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MINISTRY OF JAL SHAKTI
DEPARTMENT OF WATER RESOURCES,
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2024, NEW DELHI

विद्युत मंत्रालय
MINISTRY OF
POWER

92ND ANNUAL MEETING & INTERNATIONAL SYMPOSIUM

ON DAMS FOR PEOPLE, WATER, ENVIRONMENT AND DEVELOPMENT

29TH SEP - 03RD OCT 2024 | NEW DELHI, INDIA

Simple and Accurate Assessment of Danger Posed by Large Storm Events and Downstream Impacts Below Dams

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Rapid and Simplified Flood Hazard Analysis

The Problem

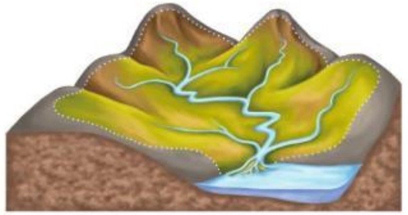
- Emergency Action Plans (EAPs) for critical infrastructure often rely on evolving (current) flood conditions and current signs of failure/distress
    - **Accurate Prediction and Modeling Available**
- Maps of hazards are often "worst-case," such as a levee failing during the peak of a 100-year event or a high hazard dam failing during PMP/PMF at peak water surface elevation.
- Static maps may severely overestimate the evacuation areas, straining available emergency resources and unnecessarily putting lives at risk (elderly, those with serious medical conditions, infants)
- Flood hazard analysis tied to mitigation measures, advanced warning is needed to deploy flood protection technologies. The more complex the solution, the more time needed
- Previously, evaluating predicted storms for single sites was expensive, time consuming and data intensive.

Rapid and Simplified Flood Hazard Analysis

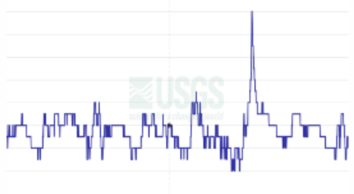
A Solution: Start with Data

There are three important pieces of data you need in hydrologic and hydraulic models (e.g. HEC-RAS), to anticipate the potential for flooding and the need for mitigation…

1. Predicted/Observed **rainfall** in gridded format

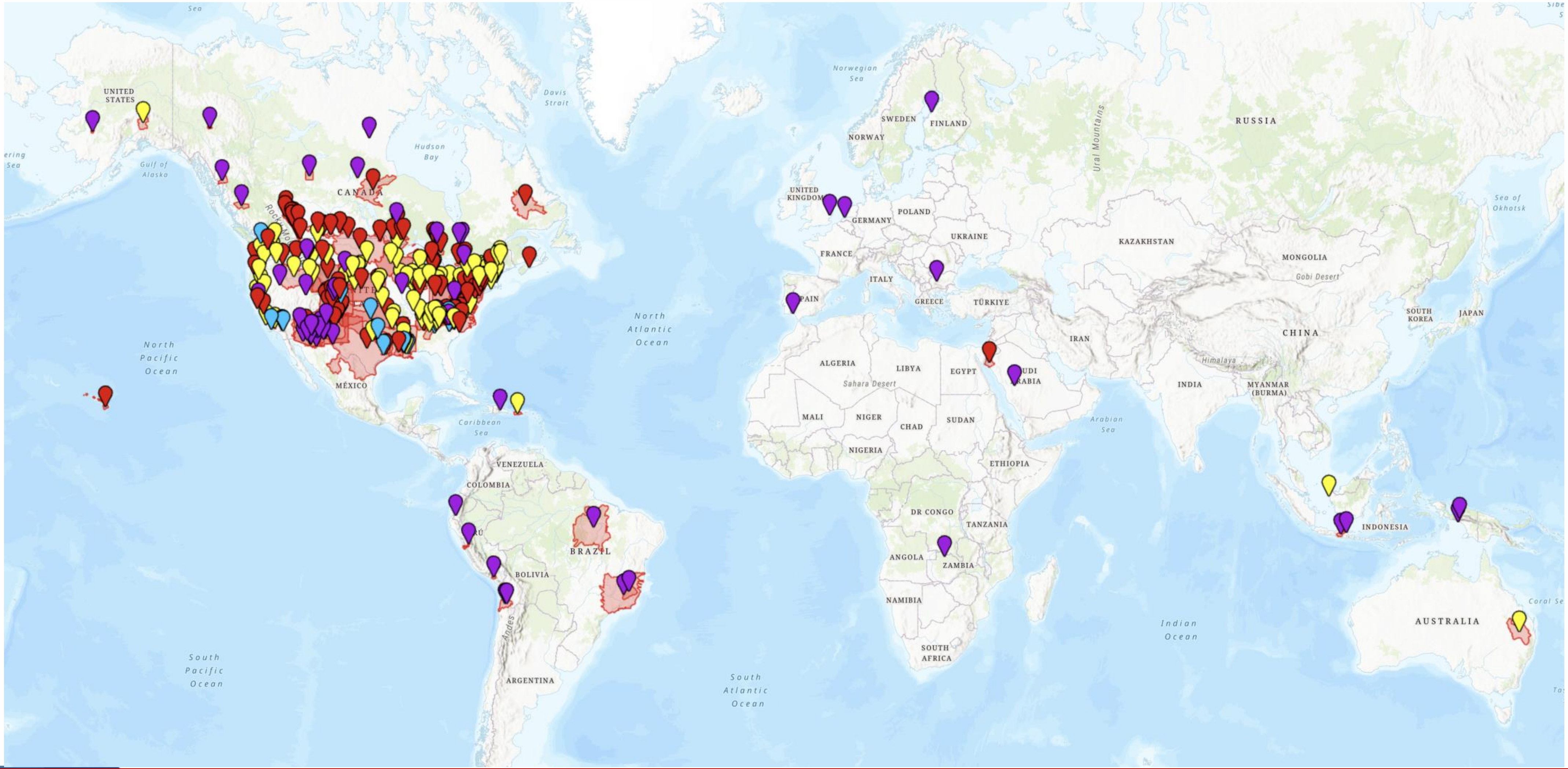


2. Watershed **characteristics**
   1. Topography
   2. Land cover
   3. Local hydraulics (dams, bridges, culverts, diversions)
   4. Soils



3. Calibration / validation **events**

PMP/Climate Change Over The Last 20 Years



Rainfall Inputs

Modern models can use (and should use) gridded precipitation data. Both HEC-HMS and HEC-RAS have made importing precipitation data quick.

