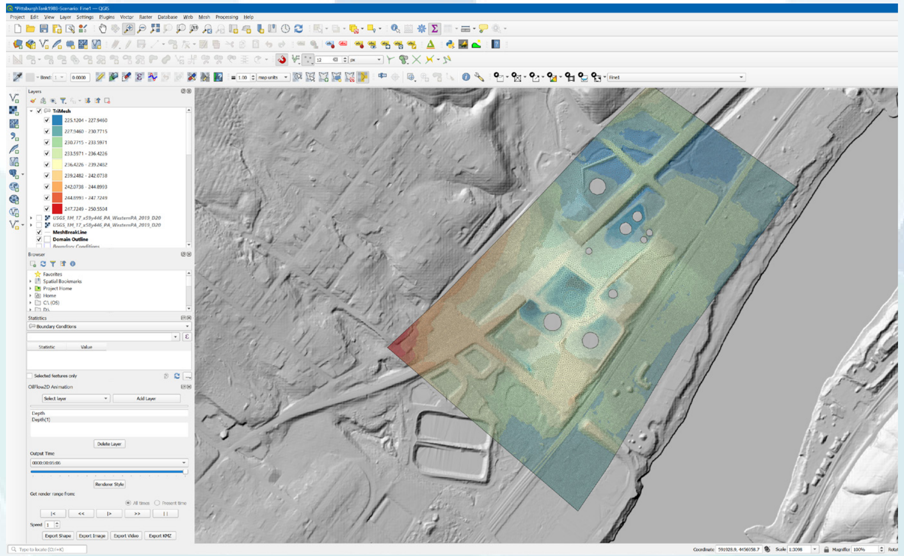
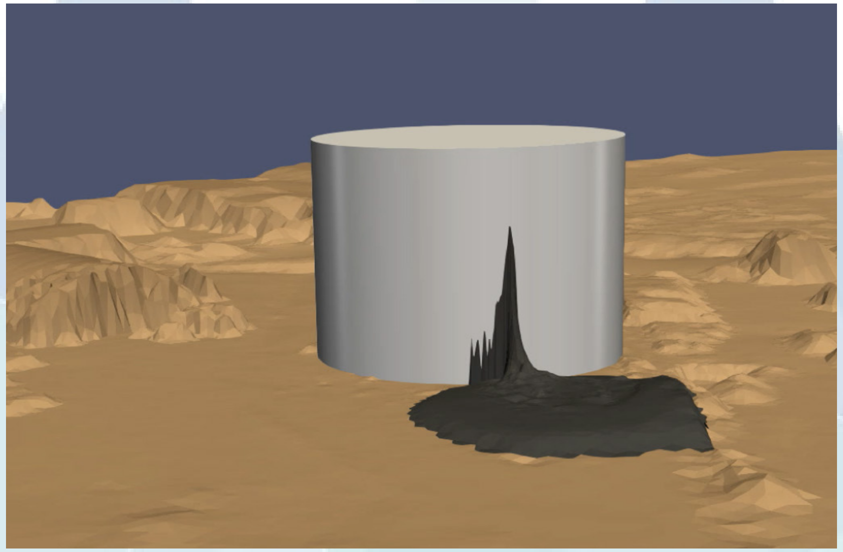
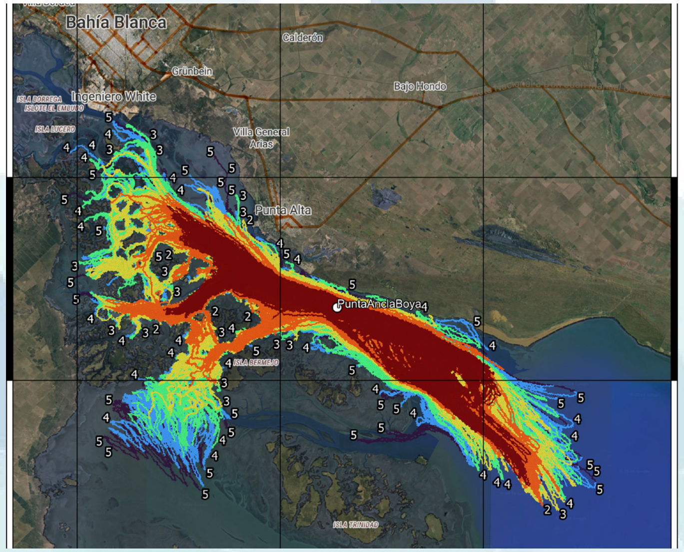
RESCUER W2 TRAINING PROGRAMME

WORKSHOP 2 UNIZAR ORGANIZATION

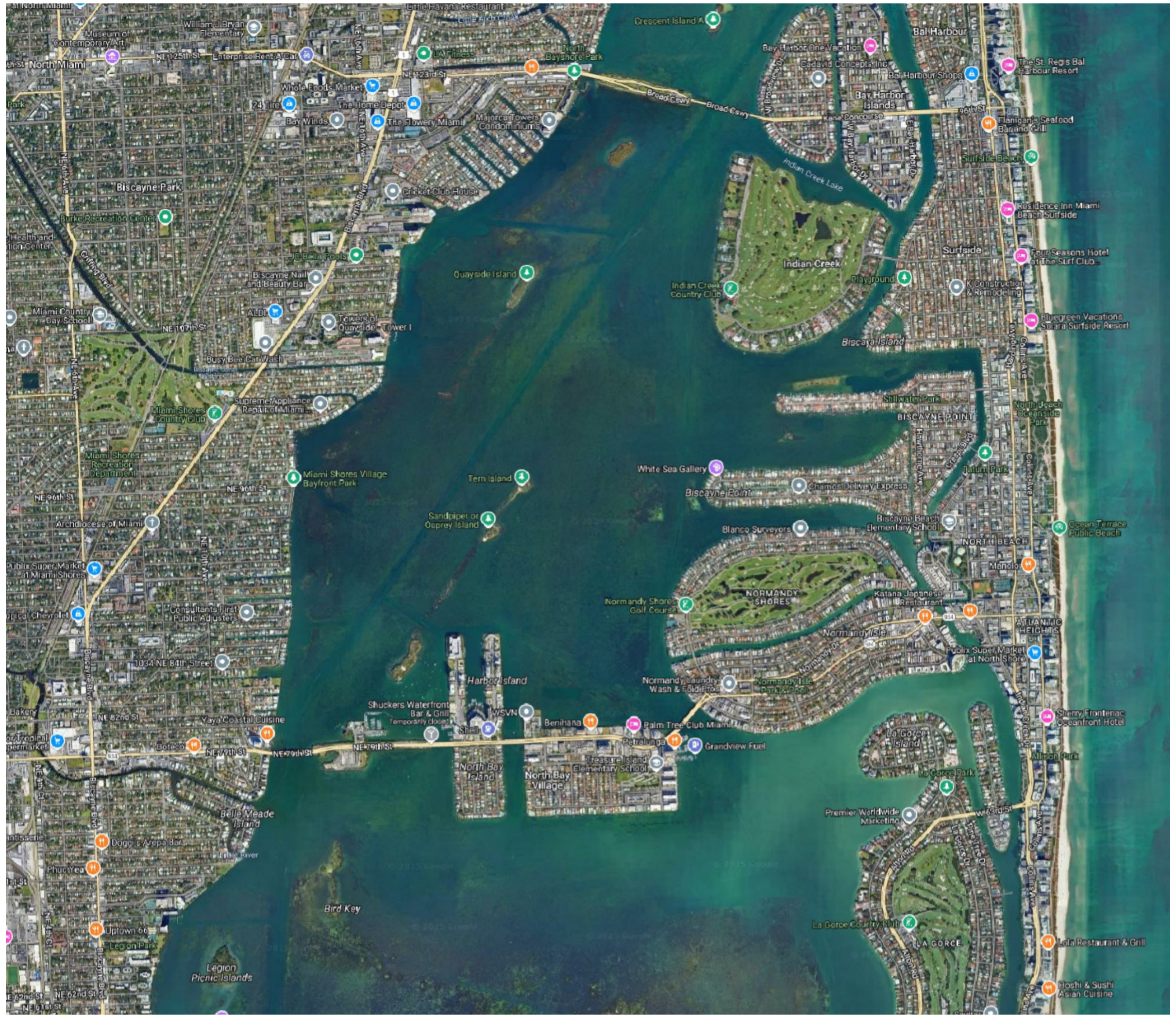






Industrial application of GPU codes

Reinaldo GARCIA, PhD
Director of Development and Applications
Hydronia, FL, USA. Hydronia Europe, Spain.
rey@hydronia.com
www.hydronia.com



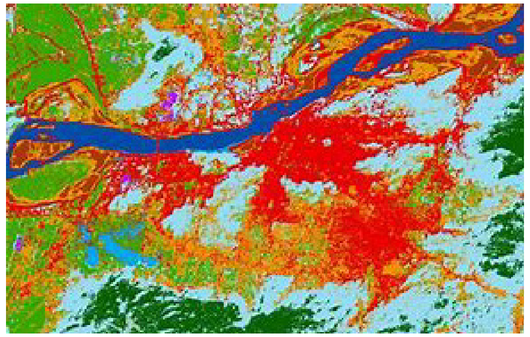
VS

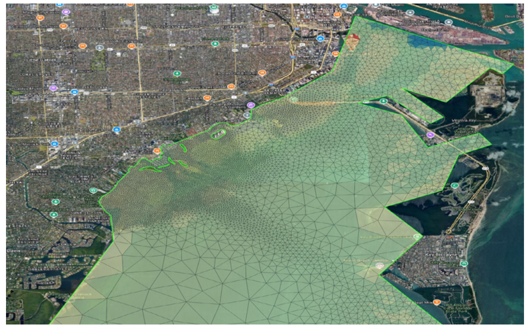
Agenda

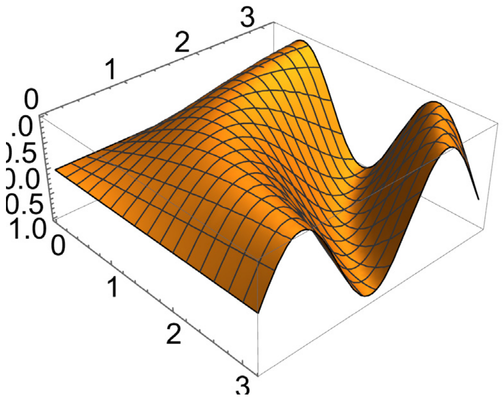
- Factors Impacting the Modeling Process
- RiverFlow2D/OilFlow2D Modeling Systems
- Three Case Studies [*“Real World”* Applications]
  - The sudden break of a large tailings dam
  - The dynamics of a large sub-tropical bay
  - Oil Pipelines and the break of an oil storage tank
- Discussion, questions, and attempt to provide answers.

Factors Affecting Cost/Effort of Industrial Modeling Applications

- Software cost
- Computer Hardware and Additional Software
- GIS Pre-processing (data processing)
- Model Conceptualization
- Model Setup
- Numerical Stability and Consistency
- ***Model Performance (Runtime)***
- Analysis of Results
- GIS post-processing







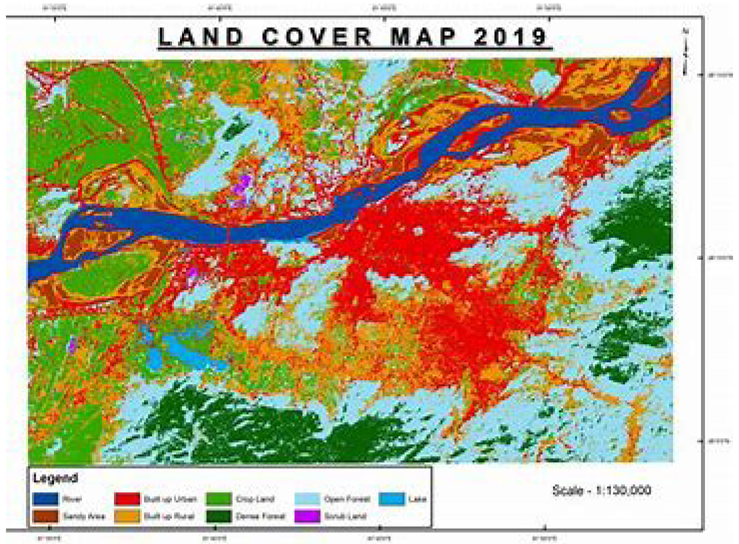
Total Cost of a Modeling Project

Factor affecting modeling cost	Cost	~ % of Total Effort
Software		??
Computer and Additional Software		??
GIS Pre-processing		??
Model Conceptualization		??
Model Setup		??
Numerical Stability and Consistency		??
Model Performance		??
Analysis of Results		??
GIS Post-processing		??
Total		100

Computer/Software Cost

- Typically, *one-time* payment
- Yearly maintenance to ensure technical support and upgrades
- Can be distributed throughout many projects
- Same for Computer and Additional Software

GIS Pre-processing and Model Conceptualization



- Common effort regardless the model performance
- Does not depend *[much]* on the selected model
- Required for all Modeling Applications

Model Setup

- Depends on Model Graphical User Interface
- Required in all Projects
- “Use the one you know best”
- SMS, QGIS, etc.

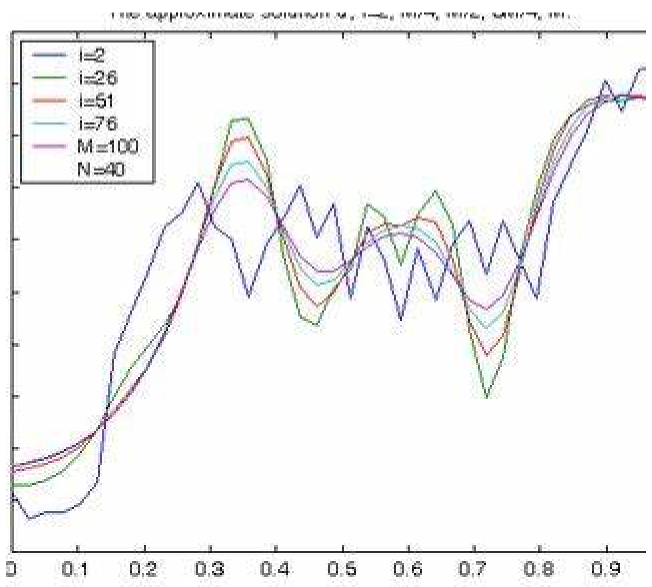
Numerical Stability and Consistency

- Highly Variable among Models

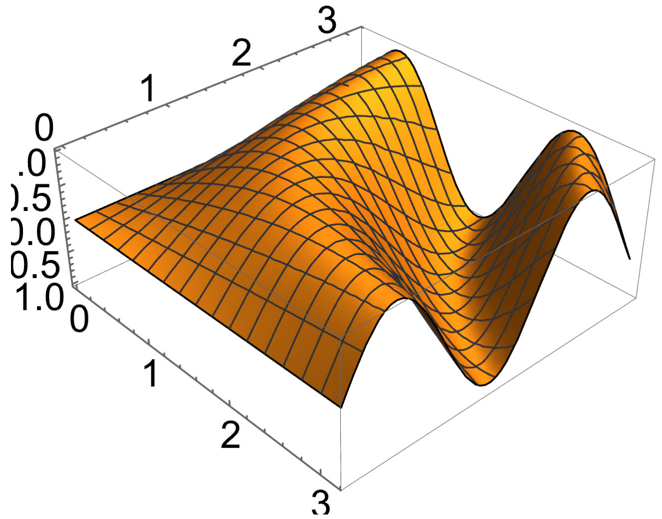
- In some models, Numerical Instabilities may require many trial-and-error runs, and tweaking the model to make it work

- Required task in all projects

- Often very time-consuming.



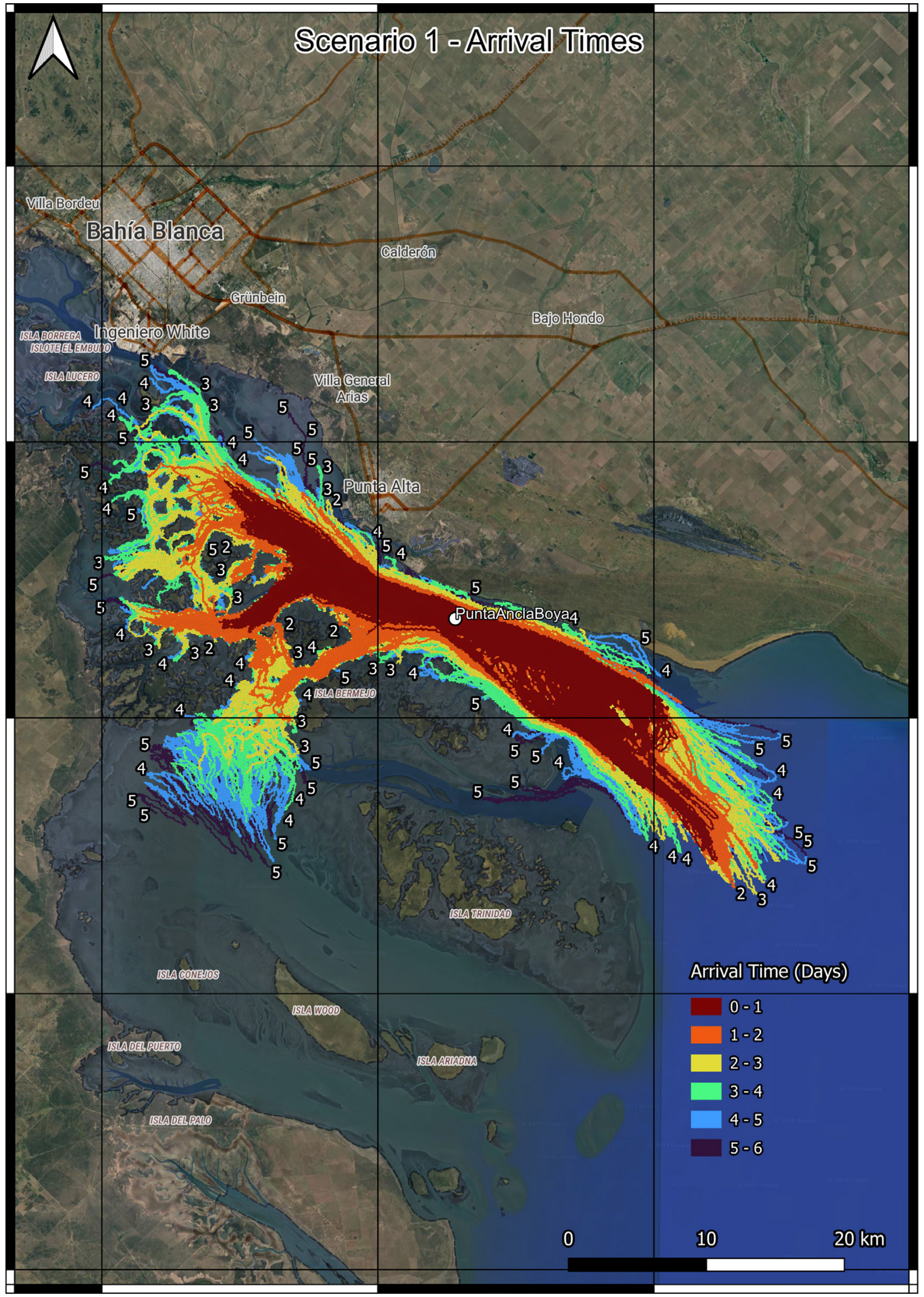
Model Performance



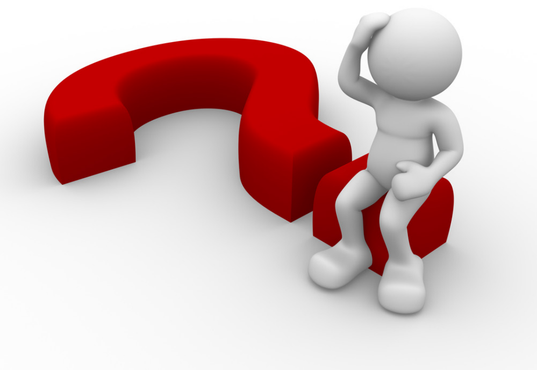
- Highly Variable among Models
- Depends on project size (number of cells) and simulation time
- Involves monitoring and waiting for runs
- Impacts most applications
- Very time-consuming task

Analysis of Results and GIS post-processing

- Common to all Models
- Required in all Projects



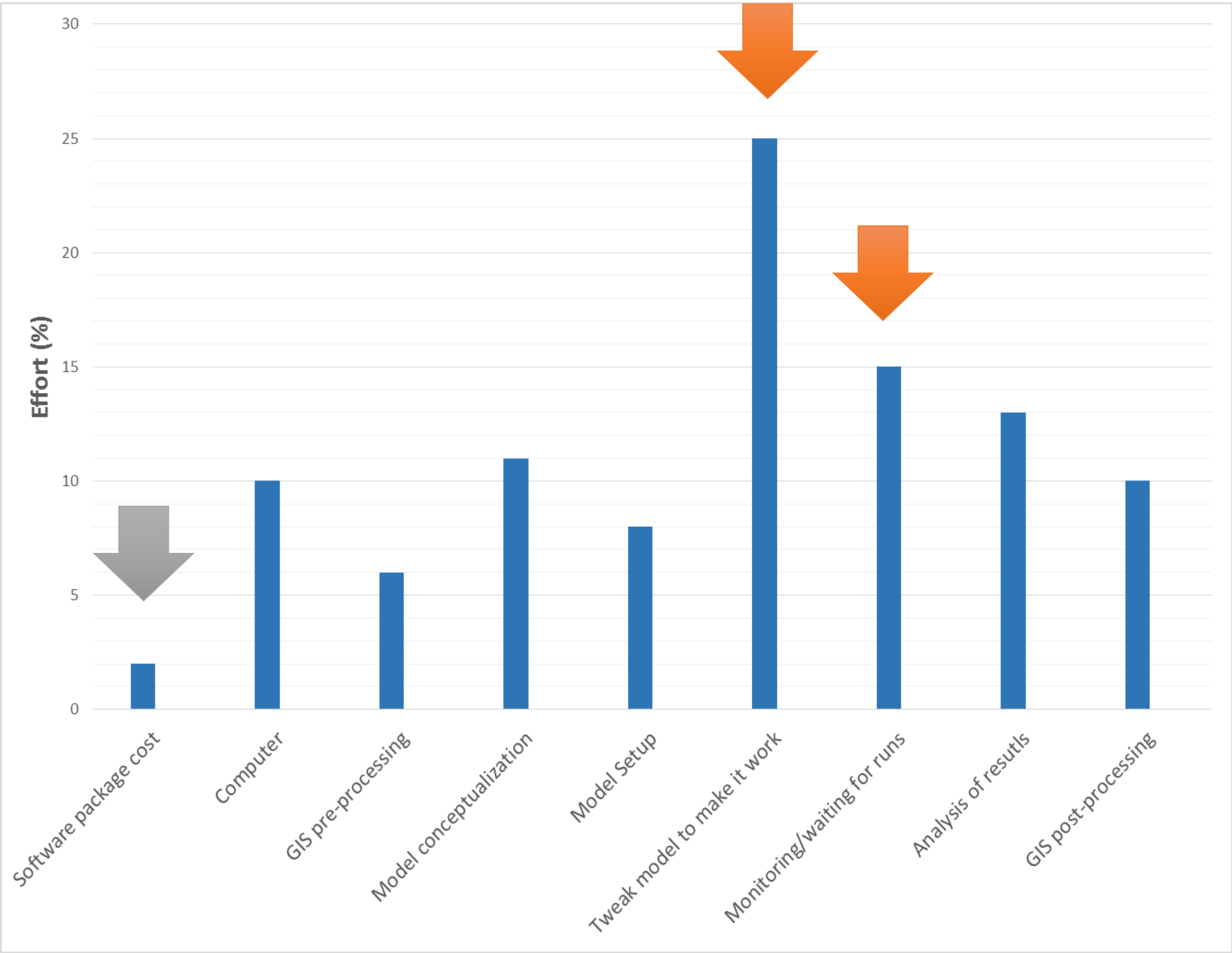
Total Cost of a Modeling Project



Factor affecting modeling cost	Cost	~ % of Total Effort
Software	One Time*	2
Computer and Additional Software	One Time*	10
GIS Pre-processing	All Projects	6
Model Conceptualization	All Projects	11
Model Setup	All Projects	8
Numerical Stability and Consistency	All Projects	25
Model Performance	All Projects	15
Analysis of Results	All Projects	13
GIS Post-processing	All Projects	10
Total		100

Factors Affecting Cost of Modeling Tasks

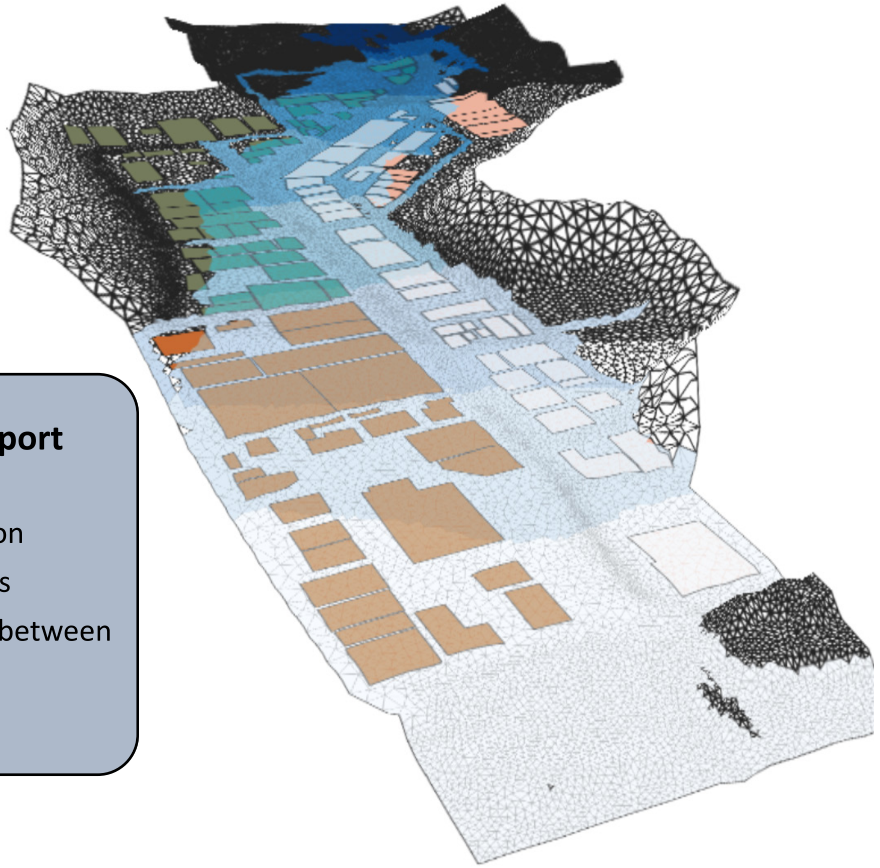
- Model package cost
- Computer and Software
- GIS pre-processing
- Model Conceptualization
- Model Setup
- **Tweak model to make it work**
- **Model Performance**
- Result analysis
- GIS post-processing



RiverFlow2D/OilFlow2D Modeling System

Developed since 2013 through an agreement between the *University of Zaragoza Computational Hydraulics Group* and *Hydronia LLC* USA.

RiverFlow2D Model



MT: Mud and Tailings Module

Two-phase non-Newtonian flow model

Wet to dry deposits

Different material properties for dam and tailings deposits

Water reservoirs and rivers

Pollutant transport

Dam breach by overtopping, piping

Bed fraction tracking

UD: Urban Drainage Module

Surface and drainage network

Integration with EPA-SWMM

PL: Pollutant Transport Module

Advection-dispersion

Multiple pollutants

First-order Reaction term between pollutants

ST: Sediment Transport Module

Suspended sediment transport

Bed load transport

Erosion and deposition

Multiple sediment classes

Bed fraction tracking (Armoring)

RiverFlow2D

2D-Hydrodynamics

Flexible-mesh, CPU-GPU

Rainfall-Evaporation-Infiltration

Point Sources

Bridges, Bridge scour, Culverts, Gates, Weirs

Dam-Breach

Wind

WQ: Water-Quality Module

Advection-dispersion

Based on EPA-WASP model

Eutrophication and other WQ processes

OilFlow2D Model System

OL: Overland Flow Model

Evaporation

Infiltration

Hydraulic structures

Heat transfer with the environment

Fluid properties vary with temperature

OP: Oil Pipeline Module

Pipeline release volume calculator

Batch run of multiple spills

Integrated mapping for thousands of spills

OW: Oil-on water spill Model

Oil trajectory by particle-tracking

Evaporation

Emulsification

Dissolution

Shore interaction

Containment Booms

Spills from moving ships

OilFlow2D

2D-Oil and Viscous Fluids Hydrodynamics

Flexible-mesh, CPU-GPU

Point sources

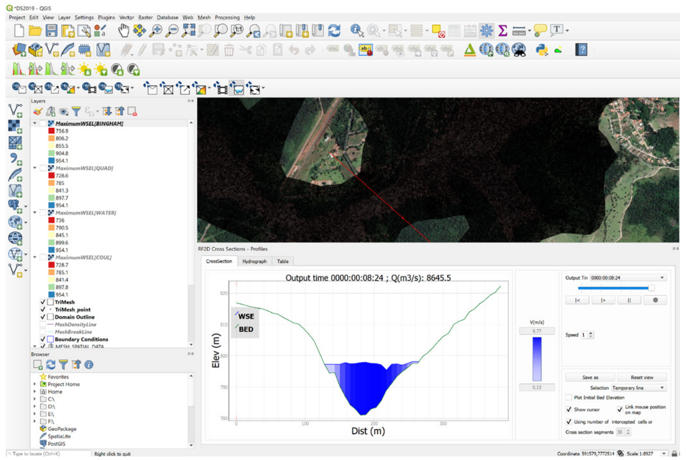
Rainfall-Evaporation-Infiltration

Hydraulic structures

Wind

Technical support in English, Spanish, French and Portuguese

QGIS-Based Graphical User Interface



RiverFlow2D Plugin for Animations

Creates dynamic animations of model results: depths, velocities, wse, concentrations, etc.

RiverFlow2D Plugin for Mapping Results

Depth, velocity, WSE, shear

Maximums

Flood arrival times

Flood duration

Hazard levels

Pollutant concentrations

Material properties

RiverFlow2D Plugin for Profiles and Cross Sections

Creates dynamic animations of profiles and cross sections

QGIS

Geographical Information System

Open-source

Programable via Python and C++

Extensible through plugins

Free access

RiverFlow2D Plugin for Mesh Generation

Automatic generation of triangular unstructured meshes

Mesh refinement through density polylines and polygons

Breaklines

Integration with Digital Elevation Models

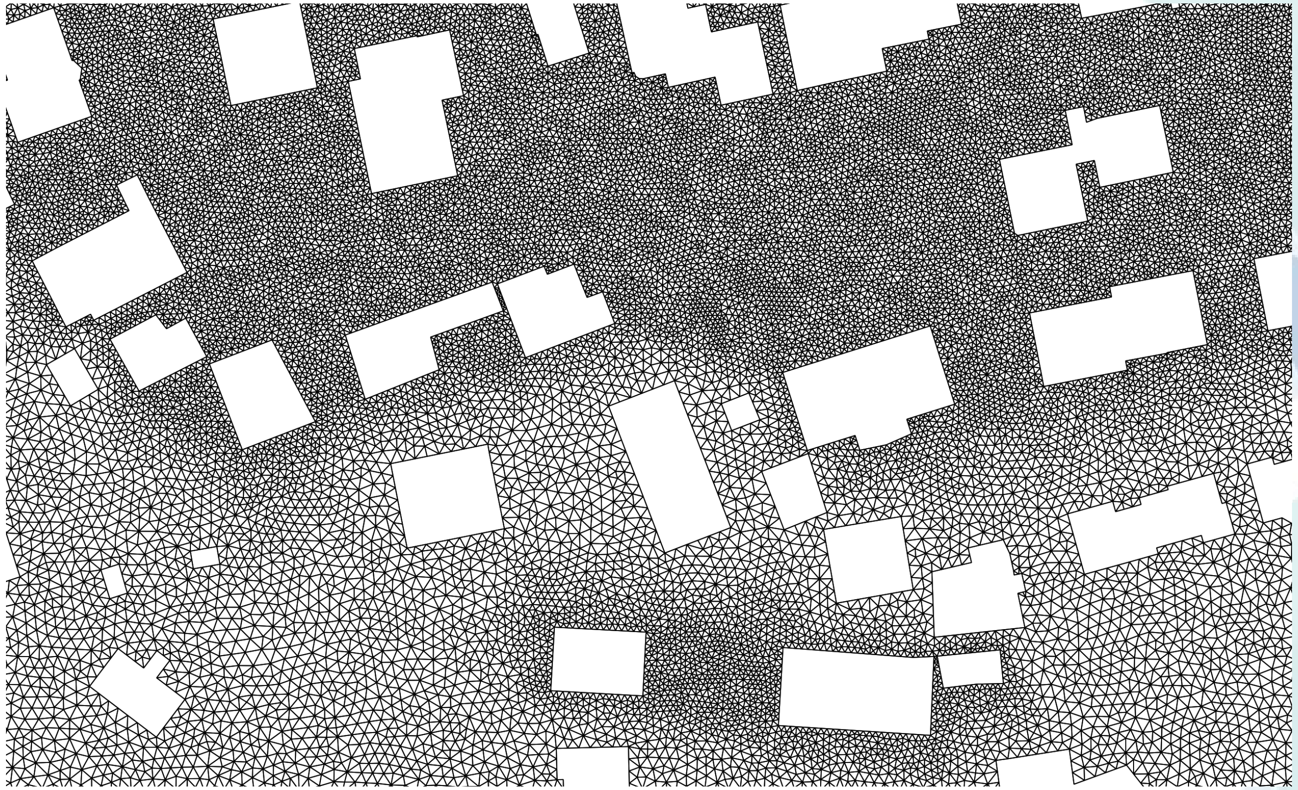
HEEF: Damage cost assessments plugin

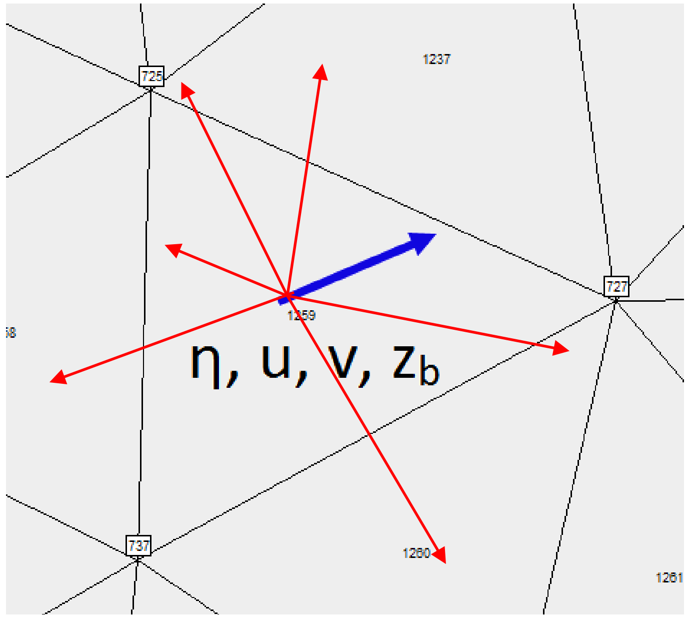
Calculates flood damage costs at buildings

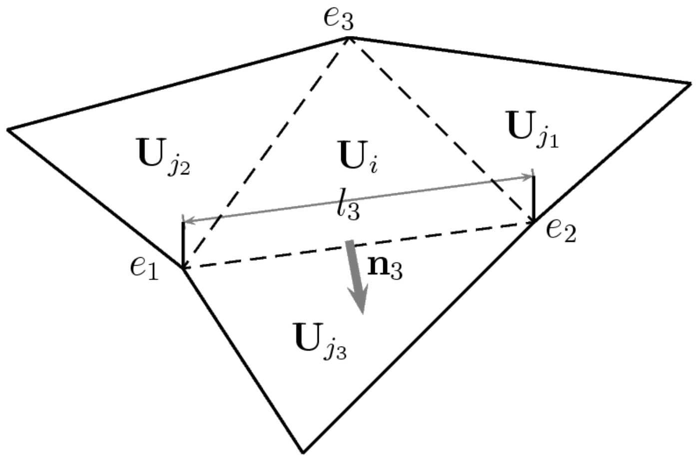
Vulnerability database

Damage cost maps

Flexible Mesh

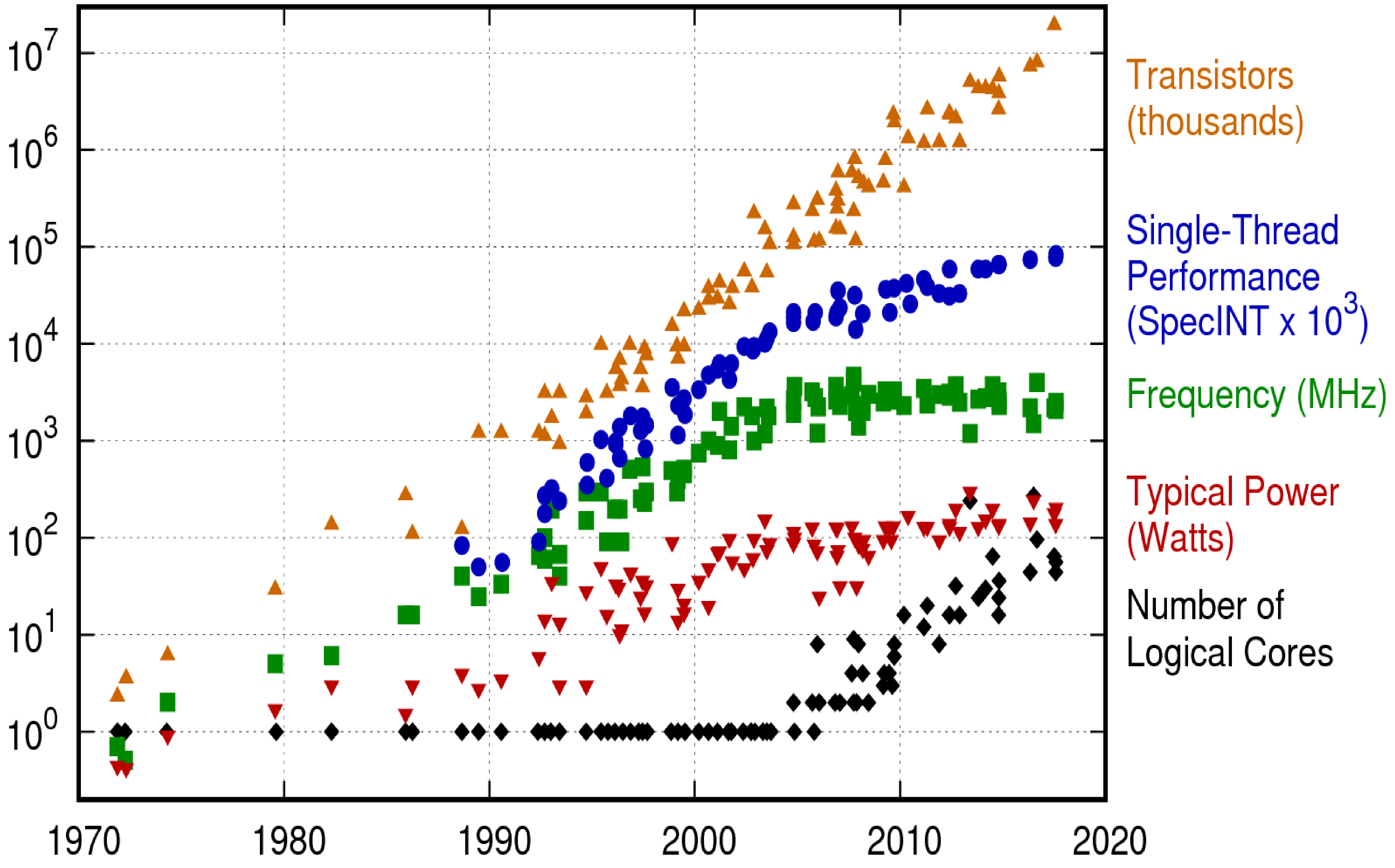






Motivation for using GPUs

42 Years of Microprocessor Trend Data



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2017 by K. Rupp

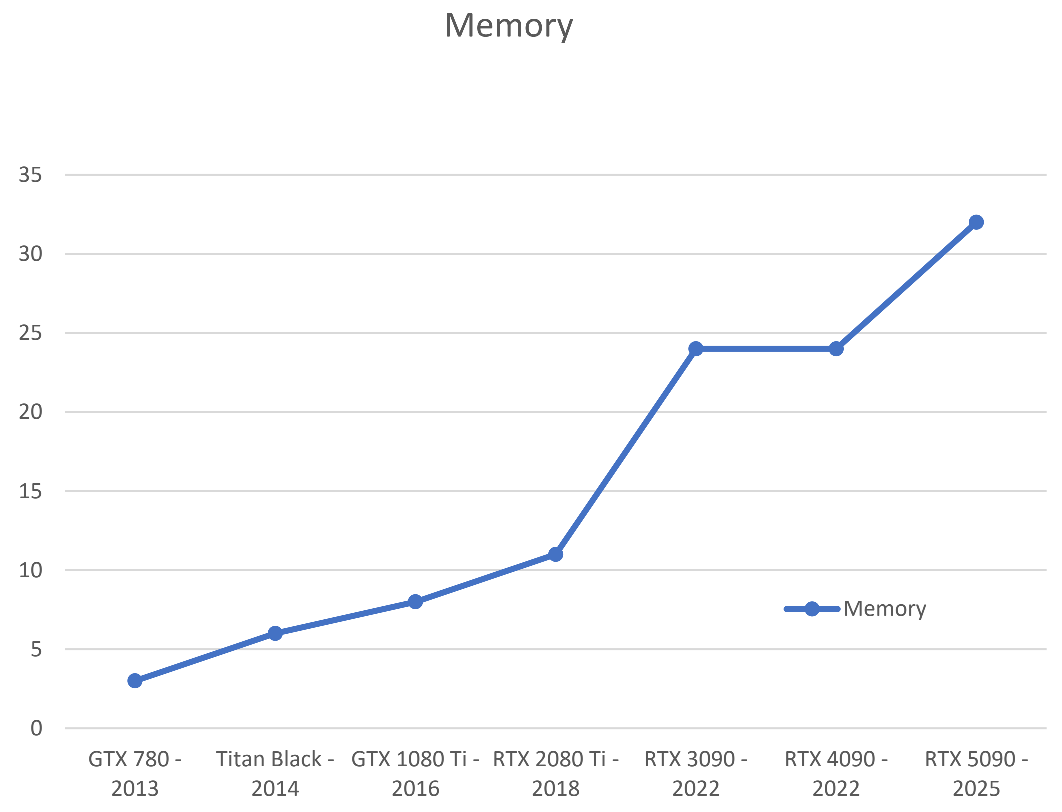
Addressing Computational Challenge with RiverFlow2D/OilFlow2D GPU

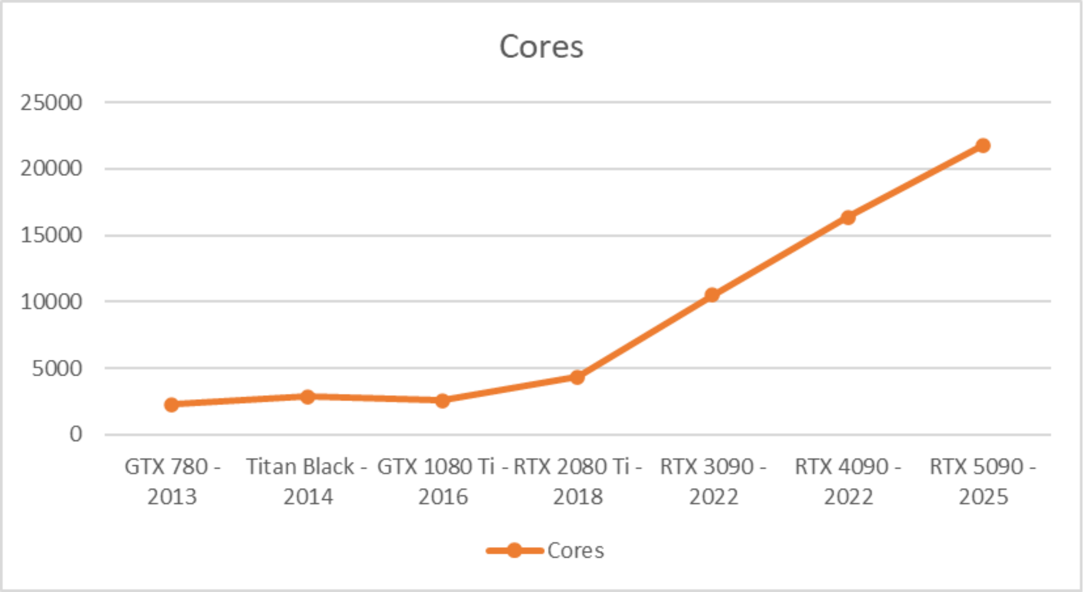
- CPU → Central Processing Unit (OpenMP)
- GPU → Video Cards
- GPUs → 15000+ processors (cores)
- Requires specialized programming (NVIDIA CUDA)

GPU CARD	Number of Cores	Memory GB	Cost US$
GTX 1080 Ti	3,584	11	700
Tesla K80	2,496	12	3,000
Tesla P100	3,584	16	6,000
Tesla V100	5,120	16	19,500

Evolution of NVIDIA Consumer GPUs

Card - Year	Memory (GB)	Cores
GTX 780 -2013	3	2304
Titan Black -2014	6	2880
GTX 1080 Ti -2016	8	2560
RTX 2080 Ti -2018	11	4352
RTX 3090 -2022	24	10496
RTX 4090 -2022	24	16384
RTX 5090 -2025	32	21760

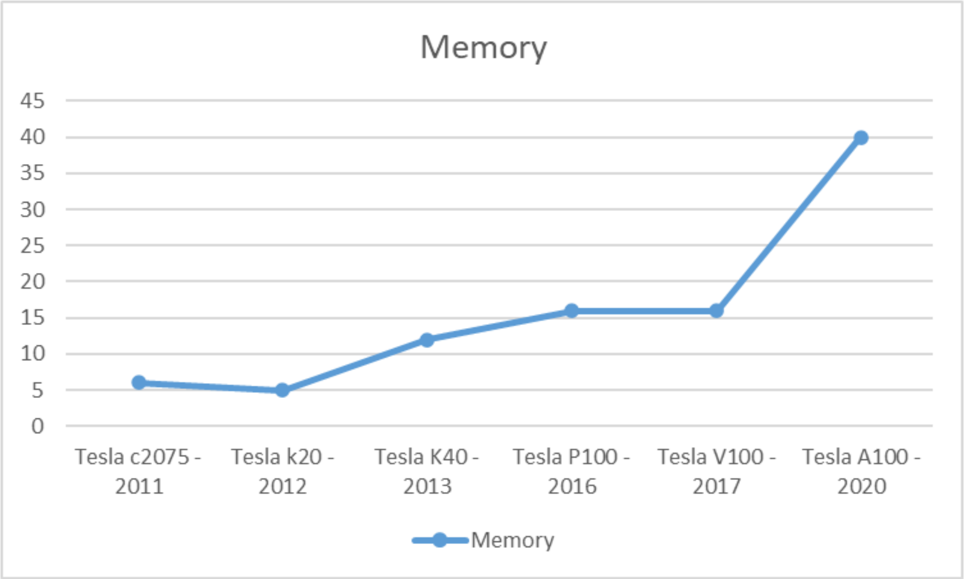


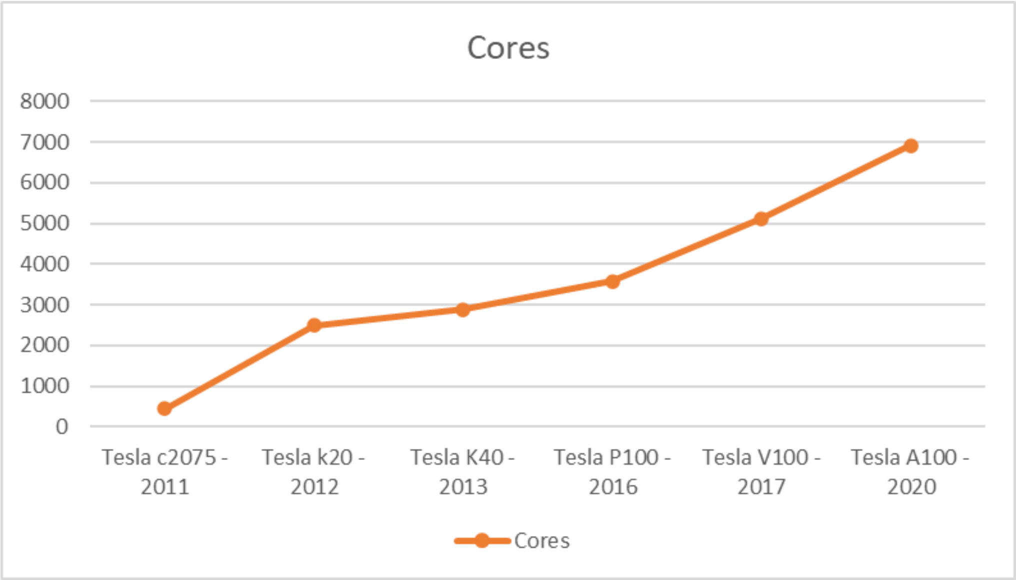


HYDRONIA

Evolution of NVIDIA High-End GPUs

GPU Card - Year	Memory (GB)	Cores	Year Intro
Tesla c2075 - 2011	6	448	2011
Tesla k20 -2012	5	2496	2012
Tesla K40 -2013	12	2880	2013
Tesla P100 -2016	16	3584	2016
Tesla V100 -2017	16	5120	2017
Tesla A100 -2020	40	6912	2020





Case Studies

"Real-World" Modeling Applications

- Brumadinho Dam Break
- Biscayne Bay Salinity Model
- Ashland Tank-break

Brumadinho Dam Break

Engineering Geology 296 (2022) 106462

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journal homepage: www.elsevier.com/locate/enggeo

A GPU-accelerated Efficient Simulation Tool (EST) for 2D variable-density mud/debris flows over non-uniform erodible beds

S. Martínez-Aranda [*], J. Murillo, P. García-Navarro

Fluid Dynamic Technologies-I3A, University of Zaragoza, Spain

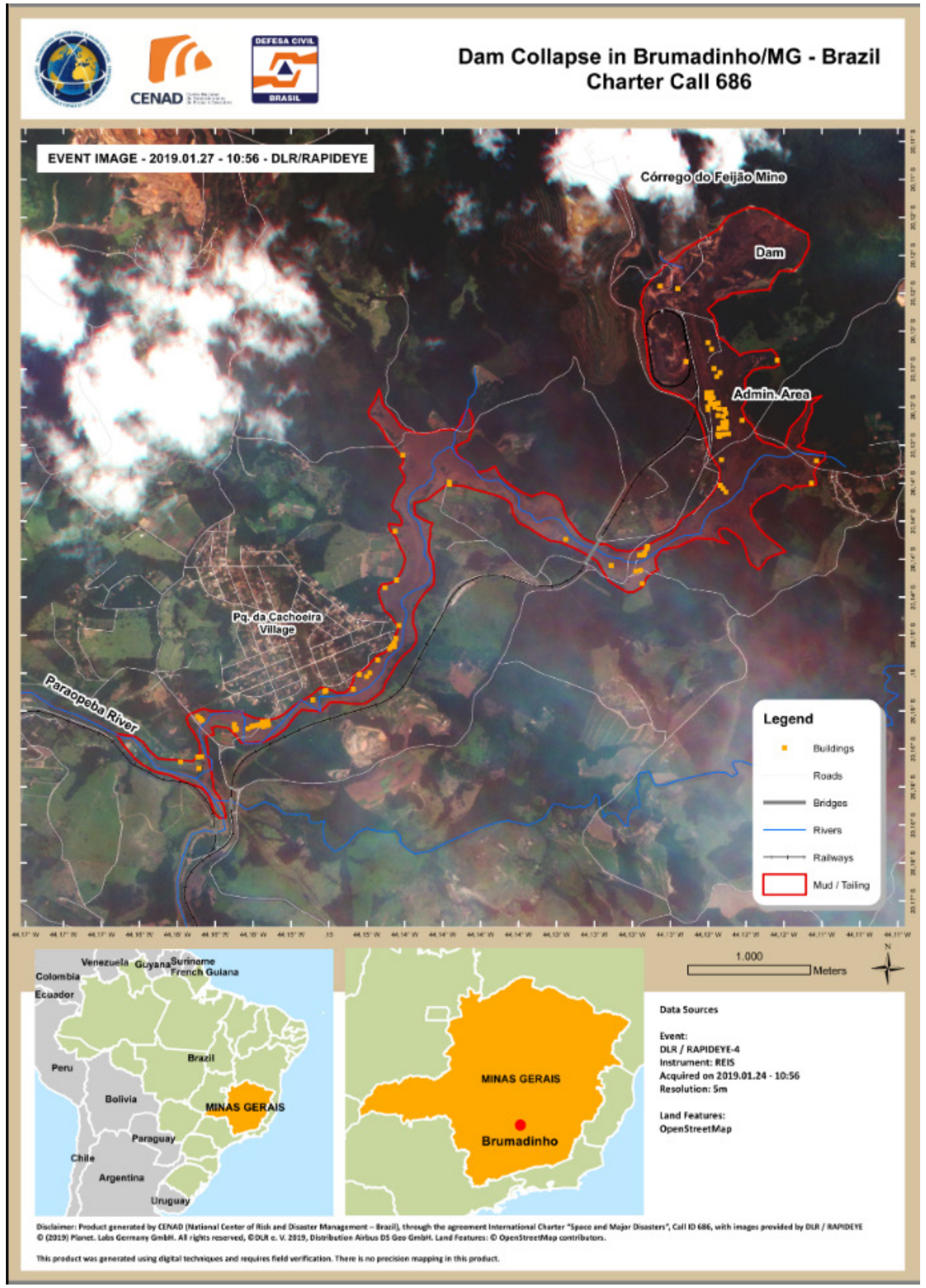
ARTICLE INFO

Keywords:
Mud/debris flow
Non-uniform erodible bed
Variable-density mixture
Augmented riemann solvers
Well-balanced schemes
Source terms integration
GPU-accelerated codes

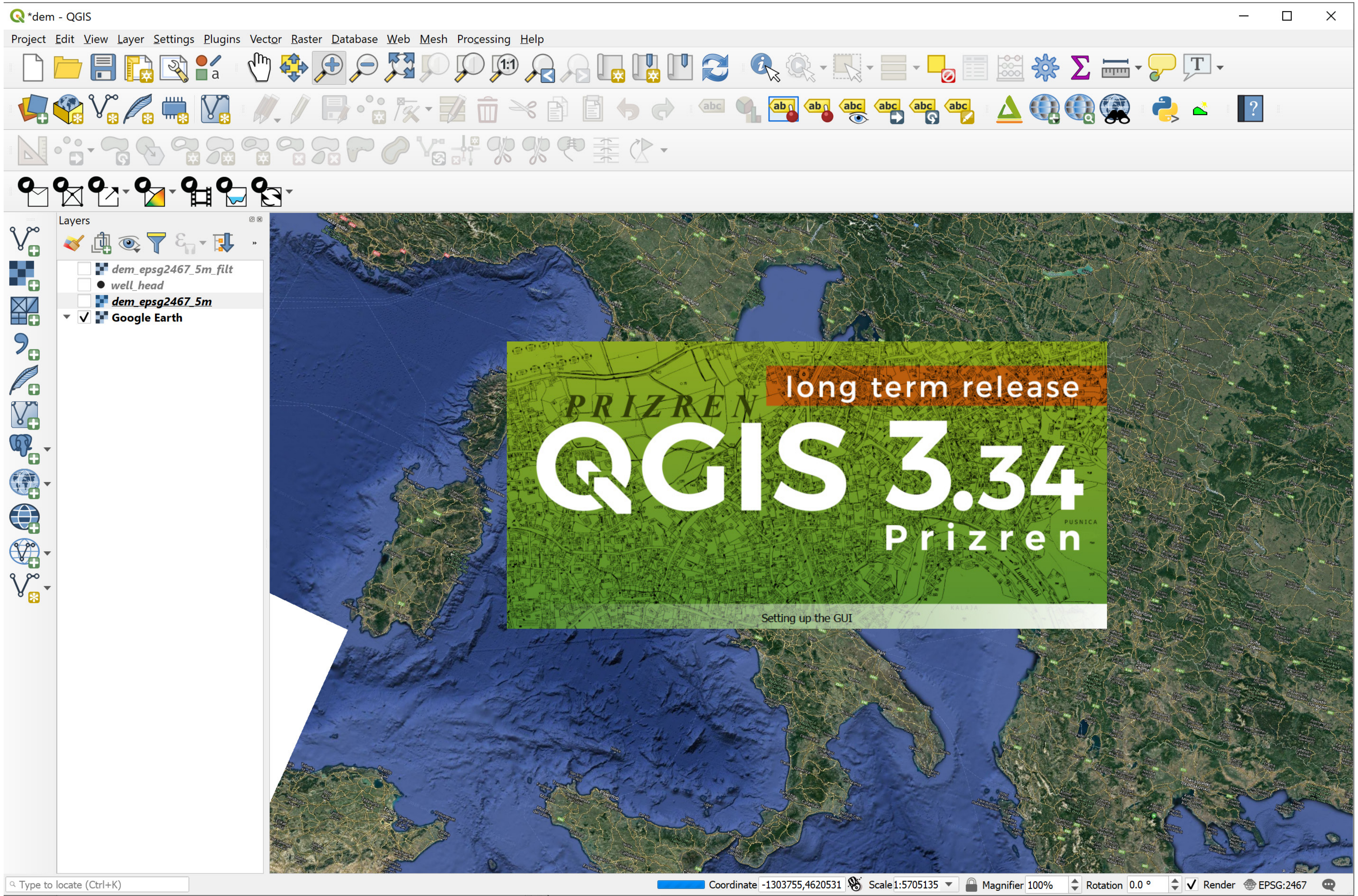
ABSTRACT

Mud/debris flows are among the most challenging gravity-driven flows in environmental and geophysical processes. Natural muddy slurries and debris are solid-laden fluids where the density of the mixture can be more than twice or three times the water density and, hence, the bulk solid phase can represent 40–80% of the flow column volume. Furthermore, these unsteady flows usually occur along steep and irregular terrain which requires a refined non-structured spatial discretization, increasing the computational times of the models. In this work a new upwind Roe-type solver for two-dimensional multi-grain mixture shallow-flow over non-uniform erodible bed is presented. The coupled system of depth-averaged equations is formed by the conservation equations for the mass and momentum of the variable-density mixture, the mass conservation equations for the N different solid phases transported in the flow and the continuity equation for the erodible bed layer, where the different solid phases can be exchanged independently modifying the bed level. The non-Newtonian rheological behavior of the multi-grain mixture is included into the momentum equations using six different basal resistance formulations. An accurate, robust and efficient x-split Augmented Roe (xA-Roe) solver for variable-density flow is derived, which requires a complete reformulation of the averaged-Roe values at the intercell edges and allows the mixture density to participate in the definition of the characteristic wave celerities of the local Riemann problem. The global time step is dynamically controlled by the wave celerities of the coupled system of equations, preserving the scheme stability even for high density gradients. The bed slope and basal resistance source terms are also upwind discretized and included into the intercell numerical fluxes, ensuring a well-balanced flux formulation in steady states and the correct treatment of wet-dry fronts. The proposed model is GPU-accelerated using a CUDA/C++ algorithm and applied to synthetic tests and the USGS debris dambreak experiments over erodible bed, demonstrating its robustness, accuracy and efficiency. Finally, the model is tested against a real-scale and long-term case, the mining-tailing dam failure occured in Brumadinho (Brazil) in 2019. The numerical results show good agreement with the observed field data and the computational cost reduction obtained with the GPU-accelerated algorithm is up to 60 times compared to a CPU-based code.

