Metropolitan Water Reclamation District of Greater Chicago

Welcome to the December Edition of the 2024 M&R Seminar Series

NOTES FOR SEMINAR ATTENDEES

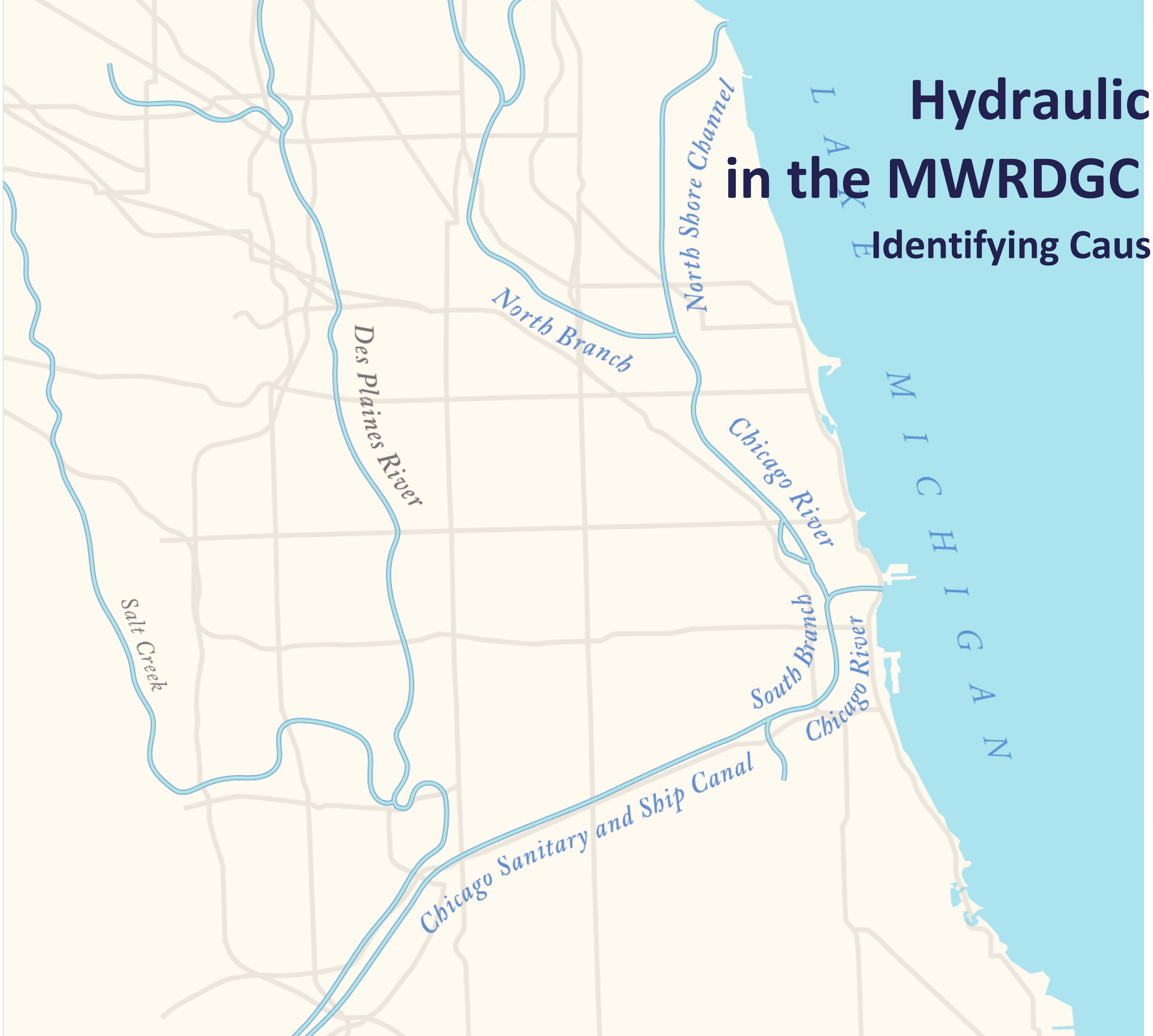
- Remote attendees’ microphones are set to be muted to minimize background noise. For attendees in the auditorium, please silence your phones.
- A question and answer (Q/A) session will follow the presentation.
- For remote attendees, please use “**Chat**” only to type questions for the presenter. For other issues, please email Pam to SlabyP@mwrd.org.
  For attendees in the auditorium, please raise your hand and wait for the microphone to ask a verbal question.
- The presentation slides will be posted on the MWRD website after the seminar.
- This seminar has been approved by the ISPE for one PDH and approved by the IEPA for one TCH. Certificates will be issued only to participants who attend the entire presentation.

Louis Storino, P.E., BCEE, Managing Civil Engineer
Metropolitan Water Reclamation District of Greater Chicago

Lou Storino is the Managing Civil Engineer in the Collection Facilities/TARP Section of the Engineering Department at MWRD. He has been with the MWRD for over 26 years and had the opportunity to work on various projects including pumping station and sewer rehabilitation, design of tunnels and reservoirs, sidestream deammonification, combined heat and power systems, energy neutrality planning and stormwater master planning. Mr. Storino is a licensed professional engineer in the State of Illinois and a Board Certified Environmental Engineer. In his free time, he enjoys volunteering in his community and travelling with his family.

Mason Throneburg, CEO
Confluency LLC

Mason Throneburg is a hydraulic modeler, project manager, and software developer with a passion for applying advanced data analysis techniques to help understand complex infrastructure operational and planning decisions. He is extremely experienced with the hydraulic modeling of large urban collection systems and was a key developer of both the Chicago Trunk Sewer model and Chicago All Pipe model, as well as a very experienced user of the District's CS-TARP model. In 2019, he co-founded Confluency, which has developed a cloud-based simulation and analytics platform that enables continuous insight into the performance of ever-changing and evolving water and wastewater networks. In his free time, he enjoys reading, biking, and exploring the Chicago outdoors with his family.



Hydraulic Analysis of Geyser Events in the MWRDGC Mainstream TARP System

Identifying Causes and Exploring Mitigation Measures

Mason Throneburg, Confluency

Lou Storino, P.E., BCEE, MWRDGC

CONFLUENCY

Phase I Tunnels:

Upper Des Plaines
6.6 miles (10.6 km)
Storage: 70 MG (265 ML)

Des Plaines
25.6 miles (41.2 km)
Storage: 405 MG (1.5 BL)

Mainstream
40.5 miles (65.2 km)
Storage: 1,200 MG (4.5 BL)

Calumet
36.7 miles (59.1 km)
Storage: 630 MG (2.3 BL)

Phase 2 Reservoirs

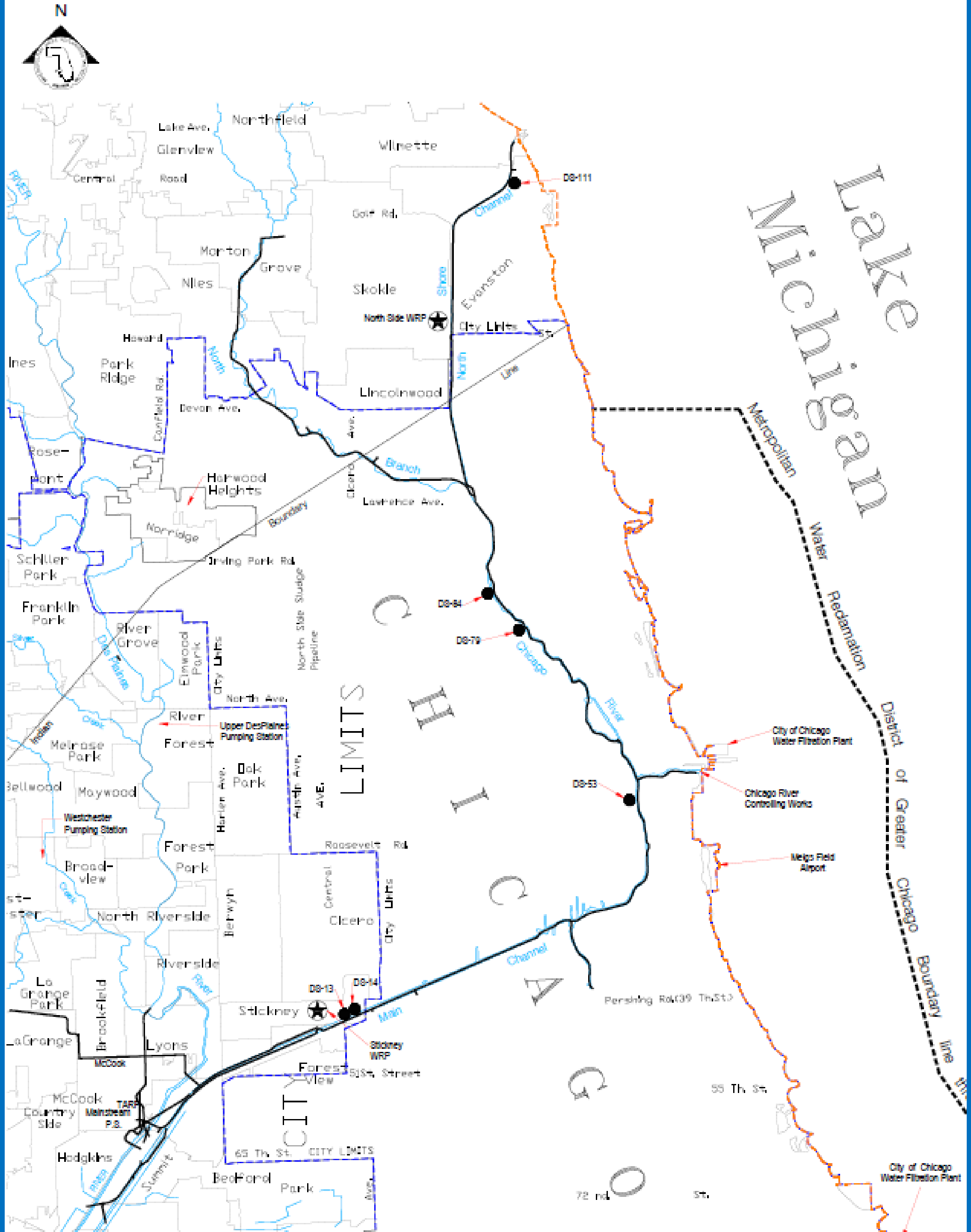
Majewski: Storage: 350 MG (1,324 ML)

Thornton: Storage: 7.9 BG (29.9 BL)

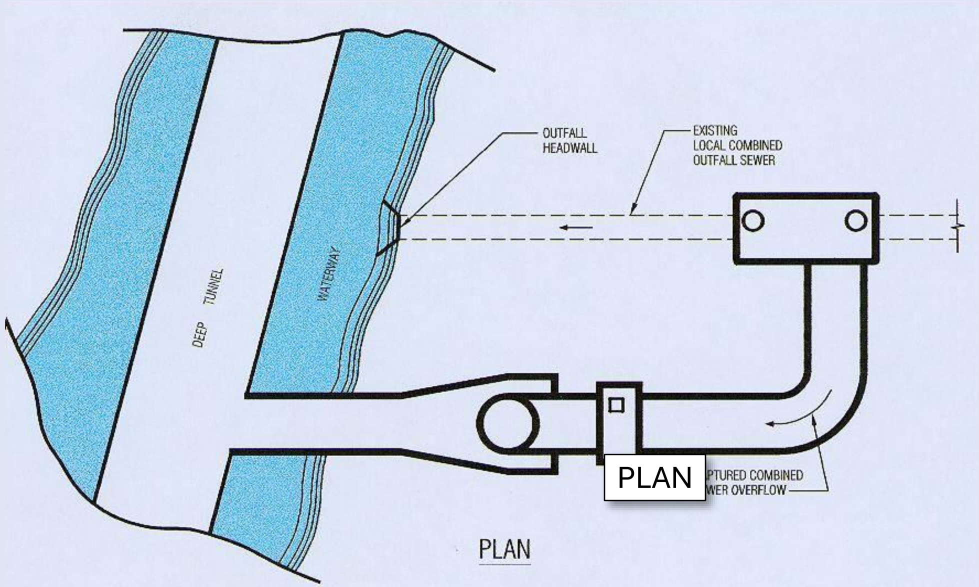
McCook: Storage: 10 BG (38 BL)

