Note that uncertainty is small for near future events, but grows as predictions are extended into the future. In the lower panels of the figure, the visualization displays the parameters that influence the model's predictions. The user can also modify these predictions based upon his or her local knowledge to perform what-if analyses.

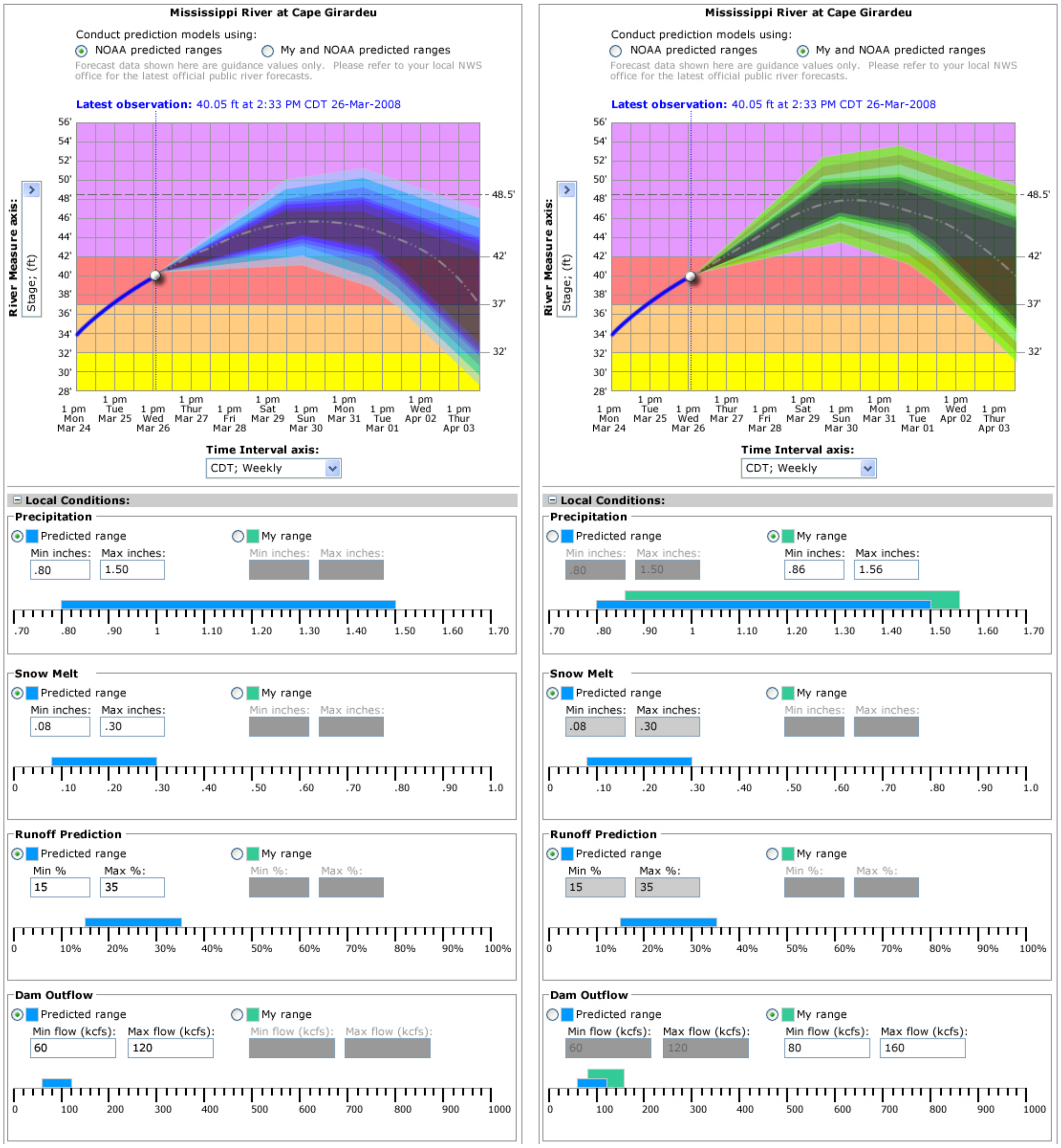

Figure 5. Comparing the results (and uncertainty predictions) from two different models (refer to the *User Modification of Model Parameters for "what if" predictions* under *User Interface Description*).

Model-driven recommendations – Summary

Our model-driven recommendations are directed toward data formatting, linkage, and representation to shorten the exploration pathways that EMs must undertake to amass and analyze the relevant weather information; to fuse information into actionable categories (e.g., weather and climate events, geographically annotated contingency effects; and concomitant timelines); and to provide EMs with additional mission-critical functionality.

Our recommendations are as follows:

A. Add *symbolically annotated* **anticipated weather events** (that the NWS predictive models single out as the precursors to the predicted flood conditions) to the NWS website. Make available the quantitative signatures, based on leading indicators and trends, of prospective flood scenarios, in order to automate the search for similar flood scenarios from the historical data archives. Present probable dynamics of the predicted flood conditions via time-spaced geography-linked local weather event evolution maps.

B. Link **summaries of anticipated flood events** from *boundary geographical regions* to local maps displaying flood predictions at the NWS site.

