Tracking spatiotemporal patterns of building vulnerabilities and evacuations during flood hazards

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Background

June 2008, Iowa City

- **Record flood by 3 feet (1993)**
- 25 buildings damaged on the UIowa Campus
- Flood damage and rebuilding costs $743M – $1B (2011 Globe Gazette) – contents in the $100Ms
- Classes cancelled and major research programs were delayed or even lost

Arts Campus

A Unique Evacuation

University of Iowa | digital.lib.uiowa.edu/flood

University of Iowa | digital.lib.uiowa.edu/flood

Open Research Questions

- Approached by University group responsible for flood planning and response.
- What are the factors that affect campus evacuations?
  - Critical infrastructure?
  - Research?
  - Student Housing?
- How to design a model that can be used to support decision-making about building evacuations on campus?
- What are the underlying spatiotemporal properties of a model for campus building evacuations?

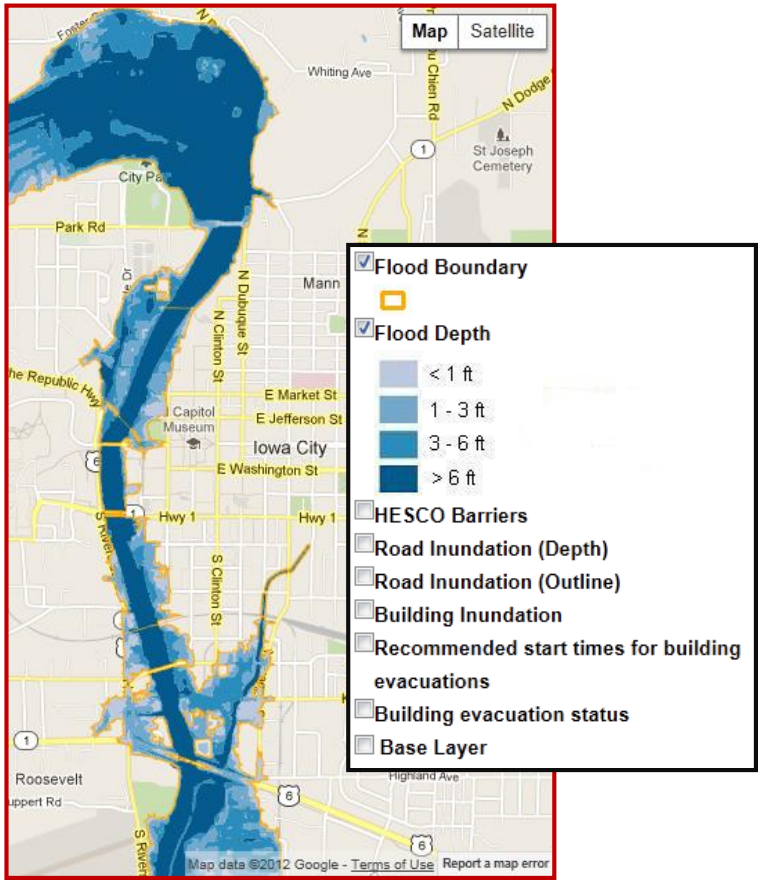
A foundation for evacuation planning

The model will

- provide a means to **analyze** and **visualize** a **time-varying flood boundary** and how it intersects with different parts of the campus
- show which parts of the campus are **vulnerable** to flooding as the **flood boundary changes** over time
- form the basis for **prioritizing evacuations** on the UI campus based on information about the **spatiotemporal properties** of the **flood boundary** combined with data about **building location, contents** and **access**

Data collection: flood boundary data

- Obtained a set of **flood depth grids** for the Iowa River from **The Iowa Flood Center**
- Our model begins with flood depth grids that equate a **17-foot** (**7,180 cfs**) flood stage along the University of Iowa campus
  - The National Weather Service (NWS) reports the University of Iowa Campus sees building damage at approx **27 feet** (**25,100 cfs**)
- Flood depth grids continue every **0.5 feet** of flood stage from **17** **through 34 feet** (**55,000 cfs**)



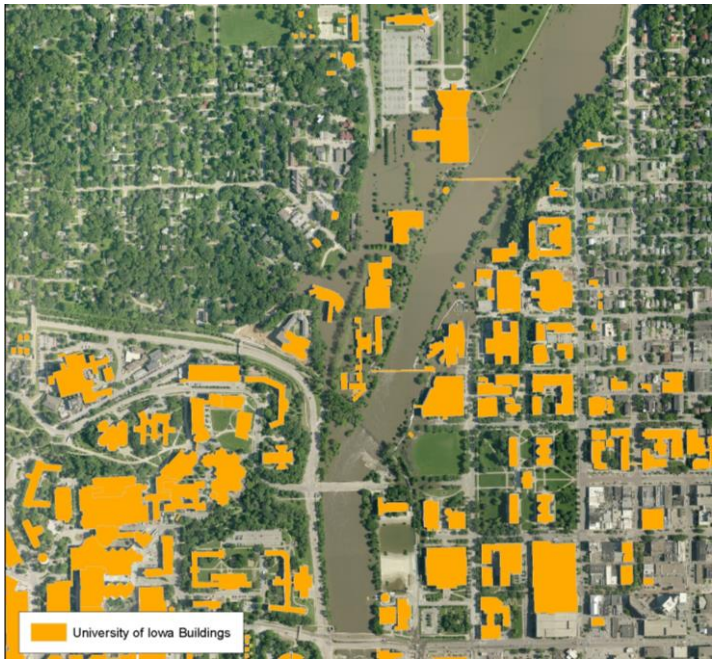
Automation

- The process of creating flood layers and formatting each into a GIS layer viewable on a webpage.
- Automation allows real-time depth grid development on the fly
  - Coffer dam
  - Sandbagging efforts

```
BEGIN
    FOR EACH waterSurface
        calculateFloodDepth(waterSurface – DEM)
        FOR EACH depthGrid
            resampleFloodDepth(5m)
            reclassifyDepthGrid {
                IF (0 < FloodDepth < 1)
                    Value = 0
                ELSE IF (1 < FloodDepth < 3)
                    Value = 1
                ELSE IF (3 < FloodDepth < 6)
                    Value = 2
                ELSE IF (FloodDepth > 6)
                    Value = 3
            }                                          } Step 1
            createPolygons(reclassifiedDepthGrids)     } Step 2
            dissolvePolygons(floodDepthPolygons)       }
            createSymbology(floodDepthPolygons)        } Step 3
            createKMLs(floodDepthPolygons)             }
        END FOR EACH
    END FOR EACH
DONE
```

