Data-Driven Geospatial Visual Analytics for Real-Time Urban Flooding Decision Support

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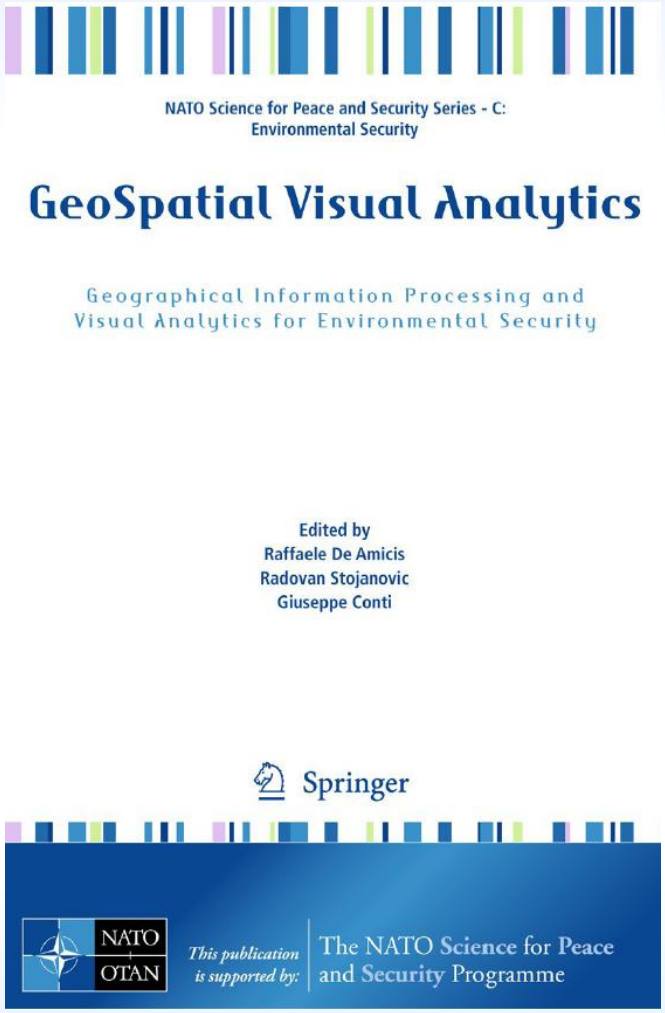
Introduction

- Real-time decision support is important for emergency management during extreme hydrological events (e.g., flooding)
  - Improved understanding and situational awareness
  - Model-based predictive control to minimize sewer overflow
- Existing water-related Decision Support System (DSS) is usually implemented for a specific problem situation without much reusable components
  - See a recent review by Argent et al. 2009 in *Environmental Modelling & Software*
- Leveraging Cyberinfrastructure and virtual sensor technology to deliver a DSS solution that's
  - loosely-coupled and extensible
  - event-driven and service-oriented

Geospatial Visual Analytics for Decision Support

- Geospatial visual analytics is an emerging multidisciplinary area
  - Supports analytical reasoning and decision-making through interactive visual interfaces (such as maps and other visual artifacts) that are linked to computational methods (*Andrienko et al., 2007*)
- Our Value-Added Features
  - Real-time Data-Driven
    - Continuously arriving streaming data
  - Real-time Event-Driven
    - User actions and sensor events
  - Model-Driven
    - Virtualization of the sensors through model-based transformation (virtual sensors)



Springer; 1st edition (December 1, 2009)

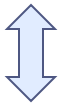
Decision Context and Goal: Urban Flooding

- Spatiotemporal distribution of intense rainfall significantly impacts the triggering and behavior of urban flooding
  - However, no general purpose decision tools yet exist for deriving rainfall data and rendering them in real-time at the resolution of urban hydrologic units (i.e.: sewershed) used for analyzing urban flooding.