C. Apply the process for storing the depictions of **likely potential scenarios** – with resulting **events** (including adverse and infrastructure specific events) time-stamped and linked to geography – and linking these depictions to the NWS website:

  i. During the after-action reviews, use *historical databases* (currently presented at the NWS site) to store local map images of past flood effects – time stamped – from previous floods, with overlaid markers for adverse effects (e.g., roads blocked by water) and infrastructure specific events.

  ii. Use “nearest close neighborhood” metrics of scenario similarities to pull up candidate scenarios from own histories *and* from those of the other EMs.

D. Apply **compact graphical format** (e.g., shape and color-coded time and geography-spaced event chain sequences) for past and predicted scenarios.

E. Combine the horizon of predictability and the spread of envelop **uncertainty visualizations** with discrete, symbolically annotated, and geographically dispersed and linked icons and object representations of probable events and adverse weather conditions. Automate translating continuous uncertainty metrics (e.g., deviations, ensemble averages, etc.) into specific representative and worst-case discrete event scenarios.

USER INTERFACE DESCRIPTION

Knowledge elicitation sessions with emergency managers provided valuable details regarding essential elements of information needed while evaluating a river's flood state. The UI design concepts presented below were guided by information gained from these sessions to ensure that desired information was presented in a manner that would assist in EMs' decision making.

Landmark Map

Emergency managers are concerned about the local area they are responsible for as well as how the current and future flood states of surrounding areas will impact them. As spatial knowledge is a key aspect in their analysis, a geographic "landmark" that is always available can be of assistance in providing an "at a glance" reference for situational awareness of the location they are analyzing detailed information of, and for keeping awareness of relevant surrounding areas and their current status.

The landmark map is presented in Figure 6, below. This map is a "hybrid" of *National map* of water gauges presented on the NWS "Water" tab and the local *River Observation maps* presented after clicking a gauge on the *National map*. This landmark map is envisioned to be highly "interactive" in its panning, zooming, and location finding abilities, removing the need for the two separate maps presented on NWS currently. The landmark map is also envisioned to be more dynamic through its ability to allow emergency managers to pick and choose which categories of gauges to present simultaneously.

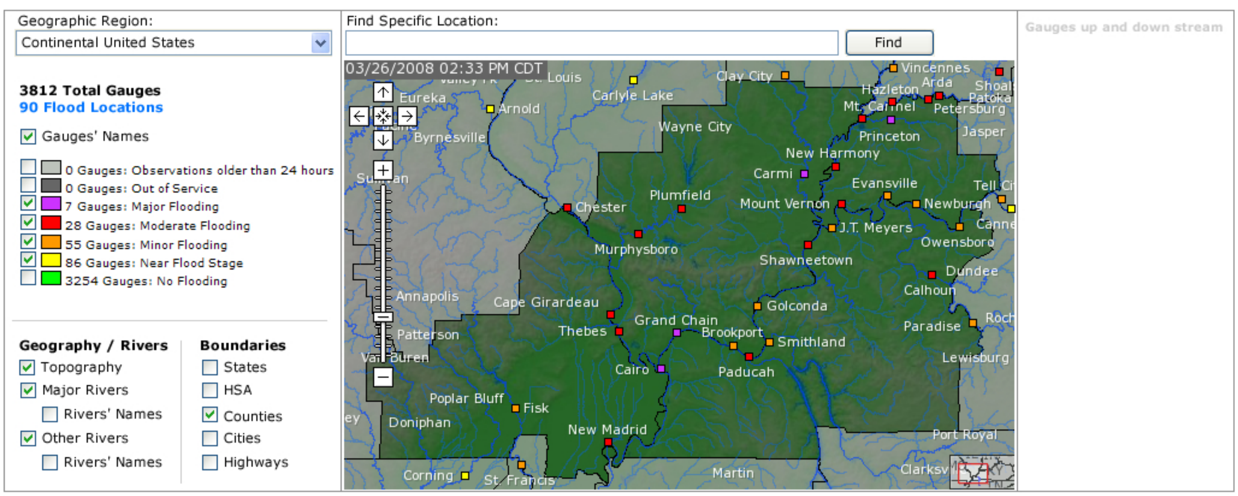

Figure 6. Interactive gauges map, zoomed into a location with only gauges in a desired state displayed.

Upon selecting a "gauge" in the landmark map, detailed information related to the gauge is presented below the map, keeping the landmark map available for maintaining a situational awareness of the gauge's geographic location and states of relevant gauges up and down stream of the selected gauge. Further assistance in obtaining and maintaining this situational awareness is obtained by making the selected gauge the most prominent on the map, and increasing the saliency of gauges up and down stream of the selected gauge by fading all other unrelated gauges into the background, as detailed in Figure 7. An additional depiction of the gauges up and down stream of the selected gauge is presented to the right of the map in a "fish eye" listing of the gauges. The selected gauge is in the center of this view, with its "flood state" depicted through color coding and its selection state detailed through its highlighting and large size. Gauges up stream are presented above the selected gauge, while gauges downstream are presented below the selected gauge. Their current state is detailed through the color coding, while their distance away is depicted in terms of the size of the gauges' box (the further away the gauge, the smaller the box, while the closer the gauge, the larger the box). Emergency managers can either use the map or the fisheye presentation of the gauges to select gauges up and downstream to obtain more detailed information regarding the area.