Data collection: spatial data

- Acquired spatial data from **Facilities Management**
  - Updated **GIS data** of all **campus roads**, **buildings** and **residence halls**, **sidewalks**, **parking lots**, and **steam tunnels** as provided by Facilities Management
  - **Statewide LiDAR data**
    - **Elevation data** for **campus terrain**, **campus buildings, river**
  - **Campus-wide orthophotos** collected June 15th, 2008 for validation

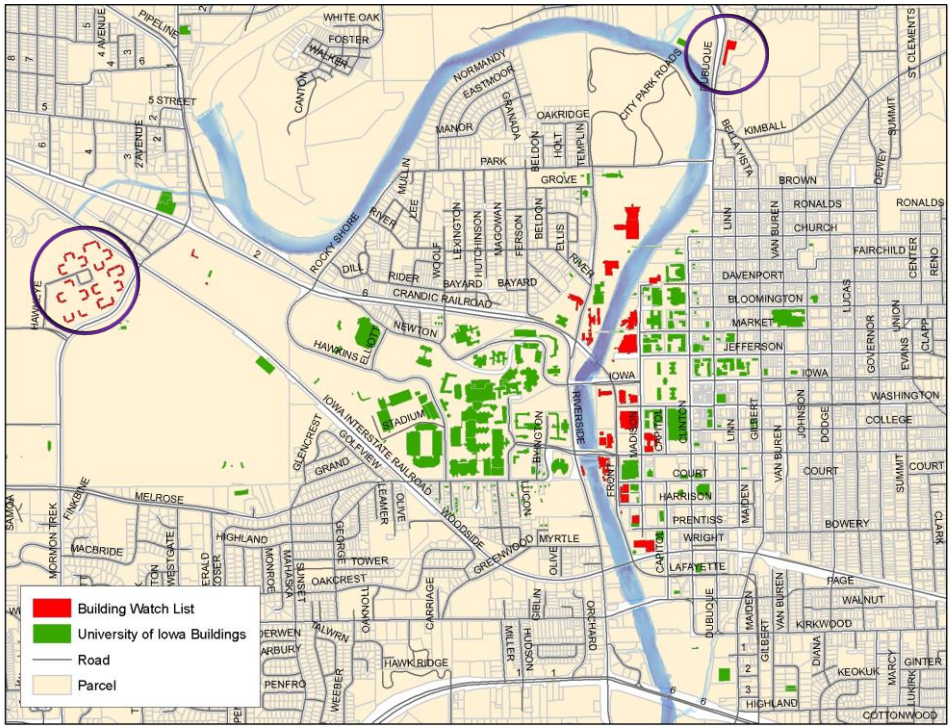


University of Iowa FERP

- The University of Iowa has a detailed **FERP** that has been updated to July 2009 and more recently in 2012
  - Details critical buildings – **building watch list**
  - Evacuation plans
- The FERP identifies 30 buildings as at-risk facilities potentially within the flooding boundary
- As part of our research, we have revealed a further **seven** facilities also inside the flood boundary

Watch list buildings

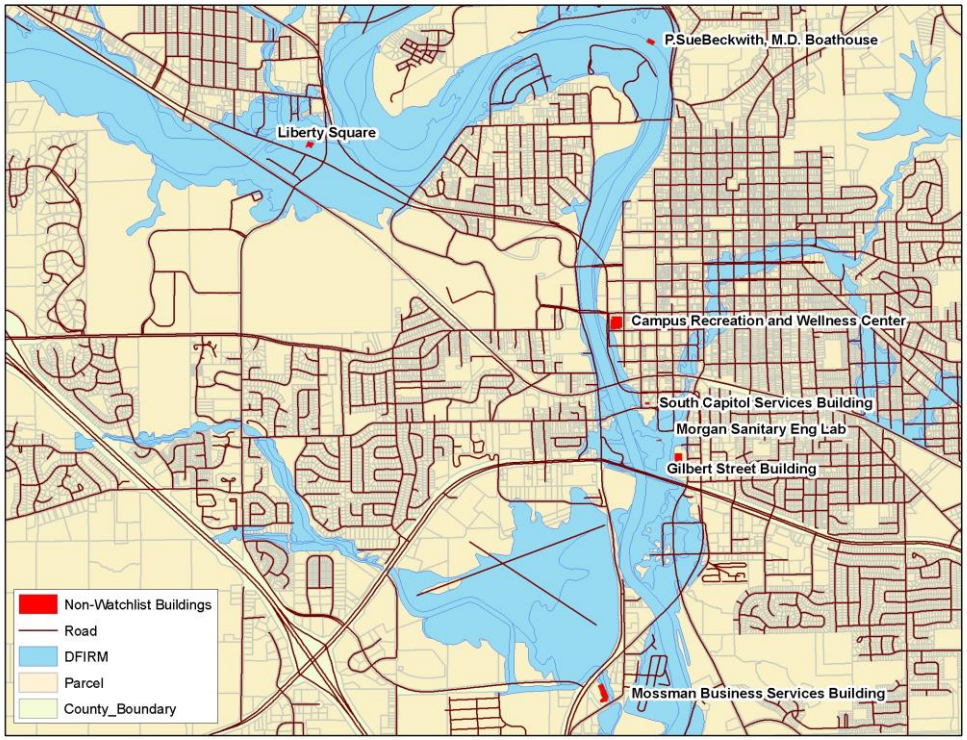
- Art Building West
- Iowa Advanced Technology Lab (IATL)
- Mayflower
- Softball Complex Equipment Building
- Theatre Building
- Voxman Music Building
- Hancher Auditorium*
- English-Philosophy Bldg
- Adler Journalism
- Becker Communications Studies Bldg
- Library
- Water Plant
- Power Plant
- Cambus Maintenance Facility



- C. Maxwell Stanley Hydraulics Lab
- Art Building
- Museum of Art
- Butler Storage and Hydraulics Annexes
- Hydraulics Lab Model Annex
- Hydraulics Research East Annex
- Hydraulics Wind Tunnel Annex
- North Hall
- Iowa Memorial Union
- Danforth Chapel
- Madison Street Services Building
- Fleet Service Building
- Hawkeye Court Apartments
- Lindquist Center

Additional buildings at possible risk

- Liberty Square
- P. Sue Beckwith, M.D. Boathouse
- Campus Recreation and Wellness Center
- South Capitol Services Building
- Morgan Sanitary Eng Lab
- Gilbert Street Building
- Mossman Business Services Building



Building the evacuation model

- Two step process:
- A spatiotemporal analysis between **flood boundaries** and **depth grids** with University of Iowa **infrastructure** have been computed to determine campus areas at risk for flooding
  - i.e., the buildings, roads, parking lots, etc.
- Based on these intersections *and* building elevations, we can determine what **features** are **vulnerable** with each **new change** in **flood stage**
- **Time** is being incorporated in the model so each flood stage and associated depth grid is associated with a **likely time of building inundation.**
- **Evacuation start time =**
  - **Time of risk** – Time needed to evacuate building contents**

