Improved Flood Inundation Modeling with LAR-IAC LiDAR Data and Orthoimagery

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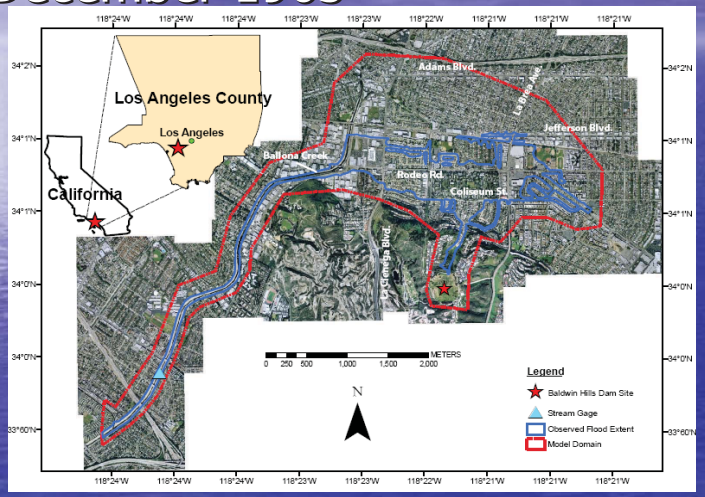
Outline

- Motivation
- Baldwin Hills Case Study
  - Terrain Modeling (LAR-IAC LiDAR)
  - Resistance Modeling (LAR-IAC Orthoimagery)
  - Results and implications relative to the value of these data and good modeling practice
- Future Directions

Motivation

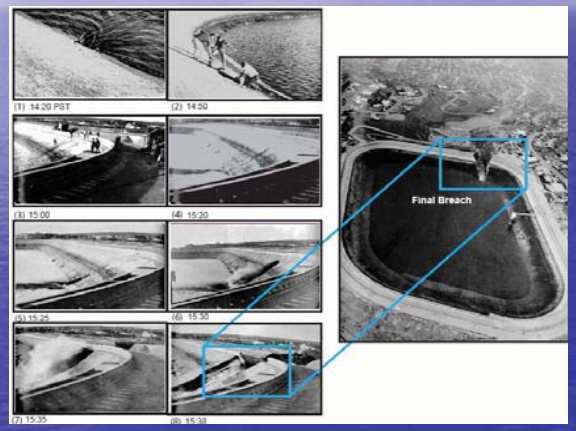
- Flood risk management requires flood simulation
  - FEMA flood zones bear on construction, insurance, etc.
  - Various return period flood predictions required for damage estimation
  - Detailed flood information (depths, velocities, timing) can support emergency management (damage zones, road closures, evacuations)
- Applications varied:
  - Dam-break
  - Riverine
  - Coastal
- Simulation capability rapidly advancing
  - Flow solvers
  - Computational Power
  - Geospatial data (LiDAR, orthoimagery)
- Sanders Team at UC Irvine: Advancing simulation science and technology
  - Better/faster simulation algorithms
  - Effective use of available data
  - Better integration within risk and emergency management frameworks

Baldwin Hills Dam Break Flood, December 1963



Gallegos, Schubert and Sanders, Adv. Wat. Res., 2009.

Failure Sequence



Baldwin Hills Study Objectives

- Assess the predictability of urban dam-break flooding
  - Flood Extent
  - Stream Flow
- Identify the necessary level of model complexity and data requirements
  - Terrain data source (LiDAR vs. NED and SRTM)
  - Uniform versus spatially distributed resistance
  - Breach geometry and breaching process
  - Reservoir condition at time of failure (height of water)
  - Impact of catch basin diversions to storm drains
  - Model resolution

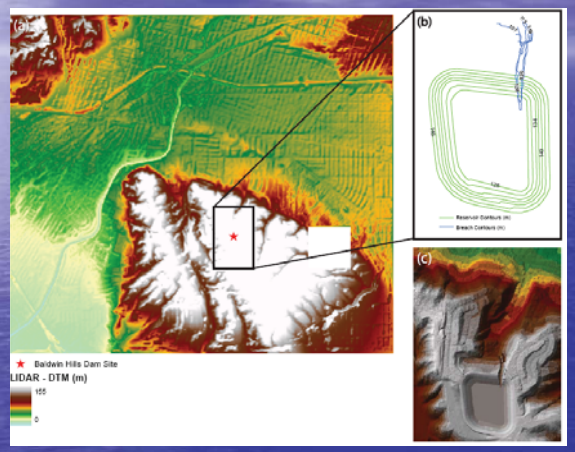
A Unique Opportunity To Examine The Predictability of Urban Dam-Break Flooding

