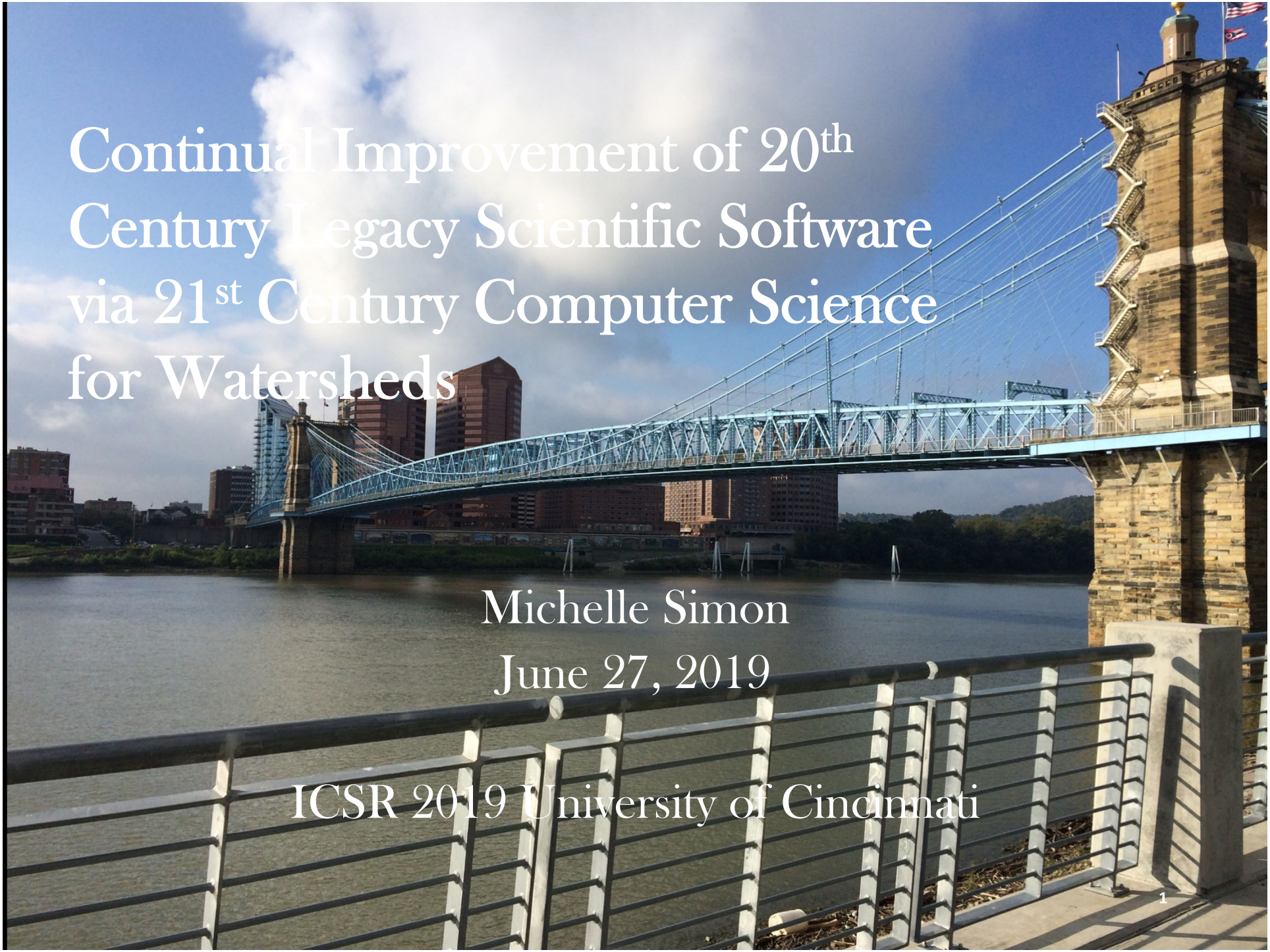


Continual Improvement of 20th Century Legacy Scientific Software via 21st Century Computer Science for Watersheds

Michelle Simon

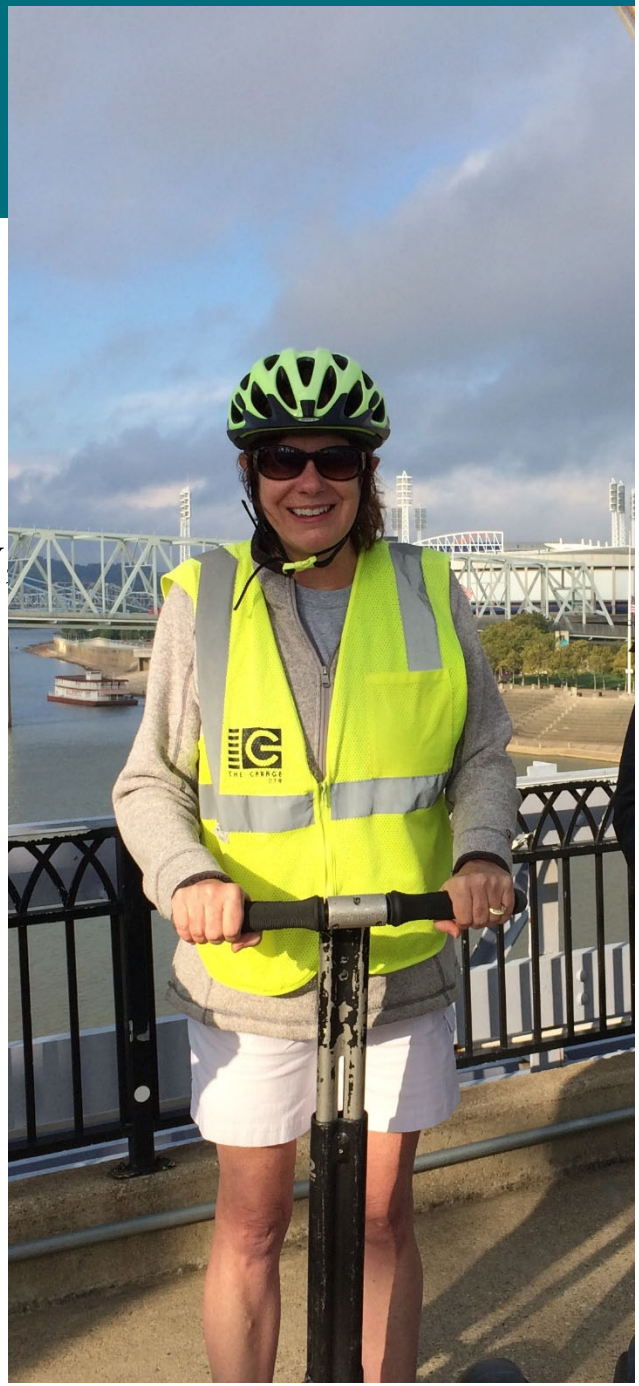
June 27, 2019

ICSR 2019 University of Cincinnati

Speaker Introduction

Michelle Simon, Ph.D., P.E.
Associate Director of Science
Water Systems Division,
National Risk Management Research Laboratory
Office of Research and Development
United States Environmental Protection Agency
Cincinnati, OH

EPA Technical POC for Storm Water Management Model (SWMM)



Disclaimer

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Outline

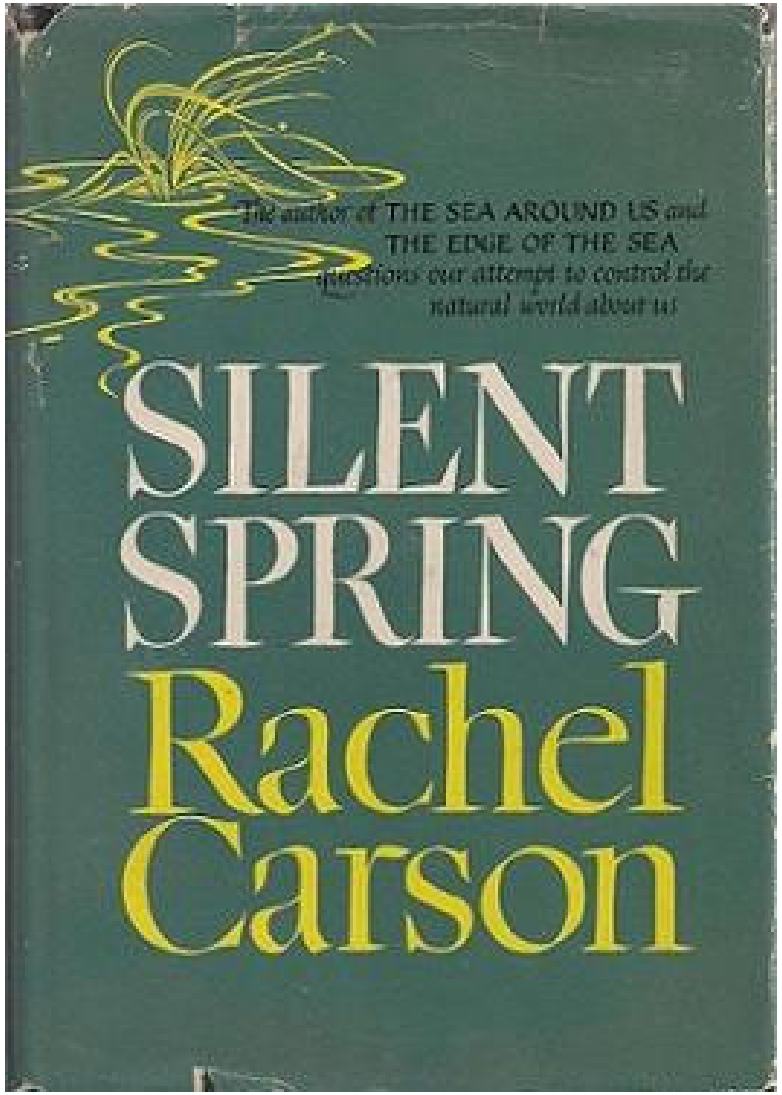
Combination of Computer Science and Environmental Science

- Environmental Protection - History
- Intersection with Computer Science
- Conclusions and Discussions

National Parks – March 1, 1872

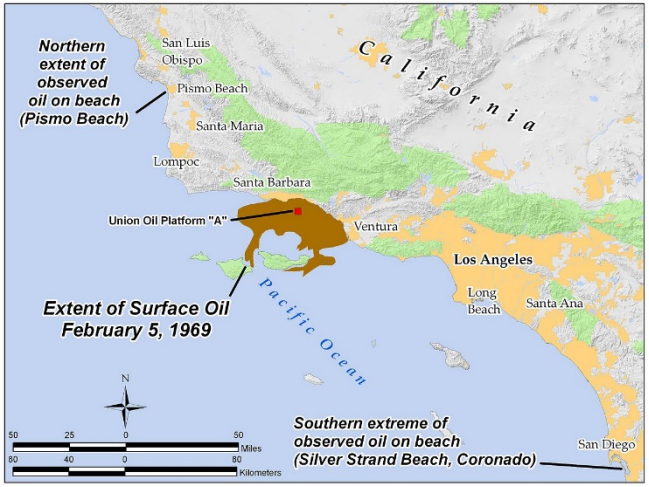
Grand Canyon - 1919

The Silent Spring – Rachel Carson 1962



Polluting the Environment

New York City veiled in smog in 1973
National Archives



By Antandrus at English Wikipedia, CC BY-SA 3.0,
https://commons.wikimedia.org/w/index.php?curid=16365110