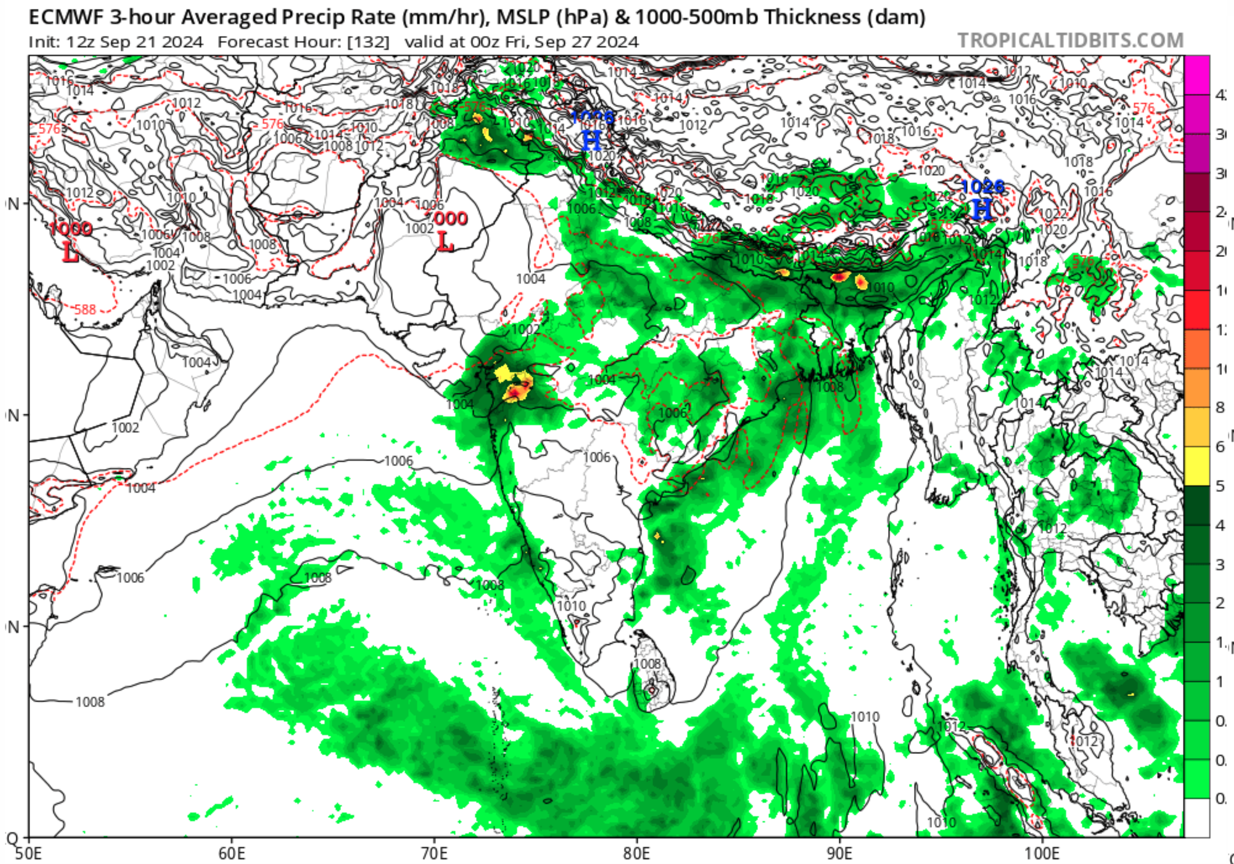
1. Smaller (<10 mi^2 or 26 km^2) watersheds can just use point data
2. Preferred grid formats include HEC-DSS and GDAL raster files (single or multiple) in the NetCDF or the GRIB file formats.

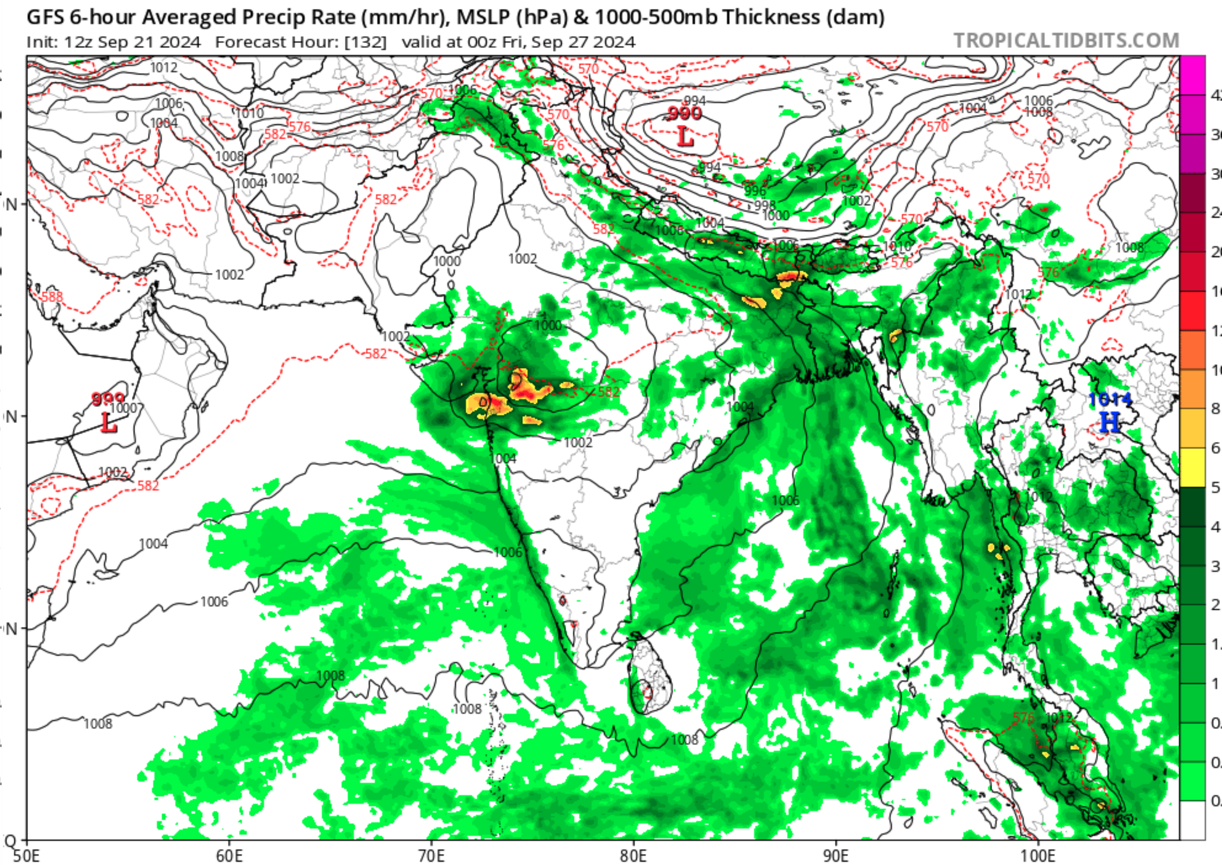
Rainfall Data Sources

- Availability and quality of rainfall data continues to improve
  - Varies depending on location
  - Work with what you have
  - Observational
  - Satellite/remote
  - Model reanalysis

Model Data

- **The Data: Example of ECMWF and GFS**





Model Data

Sources of numerical weather prediction data in gridded format- examples…

Name	Source	Recommended Date Range	Grid Cell Size
ECMWF-Global Coverage	https://www.ecmwf.int/en/forecasts/documentation-and-support/changes-ecmwf-model	>5 Days in Advance-6 hour increments	9 km
NOAA Global Forecast System (GFS)	https://www.ncei.noaa.gov/products/weather-climate-models/global-forecast	>5 Days in Advance-6 hour increments	50 km
NOAA North American Mesoscale (NAM)	https://www.ncei.noaa.gov/products/weather-climate-models/north-american-mesoscale	3-5 Days in Advance-hourly and 3-hour increments	12 km
NOAA The High-Resolution Rapid Refresh (HRRR)	https://rapidrefresh.noaa.gov/hrrr/	0-2 Days in Advance-hourly increments	3 km