- Flood extent data were measured and reported by USACE
- Stream flow data in Ballona Creek also reported
- Logistics of the dam failure comprehensively documented (CA DWR Report, among several)
  - Reservoir and breach geometry and breaching process
- LAR-IAC data provides topographic description as of 2006
  - LiDAR DTM merged with reservoir and breach data to describe 1963 topography
- Aerial imagery available to classify land surface for resistance parameterization
- Additional GIS datasets obtained: storm drain catch basins, parcel outlines
- Notes on emergency management:
  - Early stages of failure detected
  - Homes below dam were evacuated, and this undoubtedly saved hundreds of lives

Modeling Approach

- Overland flow described by BreZo (sanders.eng.uci.edu)
- Diversions to catch basins modeled with weir equation, flow instantaneously routed to Ballona Creek (sink/source pairs)
  - Weir equation includes a dimensionless discharge coefficient that varies between 0.1 and 0.5 based on City of LA lab study (used for calibration) $Q = C_D\, L\, h'\, (g\, h)^{1/2}$; $h' = \min(h_o, h)$
  - ***Examine sensitivity to*** C_D
- Topography based on LAR-IAC LiDAR survey
  - Contour maps of reservoir and breach configuration merged with LiDAR to re-create 1963 topography
  - ***Examine sensitivity to terrain data source and resolution***
  - ***Examine sensitivity to breach geometry***
- Resistance modeled with spatially distributed Manning *n* based on landcover classification
  - Classification: asphalt, concrete, vegetated surface, developed parcels with buildings
  - ***Examine sensitivity to resistance distribution***

Terrain Modeling



1963:

Breach and Reservoir Contours

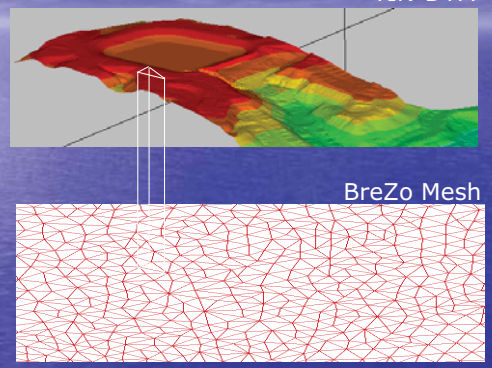
1963:

TIN-DTM

2006:

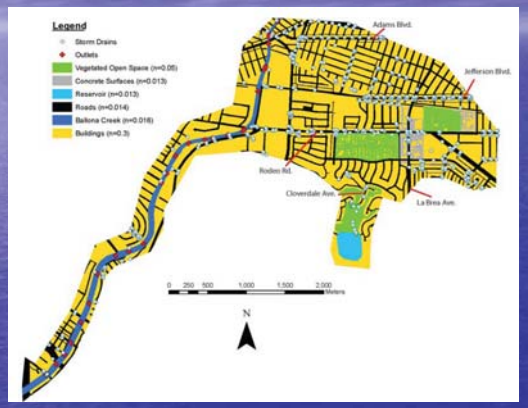
1.5 m LiDAR DTM

DTM → Computational Mesh



We consider a computational mesh resolution of 2.5, 4.9 and 9.6 m (square root of average cell area). This corresponds to a minimum of 7, 3, and 1 cell across each street.

Landcover and Catch Basin Distribution



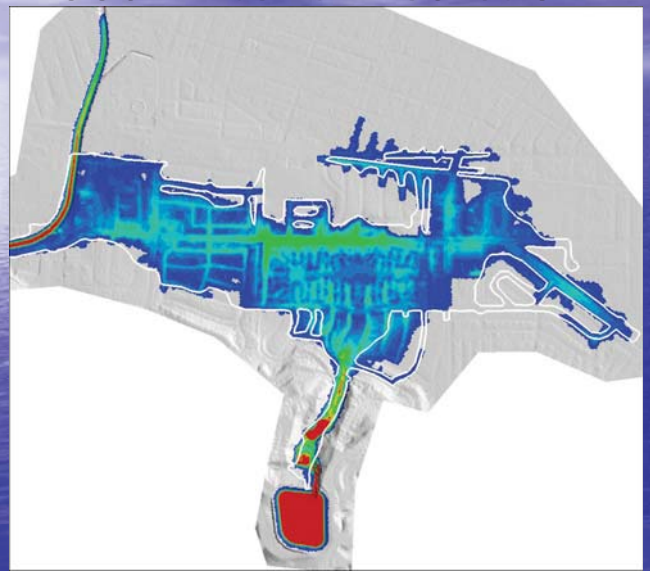
Distributed and uniform n (0.2) considered.