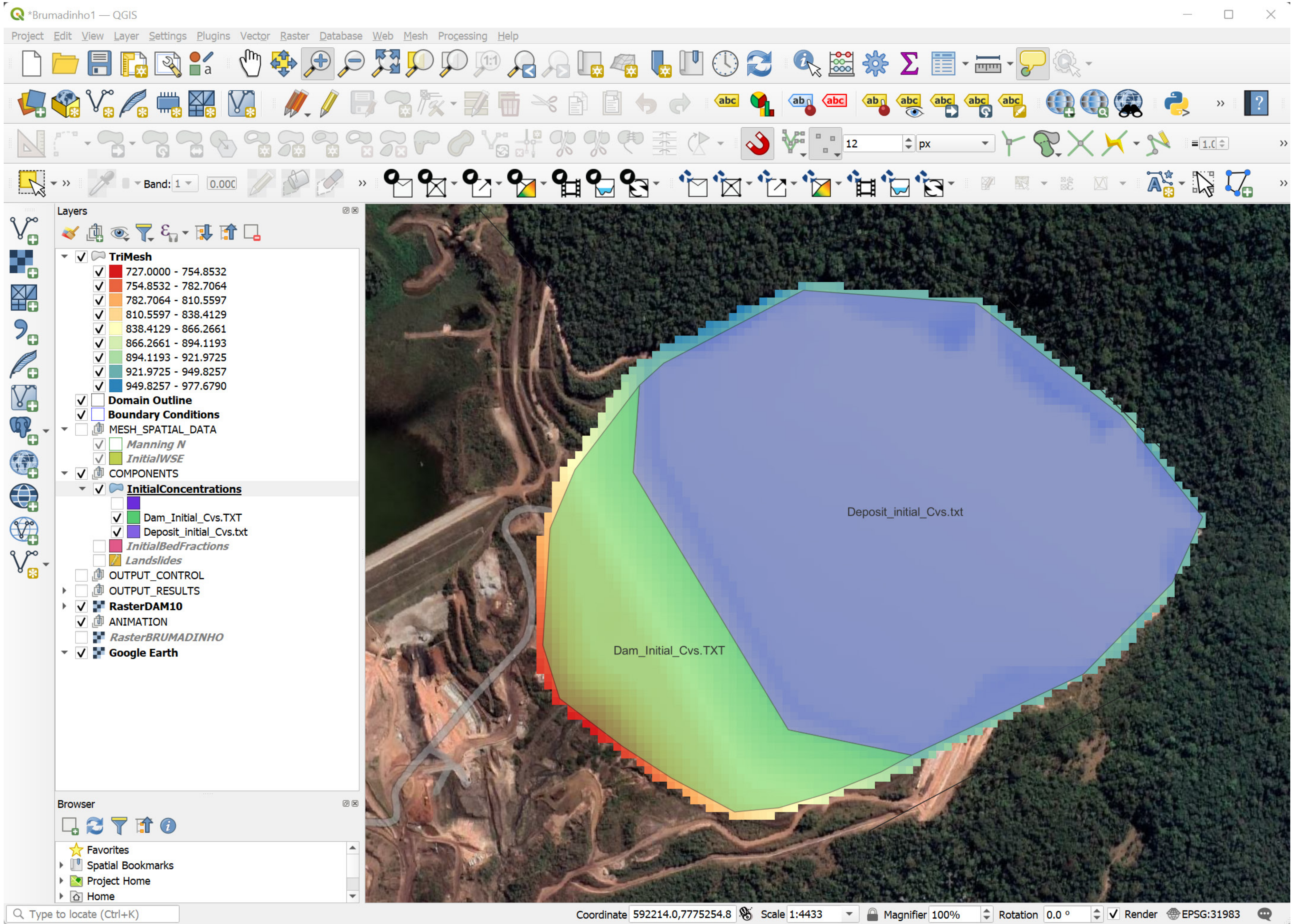
- Córrego do Feijão 80 m high iron tailings mine
- At 12:28 PM on Friday, January 25, 2019, the dam failed, impacting areas more than 8km downstream from the dam site
- Estimated death toll > 300 persons



: OilFlow2D^{TM} –QGIS Integration



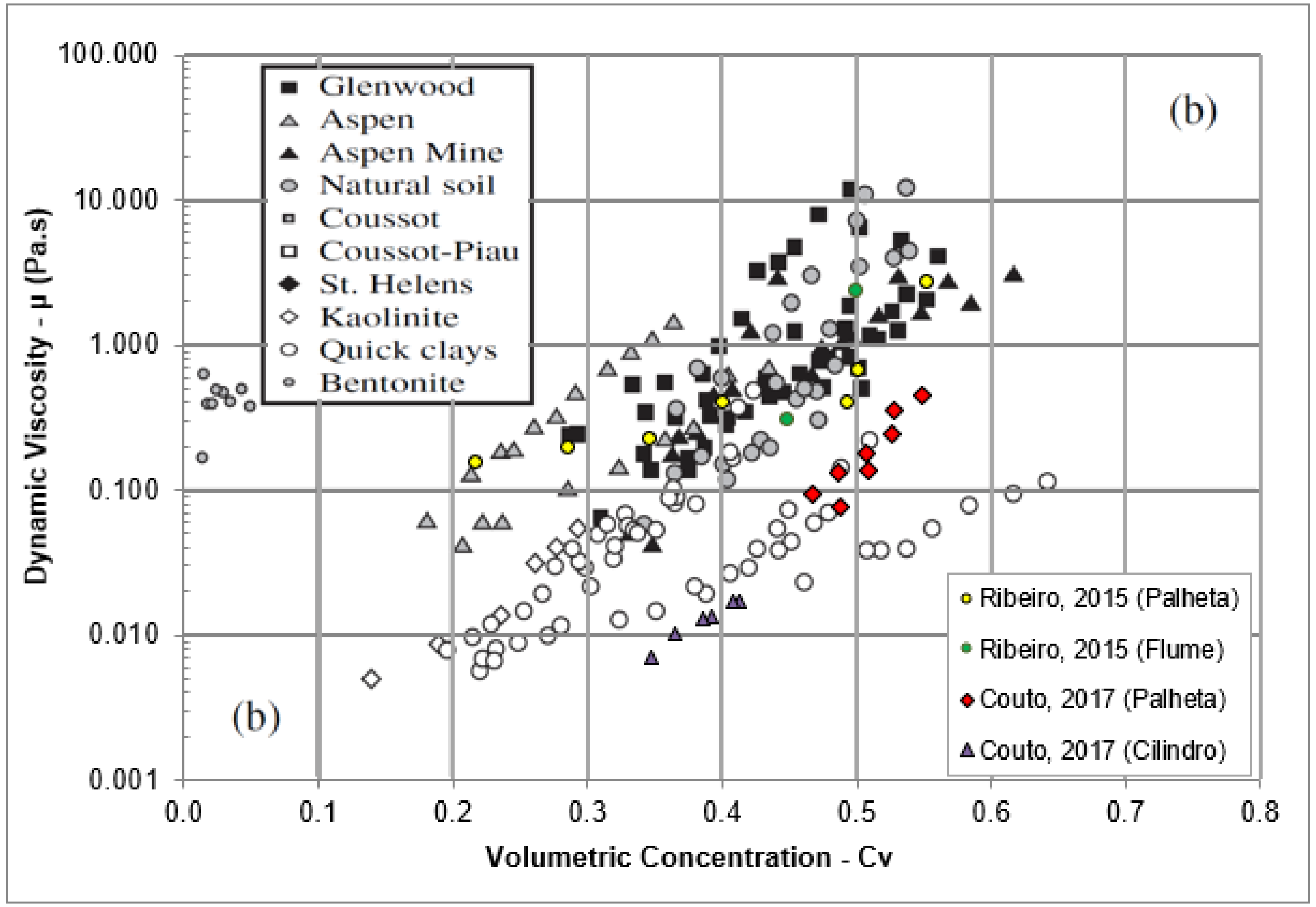
Different material properties

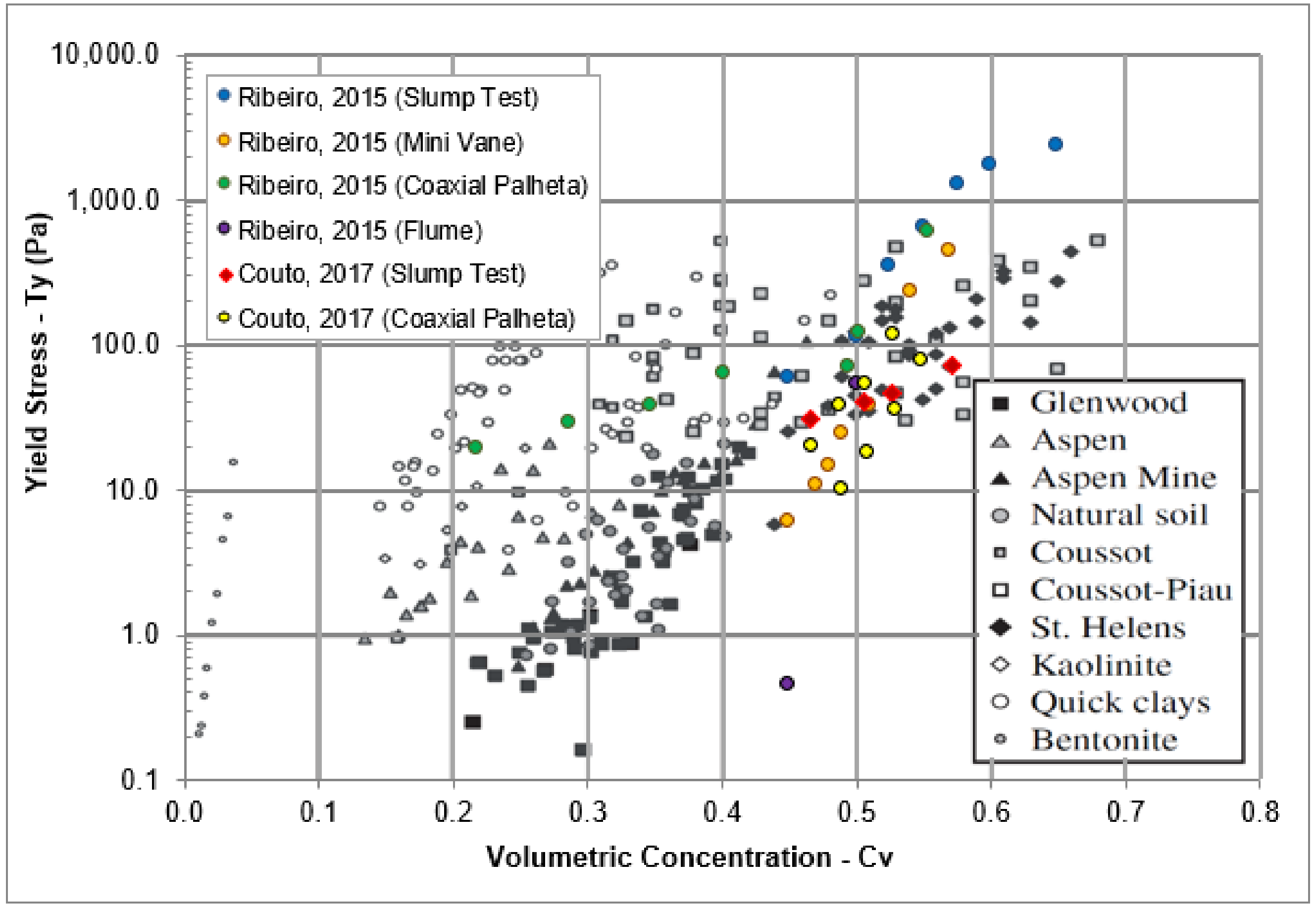


Flexible Mesh

- 382,966 Cells
- Mesh area: 10.5 km^2.
- Average cell size: 7.4 m.
- Minimum cell size: 3.6 m.
- Maximum cell size: 12.1 m.

Mudflow Parameters Estimation

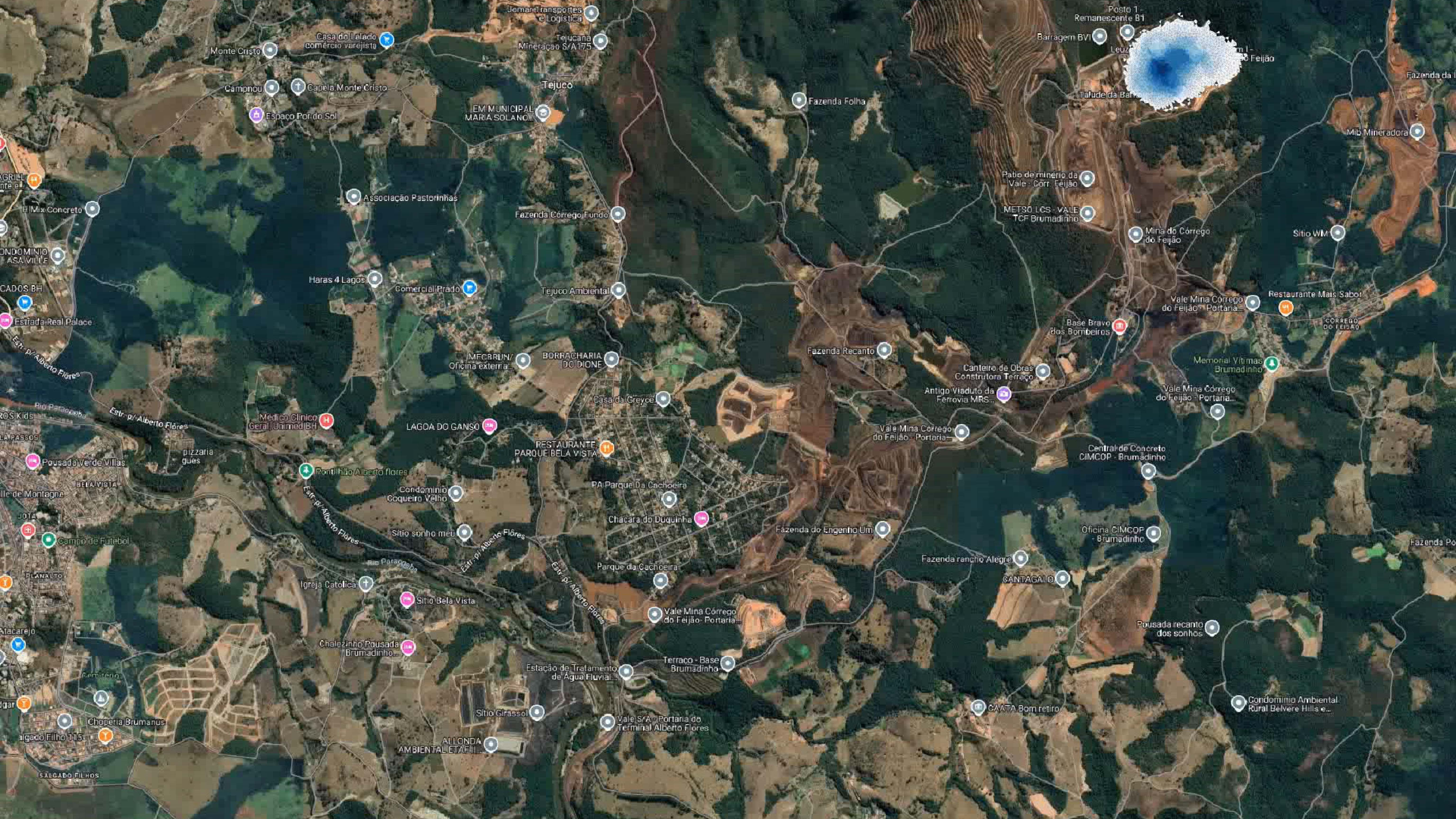




COUTO, N.M. 2015. *Retroanálise da propagação decorrente da ruptura da Barragem do fundão com diferentes modelos numéricos e hipóteses de simulação*. Dissertação de Mestrado - Universidade Federal de Minas Gerais (UFMG). Belo Horizonte, 188 p.

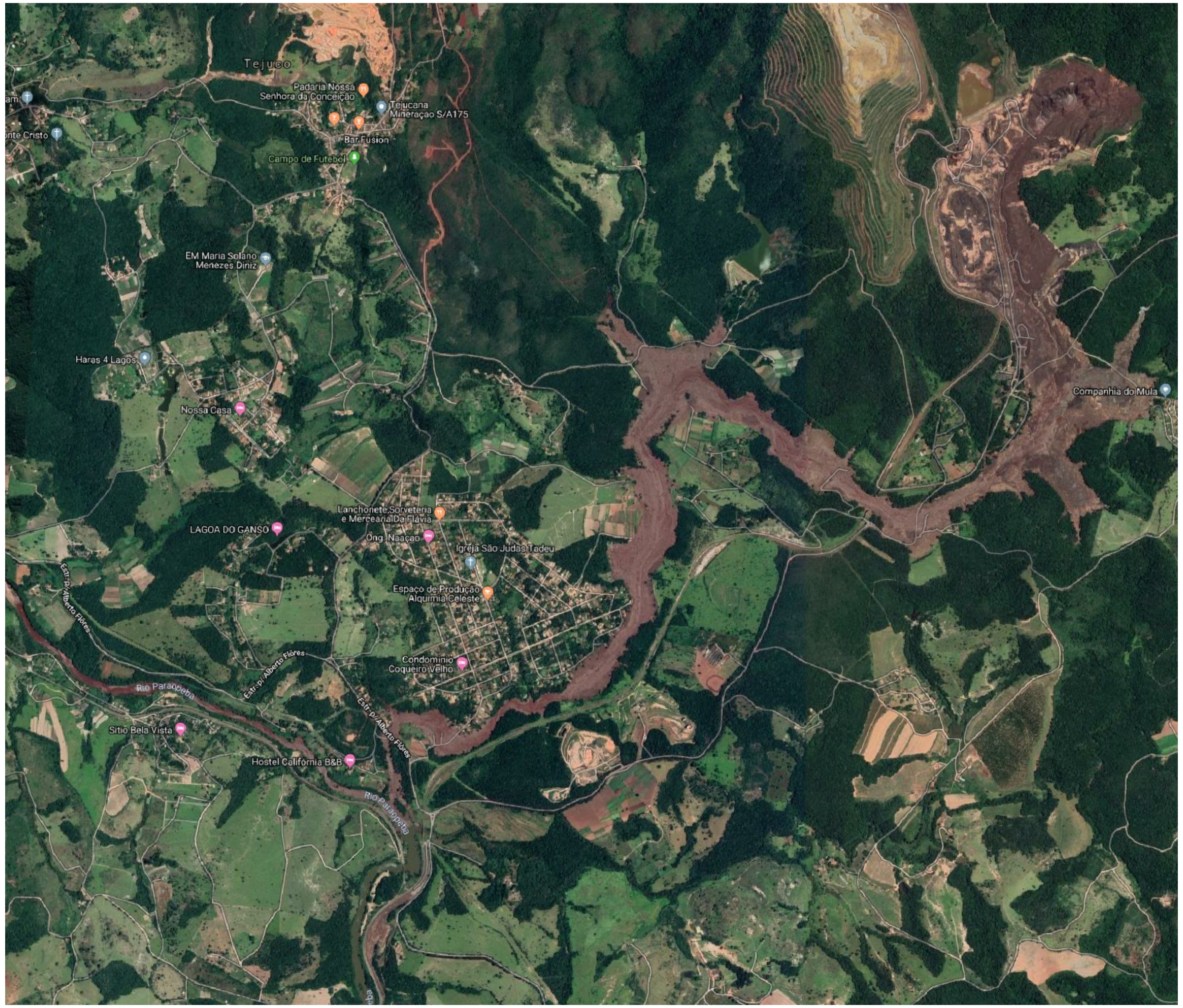
JULIEN, P. Y. Erosion and Sedimentation. Second Edition, 2010.

RIBEIRO, V. Q. F. Proposta de metodologia para avaliação dos efeitos de rupturas de estruturas de disposição de rejeitos. 2015. 267 f.. Dissertação (Mestrado) – Escola de Engenharia, Universidade Federal de Minas Gerais, Belo Horizonte, 2015

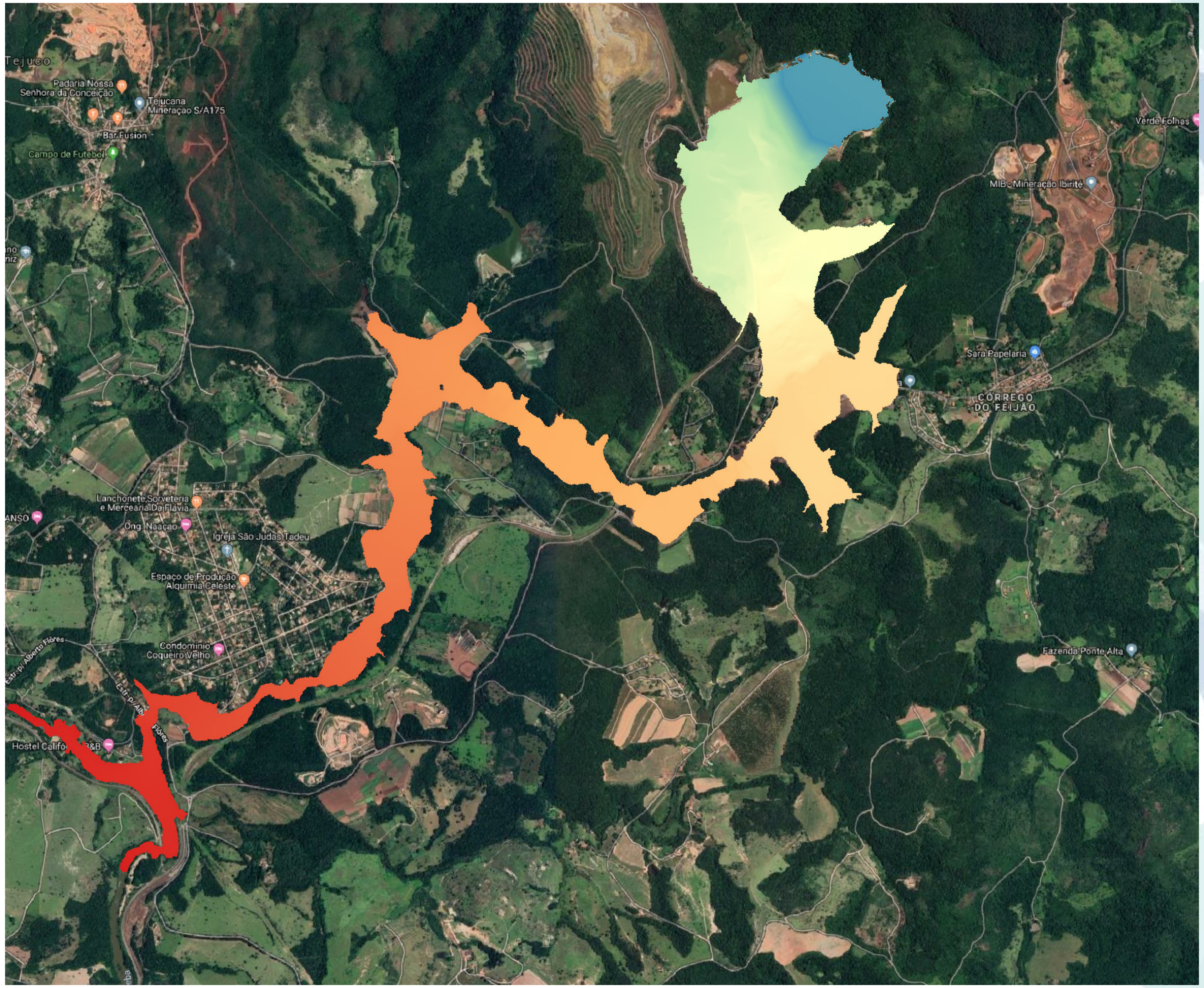


Jomar Transportes e Logística
Casa do Lalado comércio varejista
Monte Cristo
Tejucana Mineração S/A 175
Tejuco
Campnou
Capela Monte Cristo
Espaço Por do Sol
EM MUNICIPAL MARIA SOLANO...
Fazenda Folha
Posto 1 - Remanescente B1
Barragem BVI
Talude da Barr
Feijão
Fazenda da I
Mib Mineradora
Patio de minério da Vale - Corr. Feijão
METSO LCS - VALE TCF Brumadinho
Mina do Córrego do Feijão
Sitio WM
H Mix Concreto
Associação Pastorinhas
Fazenda Córrego Fundo
ONDOMINIO ASA VILLE
Haras 4 Lagos
Comercial Prado
Tejuco Ambiental
CADOS BH
Estrada Real Palace
Vale Mina Córrego do Feijão - Portaria...
Restaurante Mais Sabor
CÓRREGO DO FEIJÃO
Base Bravo dos Bombeiros
Fazenda Recanto
Memorial Vítimas Brumadinho
MECBRUN/ Oficina externa...
BORRACHARIA DO DIONE
Canteiro de Obras Construtora Terraço
Antigo Viaduto da Ferrovia MRS...
Estr. p/ Alberto Flores
Rio Paraopeba
Casa da Greyce
Vale Mina Córrego do Feijão - Portaria...
Medico Clinico Geral Unimed BH
LAGOA DO GANSO
Vale Mina Corrego do Feijão - Portaria
RESTAURANTE PARQUE BELA VISTA
Central de Concreto CIMCOP - Brumadinho
Pousada Verde Villas
BELA VISTA
pizzaria gues
Pontilhão Alberto flores
Condominio Coqueiro Velho
PA Parque Da Cachoeira
Chacara do Duquinha
Fazenda do Engenho Um
Oficina CIMCOP - Brumadinho
Campo de Futebol
Sitio sonho meu
Fazenda rancho Alegre
Fazenda Po
PLANALTO
Parque da Cachoeira
CANTAGALO
Igreja Catolica
Sitio Bela Vista
Vale Mina Córrego do Feijão- Portaria...
Pousada recanto dos sonhos
Atacarejo
Chalezinho Pousada Brumadinho...
Estação de Tratamento de Água Fluvial...
Terraço - Base Brumadinho
Cemitério
Choperia Brumanus
CAATA Bom retiro
Condomínio Ambiental Rural Belvere Hills e...
Sítio Girassol
Vale S/A - Portaria do Terminal Alberto Flores
ALLONDA AMBIENTAL ETAFII...
SALGADO FILHOS

Observed

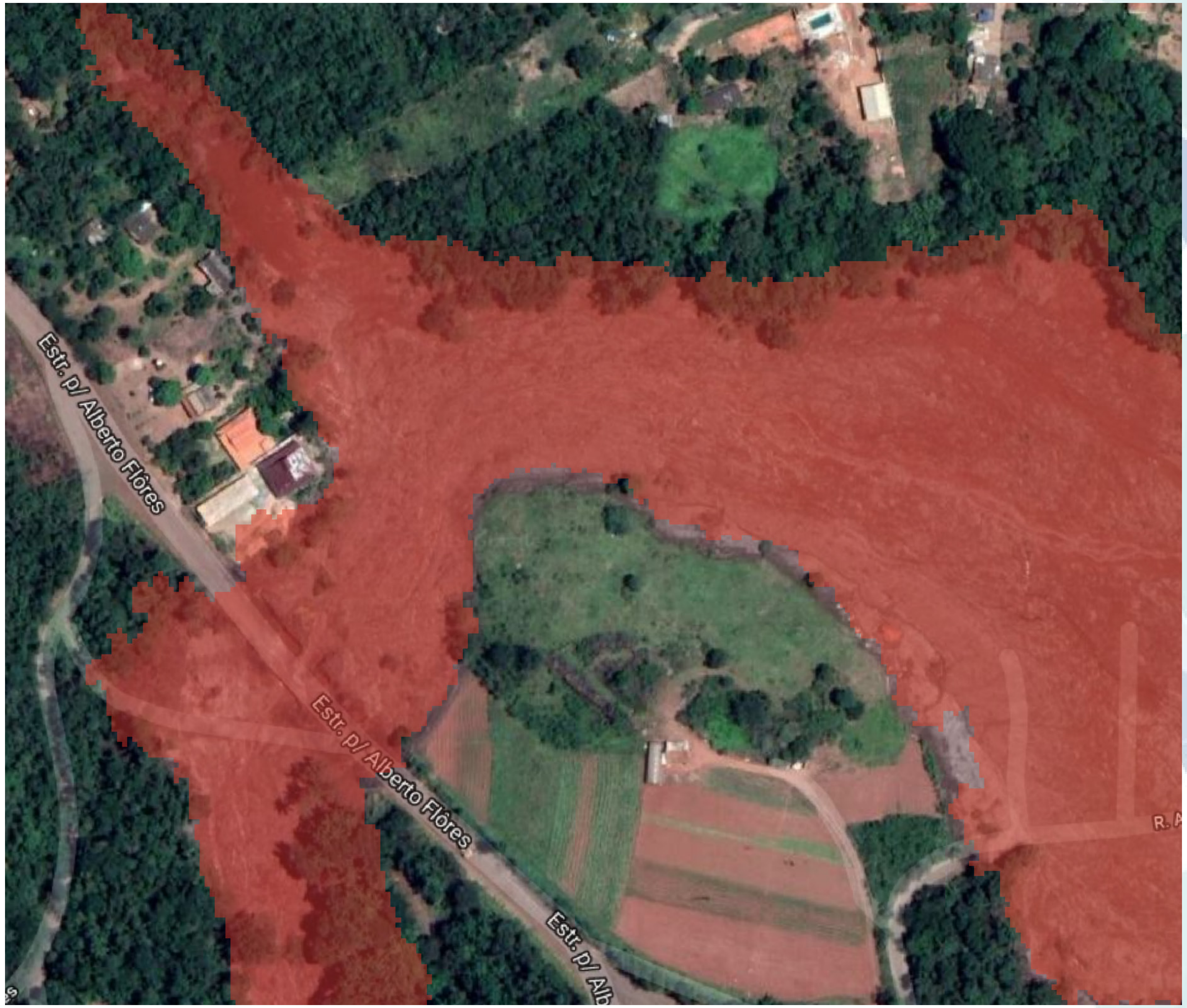


Simulated

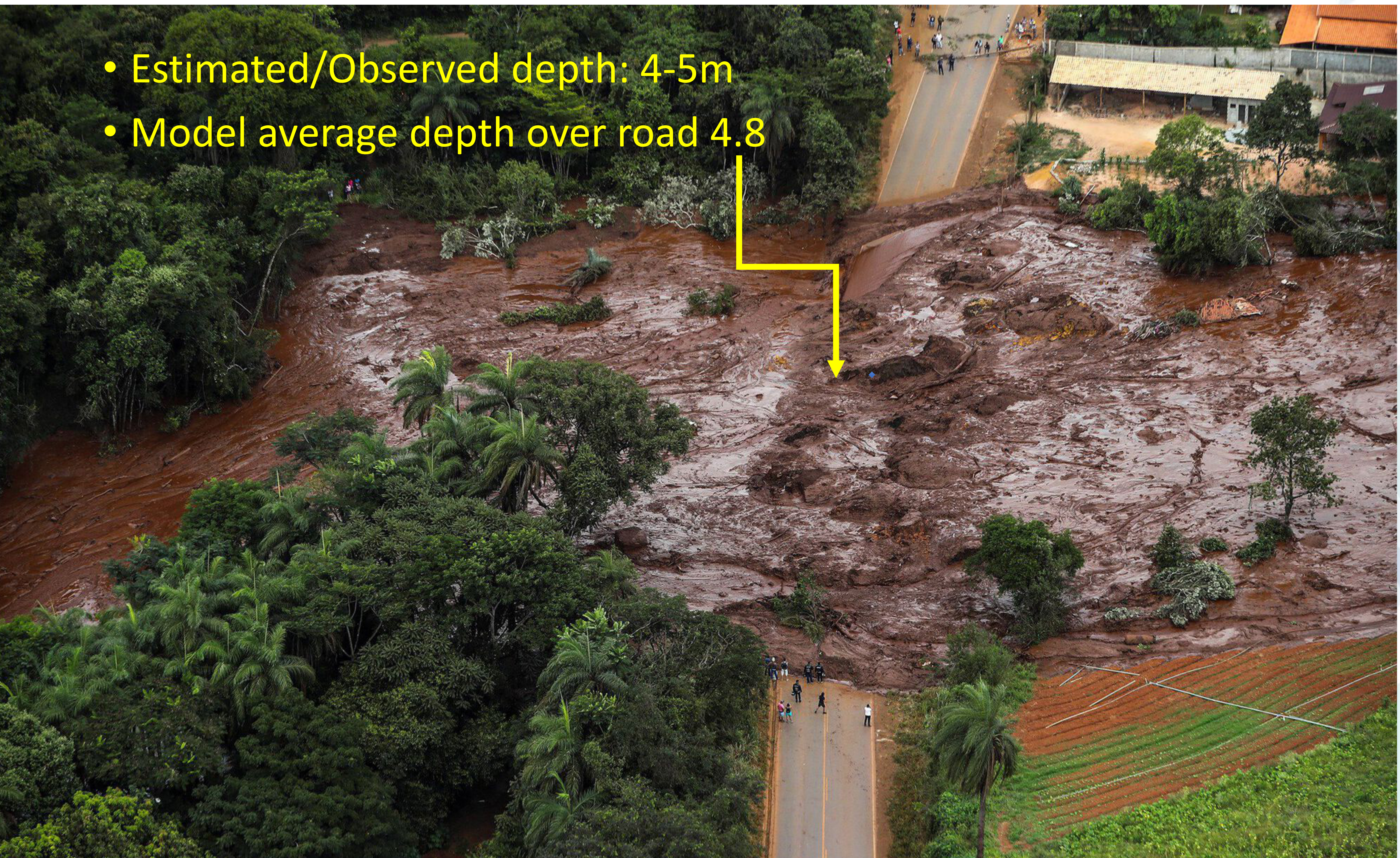


Observed

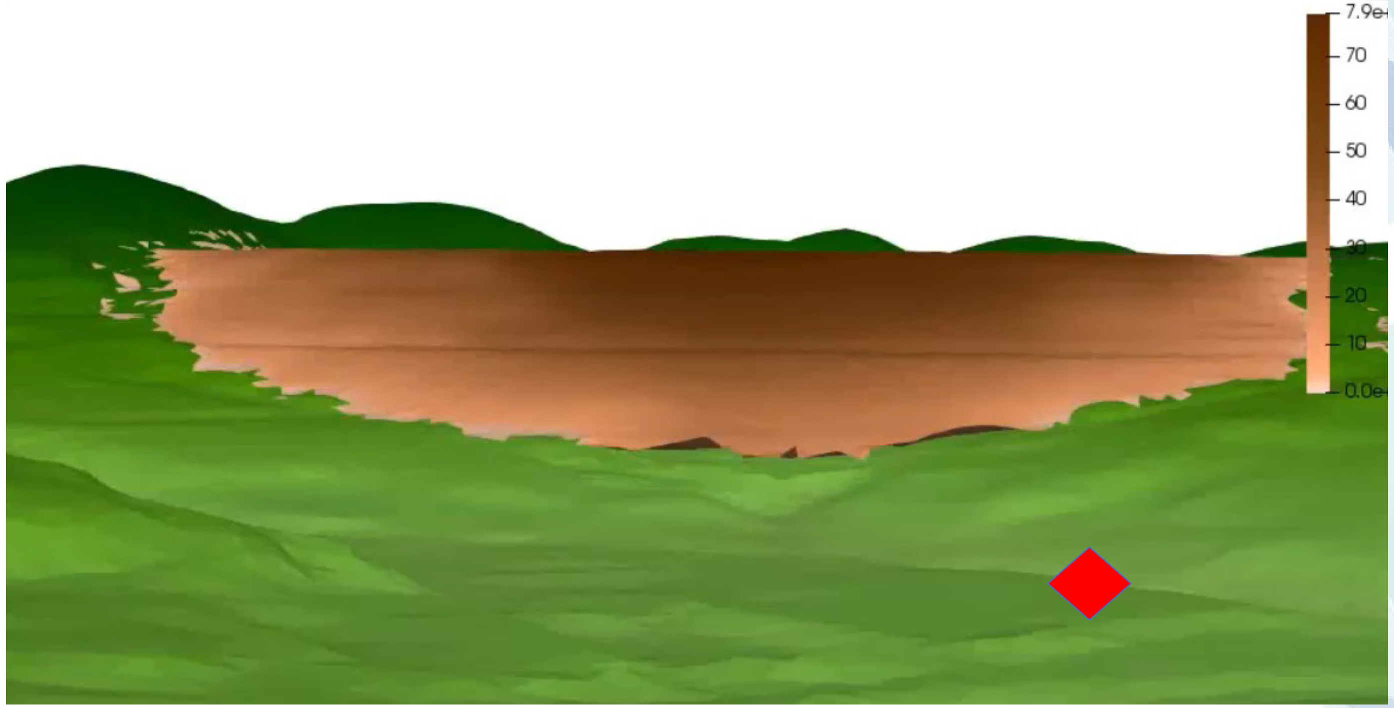
Simulated



Alberto Flores Road Crossing


• Estimated/Observed depth: 4-5m
• Model average depth over road 4.8

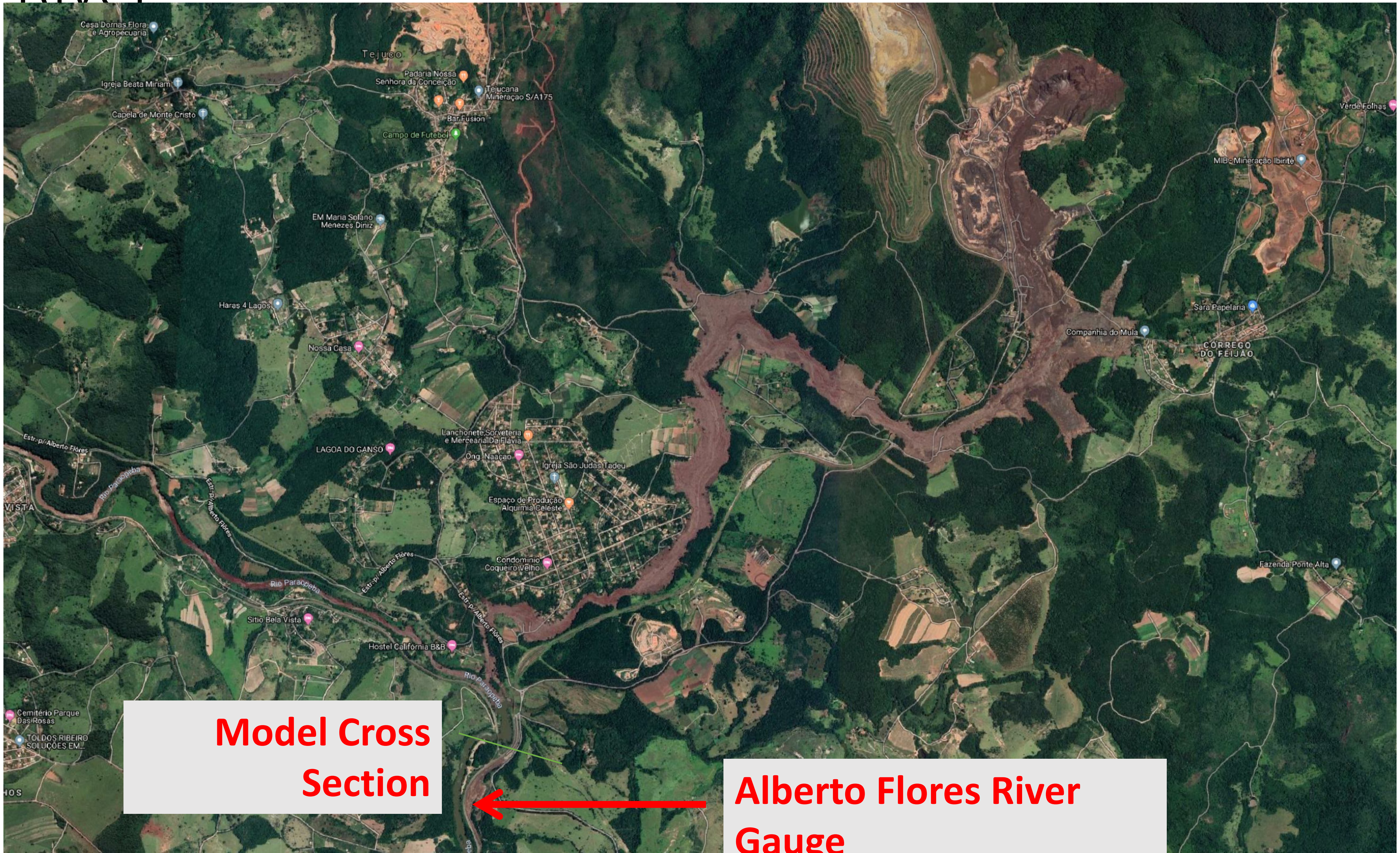
No need to guess mobilized tailings volume



Parameter	Observed	RiverFlow2D Simulation
Mobilized volume (m^3x10^6)	9.6	9.747
Time of arrival to reference point (seconds)	23	21

Inflow BC from Paraopeba River, Brazil

Comparison of Frontal Wave Arrival Time to Paraopeba River



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Agência Nacional de Águas

Gerar Gráficos

Filtrar por: Listas · Pesquisa · Setor Elétrico

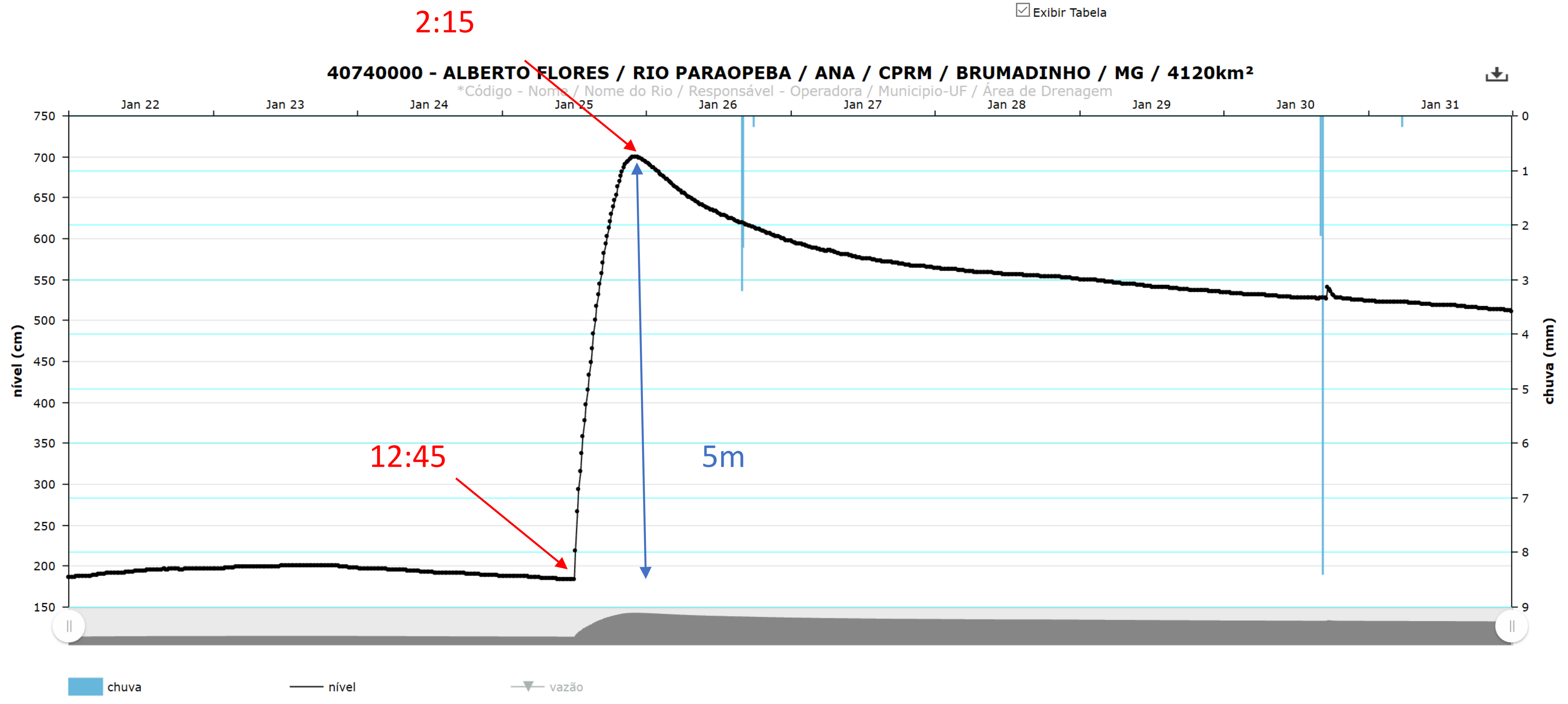
Estados:	**Origens:**	**Bacias:**	**Sub-bacias:**	**Estações:**
0 - <Todos>	0 - <Todos>	0 - <Todos>	0 - <Todos>	5 - 40740000 - ALBERTO FLORES
MG	5 - RHN	4 - RIO SÃO FRANCISCO	40 - RIOS SÃO FRANCISCO,PARAO	

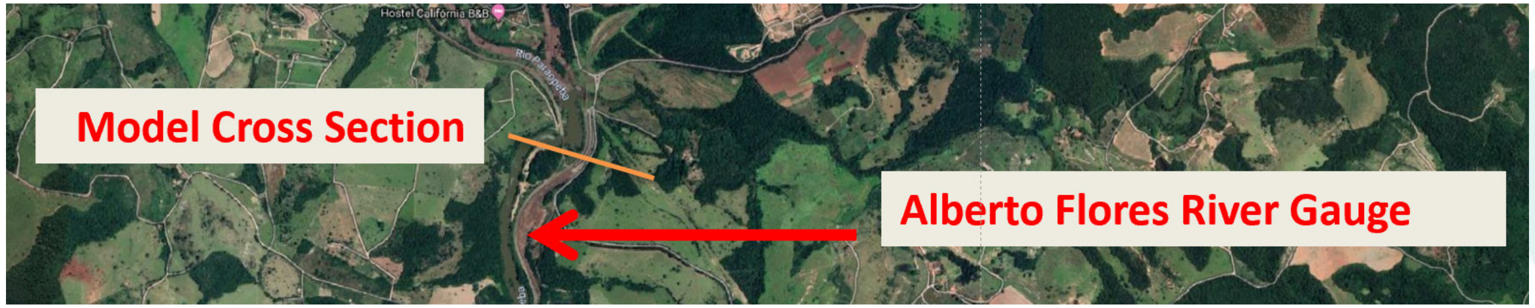
Pesquisar Por: Estação · Município · Rio
alberto flores

Status da Estação
Ativo · Manutenção · Desativada

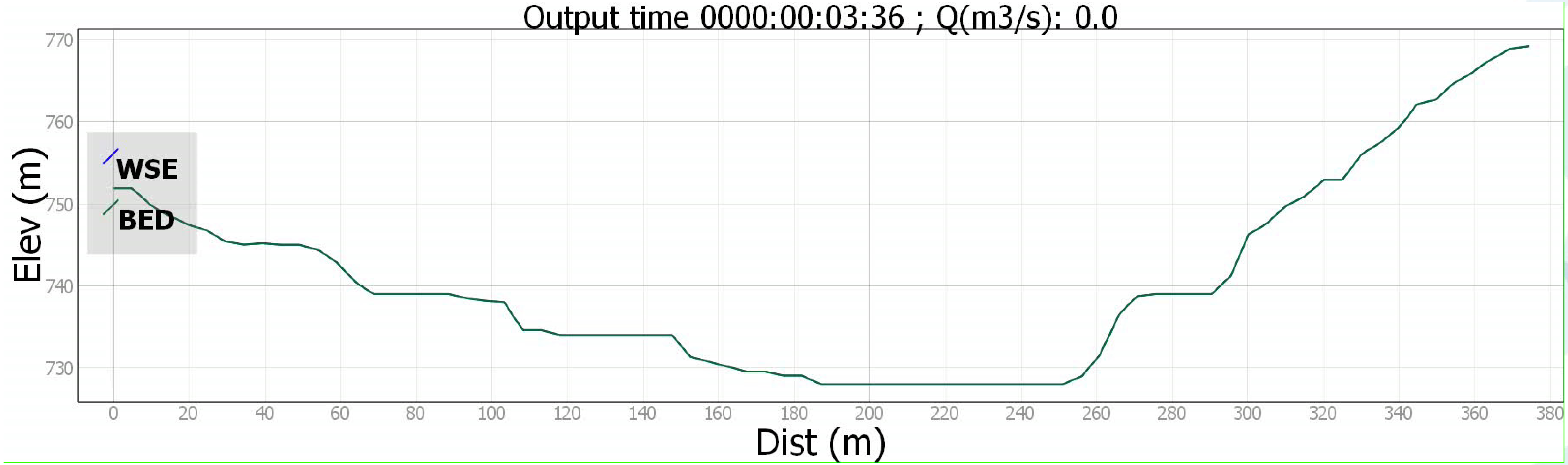
Período
De: 22/01/2019 00:00
A: 31/01/2019 23:59
1d · 7d · 1m · 3m · 1a
Exibir Tabela

Total de registros encontrados: **1**. *Dados disponibilizados no horário* ***UTC-3***.