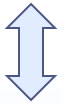
- ***Goal: Understand real-time spatiotemporal rainfall variability using NEXRAD data in an urban sewershed***

Loosely Coupled, Layered Architecture

Web User Interface
- Web 2.0 AJAX Map-centric

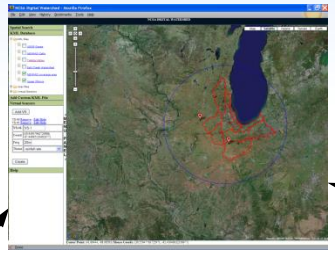


Data and Workflow Service
- Virtual Sensor Abstraction and Management Service
- Streaming Data Service (fetching, indexing, etc.)
- Workflow Service (with model integration)
- Tupelo Content and Provenance Management
- Virtual Machine Hosting



Remote Sensor Stores
- E.g.: NEXRAD Level II data from National Weather Service (NWS)'s Unidata LDM distribution system

An Implementation: Web 2.0 Geospatial Visual Analytics



Google Map AJAX Interface
User-Driven Time-Aware KML Animation

Virtual Sensor Management & Streaming Data Service

DSF Core Service

Workflow as a DSF Service

CyberIntegrator workflow tool

W3C Semantic Web
RDF
W3C OWL
W3C GRDDL
W3C SPARQL
tupelo

Content and Provenance Management Middleware

Repositories

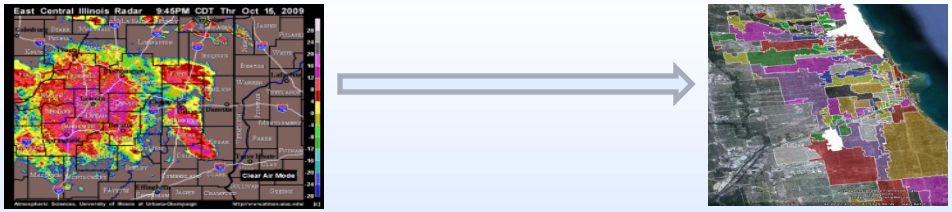
PostGIS
Spatial PostgreSQL
openRDF.org
Sesame
MySQL
semantic web framework
jena

REST: Representational State Transfer
RDF: Resource Definition Framework
AJAX: Asynchronous JavaScripts And XML
DSF: Digital Synthesis Framework for Virtual Observatory (NCSA)