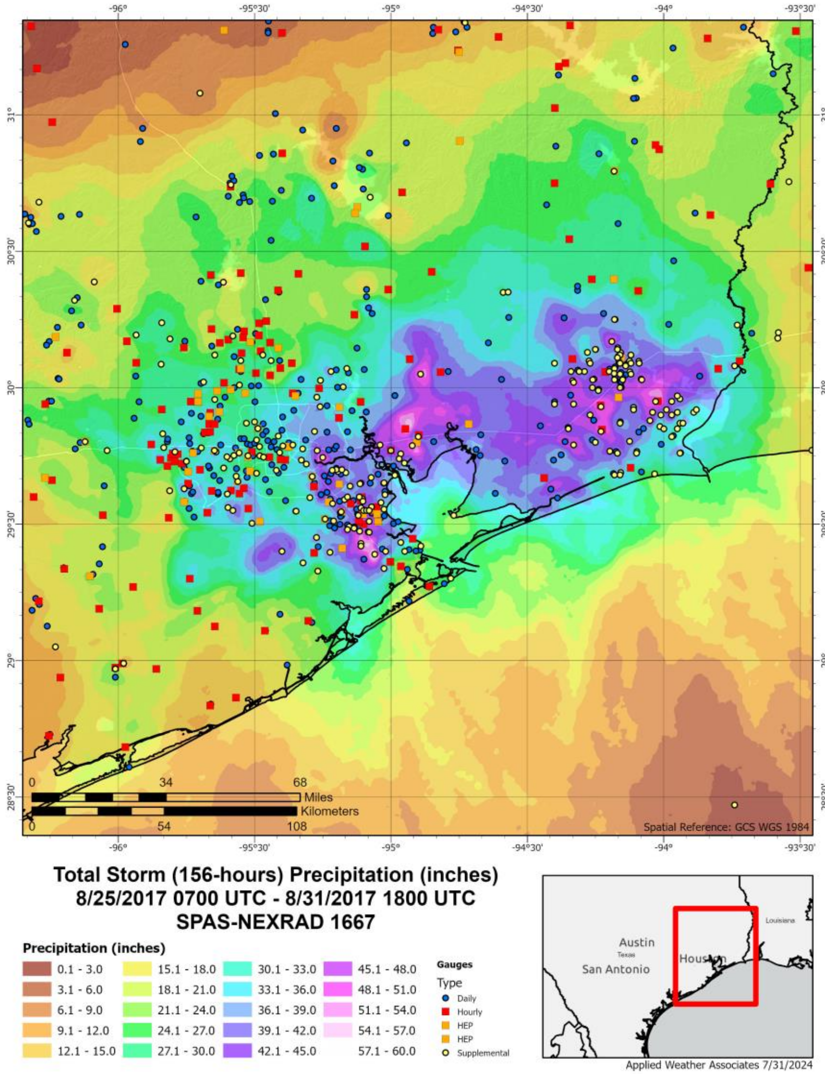
Rainfall Analysis To Develop Inputs

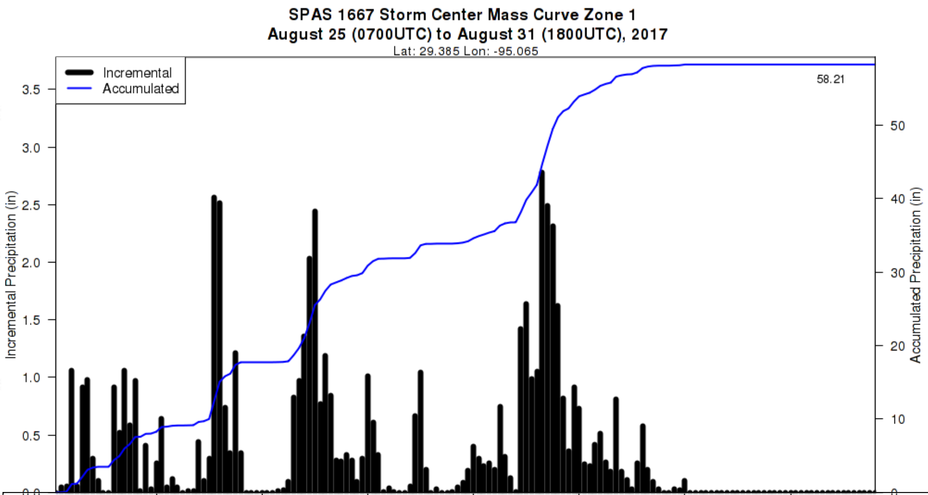
- SPAS quantifies rainfall for any return frequency for any size and duration
- Gridded output allows for "point and click" determination
- 10-year, 100-year, 500-year, PMP etc.
- In use for over 20-years and provides hourly and sub hourly gridded rainfall

We can model these hypothetical events **ahead of time** and, using ***ML***, select the modeled event that is closest to the predicted.

Once the storm gets closer, **the actual storm is modeled.**

SPAS Analysis Example Outputs





Storm 1667 - August 25 (0700 UTC) - August 31 (1800 UTC), 2017
MAXIMUM AVERAGE DEPTH OF PRECIPITATION (INCHES)