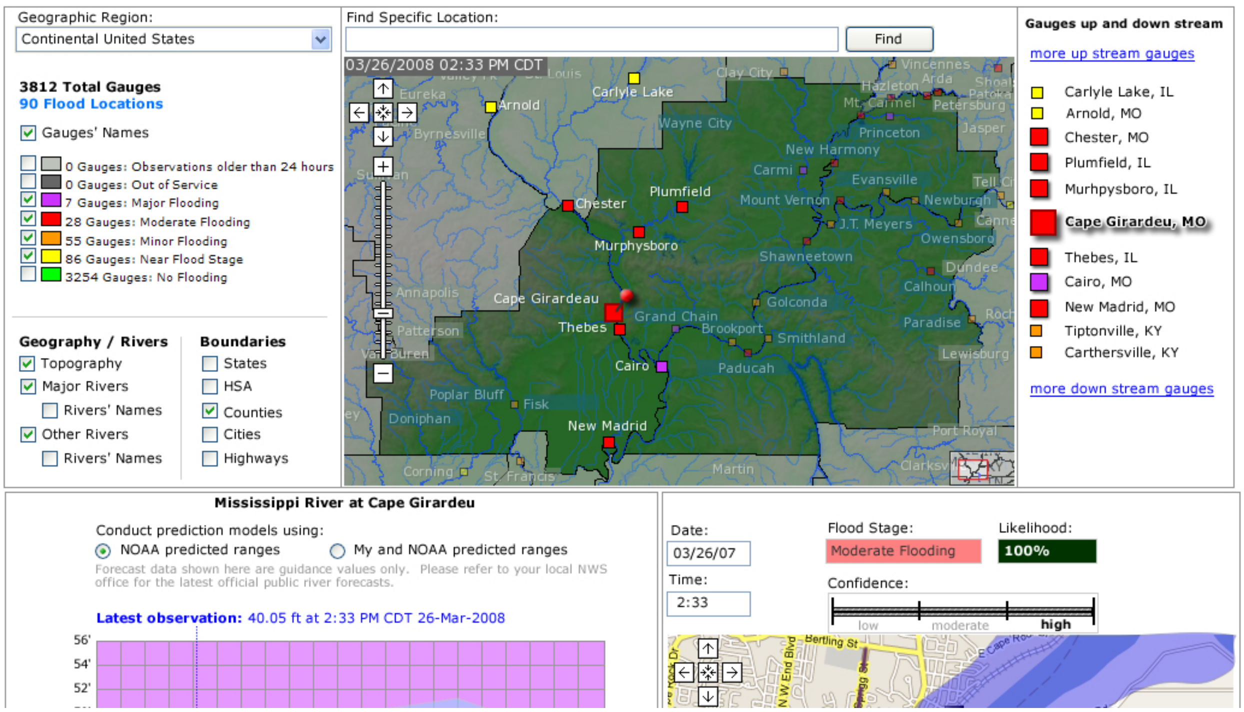

Figure 7. Interactive Gauges Map with a specific gauge selected, reducing the saliency of other gauges in the map extent that are unrelated while increasing the saliency of other related gauges both up and down stream. Details regarding the selected gauge are displayed below the map.

Gauge Details

Figure 8 shows a depiction of what would be presented below upon selecting a gauge in the landmark map. The information that can be obtained by the emergency manager in this portion of the screen includes: 1) the current state of the river's *height*, 2) the current state of the river's *extent*, 3) items/areas of concern impacted by the river at its current state, 4) estimated damage caused by the river at its current state, 5) and *predictions* regarding the river along all of these dimensions in the future.