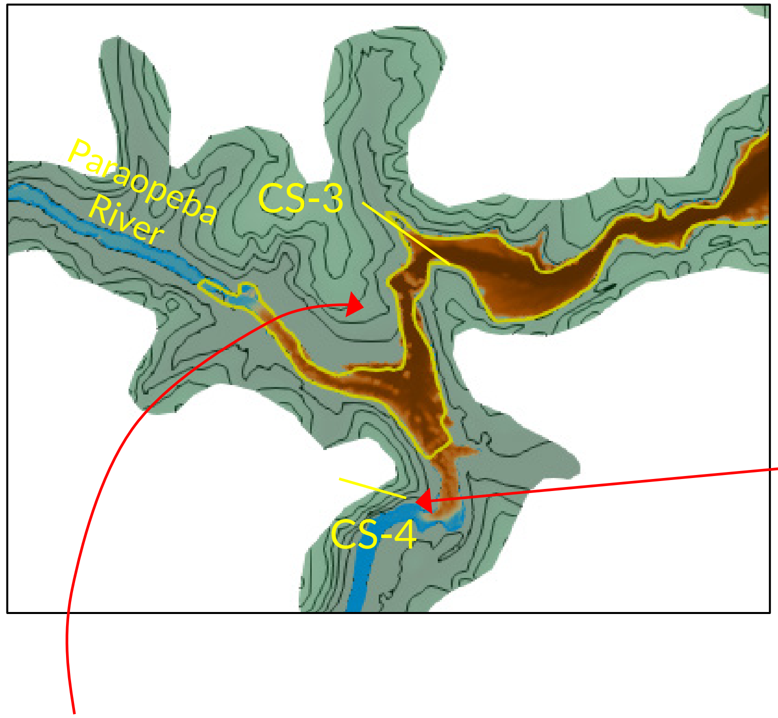


Model Cross Section
Alberto Flores River Gauge

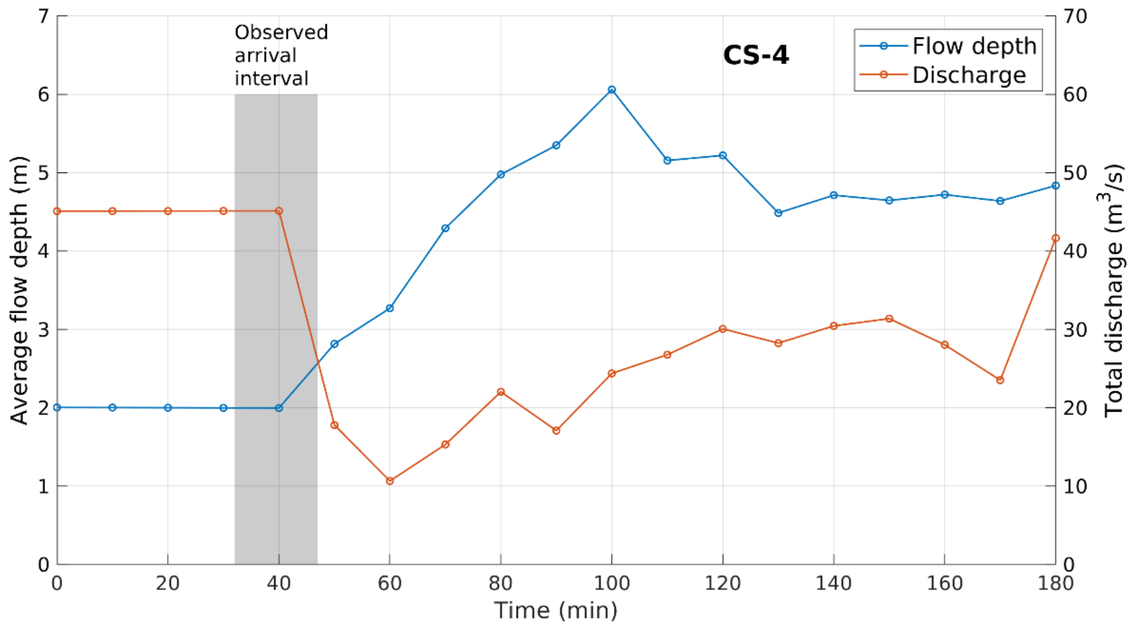


Output time 0000:00:03:36 ; Q(m3/s): 0.0
Elev (m)
Dist (m)
WSE
BED
770
760
750
740
730
0
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380

Model-Observations Comparison



Predicted temporal evolution at CS-4



	Observed	Computed
Released tailings volume (m^3)	$9.6 \cdot 10^6$	$9.747 \cdot 10^6$
Affected area (m^2)	$3.3 \cdot 10^6$	$3.604 \cdot 10^6$
Final mud elevation at CS-3 (m)	$\approx 4 - 5$	4.9
Arrival time to CS-4 (min)	$32 - 47$	43.5
Free surface increment at CS-4 (m)	5.11	4.06

Brumadinho Dam Break GPU Acceleration

NVIDIA RTX 4090 GPU	
Memory	24 GB
Cores	16,384

Mesh	No. Cells	Intel CPU	GTX 1080 Ti	RTX 3090	RTX 4090	Max Speedup
Mesh 1	19,792	00:00:12:08	00:00:00:43	00:00:00:27	00:00:00:19	16x
Mesh 2	150,055	00:04:16:31	00:00:08:45	00:00:04:03	00:00:02:05	125x
Mesh 3	1,096,772	04:04:03:32	00:02:38:27	00:01:03:15	00:00:33:12	181x

HYDRONIA

RiverFlow2D Evolution in Time

Year	Release characteristics	GPU Speed up
2010	First commercial version. Single-phase. Finite Element. CPU.	0

Biscayne Bay, FL, USA
Operational Model

Biscayne Bay Operational Model

Project Funded by the Environmental Protection Agency EPA USA (2019-2023)

A collaborative project between the University, the Government, and the Private Sector.

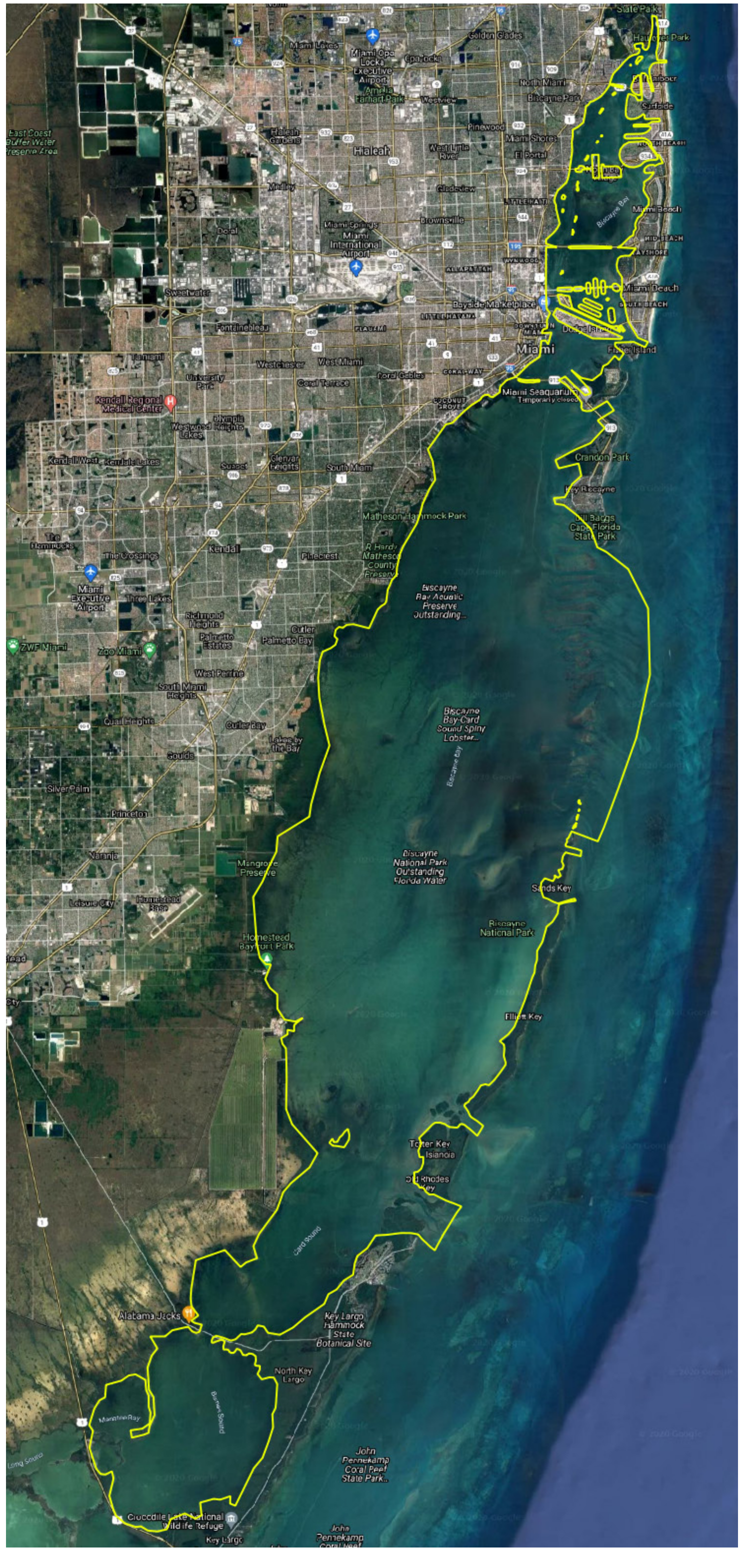
- Institute of Environment, Florida International University FIU
- DERM (Miami Dade County Division of Environmental Resources Management)
- Hydronia

BBOM Implementation

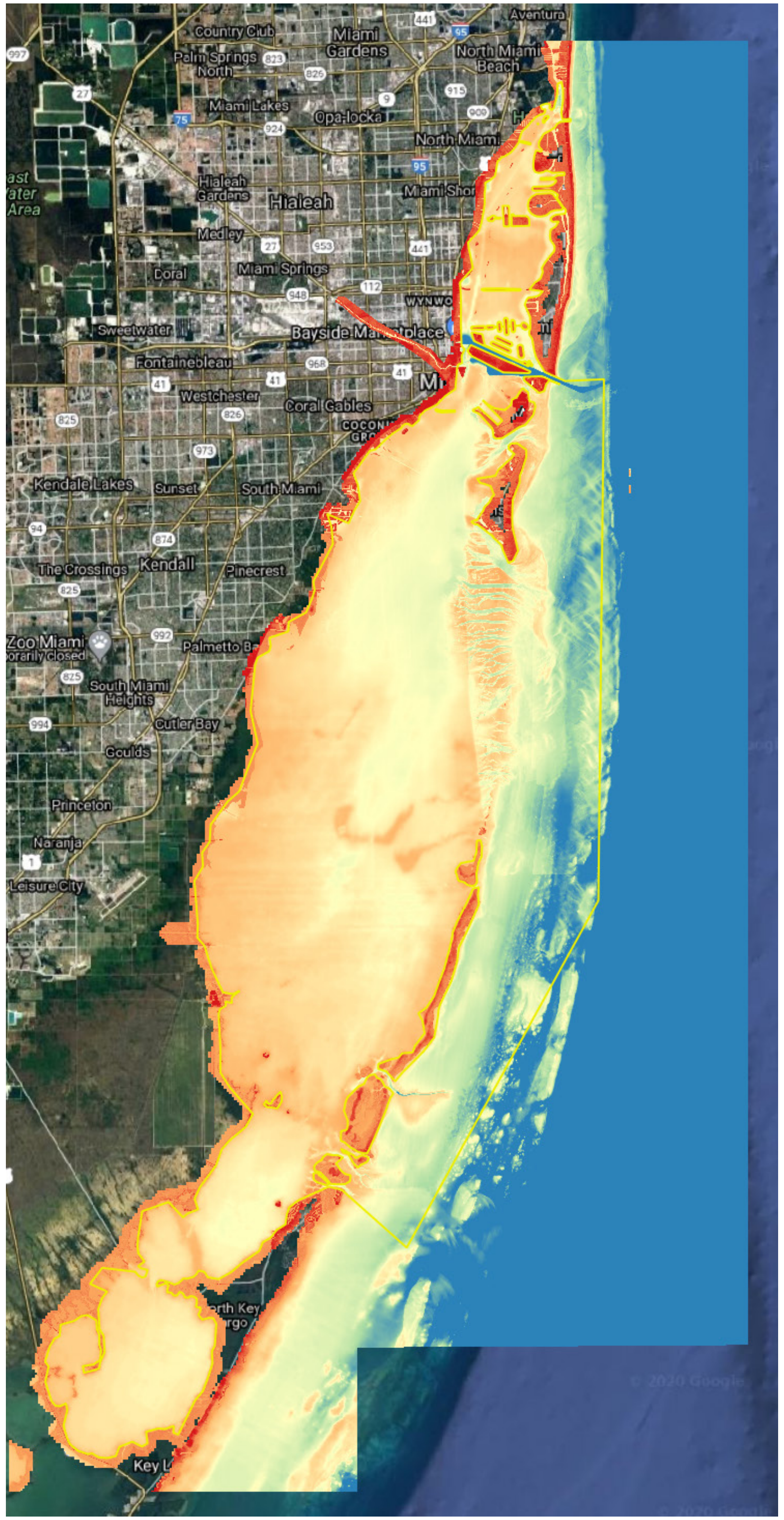
Bathymetric data

- NOAA Continuously Updated Digital Elevation Model (CUDEM) – 1/9 Arc-Second Resolution Bathymetric-Topographic Tiles.
- Updated on 2019-09-03.
- 0.5-3 m resolution.

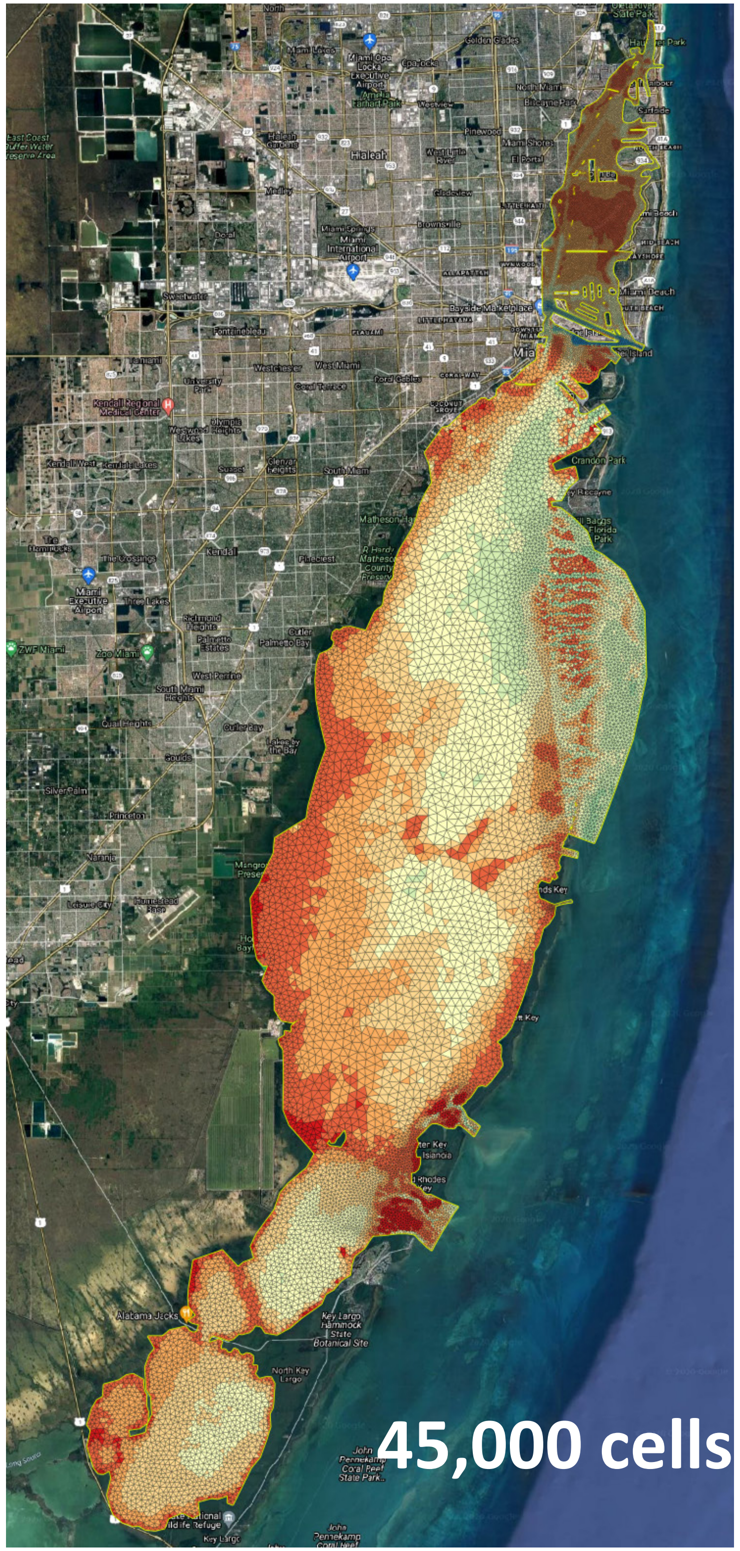
Model area (~17 x 82 km)



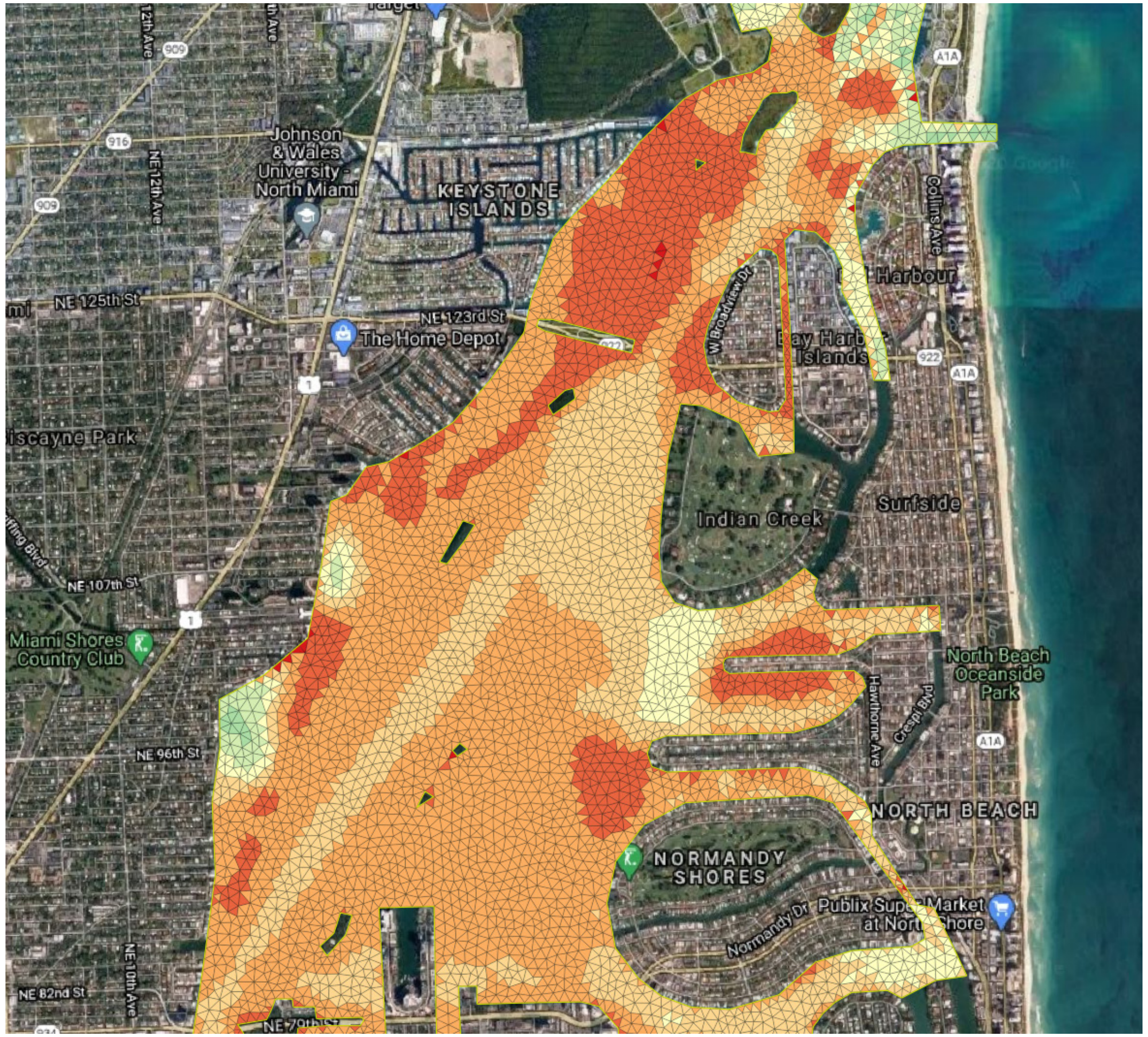
Topo-bathymetry

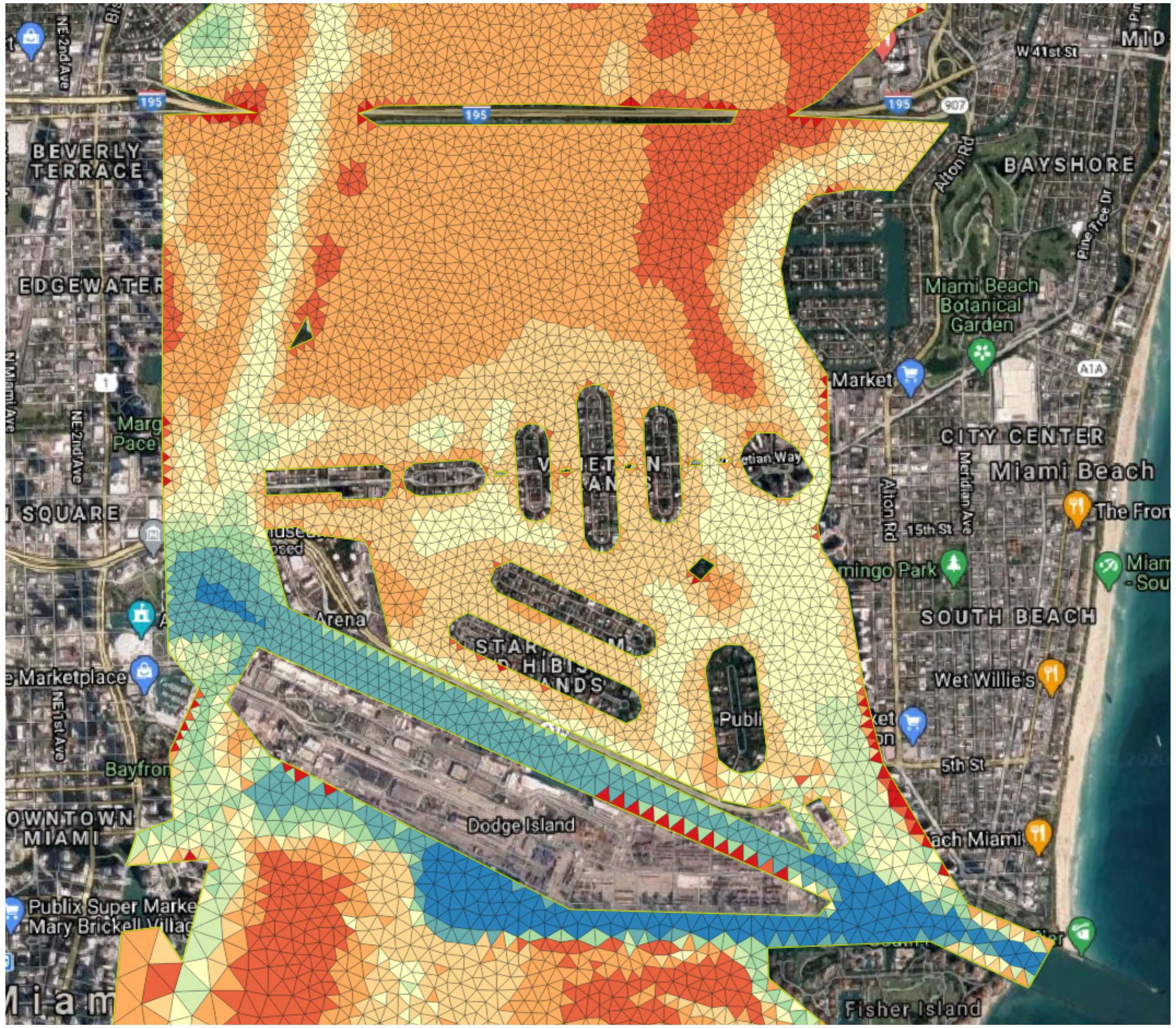


Model mesh

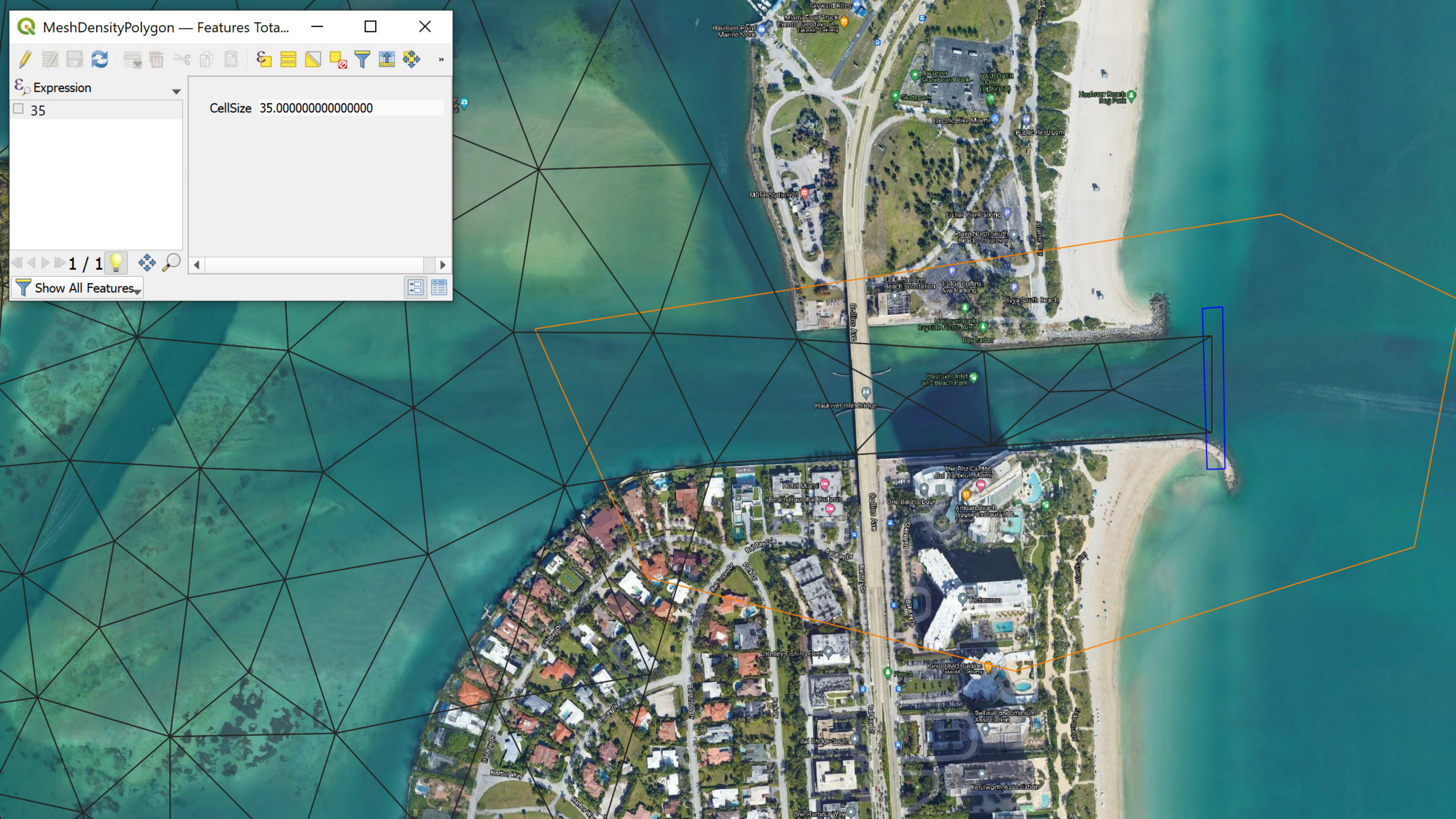


Mesh details





Skyward Kites
Miami Food Truck Events Tuesdays at...
Takeout · Delivery
Haulover Point Marine Store
Haulover Sandbar
Popular sandbar & boater hangout
Haulover Skateboard Park
HAULOVER PARK (PLAYITA)
Skatepark
Electric Bike Miami
Public Restroom
Haulover Beach Dog Park
MDFR Station 21
Fisher Pier Parking
Playa North South Beach - Haulover
FP&L Haulover Beach substation
13401 Collins Ave Parking
Playa South Beach
Haulover Park Bayside Picnic Area
Bay harbor
Collins Ave
Haulover Inlet and Beach Park
Haulover Inlet Bridge
The Ritz-Carlton Bal Harbour, Miami
Hotel Miami
Beach Haus Bal Harbour
One Bal Harbour
Artisan Beach House Restaurant &...
Bal Bay Dr
Bal Cross Dr
Park Dr
Atlantic Way
Kelley Fishing Fleet
King David Cuisine
Bellini Condominium Association
Bal Bridge South
Kenilworth Association
Harbor Way


MeshDensityPolygon — Features Tota...
Expression
35
CellSize 35.000000000000000
1 / 1
Show All Features
Haulover Inlet Bridge
Collins Ave
Haulover Inlet and Beach Park
Hotel Miami
One Bal Harbour


Skyward Kites
Collins Ave
Haulover Inlet Bridge
Electric Bike Miami
Public Restroom
Fisher Pier Parking
Playa South Beach
Skatepark
Hotel Miami
Beach Haus Bal Harbour
One Bal Harbour
Collins Ave
Bellini Condominium Association
Kenilworth Association
King David Cuisine
One Harbour Way

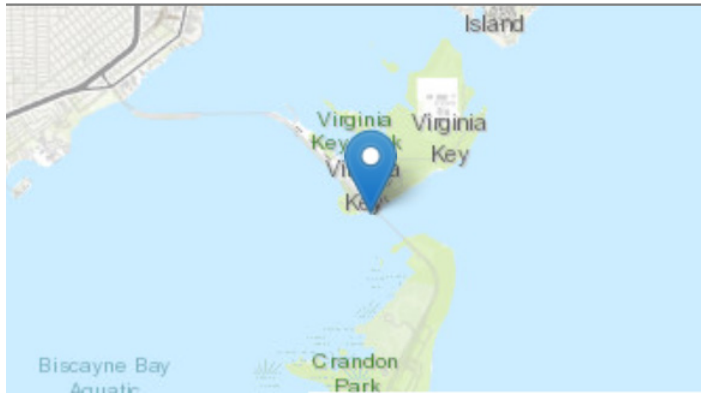
Code Enforcement Consulting
Arch Creek Dr
Little Arch Creek
Capital Financial Group
Magnolia Dr
Biscayne Bay Dr
Bayview Ln
Keystone Blvd
Mondo and Liz Island
Weiss Island

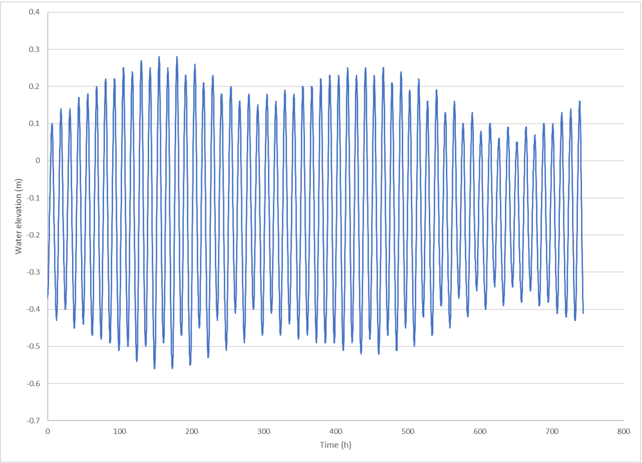

Little Arch Creek
Biscayne Bay Dr
Magnolia Dr
Capital Financial Group
Bayview Ln
Keystone Blvd
Arch Creek Dr
Alamanda Dr
20
Weiss Island

BBOM Implementation

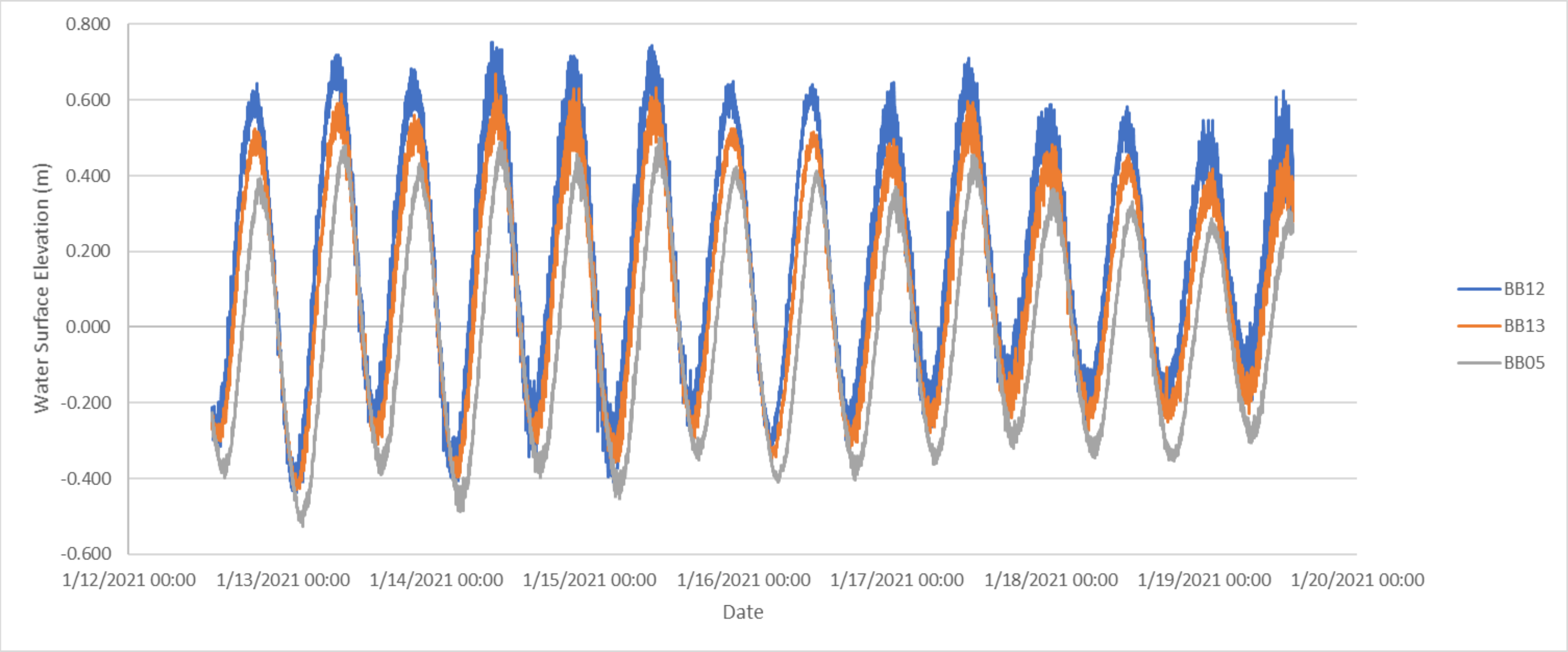
Tides

- NOAA Virginia Key station (Station id: 8723214).
- Established on 01/26/1995
- 25° 43.9' N, 80° 9.7' W
- https://tidesandcurrents.noaa.gov/stationhome.html?id=8723214





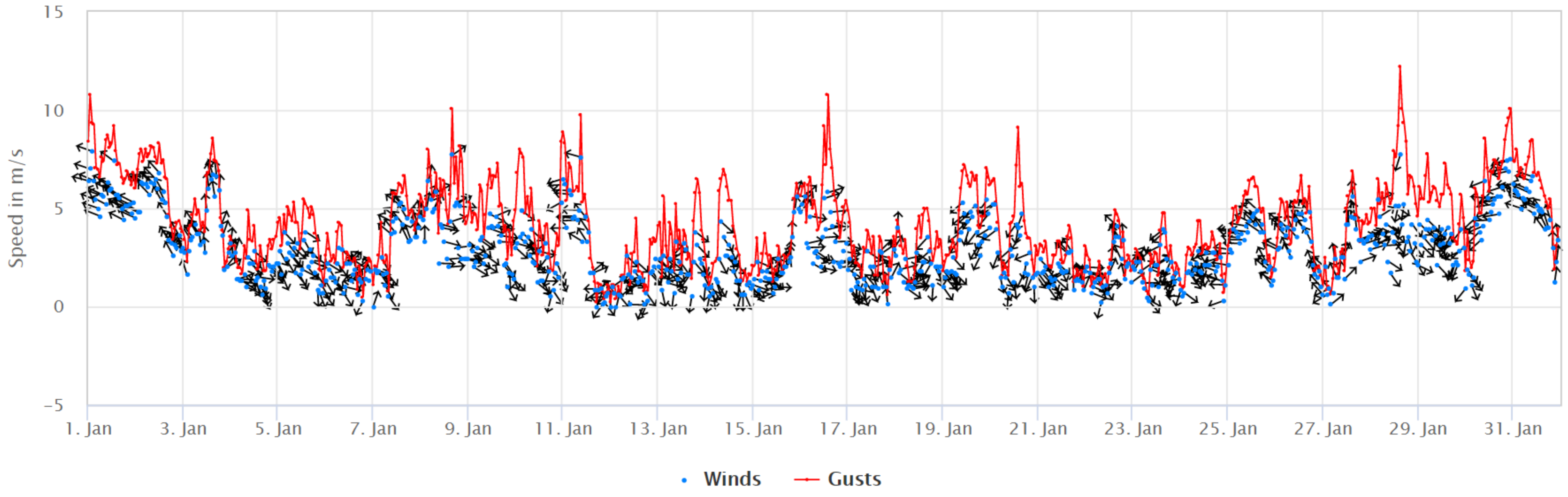
- Measured water elevations a BB05, BB12, and BB13 stations from 1/12/2021 and 1/19/2021.



BBOM Implementation

Wind velocity

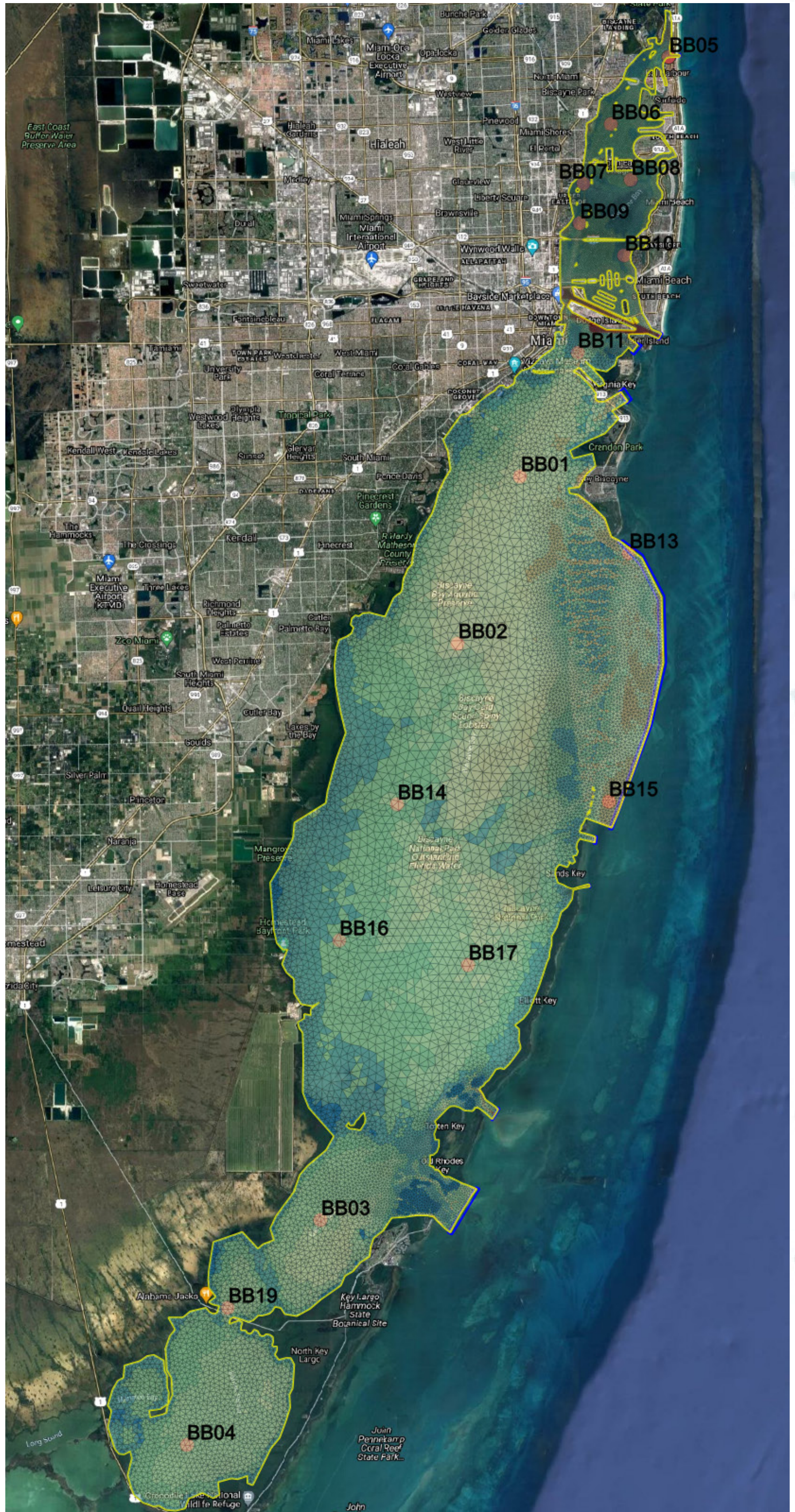
Figure 6 Wind speed at NOAA Virginia Key station 8723214 from 1/01/2021 to 1/31/2021. Source: NOAA/NOS/Center for Operational Oceanographic Products and Services.



BBOM Implementation

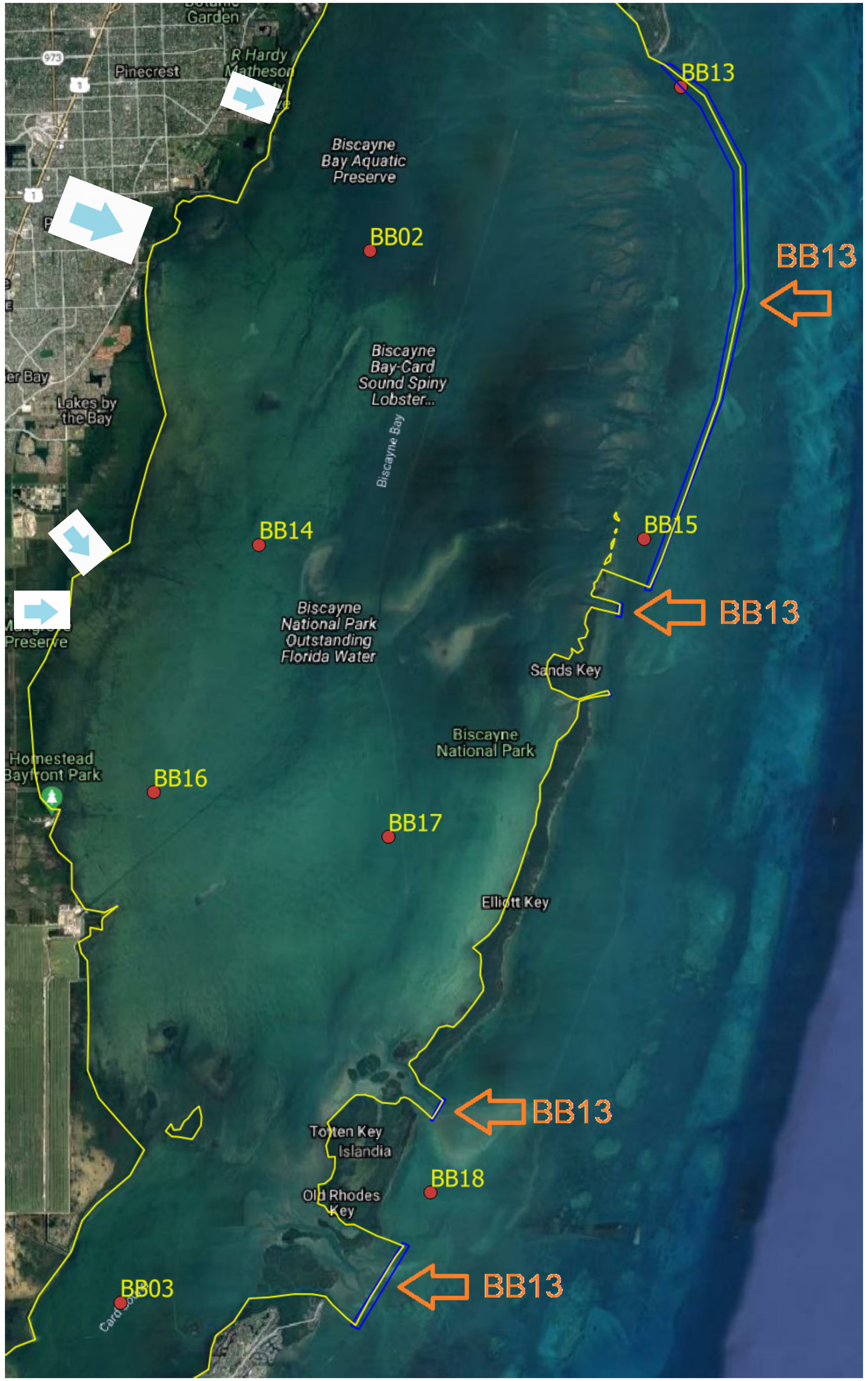
FIU Monitoring Campaigns to collect data for BOM calibration and validation

No.	Measurement campaign time period	
	Start	End
1	2017-10-10	2017-10-17
2	2018-06-20	2018-06-28
3	2019-04-01	2019-04-16
4	2019-10-29	2019-11-13
5	**2020-08-19**	**2020-10-14**
6	**2021-01-07**	**2021-01-19**



Boundary Conditions

- Tide: WSEL vs time
- Flowrate Q vs time
- Flow can enter or leave the mesh through the tide boundaries



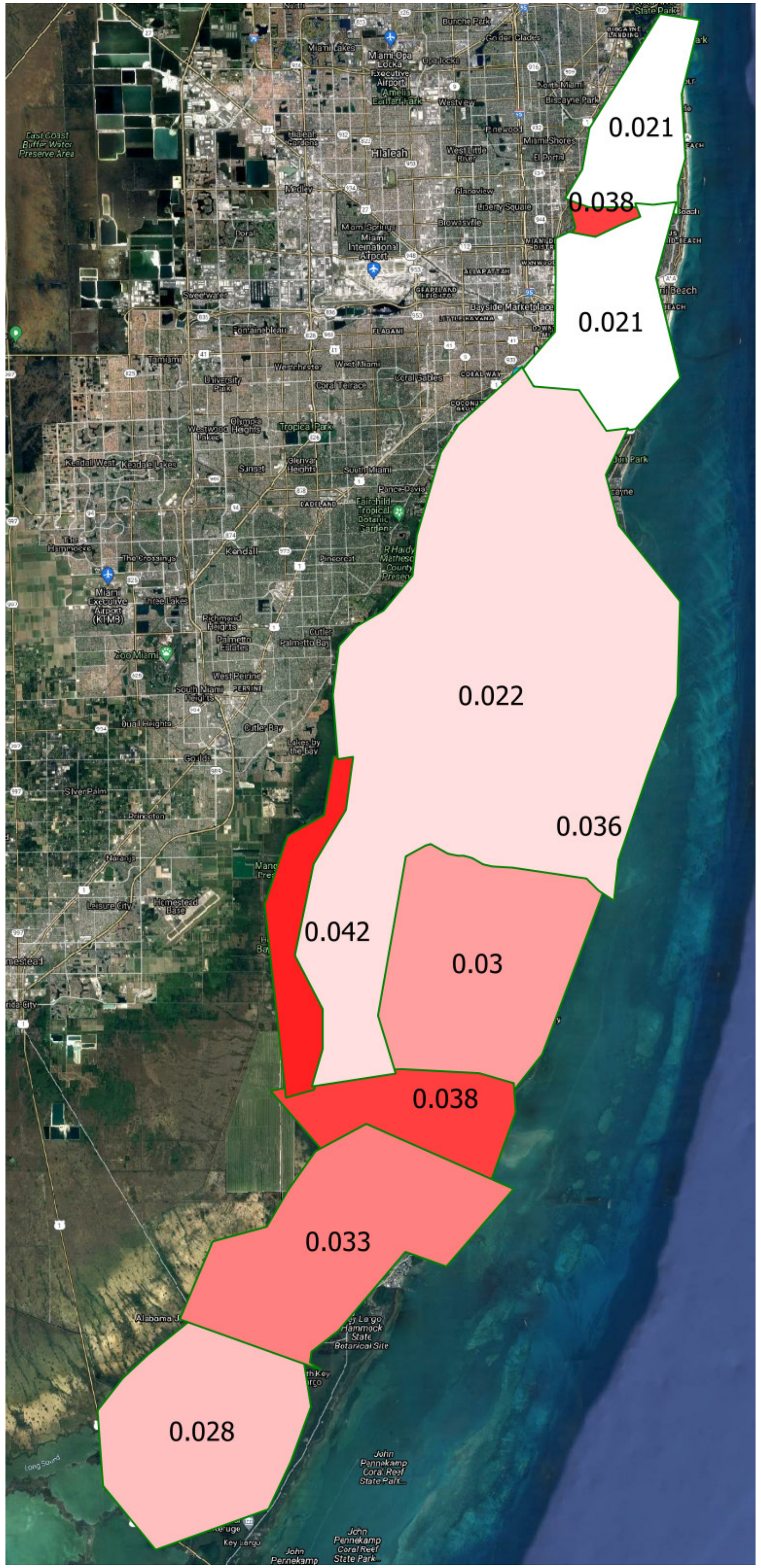
Bottom roughness

- Manning's n coefficient as calibration parameter
- Starting values derived from

Development of Two-Dimensional Numerical Model of Hydrodynamics and Salinity for Biscayne Bay, Florida

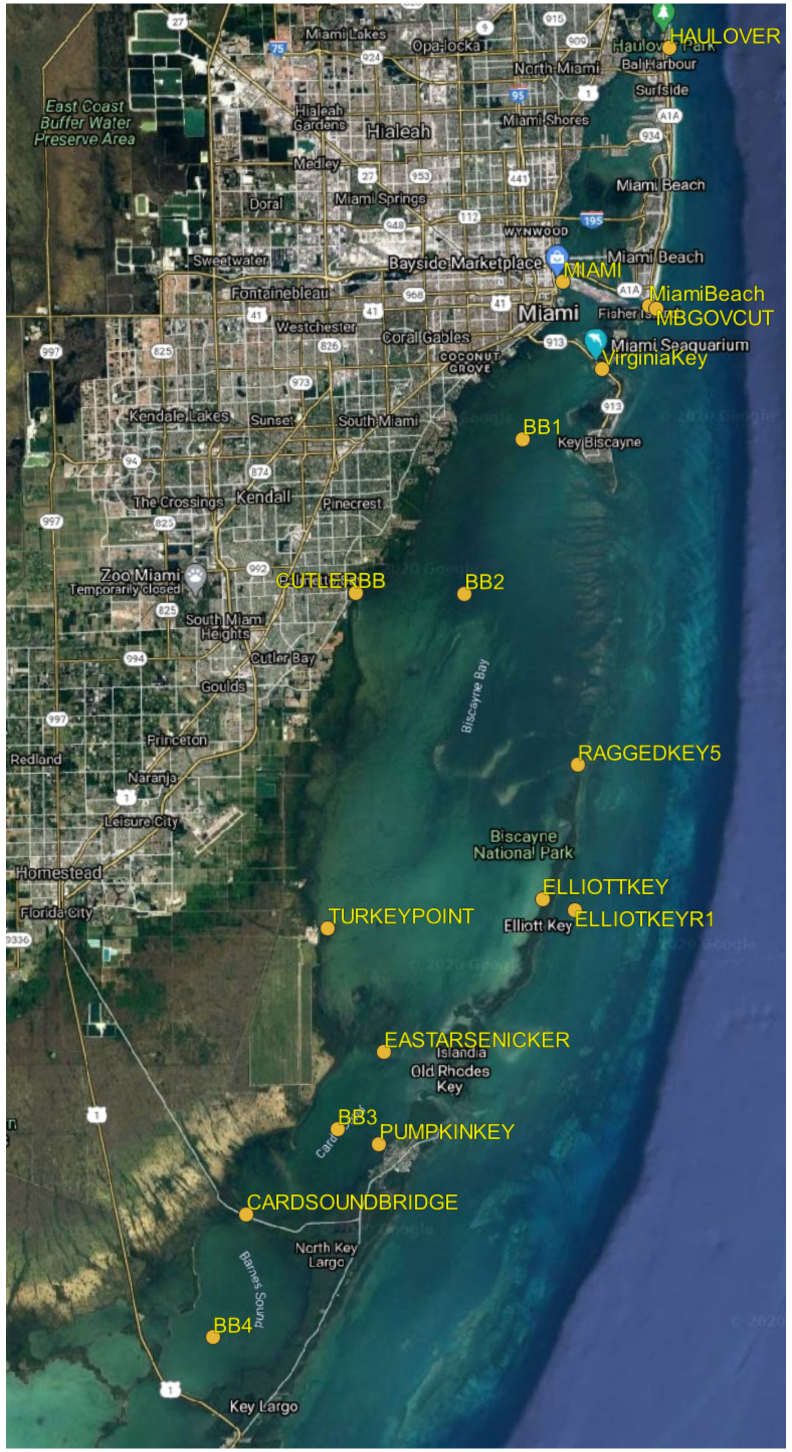
Gary L. Brown, Robert McAdory, Gregory H. Nail, Maria Soraya Sarruff, R. C. Berger, and Mitch A. Granat