Building Risk Layers

- Flood depth grids were translated into flood elevations
- Flooded buildings were identified for each flood elevation and placed into categories
  - Vulnerable basement (0.5 ft grid before flooded basement)
  - Flooded basement (revised with 2008 Flood data)
  - Vulnerable first floor (0.5 ft grid before flooded basement)
  - Flooded first floor (flood elevation and first floor elevation)
- Vulnerabilities are calculated to account for uncertainty

Data collection and preparation

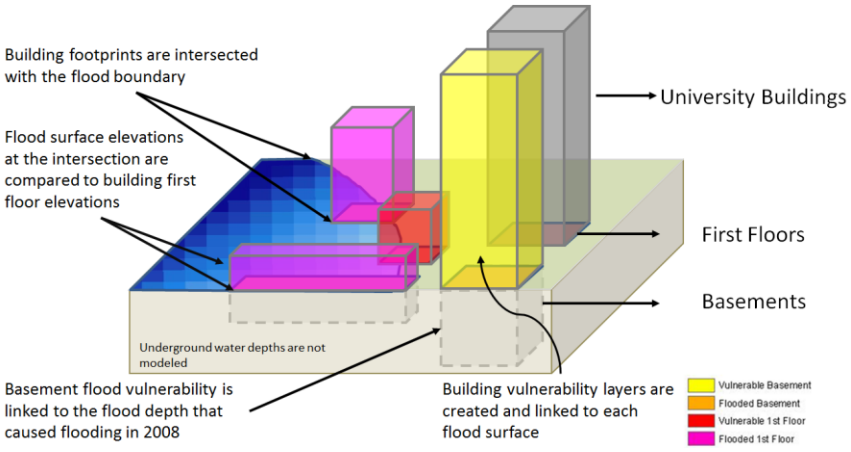
- **Basement flooding analysis**
  - Using data from the FERP, fields for the elevations of **basements**, and **sub-basements** of buildings on the watch-list were added to the GIS layer of university buildings
    - For buildings with multiple basement elevations, there is a record for each of the basement elevations
  - The estimated water table depth, the level of water in the basement, and the distance from the building to the nearest flooded area, were recorded for each flood depth
    - But during validation found this did not produce accurate results…
    - Used the data collected from interviews on when the basements flooded and what the corresponding flood elevation was at the time.

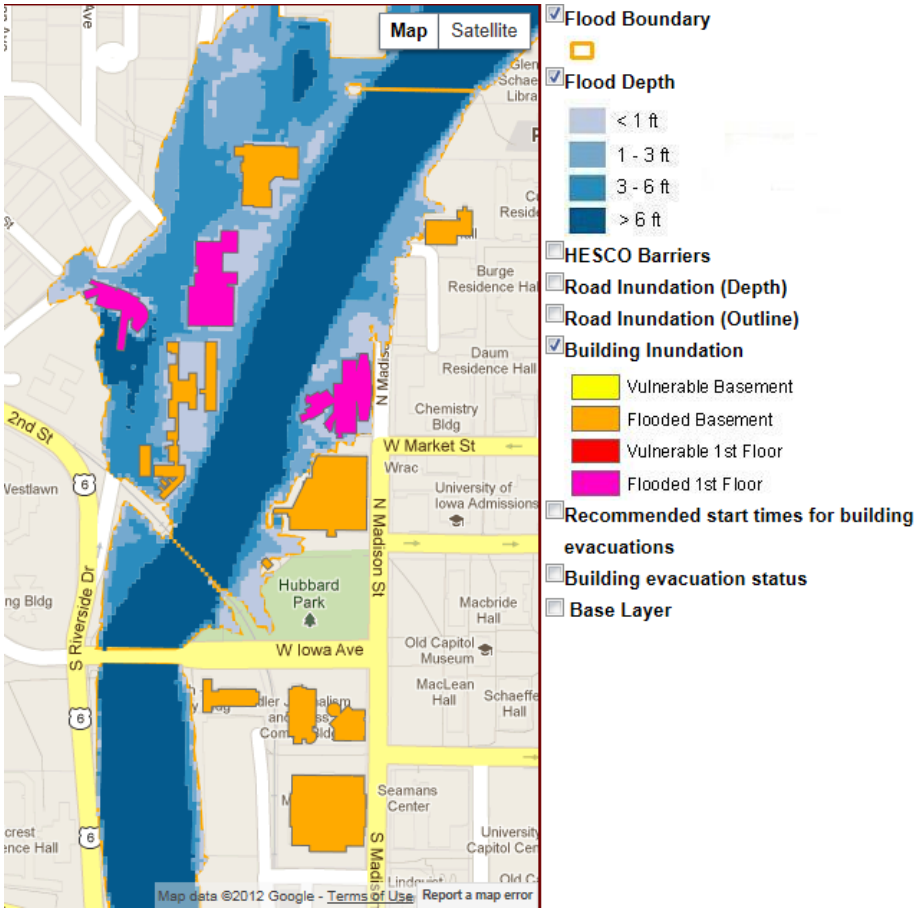
Data collection and preparation

- **First-floor flooding analysis**
  - Data from the FERP provided first-floor building elevations. The building data layer was intersected with the flood depth elevation rasters.
  - When such an intersection exists, the flood elevation depth is compared to the first floor elevation for the building
    - If the first floor elevation is less than the flood elevation, the first floor is considered flooded
    - A zonal statistic is used to calculate minimum, maximum and mean water levels on the first floor. Max was used.

Building Risk Layers

- Building risk is tied to a specific flood level.
- In real-time risk layers are displayed based on the current and forecasted flood level