NCSA

Virtual Sensors as New Sensor Streams

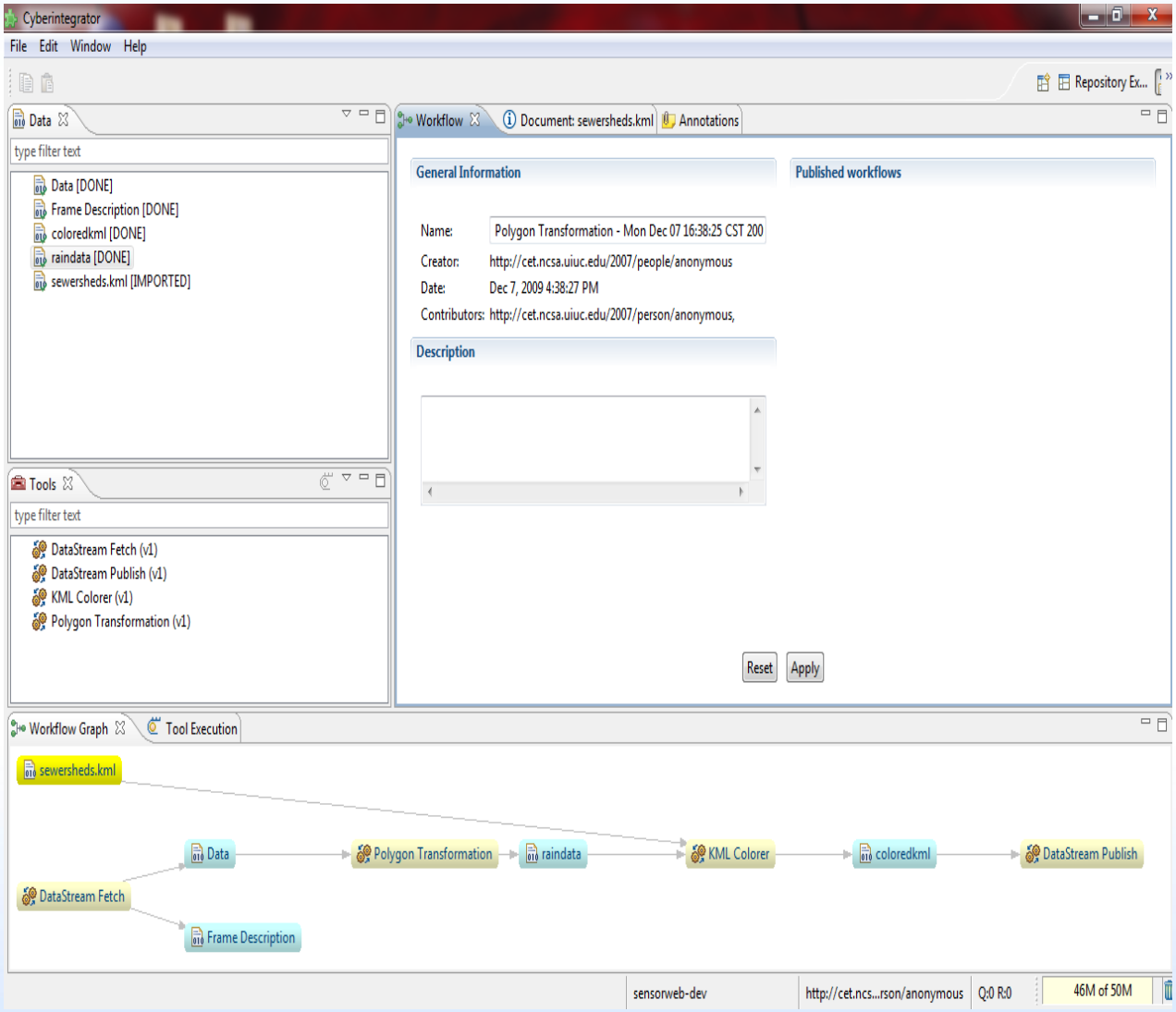
- Definition: a product of thematic, spatial, and/or temporal transformation and aggregation of one or multiple raw sensor measurement(s)
  - E.g.: polygon-based virtual rainfall sensor: real-time NEXRAD reflectivity is transformed into rainfall rate value (thematic transformation) for a given polygon area using spatial interpolation
- Results are then ***re-published*** as new “live” persistent “virtual” sensor streams
  - E.g.:the polygon-based virtual rainfall sensor is ***re-published*** as a new color-coded KML data stream