Gene Daniels/U.S. National Archives

Cuyahoga River Fire – 1952, 1969

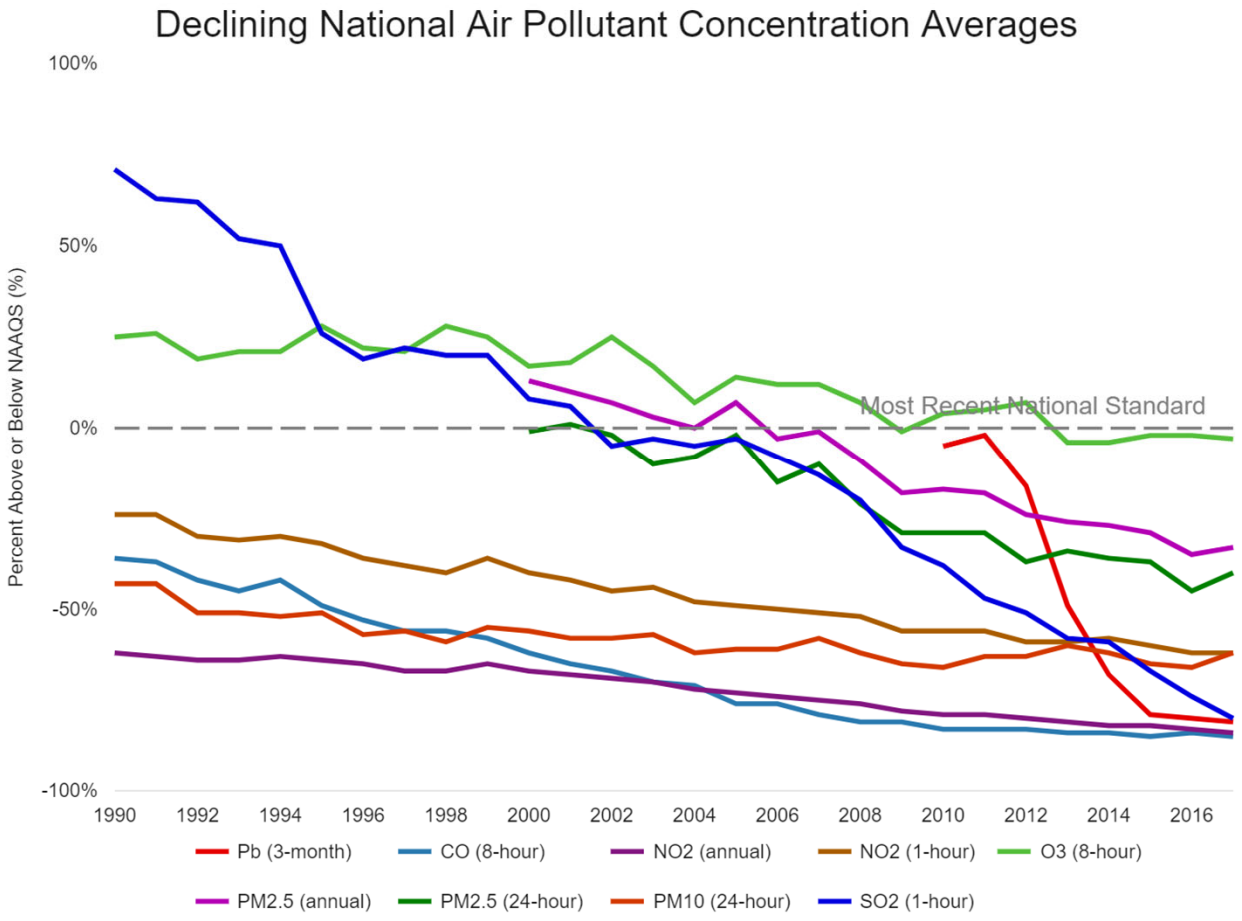
The Cleveland Press Collection

United States Environmental Protection Agency

Mission

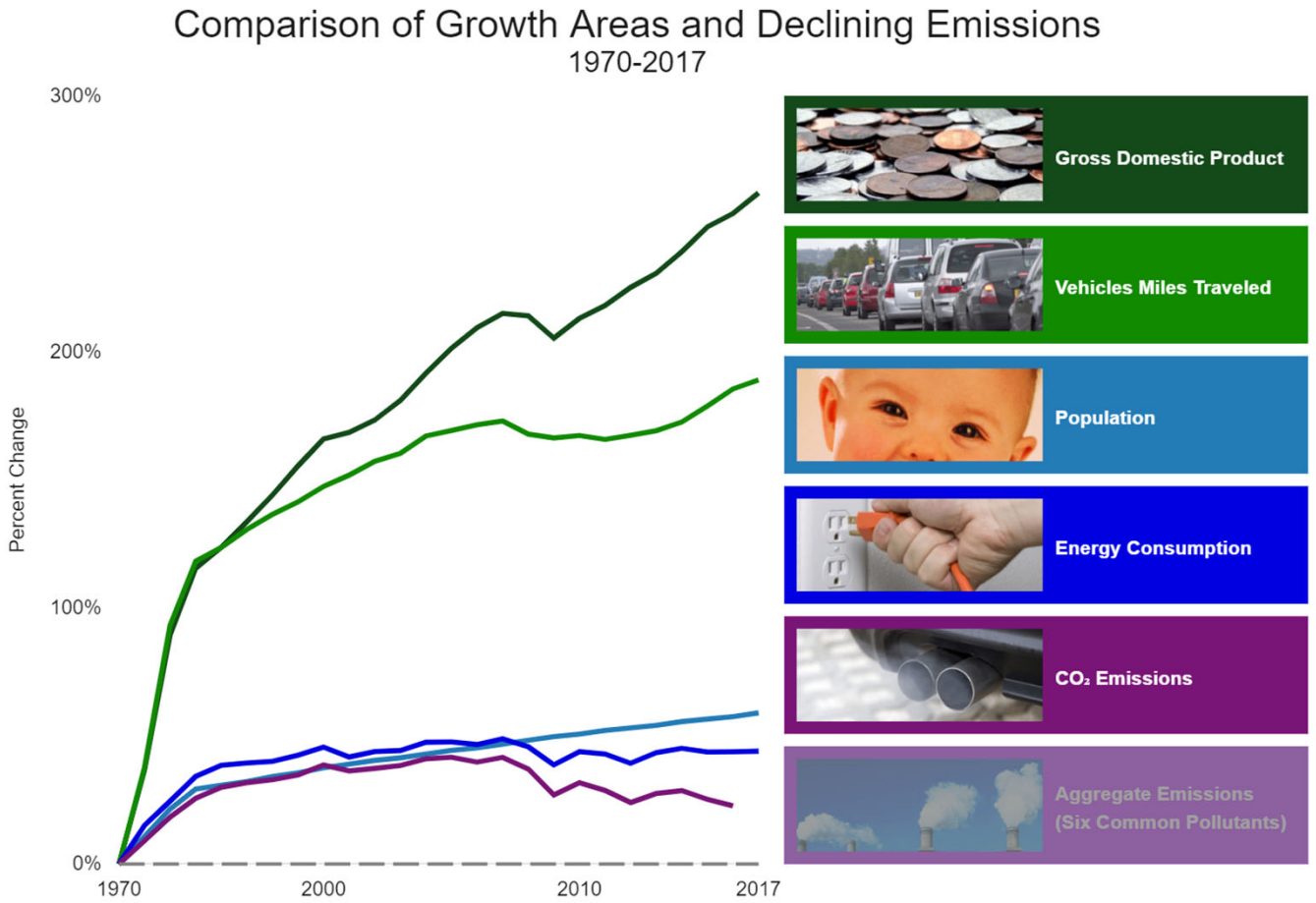
To protect Human Heath and the Environment

EPA Impact on Air Quality



https://gispub.epa.gov/air/trendsreport/2018/#growth

Economic, Population Growth and Environmental Impact

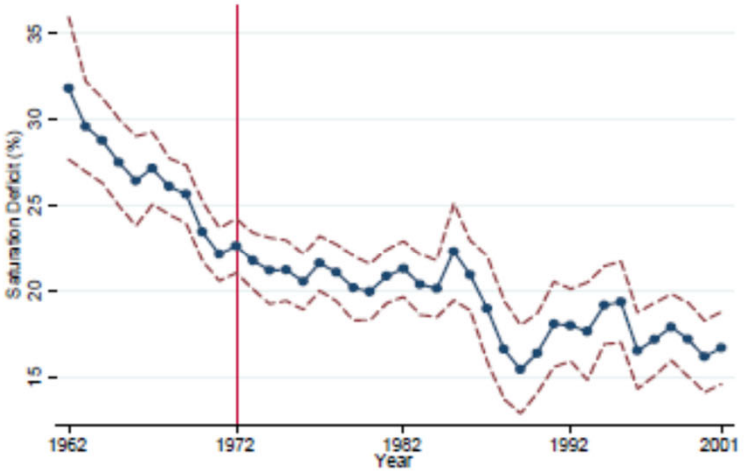


https://gispub.epa.gov/air/trendsreport/2018/#growth_w_cleaner_air

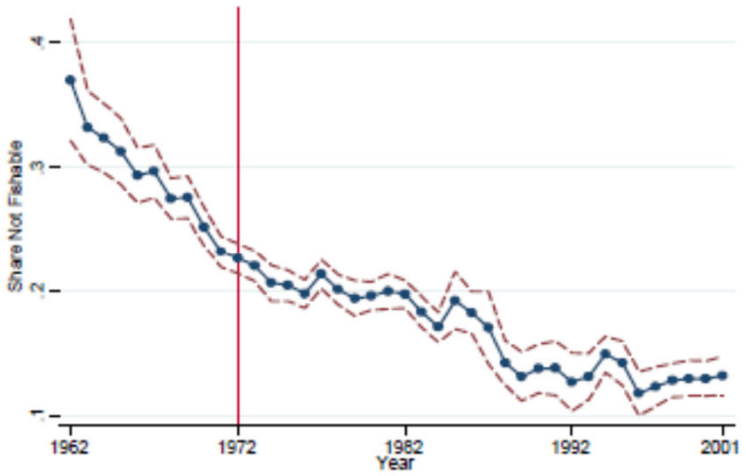
Clean Water Act Impact

Figure 2. Water Pollution Trends, 1962-2001

Panel A. Dissolved Oxygen Deficit



Panel B. Share Not Fishable

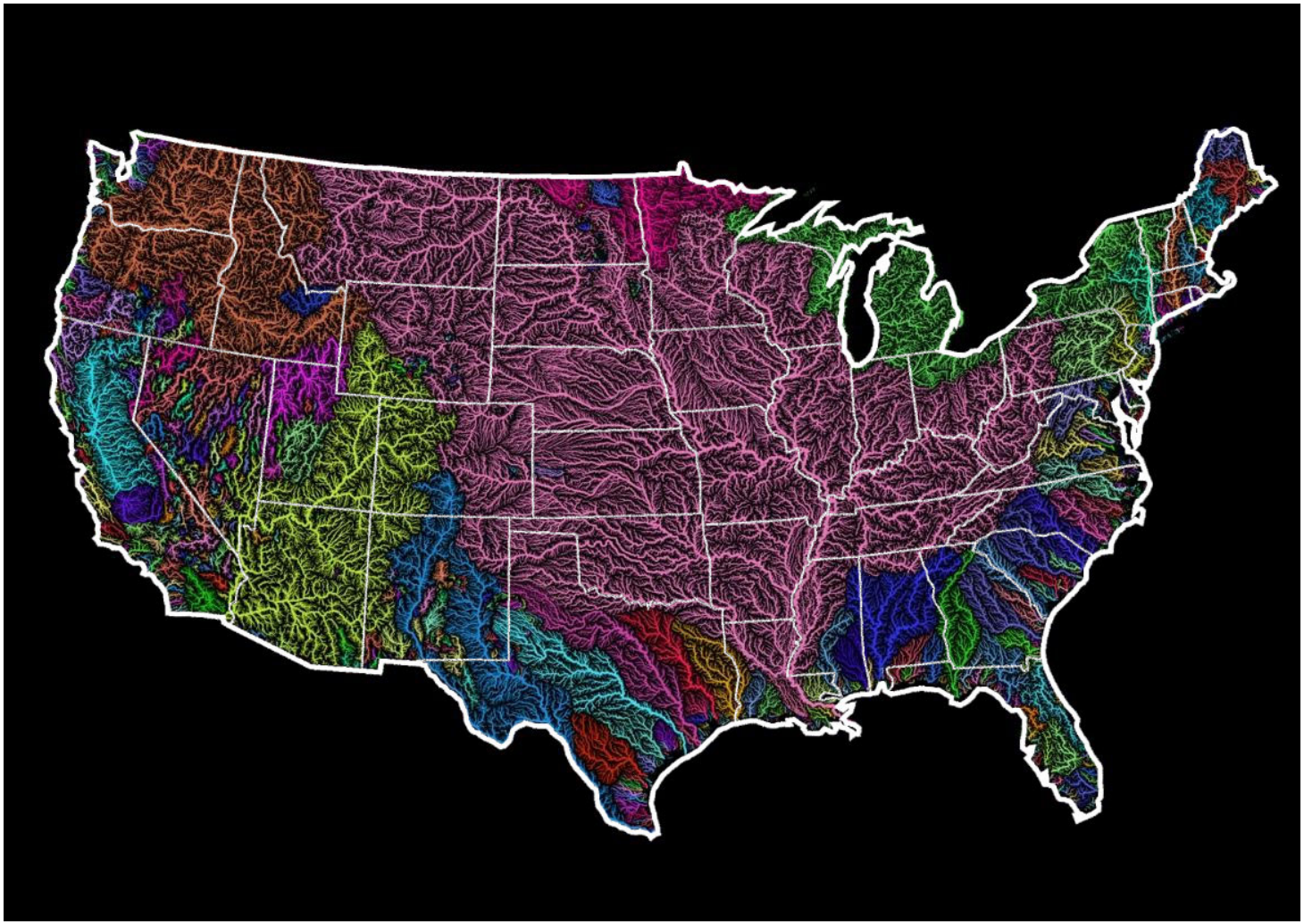


Notes: Graphs show year fixed effects plus a constant from regressions which also control for monitoring site fixed effects, a day-of-year cubic polynomial, and an hour-of-day cubic polynomial, corresponding to equation (2) from the text. Connected dots show yearly values, dashed lines show 95% confidence interval, and 1962 is reference category. Standard errors are clustered by watershed.