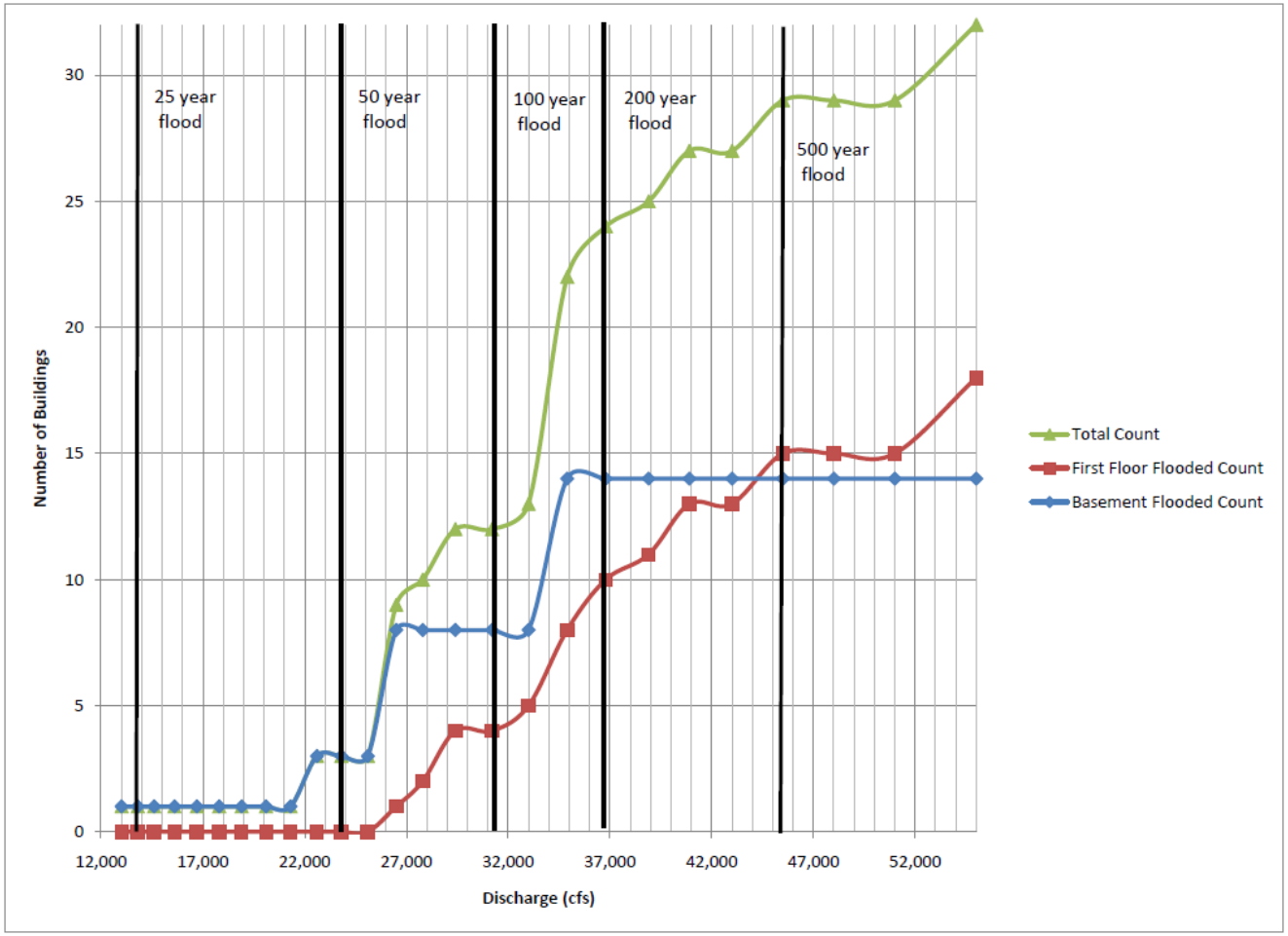


Risk Analysis Results

Two peaks

50 Year
100 Year

Related to floodplain construction regulations



Hazus-MH Depth/Damage Analysis

- The possible damage severity to each building was tracked using the average flood depth from a zonal statistics analysis in ArcGIS and then assigned a damage% from the damage curves in Hazus-MH.
- There are major differences in the damage functions and the default value does not reflect the historical depth damage relationship on the campus.

	-4 ft	-3 ft	-2 ft	-1 ft	0 ft	1 ft	2 ft	3 ft	4 ft	5 ft	6 ft	7 ft	8 ft	9 ft	10 ft
1	0.00	0.00	0.00	0.00	0.00	5.00	7.00	9.00	9.00	10.00	11.00	13.00	15.00	17.00	20.0
2	0.00	0.00	0.00	0.00	0.00	65.00	65.00	90.00	100.00	100.00	100.00	100.00	100.00	100.00	100.0
3															

Building content information

- The direct flood risk to the building is not the entire problem….
- During the summer, we interviewed representatives from each of the 30+ buildings on the watch-list
- We collected data on
  - estimated time needed for evacuation today
  - time needed for evacuation during 2008 flooding
  - details on where contents need to be moved
  - challenges encountered during 2008 flooding
  - length of time building was closed due to flooding
  - key contents that would need to be evacuated
  - details on numbers of building residents, vehicles, etc.

Diversity of vulnerable buildings

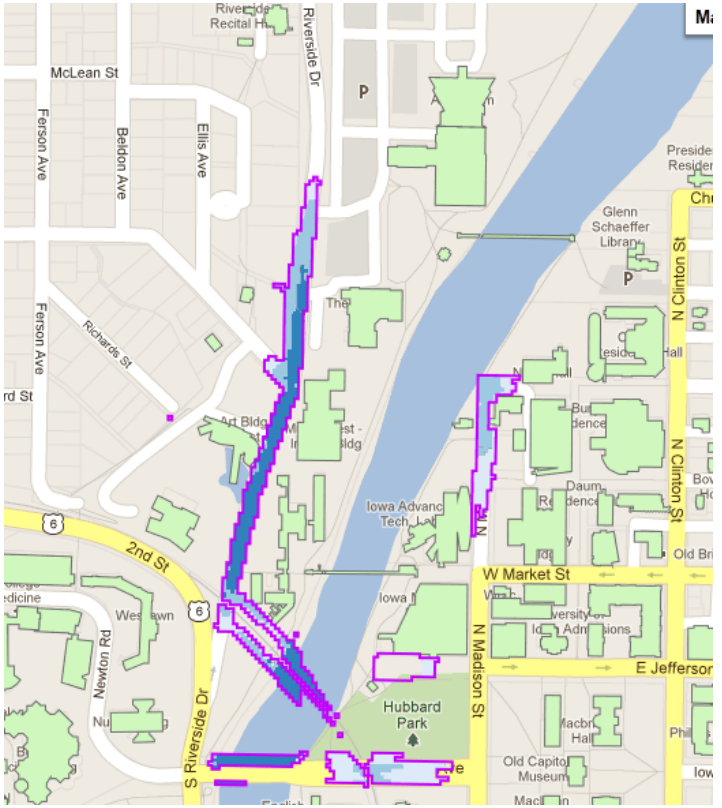
- The vulnerable buildings represent a very diverse set of needs and times for evacuation
- For example
  - The University Library
  - Mossman Business Services Building (campus mail…)
  - UIHC Patient Transportation Services
  - South Gilbert Street Building (Hawkshop, bookstore storage)
  - Lindquist Center – UITV, ITS
  - Power Plant, Water Plant, IMU…

Interview Findings

- Certain research projects can be extremely sensitive to evacuations
  - Million dollar projects cannot be moved overnight
- Residence Halls are difficult to evacuate
- If summer, key faculty or administrators who would normally lead an evacuation may be away (what do we take?)
- **Time available** for evacuation is **important**…2 days? 5 days?
- What is the maximum time available for evacuations?