NCSA Streaming Data Toolkit

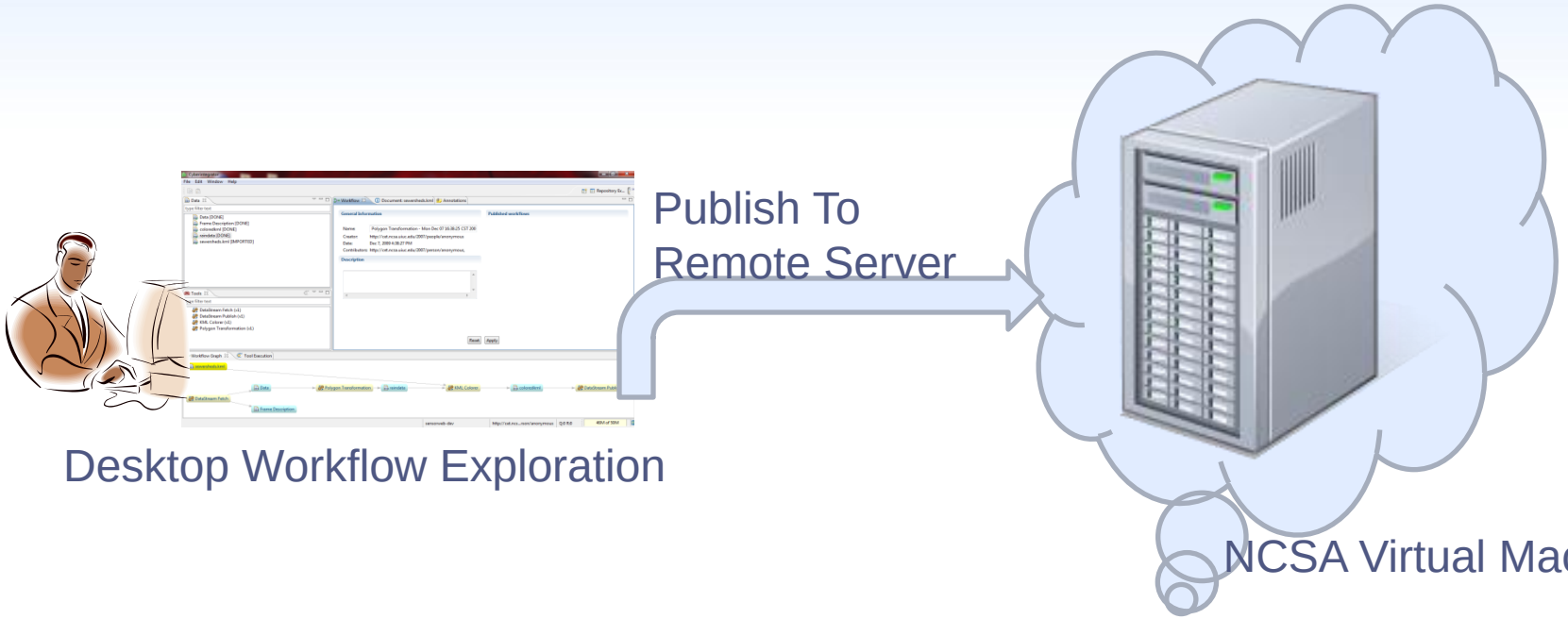
- Can model arbitrary time-series data
  - using Time-Annotated RDF – extensions for streaming
- Has implementations/wrappers for stream managers such as DataTurbine and ActiveMQ JMS
- Supports fetching, publishing, indexing and query
  - Window query; Point query; Newest, oldest; Previous, next
  - Publishing results in either CSV, XML, JSON or Open Geospatial Consortium (OGC) O&M format
- Enables the workflow tool to retrieve latest *x* frames for stream-aware computation and aggregation
- Can trigger workflow execution based on newly arrived sensor data event

CyberIntegrator: Stream-Aware Desktop Exploratory Workflow



- Identify Inputs
  - (e.g. the latest NEXRAD data)
- Link analyses and models
  - Could be Matlab, or C/C++ or Fortran code
- Provenance tracking
  - All data, metadata, configuration information stored as semantic content