https://pdfs.semanticscholar.org/bbd9/ef58e916bc76ae3c036767047e24a0e8512f.pdf

Watershed

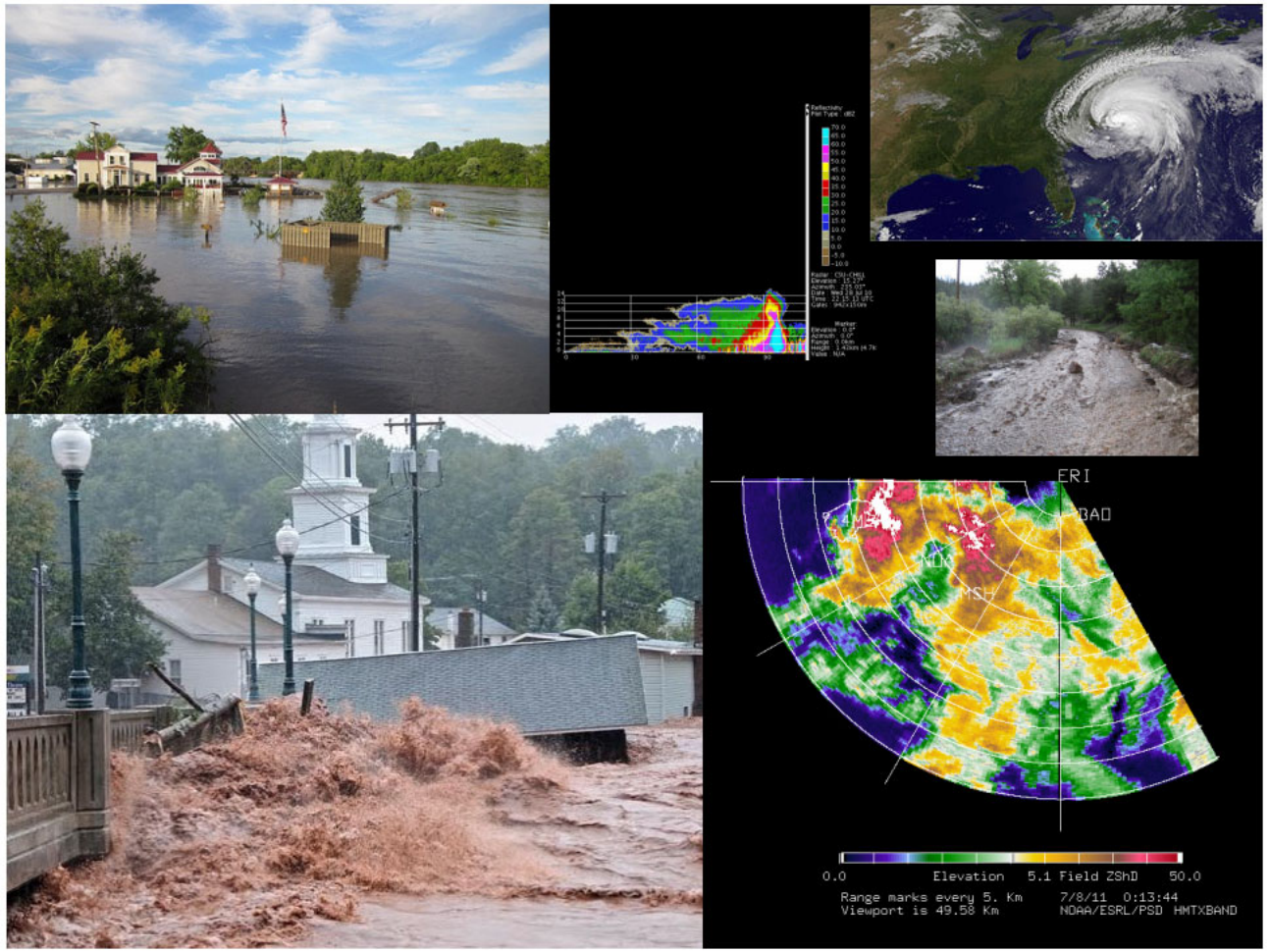
https://www.visualcapitalist.com/maps-worlds-watersheds/



Watershed Flow Animation

https://www.washingtonpost.com/videonational/animation-shows-the-mississippi-watershed-the-largest-drainage-basin-in-north-america/2016/12/08/e294b76a-bd6b-11e6-ae79-bec72d34f8c9_video.html?utm_term=.5262214d85fc

Flooding



https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/02-Gochis.pdf

Calculations for Dams

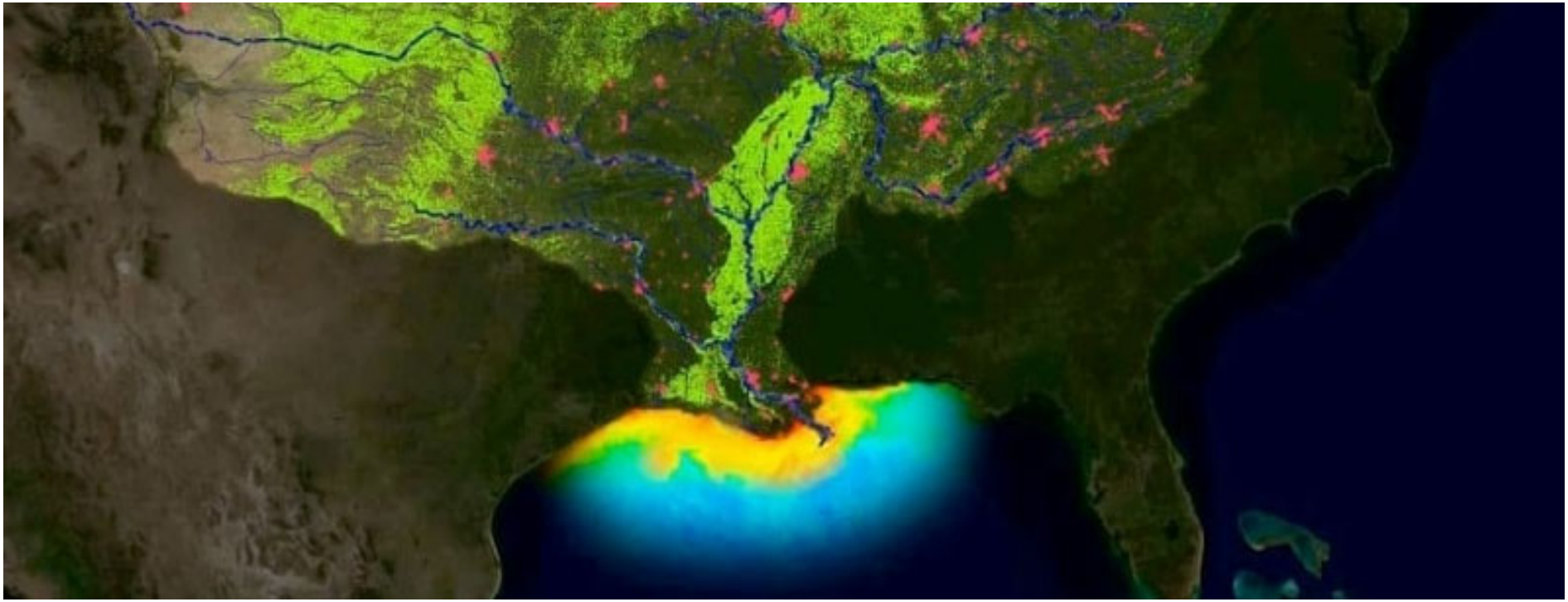
Glen Canyon Dam:

The Upper Basin States' bank account

- Pre-1963 average inflows 12,963,000 AF
- Post-1963 average inflows 10,701,000 AF

https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/CI-WATER_50yrs_26Sept12.pdf

Nutrient Runoff – hypoxia zone



US Watersheds

Watershed Model Strategy

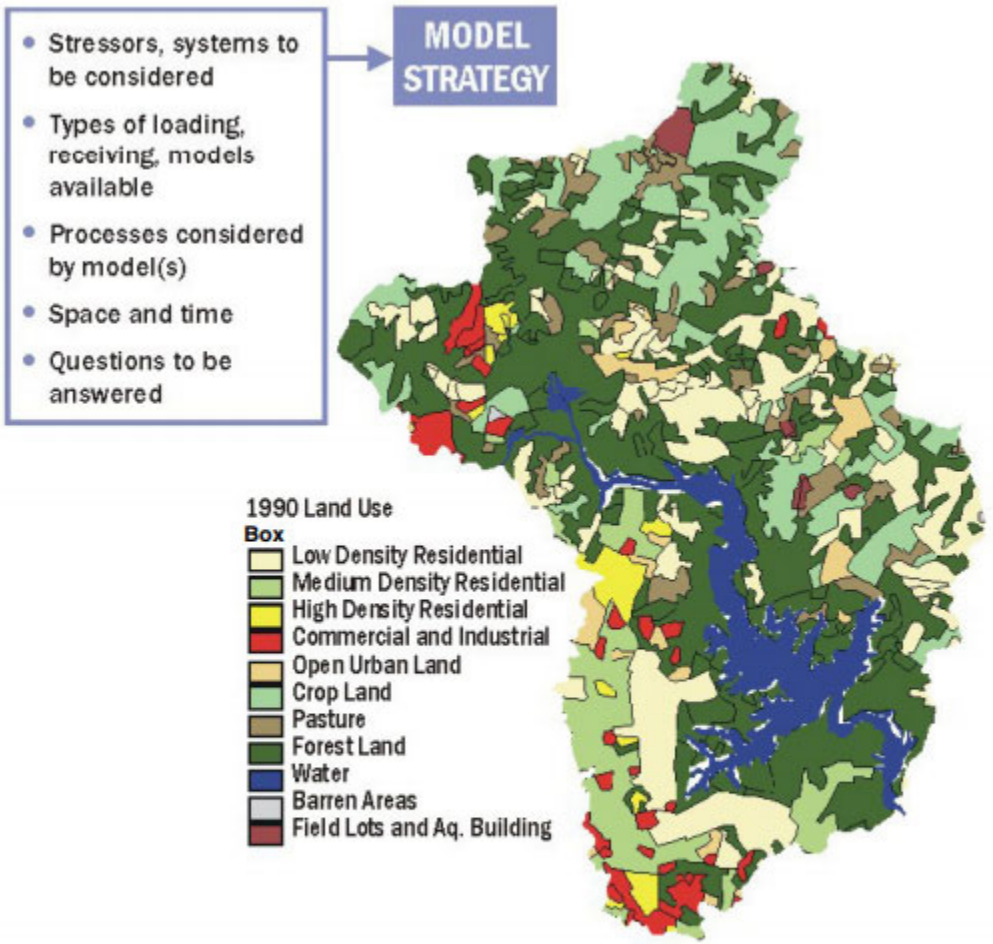
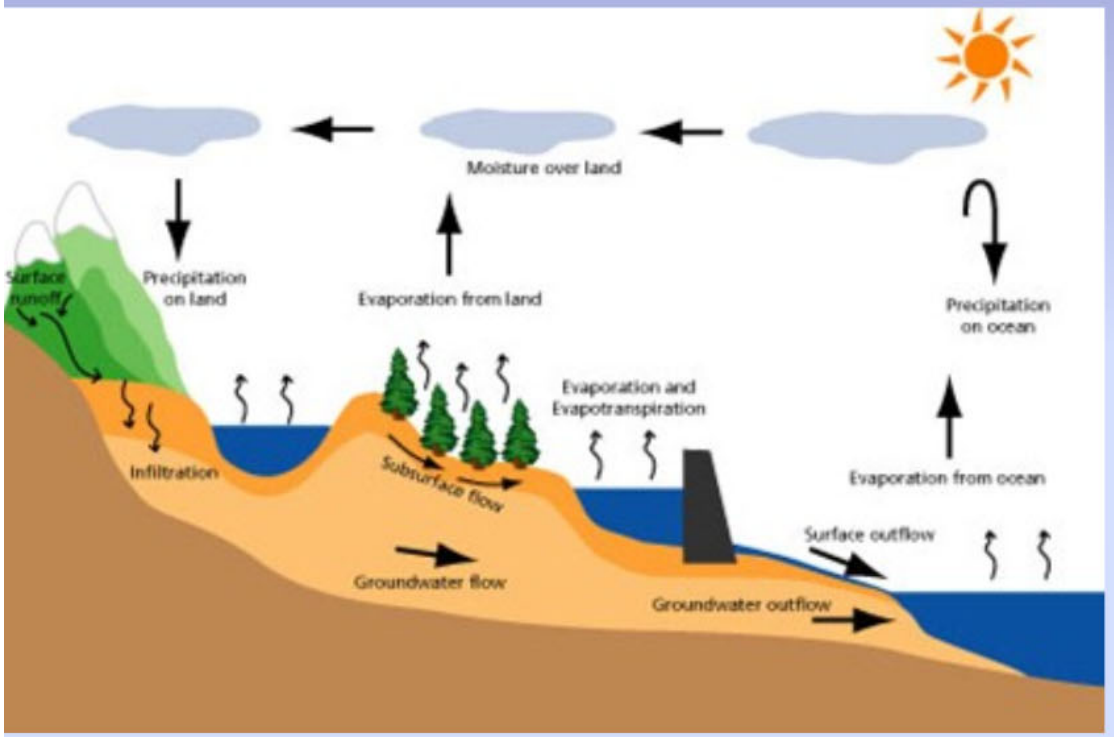


