Source: Alan White (BuzzFeed)

FLOOD MODELING: MAIN CONCEPTS AND IDEAS ON HOW TO DEVELOP FLOOD MODELS USING OPEN DATA

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OUTLINE

BACKGROUND

2D HYDRAULIC MODELING

CASE STUDY

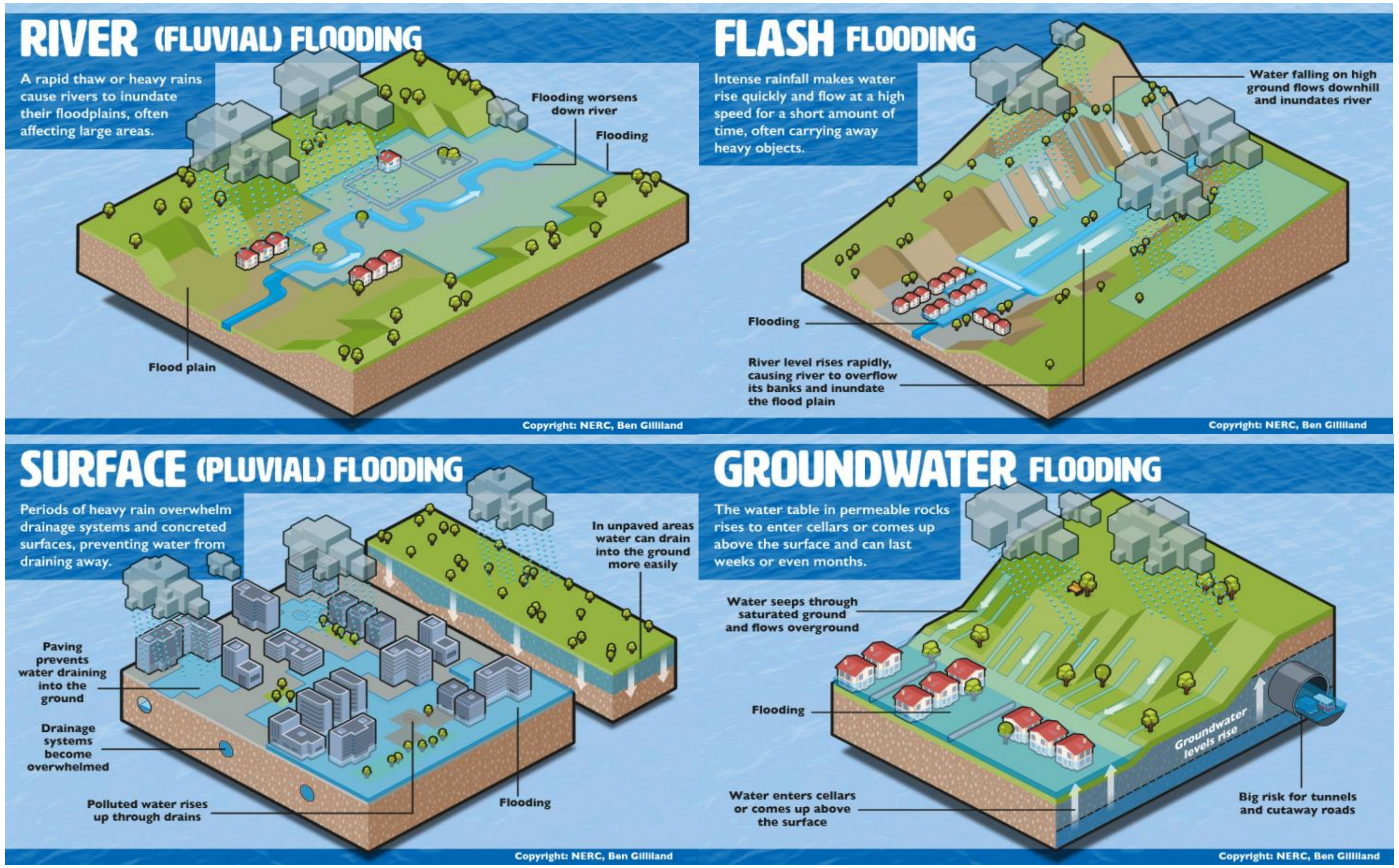
BUILD MODEL FROM SCRATCH

EXPECTED OUTPUTS

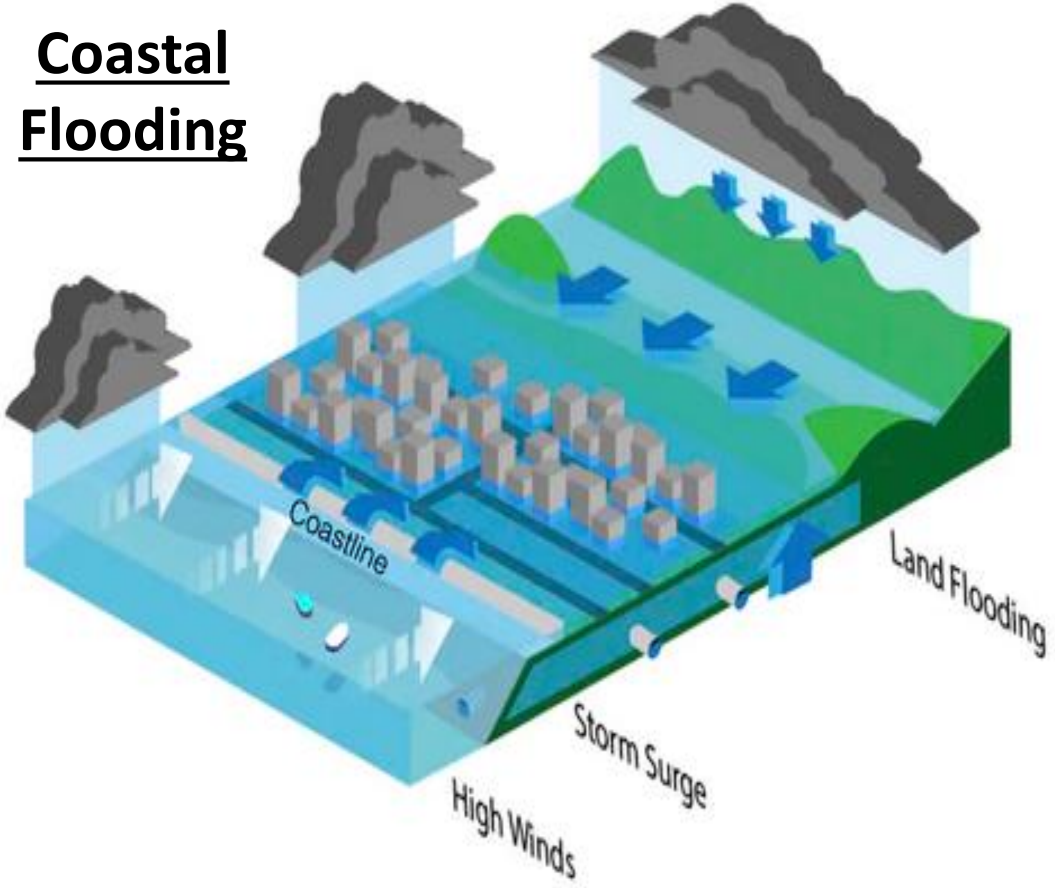
DISCUSSION Q & A

TYPES OF FLOODING

<u>Compound flooding: Interaction of multiple flood drivers (Zscheischler et al. 2018)</u>



<u>**Coastal Flooding**</u>



Source: Ben Gilliland (NERC)

Source: Thomas Wahl (UCF)

HAZARD INTERRELATION APPROACHES

I. Stochastic:

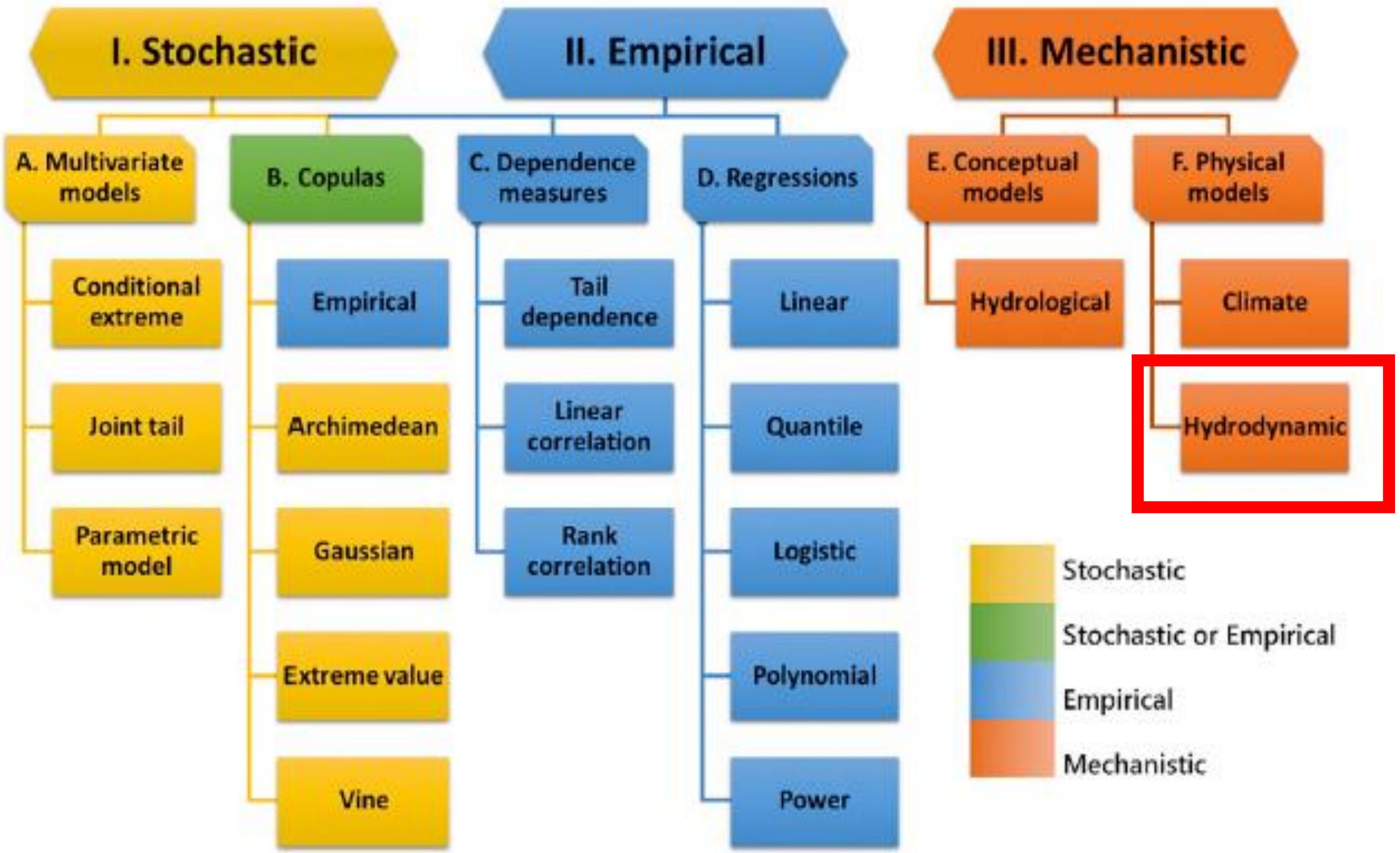
- Based on samples of different variables with random behavior evolving in time

II. Empirical:

- Based on measurements and are observation oriented

III. Mechanistic:

- Mathematically idealized representation of real phenomena



Source: Tilloy et al., 2019

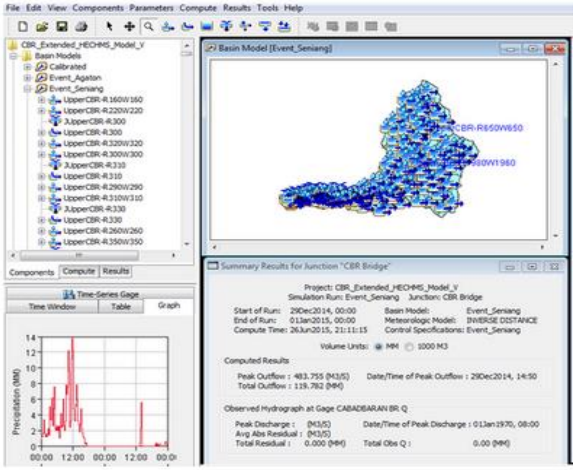
TYPES OF FLOOD MODELS

1. **Hydrologic:** Characterization of hydrologic features and systems (i.e. HEC-HMS, EPA SWMM, SWAT, GSSHA, Vflo...)