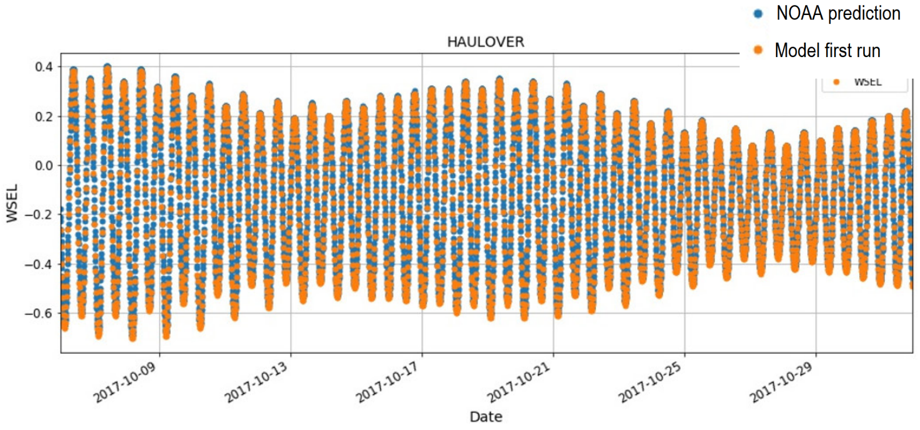
September 2003

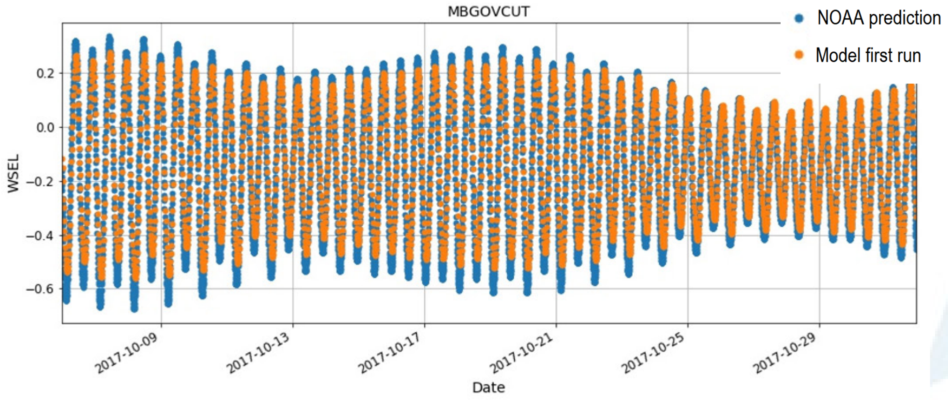


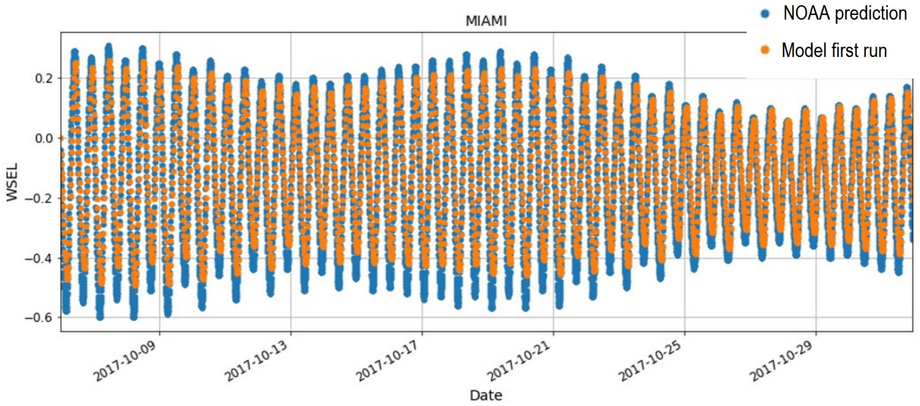
HYDRONIA

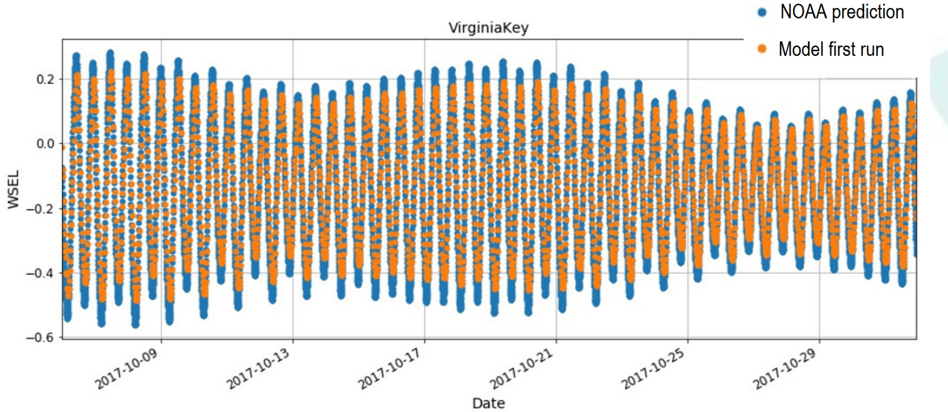
Water elevations (WSEL) from the first calibration run

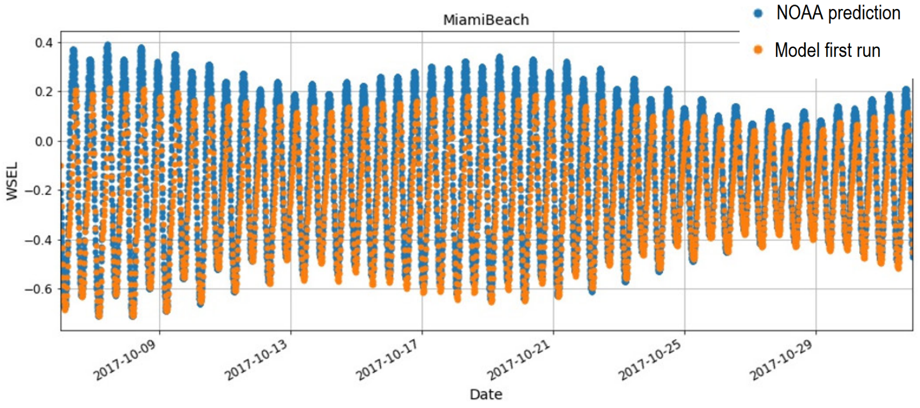


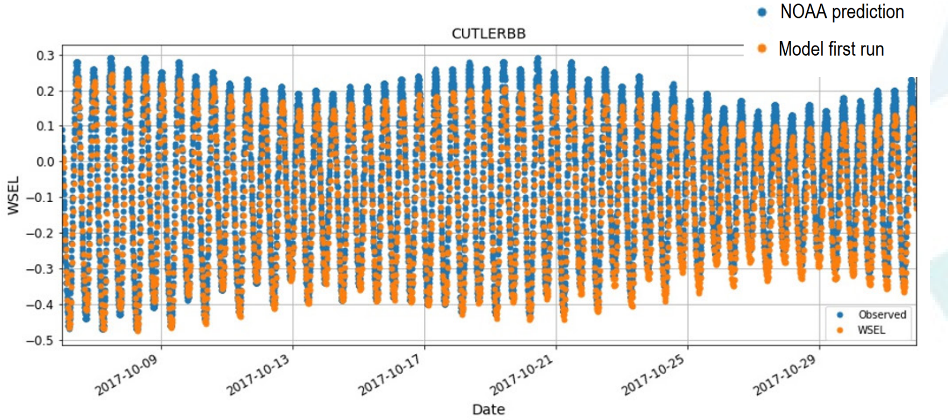




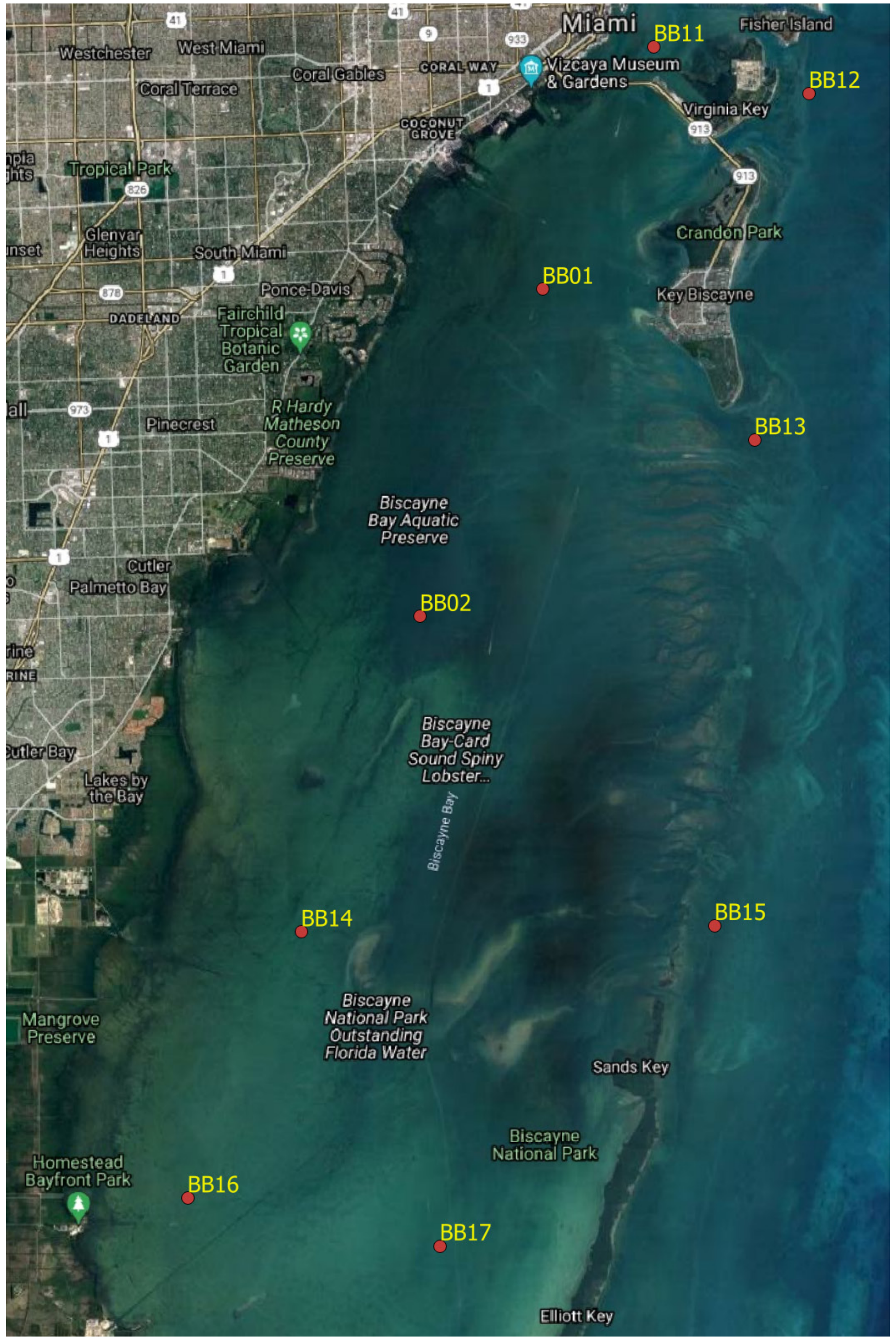


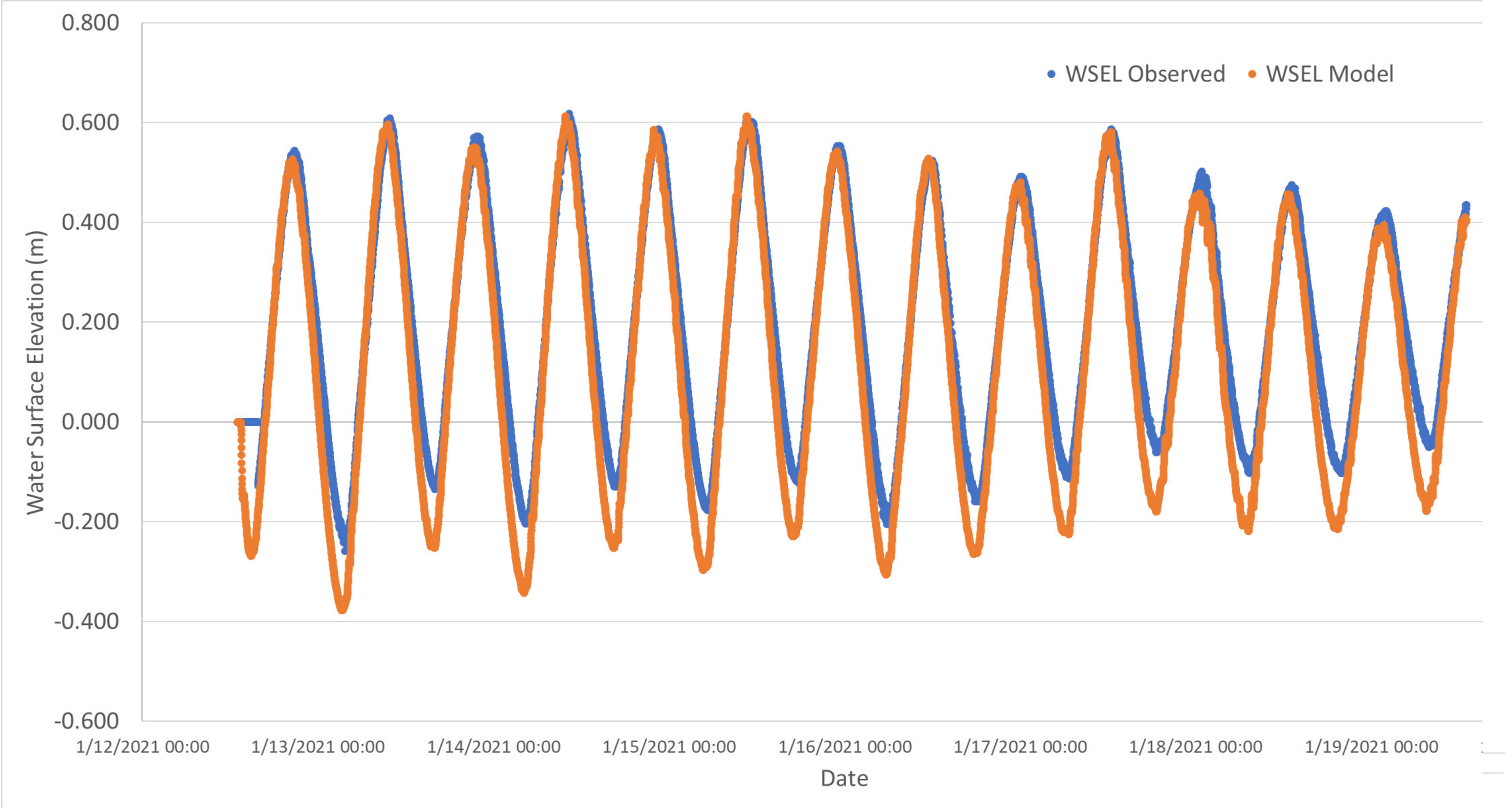


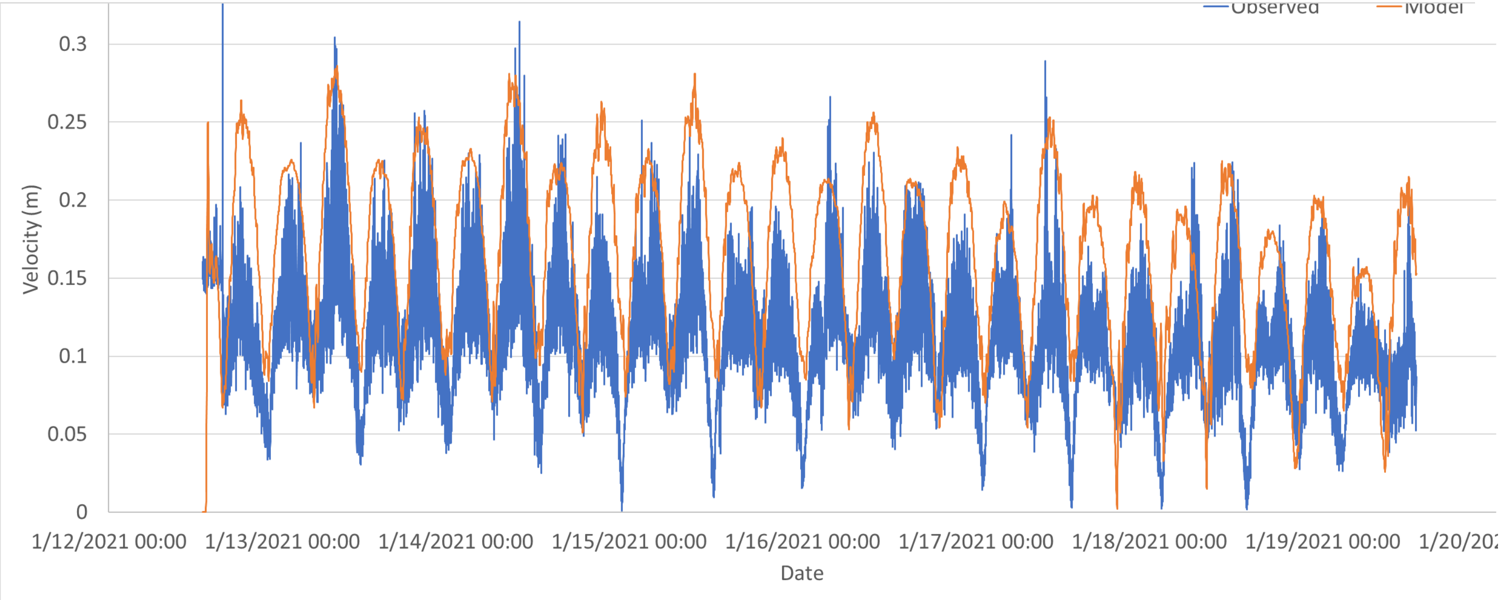




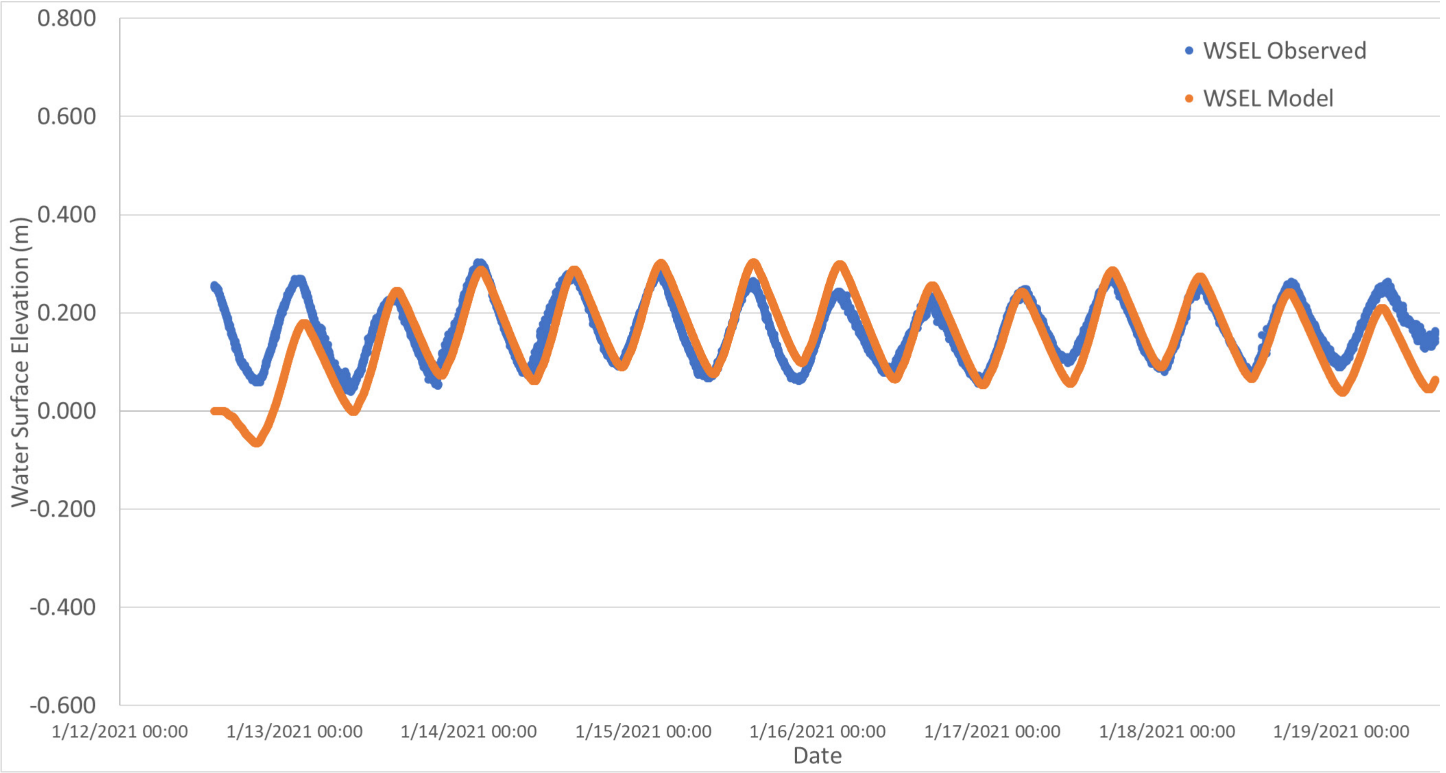
Water elevations (WSEL) and Velocities from the latest validation run (Jan-2021)

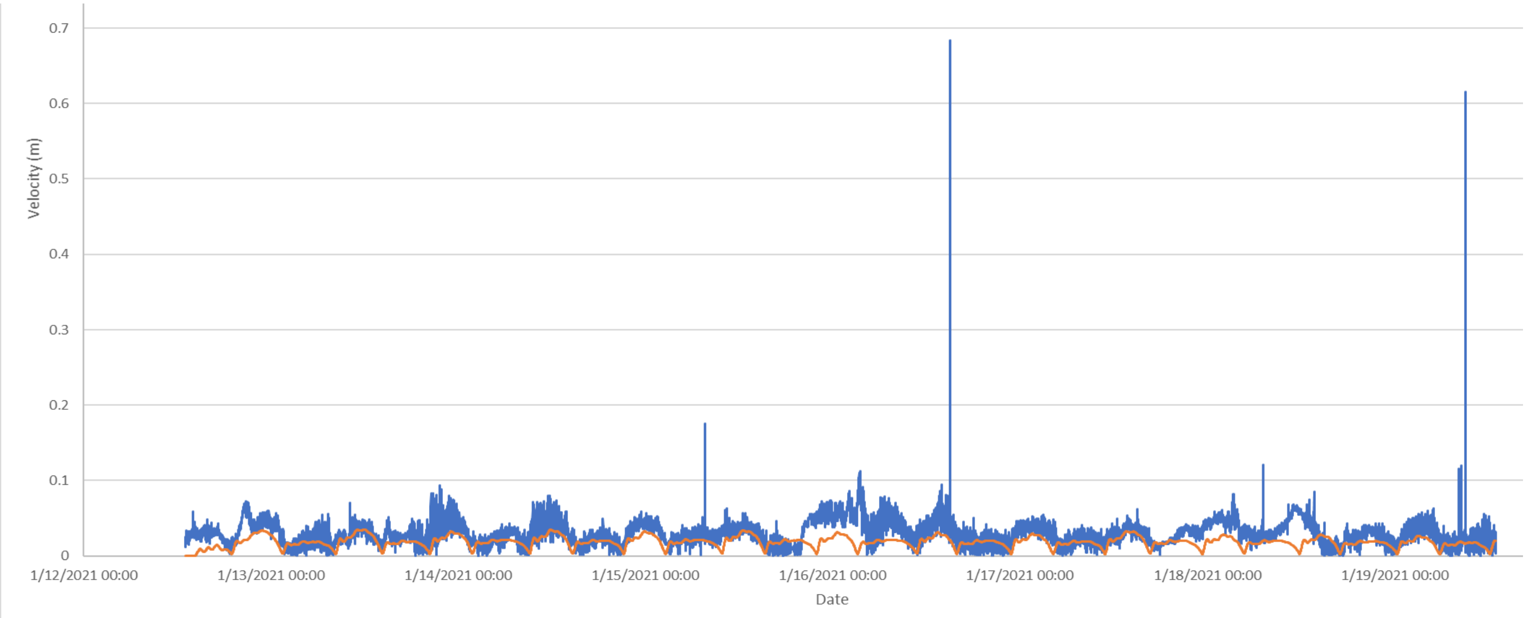




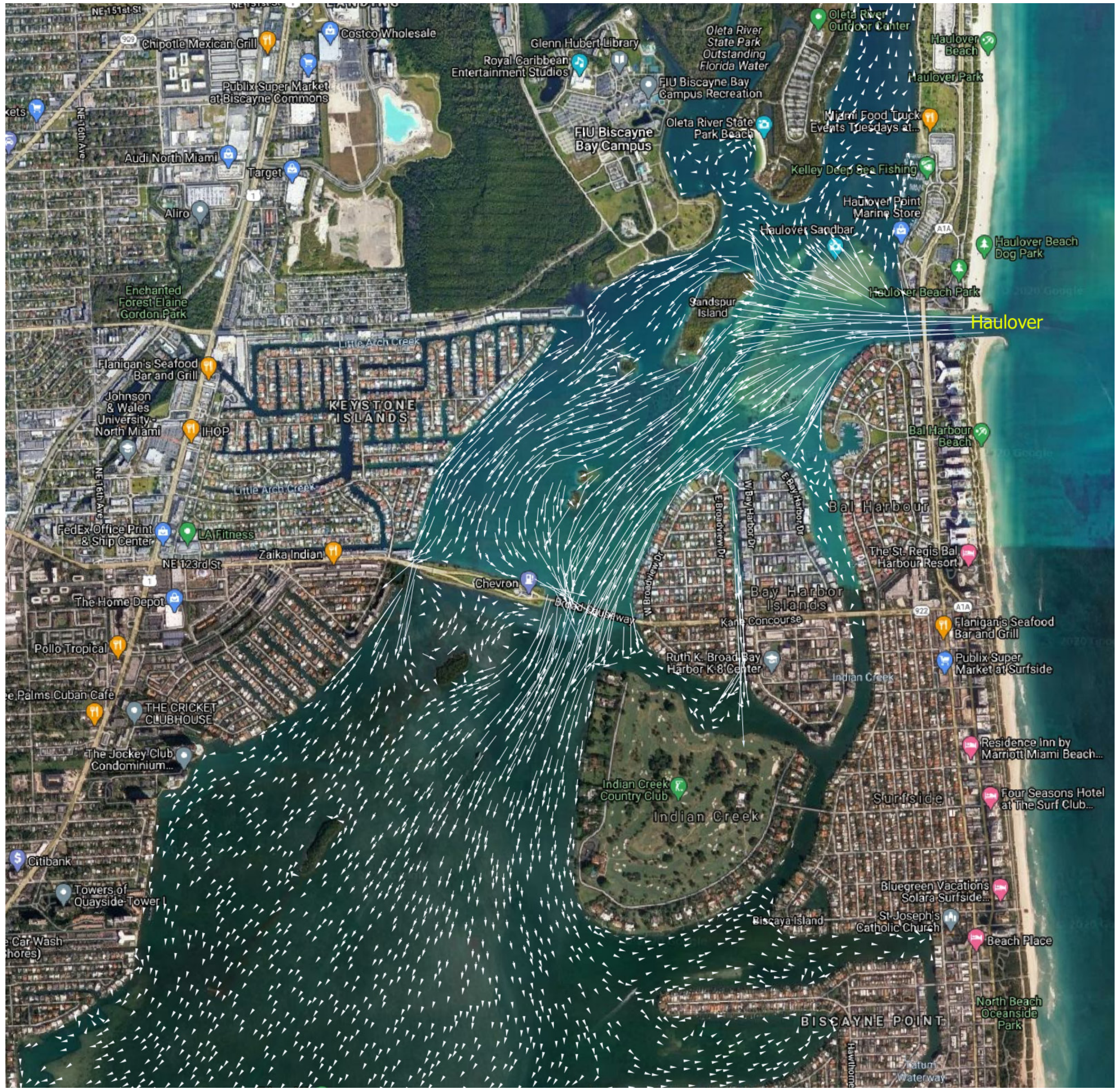


Water elevations (WSEL) and Velocities from the latest validation run (Jan-2021)



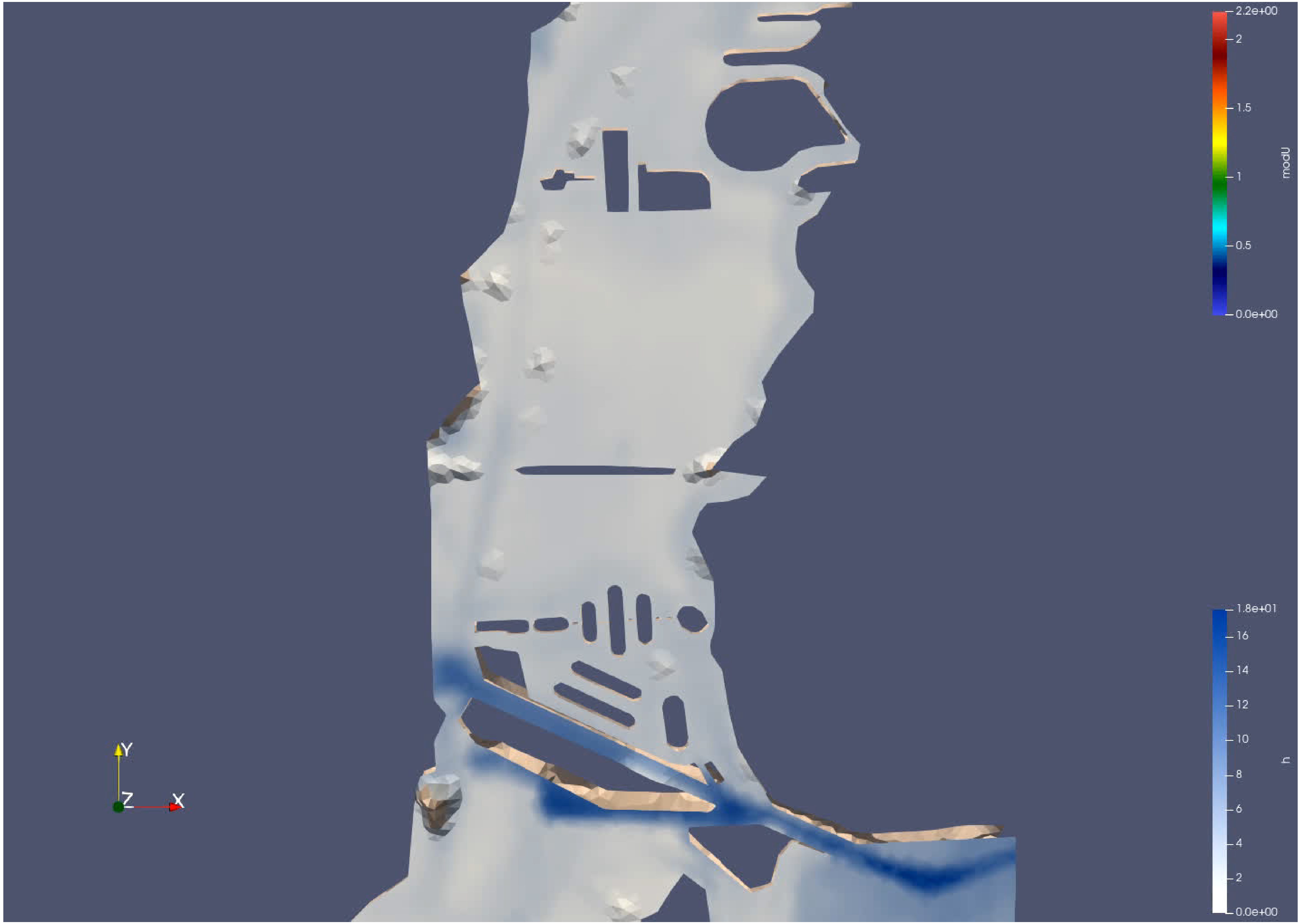


Some BBOM results

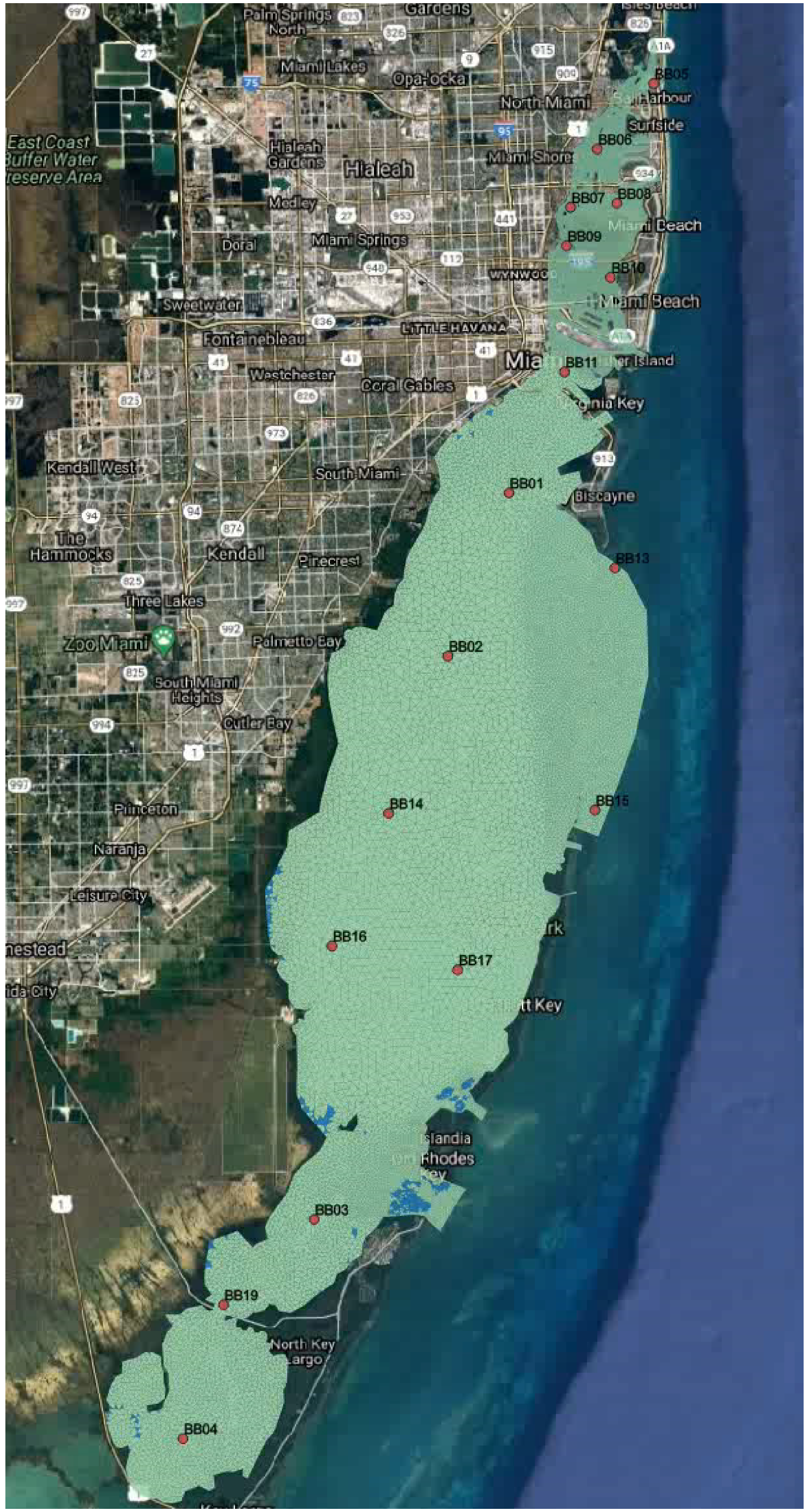


Velocity field near the northern end of Biscayne Bay. Haulover is the northern open boundary in the model.

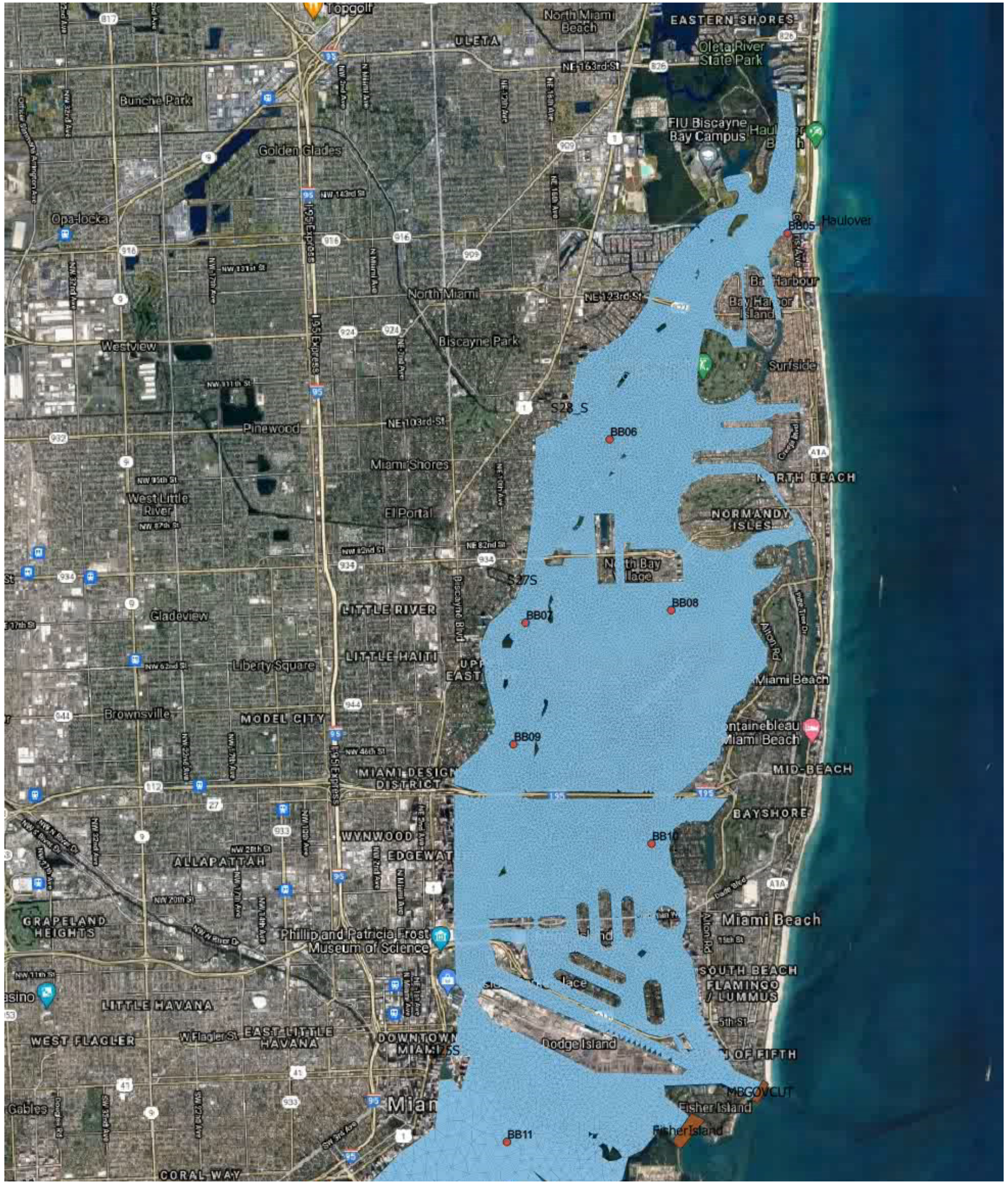
Velocity field between SR 934 and the 195. Note the higher velocities through the 195 bridges and the circulation patterns with large eddies.


2.2e+00
2
1.5
1
0.5
0.0e+00
modU
1.8e+01
16
14
12
10
8
6
4
2
0.0e+00
h
Y
Z
X

Dynamics of Salinity distribution

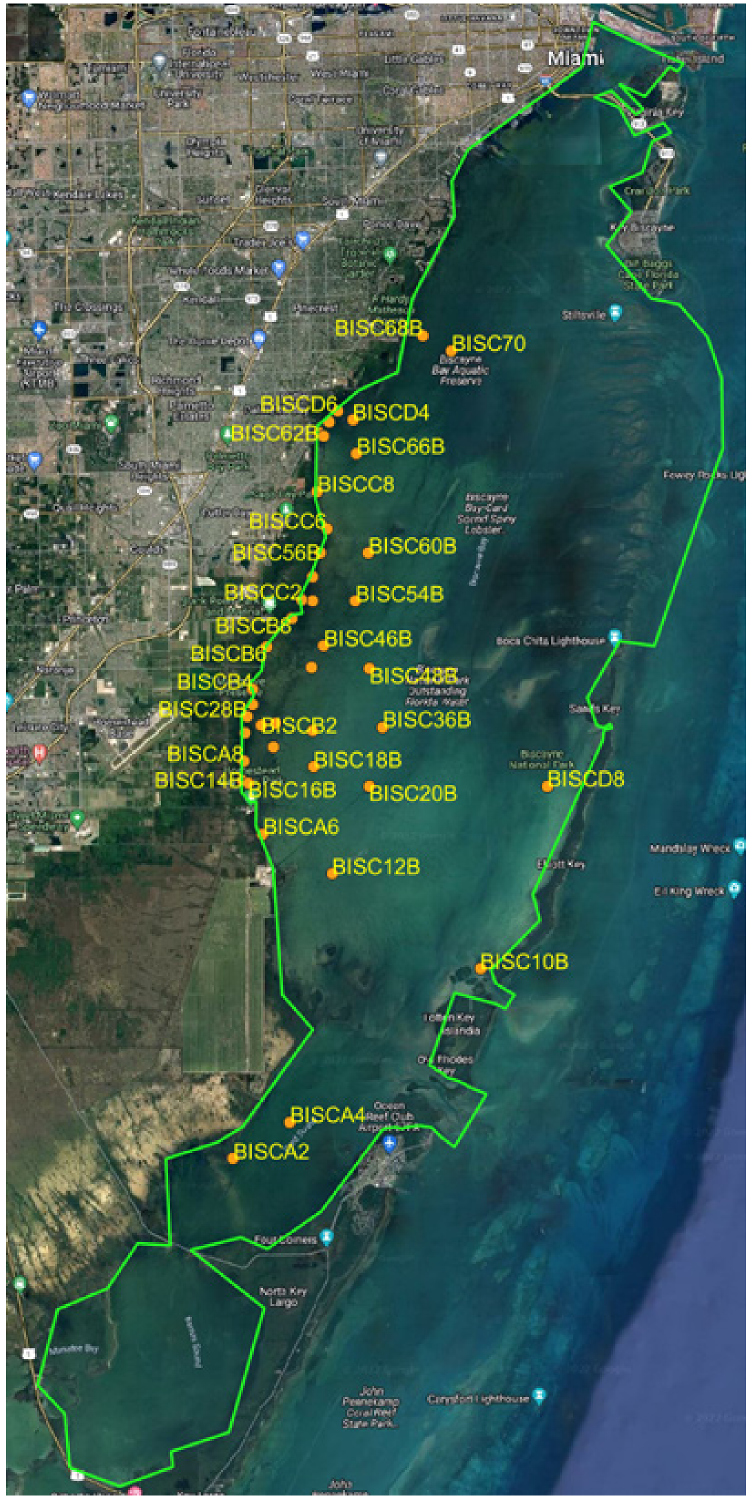


Pollutant dispersion from Miami and Little Rivers



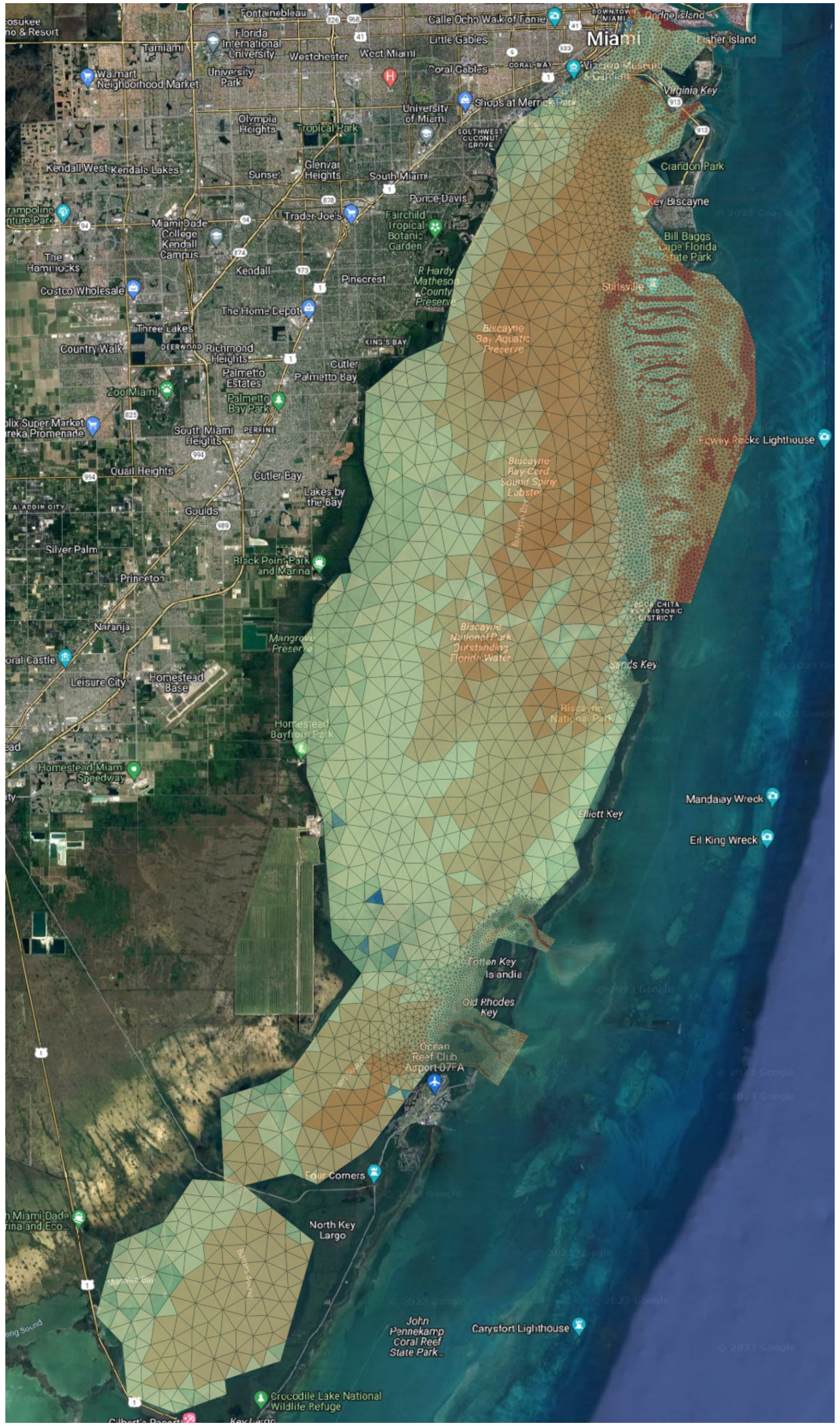
Validation Dataset

- Independent data set provided by the South Florida Water Management District (SFWMD).
- Validation period: One year
  - January 2019 and December 2019.
- Depths and salinities collected at 41 stations.



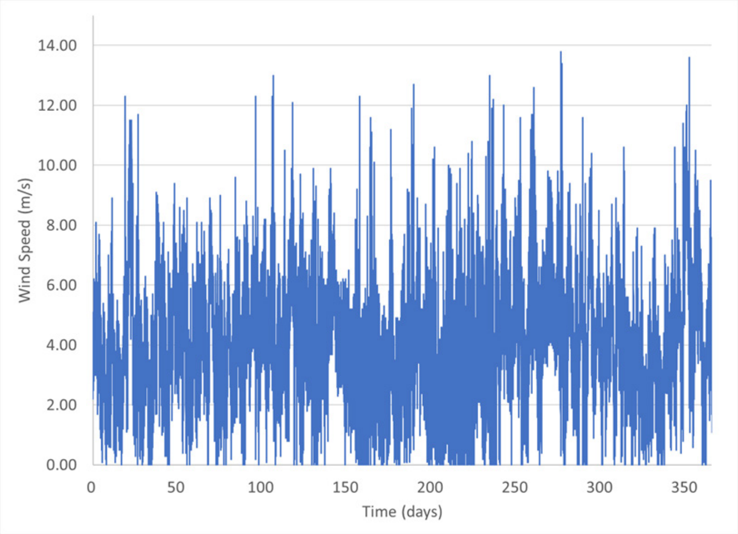
Model Implementation

- ~20,000 cell mesh
- Cell sizes: 26 m-1000 m
- Wind forces
- Tidal boundary conditions at ocean boundaries
- Inflow from canals
- Groundwater *inflow*

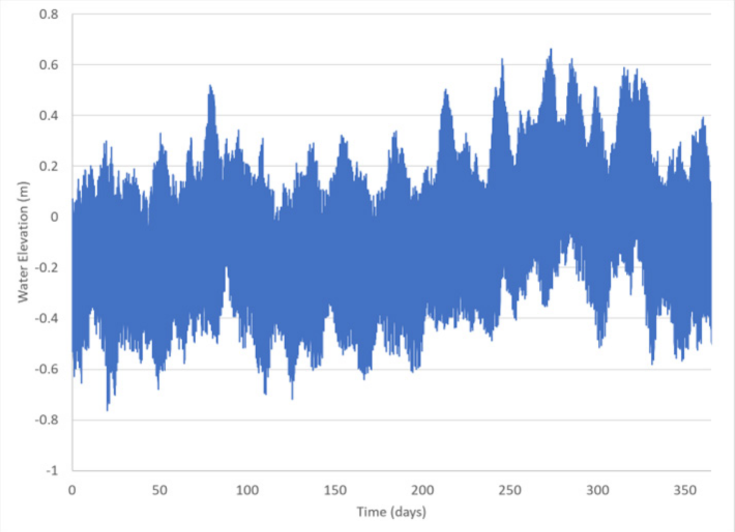


Data [January 2019 -December 2019]

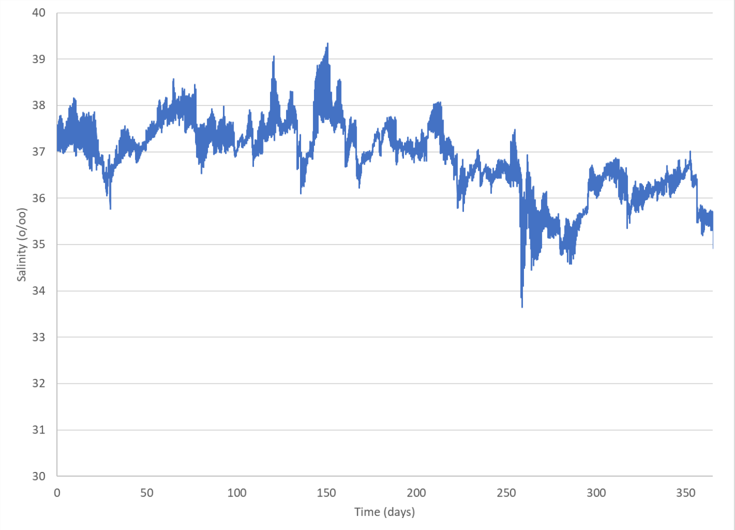
Wind velocity NOAA Virginia Key station



Tidal Elevations VK station



Salinity from SFWMD station BISC10B



Some Results

- Comparison of observed vs model water elevations
- Comparison of observer vs model salinities
- Salinity maps and animations

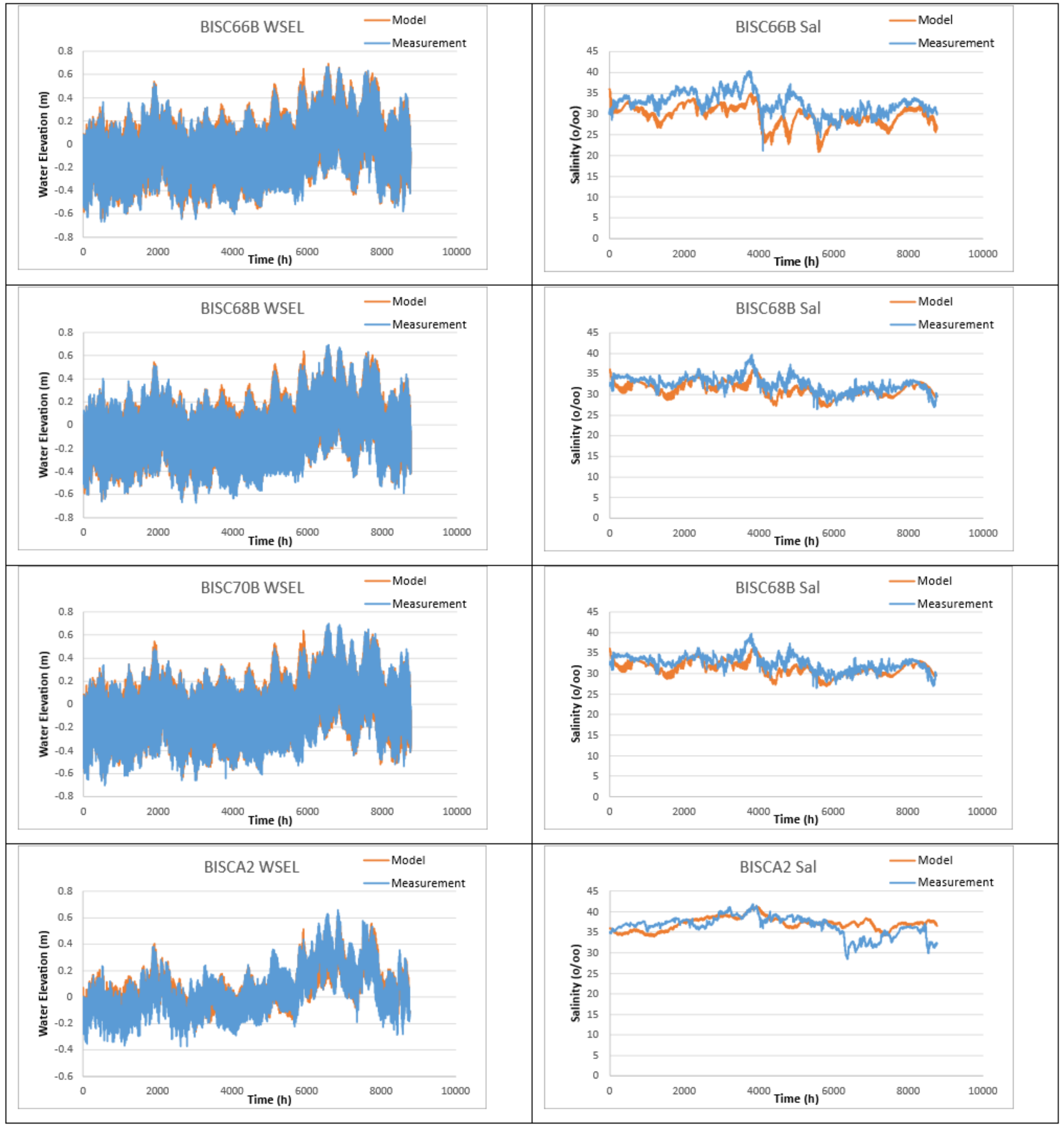


Figure 134 Water Surface elevations and salinities for stations BISC66B, BISC68B, BISC70B, and BISCA2. Comparison of model against measurements.