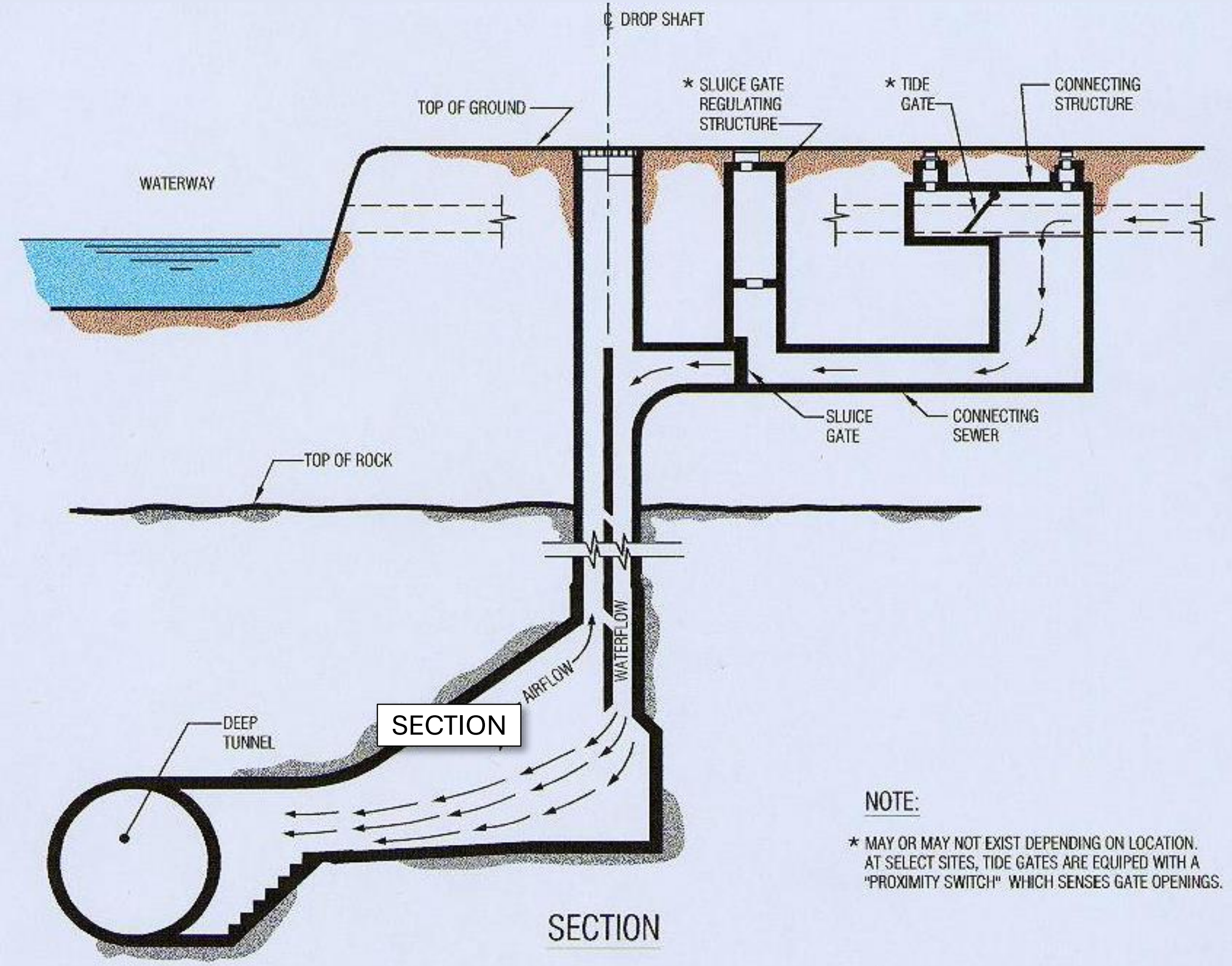
Location Map

- DSM-13/14
- DSM-53
- DSM-79
- DSM-84
- DSM-111



Typical Drop Shaft Plan - Profile


PLAN


SECTION

NOTE:

* MAY OR MAY NOT EXIST DEPENDING ON LOCATION. AT SELECT SITES, TIDE GATES ARE EQUIPED WITH A "PROXIMITY SWITCH" WHICH SENSES GATE OPENINGS.

DSM-79 – 9/11/22

Diversey and Logan Boulevard

Montrose and Harding

Photo Source: Block Club Chicago

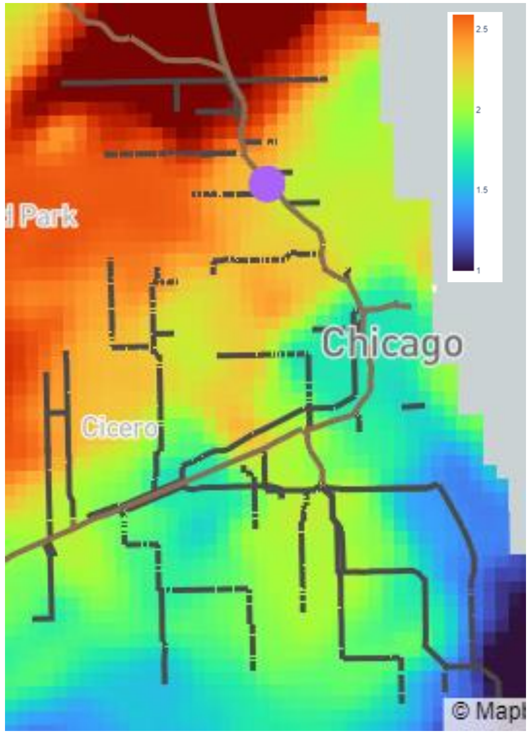
DSM-84

5/3/22

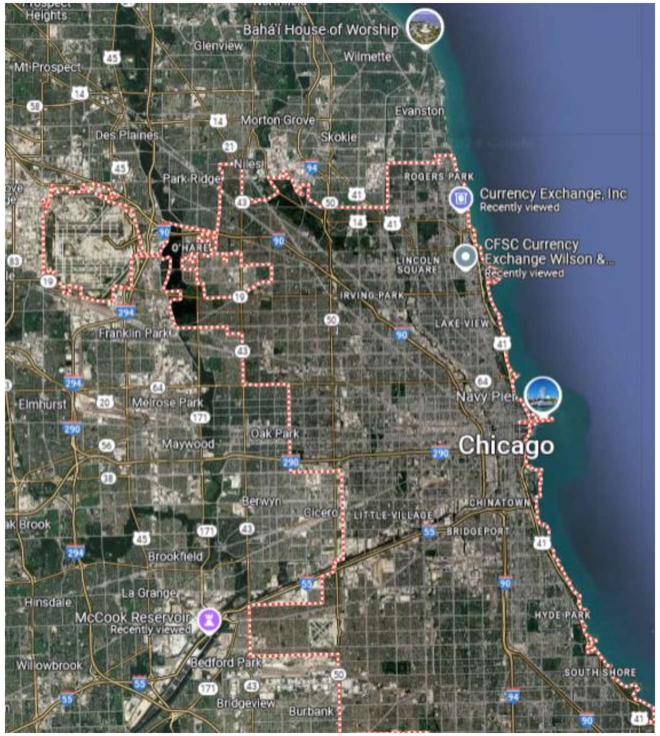
Geysers Causes are Complex

Multi-phase, Multi-scale Phenomena

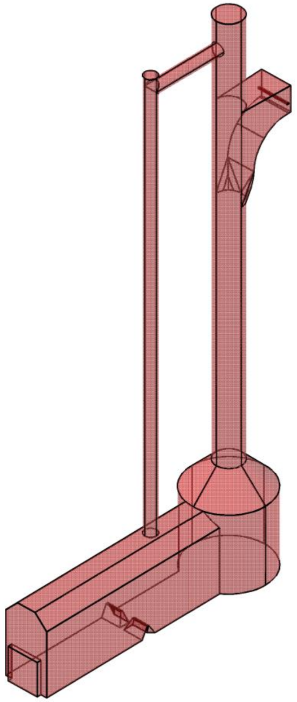
Rainfall Variability



System Scale



Local Factors



Mixed Phase

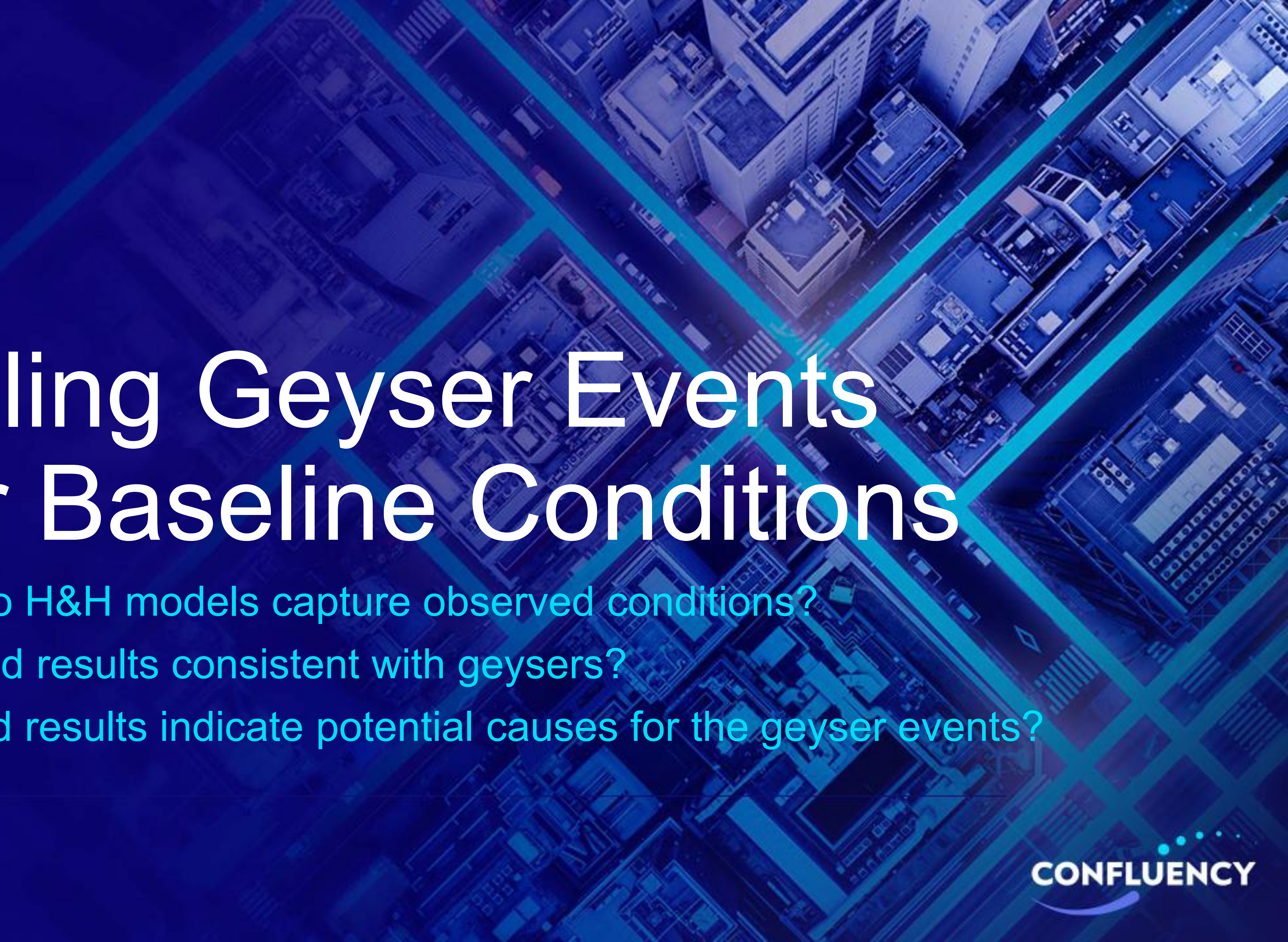
Siberia. From Wright et al, 2009

Hydraulic Geysers 101 – Cause and Factors

- What we know
  - Hydraulic grade line need NOT reach ground level
  - Air-water interaction is a critical
  - The volume of air is a key factor
  - High rates of inflow contribute to geyser risk
  - Hydraulic conditions at the time of tunnel pressurization is critical
- Less clear
  - Geyser occurrence can occur for an extended duration, with a periodicity to the event
  - Specific conditions required to (1) trap (2) pressurize (3) release air
  - Lab studies generally fail to recreate many of the key factors, partly due to scale issues

Motivating Questions

- How well do we understand the extent of geyser occurrence?
  - Is an event where no geyser is reported really a non-geyser event?
- Can we reliably simulate hydraulic conditions consistent with geysers?
- Can we distinguish between geyser and non-geyser events using models? What type of models are required?
- Can we predict the occurrence of a geyser for a given storm? What about specific locations?
- What actions can reduce/eliminate geyser risk?



Modeling Geyser Events under Baseline Conditions

- How well do H&H models capture observed conditions?
- Are modeled results consistent with geysers?
- Do modeled results indicate potential causes for the geyser events?