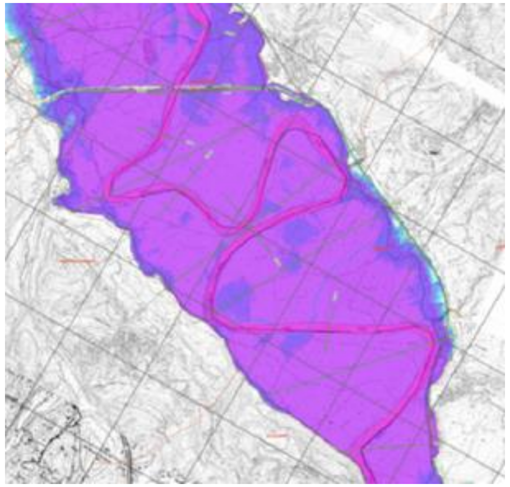
2. **Hydraulic:** Simulate flood processes over unconfined flow surfaces and channels in 1D (i.e. HEC-RAS, IBER...) and 2D (i.e. FLO-2D, Infoworks ICM,ICPR4...)

3. **Storm surge:** Increase of surge levels due to storms, hurricanes and future coastal conditions (i.e. SLOSH, ADCIRC, SWAN...)

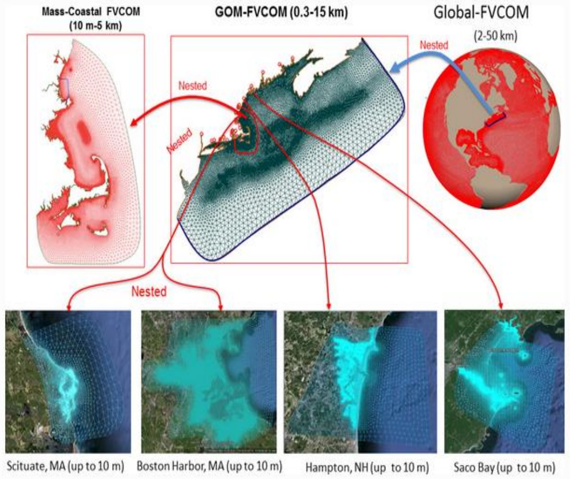
4. **Groundwater:** Surface-subsurface interactions from permeable soil strata (i.e. ModelMuse, MODFLOW)



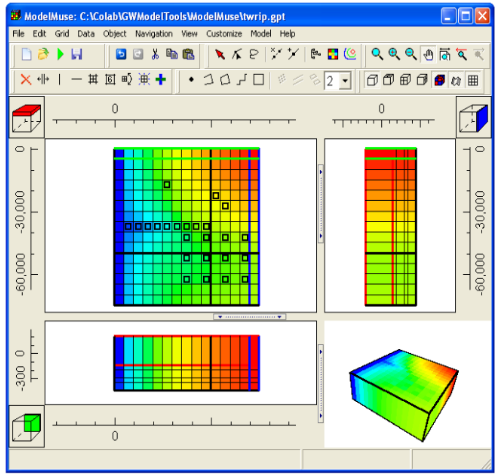
HEC-HMS hydrologic model
Source: Santillan, 2015



FLO-2D hydraulic model
Source: TRBA



FVCOM ocean circulation model
Source: FVCOM



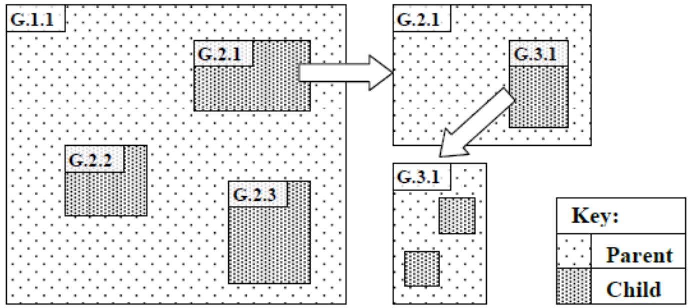
ModelMuse groundwater model
Source: USGS

MODEL LINKING TECHNIQUES

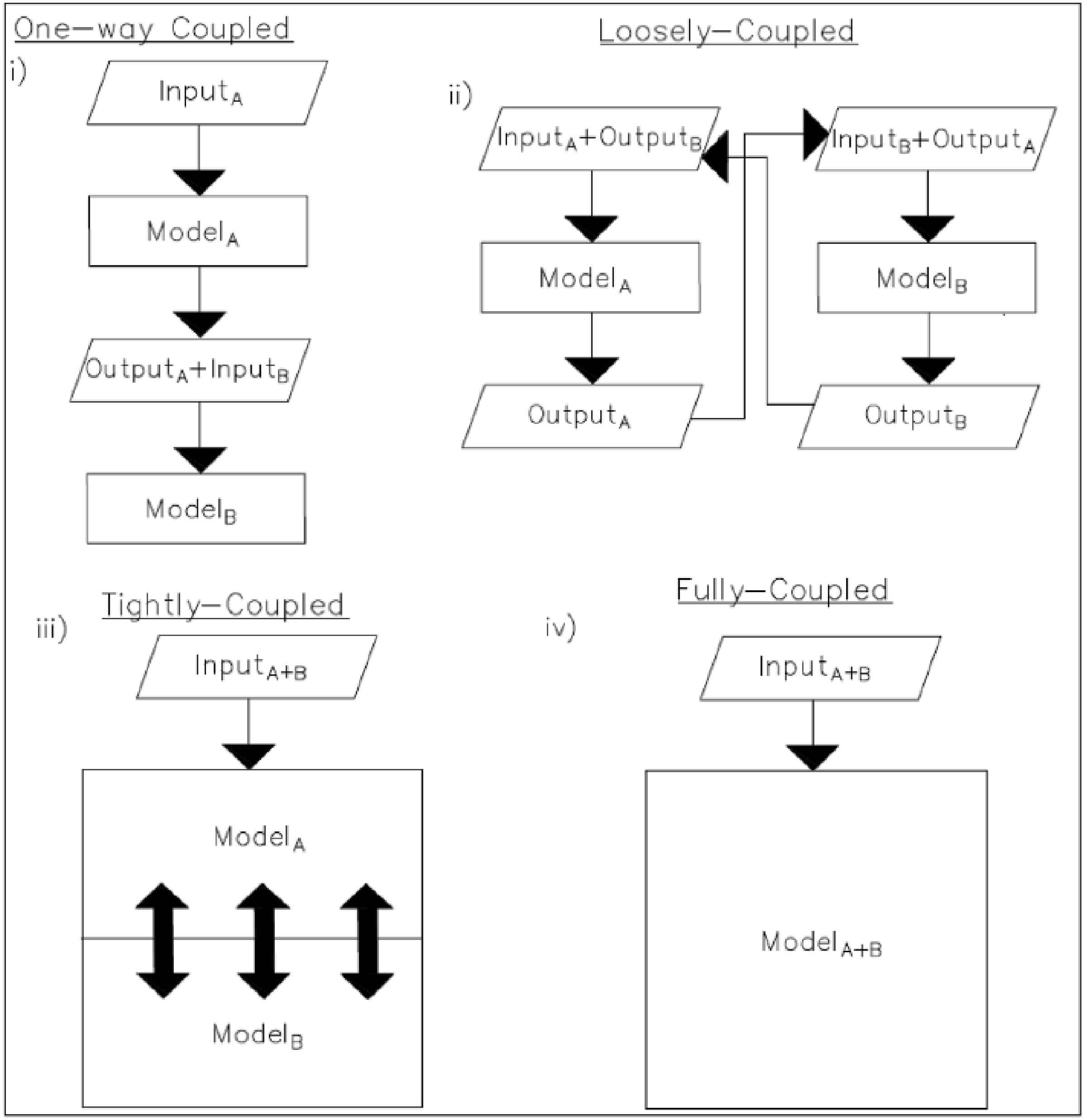
There are different techniques to combine numerical models:

- **One-way** (i.e. linking technique)
- **Two-way** (i.e. 1D + 2D models)
- **Tightly** (i.e. SWAN + ADCIRC)
- **Fully** (i.e. WASH123D)

***Grid nesting approaches** (can be one-way or two-way)



Nested model grid structure for multiple nesting
Source: Nash and Hartnett, 2019



Example on how to couple two numerical models.
Source: Santiago-Collazo et al., 2019

COMPOUND FLOODING EXAMPLES

CF can happen in coastal and inland areas

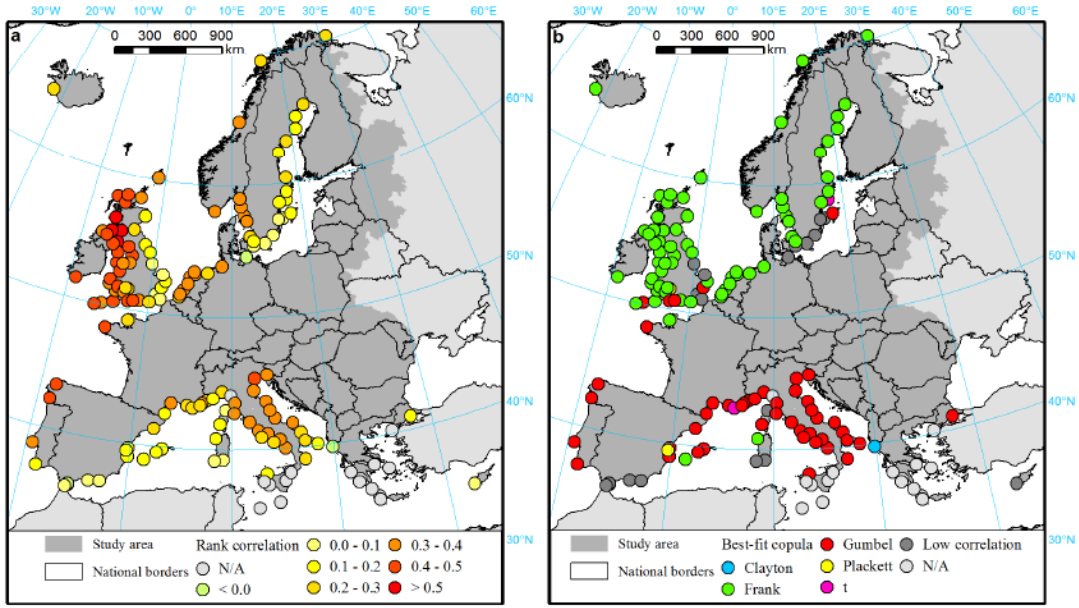
Likelihood in Europe (Paprotny et al., 2018)

- **Storm surge + river discharges (Northern)**
- **Storm surge + precipitation (Southern)**

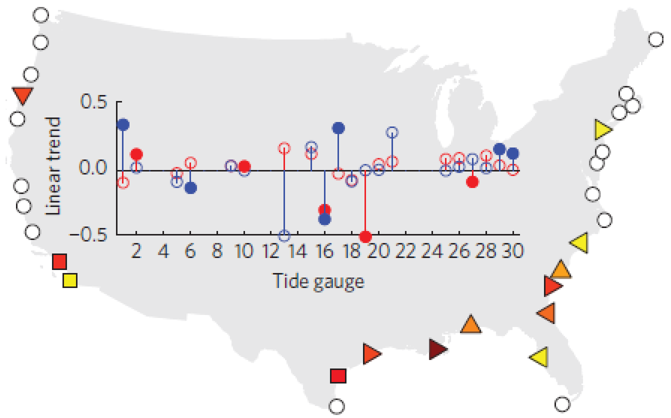
Likelihood in USA (Wahl al., 2015)

- **Atlantic/Gulf > Pacific coast**

Impacts all around the world, including the Danube basin, UK, Netherlands, Italy, US coastal cities (i.e. Hawaii, Miami, NY, NO, etc.)