Area (mi²)	Duration (hours)														
	1	2	3	4	5	6	12	18	24	36	48	72	96	120	156	Total
0.4	5.80	11.47	14.55	16.93	18.70	19.92	22.54	26.18	30.19	34.51	41.59	48.99	54.33	58.21	58.21	58.21
1	5.64	11.18	14.37	16.80	18.51	19.75	22.36	25.97	29.97	34.27	41.19	48.56	53.85	57.35	57.35	57.35
10	5.27	10.04	13.25	16.32	18.07	18.68	21.76	25.45	29.19	33.53	39.39	47.03	52.22	54.76	54.77	54.77
25	5.07	9.37	12.47	15.59	17.60	18.27	21.01	24.64	28.62	32.15	37.19	45.58	50.81	53.31	53.44	53.44
50	4.90	8.84	11.86	14.88	17.06	17.80	20.38	24.03	28.21	30.78	35.85	44.39	49.47	51.93	52.24	52.24
100	4.64	8.25	11.20	14.08	16.39	17.14	19.61	23.39	27.42	29.49	34.96	43.22	48.10	50.33	50.97	50.97
150	4.45	7.92	10.74	13.50	15.79	16.57	18.99	22.88	26.84	28.74	34.35	42.55	47.23	49.39	50.08	50.08
200	4.28	7.68	10.36	13.03	15.26	16.10	18.48	22.47	26.28	28.21	33.70	41.96	46.59	48.71	49.46	49.46
300	4.03	7.24	9.80	12.33	14.45	15.32	17.71	21.75	25.41	27.45	32.75	41.12	45.68	47.71	48.52	48.52
400	3.81	6.95	9.34	11.77	13.78	14.64	17.15	21.12	24.64	26.90	32.04	40.53	44.93	46.99	47.80	47.80
500	3.63	6.62	8.94	11.26	13.10	14.03	16.71	20.49	23.90	26.48	31.50	40.04	44.36	46.43	47.25	47.25
1,000	2.97	5.42	7.19	9.00	10.58	11.60	15.14	18.60	21.27	25.03	29.73	38.08	42.39	44.64	45.40	45.40
2,000	2.23	3.89	5.65	7.03	8.27	9.24	13.11	16.34	18.63	22.90	27.60	35.61	39.97	42.48	43.25	43.25
3,500	1.78	3.14	4.57	5.68	6.71	7.56	11.29	14.27	16.83	20.98	25.67	32.95	37.55	39.97	40.96	40.96
5,000	1.52	2.71	3.89	4.95	5.83	6.63	10.13	12.99	15.64	19.59	24.33	30.90	35.34	37.96	38.77	38.77
7,500	1.25	2.25	3.23	4.13	4.92	5.63	8.95	11.59	14.22	18.18	22.68	28.34	32.63	35.26	36.14	36.14
10,000	1.09	1.98	2.84	3.63	4.36	4.96	8.11	10.55	13.09	17.08	21.31	26.51	30.51	32.93	33.83	33.83
15,000	0.86	1.64	2.32	3.01	3.58	4.15	6.91	9.11	11.40	15.27	19.12	23.67	27.39	29.87	30.65	30.65
20,000	0.71	1.33	1.93	2.52	3.01	3.53	6.01	8.06	10.20	13.81	17.41	21.71	25.15	27.36	28.20	28.20
35,000	0.51	0.88	1.30	1.71	2.10	2.44	4.44	6.11	7.70	10.71	13.62	17.47	20.37	22.51	23.46	23.46
50,000	0.38	0.67	0.97	1.33	1.66	1.94	3.45	4.94	6.24	8.80	11.23	14.54	17.09	19.25	20.42	20.42
75,000	0.27	0.50	0.71	1.00	1.22	1.41	2.59	3.63	4.59	6.63	8.56	11.59	13.74	15.47	16.50	16.50
100,000	0.22	0.38	0.57	0.77	0.95	1.13	2.12	2.92	3.69	5.30	6.84	9.30	11.01	12.42	13.44	13.44
120,162	0.19	0.33	0.49	0.64	0.82	0.98	1.83	2.54	3.20	4.59	5.93	8.04	9.55	10.76	11.64	11.64

Watershed Characteristics-Many Good Sources

Name	Source	Type	Accuracy
Multi-Resolution Land Characteristics (MRLC) consortium	https://www.mrlc.gov/viewer/	Land Use / Land Cover	Low
2D Manning's Roughness Coefficients	Various (see slide)	Look-Up Table for Above	Needs Calibration
LiDAR	HEC-RAS > RAS Mapper > Terrain > Download Terrain Data > USGS	Topography	Varies (1/9 arc available, 3m)
LiDAR (Backup): National Map Download	USGS https://apps.nationalmap.gov/downloader	Topography	Varies (1/3 arc common, 10m)
Gridded Soil Survey Geographic (gSSURGO) Database	USDA-NRCS: https://www.nrcs.usda.gov/resources/data-and-reports/gridded-soil-survey-geographic-gssurgo-database	Soil	Varies

Watershed Characteristics-Many Good Sources

Name	Source	Type	Accuracy
National Inventory of Dams	USACE: https://nid.sec.usace.army.mil/#/	Dams	Varies by State
National Bridge Inventory	FHA: https://geodata.bts.gov/datasets/usdot::national-bridge-inventory/explore	Bridges	High
National Levee Database	USACE: https://levees.sec.usace.army.mil/data-services/services/	Levees	High

Land Use/Land Cover/Manning's Roughness

Suggested Manning's n and Percent Impervious for NLCD Land Cover

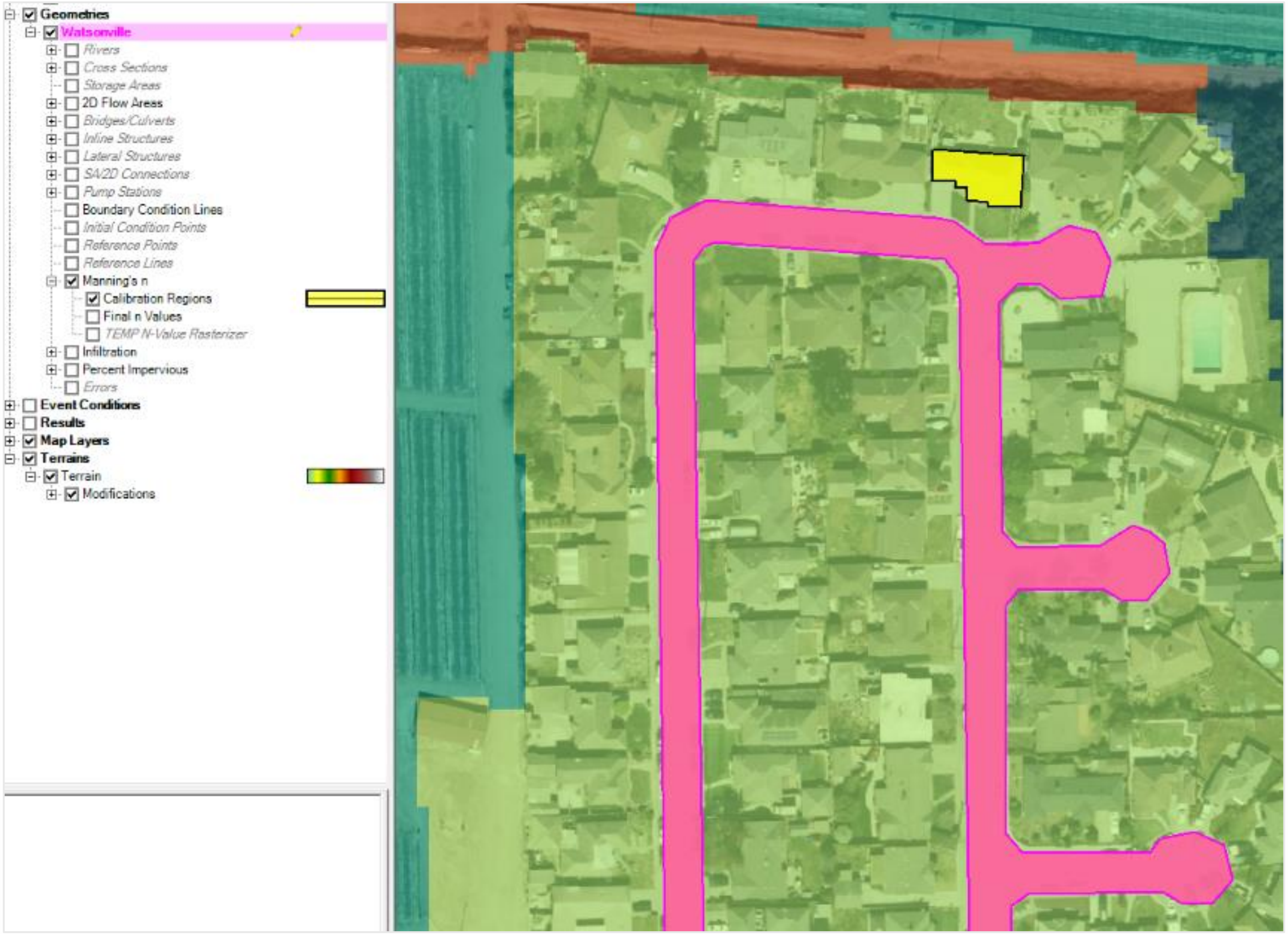
NLCD Value	NLCD Land Cover Type	Range of n (HEC-RAS 2D Manual)	Suggested Initial n	n (NRCS)	Percent Impervious
11	Open Water	0.025 - 0.05	0.035	0.04	100
12	Perennial Ice/Snow	N/A	N/A	N/A	N/A
21	Developed, Open Space	0.03 - 0.05	0.035	0.04	10
22	Developed, Low Intensity	0.06 - 0.12	0.08	0.1	35
23	Developed, Medium Intensity	0.08 - 0.16	0.12	0.08	65
24	Developed, High Intensity	0.12 - 0.20	0.15	0.15	90
31	Barren Land (Rock/Sand/Clay)	0.023 - 0.030	0.03	0.025	0
41	Deciduous Forest	0.10 - 0.20	0.1	0.16	0
42	Evergreen Forest	0.08 - 0.16	0.15	0.16	0
43	Mixed Forest	0.08 - 0.20	0.12	0.16	0
51	Dwarf Scrub*	0.025 - 0.05	N/A	N/A	0
52	Shrub/Scrub	0.07 - 0.16	0.08	0.1	0
71	Grassland/Herbaceous	0.025 - 0.05	0.04	0.035	0
72	Sedge/Herbaceous*	0.025 - 0.05	0.04	N/A	0
73	Lichens*	N/A	N/A	N/A	N/A
74	Moss*	N/A	N/A	N/A	N/A
81	Pasture/Hay	0.025 - 0.05	0.045	0.03	0
82	Cultivated Crops	0.020 - 0.05	0.05	0.035	0
90	Woody Wetlands	0.045 - 0.15	0.08	0.12	50
95	Emergent Herbaceous Wetlands	0.05 - 0.085	0.06	0.07	75