Road and Bridge Closures

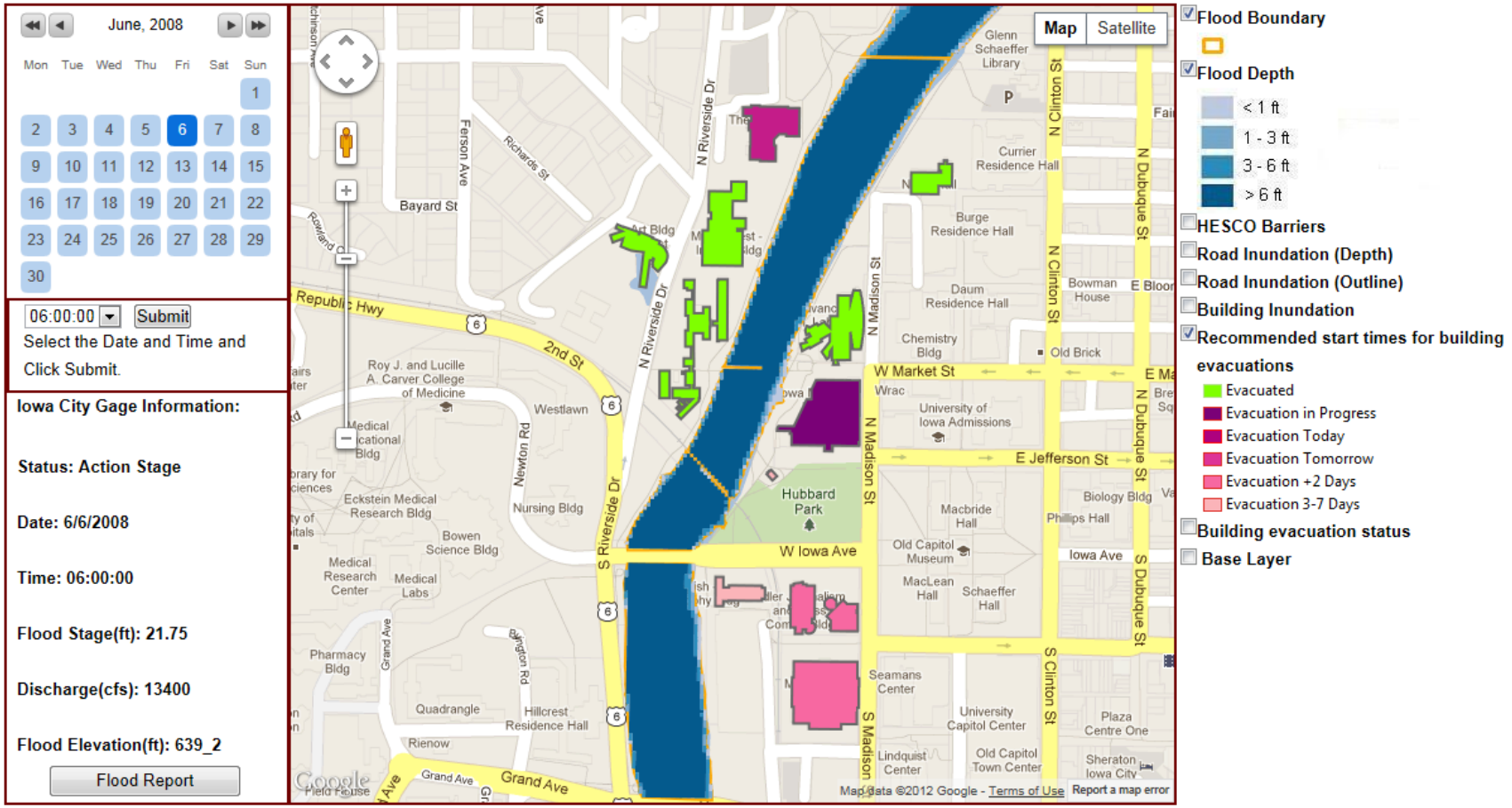
- An important variable for modeling building evacuations is road/bridge closure or access to a building.
  - Evacuations are road closure dependent
- Road and bridge closures are computed for each flood elevation
- Produces 2 additional evacuations.



Evacuation Time

- The recommended time evacuate is calculated by…
  - The time estimated to evacuate the building (determined by building interviews)
  - The expected time of arrival of flooding or the loss of building access from inundated roads or closed bridges.
  - Subtract the necessary time to evacuate the building from the expected time of arrival of flooding
  - Conservative estimate…expected time of arrival of flooding is based upon the vulnerable basement inundation time.

Evacuation Layers



Restoration Time and Priority

- An important consideration for evacuation priority is the length of time required to make the building functional again.
- Zonal statistics were used in ArcGIS to calculate the average flood depth.
- The **Hazus-MH** restoration functions were modified to estimate the time for building restoration

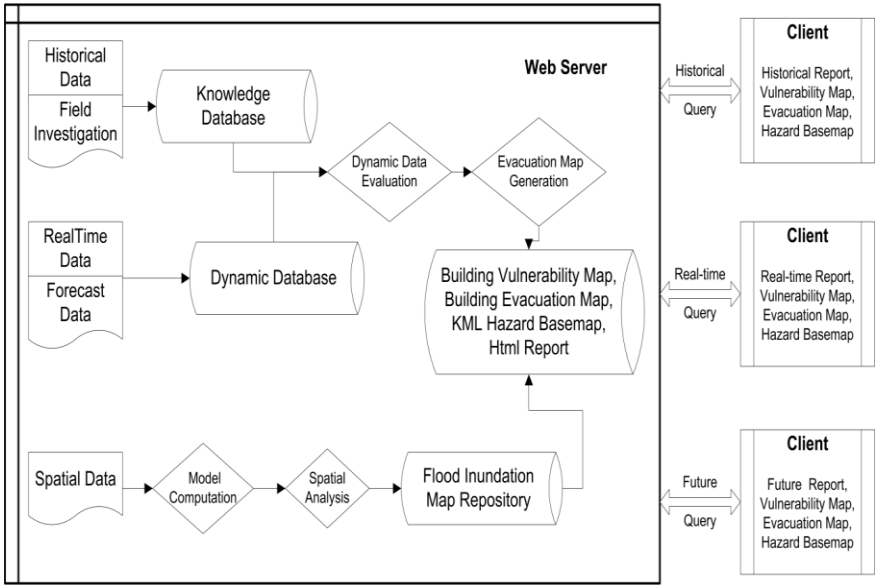
Schools

	EssntFlty	FltyDescription	Minimum	Maximum	MaxDaysToRestoration	FunctionalDepth
1	EFS1	Grade Schools (Primary and High Schools)	-4	0	360	0.50
2	EFS1	Grade Schools (Primary and High Schools)	0	4	480	0.50
3	EFS1	Grade Schools (Primary and High Schools)	4	8	630	0.50
4	EFS1	Grade Schools (Primary and High Schools)	8	12	720	0.50
5	EFS1	Grade Schools (Primary and High Schools)	12	25	900	0.50
6	EFS2	Colleges/Universities	-4	0	360	0.50
7	EFS2	Colleges/Universities	0	4	480	0.50
8	EFS2	Colleges/Universities	4	8	630	0.50
9	EFS2	Colleges/Universities	8	12	720	0.50
10	EFS2	Colleges/Universities	12	25	900	0.50
11	SDFLT	Default for School	-4	0	360	0.50
12	SDFLT	Default for School	0	4	480	0.50
13	SDFLT	Default for School	4	8	630	0.50
14	SDFLT	Default for School	8	12	720	0.50
15	SDFLT	Default for School	12	25	900	0.50