Source: Paprotny et al., 2018



Source: Wahl et al., 2015

COMPOUND FLOODING REVIEW

Research Findings

- CF models = Better estimation of current and future flood risk scenarios
- Most CF studies use physically based numerical models (hydrologic, ocean circulation or hydraulic models) to account extreme events:
  - Storm surge + precipitation in low-lying coastal watersheds
  - Storm surge + river discharges

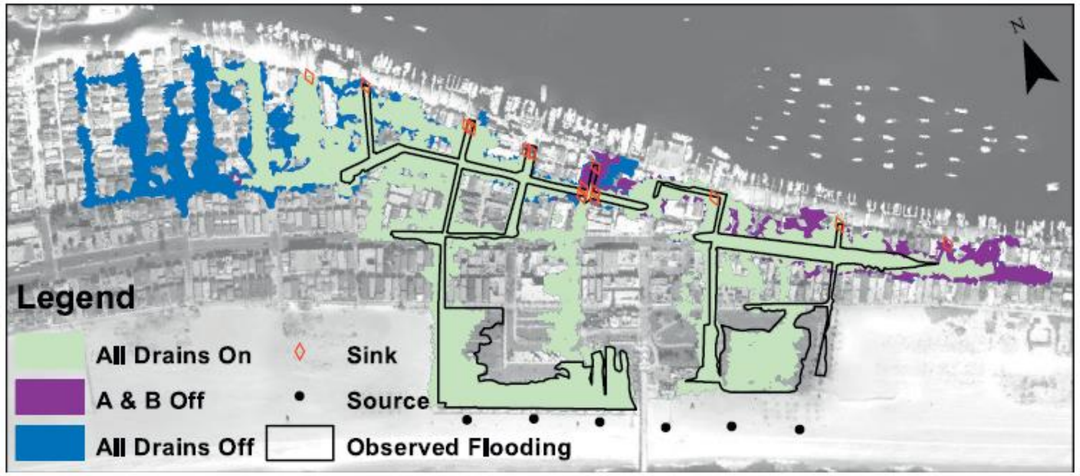
Missing knowledge

- Lack of studies that incorporate storm drain systems and groundwater flooding interactions
- Limitations are still encountered:
  - Models' inability to couple processes
  - Lack of data/measurements
  - Performance levels for calibration and validation

RESEARCH QUESTION:

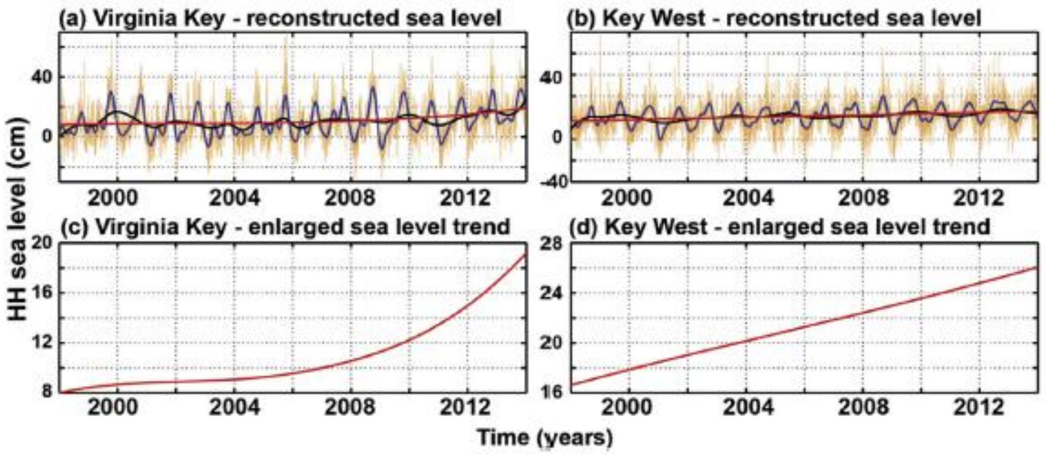
What's the role of climate and individual flood drivers in flood events?

- The response of urban catchments is influenced by:
  - Morphology
  - Hydrology
  - Hydraulic characteristics



Urban coastal flood prediction including features. Source: Sanders et al., 2014

- Climate change is increasing:
  - Global sea levels
  - Extreme precipitation events (Salas and Obeysekera, 2014)
  - Compound flooding (Vousdoukas et al., 2017)

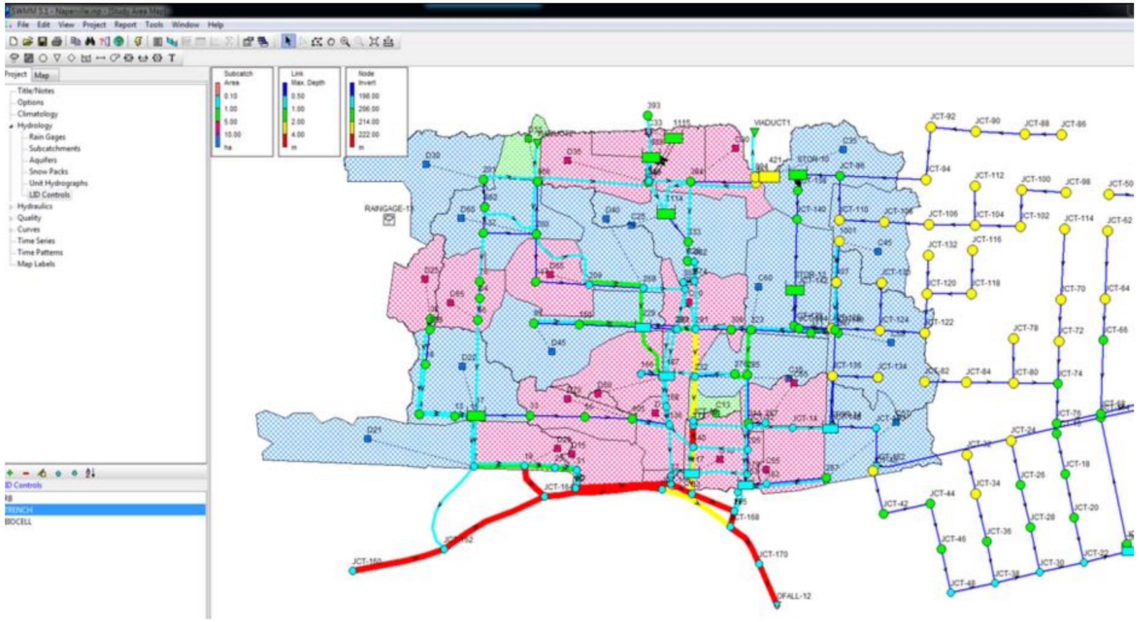


Sea level records. Source: Wdowinski et al., 2015

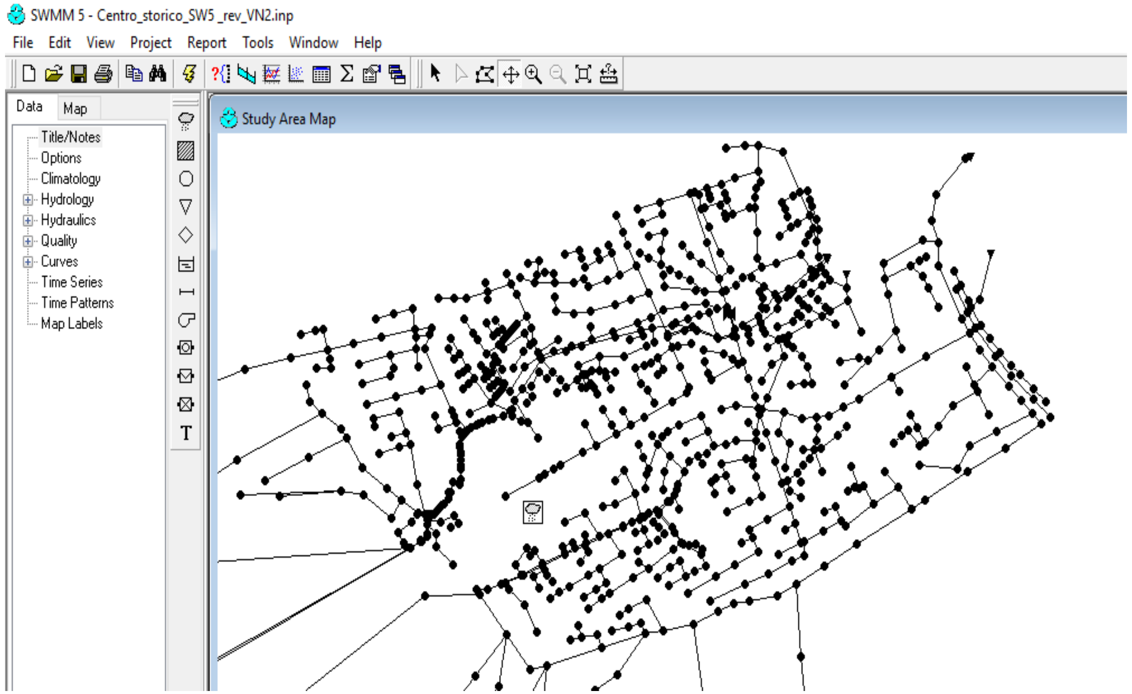
EPA SWMM

MODEL (EPA SWMM)

- **1D dynamic rainfall-runoff model for urban drainage studies (Rossman et al., 2015):**
  - **Flood control design**
  - **Flood mapping**
  - **Mitigation strategies**



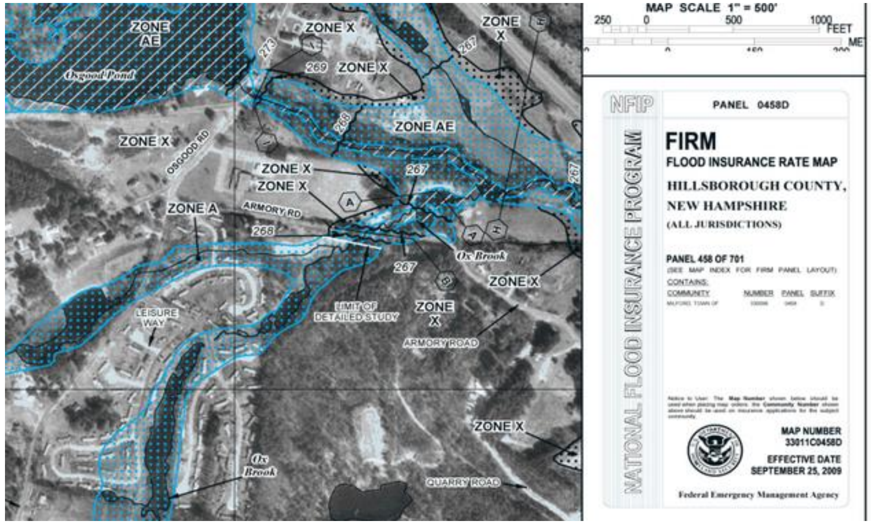
Source: Robert Dickinson (EPA SWMM)