* Alaska only

Land Use/Land Cover/Manning's Roughness

- If essential, you can override land uses / roughness coefficients by hand in RAS Mapper.
- Where might this be essential?
  - Where velocities matter or where depth can be greatly impacted by the roughness of the land
  - Do a sensitivity check on one location!

Land Use/Land Cover/Manning's Roughness



Imagery Resolution-Does It Matter?

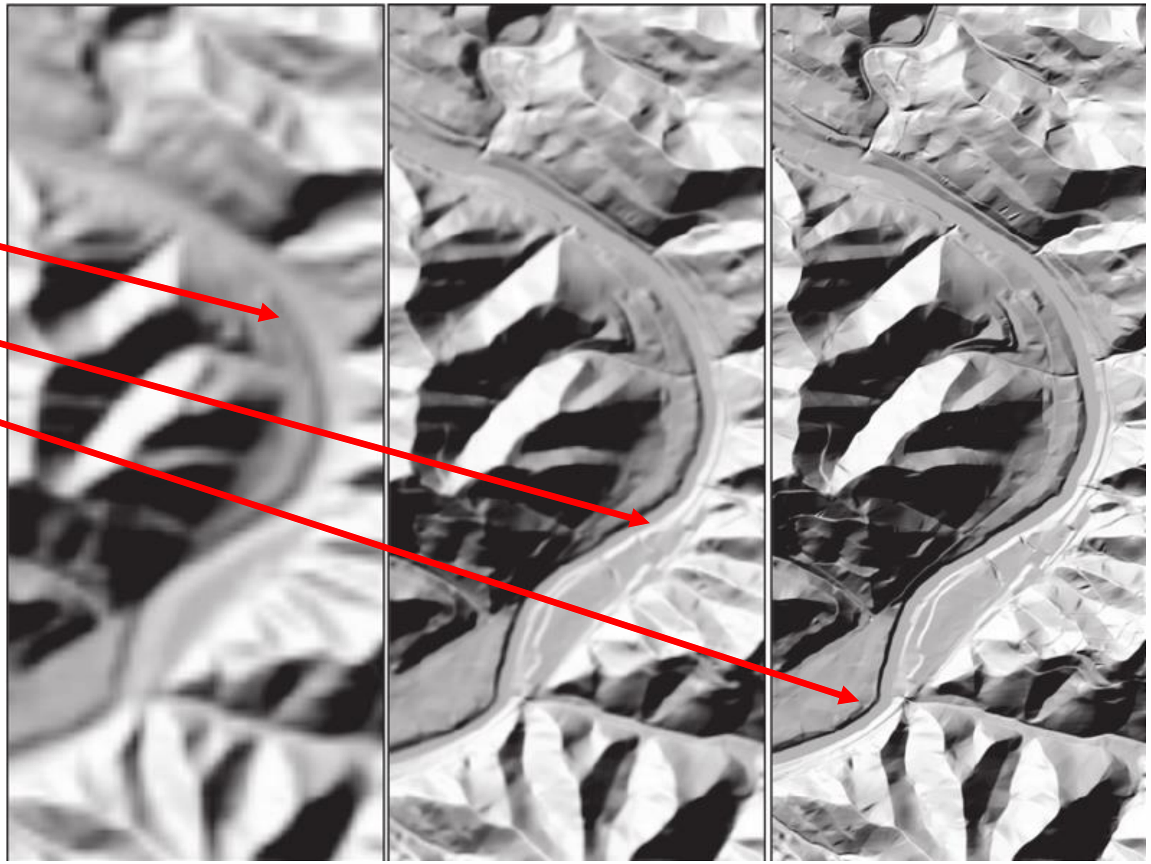
LiDAR Quality Comparison

1. 1 arc-second
2. 1/3 arc-second
3. 1/9 arc-second

Does the quality difference impact results?

Are the rivers and floodplains defined?

Are corrections needed?



HEC-RAS Model Used For Quick Results

1. Easy (sometimes!) to import gridded predicted rainfall data (low to high-resolution) or single point (station) data
2. Per the listed data sources, the watershed's hydrologic parameters can be entered directly into the model (no longer need a second model)
3. Calibration and validation events (if time allows) can be entered into the same model from quality-controlled sources (NWS and USGS)
4. Structures can be easily entered into the 2-D mesh
   a. Bridges
   b. Dams
   c. Levees
5. The outcome is inundation mapping on multiple basemaps

HEC-RAS Model Used For Quick Results

1. The run-time of the model is largely dependent on the "time-step" which is partially dictated by the quality of the LiDAR (grid size) and number of structures.
2. The outcomes of the model may or may not be impacted by including refinements
3. Example: 22 square mile watershed in California

$$\Delta T \leq \frac{\Delta X}{V} \ (with\ C = 1.0)$$

C=Courant Number
V= Flood wave velocity (wave celerity) (ft/s)
ΔT=Computational time step (s)
ΔX= Average cell size (ft)

Mesh Size	Time Step	Run Time	Outcome
20 foot x 20 foot	1 second	2h 17m	2.1 ft/s at elevation 71.8 ft
20 foot x 20 foot	10 seconds	32m	25 ft/s at elevation 71.7 ft
100 foot x 100 foot	10 seconds	26m	2.1 ft/s at elevation 71.4 ft