Hydrologic and Hydraulic Response of the MWRDGC Deep Tunnel System

Hydrology & Local System

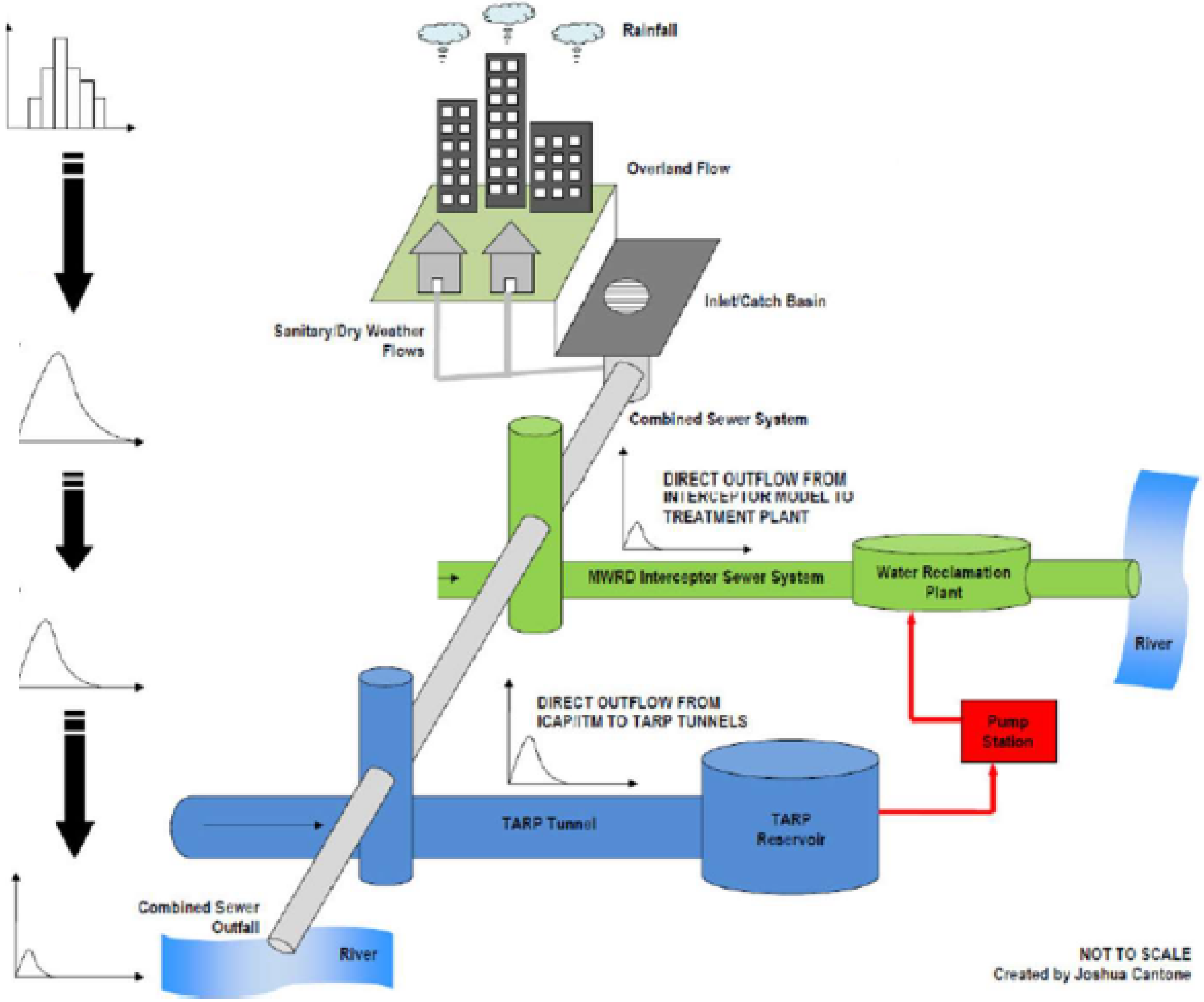
- IUHM (Suburban Flows)
- Chicago All Pipe Model, ie CAPM (City Flows)

MWRD System Hydraulics

- CS-TARP
- Integrated CS-TARP (includes City flows from Chicago Trunk Sewer Model circa 2017)

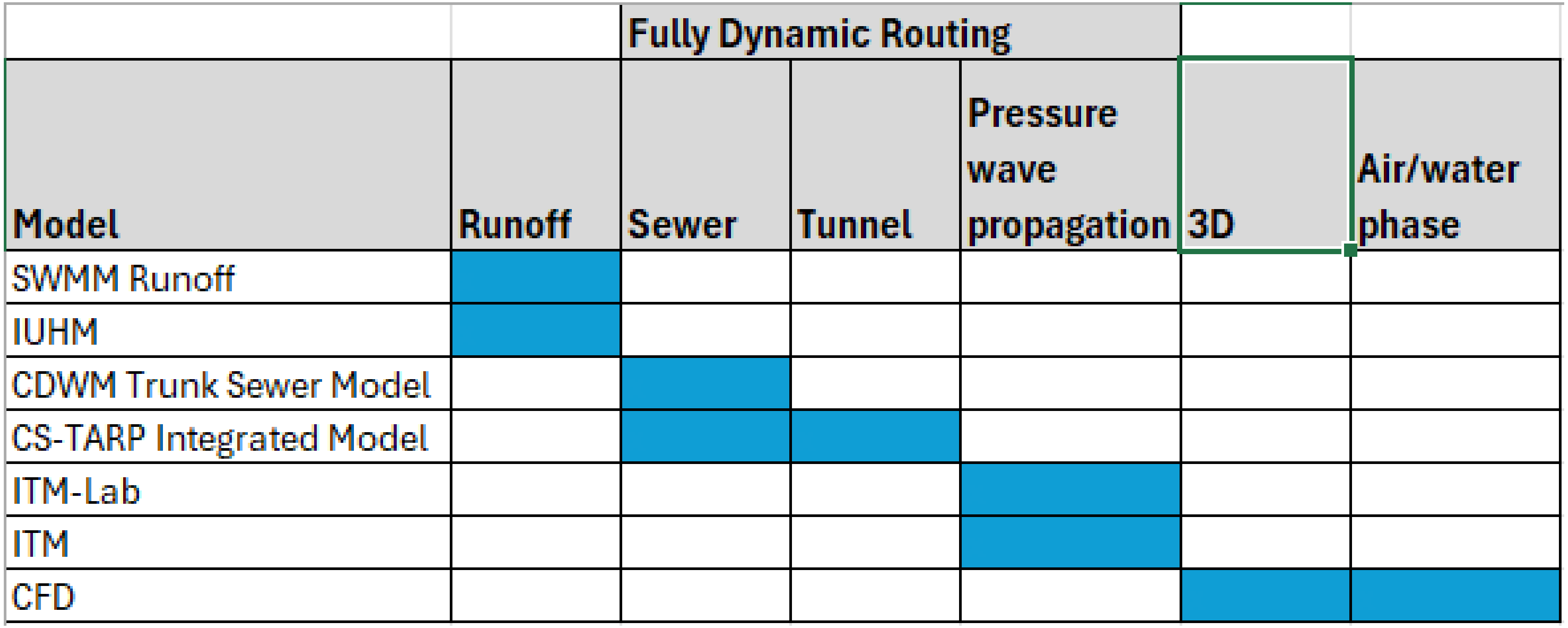
MWRD Tunnel Transients

- ITM (codebase last updated 2016, geometry last updated 2012)



Modeling TARP System Hydraulics

Multiple modeling platforms required to represent distinct hydrologic and hydraulic phenomena



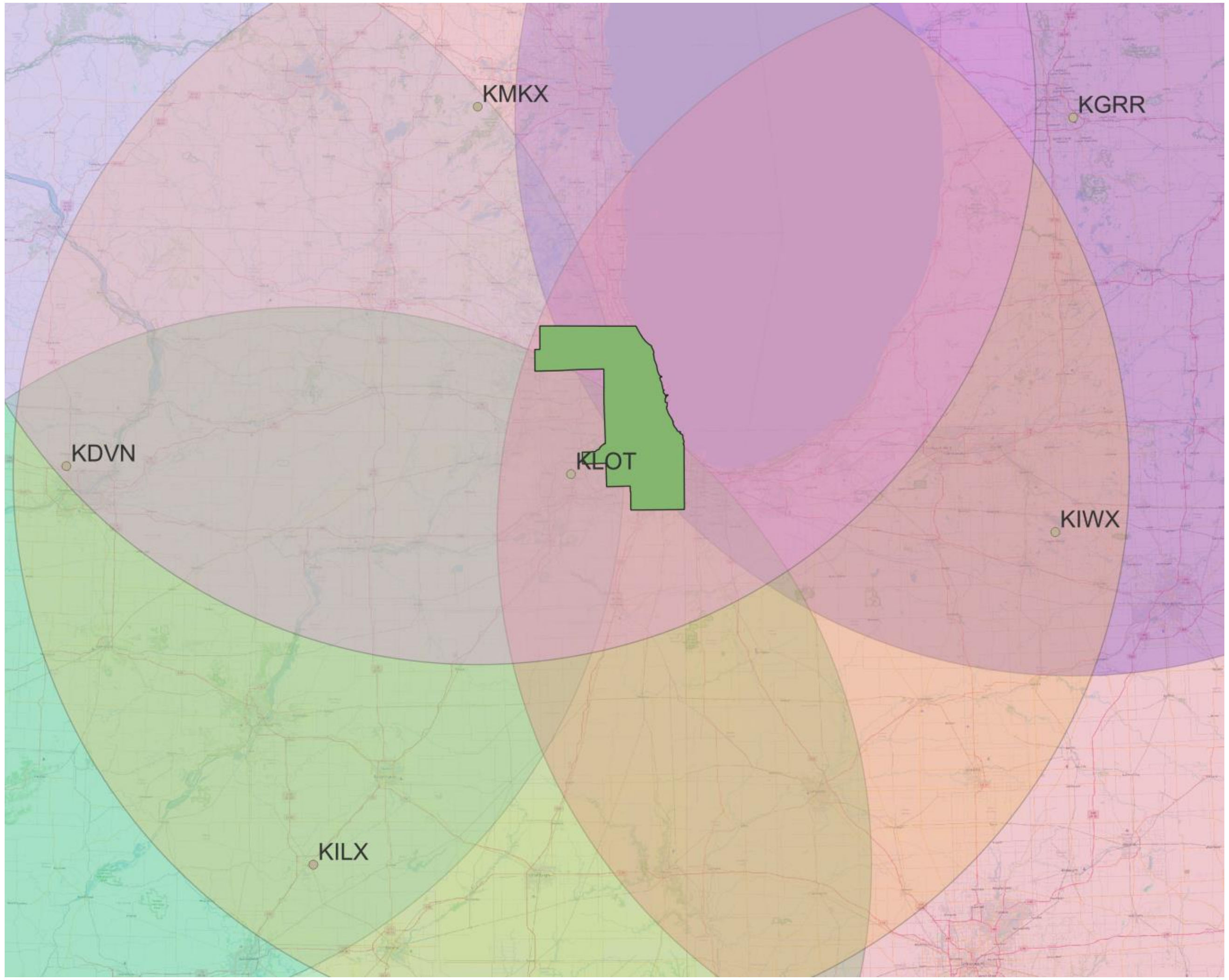
		Fully Dynamic Routing				
Model	**Runoff**	**Sewer**	**Tunnel**	**Pressure wave propagation**	**3D**	**Air/water phase**
SWMM Runoff	🟦					
IUHM	🟦					
CDWM Trunk Sewer Model		🟦				
CS-TARP Integrated Model		🟦	🟦			
ITM-Lab				🟦		
ITM				🟦		
CFD					🟦	🟦

Step 1: Estimating Rainfall

Radar Rainfall

- 6 NWS NEXRAD radars cover all or a portion of the Chicago Metropolitan Area:
  - KLOT* – ROMEOVILLE, IL
  - KMKX* - DOUSMAN, WI
  - KIWX* - NORTH WEBSTER, IN
  - KILX - LINCOLN, IL
  - KDVN - DAVENPORT, IA
  - KGRR* - GRAND RAPIDS, MI