Figure 10

https://cfpub.epa.gov/watertrain/pdf/modules/WshedModTools.pdf

Conceptual Model for Watershed Modeling



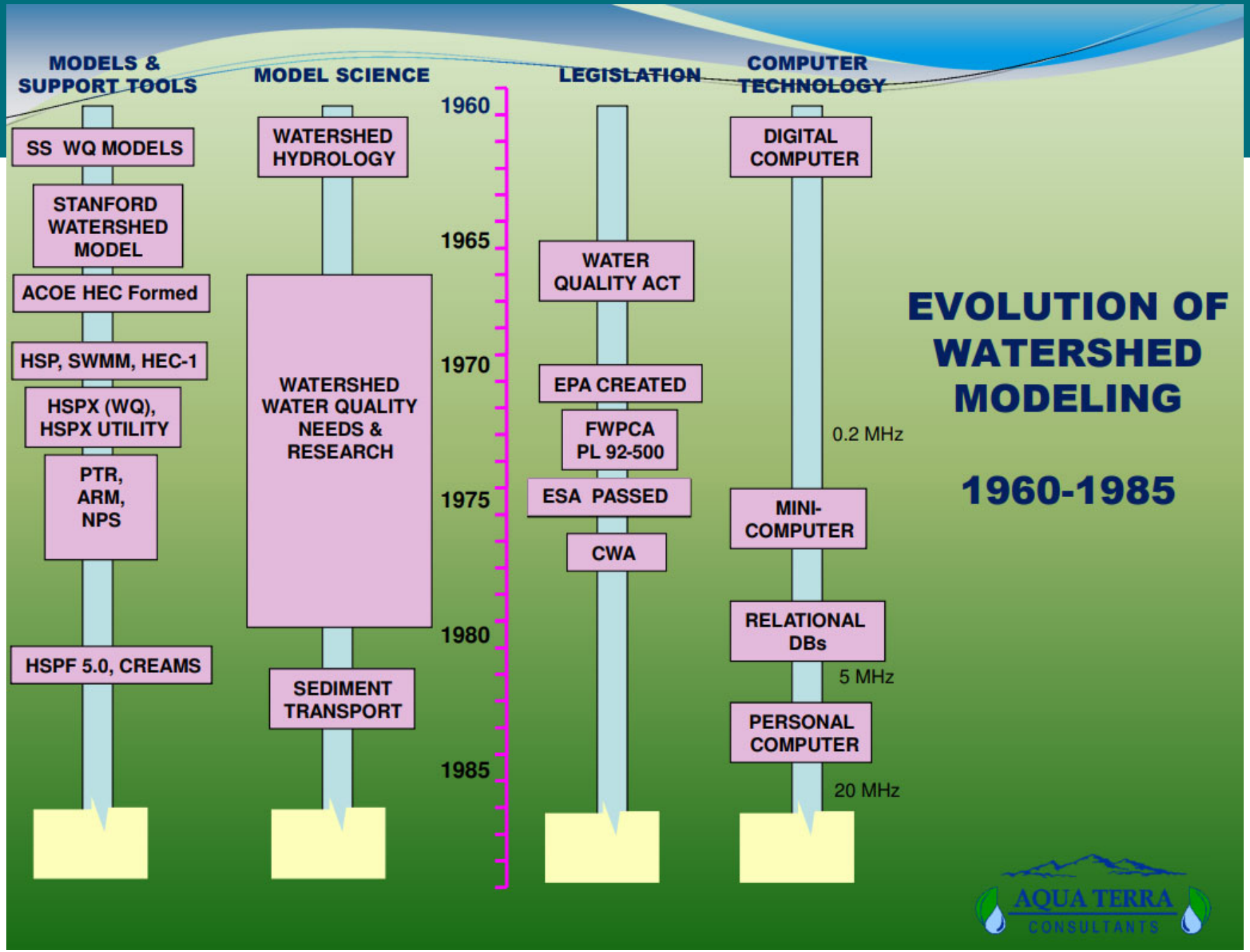
Typical Input

- Topography
- Soil Characteristics
- Land cover
- Land use
- Meteorological data

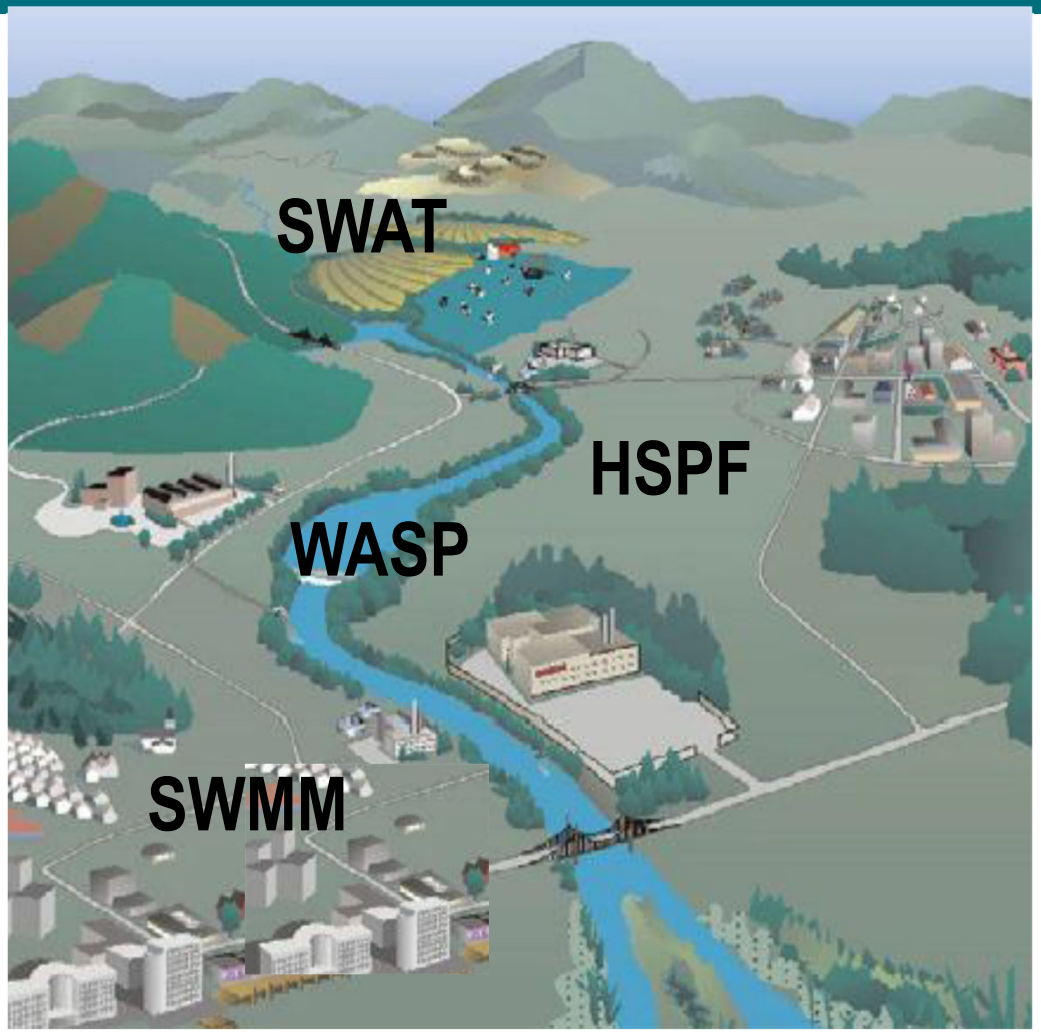
Typical Output

- Streamflow
- Subsurface Flow

https://slideplayer.com/slide/5161814/


MODELS & SUPPORT TOOLS
MODEL SCIENCE
LEGISLATION
COMPUTER TECHNOLOGY
SS WQ MODELS
STANFORD WATERSHED MODEL
ACOE HEC Formed
HSP, SWMM, HEC-1
HSPX (WQ), HSPX UTILITY
PTR, ARM, NPS
HSPF 5.0, CREAMS
WATERSHED HYDROLOGY
WATERSHED WATER QUALITY NEEDS & RESEARCH
SEDIMENT TRANSPORT
1960
1965
1970
1975
1980
1985
WATER QUALITY ACT
EPA CREATED
FWPCA PL 92-500
ESA PASSED
CWA
DIGITAL COMPUTER
0.2 MHz
MINI-COMPUTER
RELATIONAL DBs
5 MHz
PERSONAL COMPUTER
20 MHz
EVOLUTION OF WATERSHED MODELING
1960-1985
AQUA TERRA CONSULTANTS

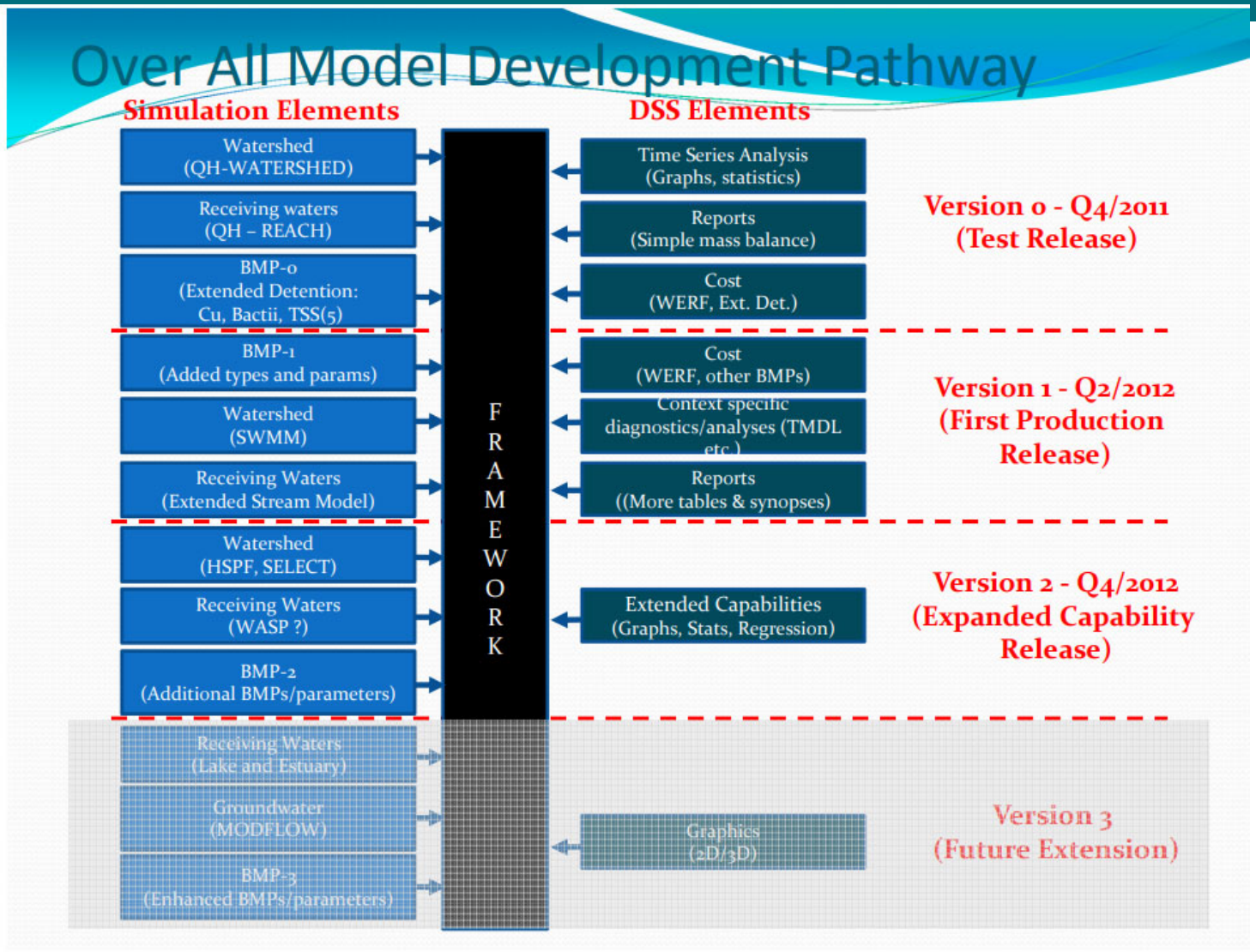
How SWMM, HSPF, SWAT, and WASP Relate



https://cfpub.epa.gov/watertrain/pdf/modules/WshedModTools.pdf

https://www.aquaterra.com/resources/pubs/fiftyyearwatershedconferencePrograms.php

Over All Model Deveopment

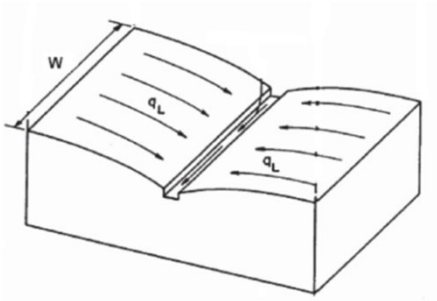


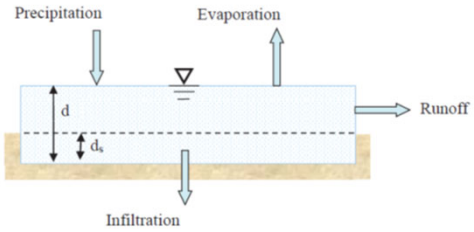
https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/LAR_50-yrs%20Modeling_Integrated%20Urban%20Water%20System.pdf