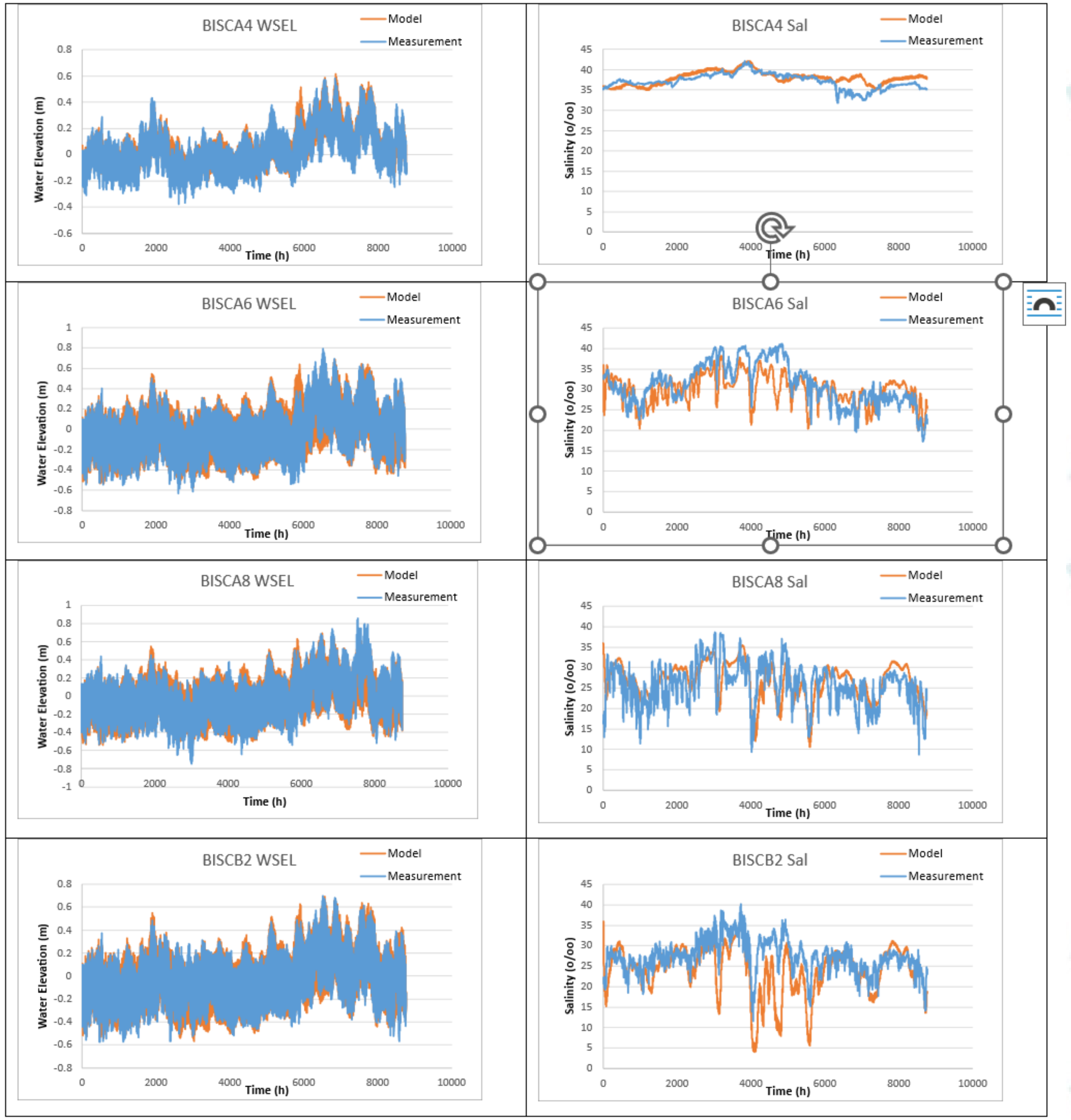


Figure 135 Water Surface elevations and salinities for stations BISCA4, BISCA6, BISCA8, and BISCB2. Comparison of model against measurements.

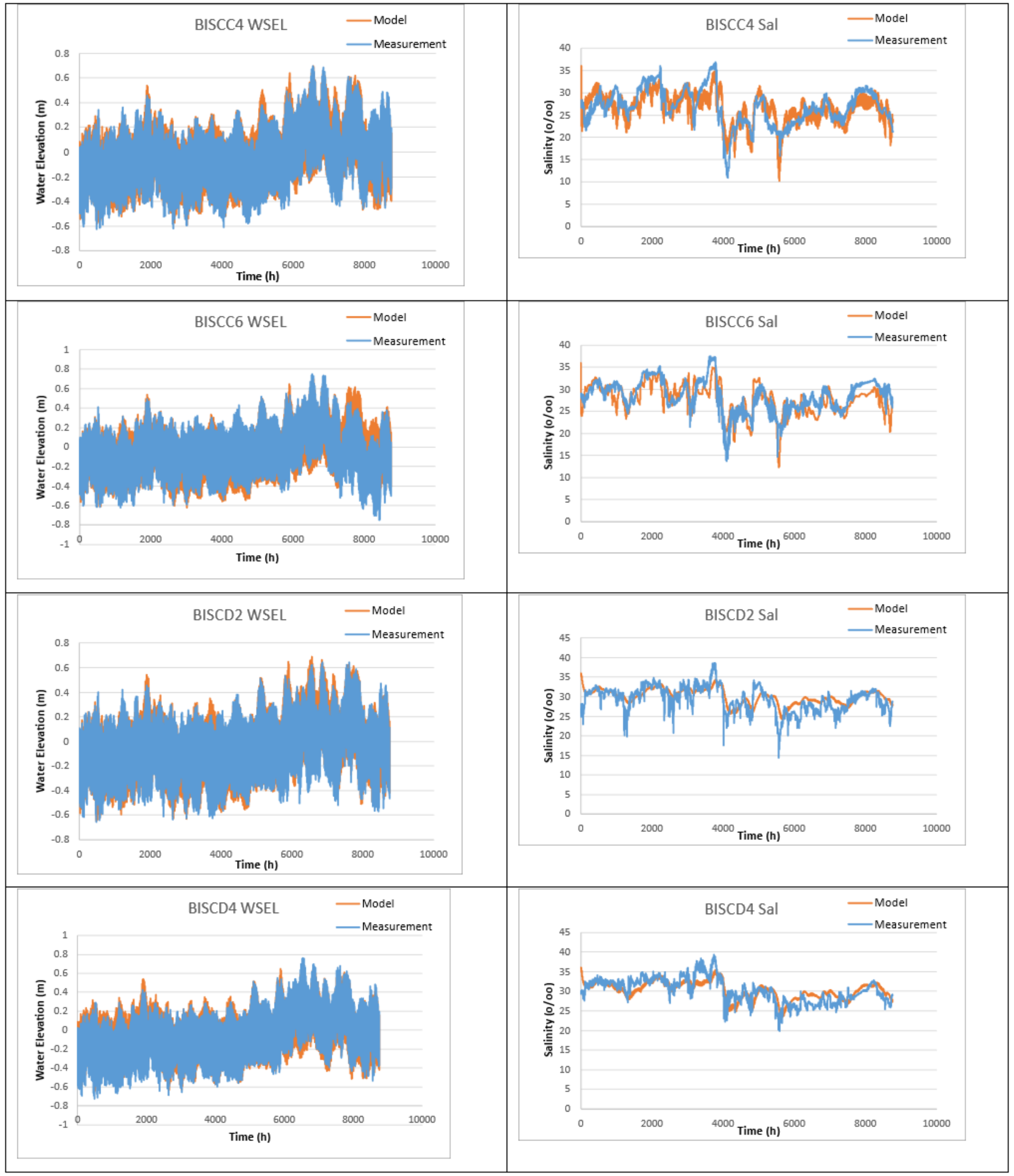


Figure 137 Water Surface elevations and salinities for stations BISCC4, BISCC6, BISCD2, and BISCD4. Comparison of model against measurements.

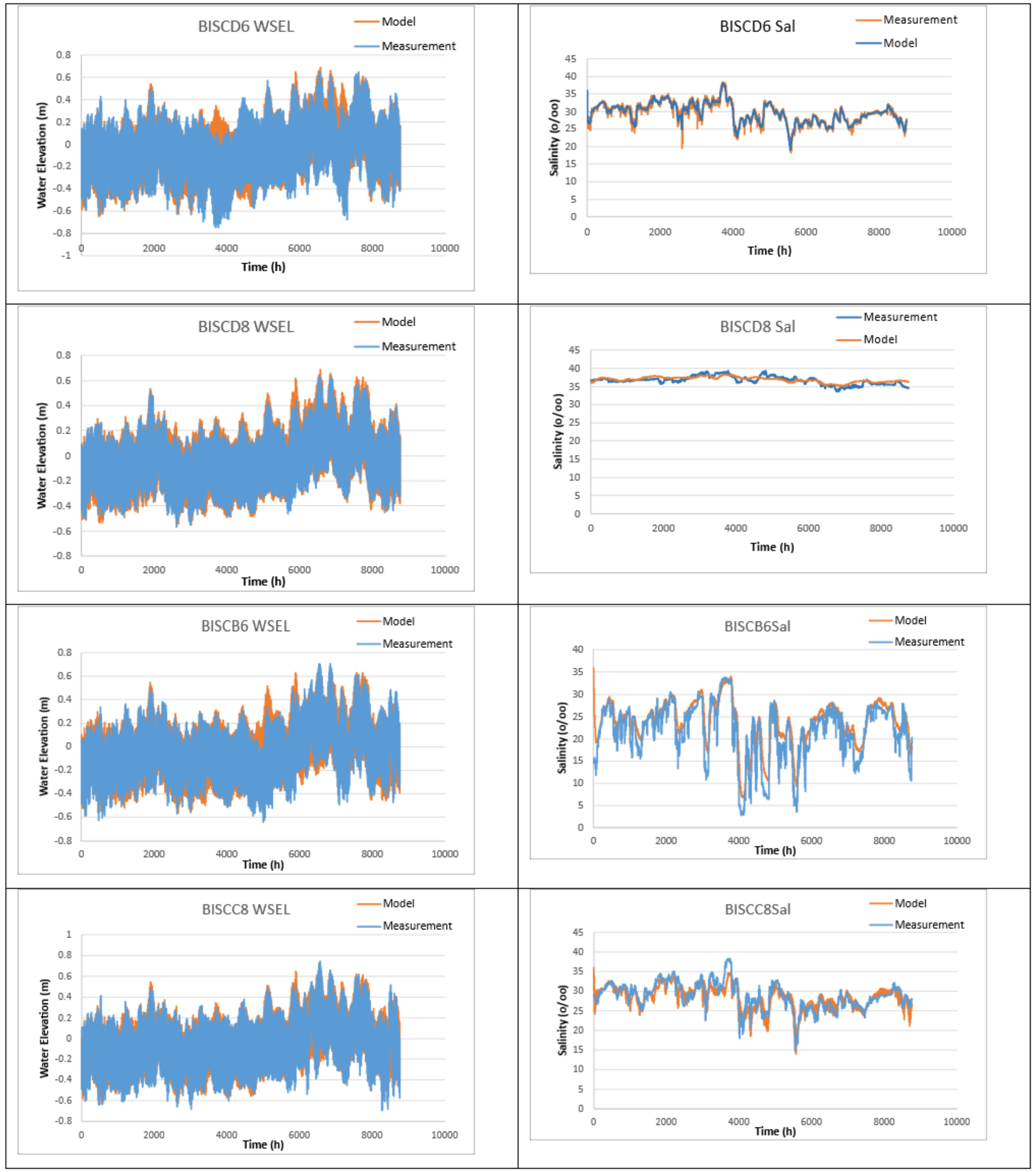


Figure 138 Water Surface elevations and salinities for stations BISCD6, BISCD8, BISCB6, and BISCC8. Comparison of model against measurements.

Table 4 Correlation Quality Indexes obtained for BBOM validation.

Station	Water Surface Elevation Correlation Index	Salinity Correlation Index
BISC10B	94.46	93.67
BISC12B	92.57	45.16
BISC14B	90.02	82.74
BISC16B	91.31	73.14
BISC18B	92.72	33.53
BISC20B	91.46	40.18
BISC22B	90.16	64.33
BISC26B	92.52	26.14
BISC28B	90.10	65.49
BISC32B	92.11	34.26
BISC34B	92.73	25.24
BISC36B	93.70	37.00
BISC40B	91.29	76.64
BISC44B	92.63	48.76
BISC46B	92.76	57.00
BISC48B	91.96	53.20
BISC52B	91.80	67.97
BISC60B	93.47	54.30
BISC62B	91.06	60.95
BISC64B	91.40	66.45
BISC66B	93.38	64.59
BISC68B	94.49	62.54
BISC70	94.34	61.57
BISCA2	93.55	37.30
BISCA4	92.90	62.99
BISCA6	90.79	66.33
BISCA8	89.68	56.24
BISCB2	92.10	51.30
BISCB4	91.99	76.00
BISCB8	91.06	72.76
BISCC2	89.17	61.45
BISCC4	91.58	72.12
BISCC6	88.59	70.70
BISCD2	91.07	68.96
BISCD4	91.85	75.16
BISCD6	88.70	96.60
BISCD8	93.72	76.81
BISC54B	89.42	91.60
BISC56B	91.31	84.23
BISCB6	92.76	51.06
BISCC8	89.96	64.32

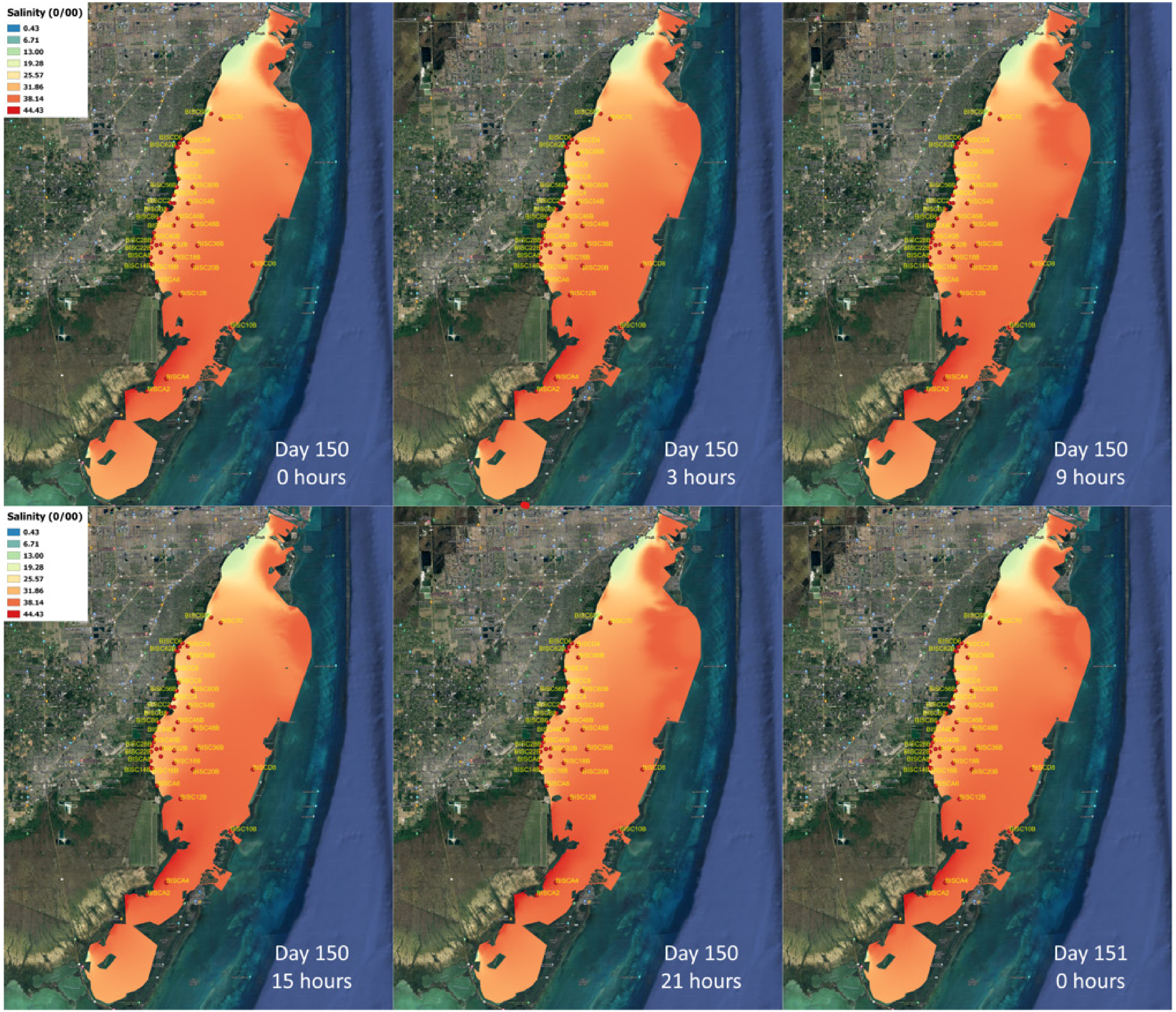
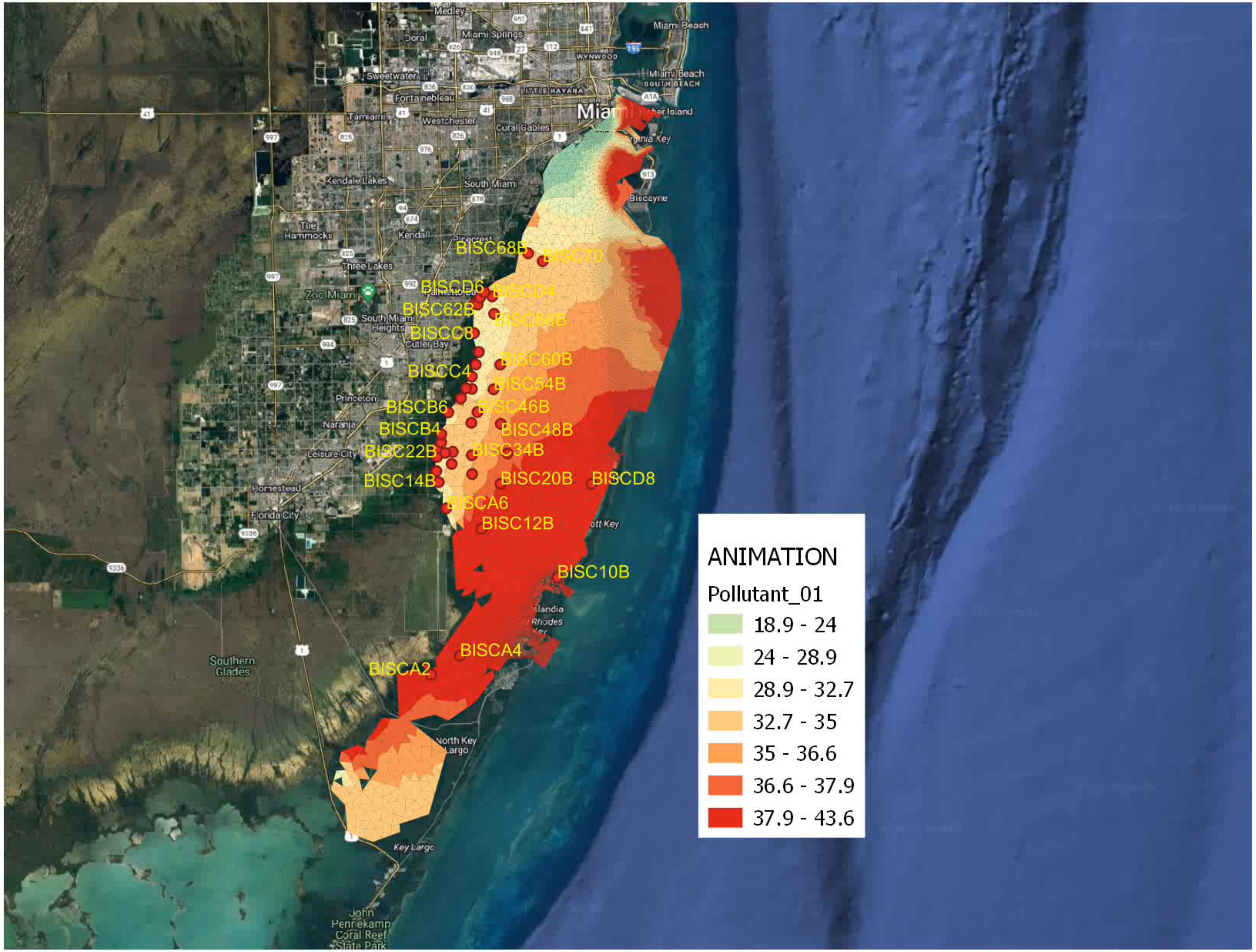


Figure 142 Salinity distribution at time 150 days, and 0, 3, 9, 15, and 21 hours.

Salinity Dynamics in Biscayne Bay [Day 150 to day 180] validation run. Feb. 2023.



BBOM Application Comments

- The results show that the model was able to reproduce measured and predicted water elevations and velocities in several Biscayne Bay locations with acceptable precision.

- Average Correlation Quality Indexes obtained during validation were for water elevations >90% and for salinity >71%.

- We found it essential to consider the combined effects of freshwater inflows from canals and groundwater, tidal forcing on the ocean boundaries, and wind stress on the water surface to be able to model water levels and salinities.

- BBOM triangular-mesh numerical engine can be adapted to irregular geometries and makes use of high-performance parallelized computations that run in multiple processor GPU hardware reducing significantly reducing runtimes of long-term scenarios.

- BBOM Graphical User Interface (GUI) based on the Open Source Geographical Information System QGIS provides a comprehensive and easy-to-use set model customization and visualization tools, including map rendering, and animations, facilitating the analysis of results.

GPU Acceleration (48h)

NVIDIA RTX 4090 GPU	
Memory	24 GB
Cores	16,384

Mesh	No. Cells	Intel CPU	RTX 4090	Max Speedup
Mesh 1	25,290	00:00:11:50	00:00:01:49	7x
Mesh 2	414,655	00:04:12:52	00:00:04:39	54x
Mesh 3	1,006,937	00:14:05:18	00:00:12:13	69x

Oil Storage Tank Break and Oil Spills from Pipelines

Modeling Oil Spills on Land Objectives

- Determine the affected area caused by crude oil spills

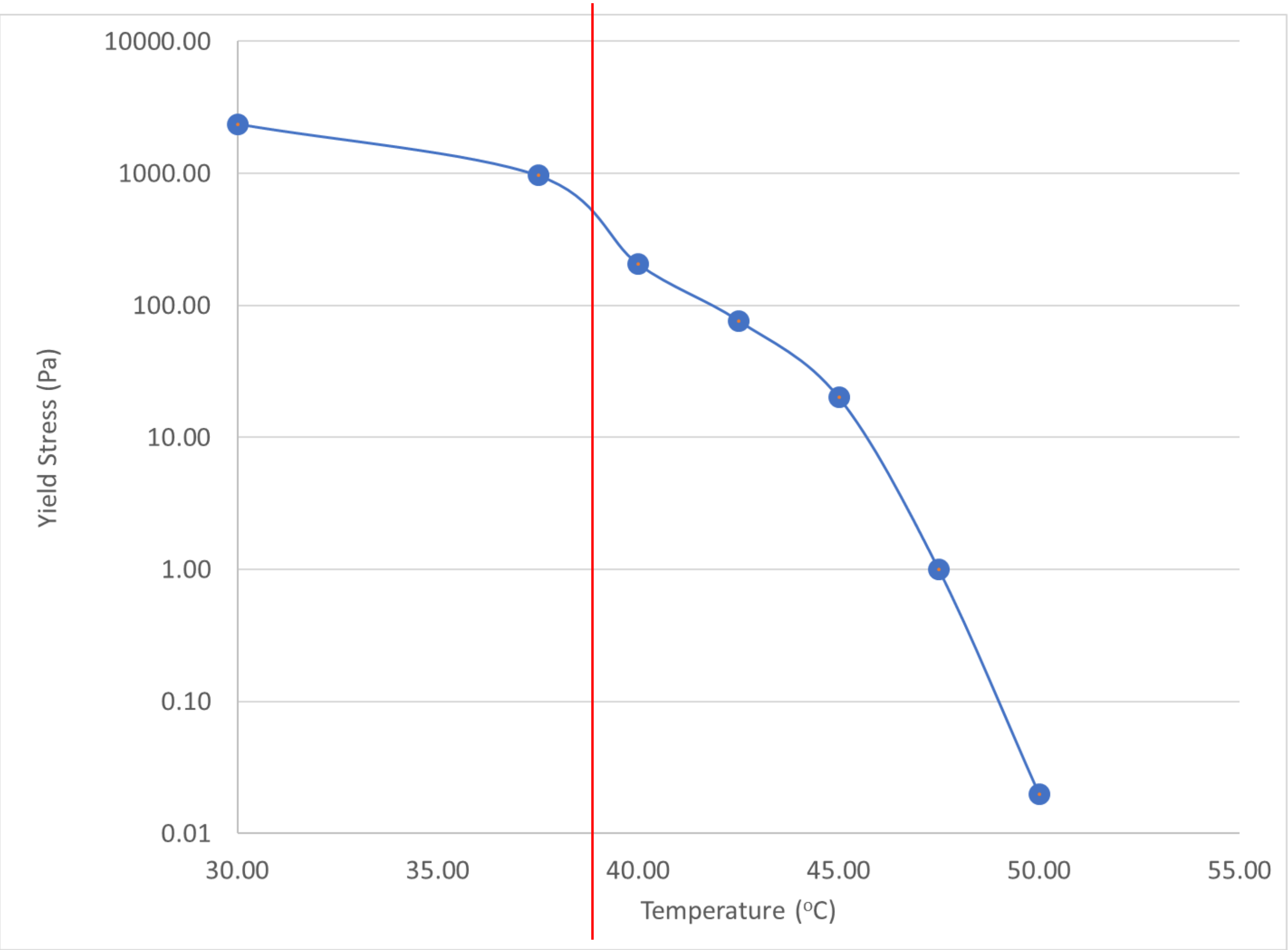
- Where and when…

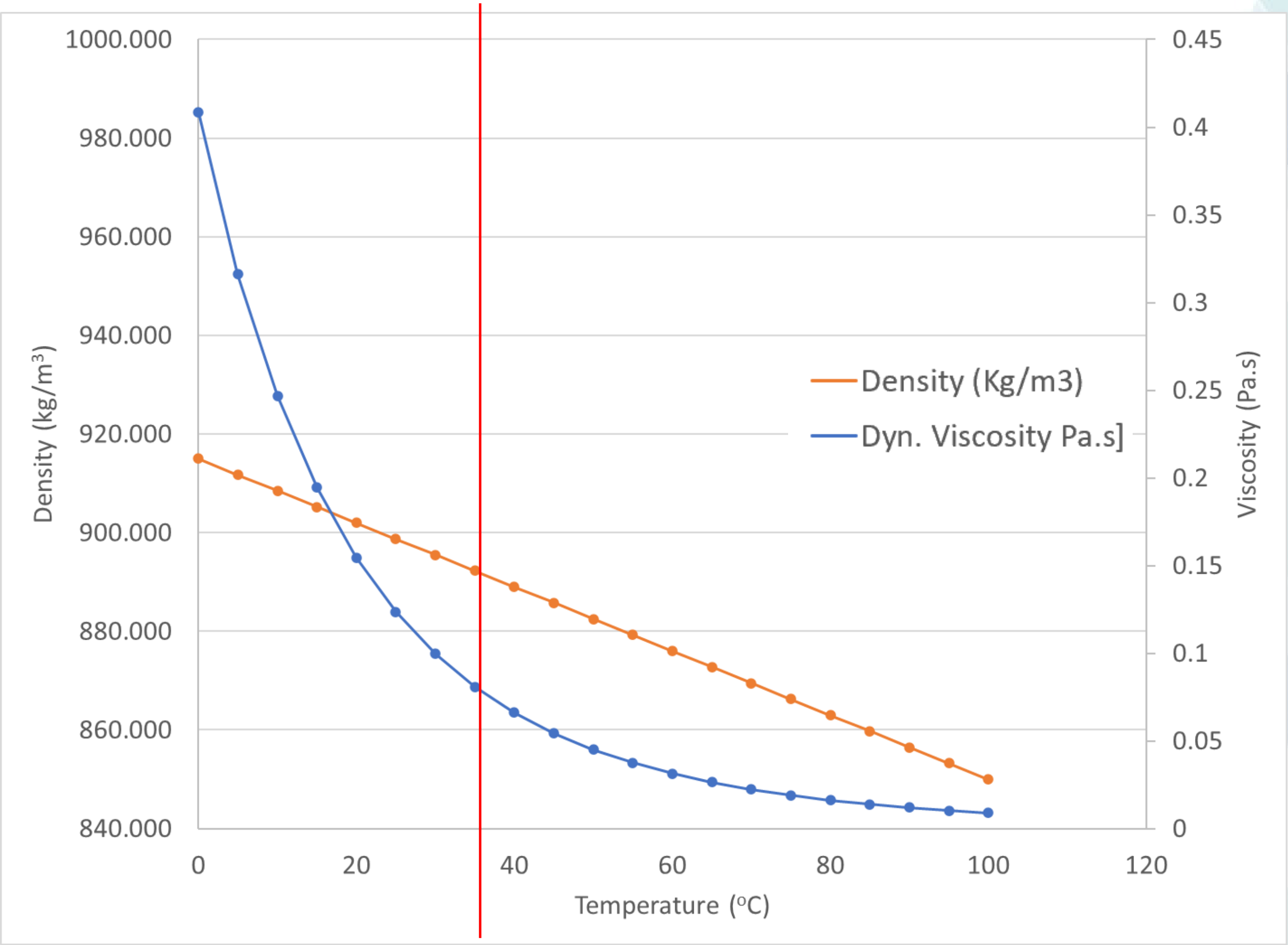
- Assessing if the oil is going to hit high consequence zones
  - Urban areas
  - Sensitive ecosystems
  - Etc.

- Oil spills from
  - Well blowouts
  - Pipelines
  - Tanks

- *Considering the dependence of the Yield Stress, Viscosity and Density on Temperature, is crucial in estimating flow runout distance and general overland flow for some crude oils*

High Pour Point Crude Oils





Pour point: The temperature below which the liquid loses its flow feasibility.
Yield stress: The shear stress required to make the fluid flow possible.

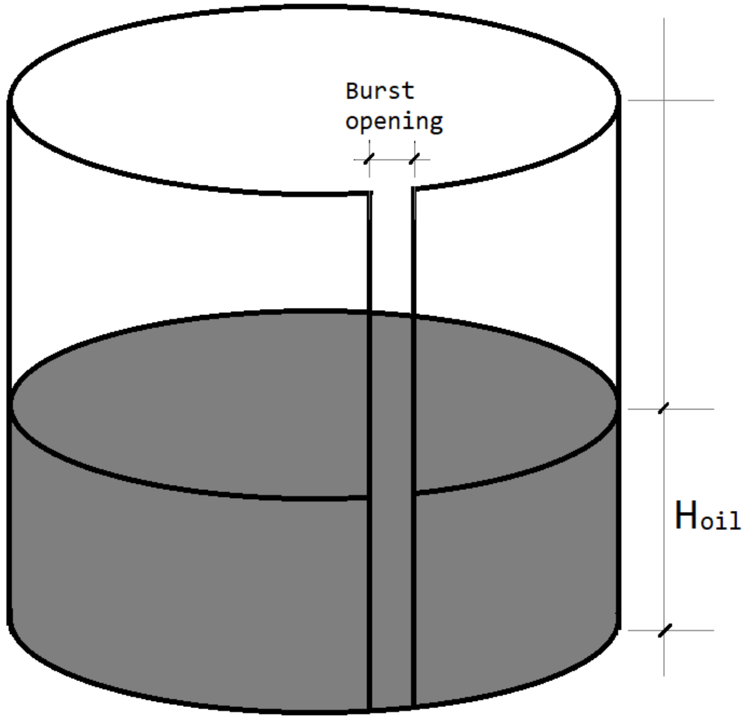
OilFlow2D Heat Transfer Model Assumptions

- Oil temperature, density, viscosity, yield stress vary in space and time (model calculated)
- Wind speed, Air temperature, and solar radiation can vary in time but are uniform in space
- Model allows different options to account for fluid properties as a function of temperature

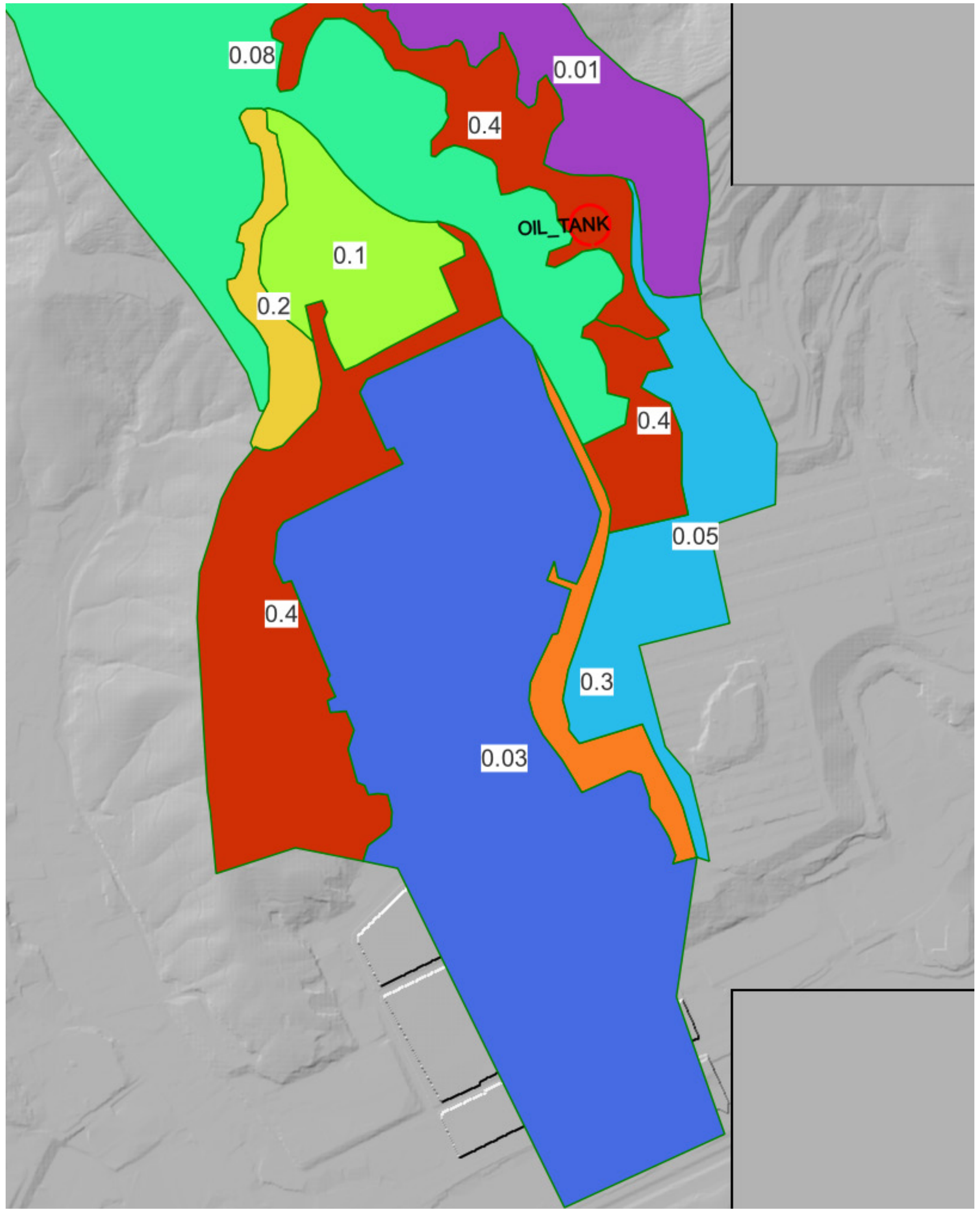
OilFlow2D Rheological Formulations

	τ_b	Parameters
Bingham	$2\tau_b^3 - 3\left(\tau_y(T) + 2\mu(T)\frac{\lvert\mathbf{u}\rvert}{h}\right)\tau_b^2 + \tau_y(T)^3 = 0$	μ, τ_y, ρ
Simplified Bingham	$\tau_b = \frac{3}{2}\tau_y + 3\mu_B\frac{\lvert\mathbf{u}\rvert}{h}$	μ, τ_y, ρ
Quadratic	$\tau_b = \tau_y + \frac{k_0}{8}\mu_B\frac{\lvert\mathbf{u}\rvert}{h} + \rho g_\psi\frac{n^2\lvert\mathbf{u}\rvert^2}{h^{1/3}}$	μ, τ_y, ρ, Manning's n

Tank burst application

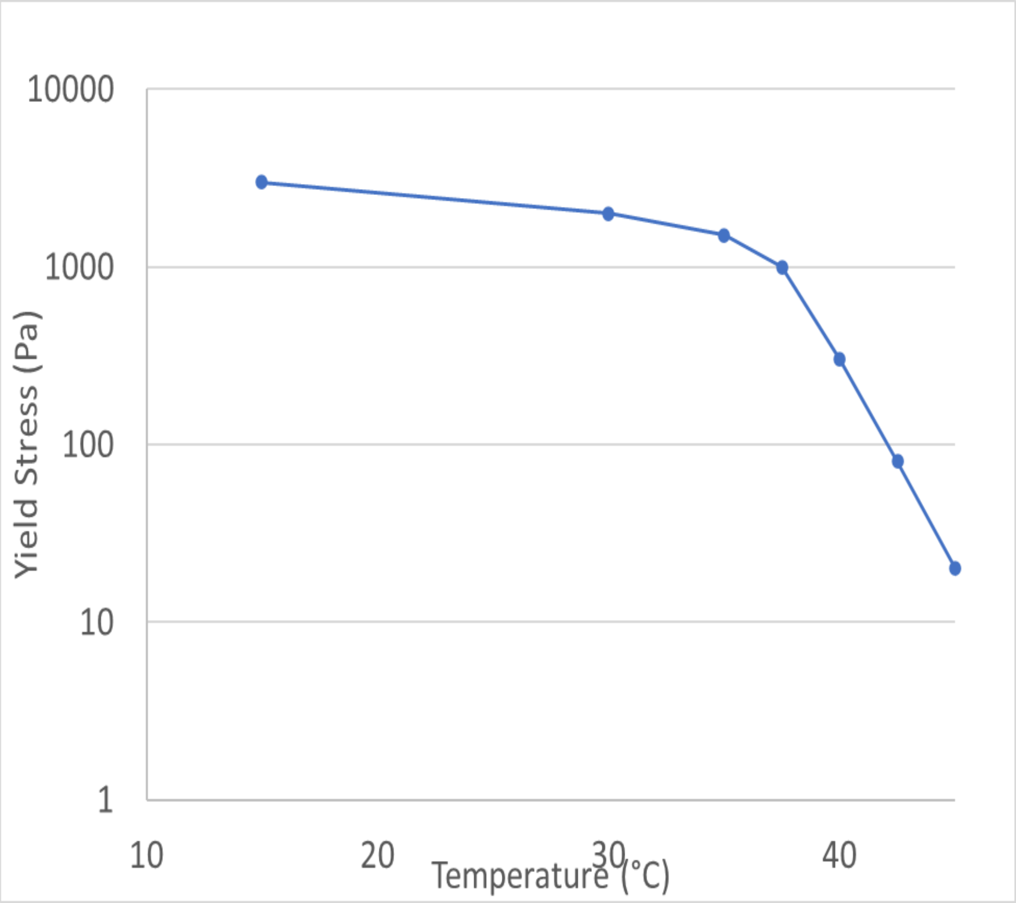


Digital Elevation Model & Manning's n Areas



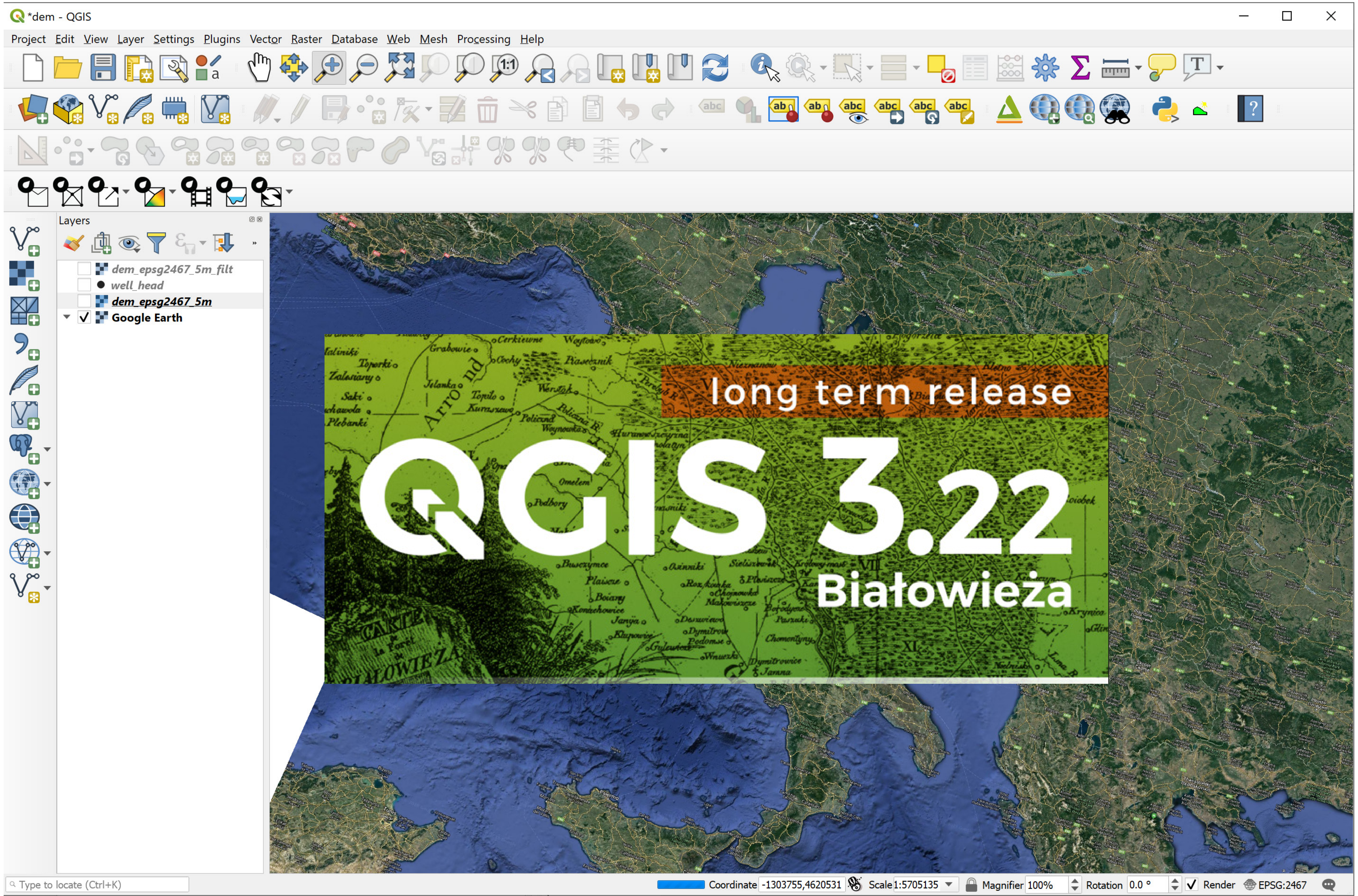
Data Summary

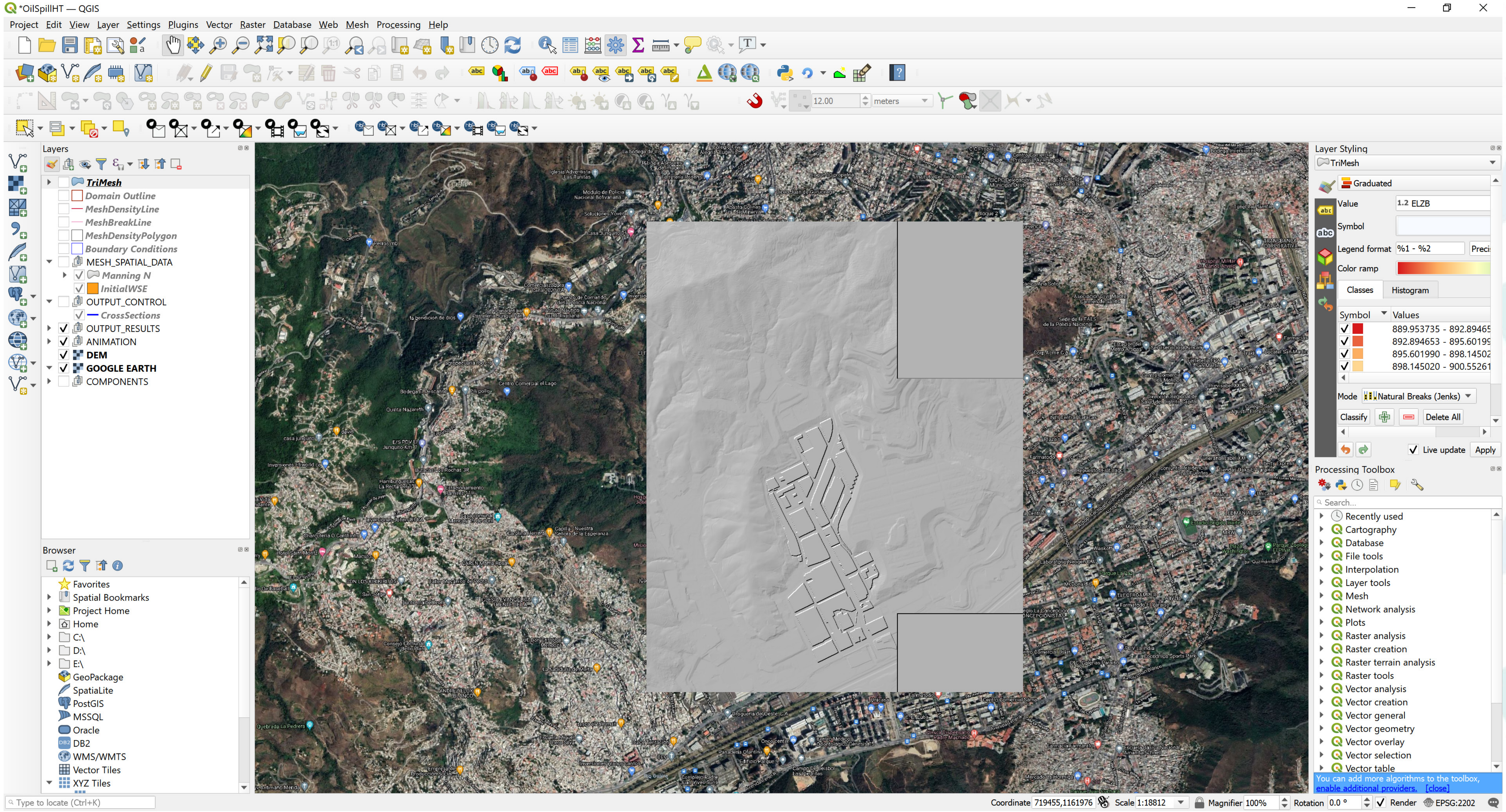
Parameter	Value
Initial oil temperature in tank	55 °C
Initial oil surface elevation in tank	910 m
Oil heat capacity Cp	1900 J/(kg·°C)
Reference density	912 kg/m^3
Density constant K	-0.627
Viscosity constant A_μ	2.6388 10^{-7}
Viscosity constant B_μ	3893
Yield stress at 50 °C	0 Pa
Yield stress at 40 °C	300 Pa
Yield stress at 30 °C	2000 Pa
Ambient temperature	26 °C
Wind velocity	2-20 m/s
Solar radiation	1 W/m^2
Rheological formulation	Quadratic



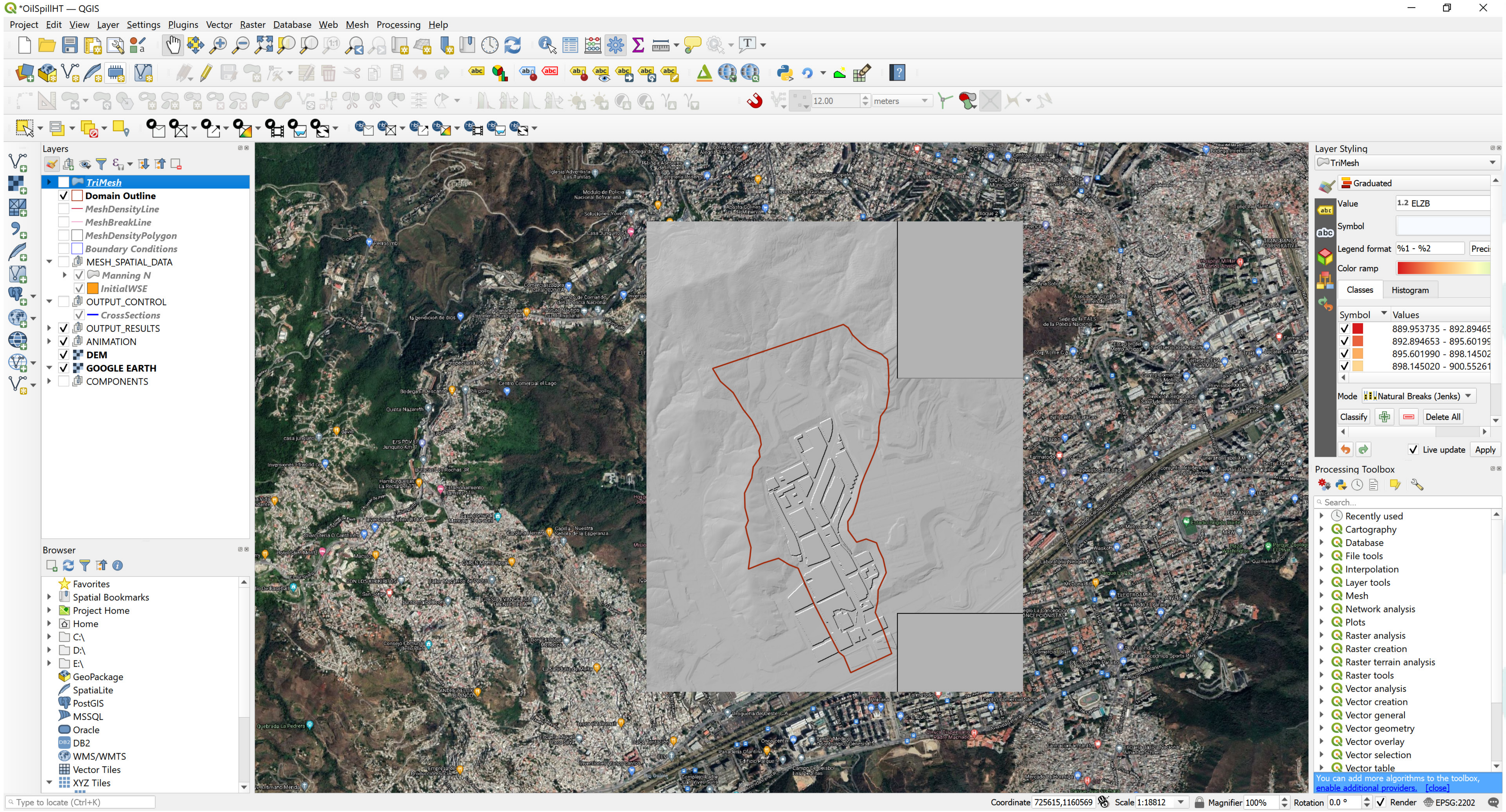
Yield stress f(t)