Weir discharge coefficient C_D expected between 0.1 and 0.5. (only calibration parameter)

Breaching Process and Initial Conditions

- Flooding initiated at 15:20 based on photographs and volume records
- Breach modeled in two stages
  - Stage 1: 15:20-15:30
    - Trapezoidal shape (70 ft at crest, 25 ft at bottom)
  - Stage 2: 15:30-
    - Breach topography surveyed after failure
- Water level prediction at 15:30 consistent with photograph at 15:30
- Flow simulated from 15:20-18:30

Flood Extent Prediction

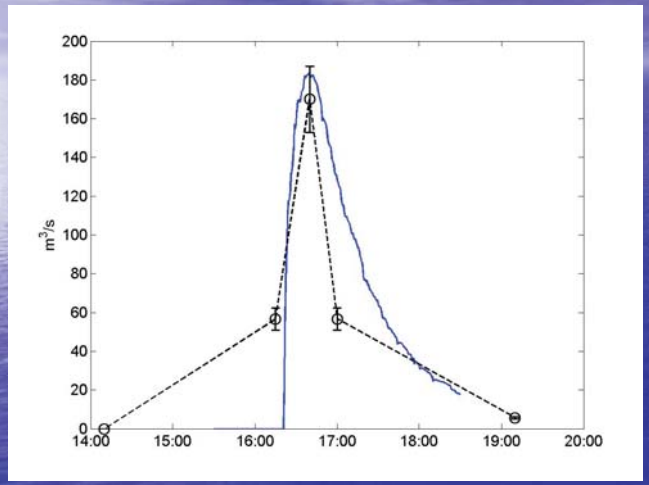


2.5 m mesh resolution

Distributed *n*

C_D=0.5

Stream Flow Prediction



10% uncertainty in stream flow observations assumed

Performance Metrics

$$F_E = \frac{E_P \cap E_M}{E_P \cup E_M}$$

F_E=Flood Extent Fit Measure
E_P=Predicted Flooded Area
E_M=Observed Flooded Area

$$F_Q = \frac{Q_P}{Q_M}$$

F_Q=Peak Discharge Fit Measure
Q_P=Predicted Peak Discharge
Q_M=Observed Peak Discharge
(170 m^3/s = 6000 ft^3/s)

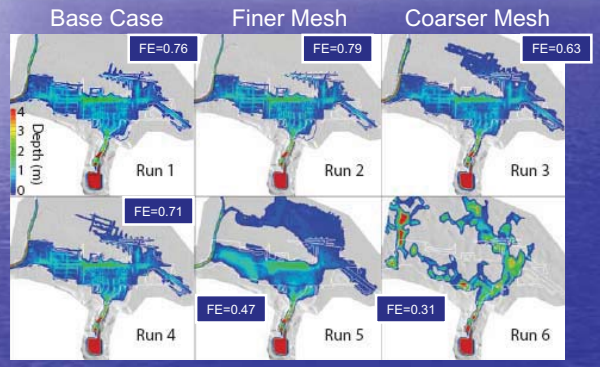
$$F_T = \frac{T_P}{T_M}$$

F_T=Travel Time (Peak) Fit Measure
T_P=Predicted Travel Time
T_M=Observed Travel Time
(Peak at 16:40 PST)

Results

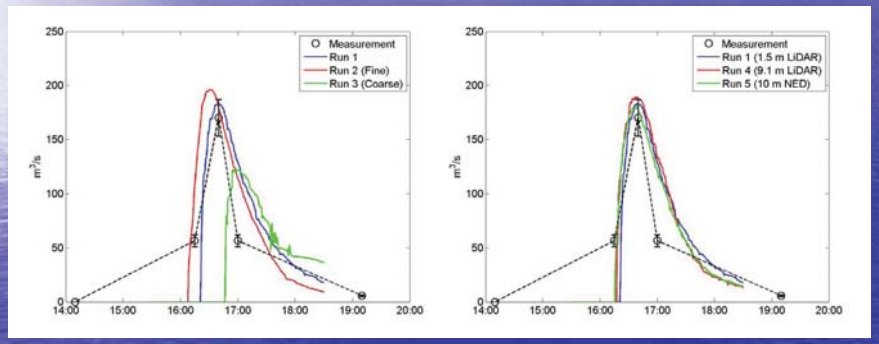
Run	Mesh	Manning n	DTM	Comment	F_E	F_Q	F_T
1	4.9 m	Distributed	1.5 m LiDAR	Base Case	0.76	1.08	1.06
2	2.5 m	Distributed	1.5 m LiDAR	Finer Mesh	0.79	1.15	0.94
3	9.6 m	Distributed	1.5 m LiDAR	Coarser Mesh	0.63	0.72	1.33
4	4.9 m	Distributed	9.1 m LiDAR	Coarsened DTM	0.71	1.11	1.02
5	4.9 m	Distributed	10 m NED	National DEM for USA	0.47	1.07	1.05
6	4.9 m	Distributed	30 m SRTM	Global DEM	0.31	NA	NA
7	4.9 m	Uniform	1.5 m LiDAR	Uniform n	0.73	0.59	1.86
8	4.9 m	Distributed	1.5 m LiDAR	Less flow to catch basins	0.69	0.98	1.09
9	4.9 m	Distributed	1.5 m LiDAR	Higher reservoir level	0.68	1.37	0.95
10	4.9 m	Distributed	1.5 m LiDAR	Breach width = dam height	0.73	1.05	0.80
11	4.9 m	Distributed	1.5 m LiDAR	Breach width = 2 x dam height	0.68	1.14	0.84
12	4.9 m	Distributed	1.5 m LiDAR	Breach width = 3 x dam height	0.65	1.16	0.82