Example: Lago La Plata, Puerto Rico

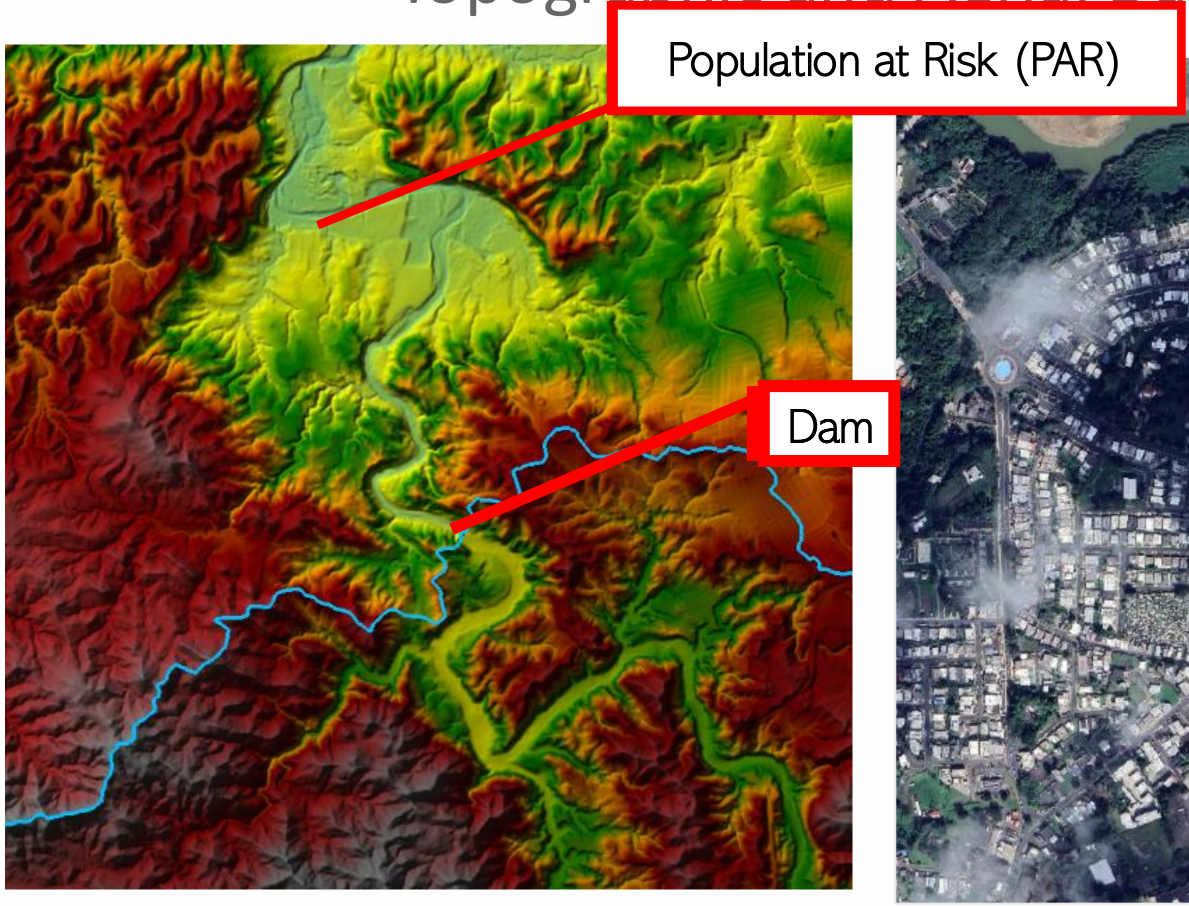
- Created in 1973 and serves as a potable water supply operated by the Puerto Rico Aqueduct and Sewer Authority (PRASA) and is part of the San Juan Metropolitan Water District (serves 425,000)
- Concrete dam is 40 meters (131 feet) tall with a 218 meter (714 feet) spillway.
- Surface area of 2.3 square kilometers (560 acres) and a drainage area of 469 square kilometers (181 square miles)
- Added **high-resolution** terrain (topographic data) in the HEC-RAS model from multiple quality-controlled sources, worldwide.
- Added **high-resolution** bathymetric data for the reservoir (USGS, 2015)
- Added available soils, land cover, bridge, dam and building data in HEC-RAS from U.S. and international data sources

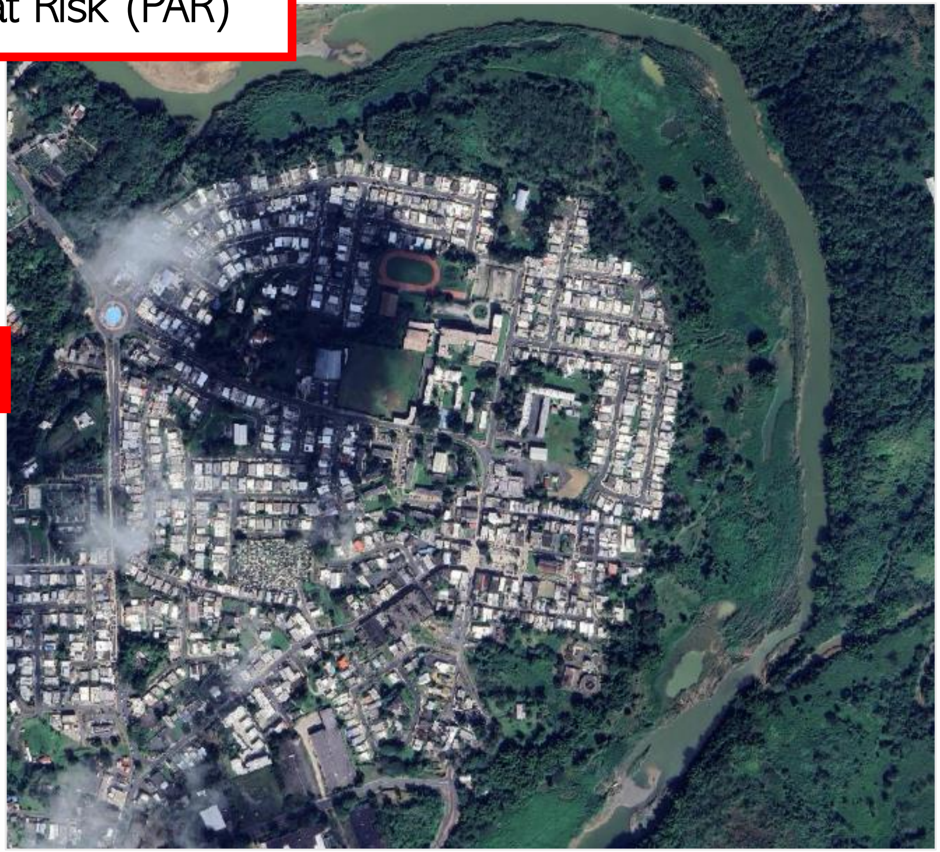
Example: Lago La Plata, Puerto Rico

- Performed a dam breach analysis in HEC-RAS 2D.
- Utilized gridded rainfall data from SPAS