Data Requirements

Either you measure it or you download it

- Soil Infiltration from a Soil database (SSURGO or STATSGO)
- Land Use – Land Cover
- National Land Cover Dataset – (NLCD)
- Climatic Data – find closest NOAA station
  - (use Stormwater Calculator)
- Site Configuration
  - Subcatchment area
  - Topography



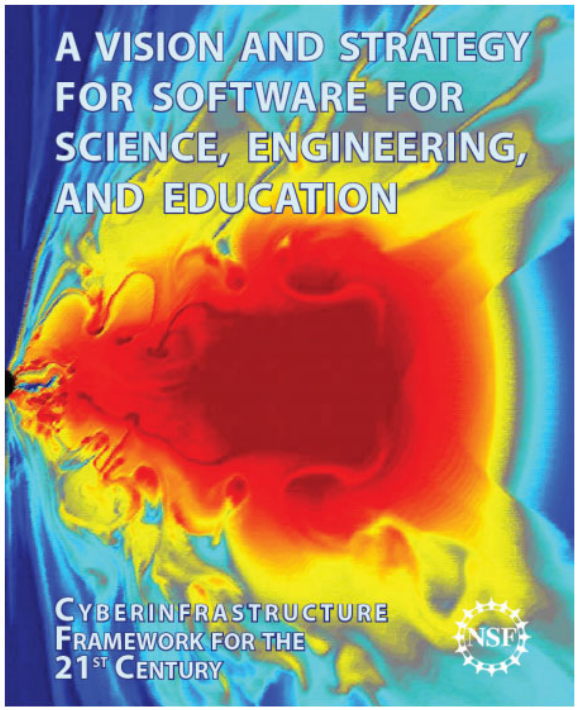


Data Management

NSF vision

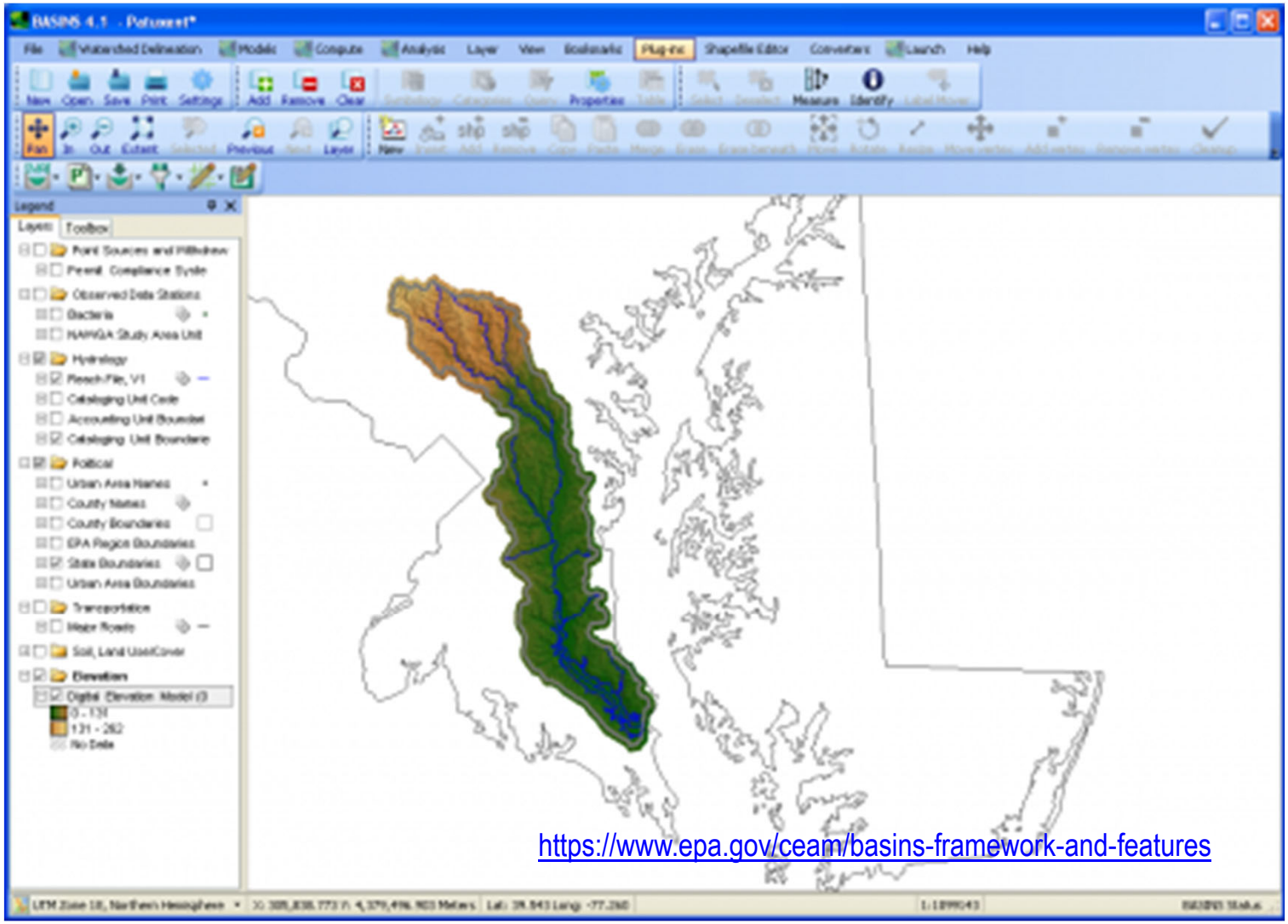
"enabling software systems are needed to create an environment in which the barrier to access is low for innovation and new discovery"

- Data Management and Preservation
- Software Sustainability



http://www.nsf.gov/pubs/2012/nsf12113/nsf12113.pdf

GUI + Data Extracting and Loading



https://datagateway.nrcs.usda.gov/

USDA Natural Resources Conservation Service
United States Department of Agriculture

Geospatial Data Gateway

Home | Login | Check Order | Status Maps | News | Data Policy | FAQ | Help | NAIP Download | Contact Us

You are here: Home / GDGHome.aspx

- Natural Resources Conservation Service
- Farm Services Agency
- Rural Development
- National Geospatial Center of Excellence (NGCE)
- Aerial Photography Field Office (APFO)
- Web Soil Survey
- eFOTG
- Geo.Data.Gov
- USGS Maps, Imagery and Publications
- National Atlas
- National Map Viewer 2.0
- US Census Bureau Geography
- Download TIGER/Line Shapefiles
- Download Public Land Survey System Data
- United States Elevation Inventory

Welcome to GDG

System Status:
Welcome to GDG 6.0.4.7481. All products and services are running normally.

PLEASE NOTE: As of April 21, 2017 the NAIP datasets are only available through the "NAIP Download" option on the home page and are no longer be available through the Gateway ordering process. Also note, NAIP images are titled by county FIPS codes. FIPS codes may be referenced by clicking on the "county FIPS" link on the Direct Download page.

The Geospatial Data Gateway (GDG) provides access to a map library of over 100 high resolution vector and raster layers in the Geospatial Data Warehouse. It is the One Stop Source for environmental and natural resources data, at any time, from anywhere, to anyone. It allows you to choose your area of interest, browse and select data, customize the format, then review and download.

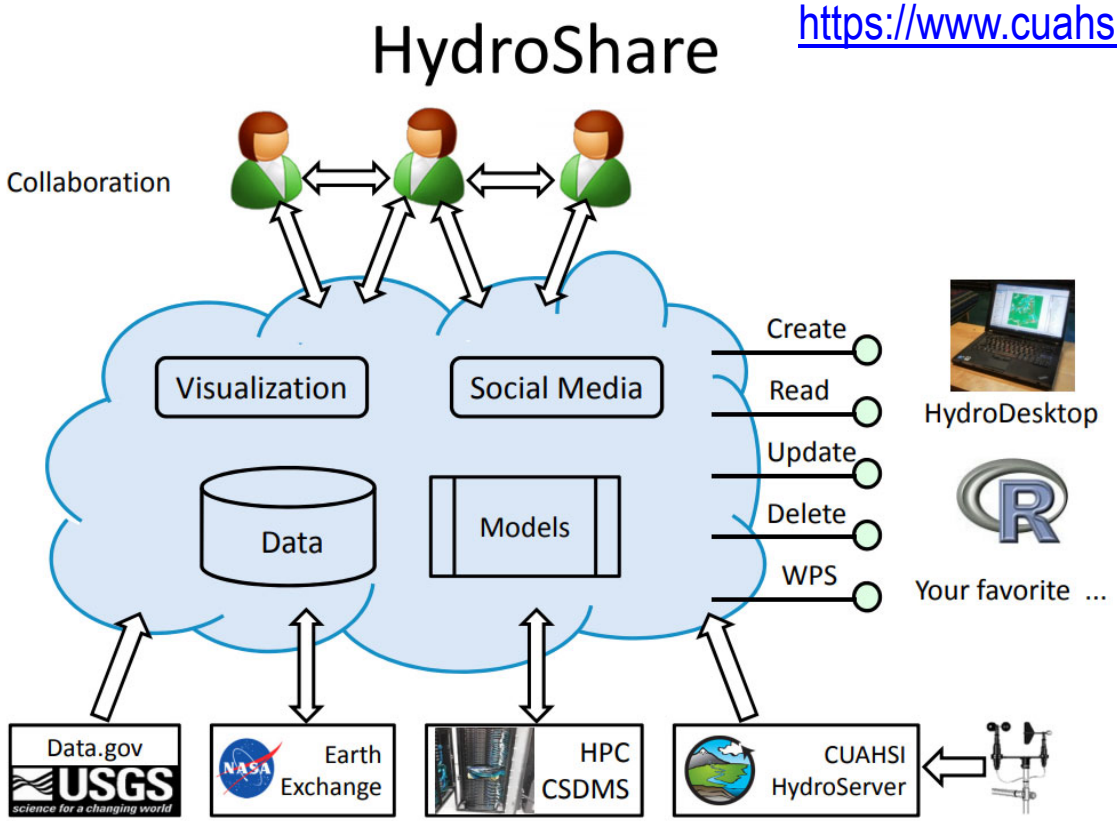
This service is made available through a close partnership between the three Service Center Agencies (SCA); Natural Resources Conservation Service (NRCS), Farm Service Agency (FSA) and Rural Development (RD).

I Want To...

- NAIP Download
- Direct Download
- Order by County/Counties
- Order by State
- Order by Place
- Order by entering Latitude/Longitude Bounding Rectangle
- Order by Interactive Map using custom Area Of Interest

CUASHI Hydrologic Data Share System

https://www.cuahsi.org/



https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/01-Tarboton.pdf

Modeling process

Mathematical Abstraction

$$\frac{\partial(\phi C)}{\partial t} = -\nabla \cdot (J_{adv} + J_{disp})$$

$$\frac{\partial(\phi C)}{\partial t} = -\frac{\partial(\phi v C)}{\partial x} + \frac{\partial^2(\phi D_h C)}{\partial x^2}$$

$$C = \frac{C_0}{2}\left[erfc\left(\frac{L - vt}{2\sqrt{D_h t}}\right) + \exp\left(\frac{vL}{D_h}\right) erfc\left(\frac{L + vt}{2\sqrt{D_h t}}\right)\right]$$

with the initial and boundary conditions:

$$\begin{aligned} C(x,0) &= 0 \qquad & x \geq 0 \\ C(0,t) &= C_0 \qquad & t \geq 0 \\ C(\infty,t) &= 0 \qquad & t \geq 0 \end{aligned}$$