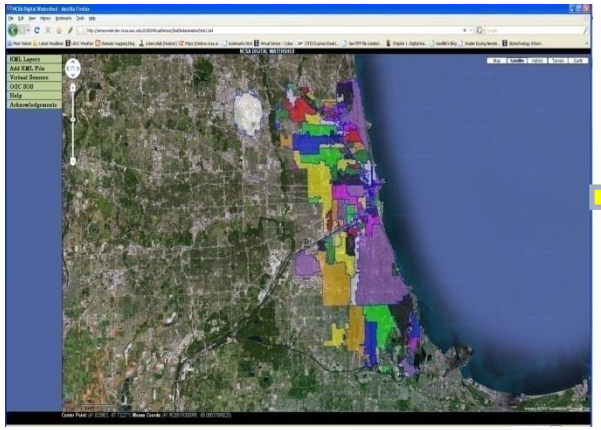
Publish A Workflow As A Web Service



- Published parametric workflow is a hosted RESTful web service
  - http://localhost:8183/cyberintegrator/engine/workflows/execute
- Each workflow has a global unique ID
  - E.g.: tag:cet.ncsa.uiuc.edu,2008:/workflow/817d17cc-3f9c-4694-9d1e-4bdcf926eab2
- Workflow execution is triggered by one of the following
  - **Event** (e.g.: new raw data arrival; or user actions by clicking a button at the user interface)
  - **Time** (e.g.: scheduled run in every 20 minutes)

Real-Time Data and Event Flow for Spatio-Temporal Animation

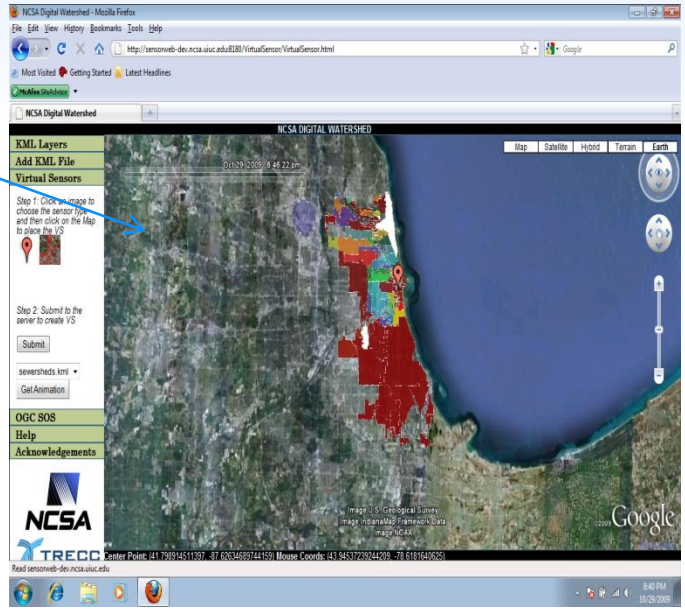
Web Front-end Map-centric Web Browser



Click a button

Animate

Play the movie in the browser



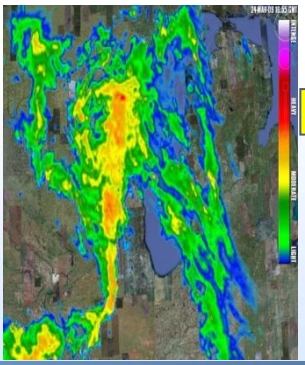
Streaming Fetcher (NEXRAD)

Polygon-based Spatial Transformation

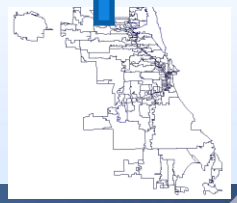
(Iteratively calculate rainfall rate for each polygon in the input KML file)

Output KML File Stream

(each frame is a color-coded sewershed map at one time step)