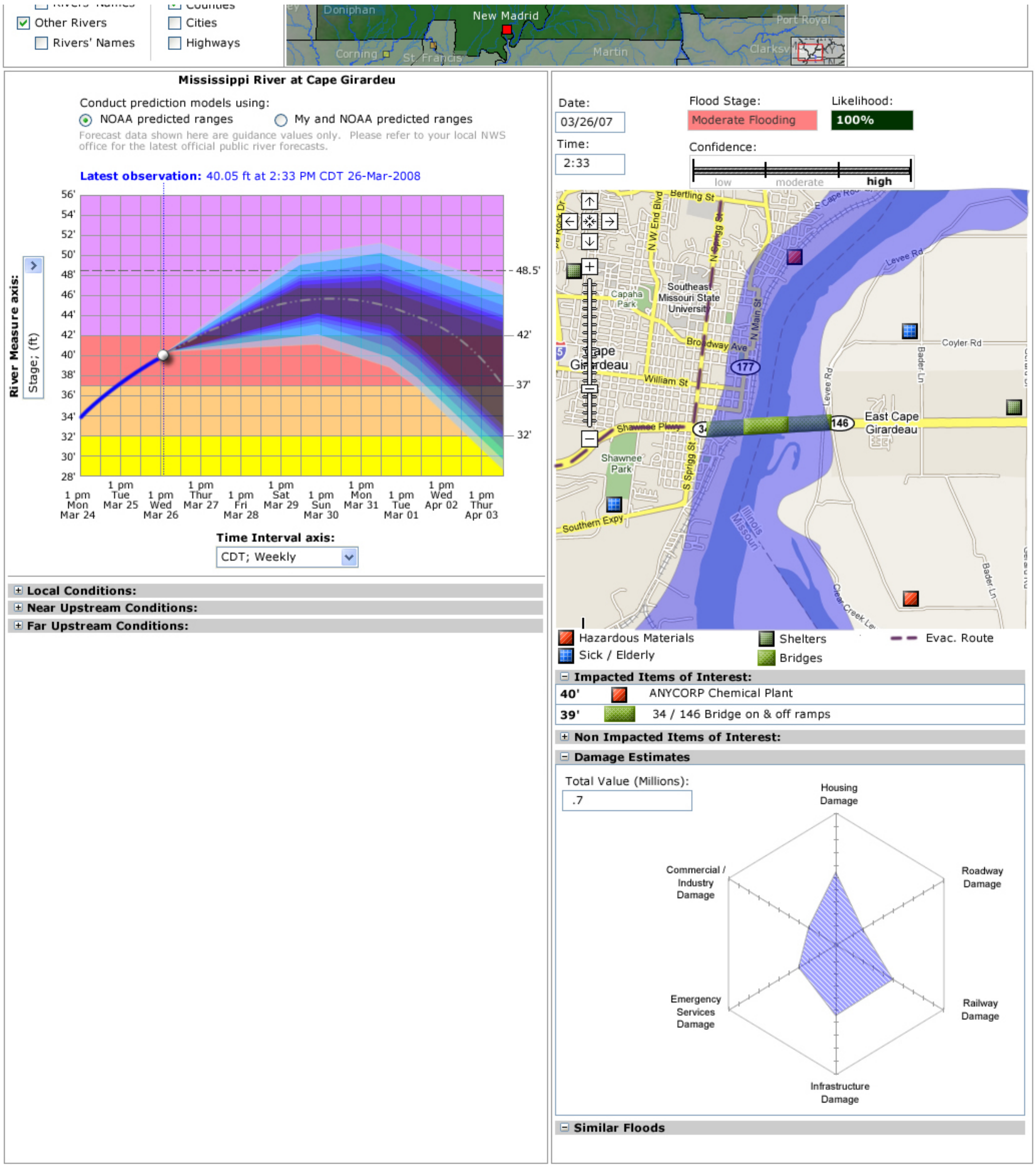

Figure 8. Details regarding the selected gauge presented below the landmark map.

River Height and Cone of Uncertainty Visualizations

Figure 9 presents a graphical depiction of the river "height" over time as well as the geographic "extent" of the river at a selected point in the graph (white marker in graph). The graph presents the "future" predictions of the river as well as a dashed line, with a *cone of uncertainty* around this dashed line. The *cone of uncertainty* presents different "shading" to depict the "likelihood" that the river will fall within the shaded region, and is designed to support users in assessing the probabilistic information associated with predictions. For example, the darkest blue region highlights the river "heights" that have a 95% or greater likelihood of occurring at those given points in time, while the lightest blue region at the furthest extent of the cone's area highlights the regions with a 5% to 10% chance of occurring at those given points in time. As can be seen, the cone become larger at further extents out in time as more uncertainty exists as to "where" the actual height of the river will be. Along with the likelihood score of the river actually reaching a certain height at a given point in the future, there is also a measurement of *confidence*. For example, the confidence in one of the heights actually occurring within the dark blue region at a "near" future time is higher than the confidence in a point falling within the dark blue region at a time far in the future. The *flood stage*, *likelihood*, and *confidence* scores for a "selected" point within the graph are presented above the map that also details the spatial *extent* of what the river will be for the selected point. Figure 9 shows the default selection point of the last measured state of the river, resulting in a *flood stage* of moderate being presented, with a *likelihood* of 100% and a *confidence* score that is at its highest since the point is not within the cone of uncertainty.