*Covers the entire MSDP sewershed area

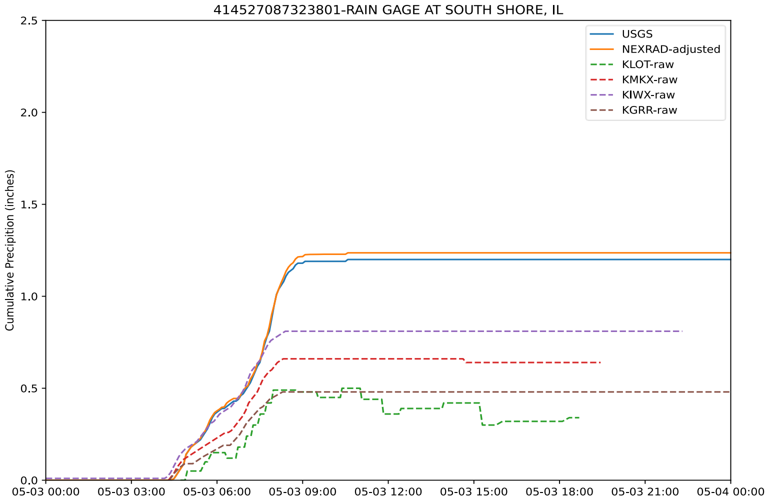


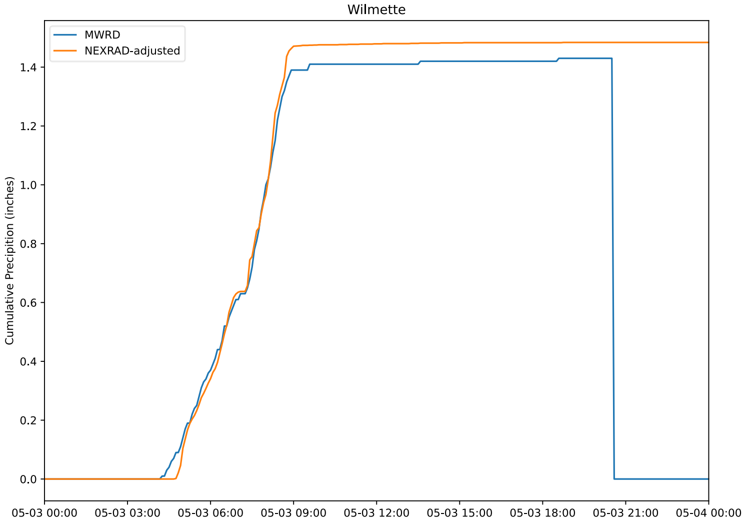
Raingage Correction of Radar Readings

- NEXRAD data needs to be corrected using raingages
- Correction is different for each radar and can vary spatially and temporally
- A triangulated “correction” surface is created for a sub-set of available ground gages
    - A correction factor is developed at each raingage for each radar at each time step:

$$cf = \frac{P_{cum.\,NEXRAD}}{P_{cum.\,gage}}$$

    - Interpolated *cf* is applied at each radar “pixel” at each timestep for each NEXRAD radar
    - Overlapping radar coverages are spatially averaged using a weighting factor – greater weights are given to radar bins with values of *cf* closer to 1 (ie., NEXRAD and raingages are in closer agreement)
- Correction factor developed using USGS precipitation gages only
- NWS and MWRD precipitation gages are used to validate the corrected data



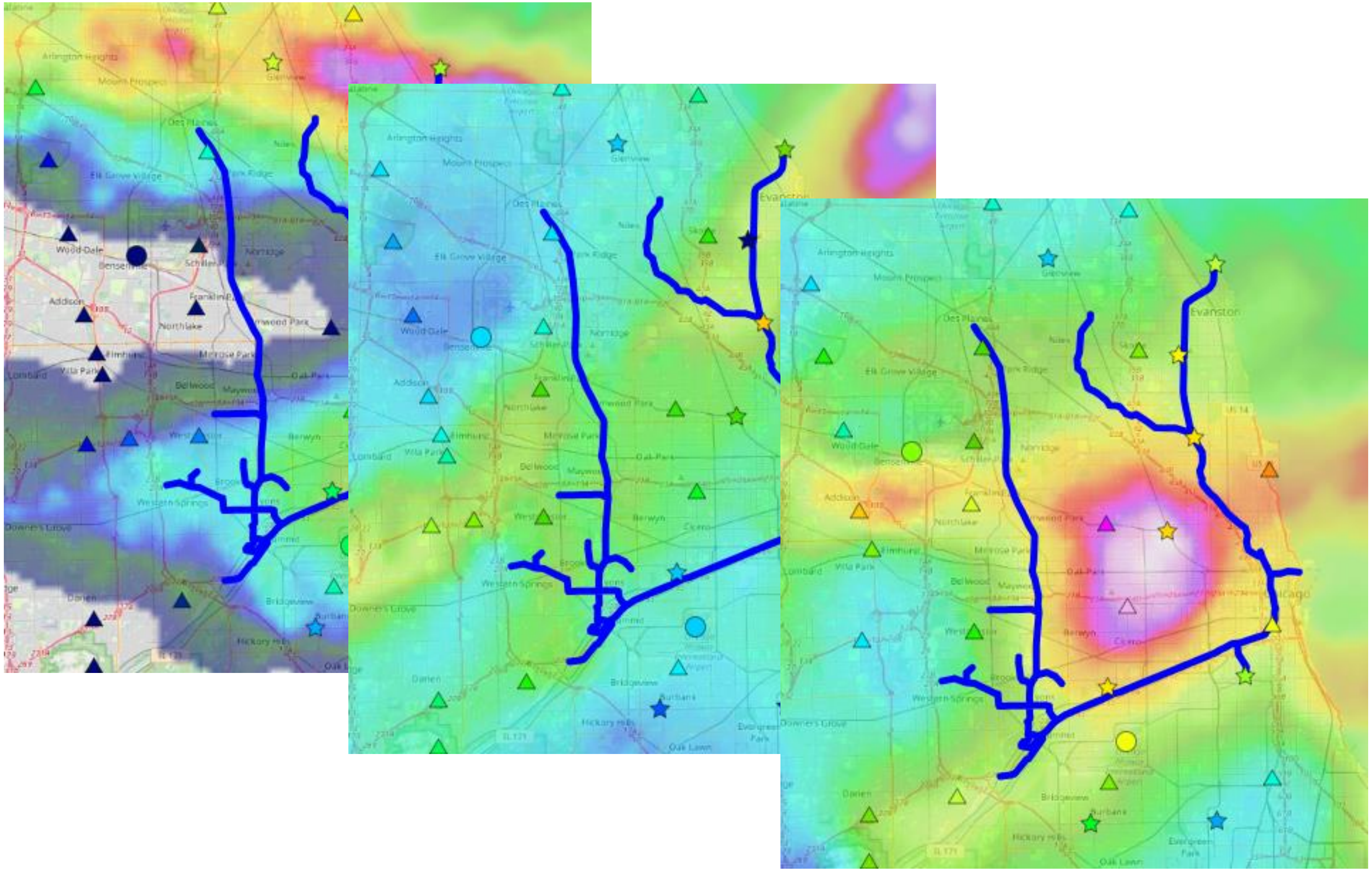


Generally good agreement

▲ USGS

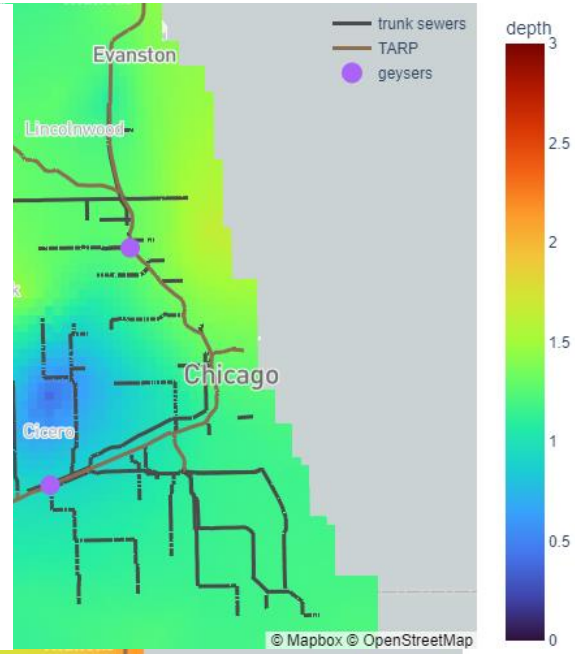
● MWRD

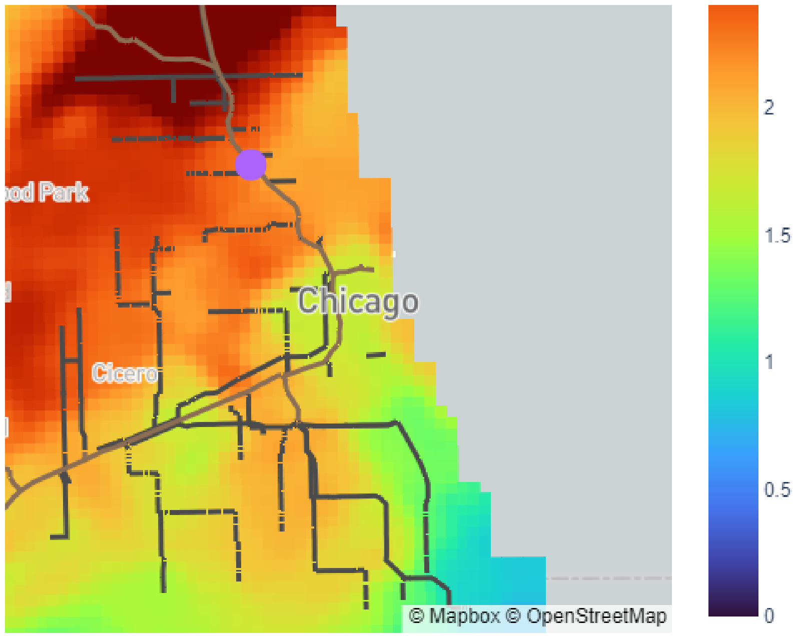
★ NWS

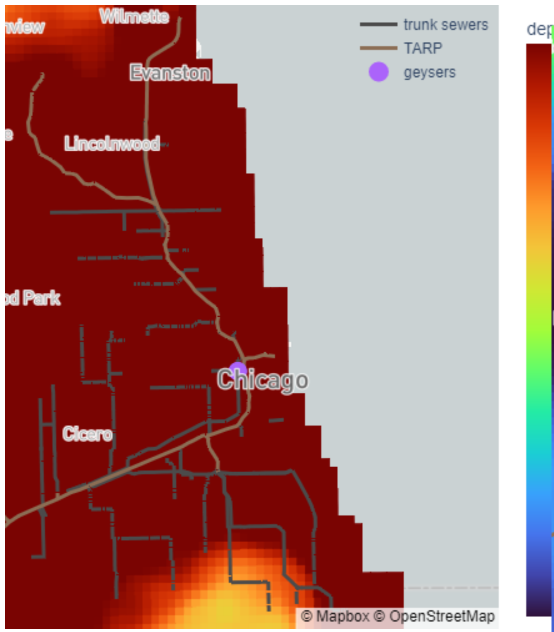


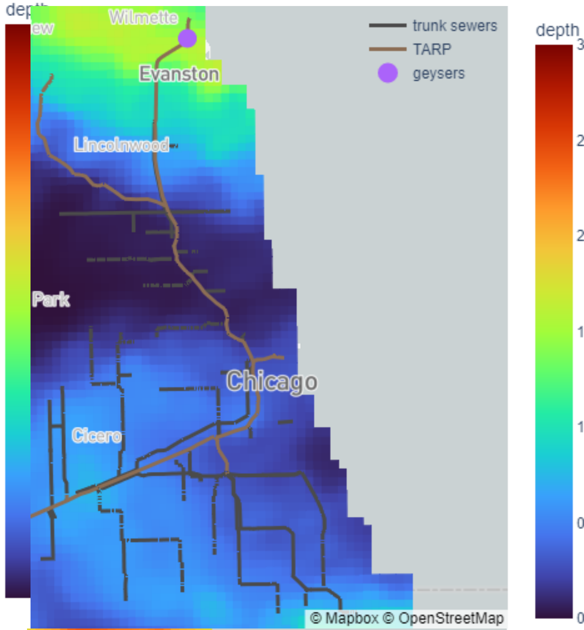
5/3/2022 (1.5in) 9/11/2022 (2.2in) 7/2/2023 (5.1in) 7/27/2023 (1.39)