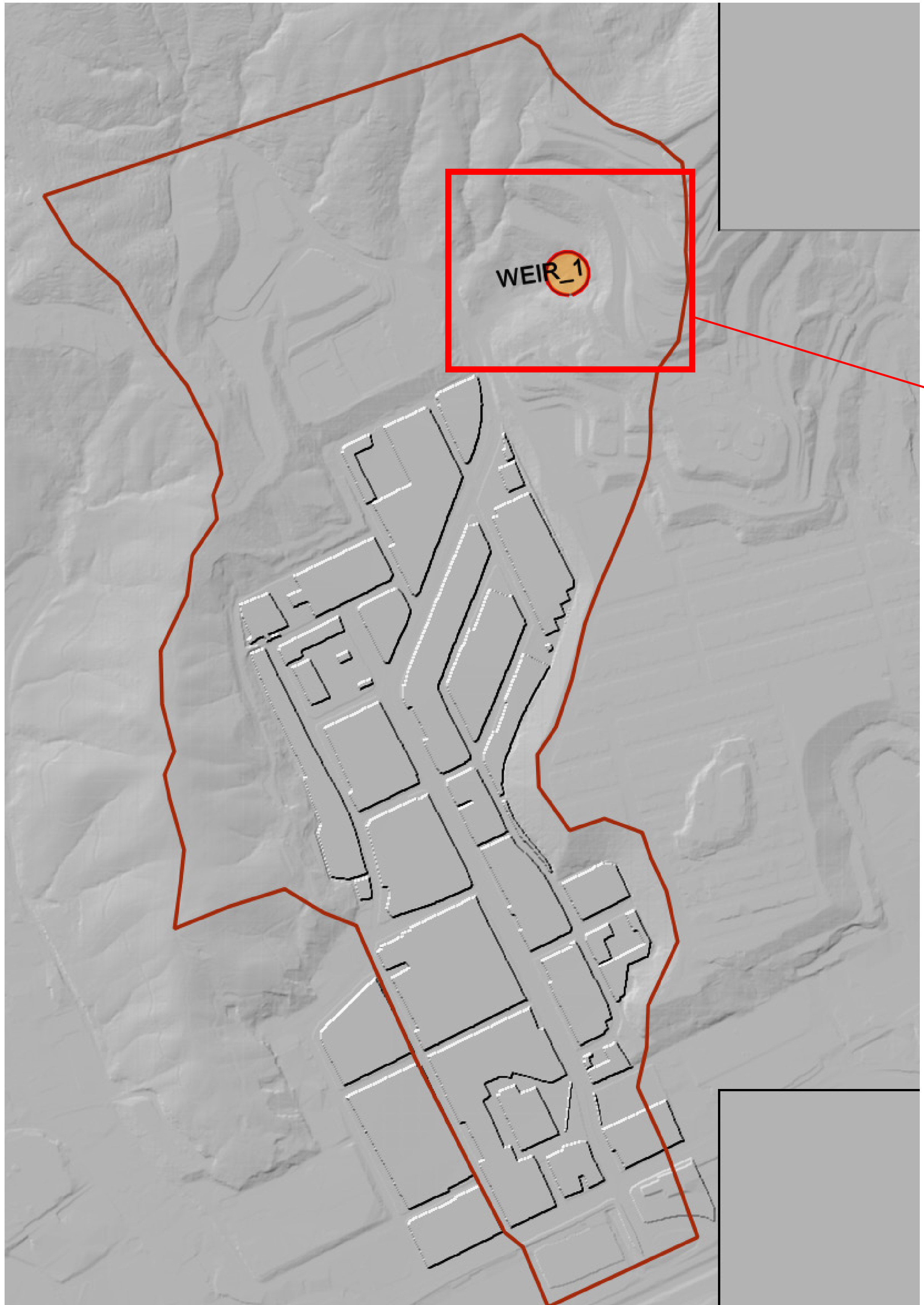
GUI: OilFlow2D –QGIS Integration




*OilSpillHT — QGIS
Project Edit View Layer Settings Plugins Vector Raster Database Web Mesh Processing Help
Layers
TriMesh
Domain Outline
MeshDensityLine
MeshBreakLine
MeshDensityPolygon
Boundary Conditions
MESH_SPATIAL_DATA
Manning N
InitialWSE
OUTPUT_CONTROL
CrossSections
OUTPUT_RESULTS
ANIMATION
DEM
GOOGLE EARTH
COMPONENTS
Browser
Favorites
Spatial Bookmarks
Project Home
Home
C:\
D:\
E:\
GeoPackage
SpatiaLite
PostGIS
MSSQL
Oracle
DB2
WMS/WMTS
Vector Tiles
XYZ Tiles
Layer Styling
TriMesh
Graduated
Value
1.2 ELZB
Symbol
Legend format
%1 - %2
Color ramp
Classes
Histogram
Symbol
Values
889.953735 - 892.89465
892.894653 - 895.60199
895.601990 - 898.14502
898.145020 - 900.55261
Mode
Natural Breaks (Jenks)
Classify
Delete All
Live update
Apply
Processing Toolbox
Search...
Recently used
Cartography
Database
File tools
Interpolation
Layer tools
Mesh
Network analysis
Plots
Raster analysis
Raster creation
Raster terrain analysis
Raster tools
Vector analysis
Vector creation
Vector general
Vector geometry
Vector overlay
Vector selection
Vector table
You can add more algorithms to the toolbox, enable additional providers. [close]
12.00
meters
Type to locate (Ctrl+K)
Coordinate 719455,1161976
Scale 1:18812
Magnifier 100%
Rotation 0.0 °
Render
EPSG:2202

Create Modeling Limits: Polygon

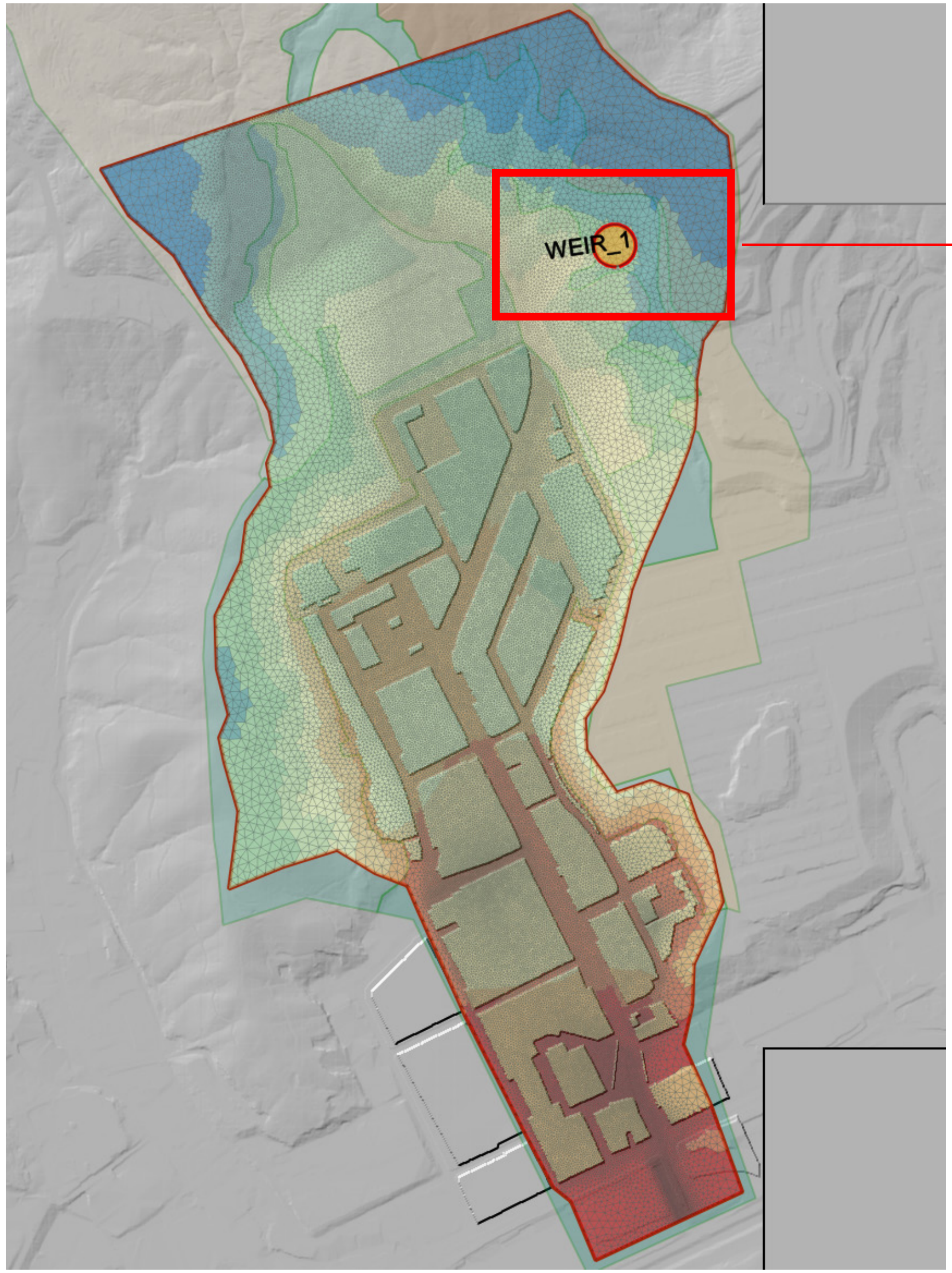


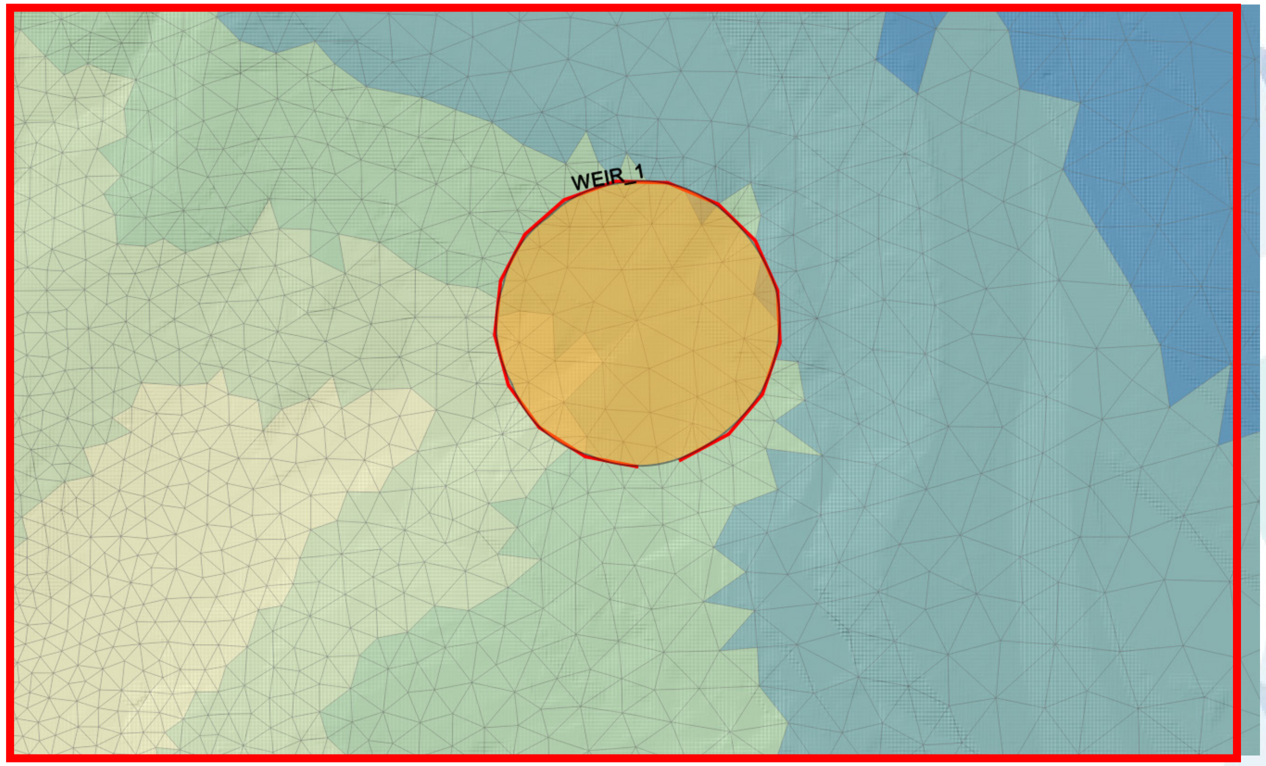


Oil Storage Tank

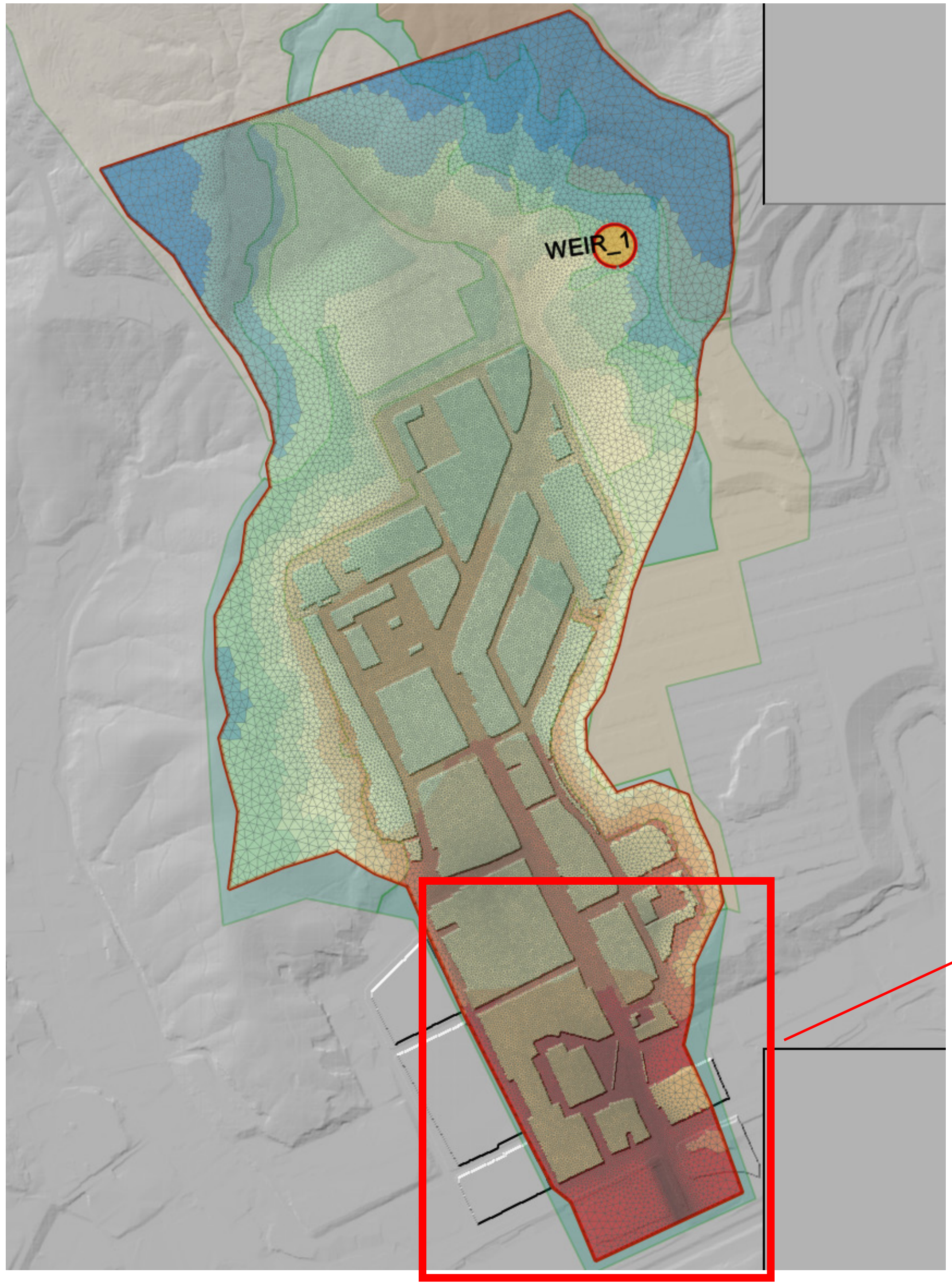
HYDRONIA

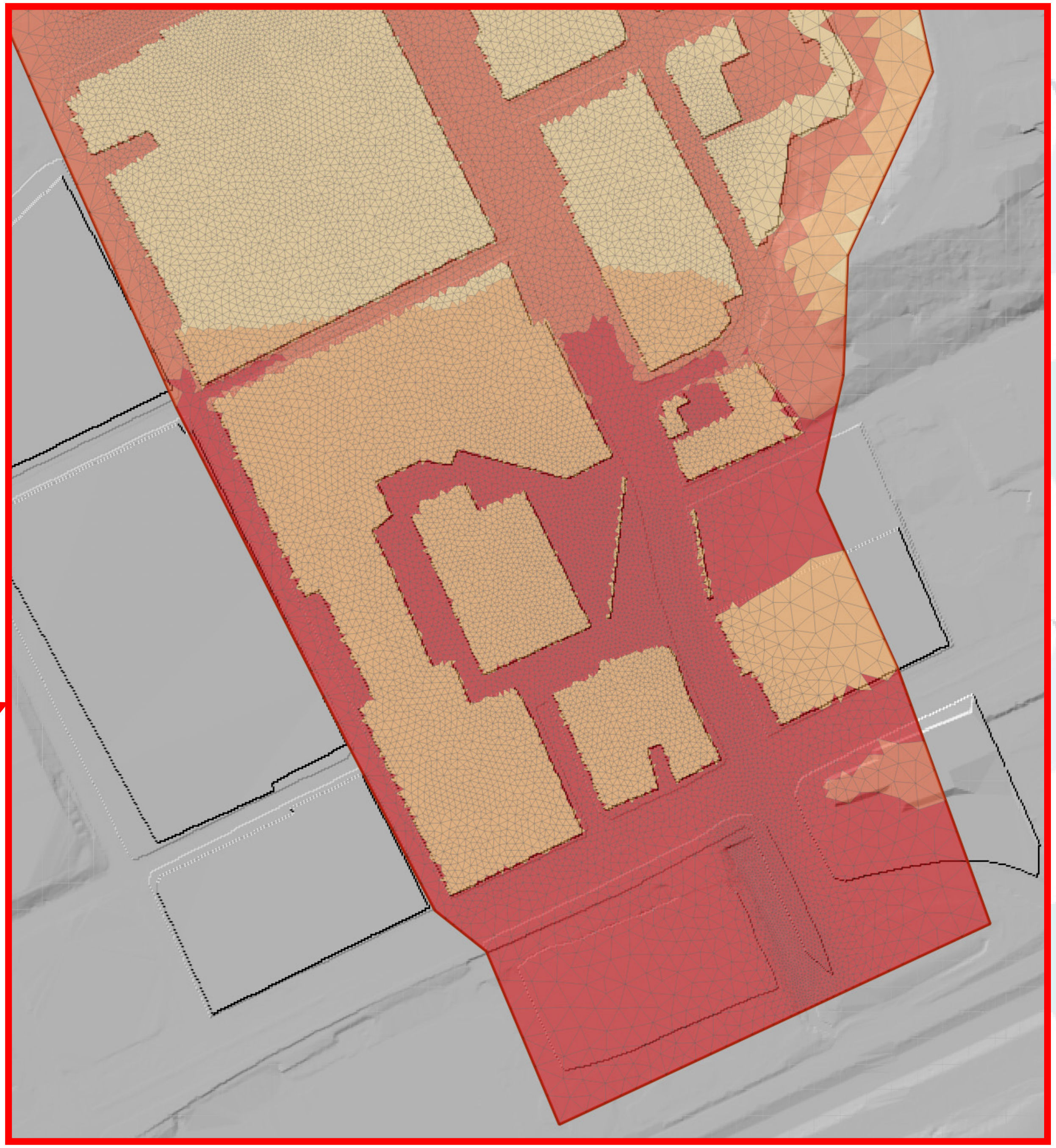
Mesh: 89,388 elements





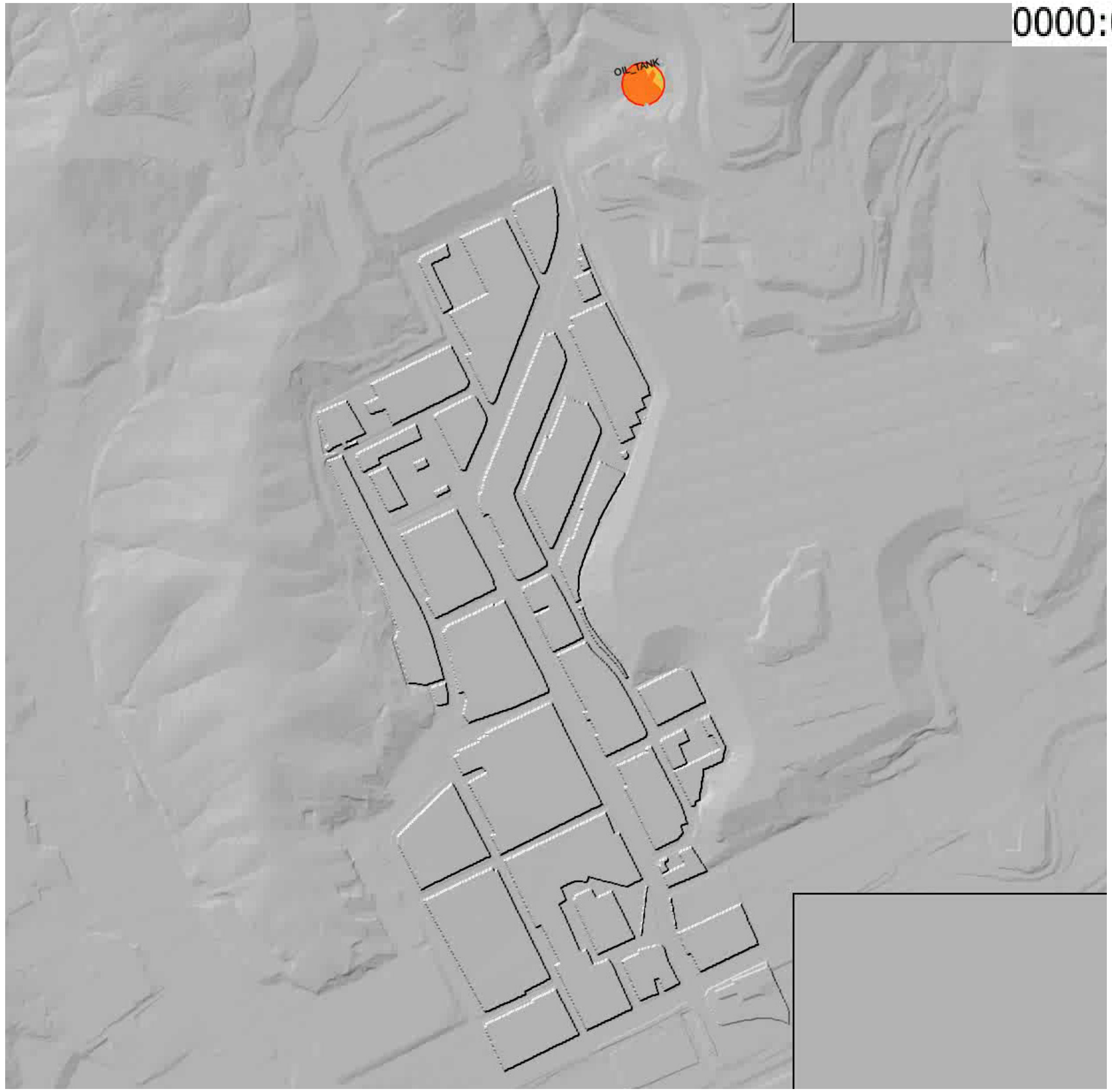
Mesh: Refinement at lower end





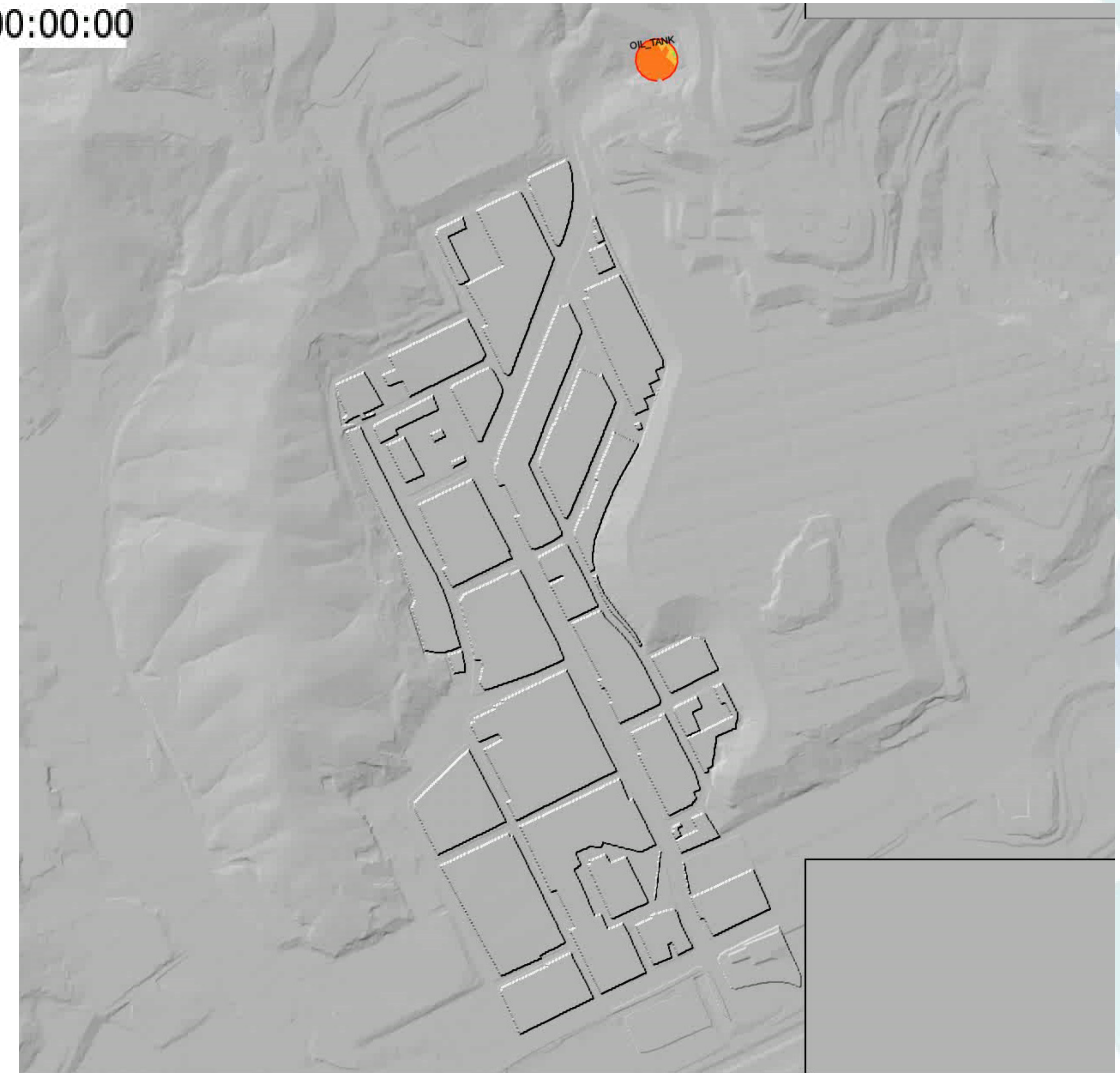
Spill Animations

Wind Speed 2 m/s



Wind Speed 20 m/s

0000:00:00:00

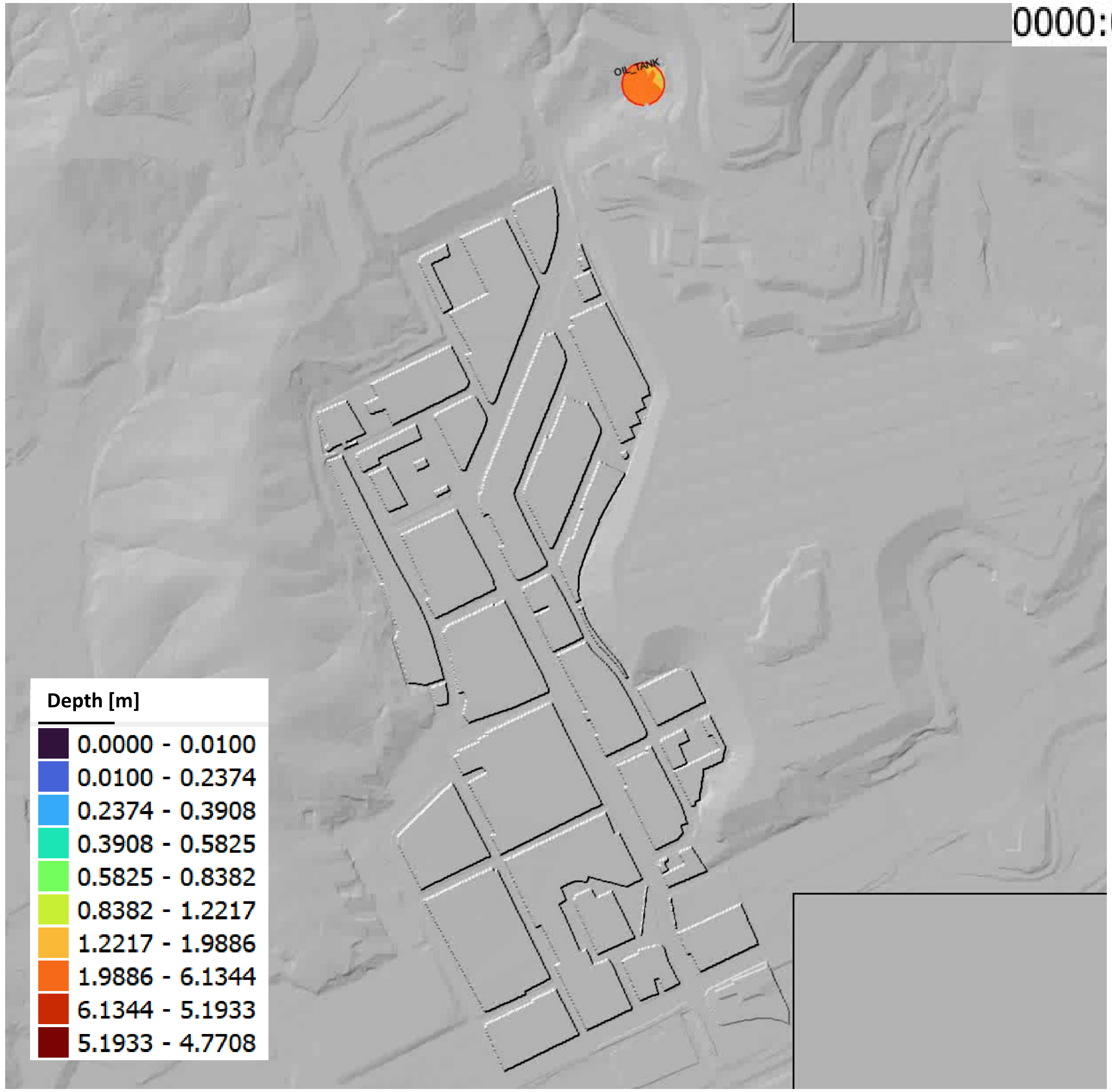


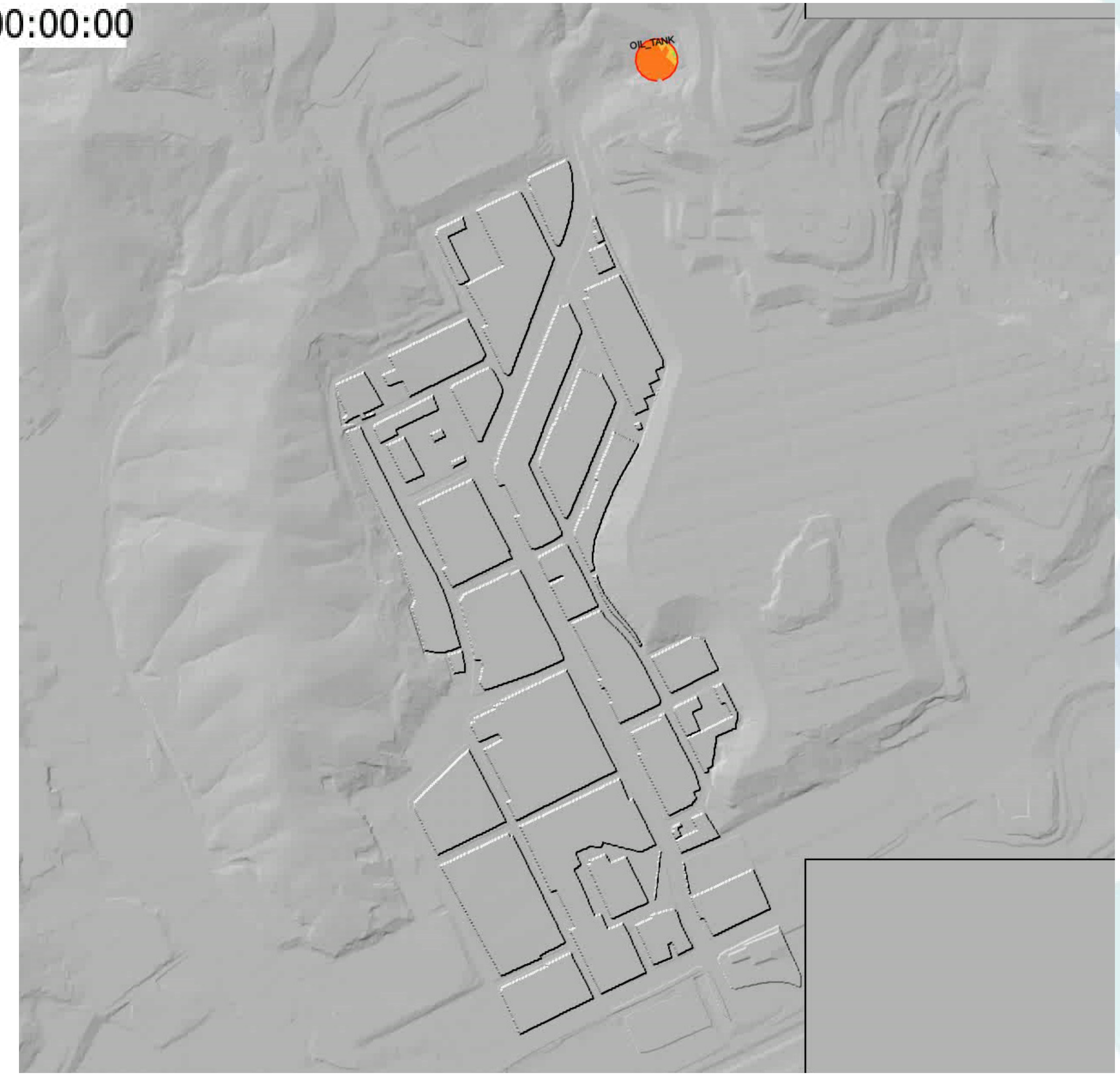
Oil Depth

Wind Speed 2 m/s

Wind Speed 20 m/s

0000:00:00:00



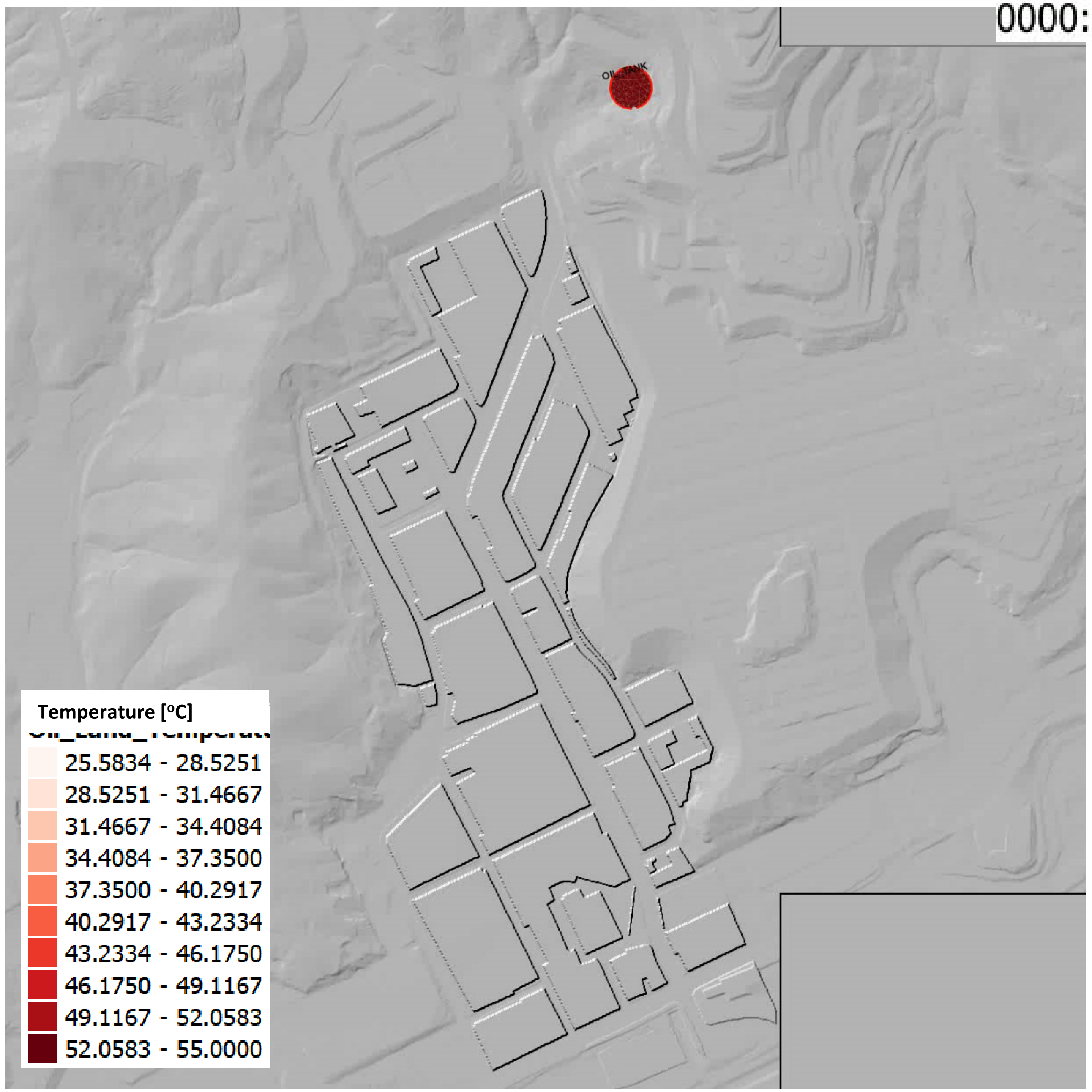


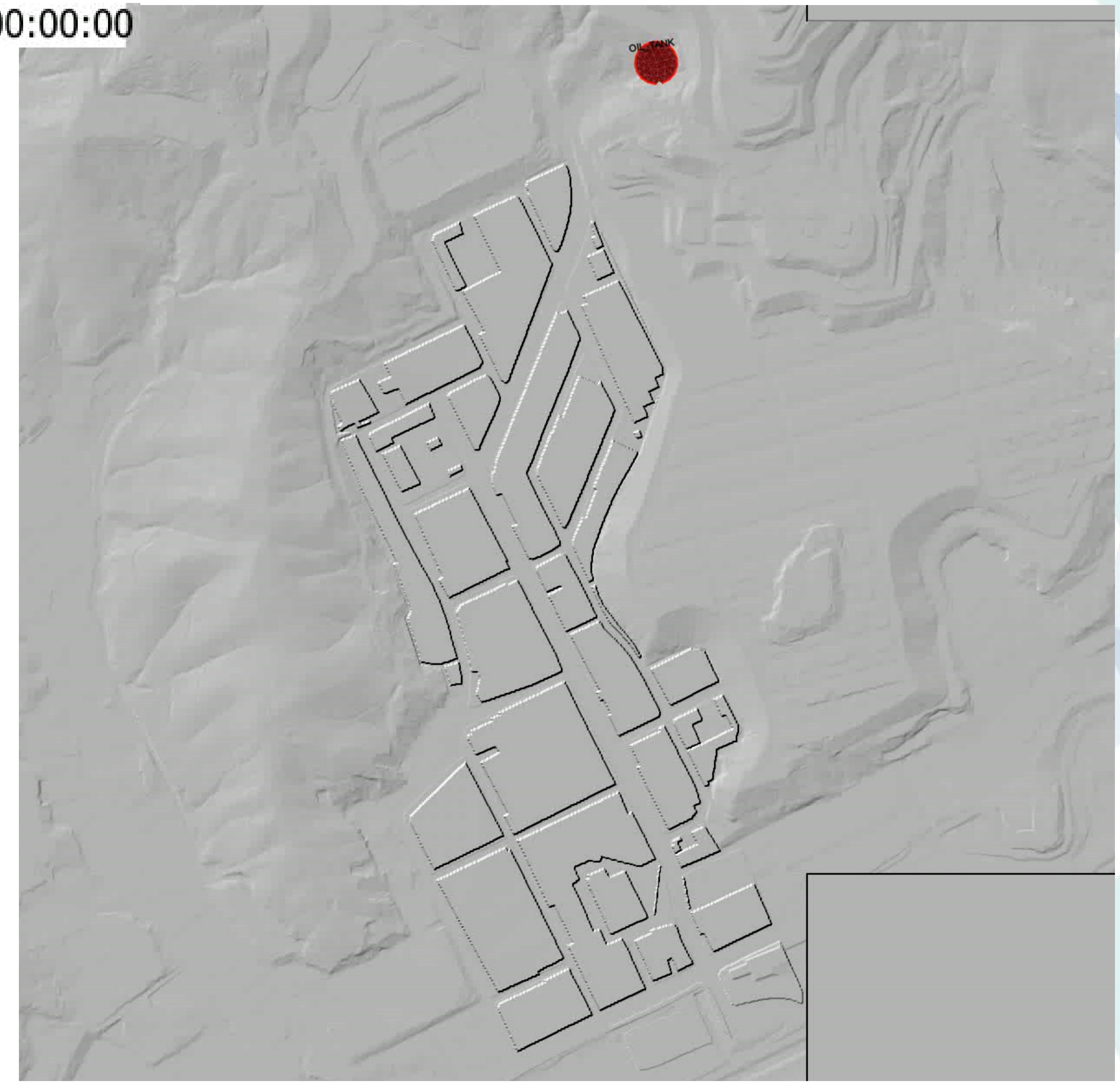
Oil Temperature

Wind Speed 2 m/s

Wind Speed 20 m/s

0000:00:00:00



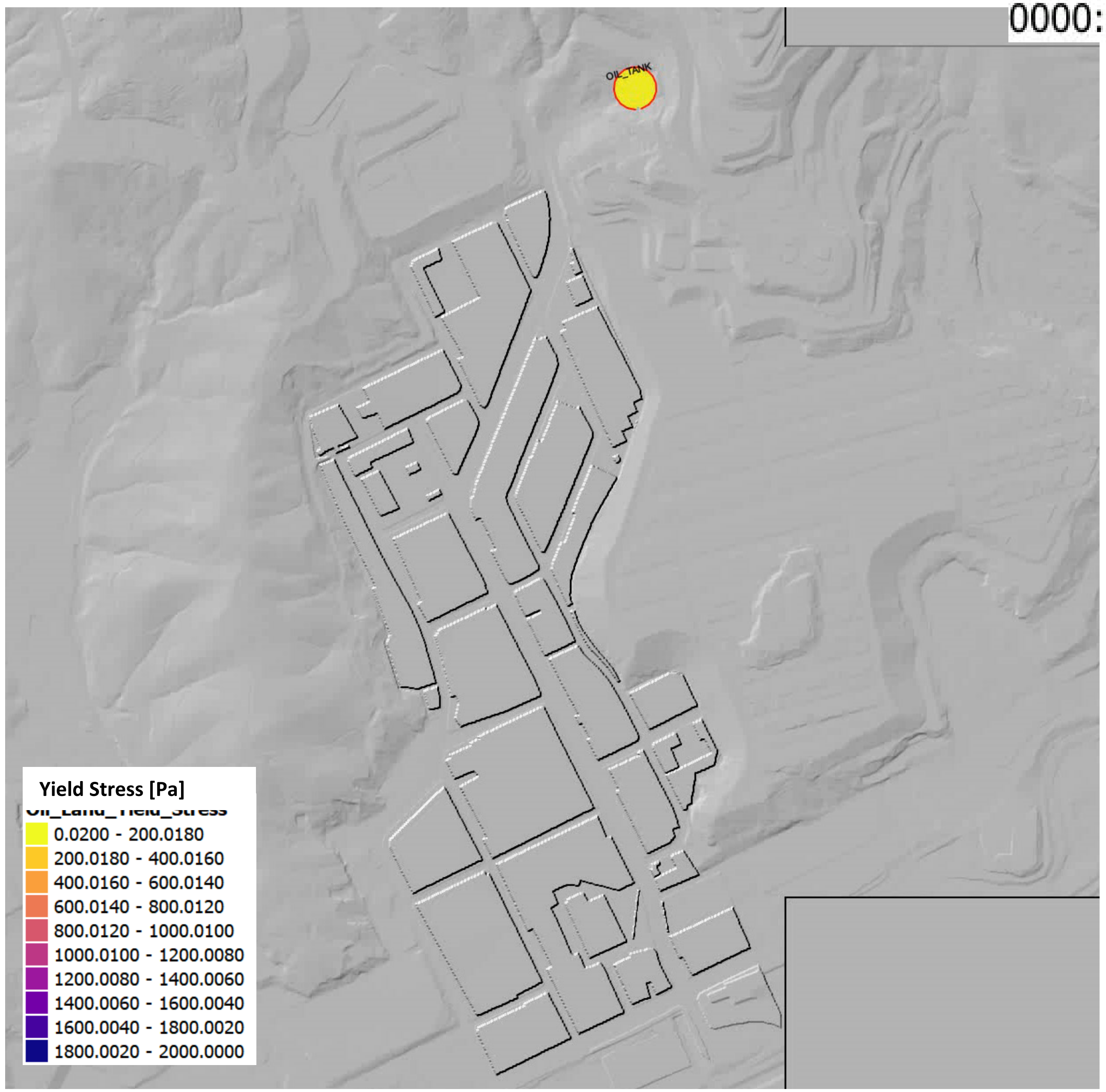


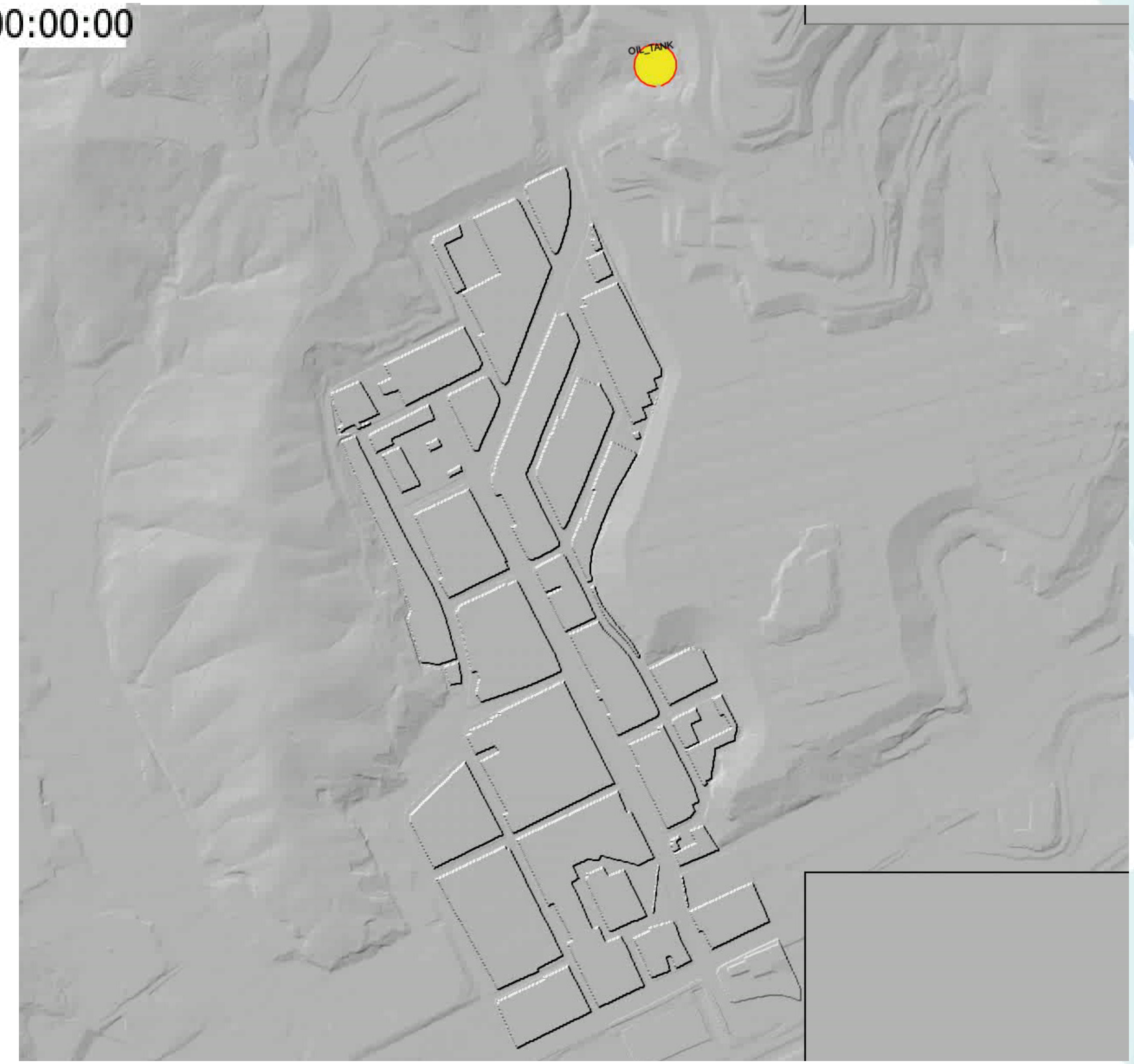
Oil Yield Stress

Wind Speed 2 m/s

Wind Speed 20 m/s

0000:00:00:00



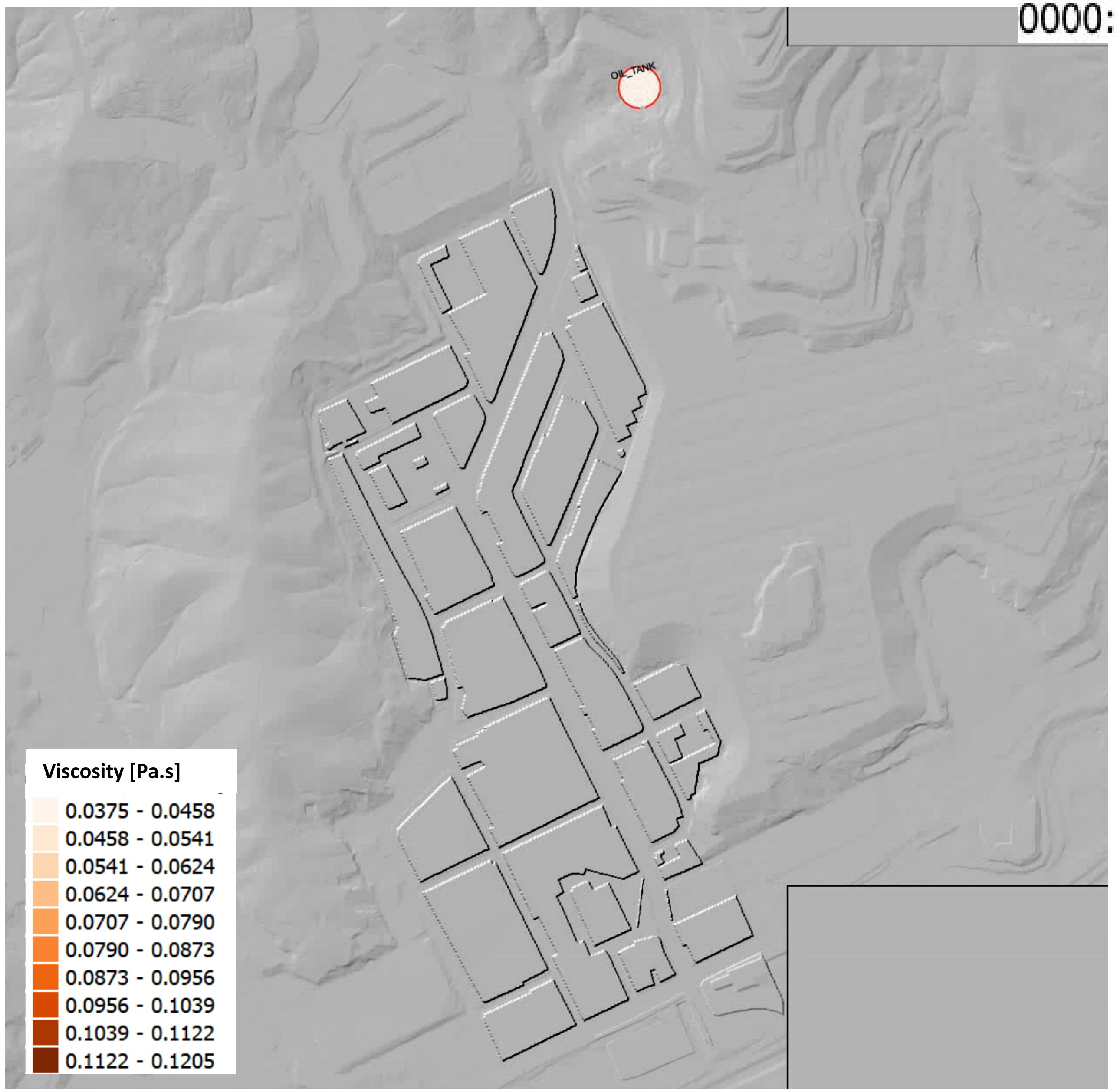


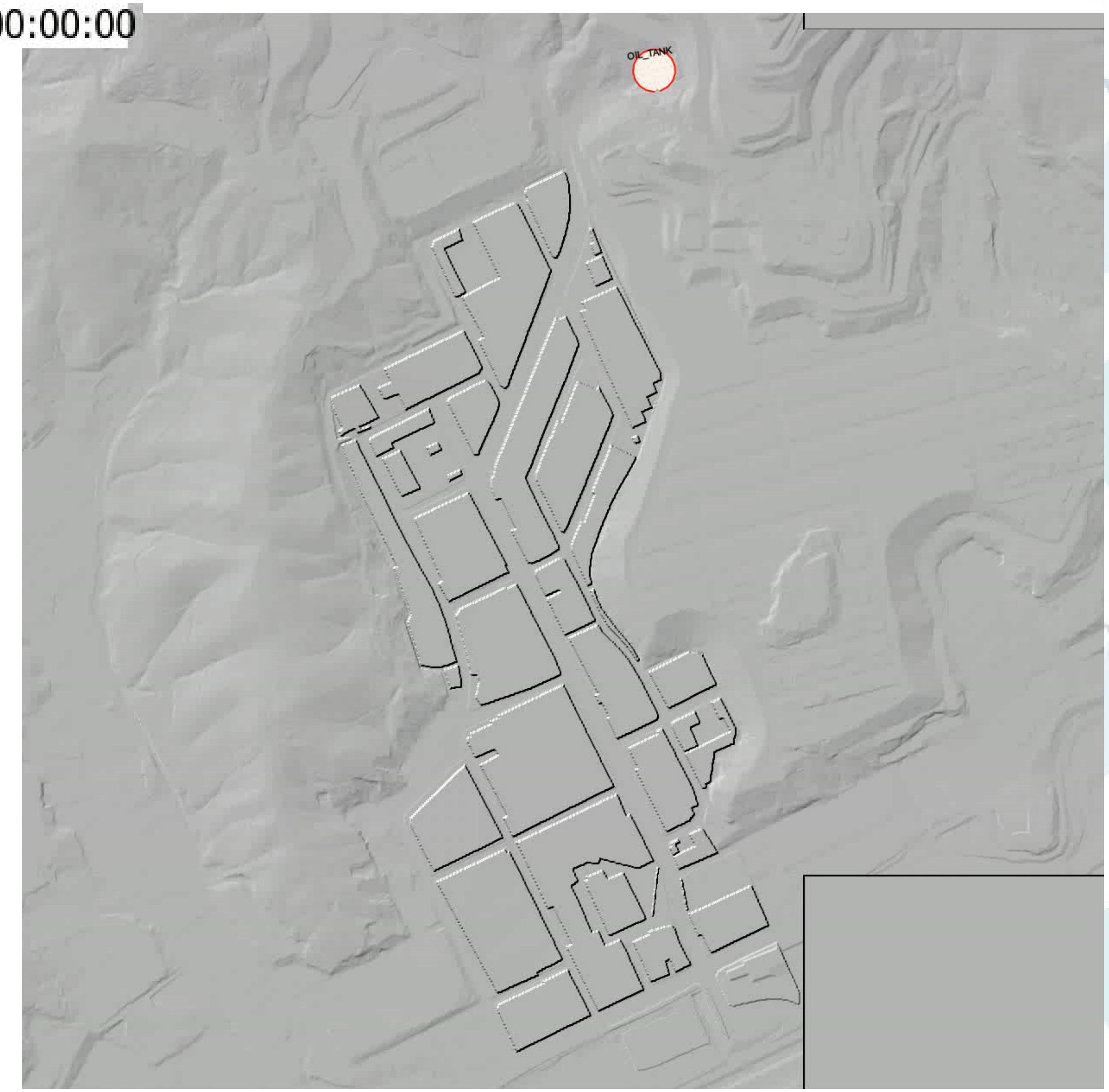
Oil Viscosity

Wind Speed 2 m/s

Wind Speed 20 m/s

0000:00:00:00





Comments

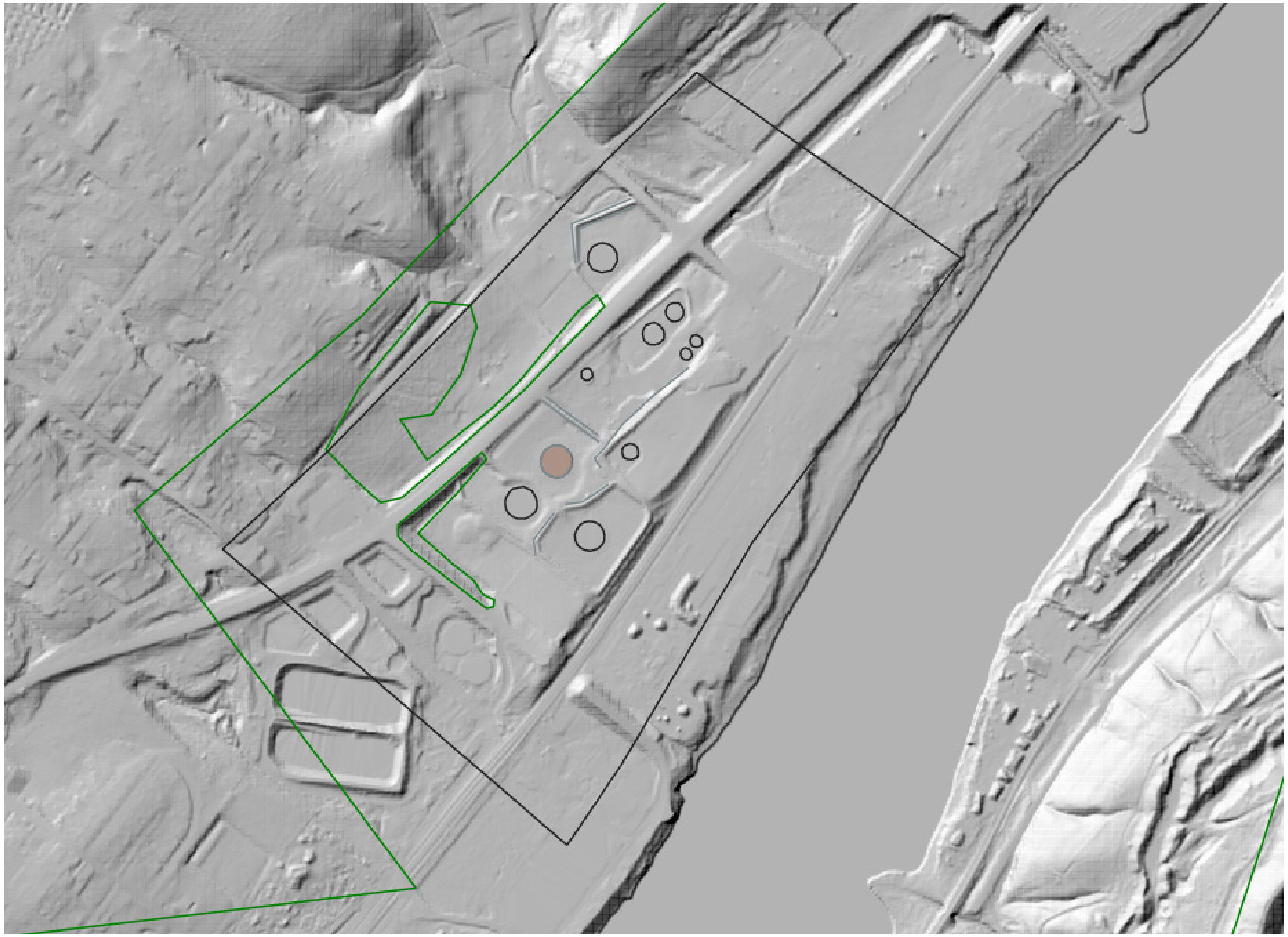
- Behaviour of some crude oils requires considering the variation of the fluid properties during spills.
- Modeling heat transfer in overland oil spill simulations can significantly improve the prediction of impacted areas.
- The OilFlow2D Heat Transfer Component is a practical model that can contribute to more realistic assessments of oil spill impacts.