Example: Lago La Plata, Puerto Rico

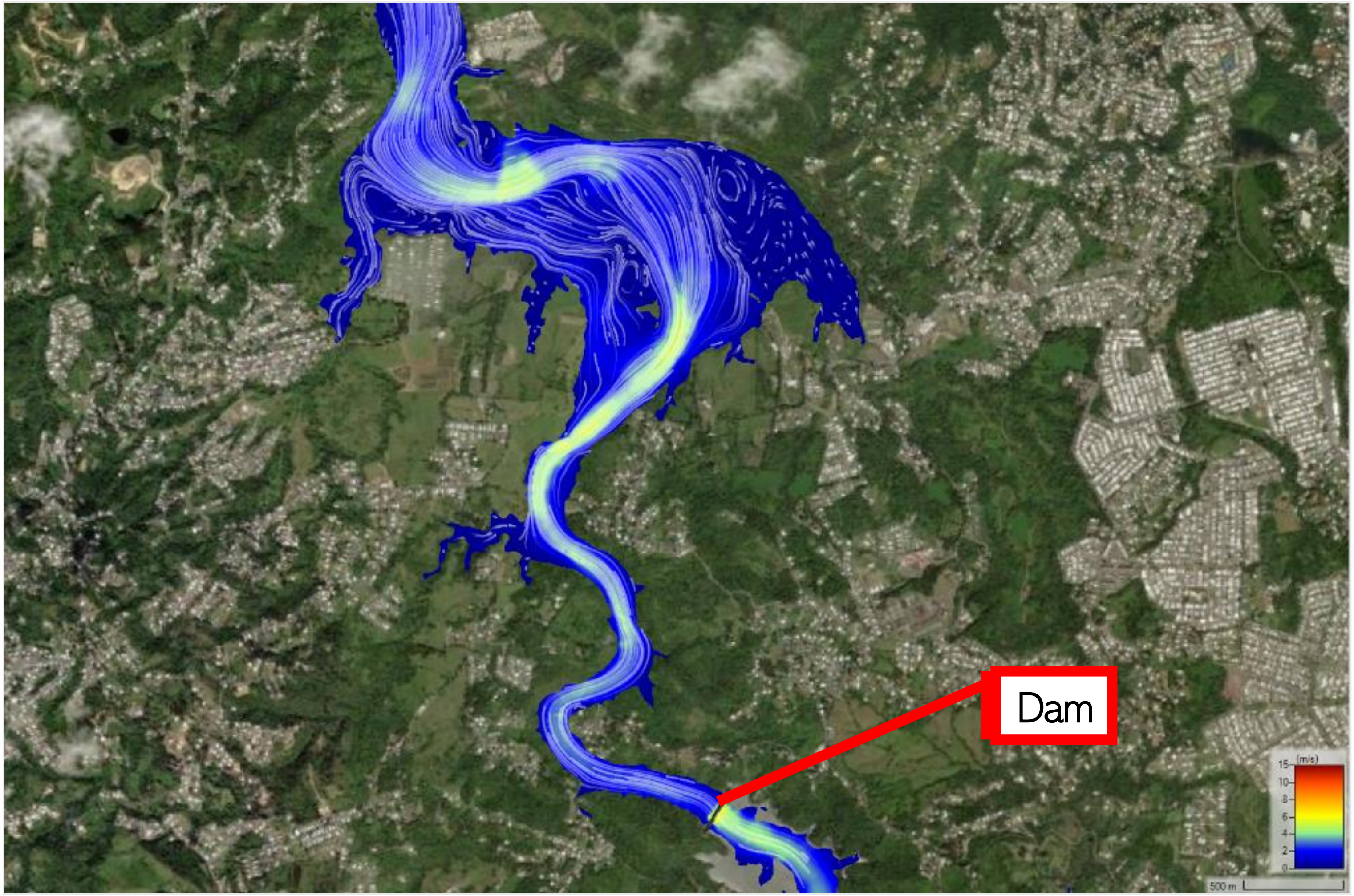
- Topographic and Aerial Data





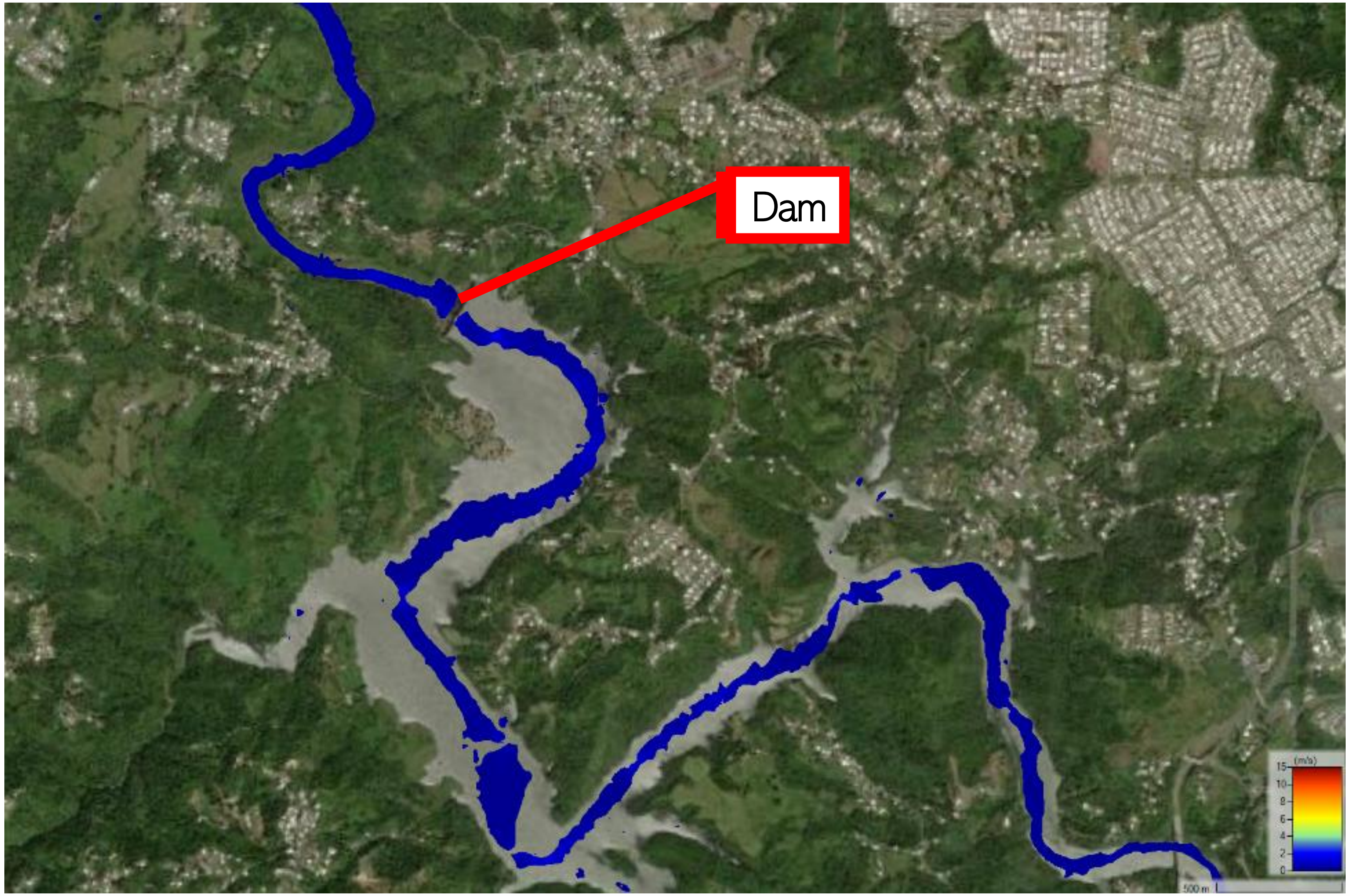
Example: Lago La Plata, Puerto Rico

- Failure at Peak



Example: Lago La Plata, Puerto Rico

- Failure Post Event
- Empty Reservoir



Example: Lago La Plata, Puerto Rico

- **The model development time for input parameters was only 3 hours.**
- The model run-time was less than 2 hours.
- The results included:
  - Velocity with eddies (full momentum equation)
  - Flow
  - Depth of flow
  - Flood elevation
  - Depth x Velocity (Risk)