Consistent Color Scale

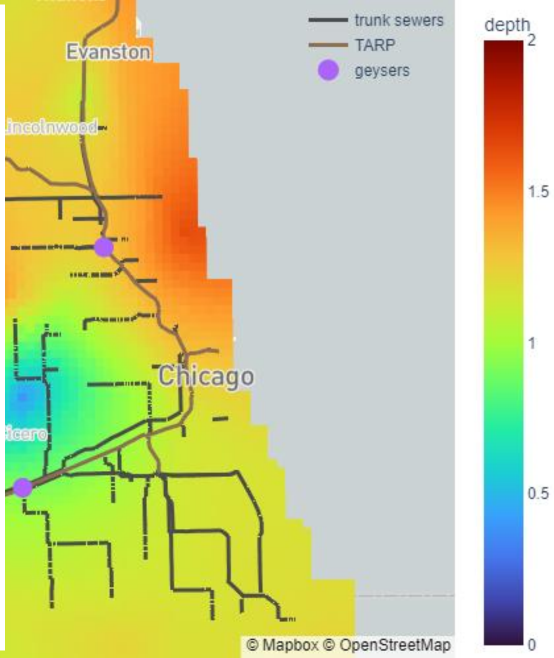


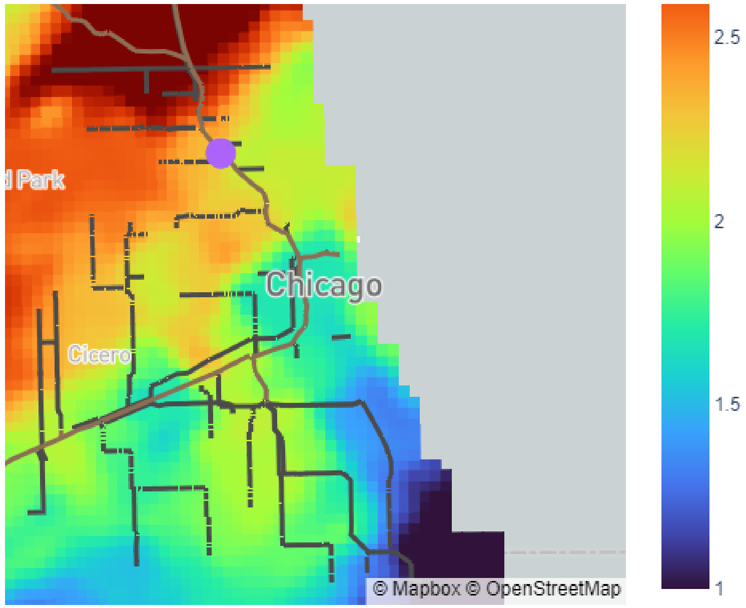


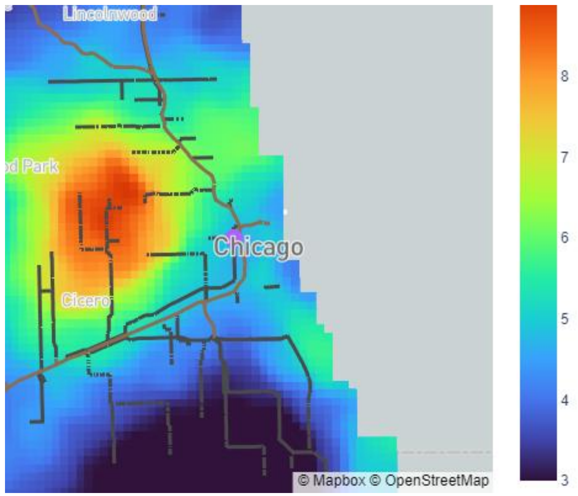


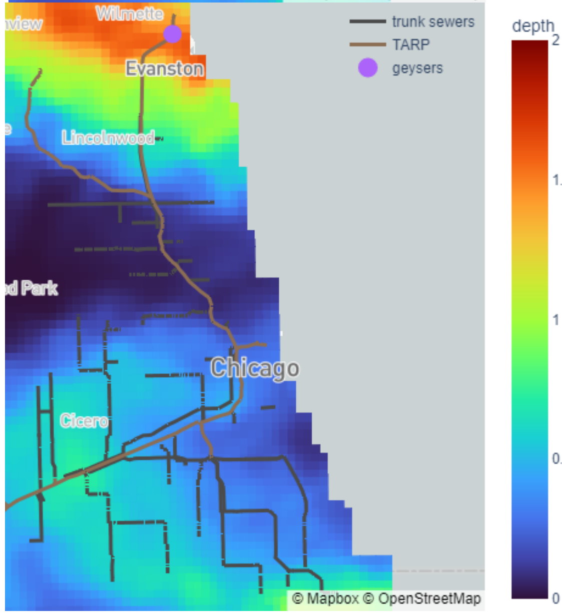


Storm-Specific Color Scale



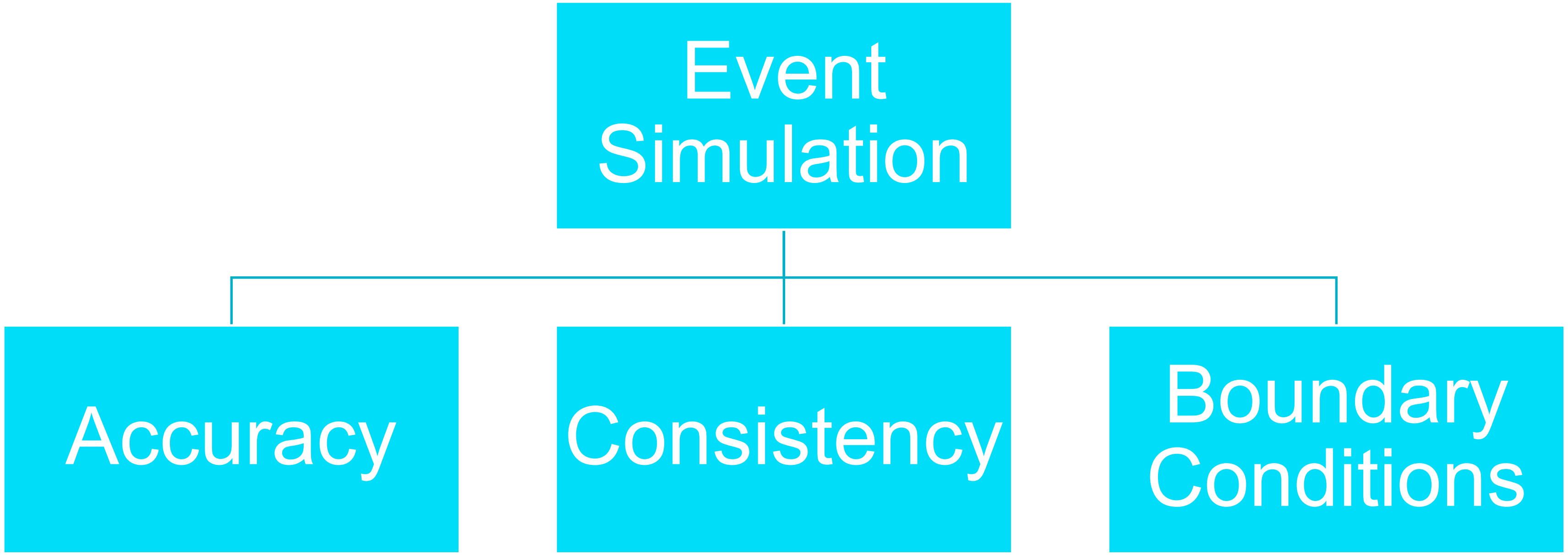






1D System Scale Hydraulic Analysis

Capturing macro-scale conditions of geyser events



Event Simulation

Accuracy

Consistency

Boundary Conditions

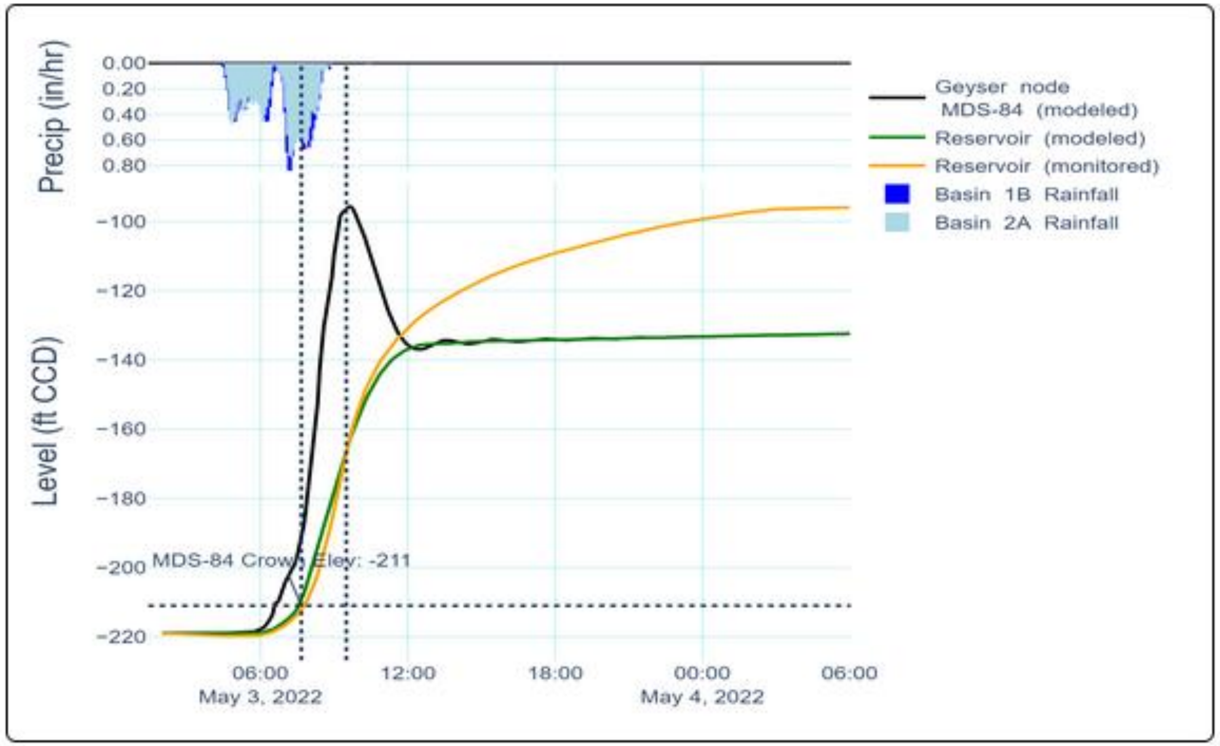
Modeled results consistent with observed system response?

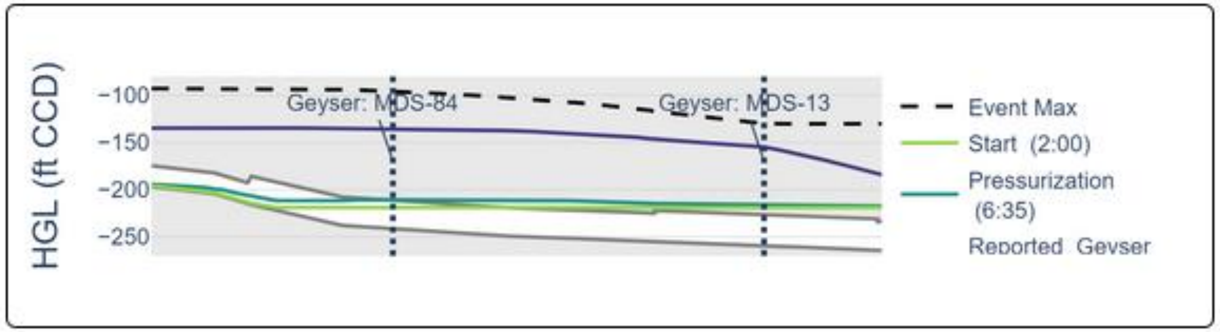
Modeled results consistent with conditions that could cause geysers

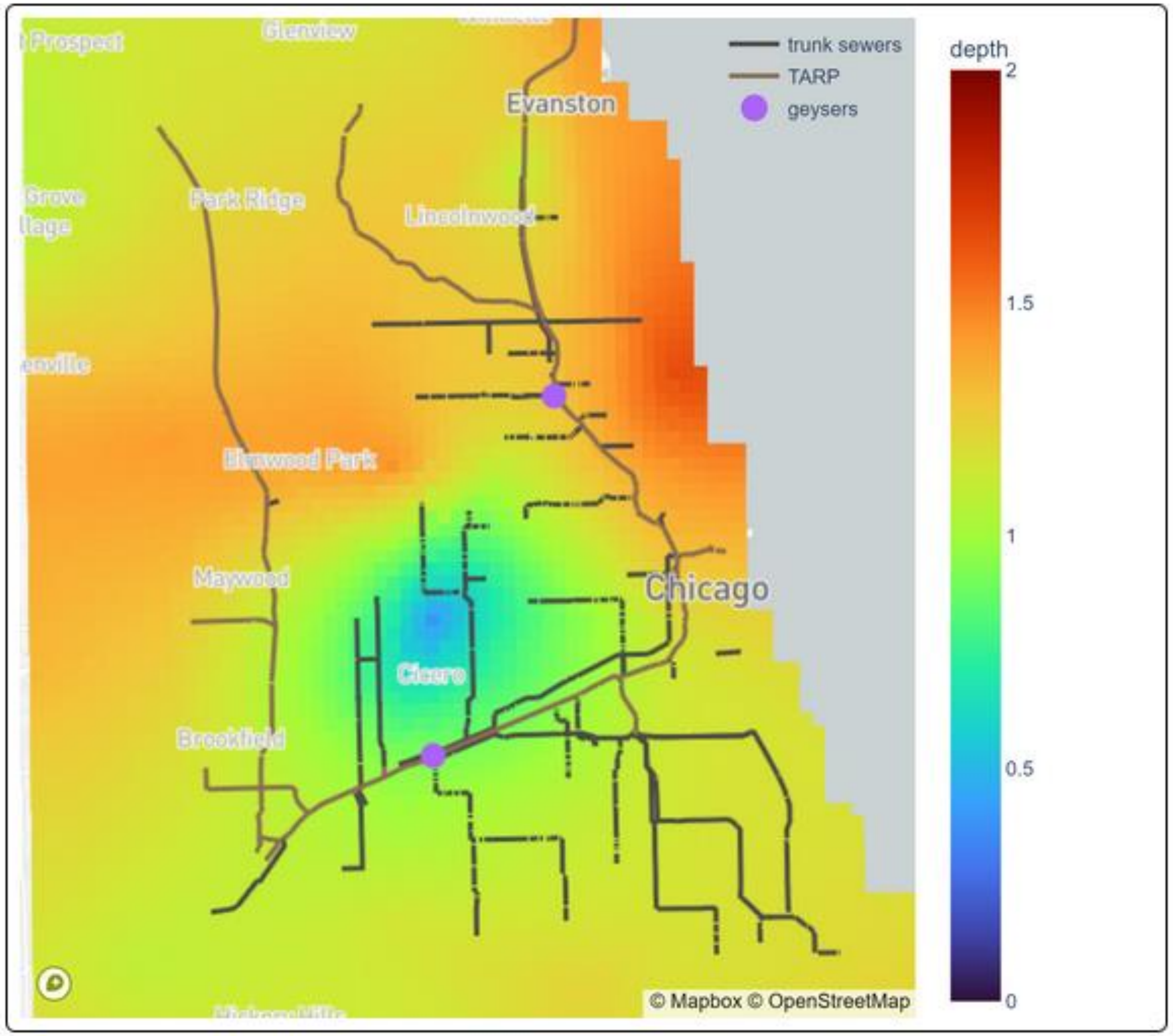
Inputs for ITM and/or CFD analysis for more complex simulation