University administrators may elect to change the evacuation recommendation time based-upon the level of importance of the building vs the time to restoration

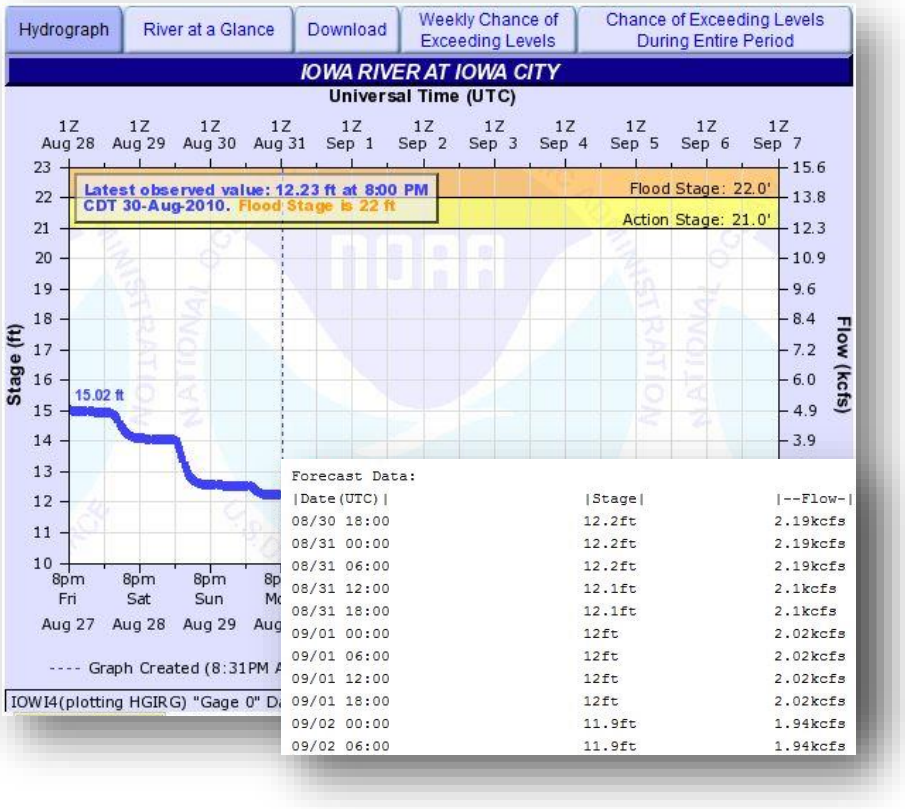
Spatiotemporal Evacuation Model

- We have developed a real-time, visual, interactive model that uses a map-based interface to allow users to **interact** and **query** the spatiotemporal characteristics of a flood event and plan for possible evacuations
- **Google Maps API** to present the model in a **web-based platform.**
- Connected to a **SQL database** for data storage.



Putting everything together

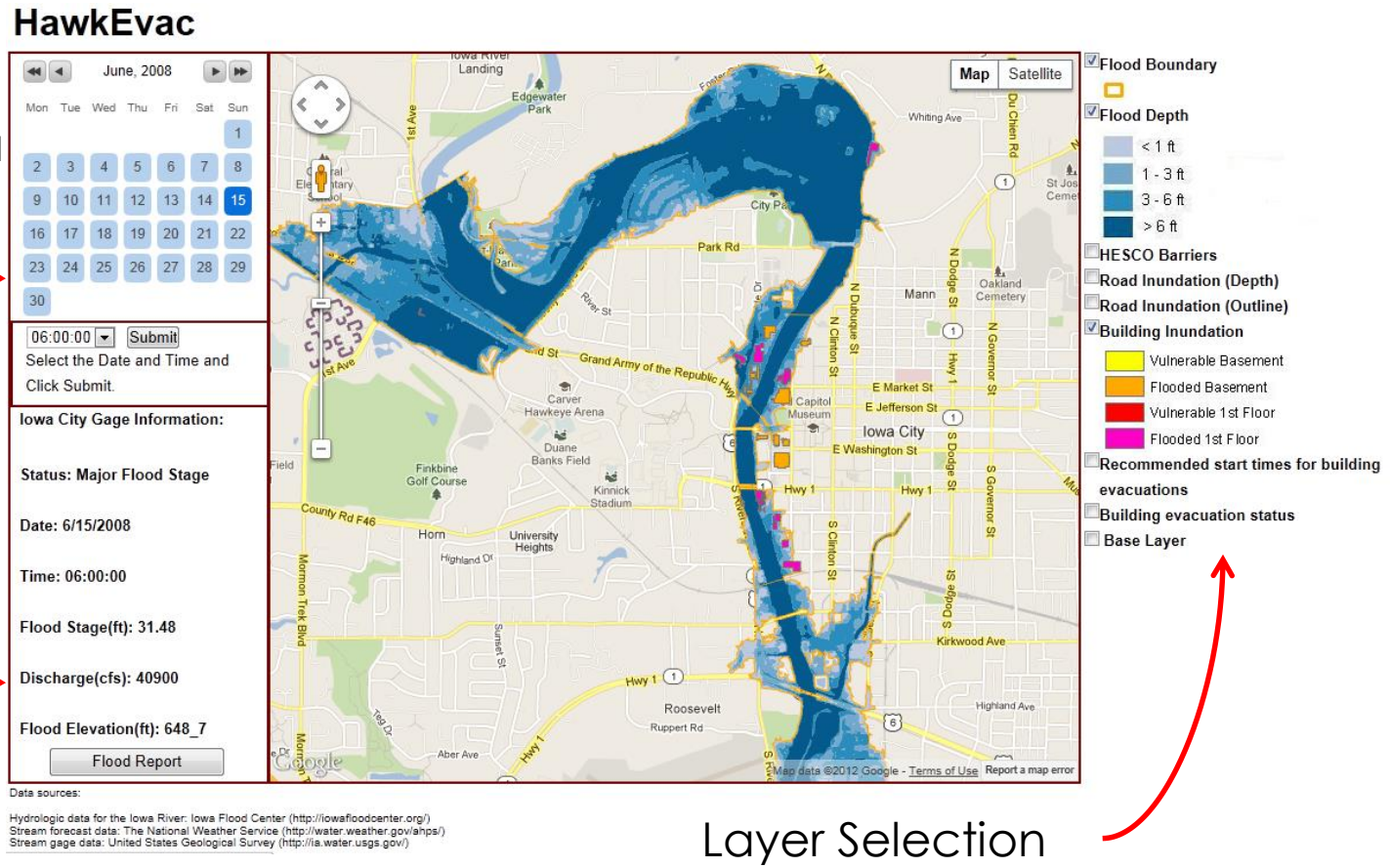
- Interactive model is based on
  - Our modeled assessments of infrastructure at risk
    - Building content information and FERP data
  - Time needed for evacuations
  - Current stream conditions and forecasts from the NWS **(or other sources)**