FEMA Guidance Document 14, 2020

Table 1: Simplified Flood Depth and Velocity Severity Raster Symbolization Categories

Flood Severity Category	Depth * Velocity Range (ft^2/sec)	Depth * Velocity Range (m^2/sec)
Low	< 2.2	< 0.2
Medium	2.2 – 5.4	0.2 – 0.5
High	5.4 – 16.1	0.5 – 1.5
Very High	16.1 – 26.9	1.5 – 2.5
Extreme	> 26.9	> 2.5

THANK YOU

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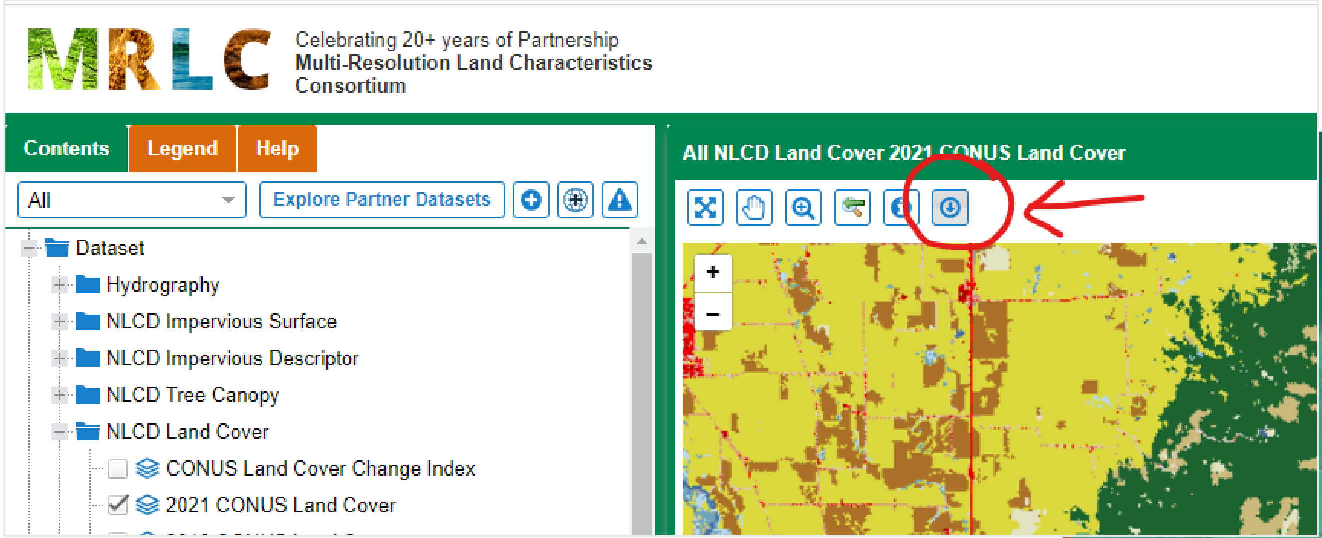
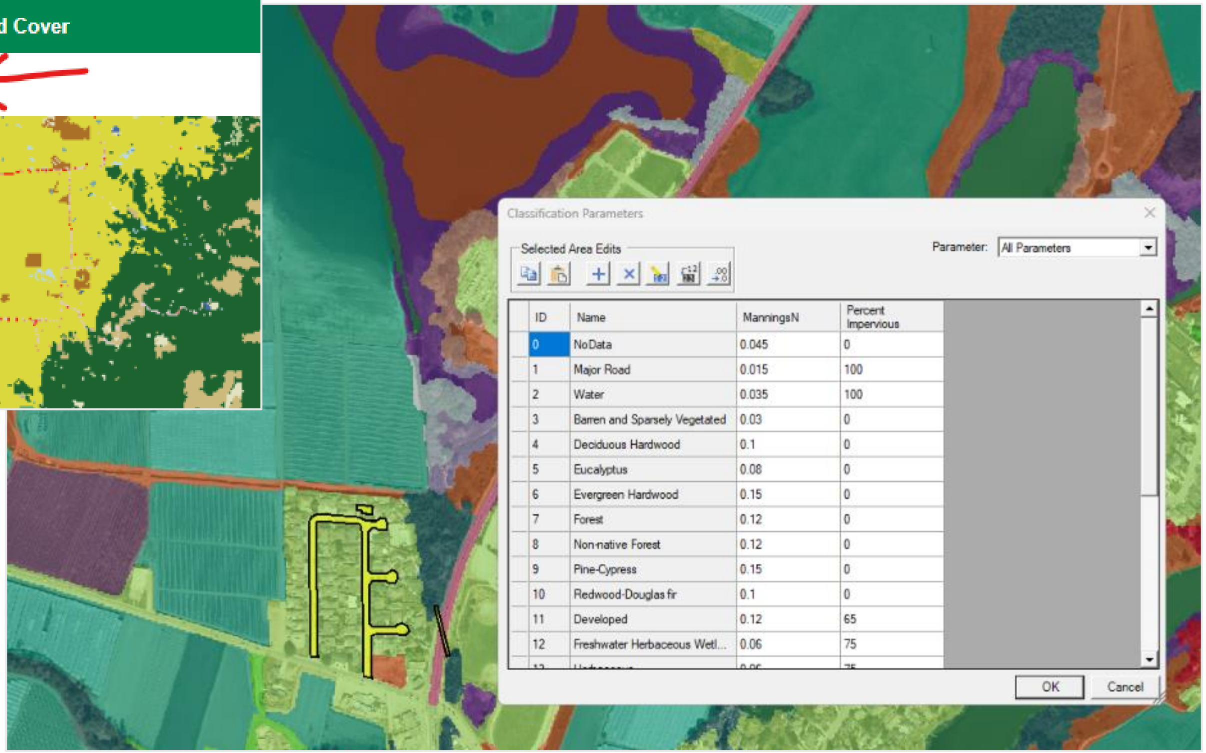
Land Use/Land Cover/Manning’s Roughness





ID	Name	ManningsN	Percent Impervious
0	NoData	0.045	0
1	Major Road	0.015	100
2	Water	0.035	100
3	Barren and Sparsely Vegetated	0.03	0
4	Deciduous Hardwood	0.1	0
5	Eucalyptus	0.08	0
6	Evergreen Hardwood	0.15	0
7	Forest	0.12	0
8	Non-native Forest	0.12	0
9	Pine-Cypress	0.15	0
10	Redwood-Douglas fir	0.1	0
11	Developed	0.12	65
12	Freshwater Herbaceous Wetl...	0.06	75