Date: 5/3/2022
Average Rainfall Depth: 1.5 inches
Geyser Dropshaft: MDS-13, MDS-84

Storm Description: Moderate rainfall evently distributed throughout service area
Initial Conditions: Reservoir roughly 25% full
Tunnel Response: Rapid filling and surcharging at the time of reported geyser



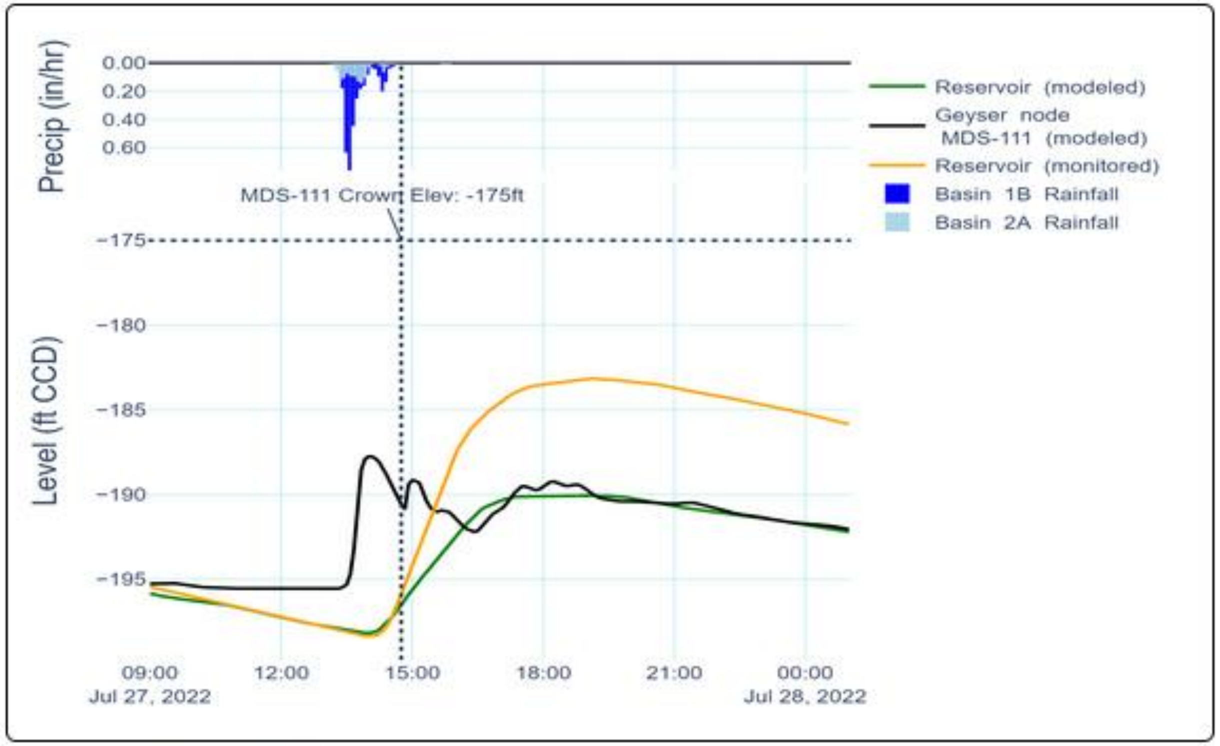


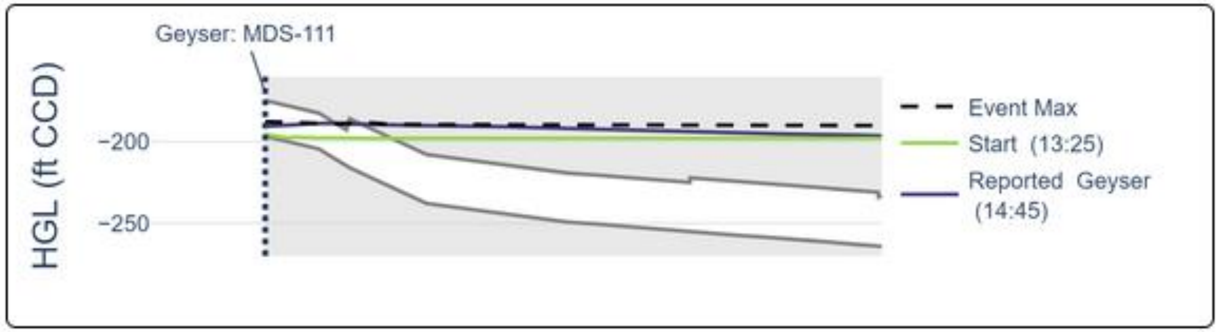


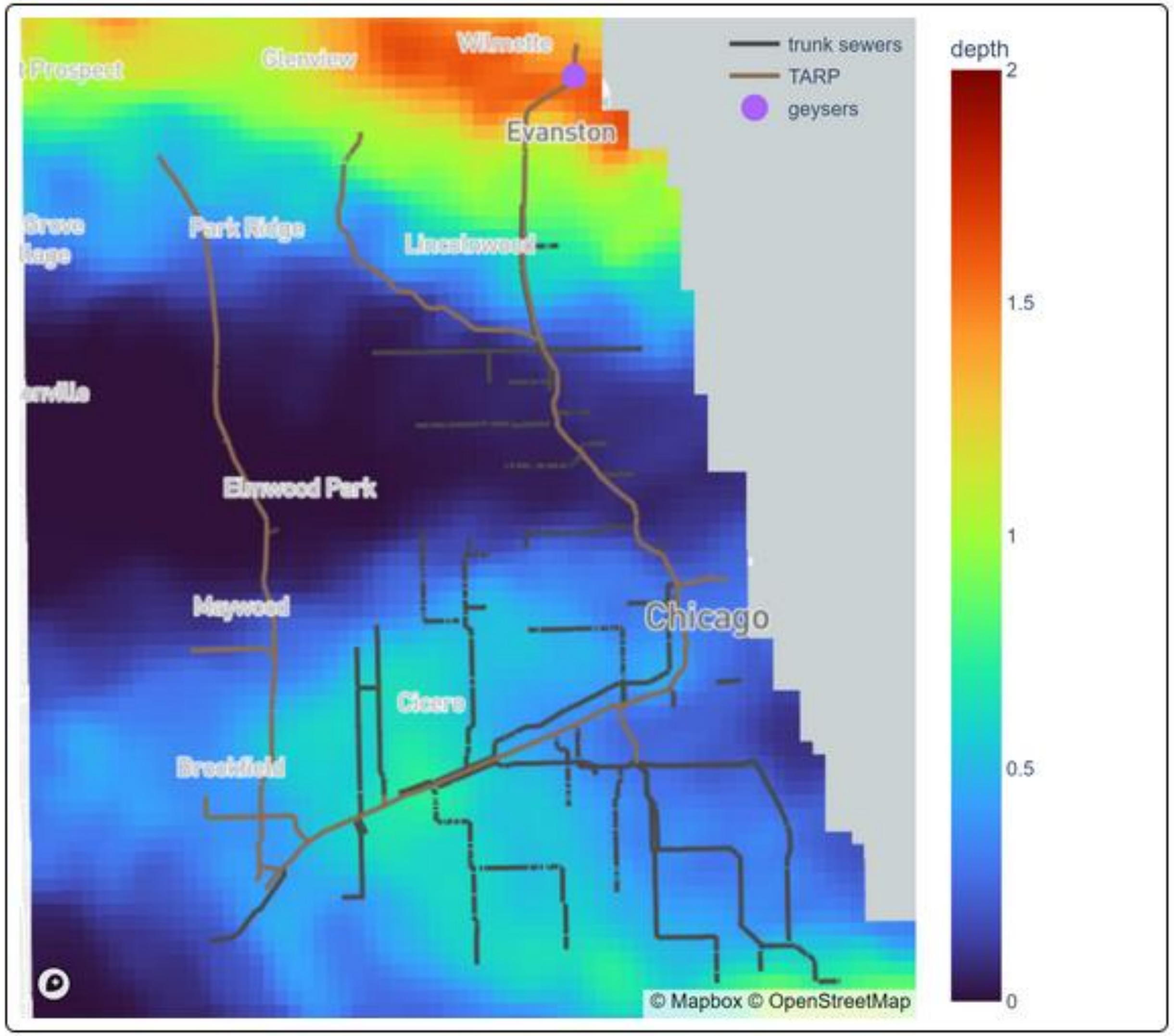
Printed: 11/22/2024

Geyser Date: 7/27/2022
Average Rainfall Depth: 1.39 inches
Geyser Dropshaft: MDS-111

Storm Description: Higher intensity localized at upstream end of MSDP tunnel
Initial Conditions: McCook Reservoir 1/3 full; tunnel 1/3 full at location of geyser
Tunnel Response: Rapid inflow, but tunnel does not fill at geyser location