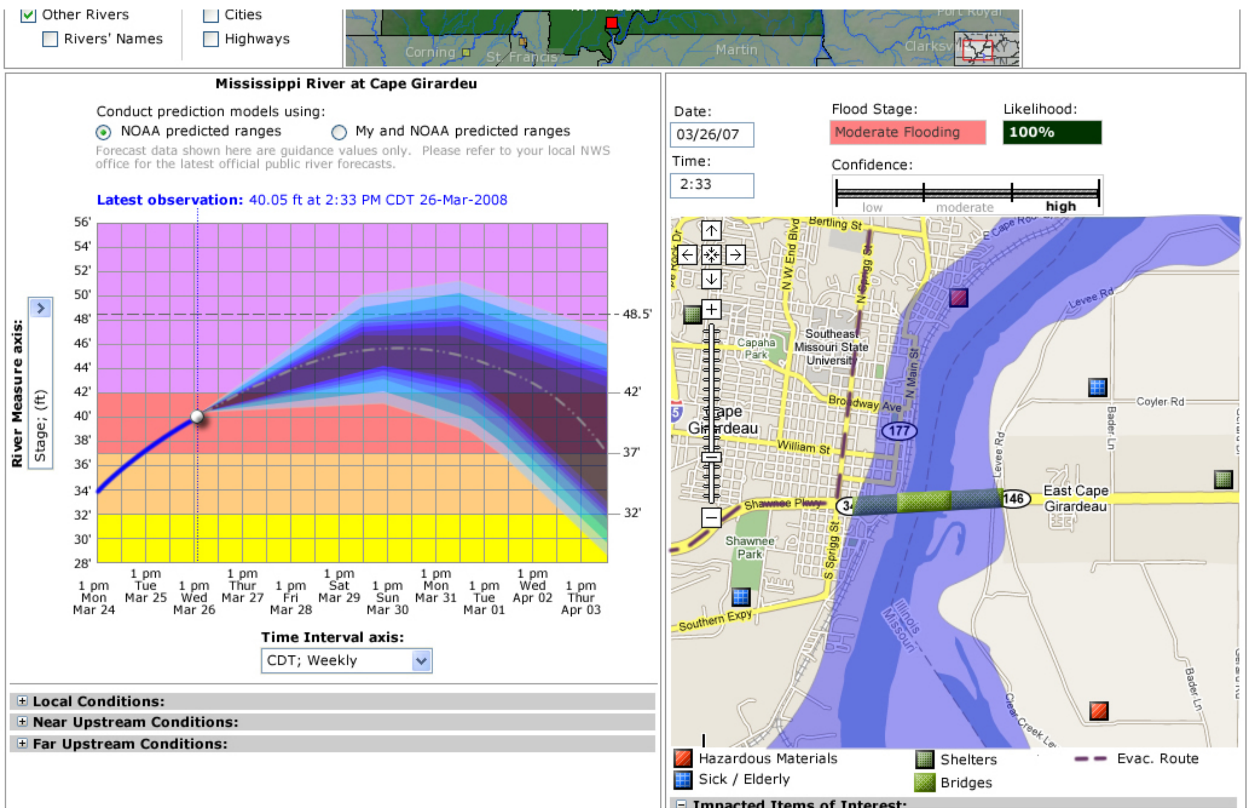

Figure 9. Detail regarding the river height and the projected future state with the cone of uncertainty. The selected point in the graph is depicted over in the map along with the likelihood and confidence of that flood stage/height occurring. NOTE: Hovering over the selected point in the graph will provide the emergency manager with an exact number of the river "height" at that point. NOTE: It is possible to change the river "height" scale to be a river "flow" scale. It is also possible to change the "Time Interval" of the graph to be shorter or longer in duration.

User Modification of Model Parameters for "what if" predictions

The model that will derive the predicted river height will use relevant factors related to local conditions as well as near and far upstream conditions. Such factors under the local, near and far upstream conductions could include *precipitation*, *snow melt*, *runoff*, and *dam outflow*. Figure 10 shows how these factors can be exposed to the user for viewing the model's predicted range of values for such factors (the *predicted* ranges). This figure also depicts how emergency managers could supply their own range of values along these factors (e.g., *my* ranges) to see *how* the model would change in light of these different ranges of values. This "what if" capability allows predictions to be more customized and offer more utility to emergency managers. Further, the visualizations of the model's inputs and outputs allows emergency managers to directly see "how" their ranges impact the model's predictions compared to predictions without the emergency managers' ranges values.