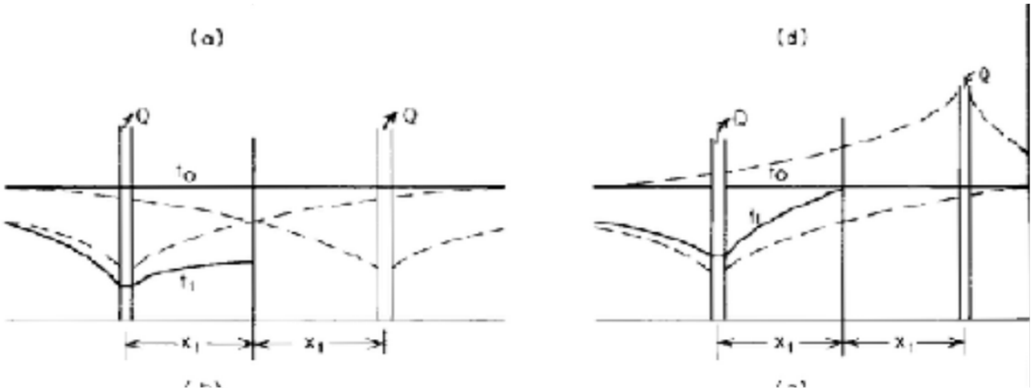
Convert Math to Code

```
// Storage layer properties
double storageThickness = theLidProc->storage.thickness;
double storageVoidFrac = theLidProc->storage.voidFrac;

//... retrieve moisture levels from input vector
surfaceDepth = x[SURF];
storageDepth = x[STOR];

//... convert moisture levels to volumes
SurfaceVolume = surfaceDepth * theLidProc->surface.voidFrac;
SoilVolume = 0.0;
StorageVolume = storageDepth * storageVoidFrac;

//... get ET rates
availVolume = (storageThickness - storageDepth) * storageVoidFrac;
getEvapRates(SurfaceVolume, 0.0, 0.0, StorageVolume, 1.0);
```

https://www.openswmm.org/SWMM51013/lidproc-c/trenchFluxRates

Numerical Methods

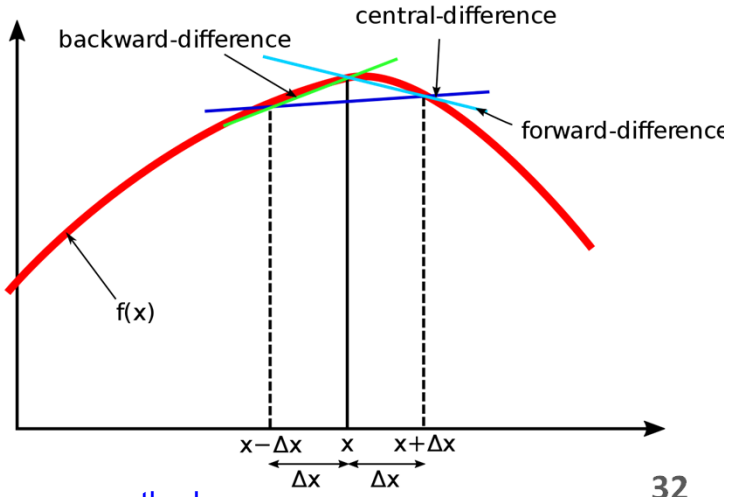
Analytical Element



http://utdallas.edu/~brikowi/Teaching/Applied_Modeling/GroundWater/LectureNotes/analytic_element.pdf

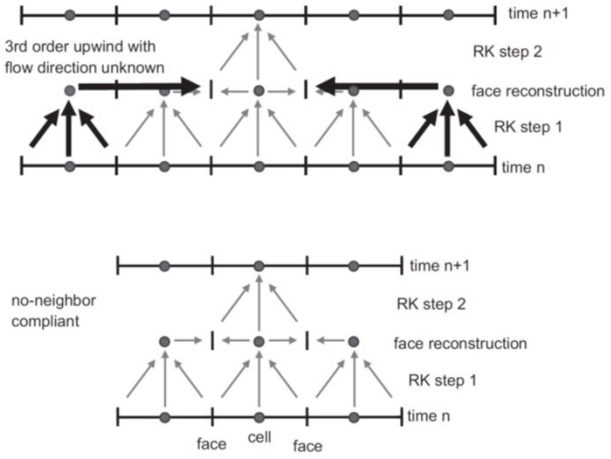
Finite Difference

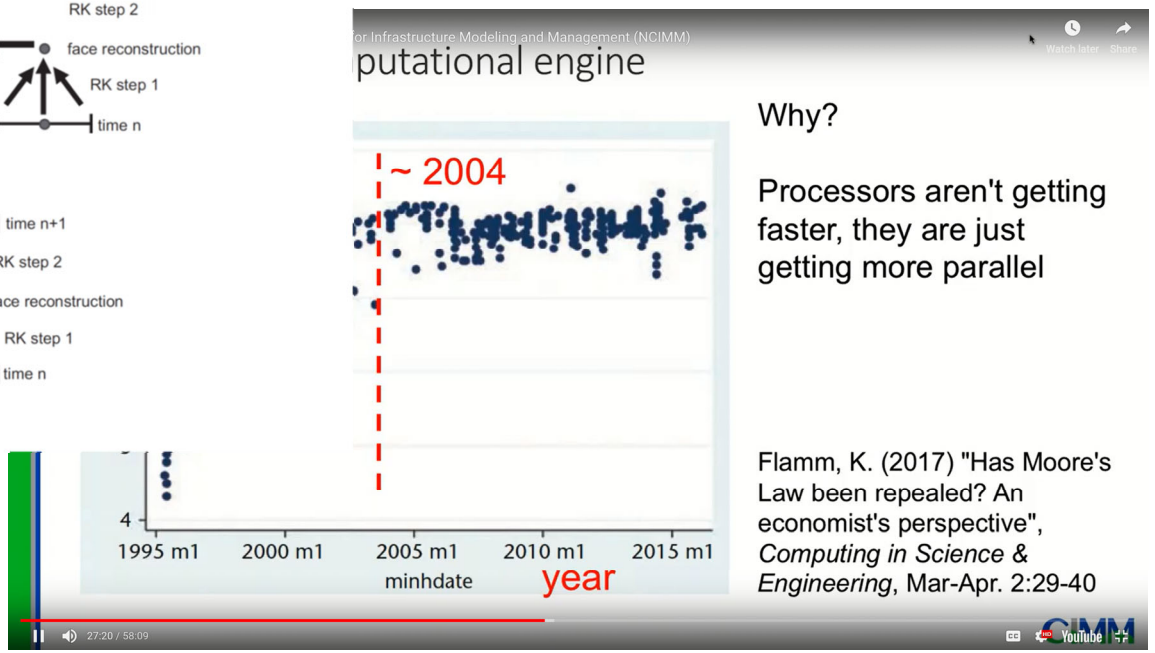
$$\delta_h[f](x) = f\left(x + \tfrac{1}{2}h\right) - f\left(x - \tfrac{1}{2}h\right)$$



https://en.wikipedia.org/wiki/Finite_difference#/media/File:Finite_difference_method.svg

New Solver



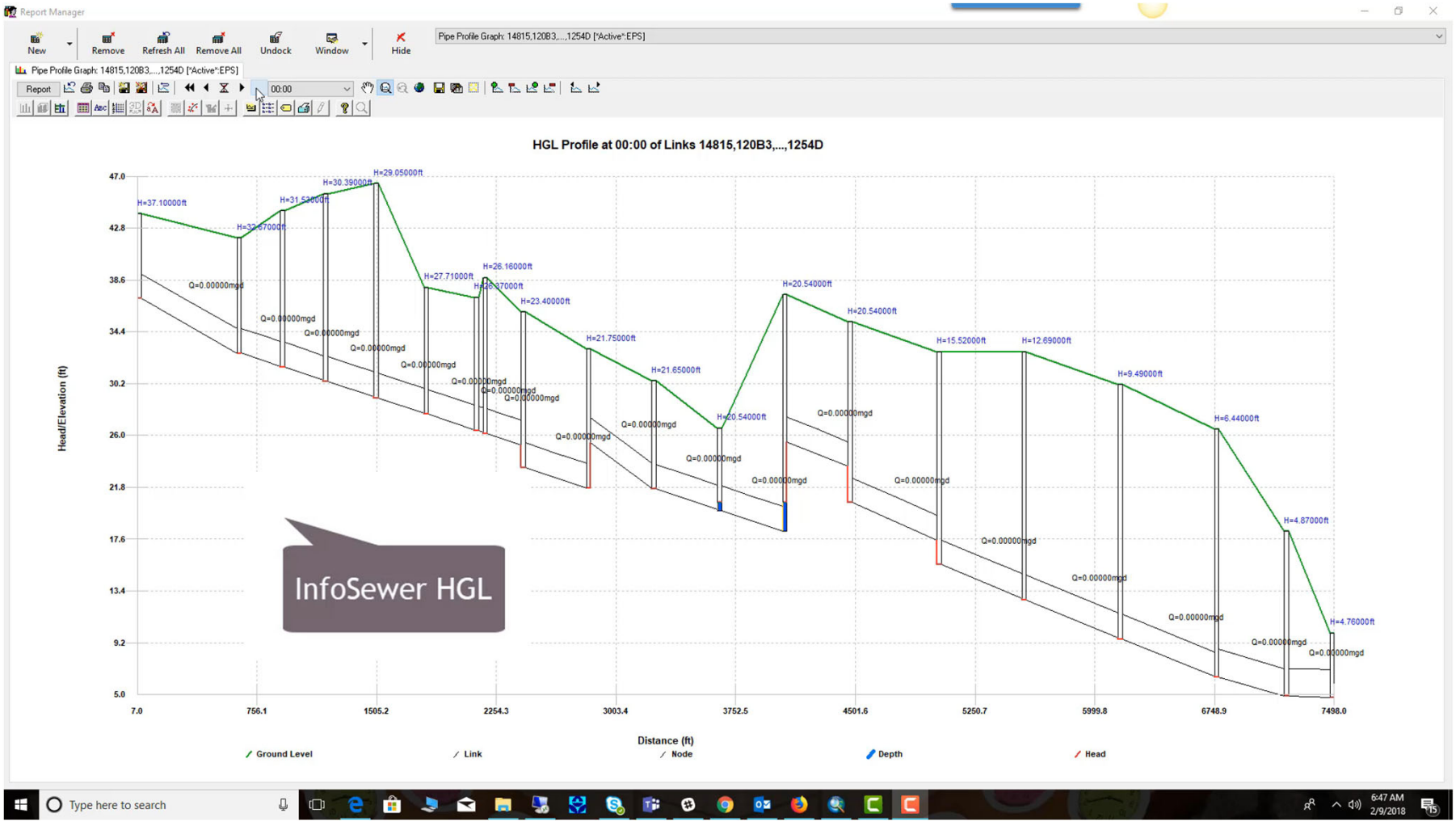


Why?

Processors aren't getting faster, they are just getting more parallel

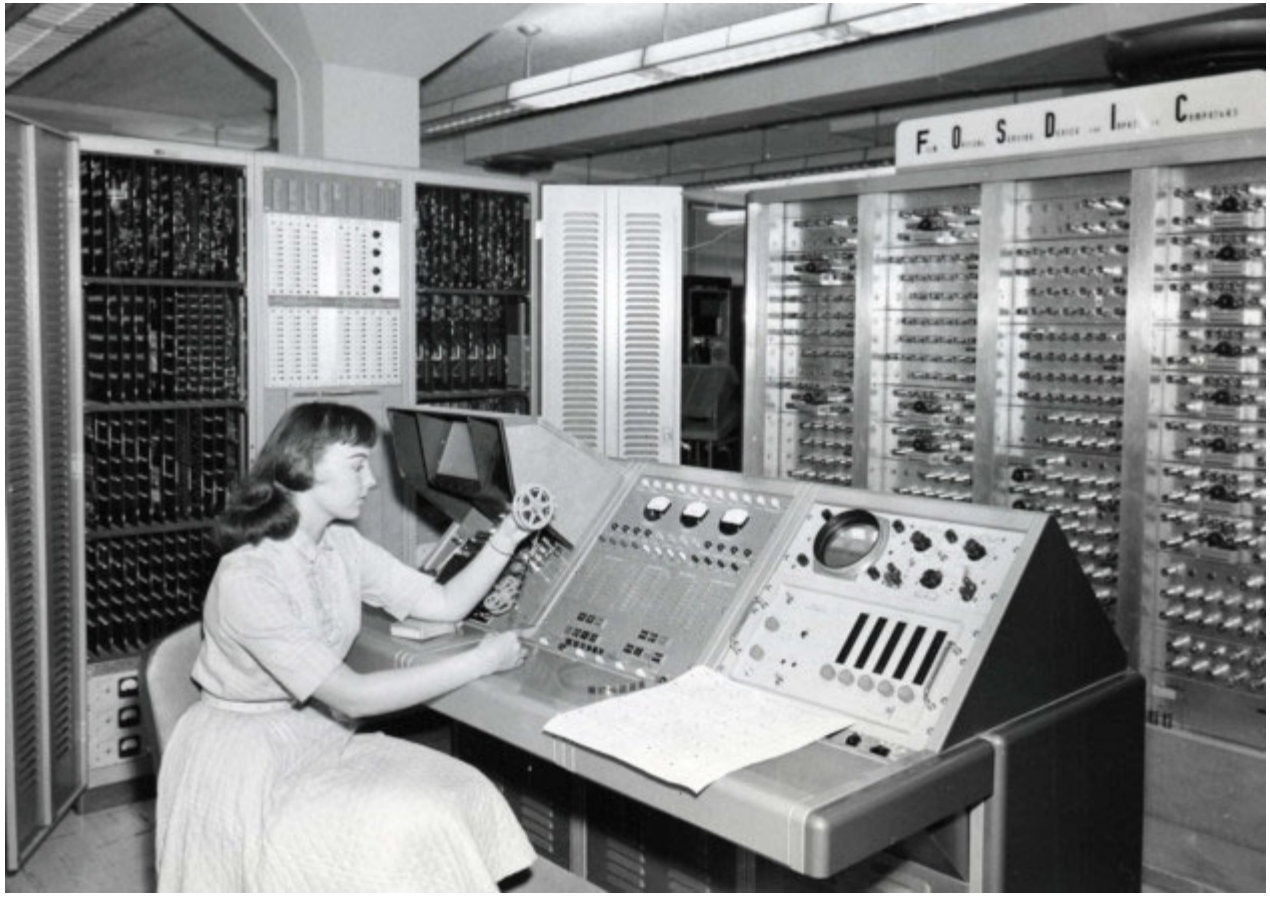
Flamm, K. (2017) "Has Moore's Law been repealed? An economist's perspective", *Computing in Science & Engineering*, Mar-Apr. 2:29-40