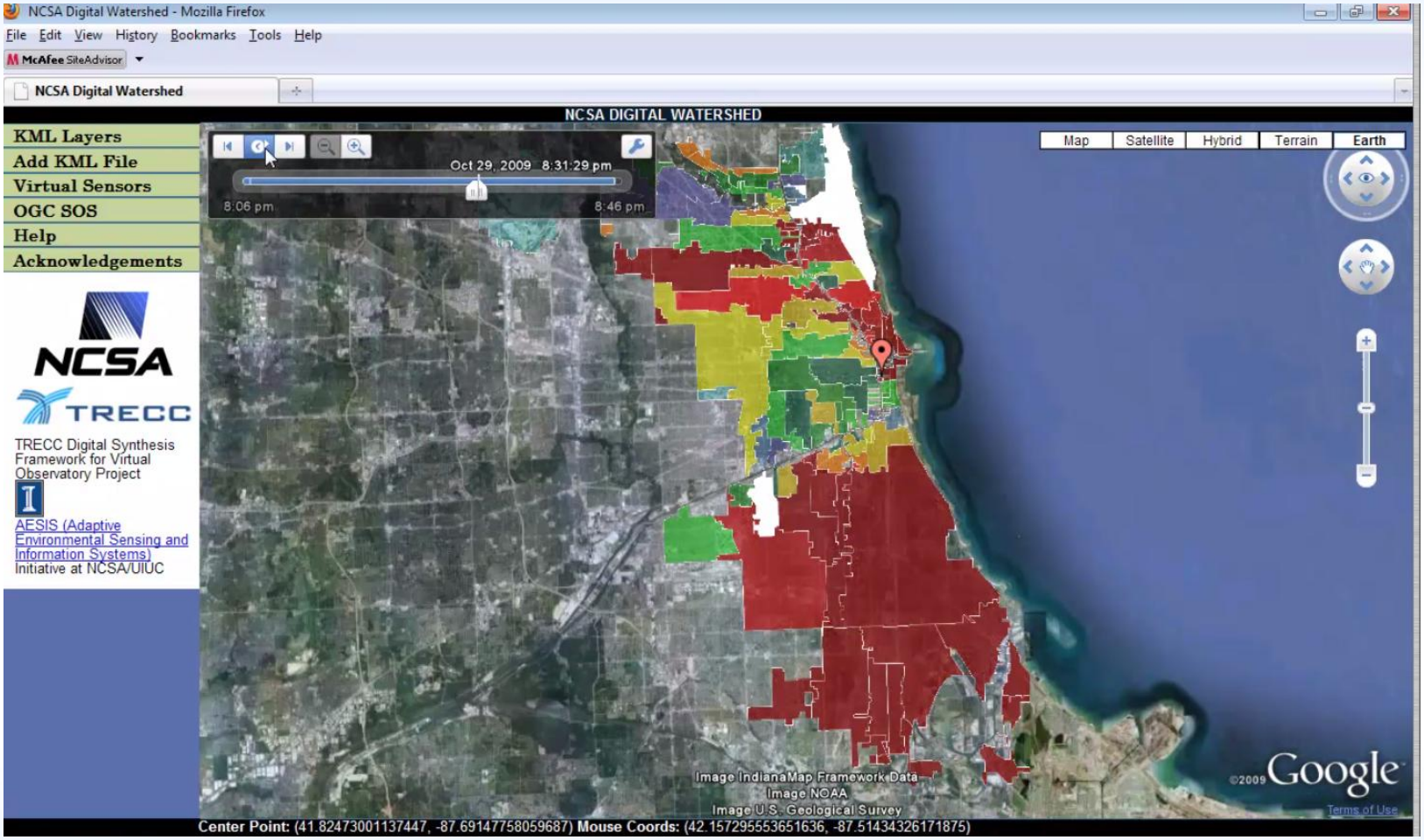
Raw NEXRAD Data



Read from the output KML stream and to auto-generate a time-aware KML file using last *x* frames

Output KML stream in the repository

A Demonstration



Different colors represent different rainfall values at different polygons.

http://www.ncsa.illinois.edu/~yongliu/demos/ACMGIS-2009Demo.mp4

Conclusions

- A Cyber-enabled real-time geospatial-temporal visual analytics system for urban flooding decision making has been prototyped
  - Loosely coupled, service oriented, and event-driven architecture
- Polygon-based virtual sensor is implemented to produce persistent virtual rainfall sensors from NEXRAD
  - Real-time geo-temporal rainfall rate visualization for urban sewershed has been demonstrated to improve understanding of urban flooding and decision making
- Incorporating new observational data sources as well as new model-based results can be done with this flexible and evolvable system
  - E.g.: Basement flooding events, CSO events, Model-predictive control results etc.

Acknowledgments

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