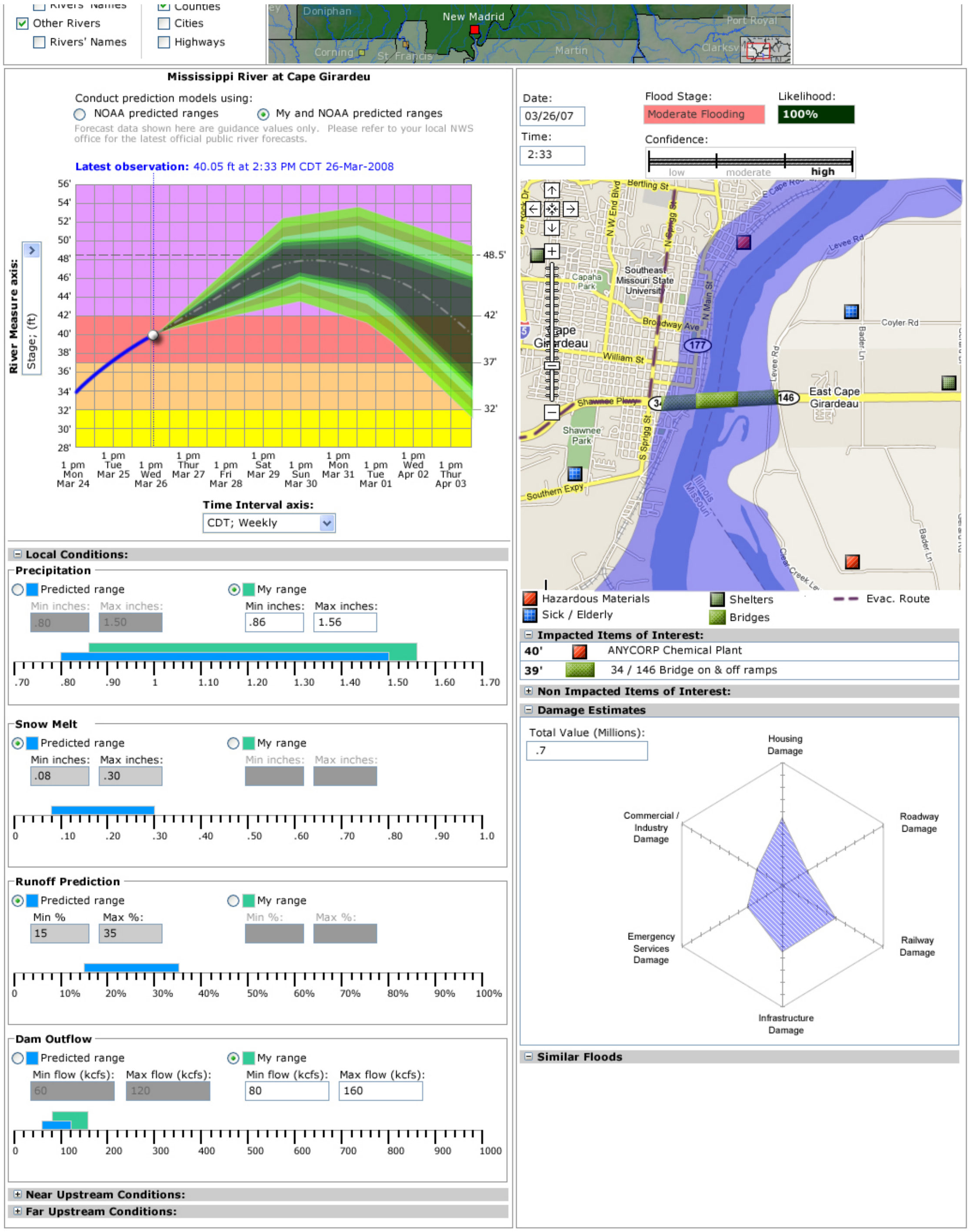

Figure 10. The *local conditions* category of factors exposed revealing the "predicted" range of values as well as offering the emergency manager the ability to enter their own modified range under the "my range" aspect for the various factors. Toggling between the "NOAA predicted ranges" and "My and NOAA predicted ranges" allows the operator to compare and contrast the two separate outputs to observe "how" their edits effected the model's predictions. NOTE: The cone of uncertainty is a different color (green) when the user has the "My and NOAA predicted ranges" than when the "NOAA ranges" is selected to further highlight "which" output set the user is looking at.

Interactivity of River Height Graph with Extent Map and Measures of Damage

Figure 11 details the view an emergency manager would obtain when selecting a point within the cone of uncertainty in the river height graph. As noted earlier in the *River Height and Cone of Uncertainty Visualization* section, an overall "score" for that point in terms of the *flooding stage, likelihood* of that stage, and *confidence* in that prediction is depicted above the map view of that location. As was seen earlier when the default selection point of the last measured state of the river is selected, the current extent of the river is visible as the "blue" highlighted section in the map. When a point within the cone of uncertainty is selected though, the difference between the current and future state of the river is highlighted in the color of the predicted flood stage (in Figure 11, the difference is highlighted in purple as the predicted flood state is "Major Flooding").

Underneath the map of impacted flood region, there are two collapsible "items of interest" sections. One section contains a listing of the items that have *been* impacted by the flood, while the other lists item that have *not been* impacted by the flood. In Figure 11, the *impacted* items list has been expanded to reveal: 1) the items that have already been impacted by the flood at its current stage (highlighted in blue), and 2) the items that *will be* impacted if the river moves to the selected height within the cone of uncertainty (here, the items highlighted in purple since the river would be in a "Major Flooding" stage at the selected point within the cone of uncertainty). If these "items of interest" can be "geo coded," it would be possible to also display them within the "map" as well, allowing the emergency manager to obtain a quick means of identifying "where" these items are and "how" the flood has impacted them. From interviews with emergency managers, "items of interest" include: 1) evacuation routes, 2) bridges, 3) chemical plants (i.e. hazardous material areas), 4) nursing homes & hospitals (i.e. areas with concentrations of elderly & sick who need assistance in evacuating), and 5) shelters.

Below the "items of interest" list is a depiction of the damage that has occurred to the flooded region. A "total" value is provided that details the amount of damage that "would" occur if the flood reached the selected point in the cone of uncertainty. The Spider Diagram below shows how much of the total damage a certain measured dimension of damage accounts for the total value (i.e., if "housing" accounted for 50% of the total damage, while "roadway" and "railway" accounted for 25% each, then the "housing" dimension point would be *2 times* further out than the roadway and railway points, which would be equal in their distance out). As all the dimensions are plotted, an area is created by connecting all of the plotted dimensions' points. The "blue" area represents the damage that has been accounted for by the flood up to the last known measurement of the river. When a point within the cone of uncertainty is selected, another area is created by plotting how much each of the dimensions would account for the total amount of damage along the different dimensions of damage and connecting them. The simultaneous presentation of these *current* and *future* states of damage areas allows for a comparison of "how" future flood states impact an area and along which dimensions.

At the bottom of the screen, the emergency manager is provided with a listing of historic floods that resemble the selected point within the cone of uncertainty. Selecting a previous flood would provide details regarding the flood that would assist the emergency managers in preparing their response.