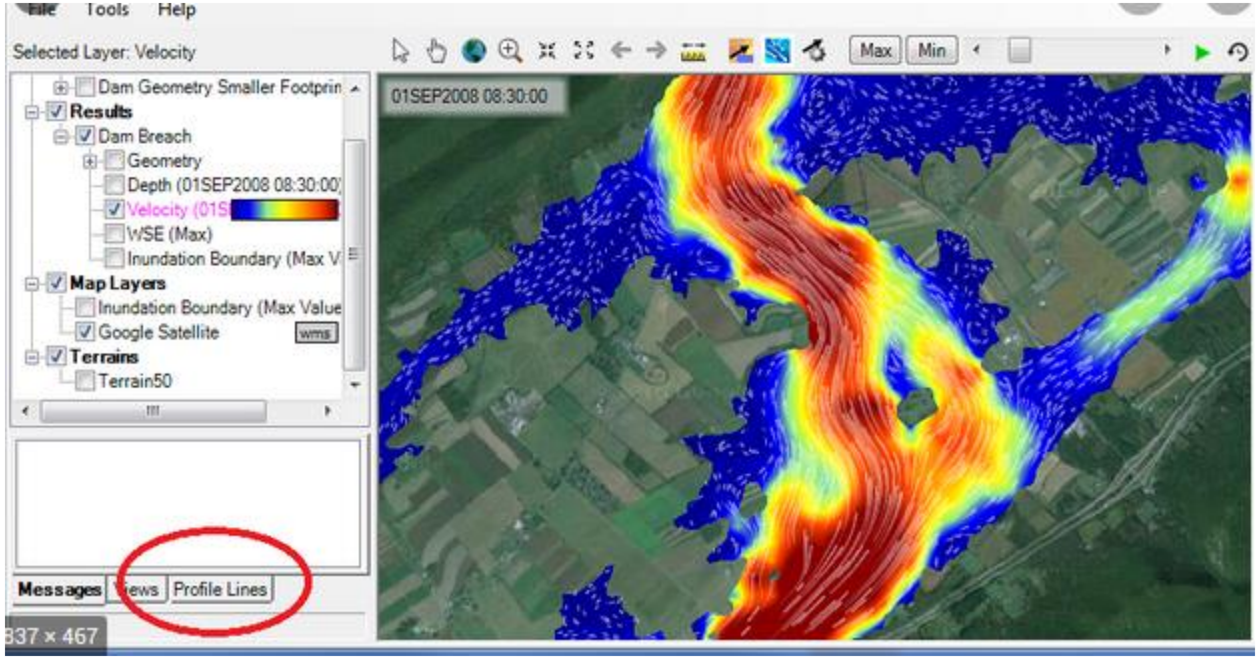
Pipe system of Palermo. Source: Gabriele Freni

MODEL (HEC-RAS)

- Developed by the US Army Corps of Engineers (USACE)
- 1D steady flow, 1D-2D unsteady flow, sediment transport and water quality modeling
- Open access software
- Most widely used tool worldwide for channel flow analysis and floodplain delineation



Flood insurance map. Source: FEMA



1D-2D unsteady flow simulation. Source: HECRAS

MODEL (FLO-2D)

- **Grid-based volume conservation model that combines hydrology and hydraulics**
- **Compute superficial flow routing schemes, flow exchange between channel and floodplain, flood wave propagation and inundation dynamics in urban and rural environments**
- **Governing equations:**

Continuity

$$\frac{\partial h}{\partial t} + \frac{\partial h\,V}{\partial x} = i$$

Dynamic wave momentum

$$Sf = So - \frac{\partial h}{\partial x} + \frac{V}{g}\frac{\partial h\,V}{\partial x} - \frac{1}{g}\frac{\partial V}{\partial t}$$

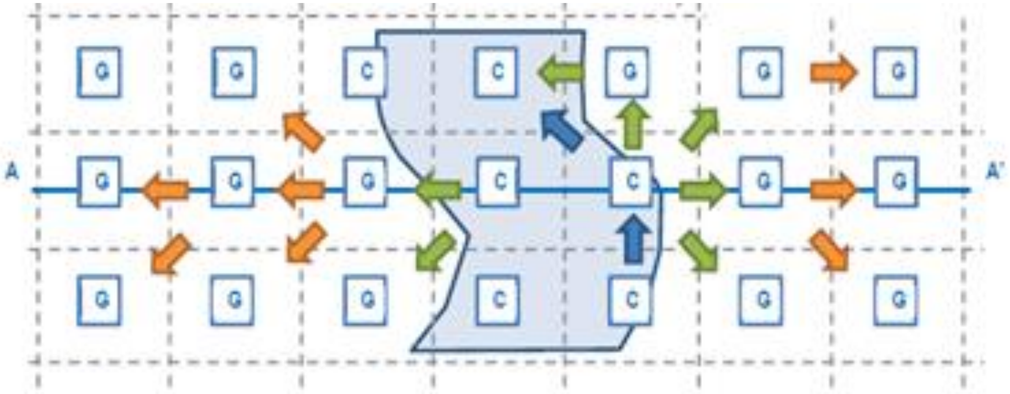
i = EXCESS RAINFALL INTENSITY

h = FLOW DEPTH

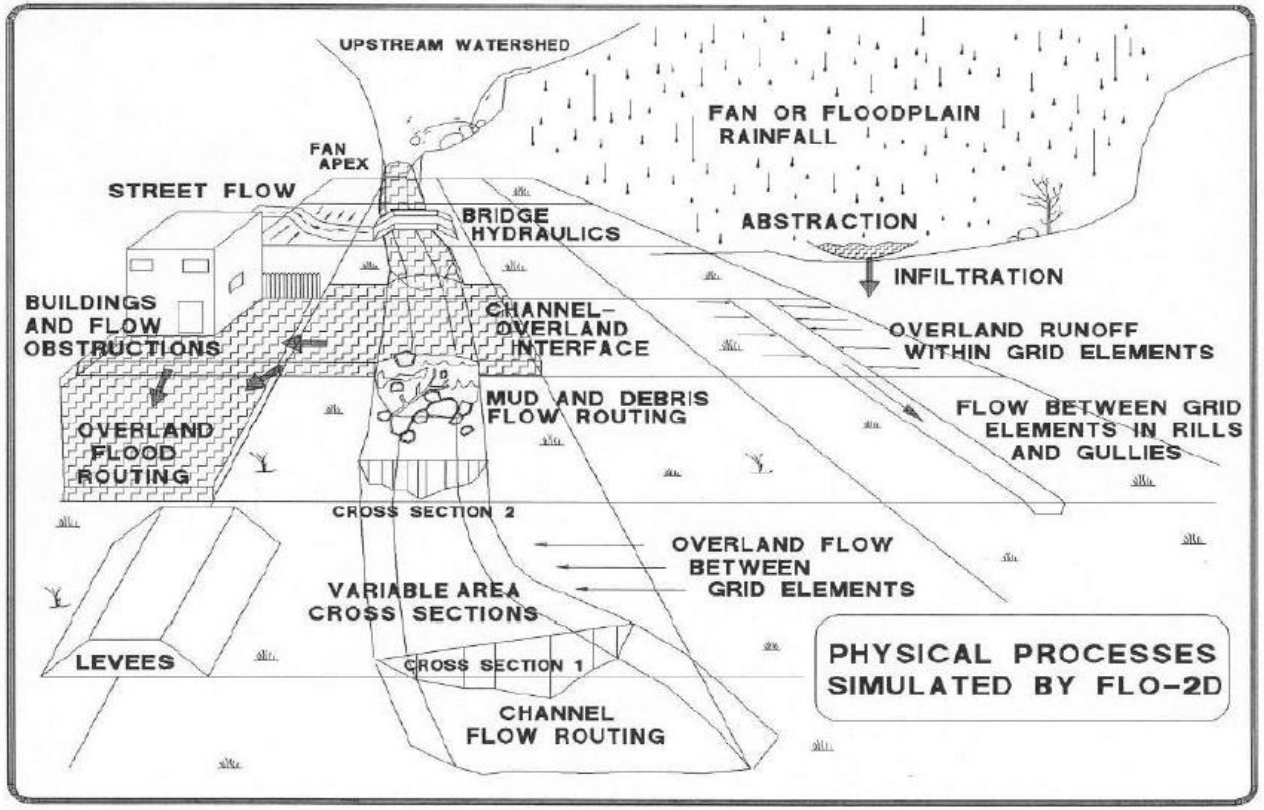
V = DEPTH-AVERAGED VELOCITY IN 1 OF THE 8 FLOW DIRECTIONS

Sf = FRICTION COMPONENT

So = BED SLOPE GRADIENT



FLO-2D 8 potential flow directions. Source: Antonio Annis



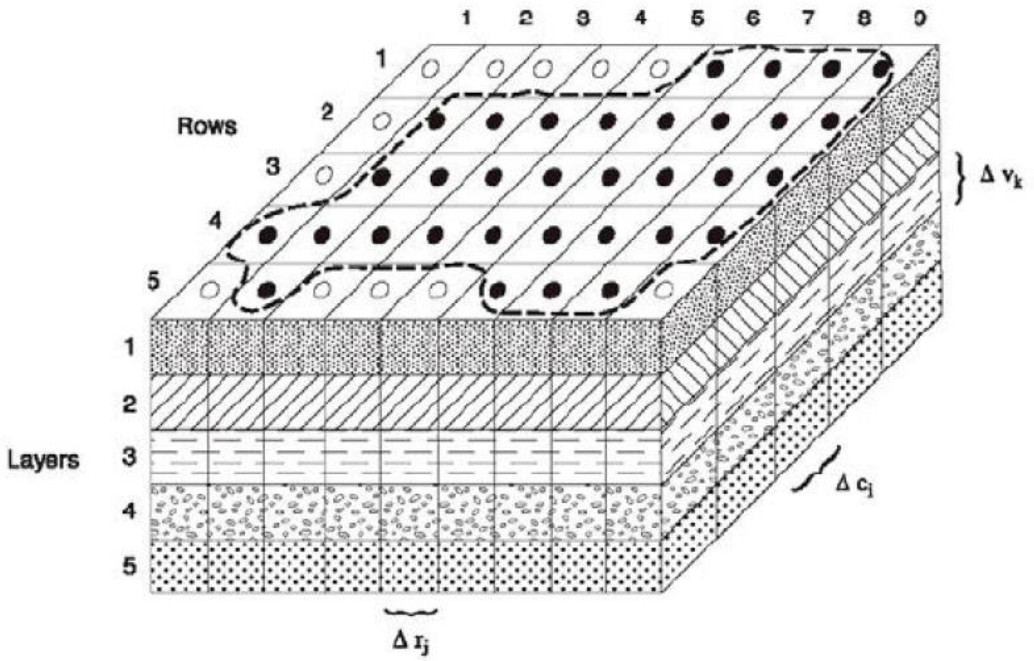
Physical processes simulated by FLO-2D. Source: FLO-2D Reference Manual

MODEL (MODFLOW-2005)

- **Groundwater flow for confined or unconfined layers is simulated using a block-centered finite-difference approach**
- **Three-dimensional transient groundwater flow equation combines the Darcy's and mass conservation laws**

$$\frac{\partial}{\partial x}\left(K_{xx}\frac{\partial h}{\partial x}\right)+\frac{\partial}{\partial y}\left(K_{yy}\frac{\partial h}{\partial y}\right)+\frac{\partial}{\partial z}\left(K_{zz}\frac{\partial h}{\partial z}\right)+W=S_s\frac{\partial h}{\partial t}$$

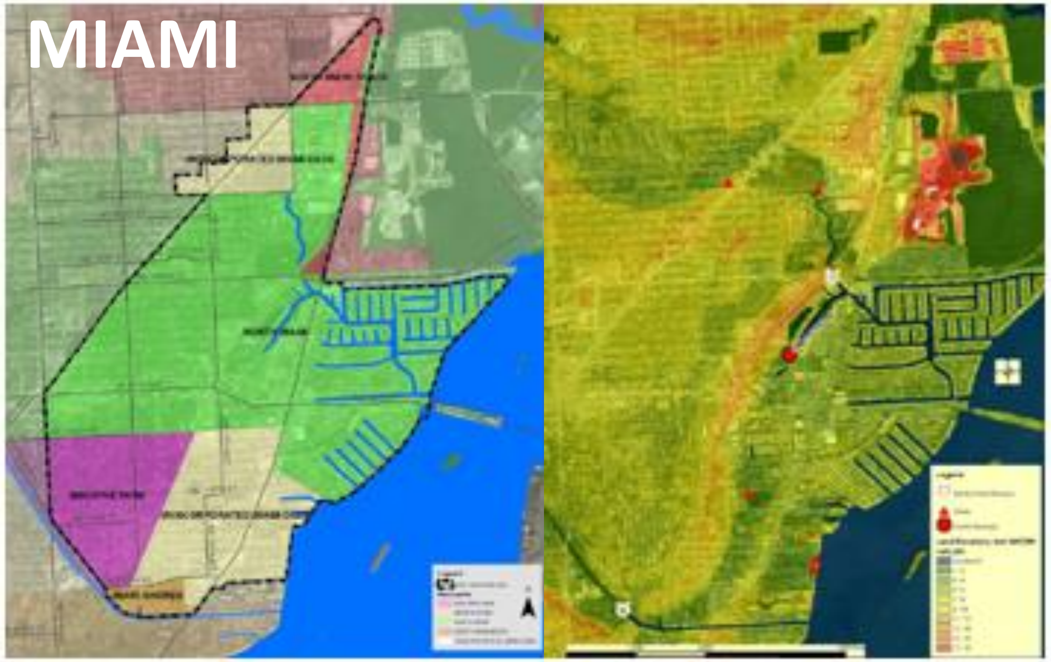
x, y, z = SPACE VARIABLES; t = TIME VARIABLE
h = HYDRAULIC HEAD
Kx, Ky, Kz = HYDRAULIC CONDUCTIVITY IN X-,Y-,Z-COORDINATE DIRECTION
W = TERM WHICH COMBINED ALL SOURCES AND SINKS
Ss = SPECIFIC STORAGE