Flood Extent Predictions



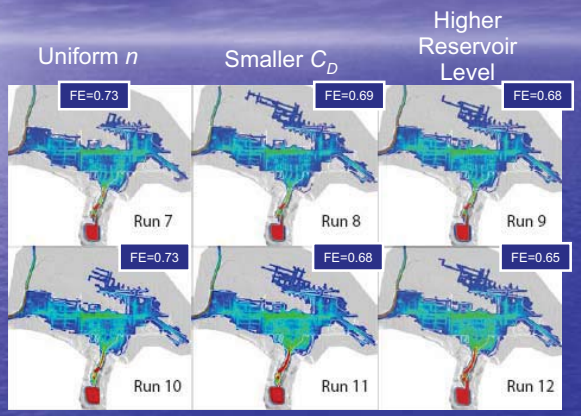
9.1 m LiDAR 10 m NED 30 m SRTM

Stream Flow Predictions



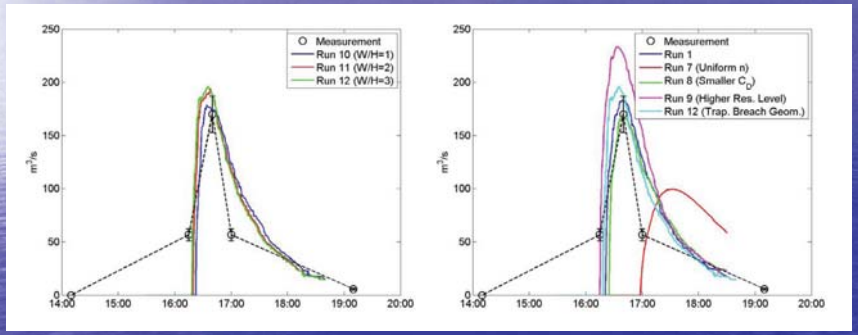
Mesh Resolution Sensitivity Terrain Source Sensitivity

Flood Extent Predictions



Increasing Breach Width →

Stream Flow Predictions



Breach Width Sensitivity

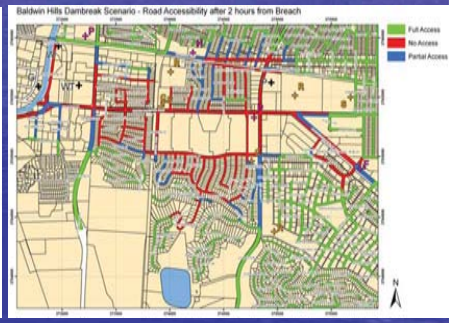
Key Findings of Baldwin Study

- Street flows are important
  - Terrain data should capture depressions in land surface
    - ***LiDAR data improves flood prediction accuracy compared to NED***
  - Minimum of three computational cells across each street required for accuracy
    - Coarser grids over-predict flood extent and under-predict stream flow
- Spatially distributed resistance parameters recommended
    - Most important for stream flow prediction
    - Use available data for landcover classification
    - Should not calibrate based on flood extent data
- Catch basin diversions are important and should be modeled.
  - Weir equation for catch basin inflow performed well here.
- Complexity of model appears justified, i.e., no obvious way to simplify without sacrificing performance.
  - Comparable uncertainty due to breach geometry, water levels, terrain data accuracy, and catch basin diversions
- Reservoir level and dam condition should be monitored to support dam-break flood forecasting
  - NASA SWOT Mission might contribute, but revisit time probably too long
  - Better to install and network local sensors

Next Steps…flood impacts

Predicting Building Damage

Predicting Road Conditions



Acknowledgments

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