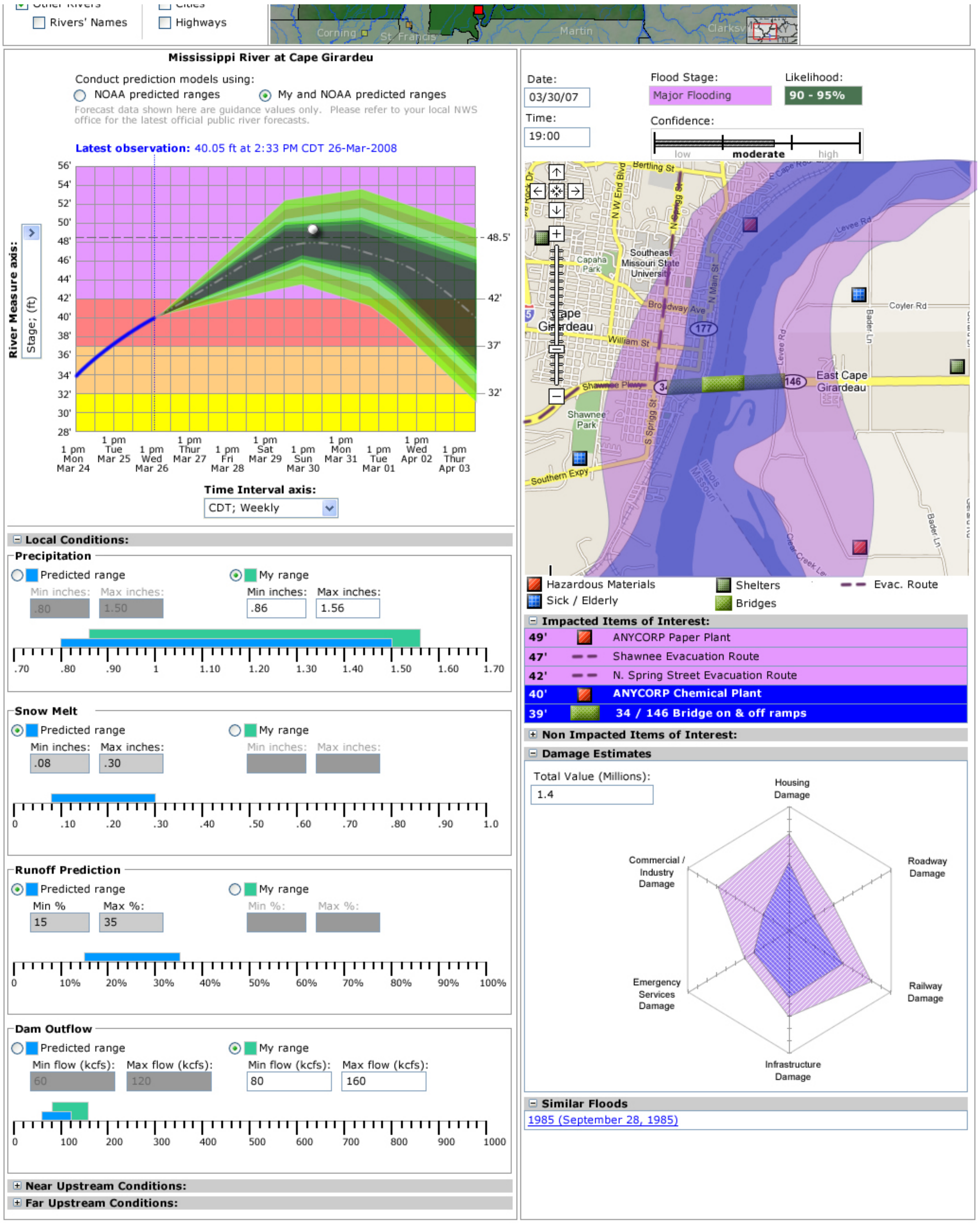

Figure 11. Clicking within the cone of uncertainty allows the emergency manager to compare and contrast the current and future stages of the river along in terms of area impacted and cost of the flood.

This document describes several measures for evaluating uncertainty and reasoning about the future.

NOTE ON CONFIDENCE VS. PROBABILITY VS. LIKELIHOOD

Probability of a given hypothesis (e.g., event) is typically a latent measure, although it can be approximated from history (including the probability conditioned on specific events). Based on the knowledge (i.e., model of the environment and concomitant history-based reliability statistics) and the available data (e.g., observed recent history of the environment), one can assess the likelihood and confidence measures about one or several hypotheses (e.g., about future events), in order to reason about the future (as illustrated in Figure 12; the reasoning examples which tie together different assessments are not discussed in this document).