THE ASHLAND OIL SPILL, FLOREFFE, PA

- Instantaneous and complete Diesel Fuel Storage Tank failure
- January 2, 1988
- Ashland Oil Terminal, Floreffe, Pennsylvania, near the Monongahela River 24 miles upstream of Pittsburgh
- Released 90,000 barrels (~15,000 m^3) of diesel oil
- Within hours, an estimated 18,000 barrels (3840 m^3) of diesel had entered the river.

THE ASHLAND OIL SPILL, FLOREFFE, PA

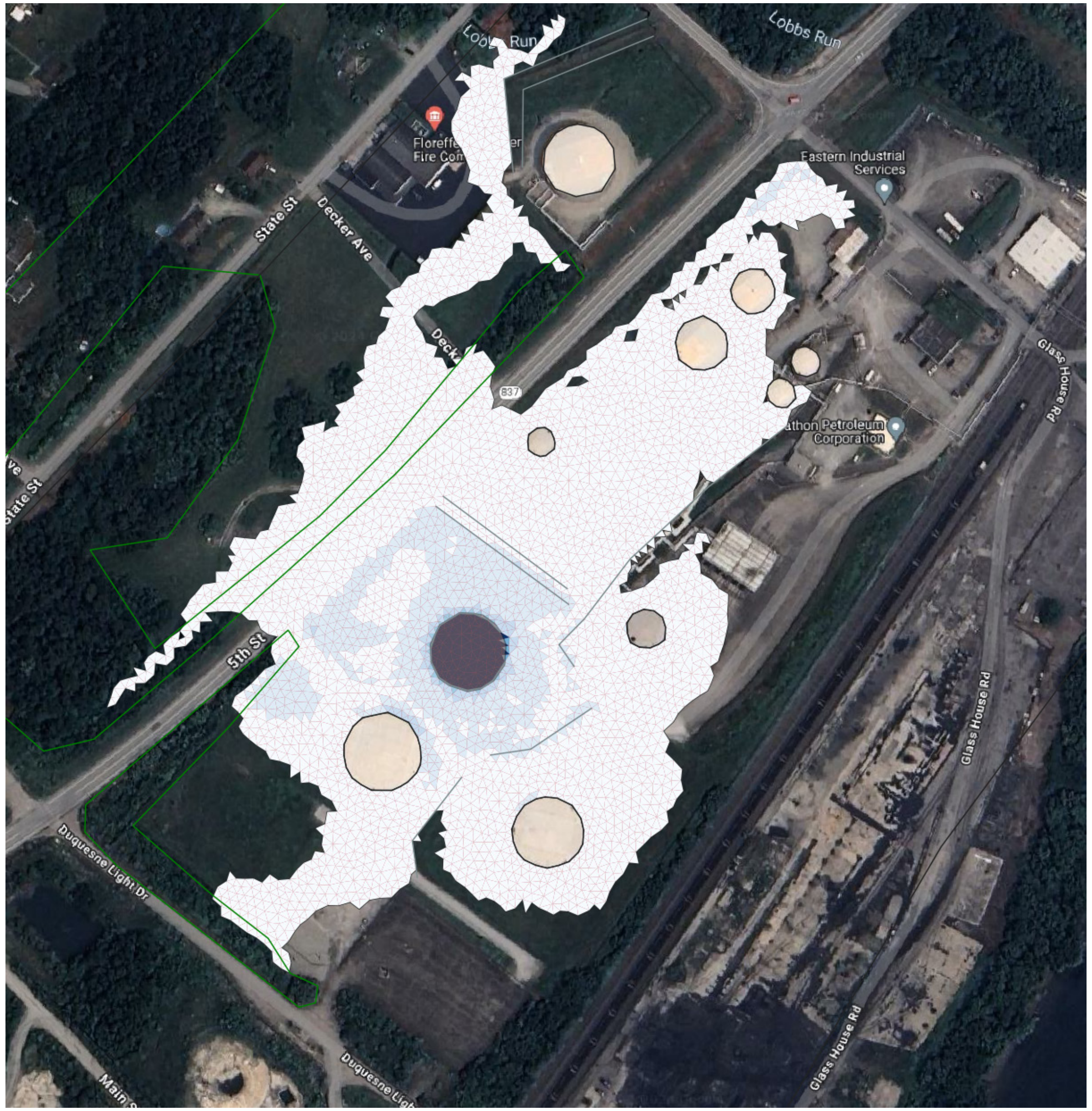
THE ASHLAND OIL SPILL, FLOREFFE, PA



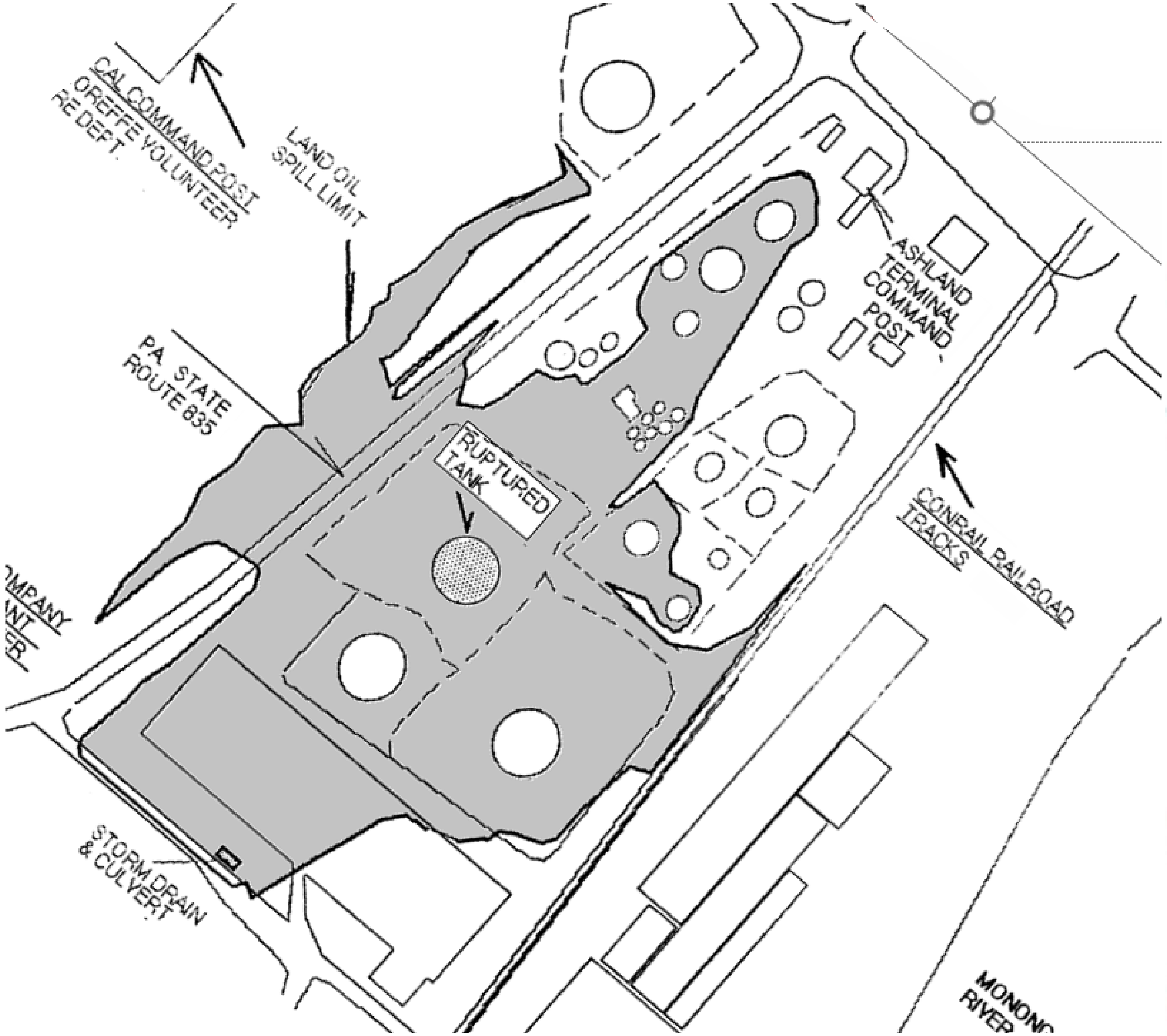
THE ASHLAND OIL SPILL, FLOREFFE, PA


0000:00:00:00
Decker Ave
Walnut St
State St
Walton Rd
Floreffe Volunteer Fire Company
A+ Landscape Design & Tree Service
3rd St
5th St
Glass House Rd
2nd St
Decker Ave
Matthews Bus
Marathon Petroleum Corporation
1st St
Glass House Rd
2nd St
837
Alice Ave
1st St
Park
Dollar General
Dollar store
Monongahela River
Duquesne Light Dr
Main St
5th St
Glass House Rd
Duquesne Light Dr
Main St
Glass House Rd
Riverview Rd
Bunola River Rd
Oil Depths (m)
0.0000 - 0.0787
0.0787 - 0.2218
0.2218 - 0.3847
0.3847 - 0.5573
0.5573 - 0.7575
0.7575 - 0.9628
0.9628 - 1.1900
1.1900 - 1.4540
1.4540 - 2.2550

THE ASHLAND OIL SPILL, FLOREFFE, PA

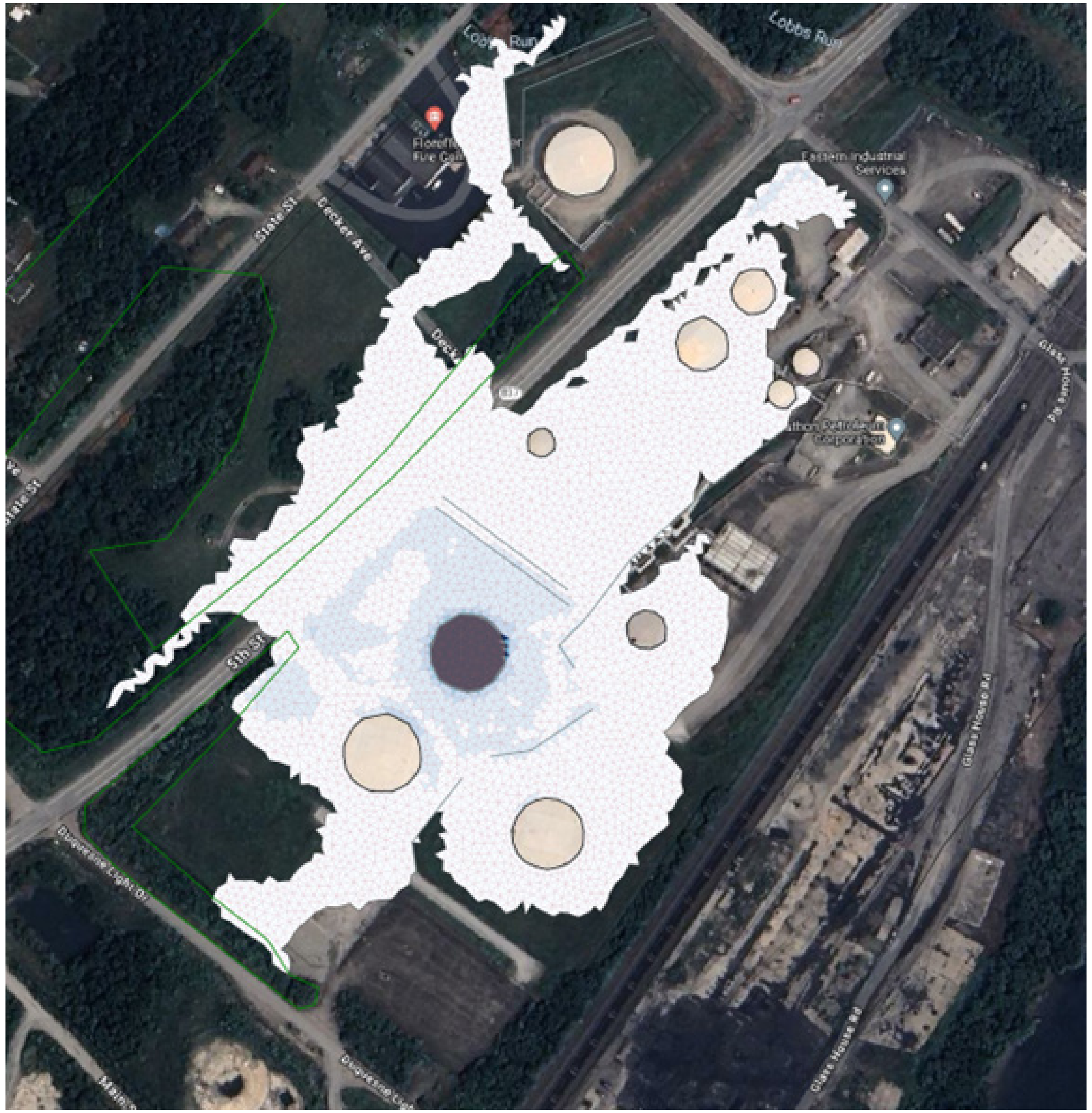


OilFlow2D Impacted Area



Impacted Area Reported

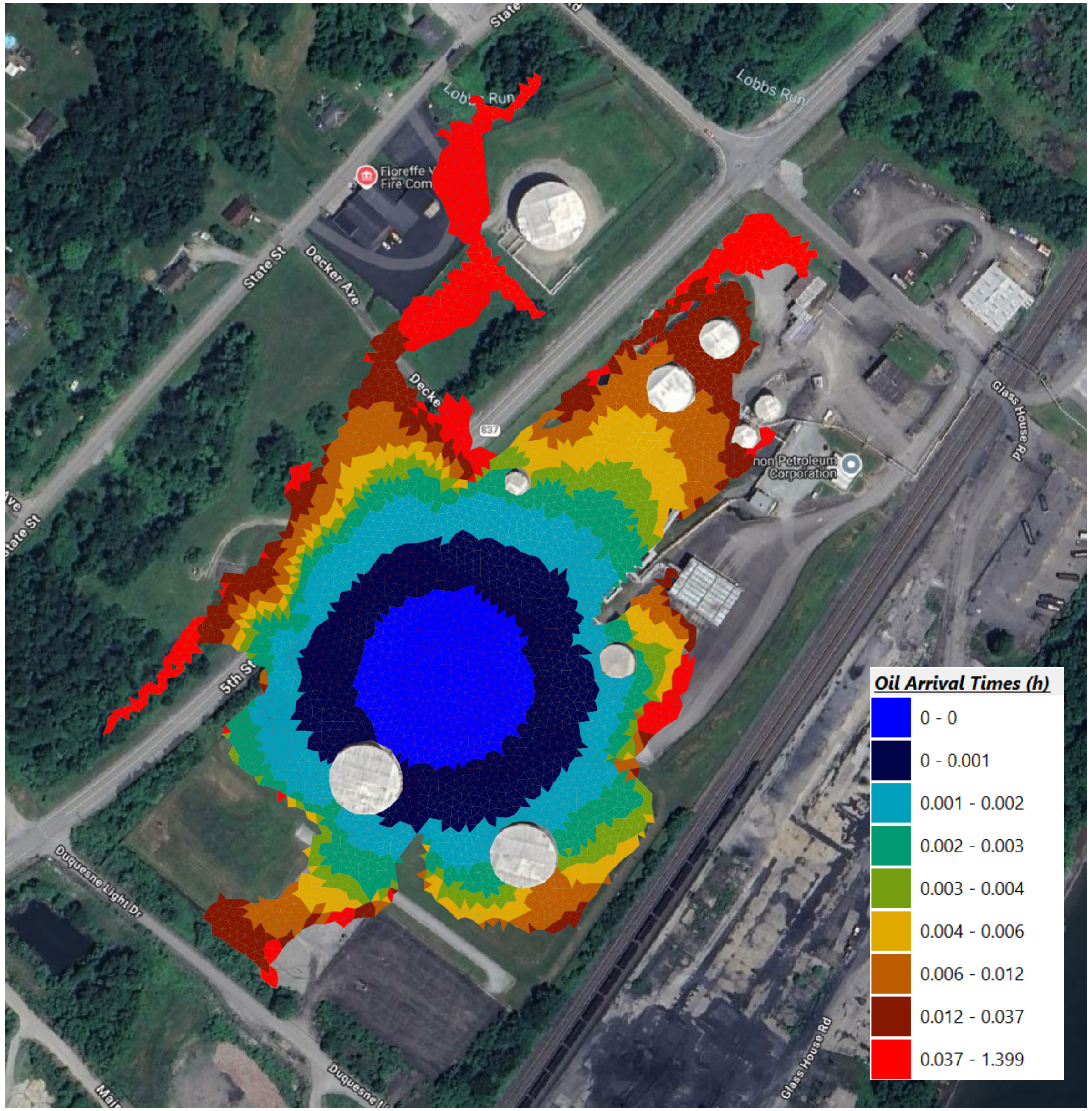
Impacted areas as a function of Oil Properties



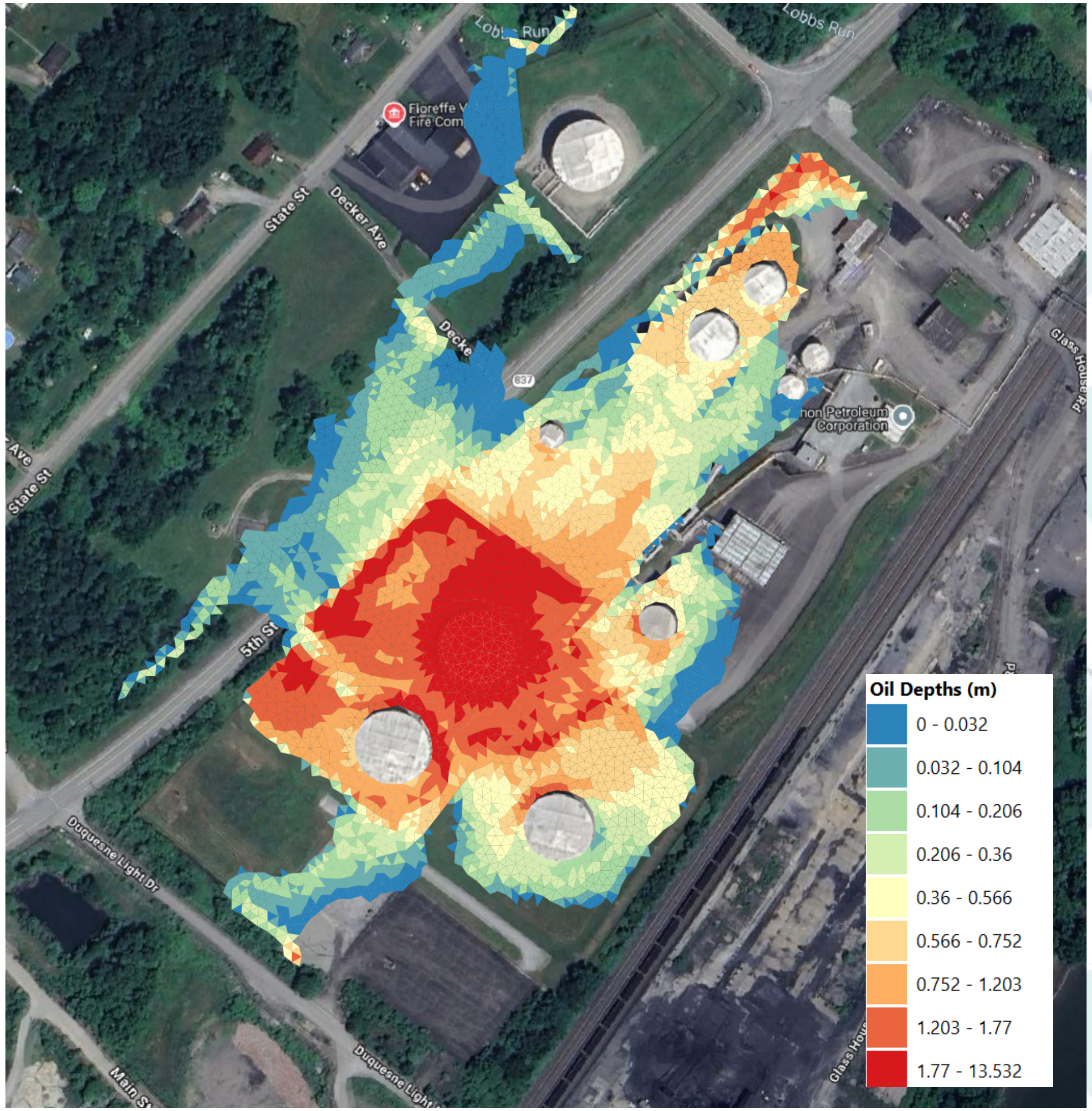
No-heat transfer low viscosity

Higher viscosity by cooling

Oil arrival times and maximum depths



Oil Arrival Times



Oil Depths

GPU Acceleration

NVIDIA RTX 4090 GPU	
Memory	24 GB
Cores	16,384

Mesh	No. Cells	Intel CPU (16 cores)	RTX 4090 (16,384 cores)	Max Speedup
Mesh 1	22,345	00:00:02:51	00:00:00:36	5x
Mesh 2	508,362	00:02:24:20	00:00:06:45	21x
Mesh 3	1,118,866	00:09:16:56	00:00:18:42	30x

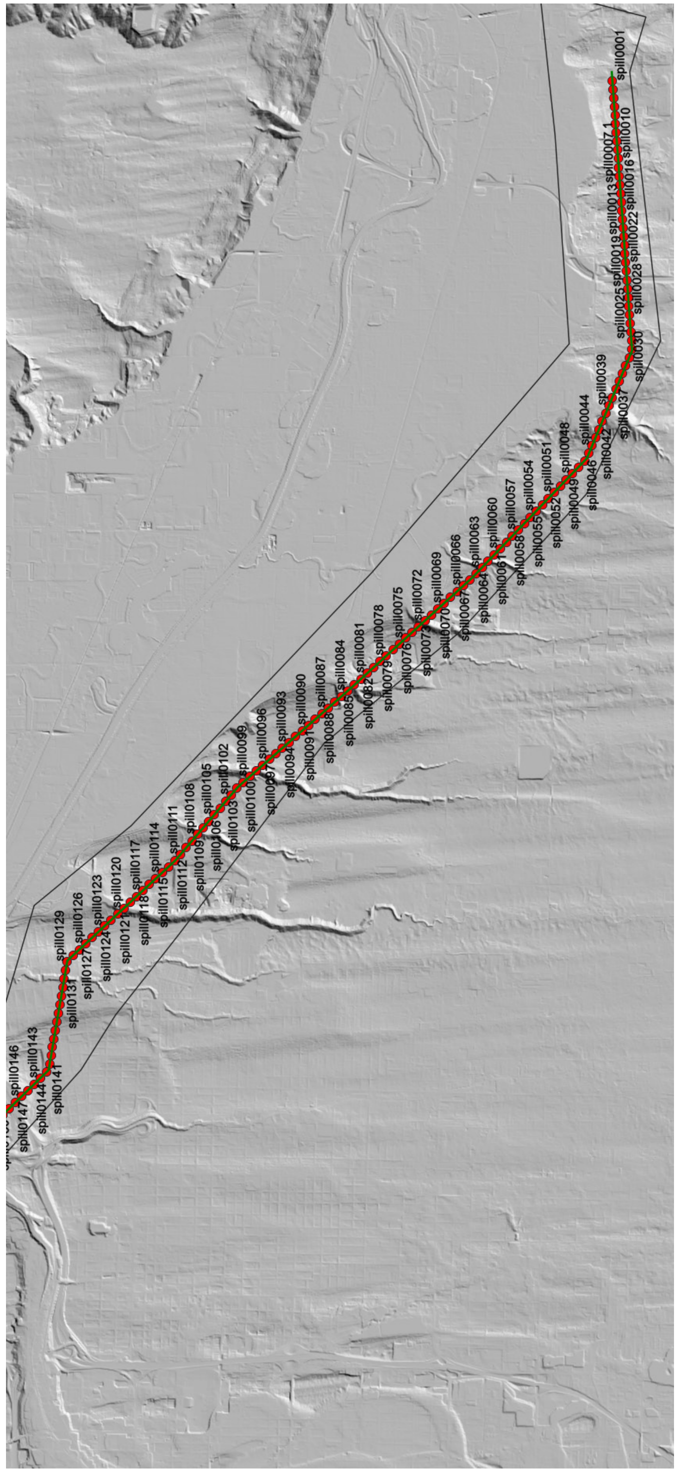
Oil Pipeline Spill Modeling

Or why GPU Brute Force is not always the first option

Oil Spills From Pipeline Bursts

Some country requirements

- Pipeline Spill risk assessment
- Thousands of spills along the pipeline
- Brute-force approach is seldom the best approach
- Also requires optimizing post processing to make it practical



Oil Pipeline Module

Pre-processing

- Allows entering a pipeline polyline and multiple spill points.
- Automatic creation of the sources layer for batch processing of the overland oil spills.
- Computation of the steady state initial pressure distribution along the pipeline given the oil flow rate and pressure head.
- Considers the closing time of block valves.
- Calculates the output flow rates from leaks of any diameter in two stages: The period between the initial time and valve closing and the period between the closing of valves and the final oil drainage from the pipeline during depressurization.
- The pipeline polyline can contain elevations, or the program can assign elevations from the Digital Terrain Model raster.

Oil Pipeline Module

Post-processing

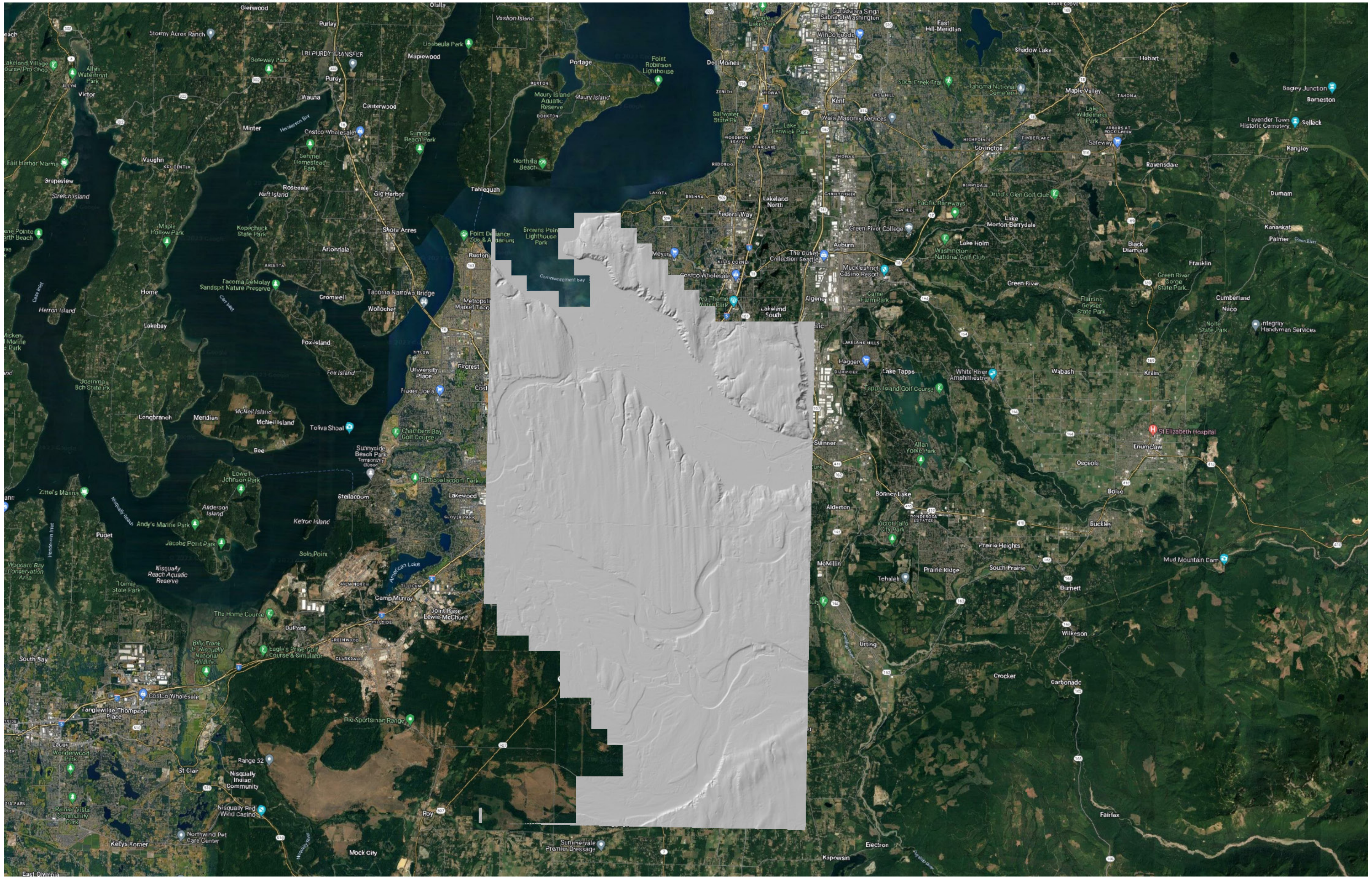
- Numeric output includes for each spill point:
    - The outflow hydrograph (oil discharge vs time),
    - Total oil volume drained from upstream and downstream of the spill point.
    - Oil volume drained from upstream and downstream of the spill point before valve closure.
    - Oil volume drained from upstream and downstream of the spill point after valve closure.
- Pressure head along the pipeline for the initial conditions.
- General table of hydrographs for all spills.
- Map batch processing to generate depth and affected area maps for all spills.
- Spill ID stamp for shape files.
- Integrated map in a single shape file for all spills.

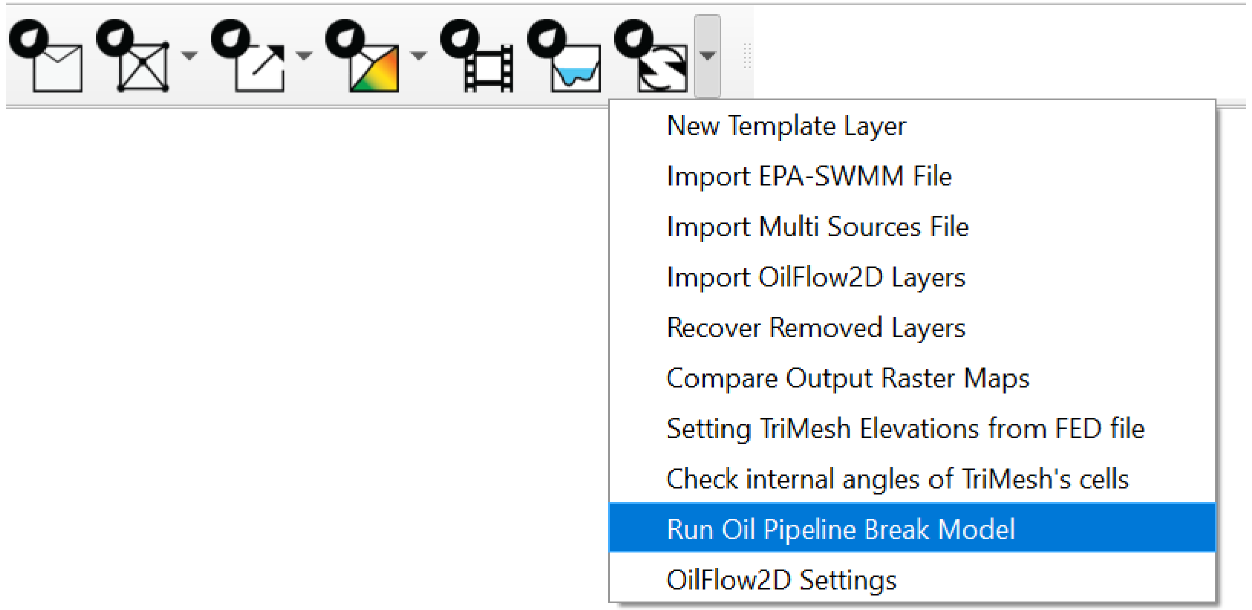
OilPipeline Application Workflow

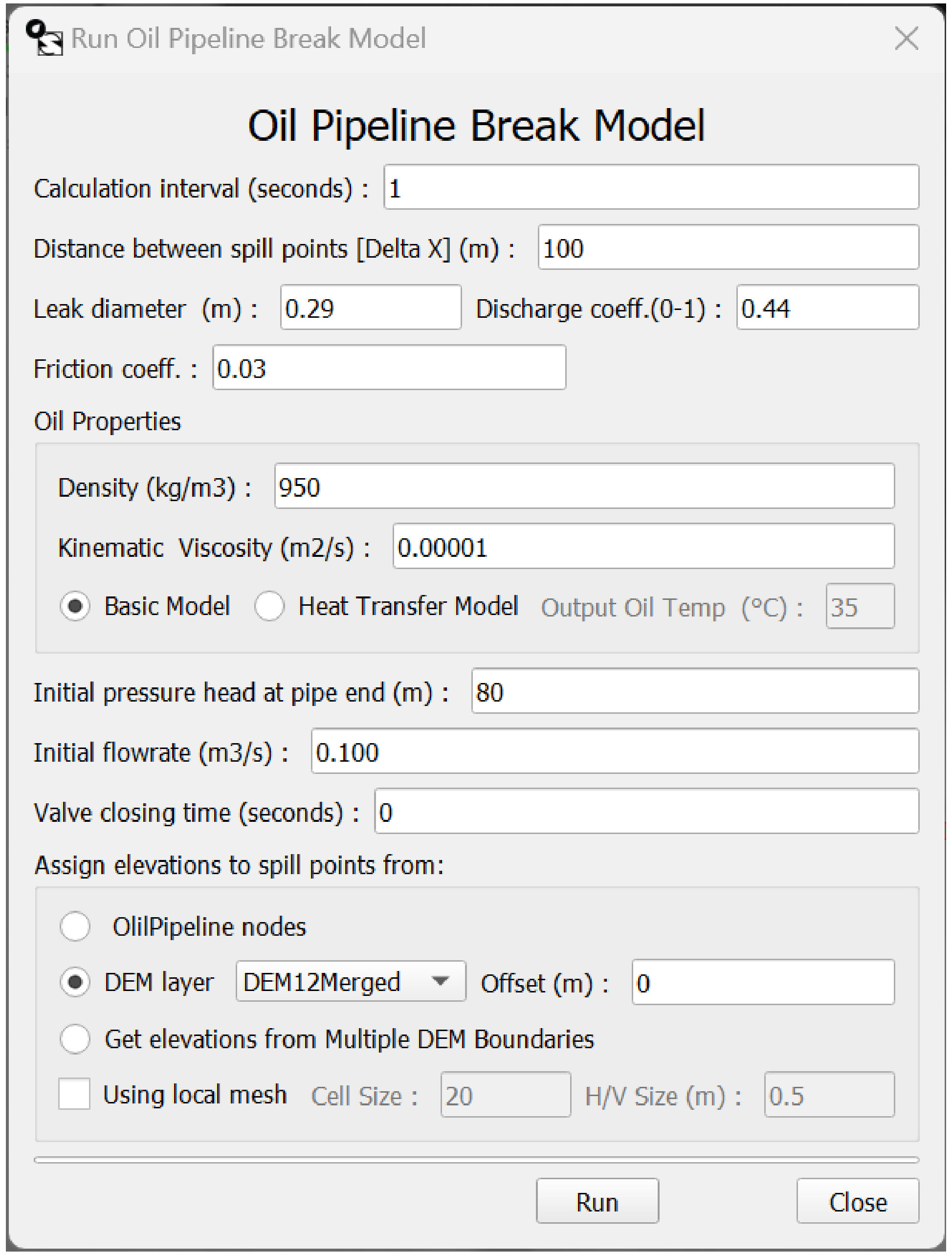
1. Open QGIS
2. Create a new OilFlow2D Project
3. Load Terrain Elevations (DEM)
4. Create empty *OilPipeline* and *Valves* layers
5. Enter pipe polyline
6. Enter Valve location points
7. Run the program to calculate Q vs time for each spill and generate *Sources* layer

Terrain Elevations: USGS

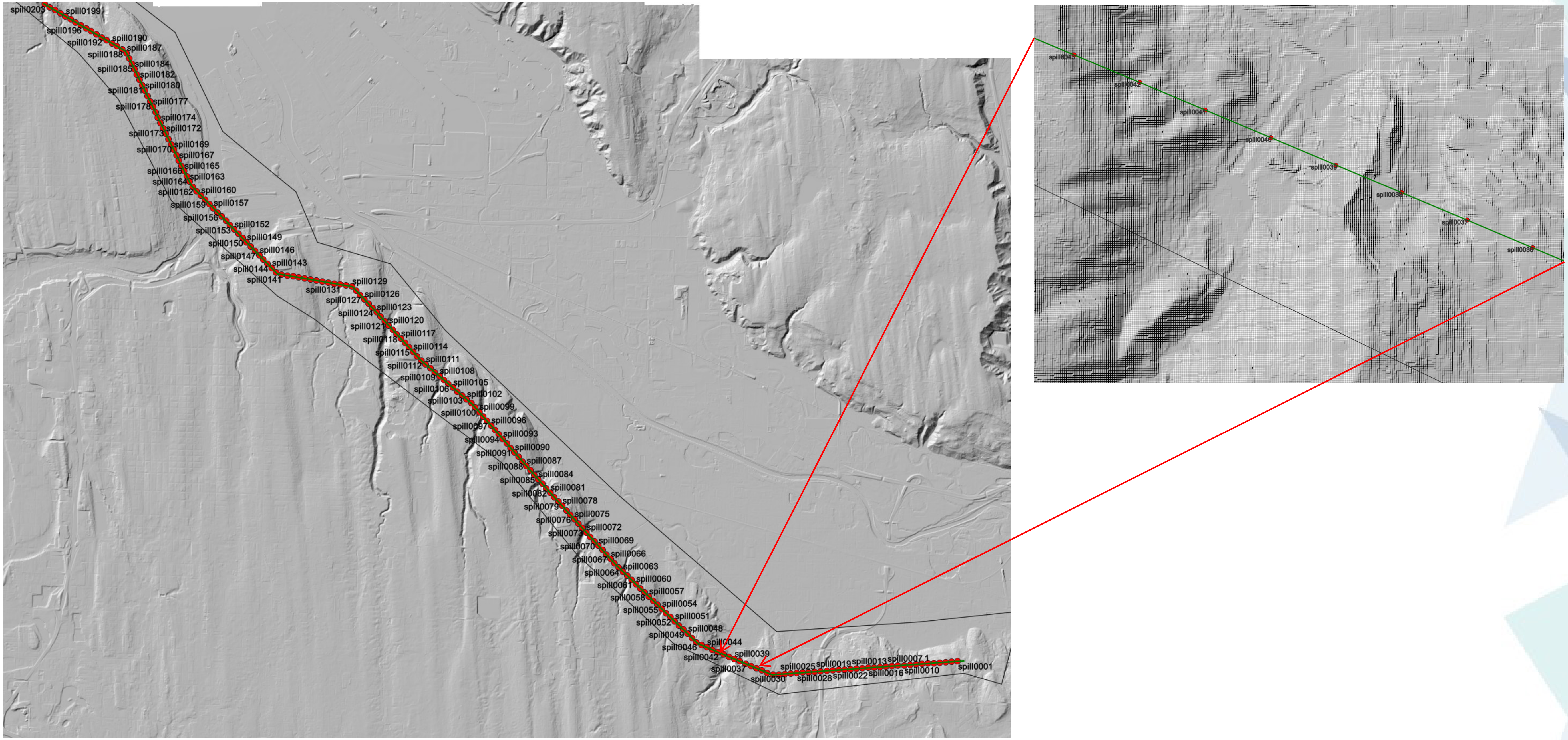
https://apps.nationalmap.gov/downloader/#/




New Template Layer
Import EPA-SWMM File
Import Multi Sources File
Import OilFlow2D Layers
Recover Removed Layers
Compare Output Raster Maps
Setting TriMesh Elevations from FED file
Check internal angles of TriMesh's cells
Run Oil Pipeline Break Model
OilFlow2D Settings


Run Oil Pipeline Break Model
Oil Pipeline Break Model
Calculation interval (seconds) : 1
Distance between spill points [Delta X] (m) : 100
Leak diameter (m) : 0.29
Discharge coeff.(0-1) : 0.44
Friction coeff. : 0.03
Oil Properties
Density (kg/m3) : 950
Kinematic Viscosity (m2/s) : 0.00001
Basic Model
Heat Transfer Model
Output Oil Temp (°C) : 35
Initial pressure head at pipe end (m) : 80
Initial flowrate (m3/s) : 0.100
Valve closing time (seconds) : 0
Assign elevations to spill points from:
OlilPipeline nodes
DEM layer
DEM12Merged
Offset (m) : 0
Get elevations from Multiple DEM Boundaries
Using local mesh
Cell Size : 20
H/V Size (m) : 0.5
Run
Close

Automatic Generation of Spill Sources

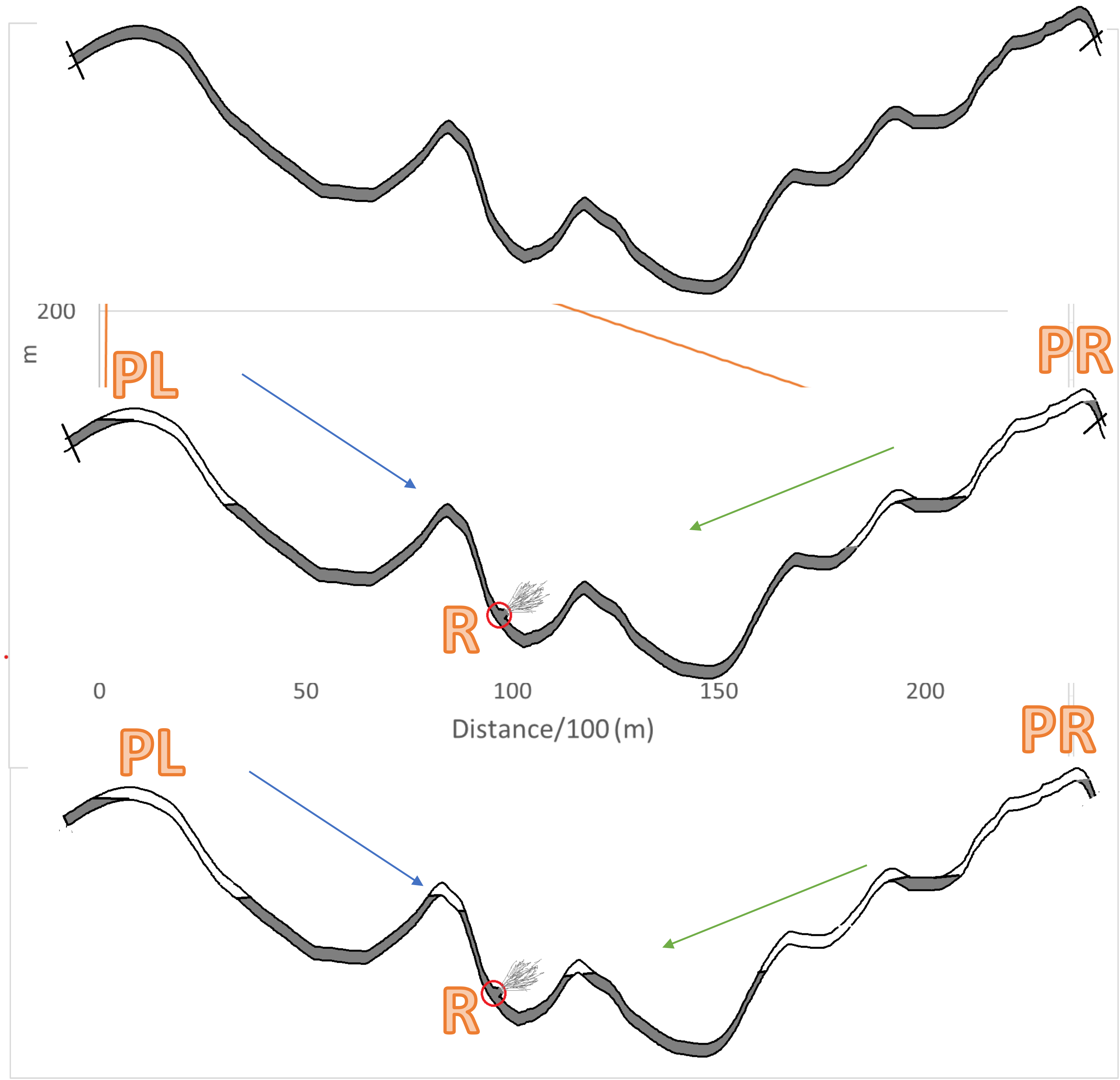


Puyallup Fish Hatchery
Clarks Creek
14th St SW
15th Ave SW
15th Ave SW
12th St SW
Tomishinets
spill0044
spill0043
spill0042
spill0041
spill0040
spill0039
spill0038
spill0037
spill0036
spill0035
spill0034
spill0033
spill0032
G Grace Junk Removal
12th St SW
17th Ave SW
Top Hat Chimney Sweep & Repair
Maplewood Spring
14th St SW
Brown Community Garden
19th Ave SW
19th Ave SW
20th Ave SW
14th St SW
Hummingbird Hl Trl
11th St Pl SW

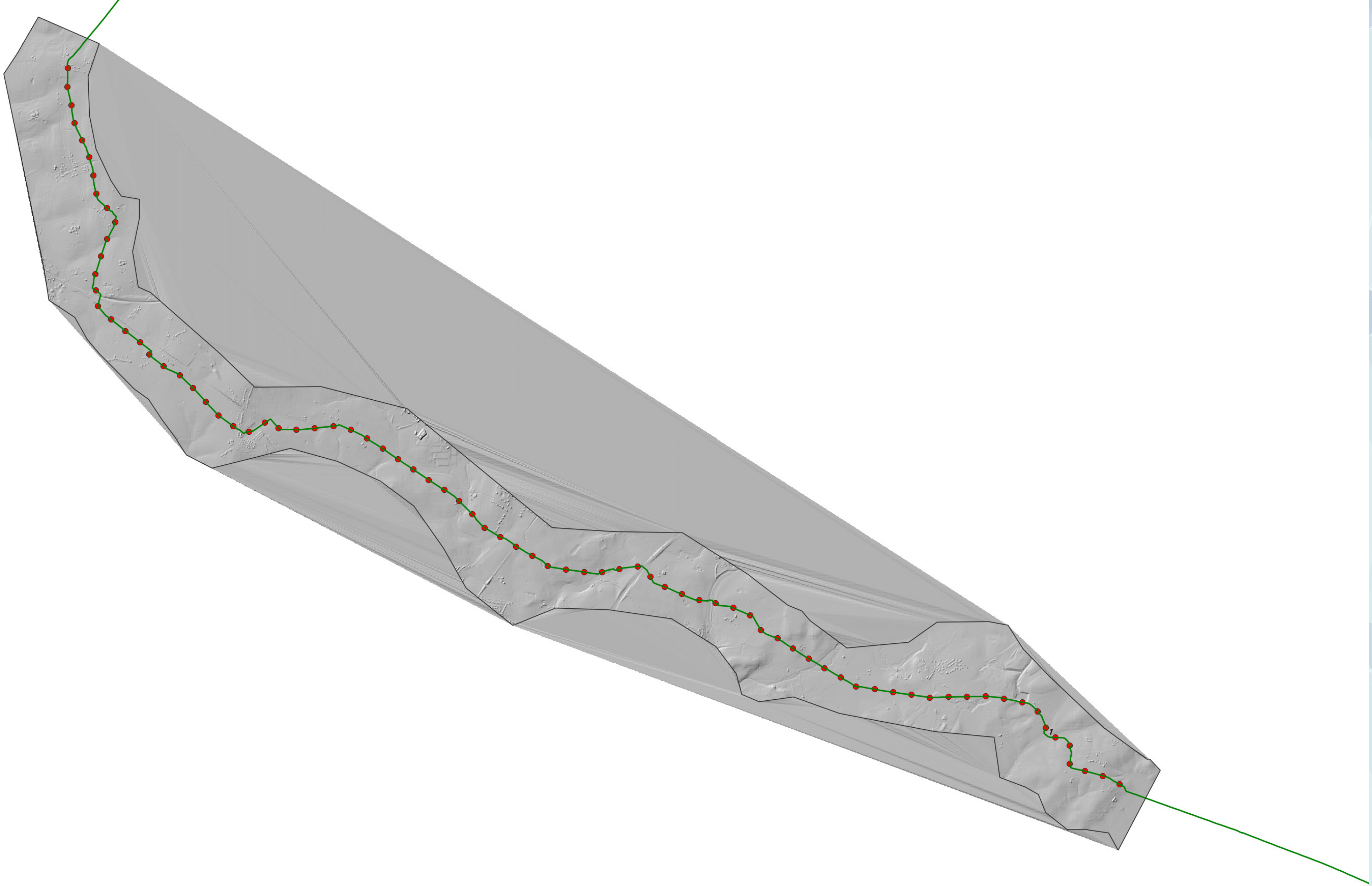
Oil leak discharge Calculation

- Initial steady state: Q, Pressure
- For each leak point
    - From PL to R and from PR to R apply Quasi-Unsteady 1D Continuity and Energy equations
    - Export *Q vs time* table for each leak point