HawkEvac

Historical, Real-time and Forecasted data

Detailed Flood information



Layer Selection

Reporting

- Future evacuations based on time to evacuate – time of flooding
- 6 groups of evacuations
  - Evacuated
  - Evacuations in Progress
  - Evacuations Beginning Today
  - Evacuations Beginning Tomorrow
  - Evacuations Beginning in 2 days
  - Evacuations Beginning in 3 – 7 days
- Information on basements and first floors are included

University of Iowa Flood Evacuation Report

Report Date:06/06/2011

Buildings recommended for evacuation:

Building Name	HasBasement	Evacuation Date	Basement FloodRisk	1stFloor FloodRisk	Evactime (days)
Mayflower**	Y	5/30/2008 6:00:00 AM	6/6/2008 6:00:00 AM	No Risk	7
North Hall**	Y	6/4/2008 6:00:00 PM	6/9/2008 6:00:00 PM	No Risk	5
Iowa Advanced Technology Laboratories	Y	6/5/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	7
Art Building**	Y	6/5/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	7
Art Building West	Y	6/5/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	7
Music West - Interim Building	Y	6/5/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	7

Recommended evacuations beginning today:

Building Name	HasBasement	Evacuation Date	Basement FloodRisk	1stFloor FloodRisk	Evactime (days)
Iowa Memorial Union	Y	6/6/2008 6:00:00 AM	6/13/2008 6:00:00 AM	No Risk	7

Recommended evacuations beginning tomorrow:

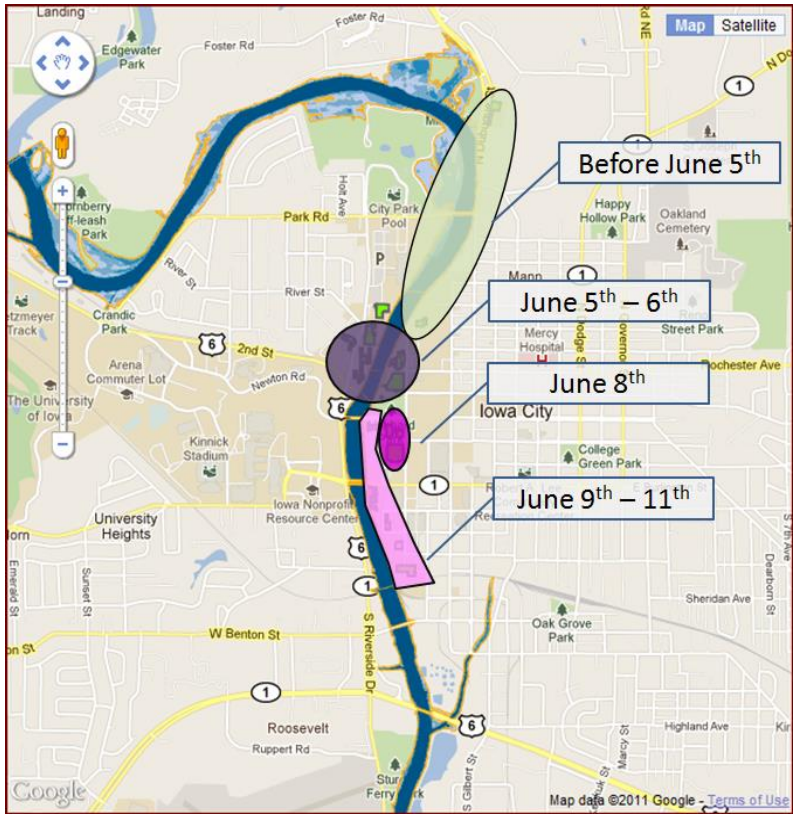
Building Name	HasBasement	Evacuation Date	Basement FloodRisk	1stFloor FloodRisk	Evactime (days)
Theatre Building**	Y	6/7/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	5
C. Maxwell Stanley Hydraulics Laboratory	Y	6/7/2008 6:00:00 AM	6/12/2008 6:00:00 AM	No Risk	5

Recommended evacuations beginning in 2 days:

Building Name	HasBasement	Evacuation Date	Basement FloodRisk	1stFloor FloodRisk	Evactime (days)
Becker Communications Studies Building**	Y	6/8/2008 6:00:00 AM	6/13/2008 6:00:00 AM	No Risk	5
Library**	Y	6/8/2008 6:00:00 AM	6/13/2008 6:00:00 AM	No Risk	5
Phillip J. Adler Journalism Building	Y	6/8/2008 6:00:00 AM	6/13/2008 6:00:00 AM	No Risk	5
Hydraulics Research East Annex**	Y	6/8/2008 6:00:00 AM	6/13/2008 6:00:00 AM	No Risk	5