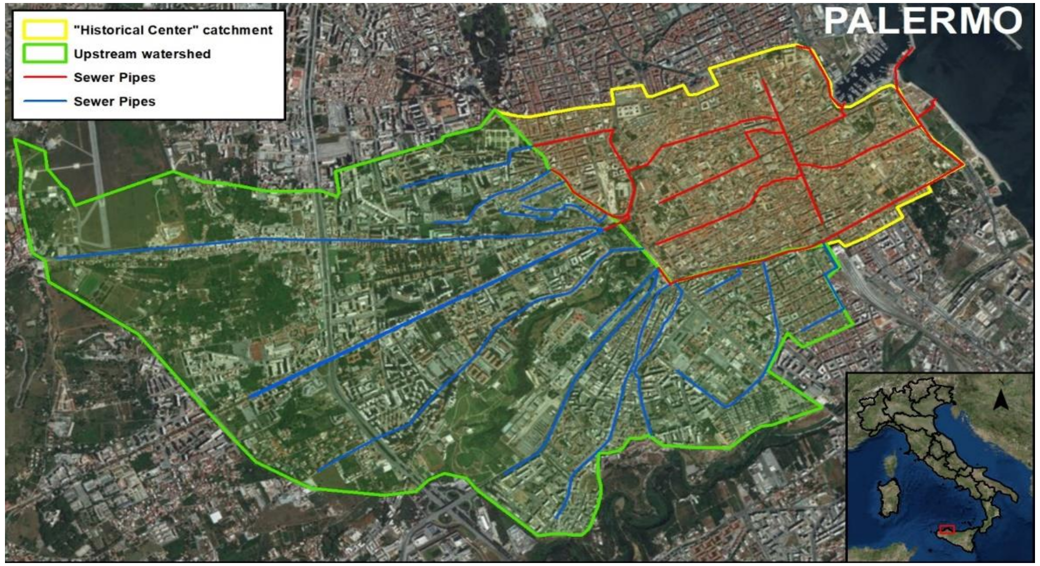


Finite difference grid in MODFLOW-2005. Source: Harbaugh, 2005

EXAMPLE: FLOOD RISK EVALUATION

Characteristics	Arch Creek Basin (Miami)	Palermo (Italy)
Climate	Tropical monsoon	Mediterranean
Topography	Flat topography	Steep slope floodplain
Precipitation	1570 mm | 61.9 inches	605 mm | 23.8 inches
Pluvial	High risk	High risk
Fluvial	Medium risk	Medium risk
Coastal surge	High risk	Low risk
Groundwater	Unconfined aquifer	Confined aquifer
Sea level rise	5-13 mm/year	10 mm/year
Flood risk	Very high	High

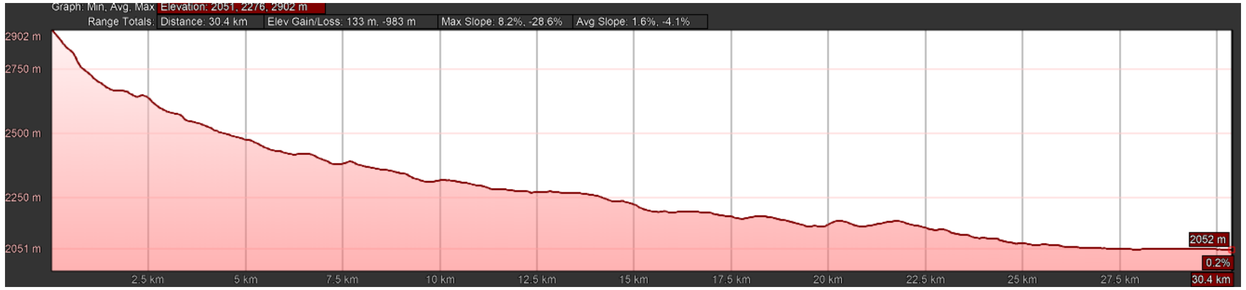


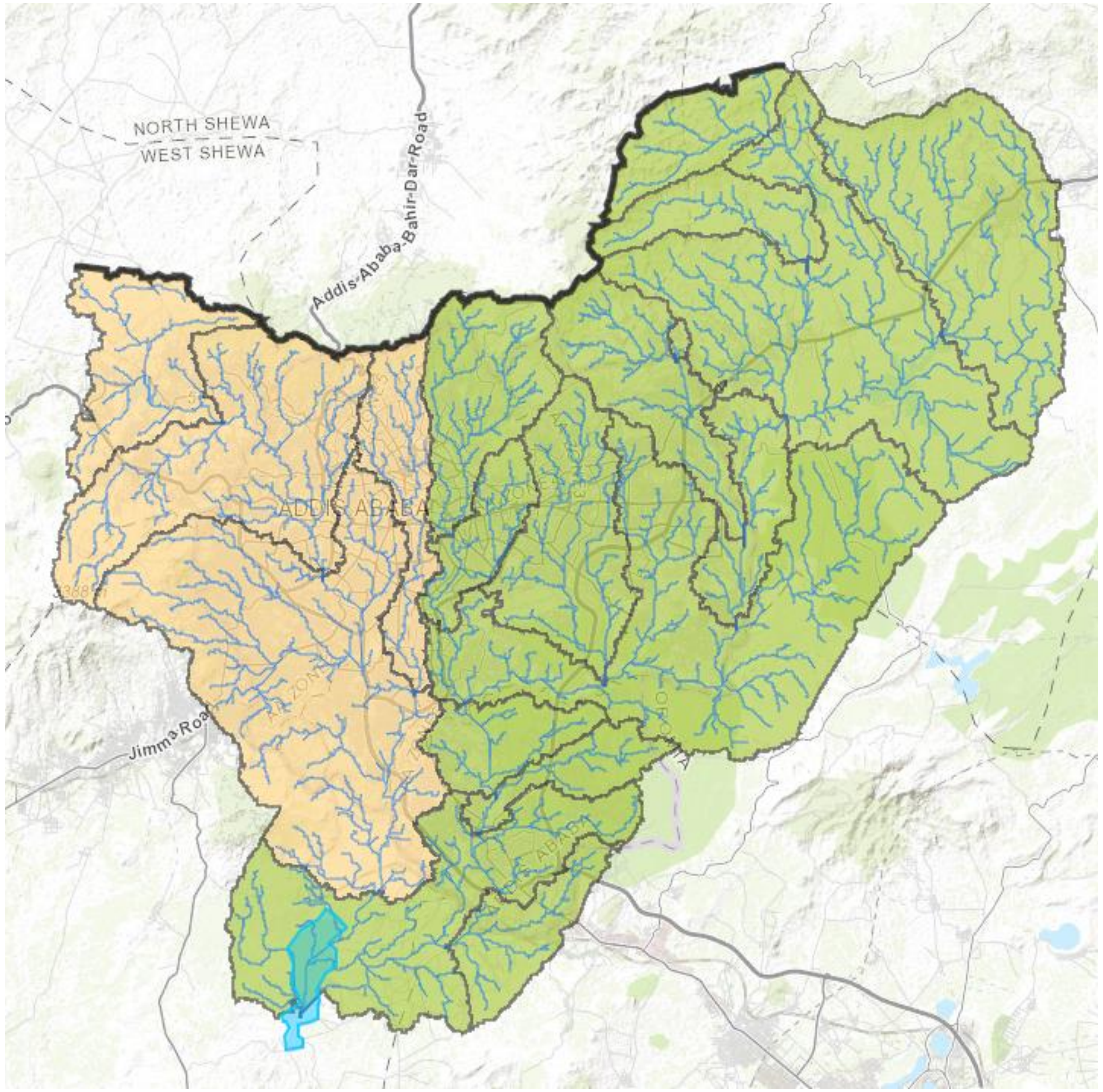


CASE STUDY: ADDIS ABABA

Characteristics:

- Avg. annual precipitation ≈ 1120 mm
- Upper part of the Awash River basin
- Drainage area ≈ 110,000 km^2
- Sub-catchments:
  - Big Akaki (900 km^2)
  - Little Akaki (500 km^2)
- <u>Mountains and floodplain valley</u>





River network in Addis Ababa
Source: ArcMap

CASE STUDY: ADDIS ABABA

Why does it flood?

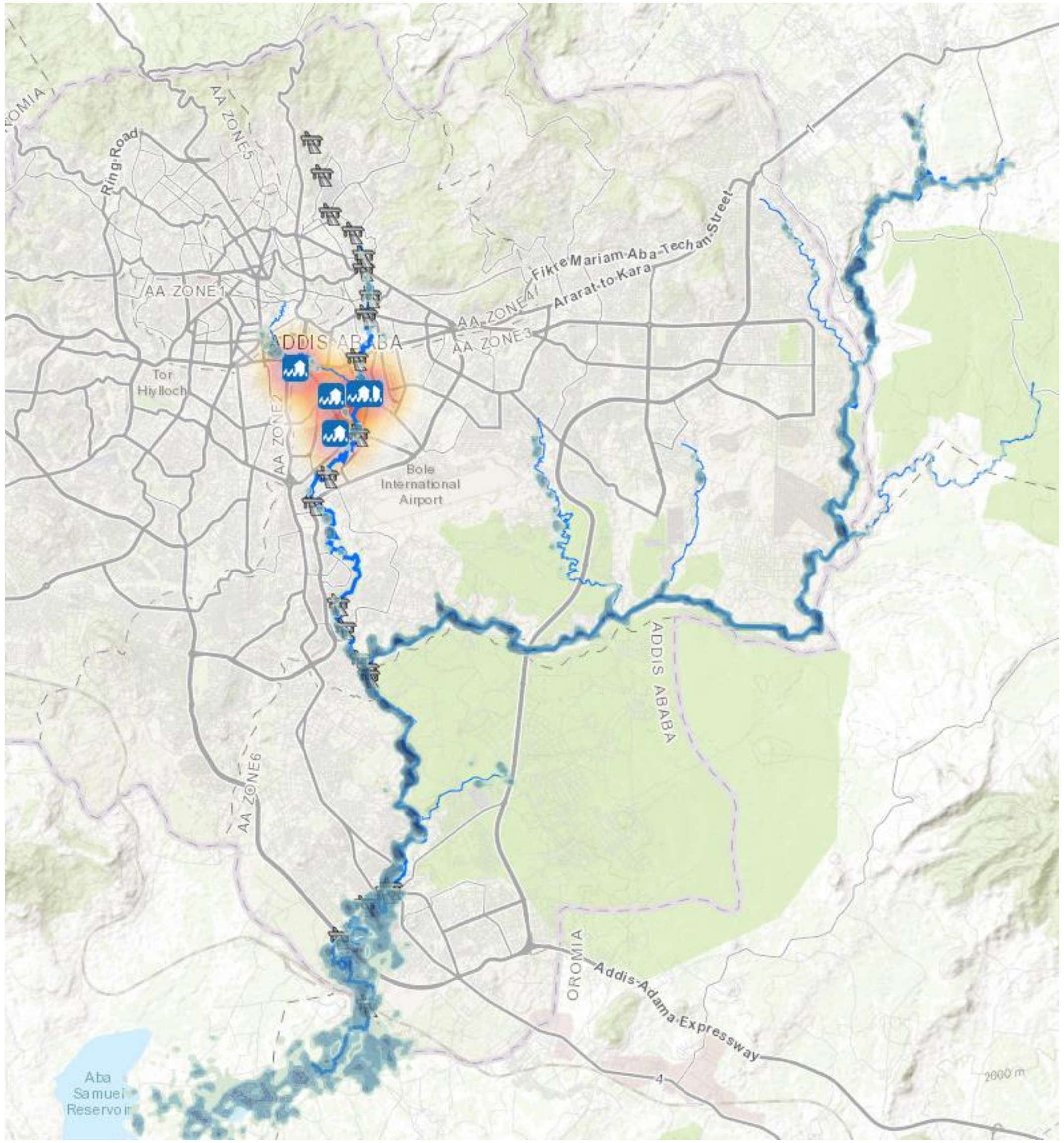
- Rapid urbanization
- Deforestation
- Impervious surfaces
- Inadequate urban planning
- Informal settlements
- Poor road design and urban drainage infrastructure
- Sewer and river blockages