Hydraulic Animation
(Courtesy of Robert Dickinson, Innovyze)



Old Computers

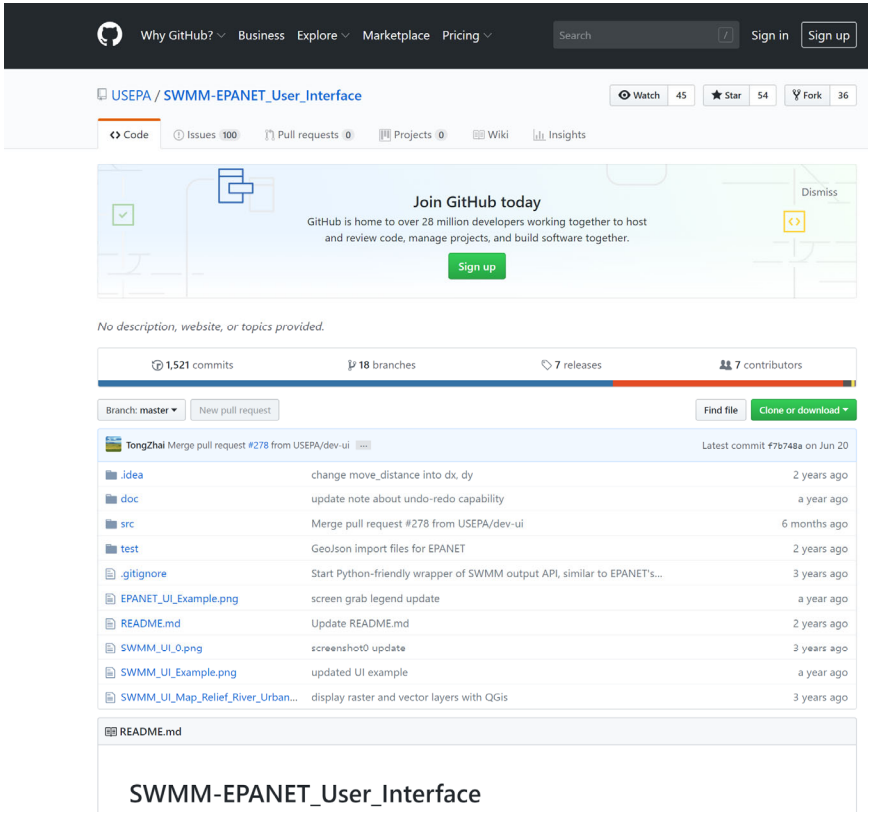
https://www.eadt.co.uk/property/computers-i-ll-give-them-five-years-shows-how-wrong-you-can-be-1-4445178



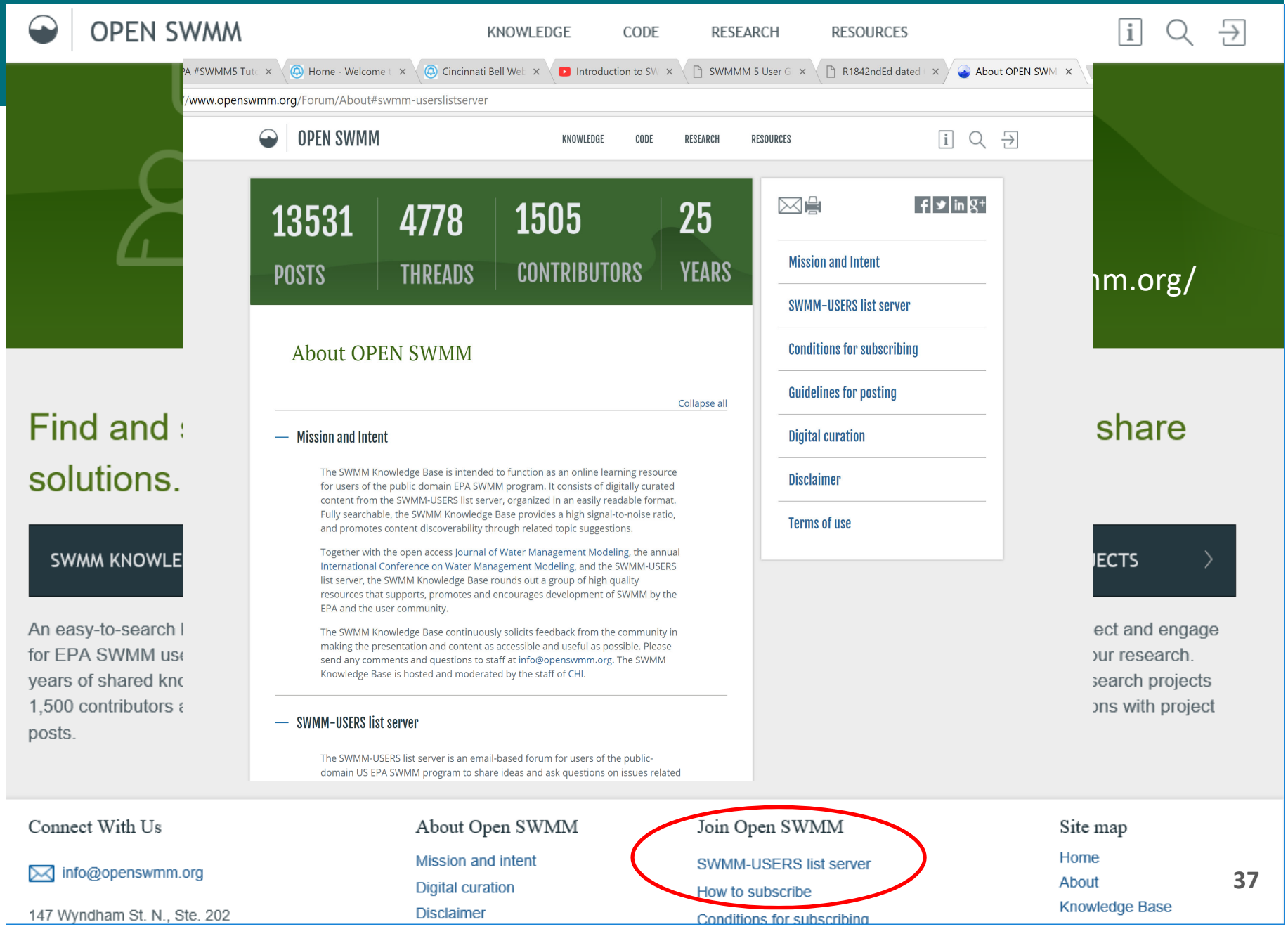
https://www.computerhistory.org/timeline/1980/

Developmental Actions

- Development tools and tricks
- Technical Support – OPENSWMM
- GitHub
  - Track Code versions and changes
  - Developmental Tools, e.g., CI, doxygen
  - Debugging
  - Code testing
    - Unit Testing
    - Feature Testing
    - Result Regression Testing
    - Coverage Testing
- Uncertainty\ground-truthing
  - PEST – Suraj Kamble, Xuanyi Lin
  - Calibration



Technical Support - OPEN SWMM



Innovations – Cloud Computing

Figure 4 is an example of accessing services in the cloud through Web 2.0 and media control interface APIs.

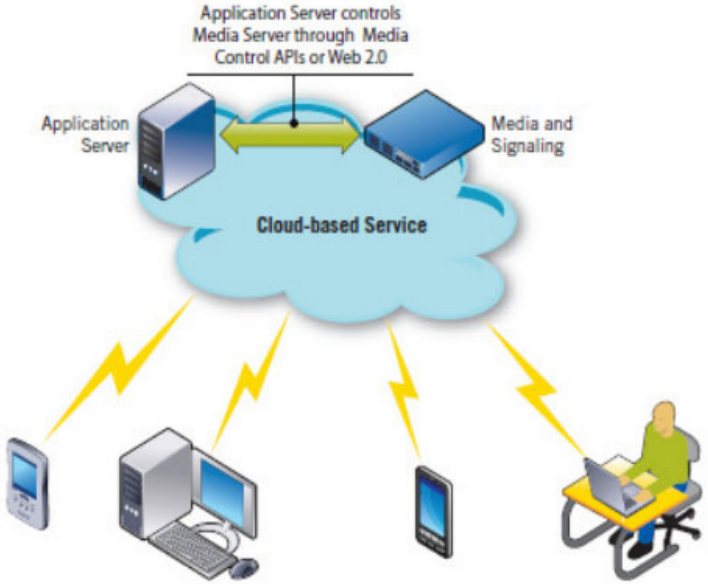


Figure 4. Accessing the Communications Capabilities from Within the Cloud

https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/03-Haire.pdf

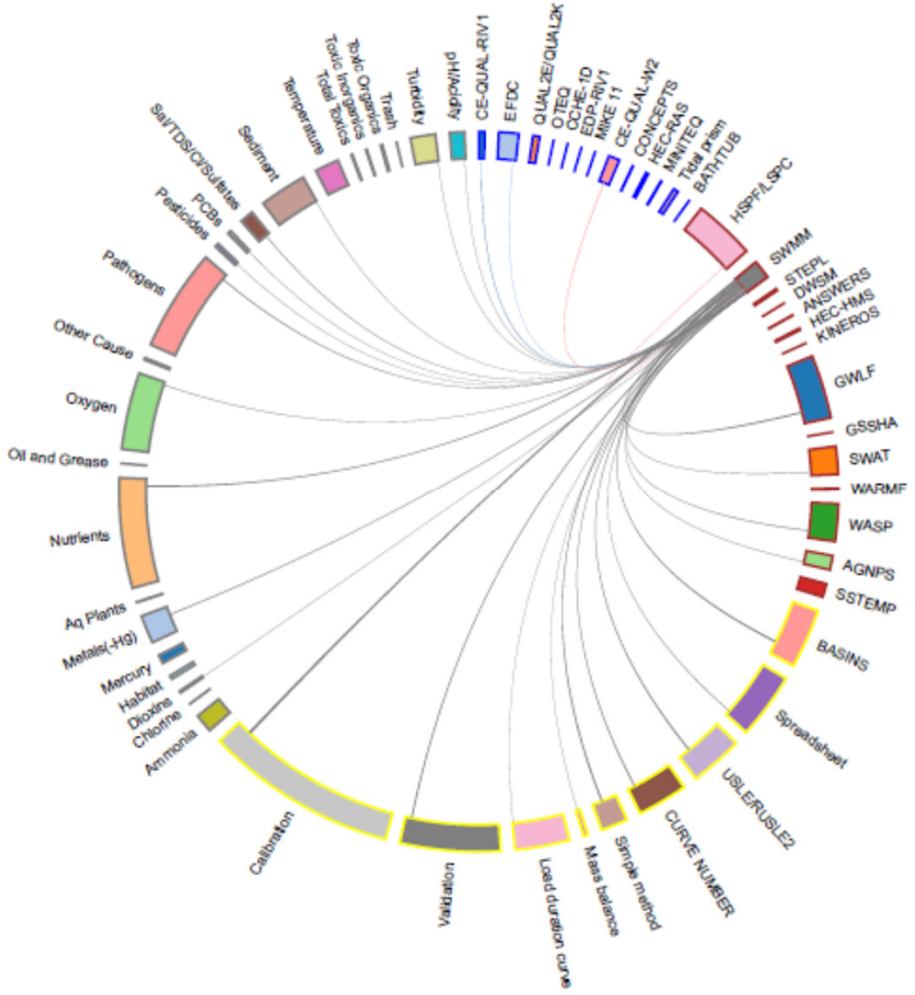
The Future

Overview

- Background:
  - Initial Research Problem
  - The Internet-of-Things (IoT)
  - Types of Cloud Computing
  - Development of the IoT for Infrastructure Monitoring and Control (DRTC/OptiRTC)
- Modeling-as-a-Service (MaaS)
- What does all of this look like in the real world?
- Closing thoughts