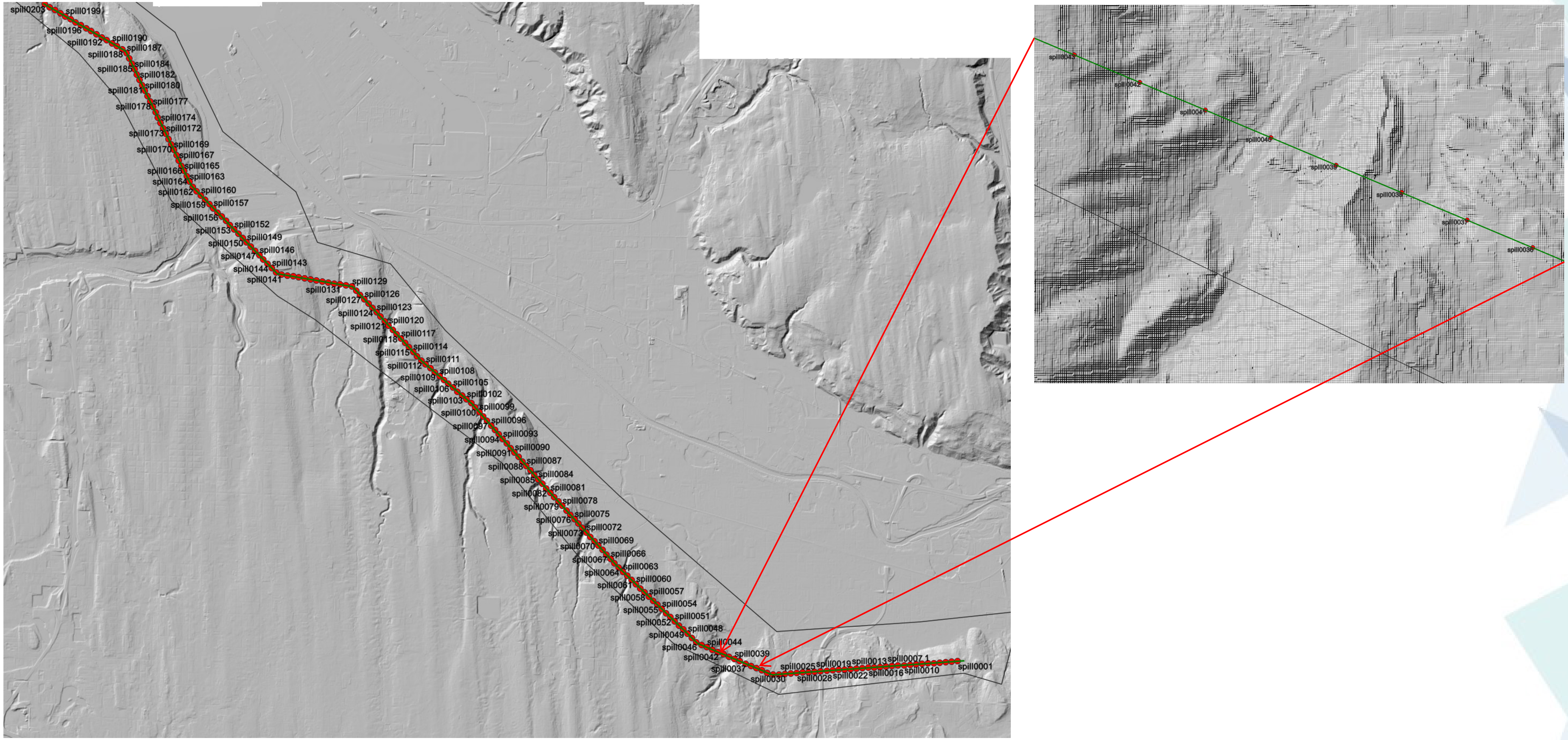
Time (s)	Time (h)	spill0001 (m3/s)	spill0002 (m3/s)	spill0003 (m3/s)	spill0004 (m3/s)	spill0005 (m3/s)	spill0006 (m3/s)	spill0007 (m3/s)
0	0	1.9755	1.9678	0	0.1769	1.6717	2.2839	2.387
1.0008	0.000278	1.9666	1.952	0	0.175	0.2971	2.2667	2.37
2.0016	0.000556	1.9577	1.9362	0	0.173	0.2944	2.2493	2.354
2.9988	0.000833	1.9488	1.3188	0	0.1711	0.2917	2.2318	2.338
3.9996	0.001111	1.9397	0	0	0.1692	0.289	2.2142	2.322
5.0004	0.001389	1.9306	0	0	0.1672	0.2863	2.1965	2.305
6.0012	0.001667	1.9214	0	0	0.1653	0.2835	2.1787	2.288
6.9984	0.001944	0.6228	0	0	0.1633	0.2808	1.7053	2.272
7.9992	0.002222	0	0	0	0.1613	0.278	0.5512	2.255
9	0.0025	0	0	0	0.1593	0.2752	0.543	2.238
10.0008	0.002778	0	0	0	0.1573	0.2724	0.5348	1.935
11.0016	0.003056	0	0	0	0.1553	0.2696	0.5265	0.611
11.9988	0.003333	0	0	0	0.1532	0.2667	0.5182	0.603
12.9996	0.003611	0	0	0	0.1512	0.2639	0.5098	0.595
14.0004	0.003889	0	0	0	0.1491	0.261	0.5014	0.58
15.0012	0.004167	0	0	0	0.147	0.2581	0.4929	0.580
15.9984	0.004444	0	0	0	0.145	0.2552	0.4843	0.572
16.9992	0.004722	0	0	0	0.1429	0.2523	0.4757	0.564
18	0.005	0	0	0	0.1407	0.2493	0.4671	0.556
19.0008	0.005278	0	0	0	0.1386	0.2464	0.4584	0.54
20.0016	0.005556	0	0	0	0.1365	0.2434	0.4496	0.539
20.9988	0.005833	0	0	0	0.1343	0.2404	0.4408	0.531
21.9996	0.006111	0	0	0	0.1322	0.2374	0.4319	0.523
23.0004	0.006389	0	0	0	0.13	0.2343	0.423	0.515
24.0012	0.006667	0	0	0	0.1278	0.2313	0.414	0.506
24.9984	0.006944	0	0	0	0.1256	0.2282	0.405	0.498
25.9992	0.007222	0	0	0	0.1234	0.2252	0.3959	0.489
27	0.0075	0	0	0	0.1212	0.222	0.3868	0.481
28.0008	0.007778	0	0	0	0.1189	0.2189	0.3775	0.472
29.0016	0.008056	0	0	0	0.1167	0.2158	0.3683	0.464
29.9988	0.008333	0	0	0	0.1144	0.2126	0.3589	0.455
30.9996	0.008611	0	0	0	0.1121	0.2094	0.3495	0.446
32.0004	0.008889	0	0	0	0.1098	0.2063	0.3401	0.438



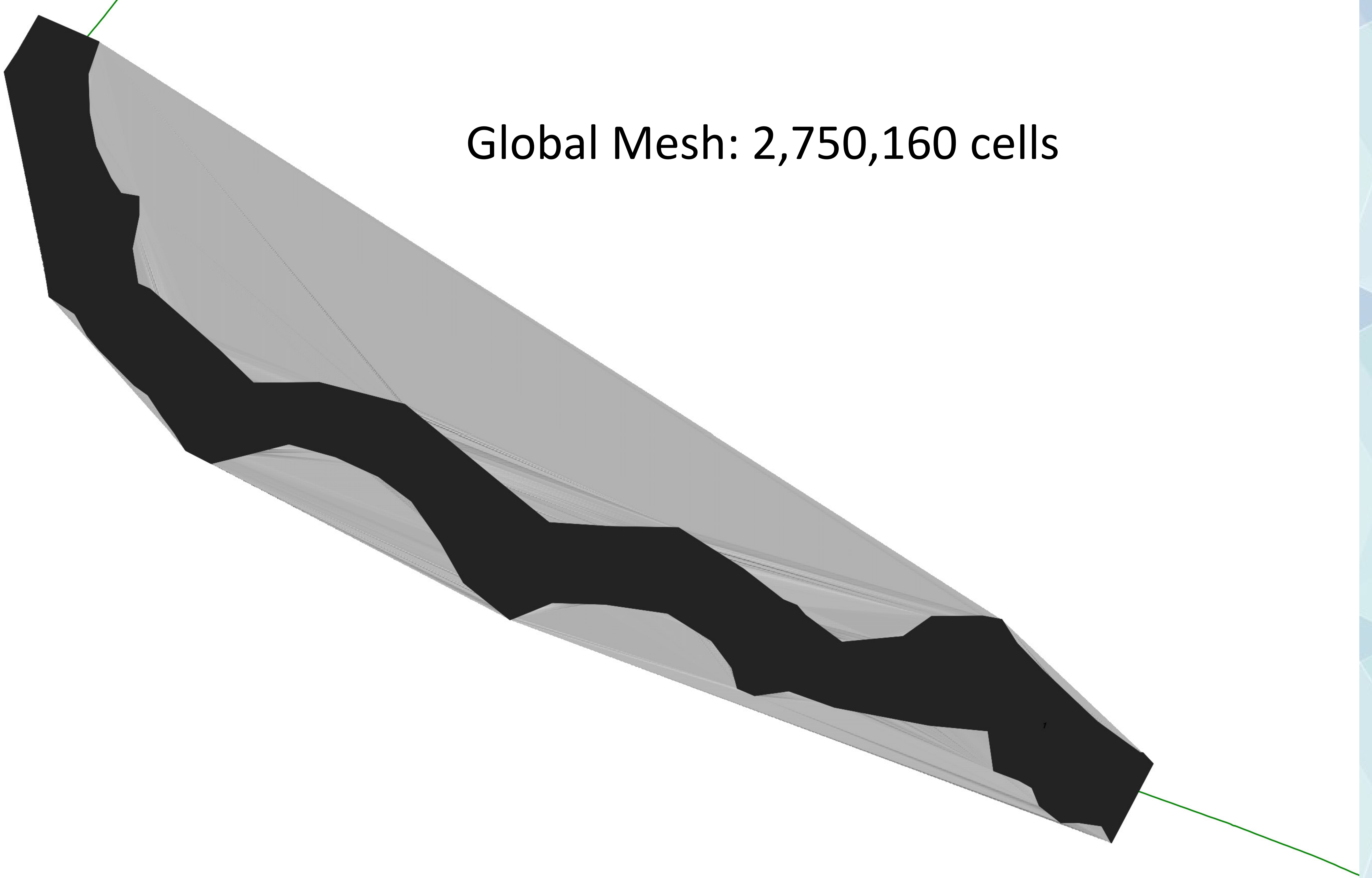
Oil Spill Spreading Animation for Spill 116

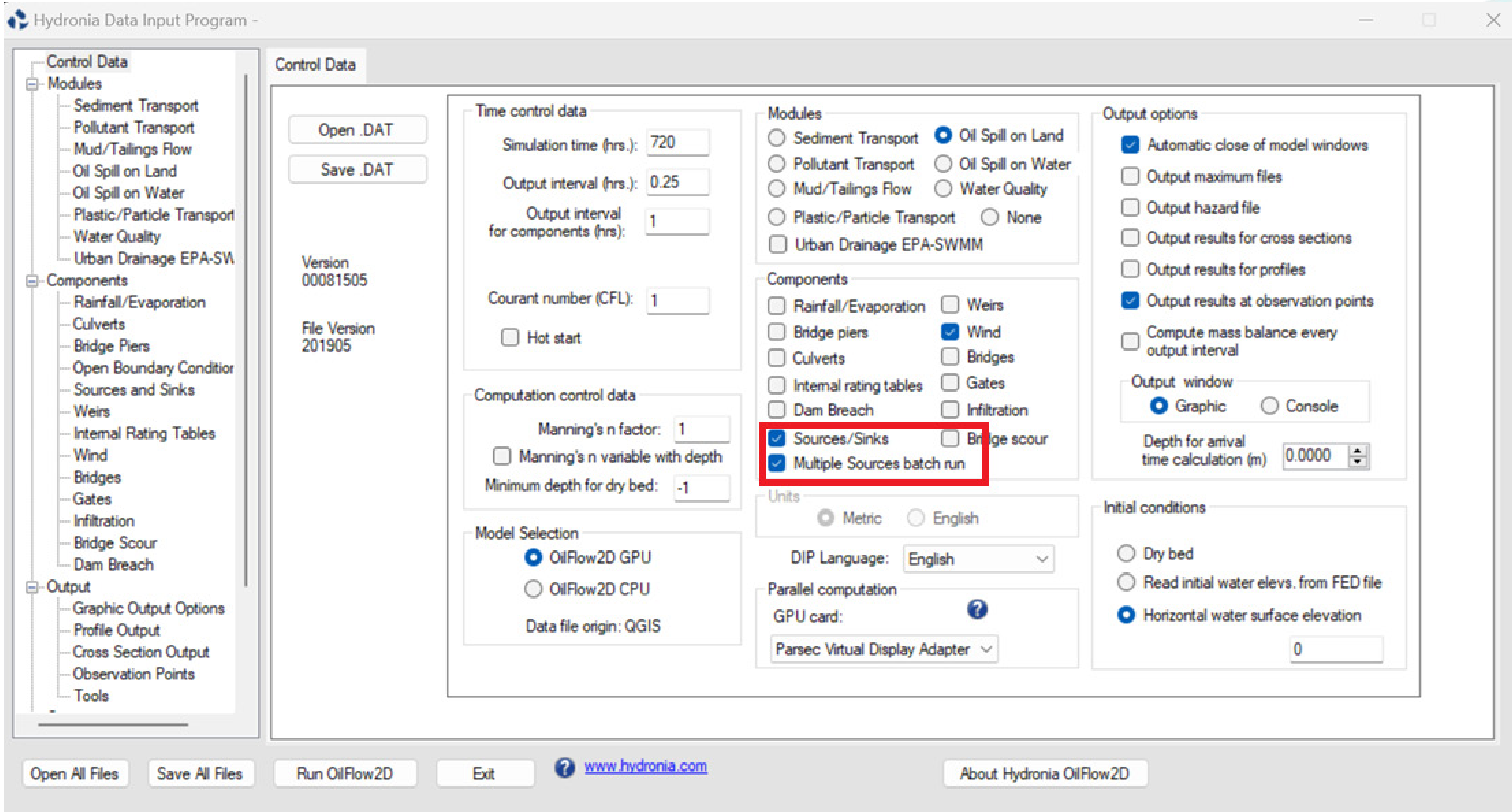


User Defined Spill Sources



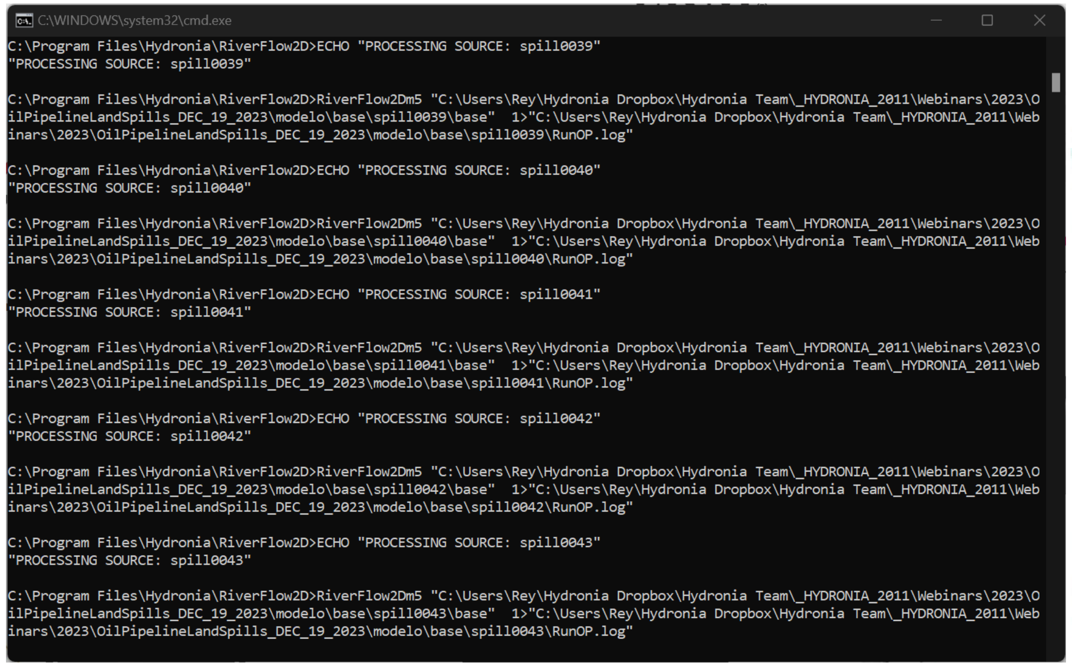
Global Mesh: 2,750,160 cells

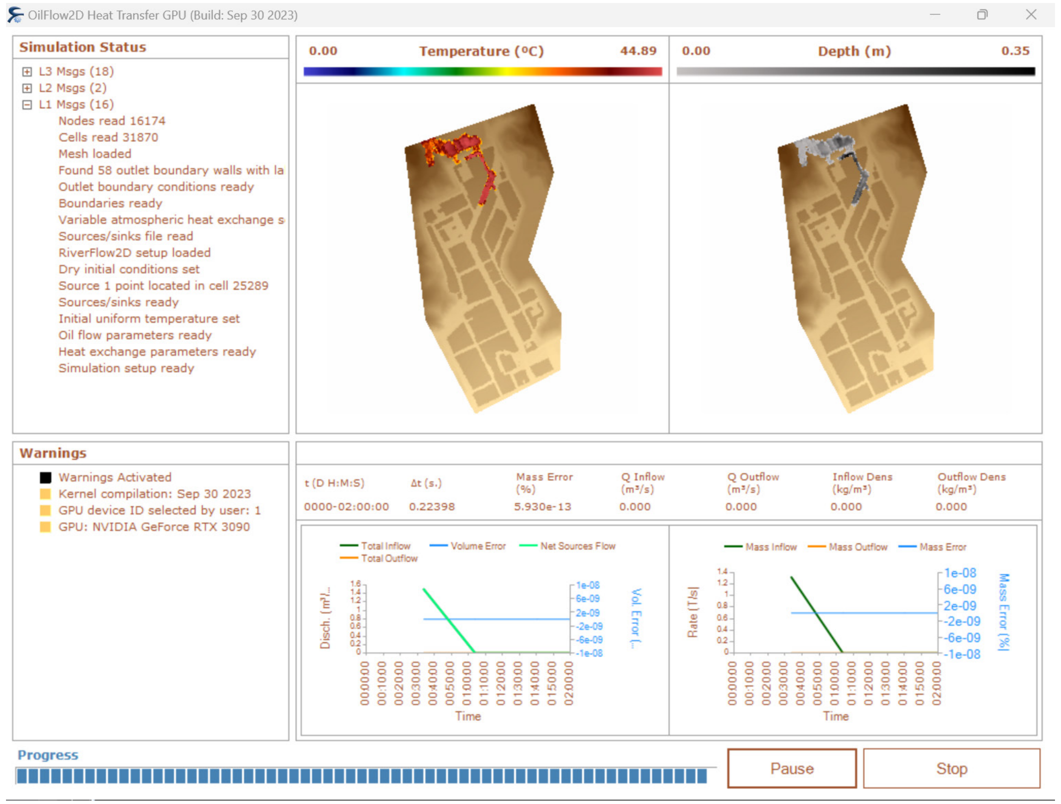


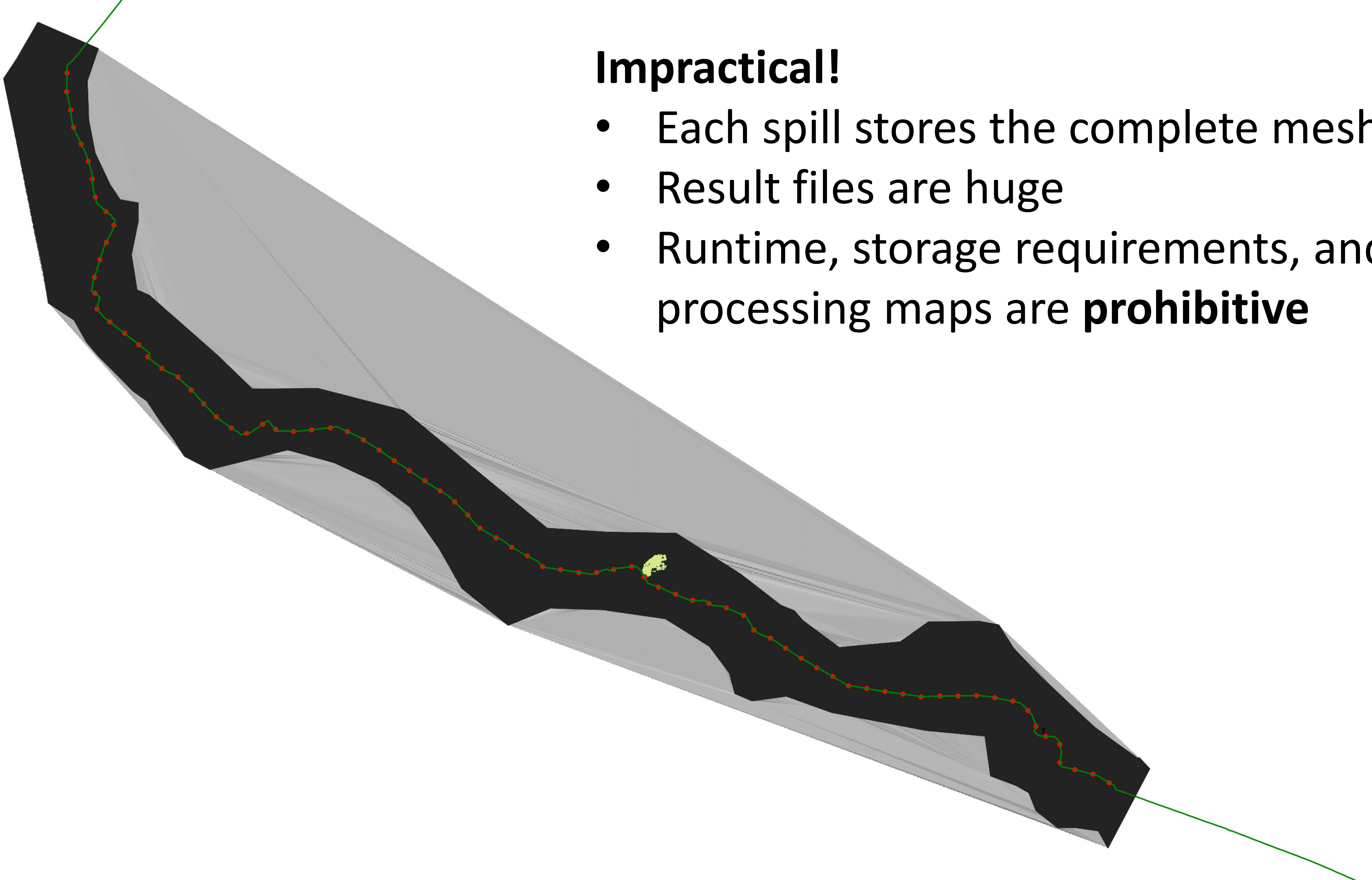

Hydronia Data Input Program -
Control Data
Modules
Sediment Transport
Pollutant Transport
Mud/Tailings Flow
Oil Spill on Land
Oil Spill on Water
Plastic/Particle Transport
Water Quality
Urban Drainage EPA-SW
Components
Rainfall/Evaporation
Culverts
Bridge Piers
Open Boundary Conditior
Sources and Sinks
Weirs
Internal Rating Tables
Wind
Bridges
Gates
Infiltration
Bridge Scour
Dam Breach
Output
Graphic Output Options
Profile Output
Cross Section Output
Observation Points
Tools
Control Data
Open .DAT
Save .DAT
Version
00081505
File Version
201905
Time control data
Simulation time (hrs.): 720
Output interval (hrs.): 0.25
Output interval
for components (hrs): 1
Courant number (CFL): 1
Hot start
Computation control data
Manning's n factor: 1
Manning's n variable with depth
Minimum depth for dry bed: -1
Model Selection
OilFlow2D GPU
OilFlow2D CPU
Data file origin: QGIS
Modules
Sediment Transport
Oil Spill on Land
Pollutant Transport
Oil Spill on Water
Mud/Tailings Flow
Water Quality
Plastic/Particle Transport
None
Urban Drainage EPA-SWMM
Components
Rainfall/Evaporation
Weirs
Bridge piers
Wind
Culverts
Bridges
Internal rating tables
Gates
Dam Breach
Infiltration
Sources/Sinks
Bridge scour
Multiple Sources batch run
Units
Metric
English
DIP Language: English
Parallel computation
GPU card:
Parsec Virtual Display Adapter
Output options
Automatic close of model windows
Output maximum files
Output hazard file
Output results for cross sections
Output results for profiles
Output results at observation points
Compute mass balance every
output interval
Output window
Graphic
Console
Depth for arrival
time calculation (m) 0.0000
Initial conditions
Dry bed
Read initial water elevs. from FED file
Horizontal water surface elevation
0
Open All Files
Save All Files
Run OilFlow2D
Exit
www.hydronia.com
About Hydronia OilFlow2D

Batch Run of All Spills

- Automate running thousands of spills
- Little user action required
- Results for each spill are written in separate directories







Impractical!

- Each spill stores the complete mesh
- Result files are huge
- Runtime, storage requirements, and processing maps are **prohibitive**

Alternative: Local Mesh Optimization

- Local meshes are automatically generated for each spill

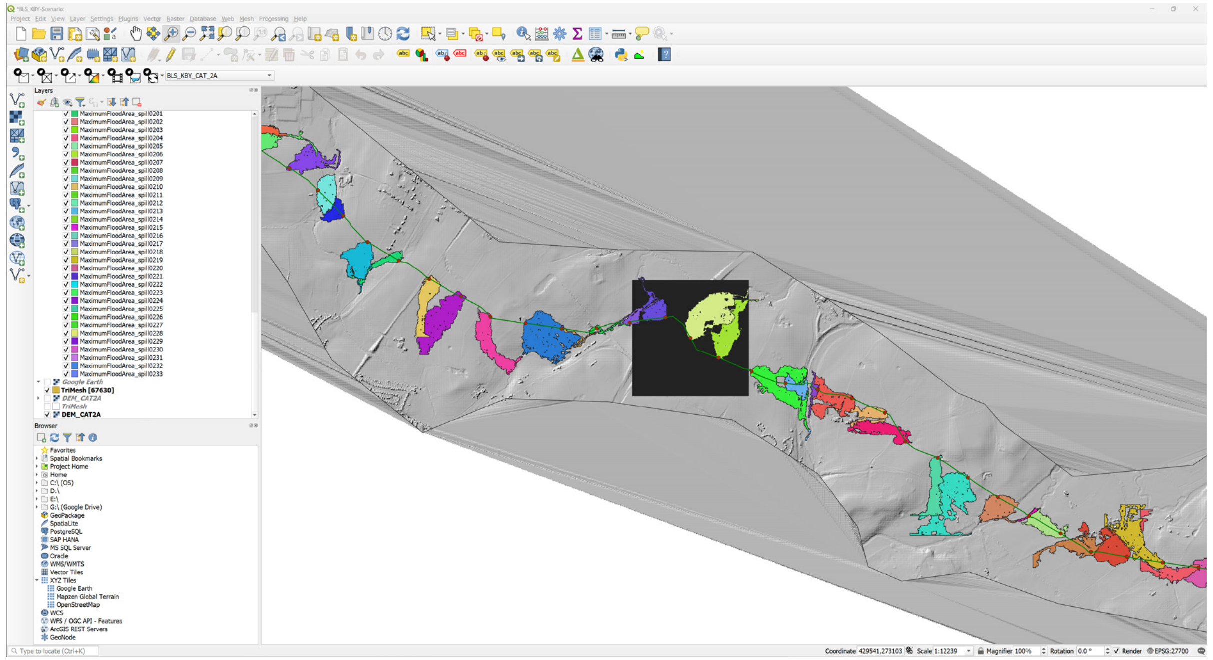
- Global mesh is not required

- If the oil impacts the mesh boundary for a given spill, the domain is automatically extended and a new run is performed

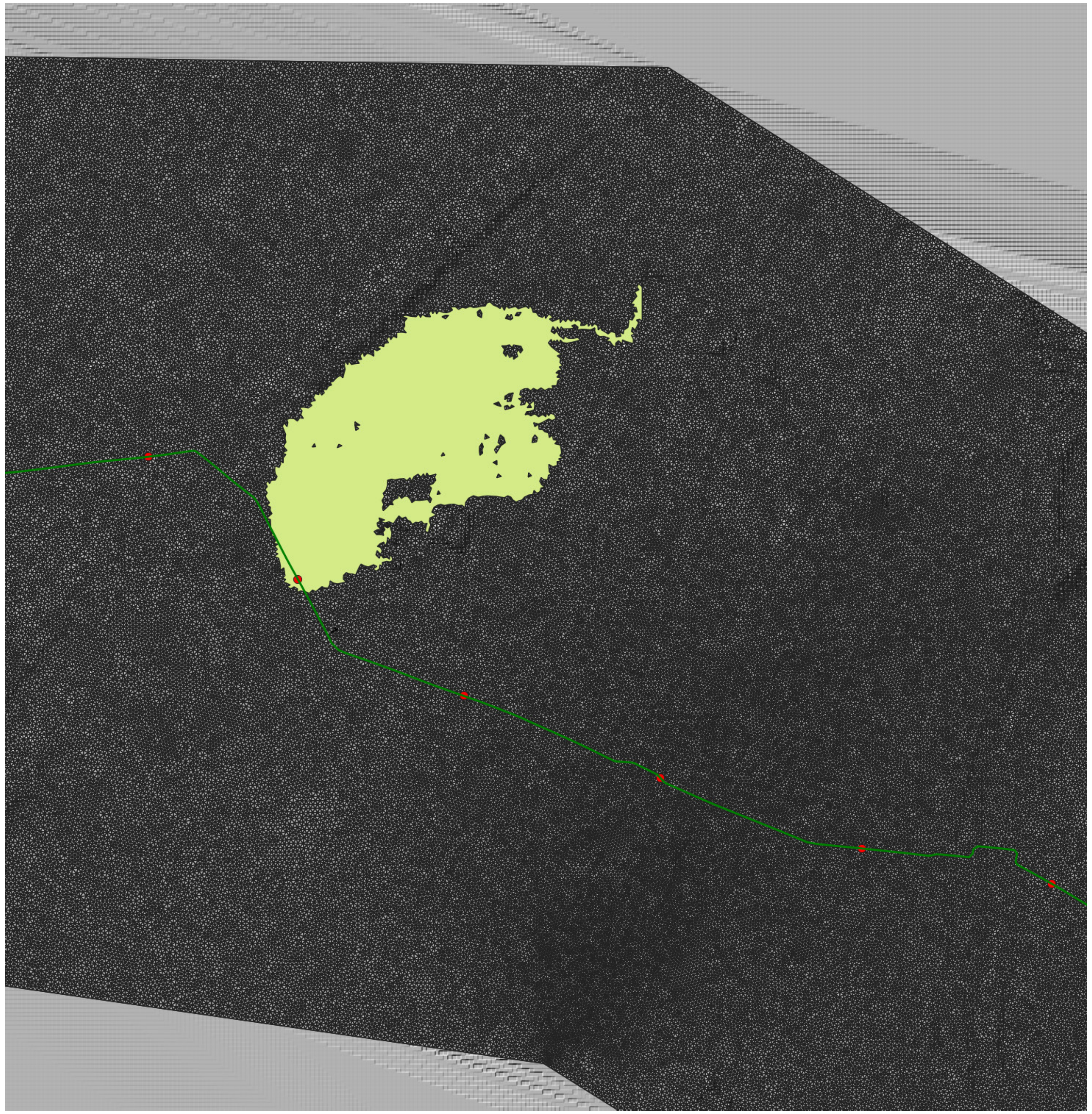
- The process finalizes when all spills are contained within their respective domains.

Advantages

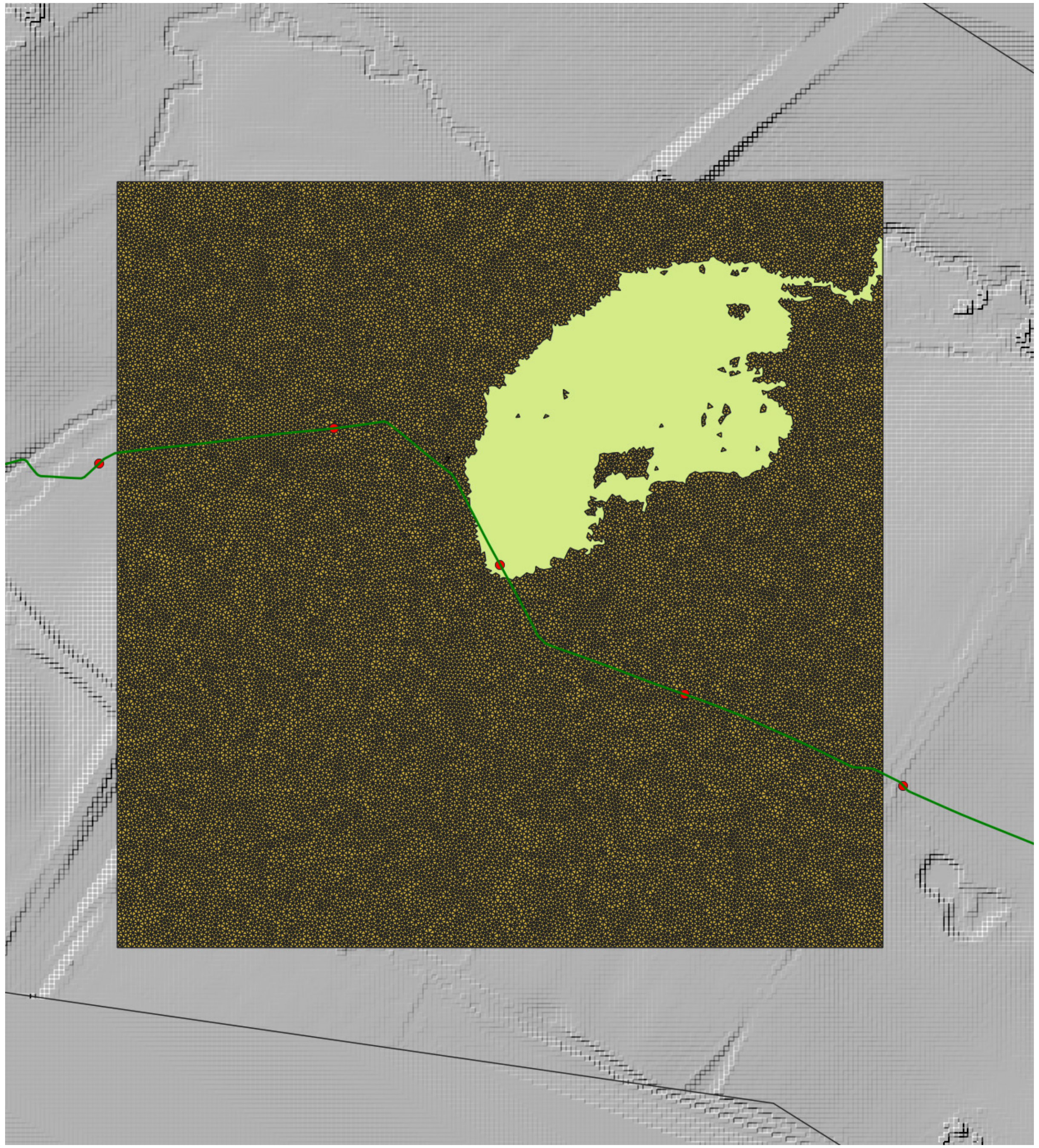
- Minimum user intervention
- Global mesh is not required
- Much smaller meshes
  - Increased local resolution
  - Shorter runtimes
  - Smaller file sizes
  - Shorter map generation times

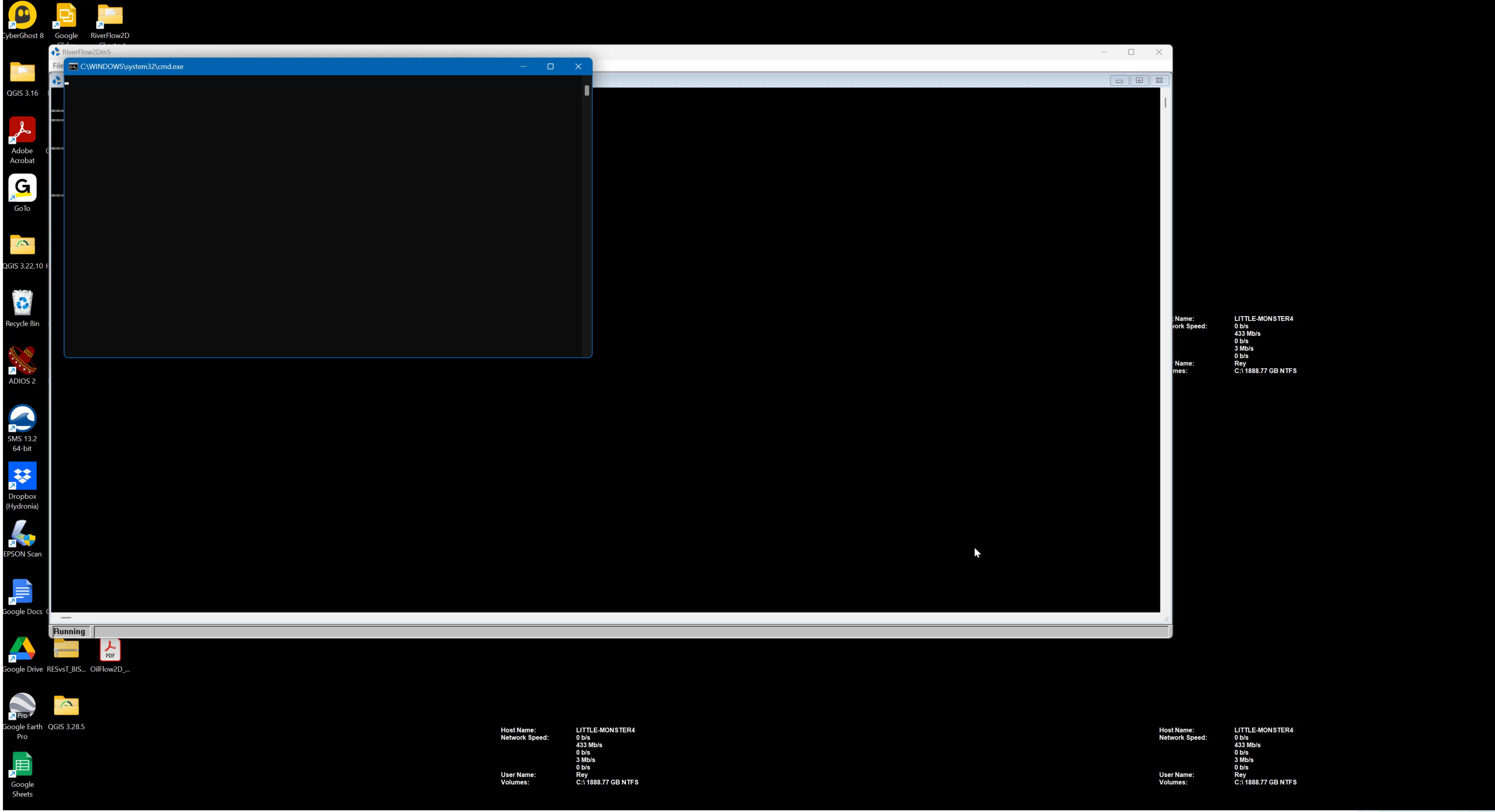


Global Mesh: 2,750,168 cells

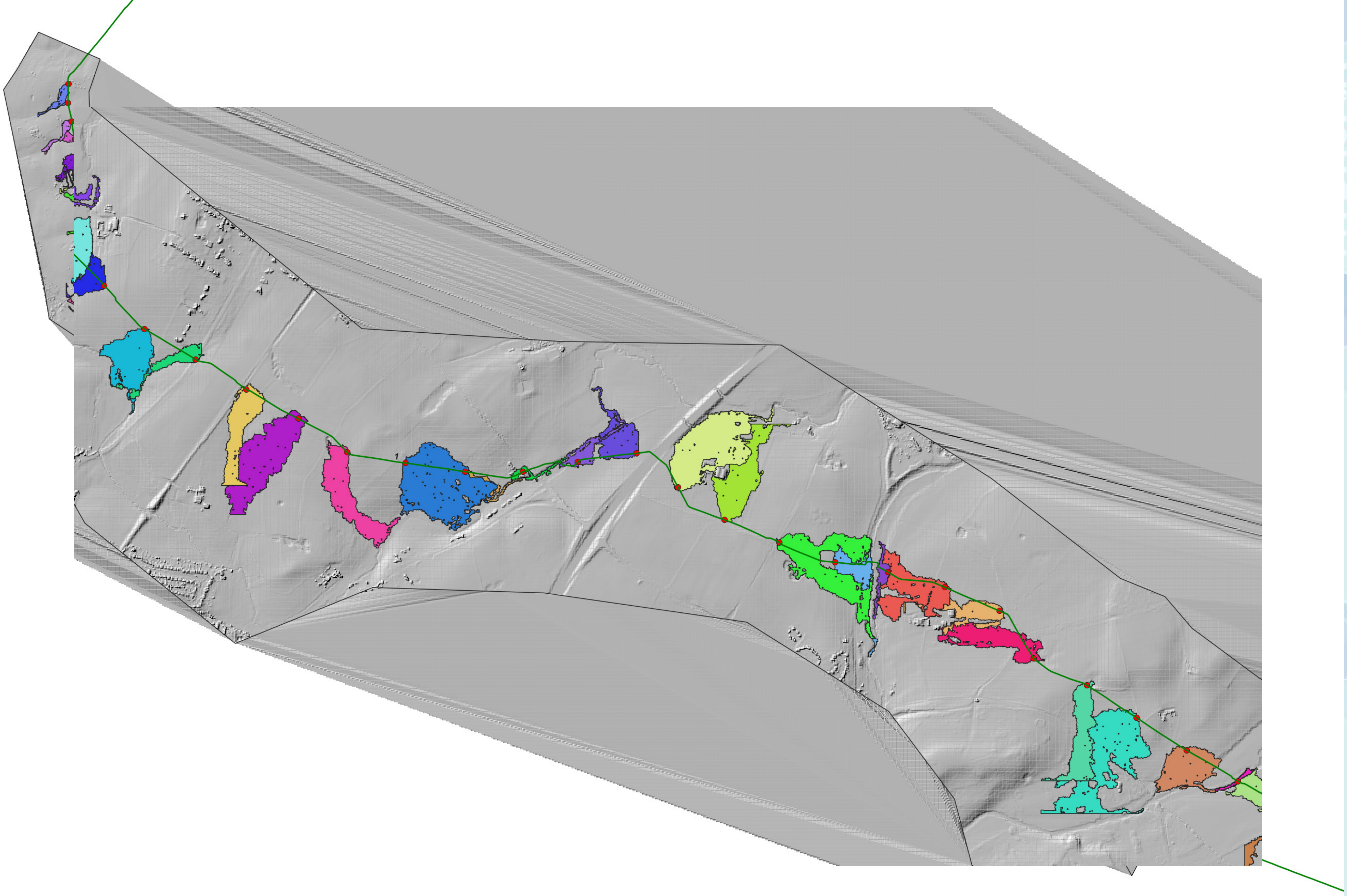


Local Mesh 67,630 cells





CyberGhost 8
Google Slides
RiverFlow2D Shortcut
QGIS 3.16
Adobe Acrobat
GoTo
QGIS 3.22.10
Recycle Bin
ADIOS 2
SMS 13.2 64-bit
Dropbox (Hydronia)
EPSON Scan
Google Docs
Google Drive
RESvsT_BIS...
OilFlow2D_...
Google Earth Pro
QGIS 3.28.5
Google Sheets
RiverFlow2Dm5
C:\WINDOWS\system32\cmd.exe
Running
Host Name: LITTLE-MONSTER4
Network Speed: 0 b/s
433 Mb/s
0 b/s
3 Mb/s
0 b/s
User Name: Rey
Volumes: C:\ 1888.77 GB NTFS

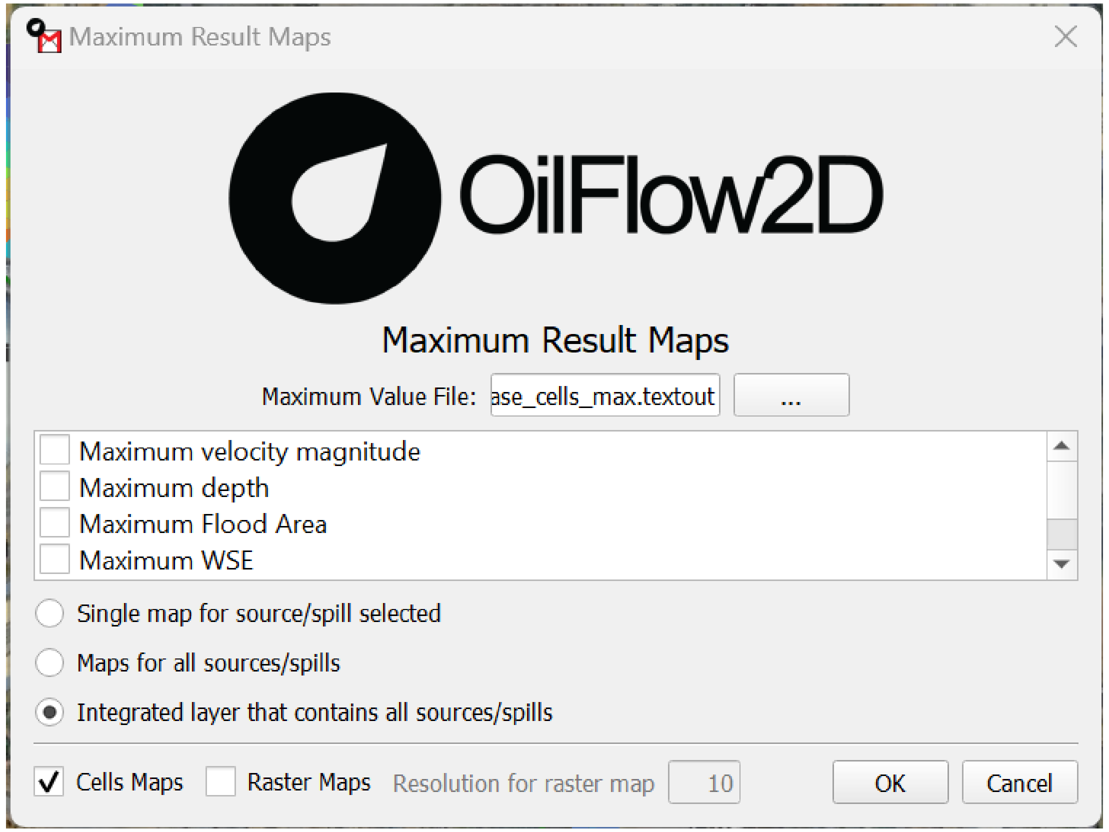


Optimized Algorithm Improvements

	Global Mesh	Local Meshes
Number of cells	2.7 M	67k
Run time (81 spills)	8 hours	1.5 hours
Project size	1.39 TB	36 GB
Map processing time	4 hours	3 minutes

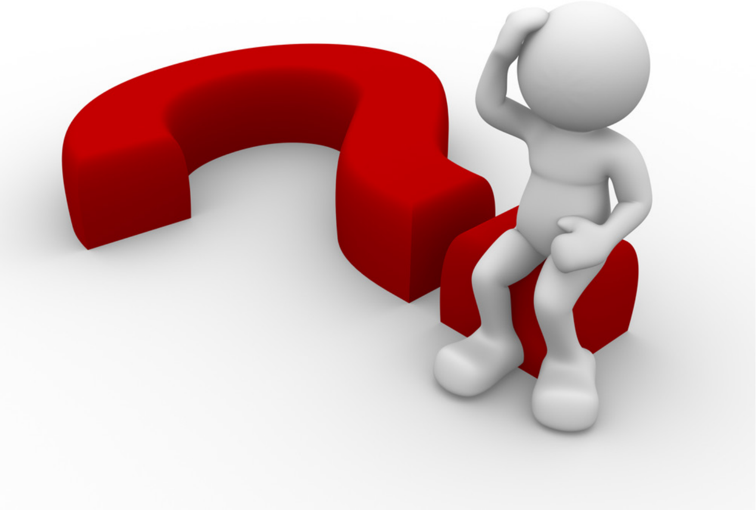
Maps/Shapefiles Generation Automation

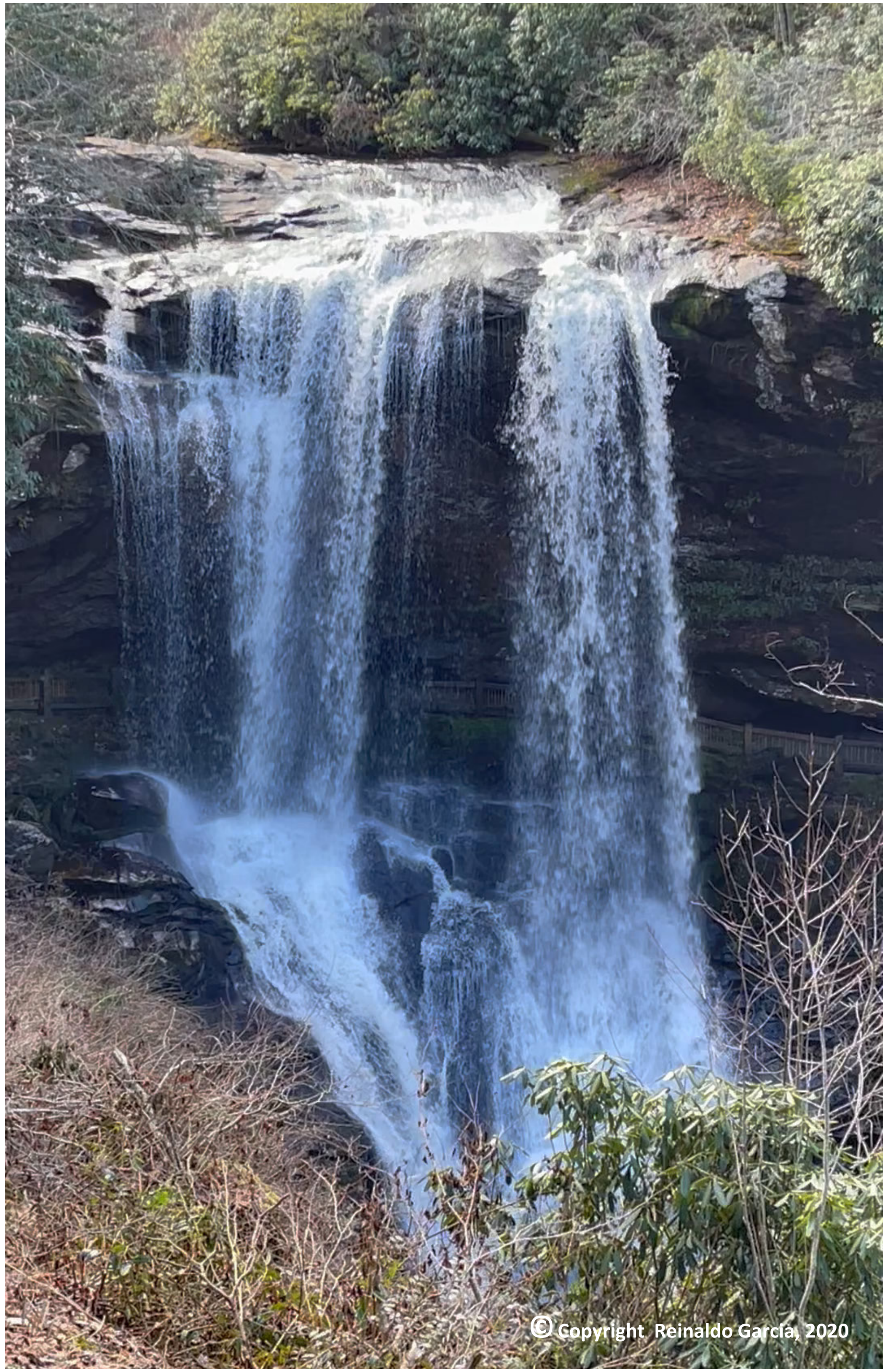
- All spills map with a single click



Final Thought

- ***Often you should stop programming for a moment and try to see the big picture***





rey@hydronia.com

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