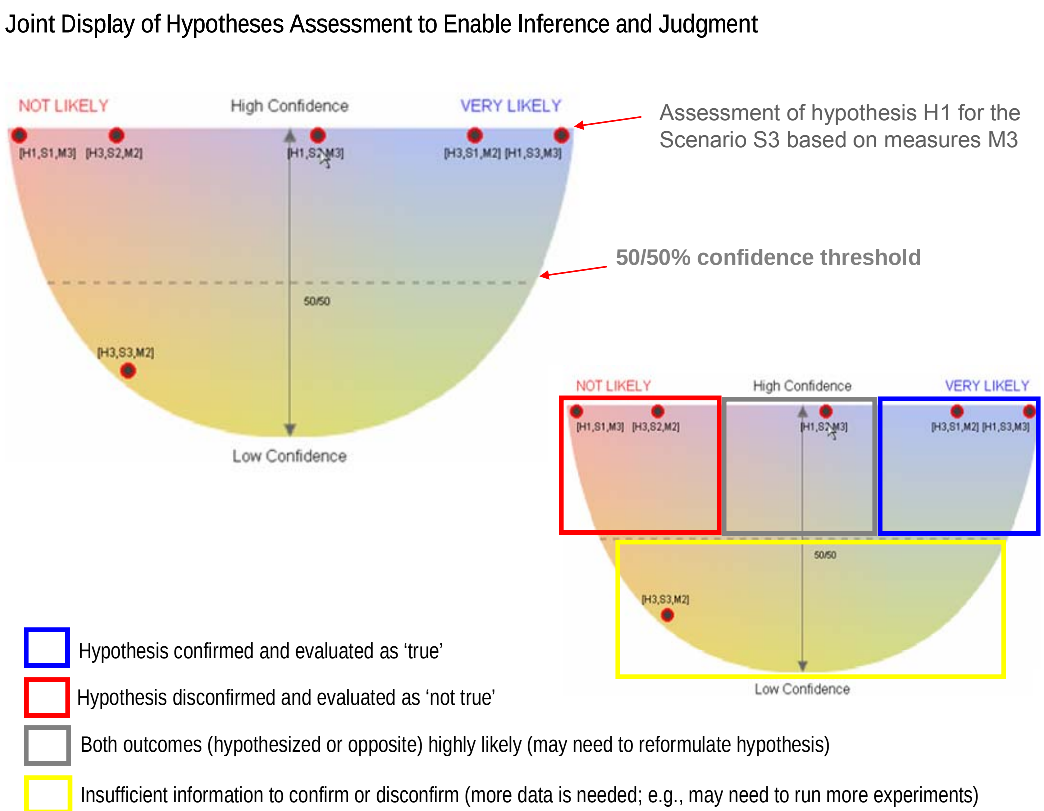

Figure 12. Combining Likelihood and Uncertainty Assessments – illustration.

<u>*Definition 1*</u>: **Probability** of an outcome is a measure of the *average rate* of the corresponding event of interest (i.e., the event that results in the given outcome) expressed as a fraction of the total number of all the possible events of interest (e.g., the probability of the given outcome is 1/10 implies that exactly one-out-of-every-ten events of interest, on average, will result in the corresponding outcome).

<u>*Definition 2*</u>: **Likelihood** of a hypothesis A given the measurements B is a measure of how likely it is that A *is true* when B *is observed*. The corresponding measure is the conditional **probability** of A is true given B, denoted as $\Pr(A \text{ is true} \mid B)$. It can be expressed as a percentage, with 100% meaning A is almost always true if B is observed.

Note: B is observed implies that $\Pr(\mathrm{B}) = 1$, and hence $\Pr(\mathrm{A}) = \frac{\Pr(\mathrm{A\ is\ true} \mid \mathrm{B})}{\Pr(\mathrm{B} \mid \mathrm{A\ is\ true})}$. Thus, we can estimate **likelihood** of a hypothesis A **independent of** the measurements B, if we can assess, for a given model, both $\Pr(\mathrm{A\ is\ true} \mid \mathrm{B})$ and $\Pr(\mathrm{B} \mid \mathrm{A\ is\ true})$.

Definition 3A: **Confidence of the assessment** that a hypothesis A is true given the measurements B is a probability measure of how strongly the data B support the above assessment of A. The corresponding measure is a function of the conditional probability of B given A is not true defined as $1 - \Pr(\mathrm{B} \mid \mathrm{A\ is\ not\ true})$ (e.g., if the confidence of the assessment that A is true based on the measurements B is said to be .95, it means that there is only a .05 probability that the measurements B could be observed when A is not true; and hence, based on the measurements B, we can assess *with high confidence* that A is true). Also, confidence of the assessment that a hypothesis A is false given the measurements B is defined as $1 - \Pr(\mathrm{B} \mid \mathrm{A\ is\ true})$.

Definition 3B: **Confidence** associated with assessing a hypothesis A given the measurements B is a probability measure of how strongly the data B support the assessment of A. It is the function of the *confidence of the assessment* that A is true and the *confidence of the assessment* that A is false, given the measurements B, defined as $\max\{1 - \Pr(B \mid A\ is\ \mathrm{not}\ true), 1 - \Pr(B \mid A\ is\ true)\}$ (e.g., if the confidence of the assessment of A based on the measurements B is said to be .95, it means that there is no more than a .05 probability that the measurements B could be observed independent of whether A is true or not; and hence, based on the measurements B, we can assess *with high confidence* whether A is true or not).

Note: Suppose that $\Pr(\mathrm{A\ is\ true} \mid \mathrm{B}) = 0.5$ and $\Pr(\mathrm{A\ is\ not\ true} \mid \mathrm{B}) = 0.5$ (i.e., A is equally likely to be true or false given B). This implies that we can *neither* confirm that a hypothesis A is true *nor* confirm that a hypothesis A is false based on the measurements B.

The likelihood ratio for a positive result tells you how much the odds of the disease increase when a test is positive. The likelihood ratio for a negative result tells you how much the odds of the disease decrease when a test is negative. You can summarize information about the diagnostic test itself using a measure called the likelihood ratio. The likelihood ratio combines information about the sensitivity and specificity. It tells you how much a positive or negative result changes the likelihood that a patient would have the disease.

Note: **Confidence** is subjective as it is typically assessed given not only the available tangible empirical data, but also the subjective data (e.g., from past experience) available to the assessor (whose experience differs from other assessors).

Definition 4: **Truthfulness** of a hypothesis is a judgment (!) based on the available empirical data for whether the hypothesis could be categorized as 'true', 'untrue', 'inconclusive', and so on (see Figure 1 for 4 categorical areas).

Definition 5: **Prevalence** of a phenomenon is the proportion of experiments (or executable model runs) in which the phenomenon can be observed.

Definition 6: **Significance** – A probability measure of how strongly the data support a certain result (usually of a statistical test). If the significance of a result is said to be .05, it means that there is only a .05 probability that the result could have happened by chance alone. Very low significance (less than .05) is usually taken as evidence that the data mining model should be accepted since events with very low probability seldom occur. So if the estimate of a parameter in a model showed a significance of .01 that would be evidence that the parameter must be in the model.