https://www.aquaterra.com/resources/pubs/fiftyyearconfproceedings/07-Quigley.pdf

TMDL Tool Demonstration



https://owml.vt.edu/tmdl/

Linking SWMM and PEST

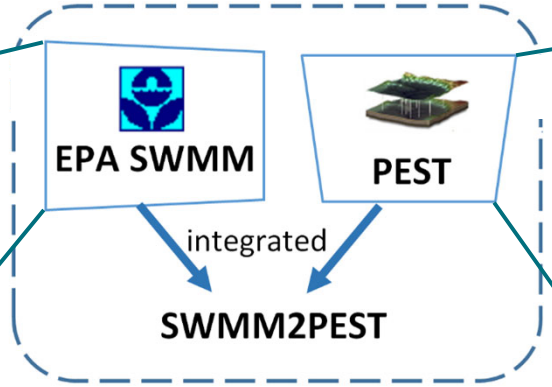
SWMM2PEST

An integration of the SWMM and PEST scientific programs

Dynamic rainfall-runoff simulation model

Version 5.1.013 was released in 2018

About 45,500 LoC



Model-Independent Parameter Estimation and Uncertainty Analysis

Version 15 was released in 2018

About 210,000 LoC

Metamorphic testing on SWMM2PEST

Hierarchical Metamorphic Relations for Testing Scientific Software

Xuanyi Lin Michelle Simon Nan Niu

Our ongoing work

Exploratory Metamorphic Testing for Scientific Software

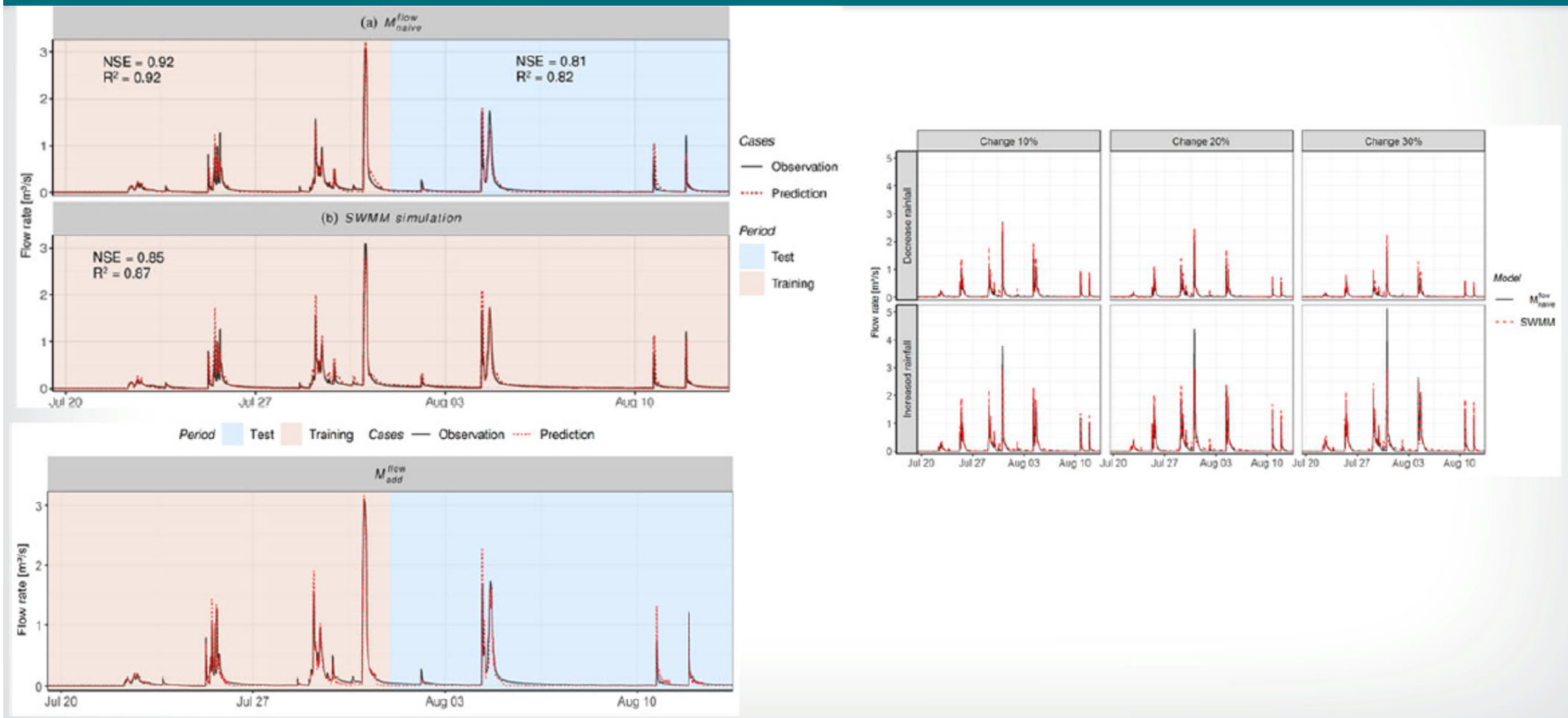
Xuanyi Lin
University of Cincinnati, USA

Michelle Simon
Environmental Protection Agency, USA

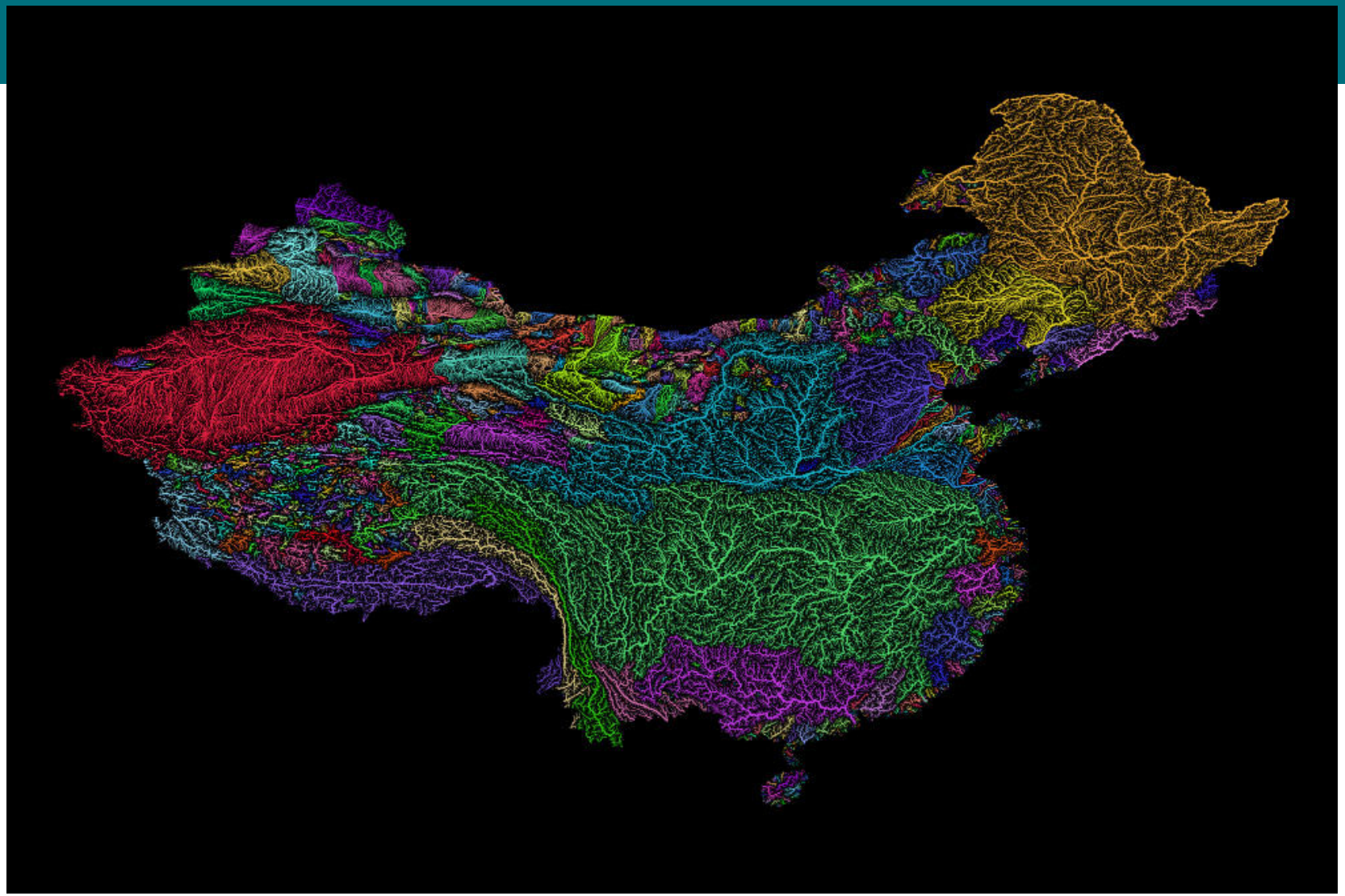
Nan Niu
University of Cincinnati, USA

	Resultless	Decreased	Unchanged	Increased	Bug	Mismatch	Constraint
FS10 (N=275)	24.4%	16.0%	4.7%	54.9%	1	1	1, 2
Villanova (N=194)	3.6%	27.3%	6.2%	62.9%	1	1	1, 2

Yang Yang's Dissertation
Machine Learning and SWMM

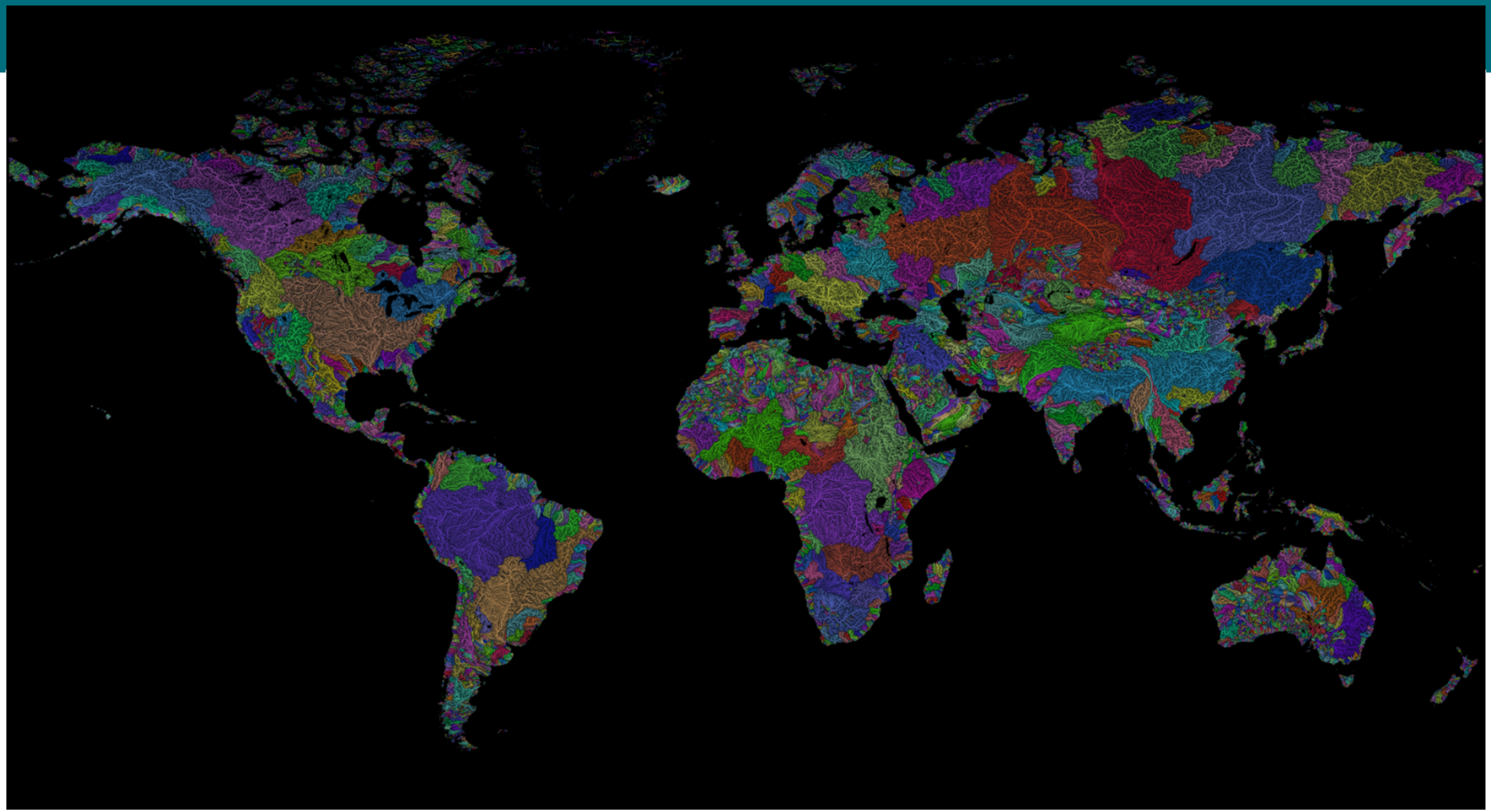


Watersheds of China



https://www.google.com/search?q=watersheds+of+china&tbm=isch&source=iu&ictx=1&fir=9W1dCrQwG_QGoM%253A%252CQGstx7B0bcCxGM%252C_&vet=1&usg=AI4_-kSx2vt2GtcUfpUaalV3OsispvQaCQ&sa=X&ved=2ahUKEwi0-_DB39_iAhXsmuAKHQGaBMoQ9QEwAHoECAAQBA#imgrc=9W1dCrQwG_QGoM:

Watersheds of the World



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Thank You!

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