Urban flooding in Addis Ababa
Source: CLUVA

CASE STUDY: ADDIS ABABA

Flood model

- 2D hydraulic model FLO-2D for open channel hydraulics
- DEM 30m (USGS website)
- 50m grid model resolution
- 200 year return period hydrograph (peak discharge 27m^3/s)
- River geometry (Global database)
- Crowdsourced data and VGI



Urban Flooding in Addis Ababa
Source: Francisco Peña

HOW TO BUILD A MODEL FROM SCRATCH

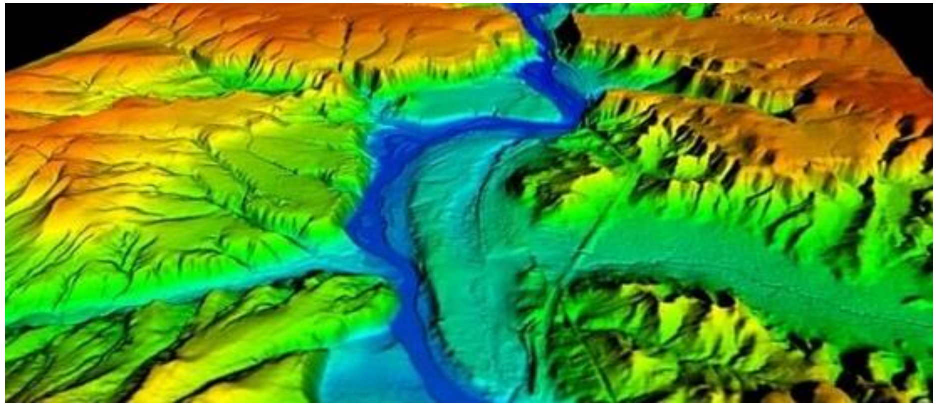
Data collection

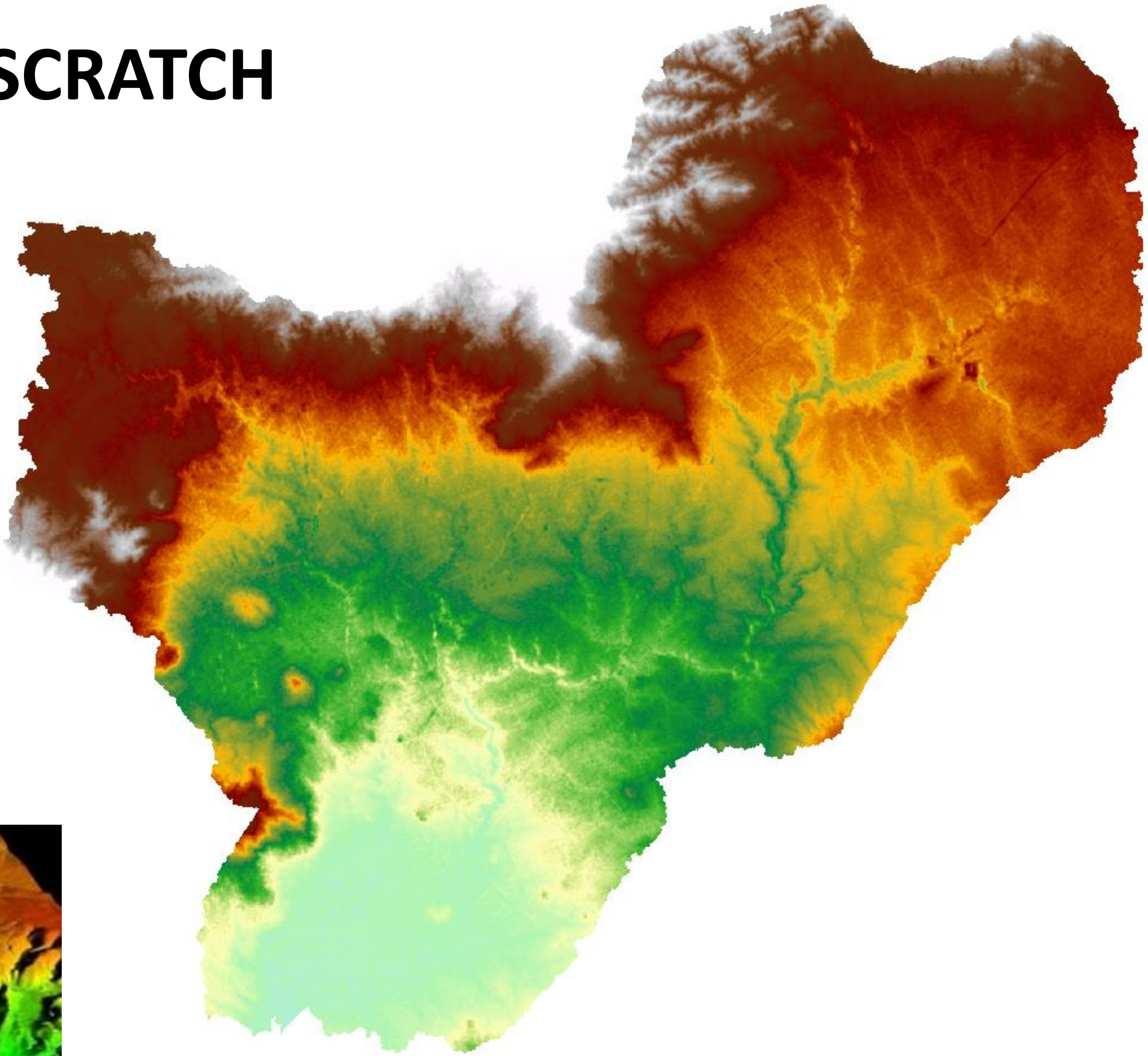
- Digital Elevation Model (DEM)
- Hydrology
- Land use cover
- Urban features
- Channel bathymetry
- Storm drain data
- Volunteered Geographic Information (VGI)

HOW TO BUILD A MODEL FROM SCRATCH

Digital Elevation Model (DEM)

- USGS EARTH EXPLORER
- JAXA
- INGV (Italy)
- INEGI (Mexico)
- Regional Geoportals



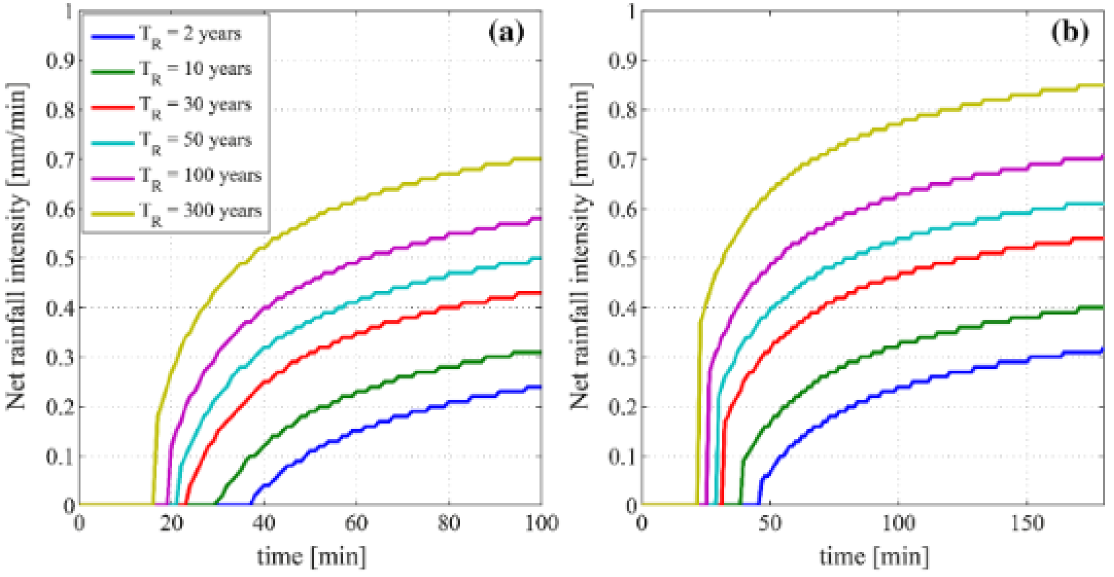


Digital Elevation Models
Source: The Engineering Community and Francisco Peña

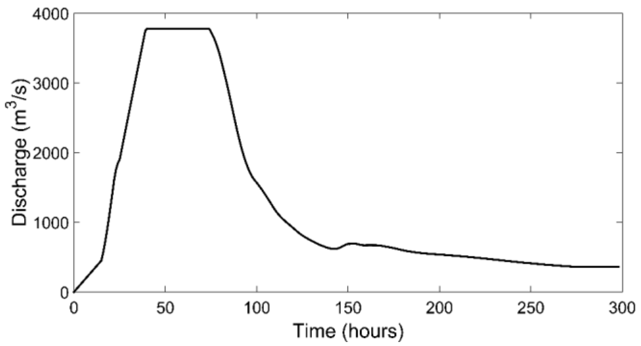
HOW TO BUILD A MODEL FROM SCRATCH

Hydrology

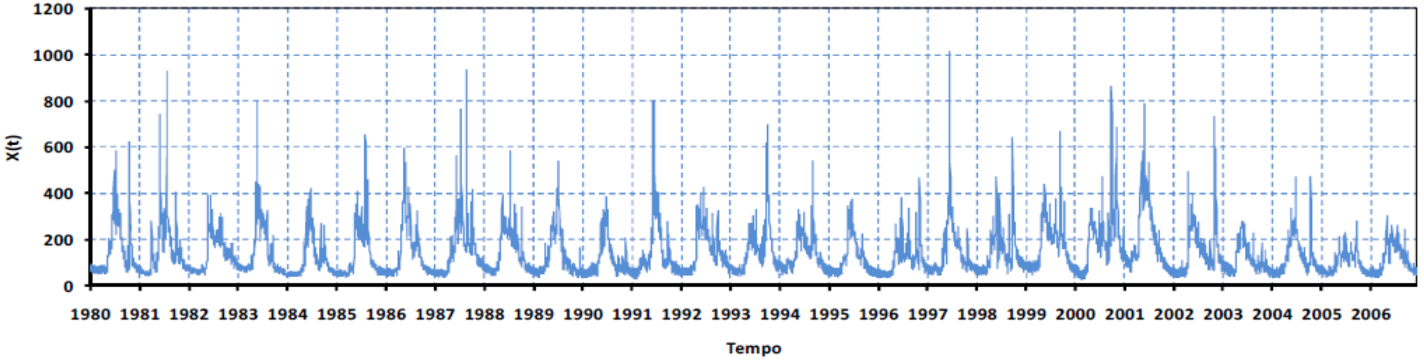
- NOAA Atlas 14
- NOAA Tides & Currents website
- USGS (Waterwatch or Waterdata)
- Scientific publications
- Regional Geoportals