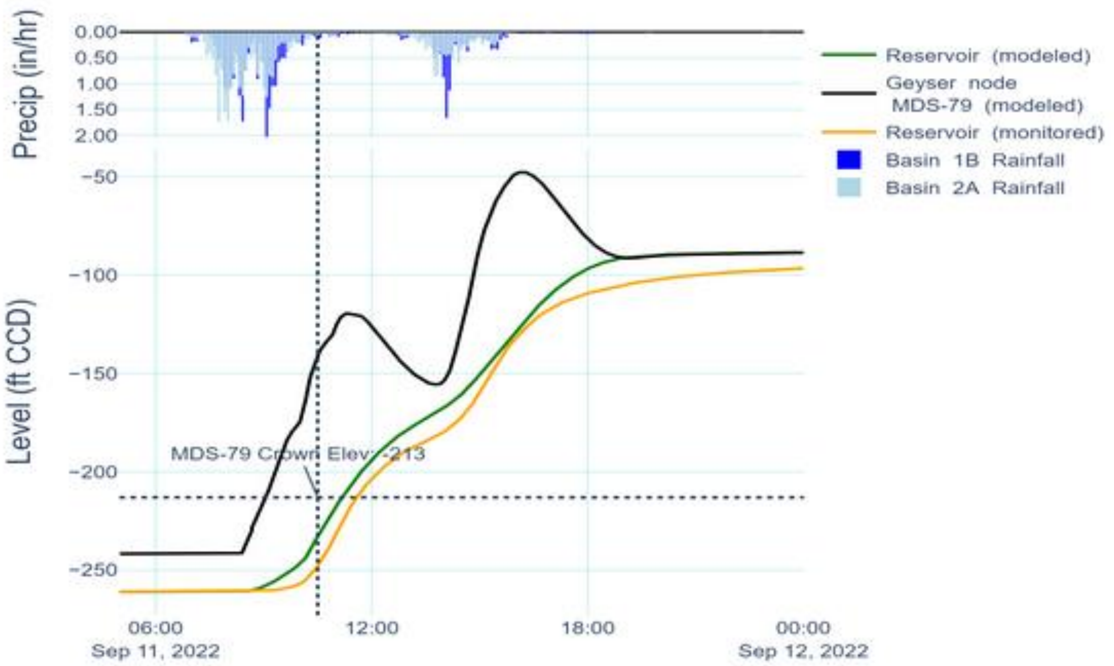


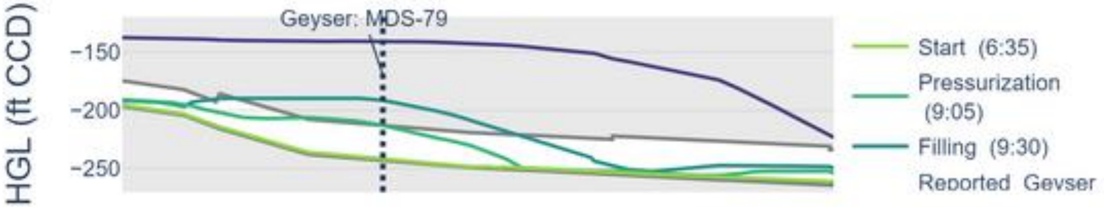


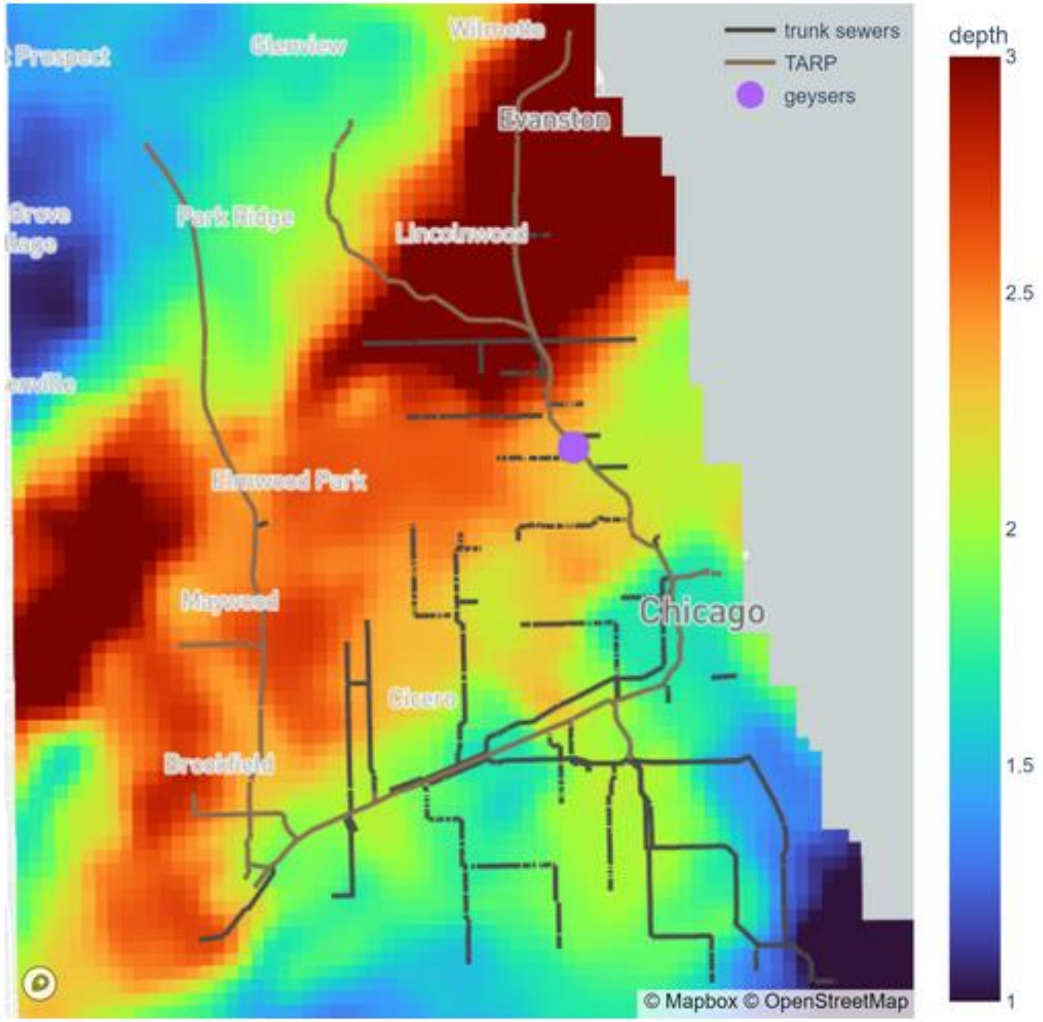
Printed: 11/22/2024

Geyser Date: 9/11/2022
Average Rainfall Depth: 2.2 inches
Geyser Dropshaft: MDS-79

Storm Description: Highly varied with max. accumulation at upstream extents of MSDP tunnel
Initial Conditions: Reservoir and tunnel relatively empty
Tunnel Response: Rapid filling and surcharging at the time of reported geyser



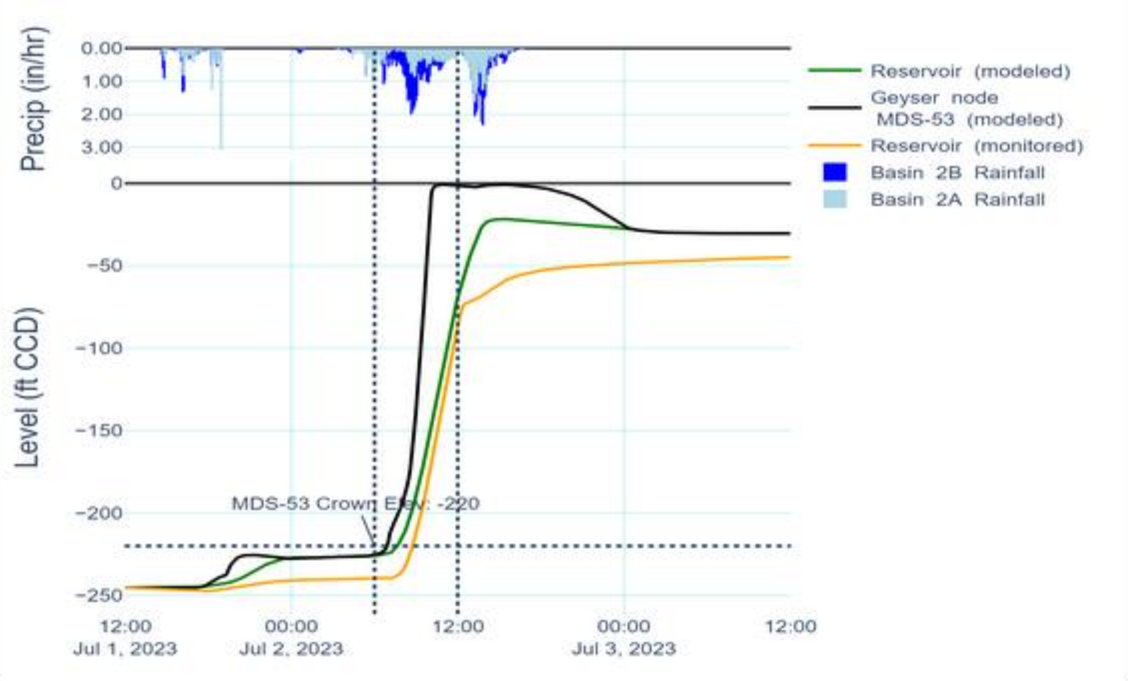


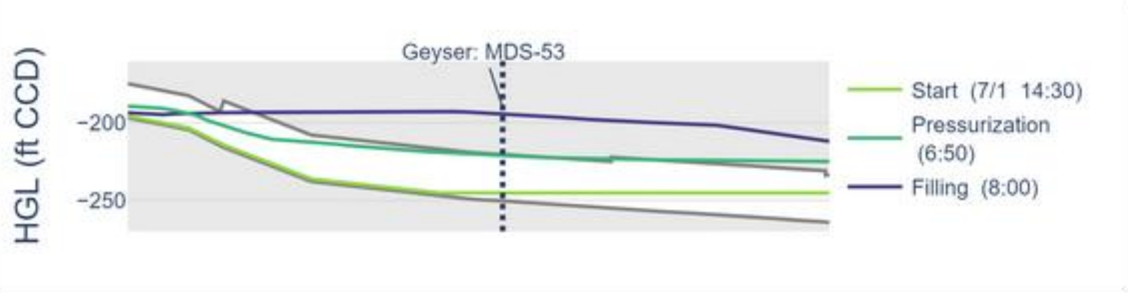


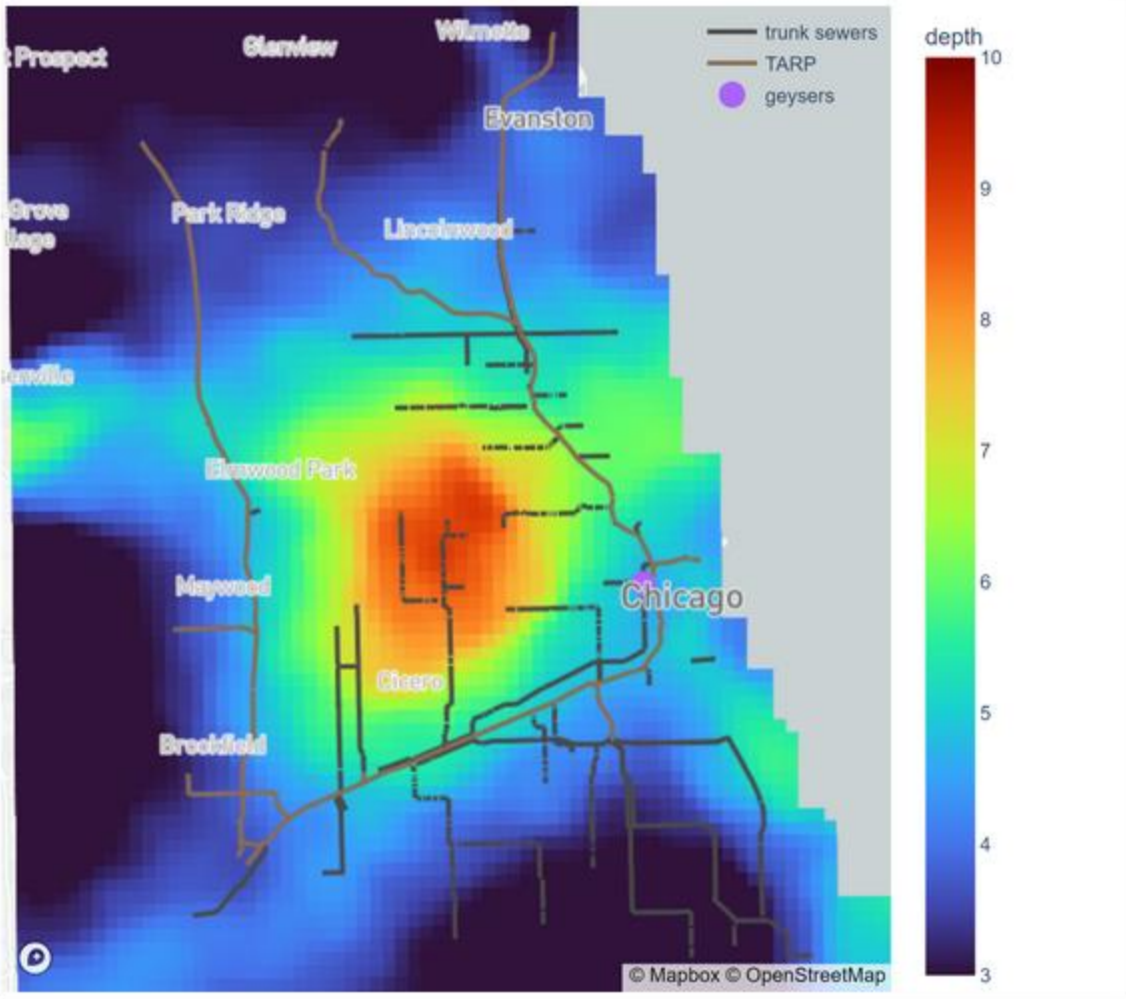
Printed: 11/22/2024

Geyser Date: 7/02/2023
Average Rainfall Depth: 5.13 inches
Geyser Dropshaft: MDS-53

Storm Description: Intense rainfall across MSDP service area; Localized 9-10" depths on west side of Chicago
Initial Conditions: McCook Reservoir roughly 15% full; tunnel empty
Tunnel Response: Very rapid filling at time of geyser







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Summary of Baseline Conditions Modeling

Event	Depth (in)	Rainfall St. Dev. (in)	Geyser Location	Initial System Conditions	Model vs Monitoring Summary	Modeled Hydraulics Consistent with Geyser
5/3/2022 NEXRAD	1.50	0.18	North Branch (MDS-13, MDS-24, MDS-84)	McCook: 25% full (873 MG) Tunnel: full at geyser, roughly 2/3 full upstream	23% underprediction in McCook inflow Peak HGL at CN03 is underpredicted by 71 ft	Rapid filling of tunnel at geyser location at the time of geysering
7/27/2022	1.39	0.21	Northmost section of Mainstream in Evanston (MDS-111)	McCook: 33% full (1,158 MG) Tunnel: 33% full at geyser	43% underprediction in McCook inflow (~83 MG due to small event) Level at CN03 has minor response for both	Tunnel does not fill at geyser location
9/11/2022	2.19	0.62	Middle of North Branch of Chicago River (MDS-79)	McCook: empty Tunnel: empty	9% overprediction of McCook inflow (~2.5BG) Good match of level at CN03	Rapid filling of tunnel at geyser location , roughly one hour earlier than reported geyser
7/2/2023	5.13	1.71	South Chicago River/Loop (MDS-53)	McCook: 15% full (523 MG)	100% overprediction of inflow (5.6 BG) Good match of level at CN03	Rapid filling of tunnel at geyser location in general time window

Legend

Underpredict

Overpredict

Modeled hydaulic response inconsistent with geyser

- ***CN03*** *is a monitored dropshaft on the wild branch of the North Branch of the Chicago River*
- *Underprediction/Overprediction were assigned for locations that included (1) at least 200 MG difference in inflow and (2) a difference of 25% or more*