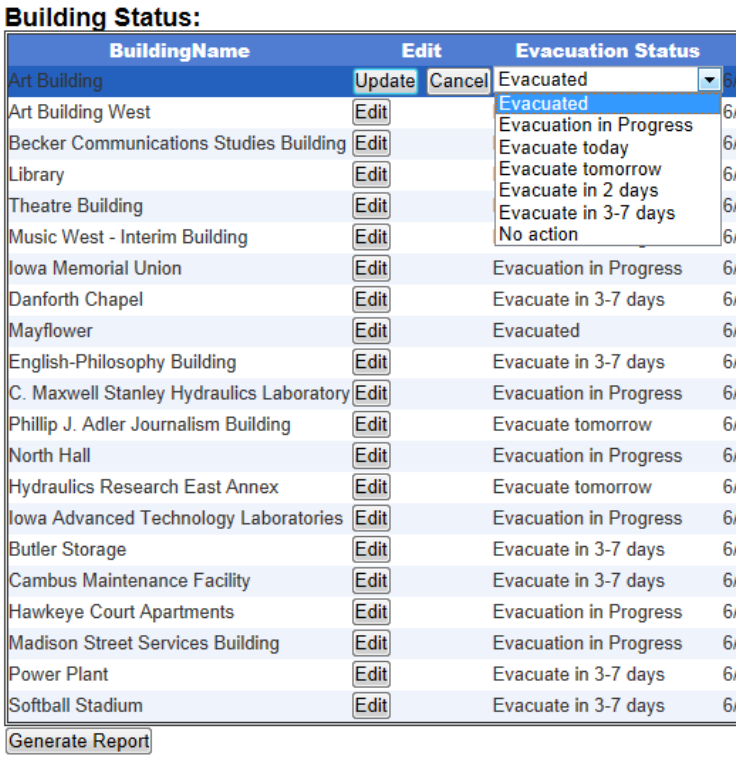
2008 Iowa City Flood Results

- There is a spatiotemporal progression of flood evacuation start times across the University of Iowa campus.
- Not related to any flood surge movement downstream.
- Essential in understanding this pattern during real-time evacuations for congestion around evacuated buildings.
- Differences for every flood.



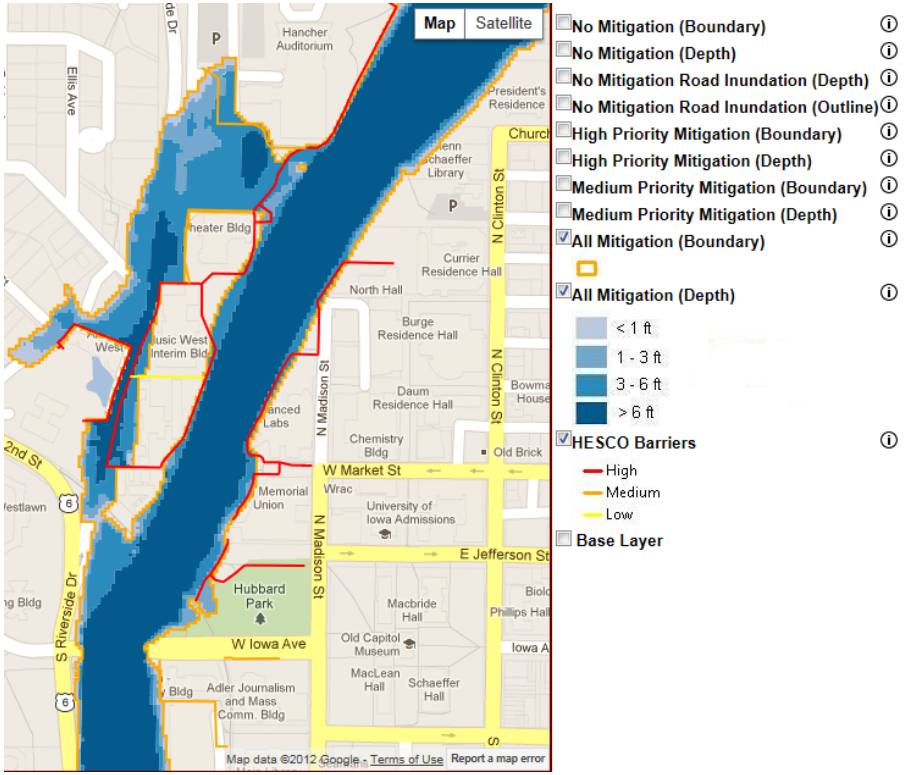
User Interaction

- Flood officials at the University requested a means for identifying what actually happens versus what we suggest should happen.
- Form was designed to provide the user with designating the current evacuation status for each vulnerable building
  - Flash flooding
  - University decision
- An additional layer is also present in the application.



Temporary Mitigation on Campus

- Future floods on campus will be mitigated with the use of HESCO barriers.
- The Iowa Flood Center used a HESCO layer to simulate the changes to the floodplain as a result of the mitigation measures.
- At this time evacuation recommendations are only calculated on the NO mitigation layers.



….And model validation

Table 1
Actual flooded campus buildings in 1993 versus predicted flooded buildings by the model.

Building	Flooded in 1993	Flooded in simulation	Calculated evacuation time (days)	Actual evacuation start date 1993	1993 Evacuation time (days)	Modeled evacuation start date
Theater building	♦	♦	5	7/6/1993	0	7/7/1993
Art building #1	♦	♦	7	7/6/1993	0	7/7/1993
Art museum	♦	♦	7	7/6/1993	0	7/7/1993
Residence hall	♦	♦	6	Before 7/1/1993	N/A	Before 7/1/1993
English building	♦	Not flooded	3	7/13/1993	2	No evacuation predicted
Power plant	♦	♦	3	Not evacuated	N/A	7/9/1993
Library	♦	Not flooded	7	Not evacuated	N/A	No evacuation predicted
Hydraulics	♦	♦	5	7/13/1993	2	7/9/1993
Liberal arts	♦	♦	5	7/12/1993	3	7/7/1993
Art building #2	Not flooded	♦	6.5	Did not exist	N/A	7/7/1993
Technologies building	Not flooded	♦	7	Not evacuated	N/A	7/7/1993

Future Work

- Extend model to capture **recovery times**
  - The depth of water predicted inside the building.
  - Important for faculty, staff, and students.
- Enhanced evacuation times based on…
  - Floor area that will be evacuated.
  - What is being evacuated.
  - Distance the contents must travel.
- Basement flooding

Thank You

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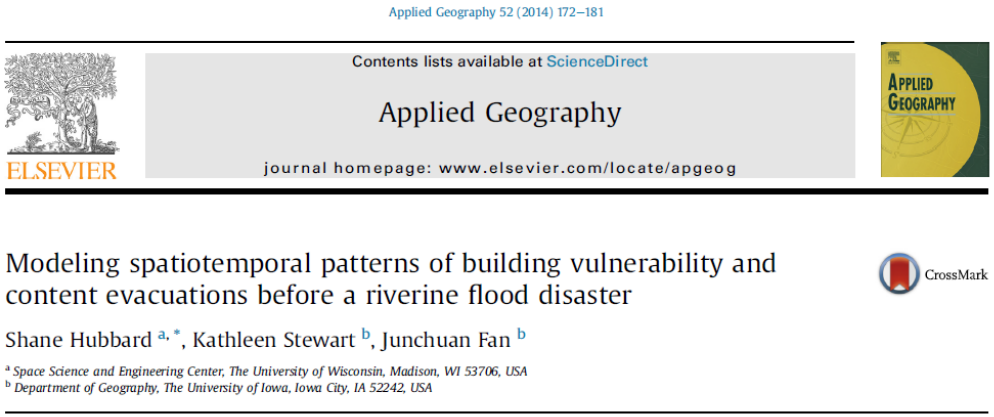

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