Inflow hydrograph. Source: De Risi et al., 2020



Inflow hydrograph. Source: Francisco Peña

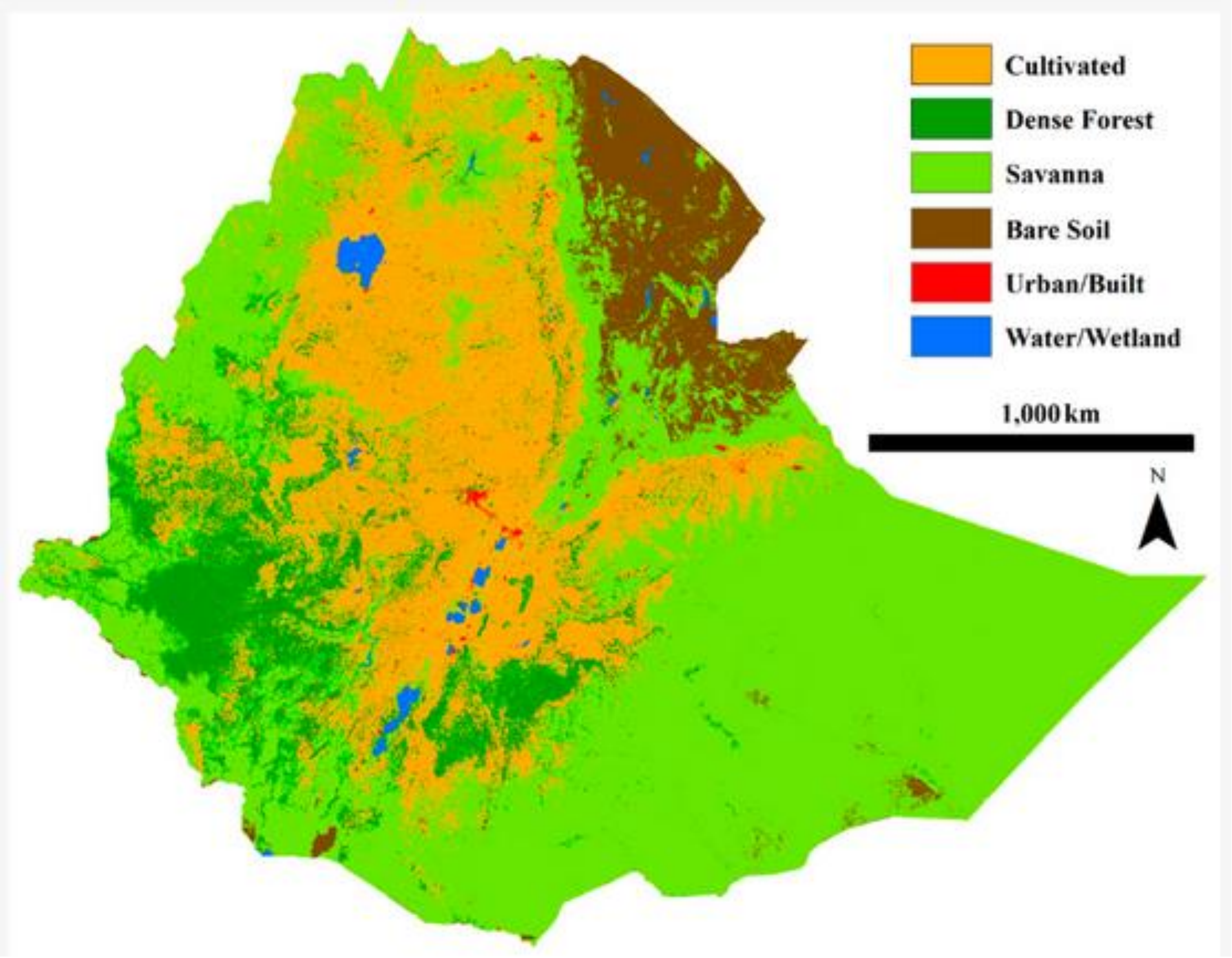


Time plot to represent time series data. Source: ISPRA 2013

HOW TO BUILD A MODEL FROM SCRATCH

Land Use Cover

- USGS
- International organizations
- National and Regional Geoportals
- Scientific publications
- GIS Hubs
- Open data repositories

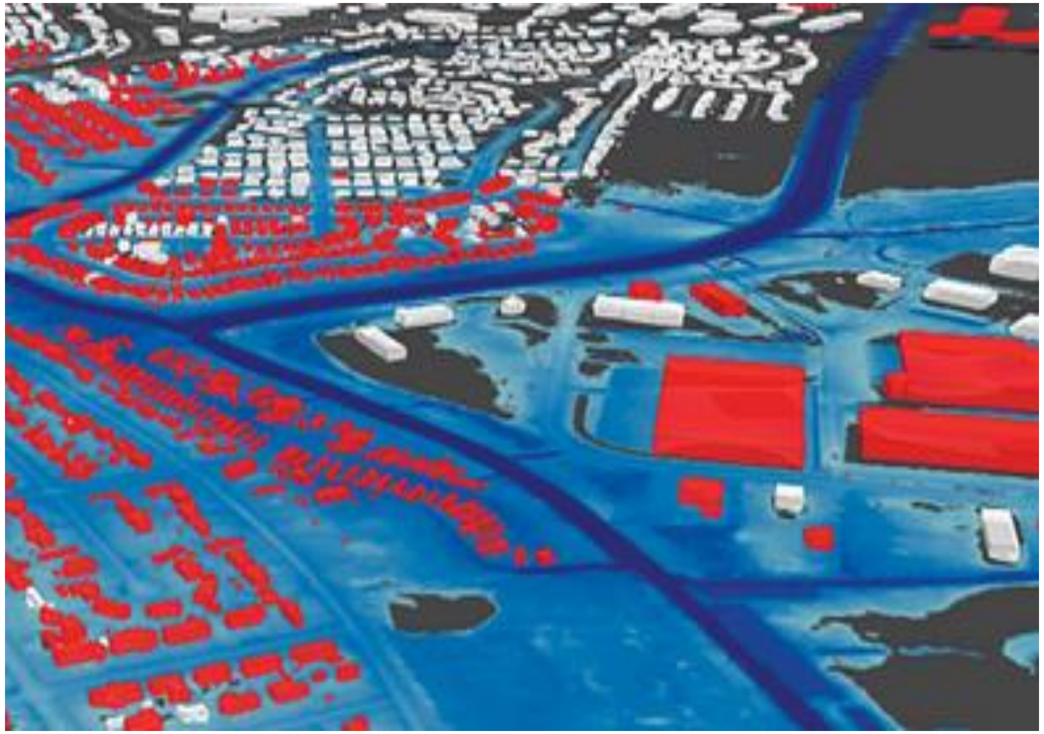


Land cover map of Ethiopia for 2017. Source: Kamathi et al., 2020

HOW TO BUILD A MODEL FROM SCRATCH

Urban features

- National and Regional Geoportals
- GIS hubs and open data repositories
- Manual digitalization

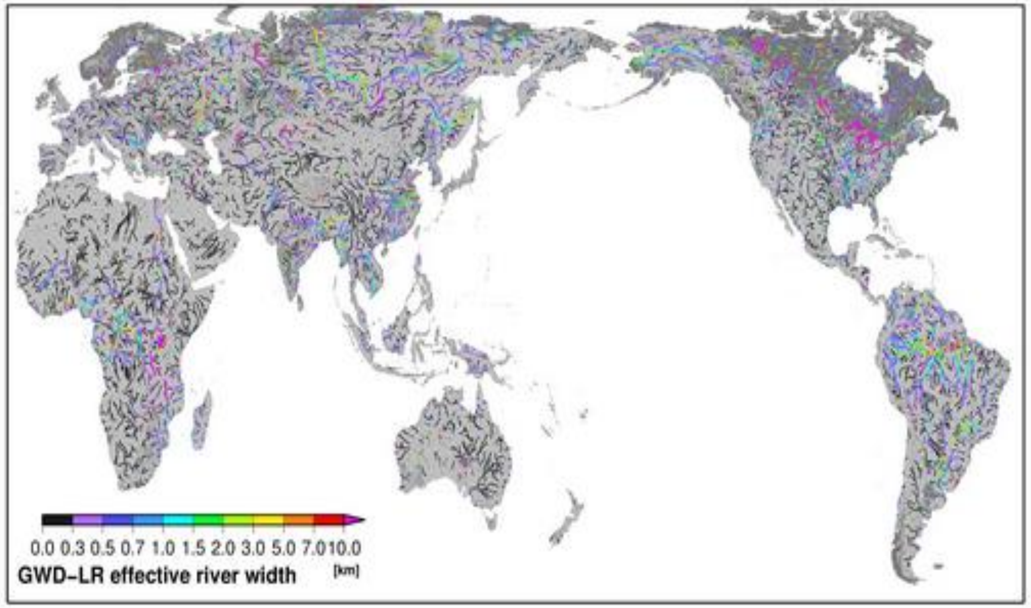


Example of urban features in flood models.
Source: ESRI and Francisco Peña

HOW TO BUILD A MODEL FROM SCRATCH

Channel Bathymetry

- National and Regional Geoportals (Bathymetric Data Viewer)
- Global river database:
  - HydroSHEDS (Andreadis et al., 2012)
  - HYDRO1K
  - Global Width Database of Large Rivers (GWD-LR)
- Geomorphological laws (Leopold and Maddock, 1953)
- Manual digitalization (GIS Software/GE)

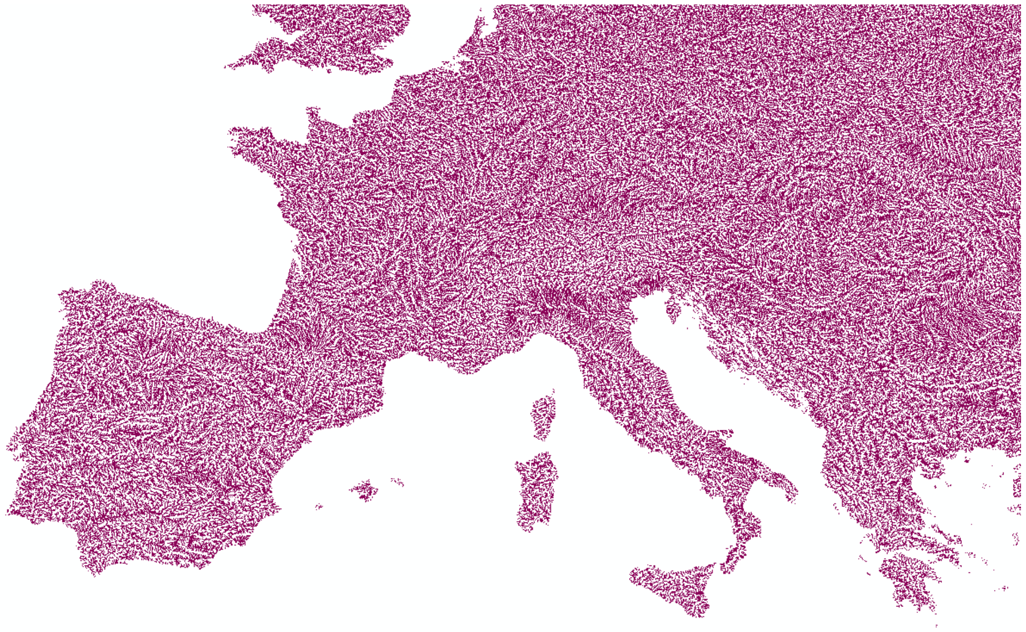


MERIT Hydro river width map database.
Source: Yamazaki et al. 2019

HOW TO BUILD A MODEL FROM SCRATCH

Channel Bathymetry

A simple global river bankfull width & depth database (Andreadis et al., 2012)



ESRI Shapefiles as ZIP files per continent

http://gaia.geosci.unc.edu/rivers/

HYDROSHEDS RIVER

FID	Shape *	cat	a_cat	a_ARCID	a_UP_CELLS	a_AREA	a_WIDTH	a_WIDTH5	a_WIDTH95	a_DEPTH	a_DEPTH5	a_DEPTH95
0	Polyline	2	3449	3449	138	1061.67	56.59	18.82	172.42	1.35	0.58	3.28
1	Polyline	5	3467	3467	108	49596.01	389.9	120.02	1283.25	6.08	2.49	15.35
2	Polyline	7	3479	3479	26100	2828.13	92.55	30.18	287.59	1.98	0.84	4.86
3	Polyline	22	3505	3505	7900	1541.32	68.24	22.52	209.48	1.56	0.66	3.81
4	Polyline	23	3507	3507	22004	2680.19	90.09	29.41	279.64	1.94	0.82	4.76
5	Polyline	24	3508	3508	25130	2784.95	91.84	29.95	285.29	1.97	0.83	4.83
6	Polyline	25	3509	3509	362	55	12.8	4.52	36.76	0.42	0.19	1

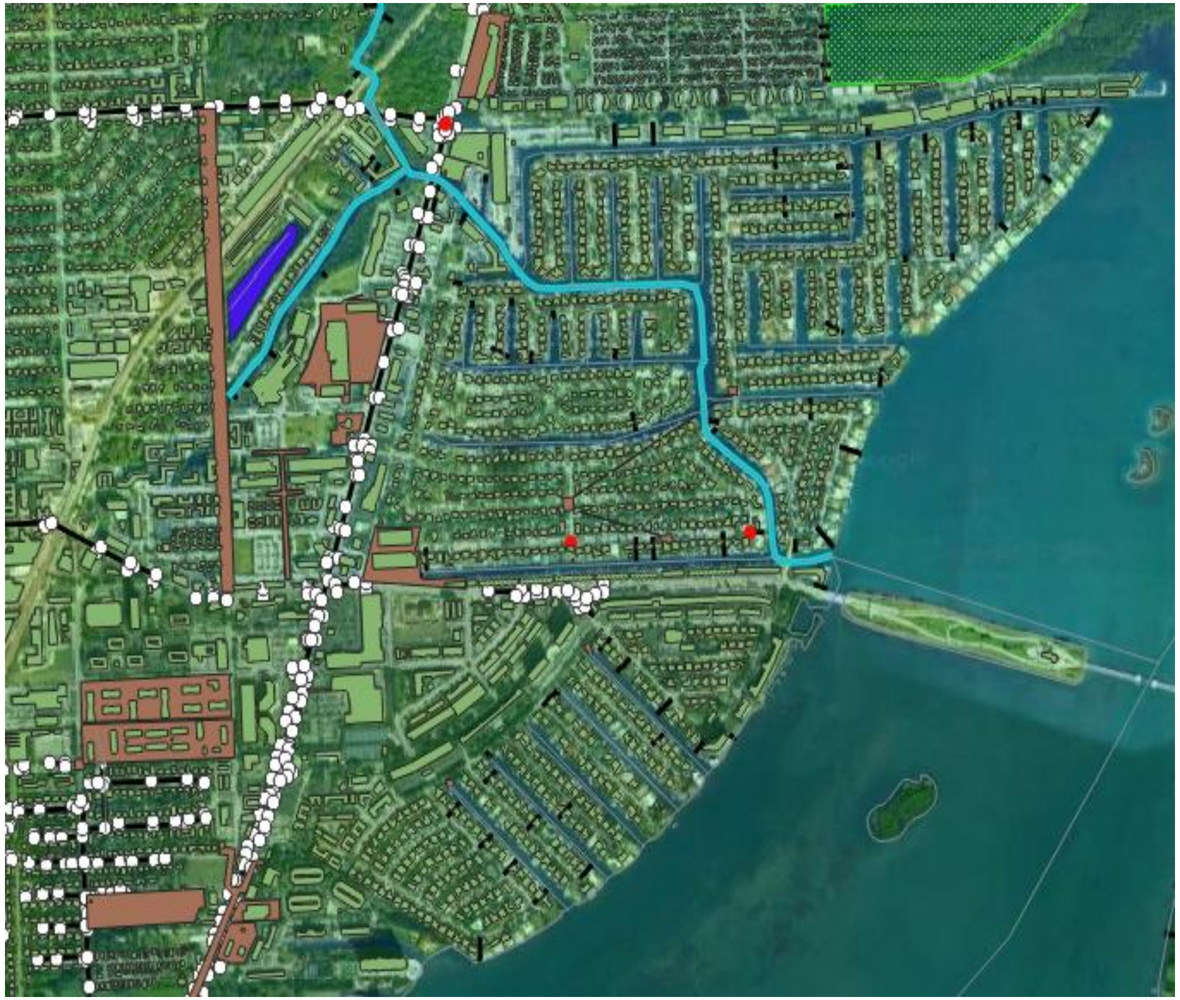
HydroSHEDS hydrography dataset.
Source: Andreadis et al. 2012

HOW TO BUILD A MODEL FROM SCRATCH

Storm Drain System

- Regional Geoportals
- Private entities

Types of storm drain inlets
Source: FLO-2D Storm Drain Manual



Elevation, land use, bathymetry and storm drain data.
Source: SFWMD (Miami)

HOW TO BUILD A MODEL FROM SCRATCH

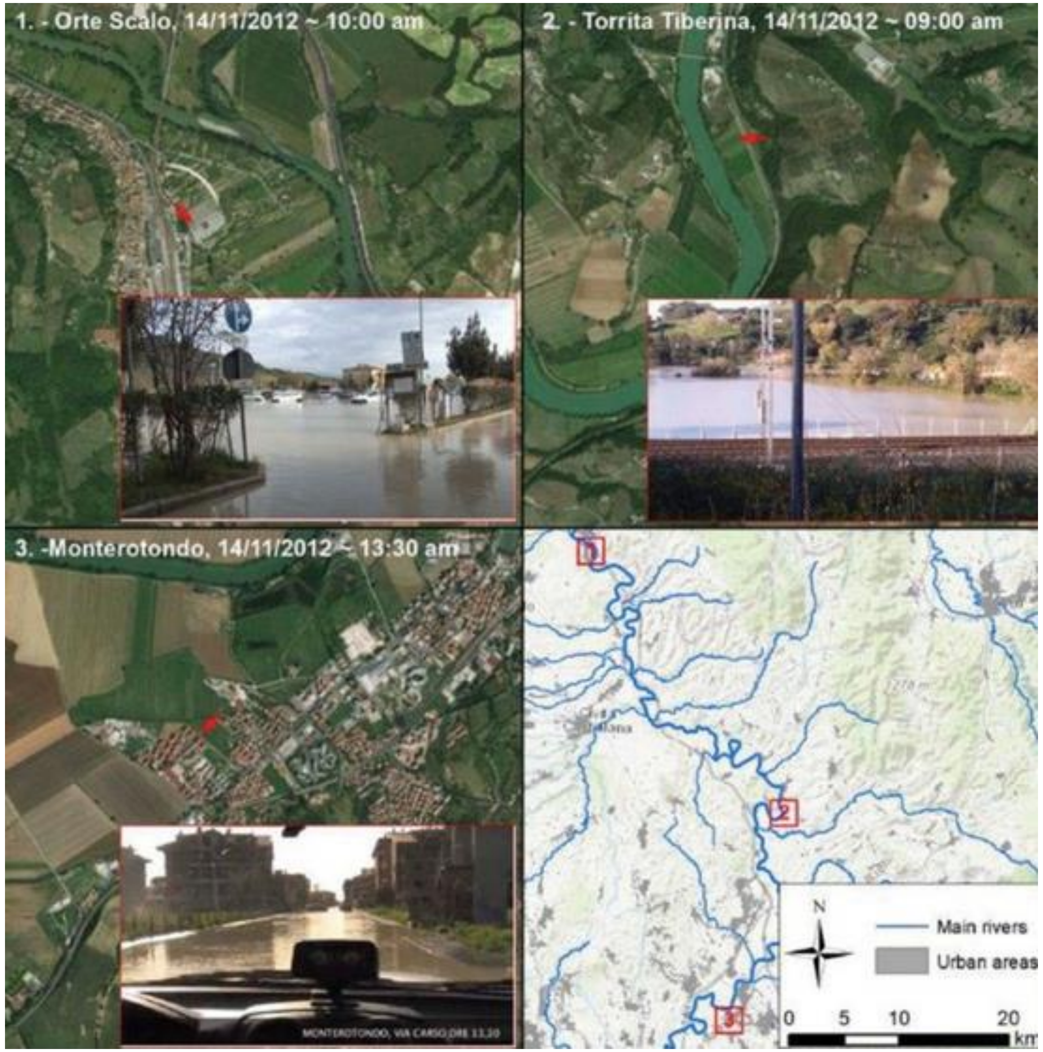
Crowdsourcing and Volunteered Geographic Information (VGI)

- Multimedia content:
  - Web browser
  - Social media platforms
  - Newspaper

Citizens as sensors to calibrate and validate flood models

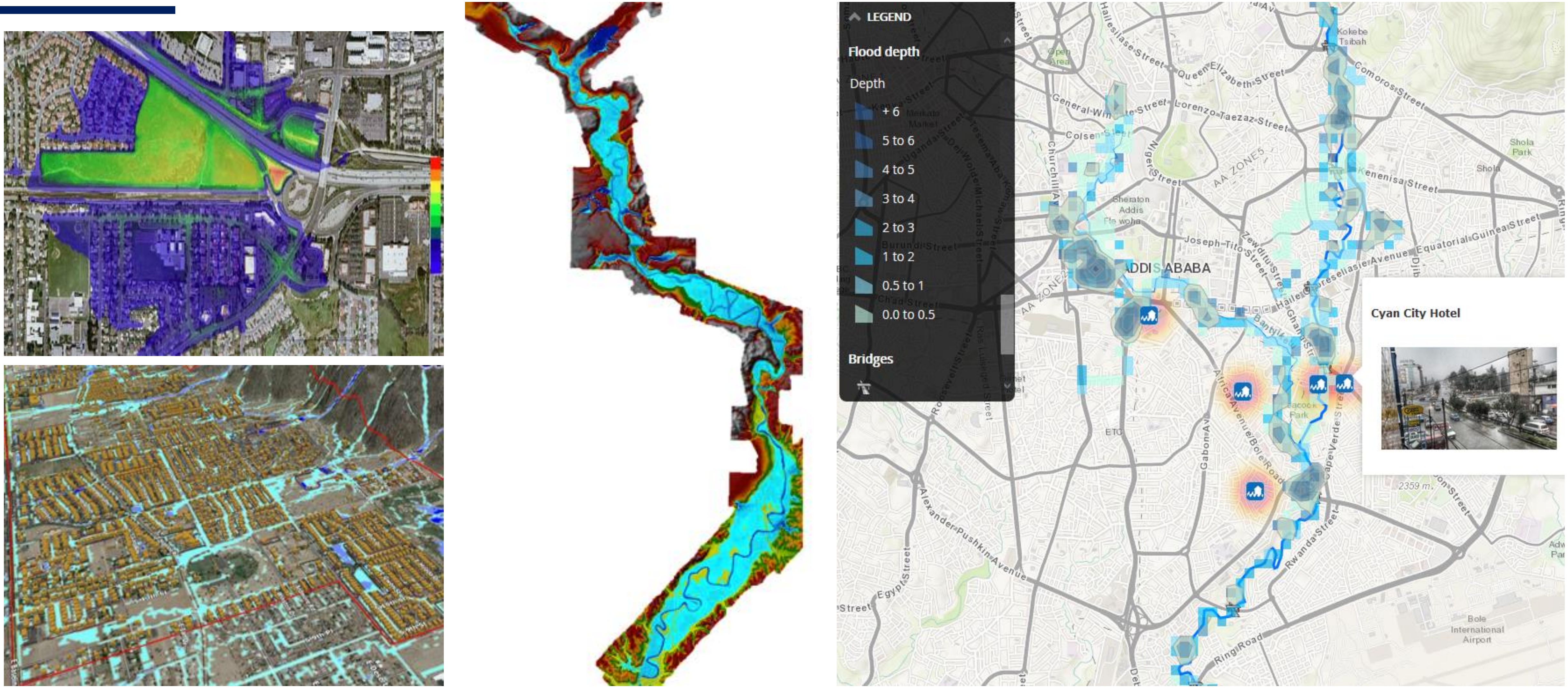
Integrating VGI and 2D hydraulic models into a data assimilation framework for real time flood forecasting and mapping

Antonio Annis[a,b] and Fernando Nardi[a,c]



Location of crowdsourced images selected for a specific flood event.Source: Annis and Nardi 2019

EXPECTED OUTPUTS



Flood hazard mapping products
Source: FLO-2D and Francisco Peña

EXPECTED OUTPUTS

- Important to understand the impacts of flooding in cultural and historical sites
- Identification of relevant/negligible flooding mechanisms to develop simplified flood studies
- All models are wrong, but some are useful = Better estimation of flood risk = Better policy making = More resilient cities

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