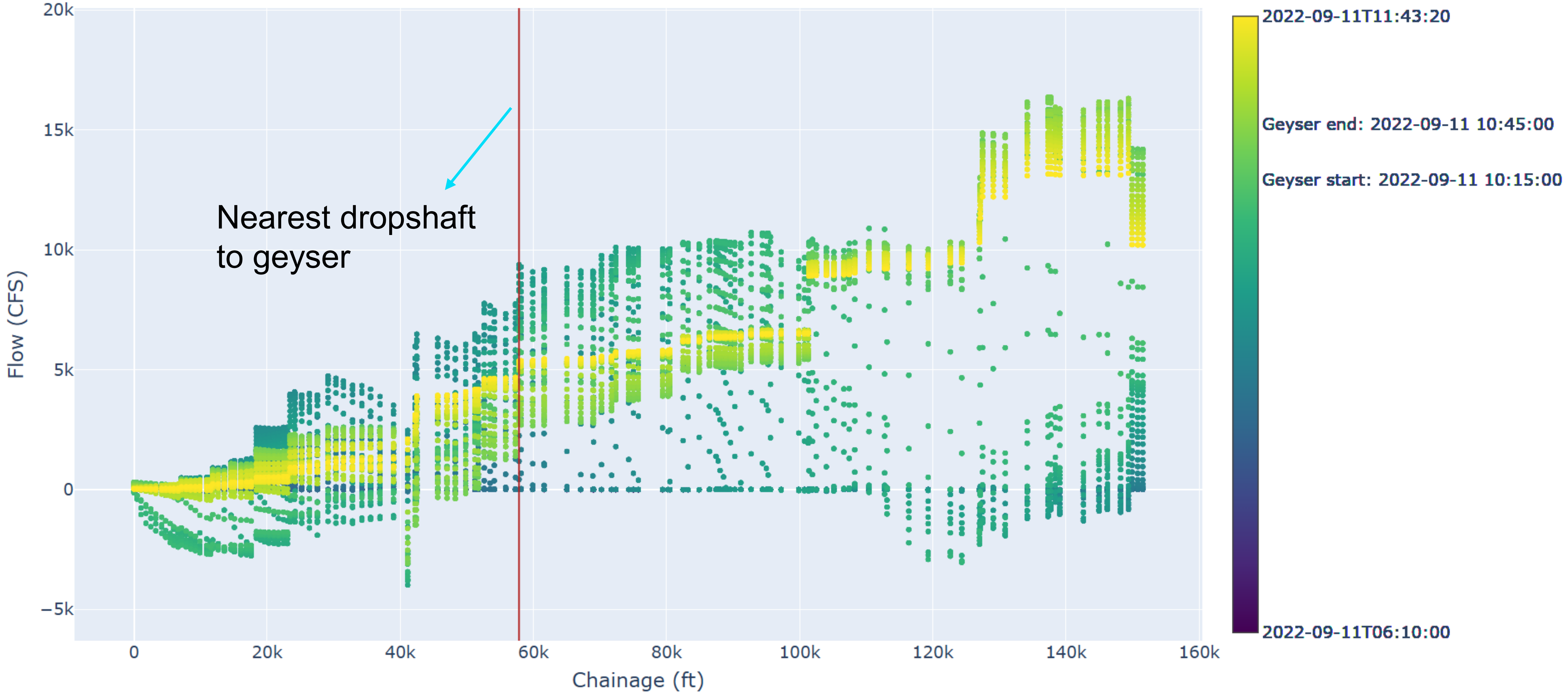
Geyser Risk Literature Review

Exploration of metrics denoting potential geyser risk

Metric	Description	Findings
Q*	• $Q^* = \frac{Q}{\sqrt{gD^5}}$ (Vasconcelos & Wright) • $OR\ Q^* = \frac{Q}{\frac{\pi}{2^{10/3}n} D^{8/3} S^{1/2}}$ (Lokhandwala et al, EWRI, 2024) • Q* is a dimensionless variable for normalized flow based on tunnel geometry and attributes. • Researchers have found high Q* (>0.5) increases risk of air entrapment/entrainment and potential geysering, but relationship depends on system geometry	• 2nd form preferred, more explainable & generalizable (based on Manning's Equation) • We do see significant Q* during geyser events along tunnel, but not specific to geyser locations or timing • Q* > 1 and Surcharge >= 1 tend to be closely related, but not always
Froude	• $Fr = \frac{u}{\sqrt{gL}}$ • Froude number is a dimensionless variable that compares inertial to gravitational forces • Higher Froude means inertial forces more dominant, which could increase potential for turbulence, wave formation, and entrainment -> potential geysering	• No instances of supercritical flow (Fr>1), but I flow nears criticality (Fr ~1) for some nodes/events
Bidirectional filling	• Bidirectional filling can cause air entrapment when there is an unpressurized segment bordered by pressurized segments on both sides -> potential geysering	• Limited instances of this, centered on segments of TARP where diameter changes
Time/rate of pressurization	• Various metrics can be defined for the time or rate of pressurization/filling across TARP. • Rapid filling could induce entrapment/entrainment	• There are sections with rapid filling, varies across events and across TARP • No specific threshold for geyser risk known

Flow Profile(9/11/2022)

High rates of TARP inflow near geyser


Nearest dropshaft to geyser

Q* Profile (9/11/2022)

- Q* normalizes flow based on pipe diameter, roughness, & slope
- Q* has minor peak at geyser location compared to neighbors, but much smaller than other locations downstream
- Q* at the time of pressurization <1 (and higher elsewhere)

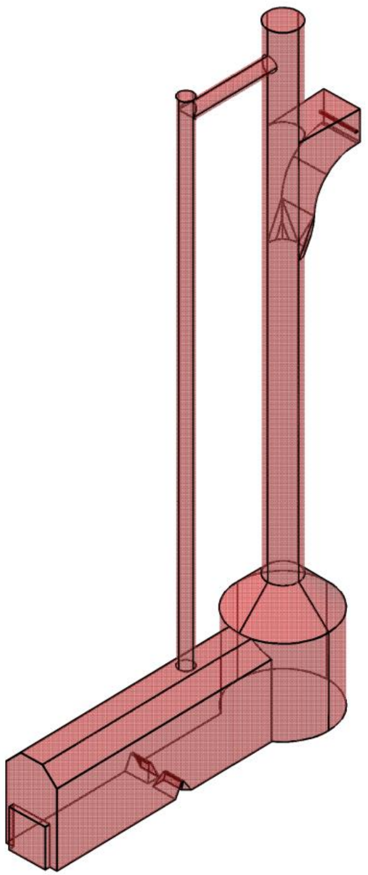
Max Q* = 1.8 at geyering location

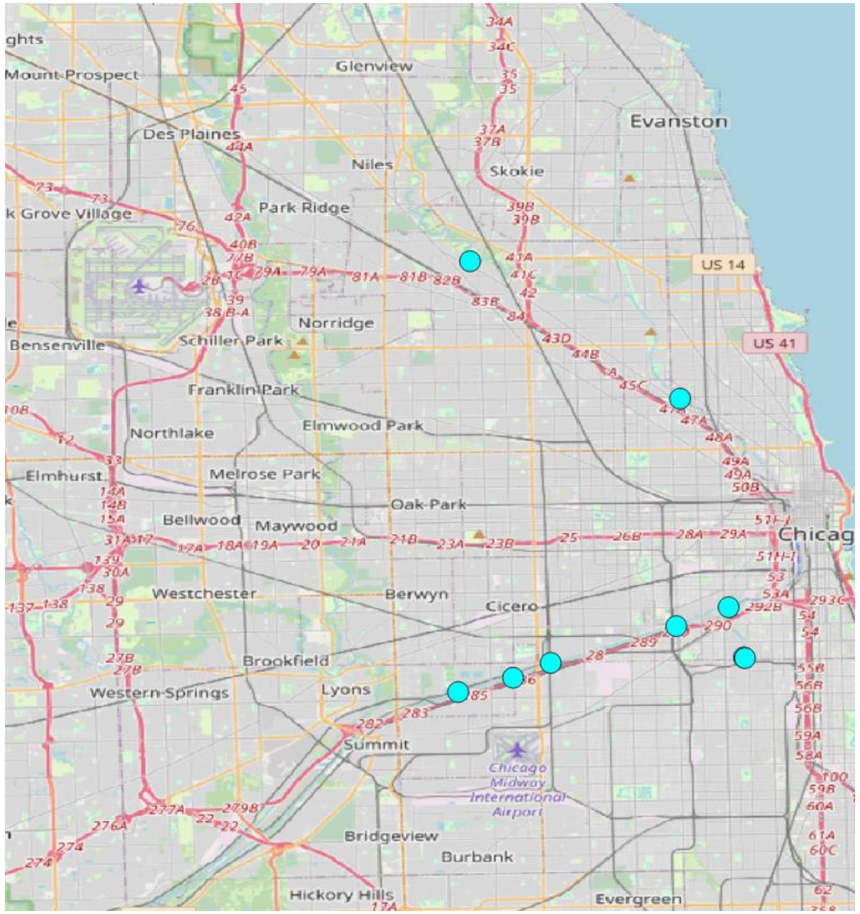
Typical Q* levels vary across TARP, much higher generally in certain segments

Dropshaft Geometry – Bucket Dropshafts

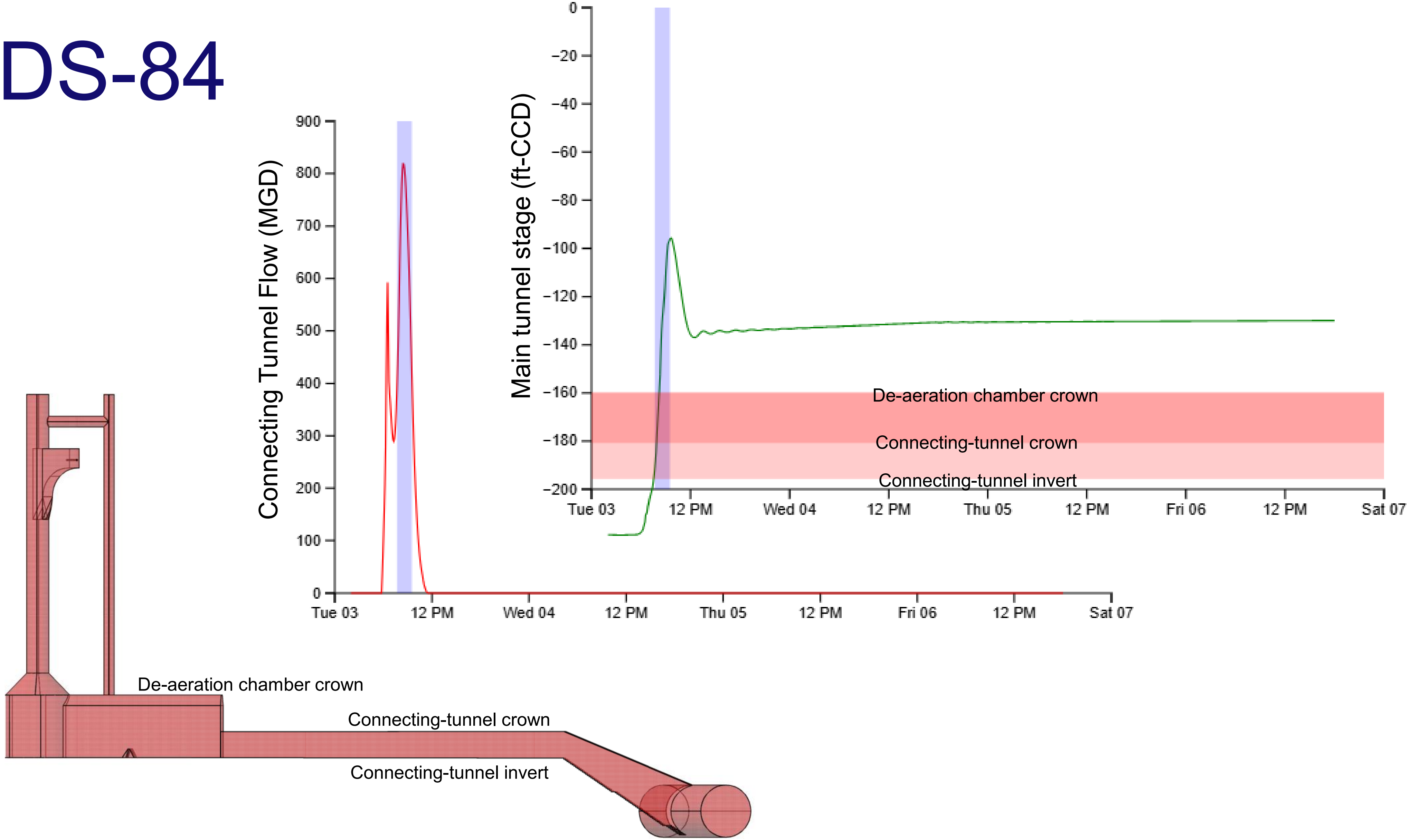
Interaction between local geometry and system hydraulics may contribute to risk

- Two primary styles of dropshaft in TARP
- E15 – “Split Barrel” dropshaft
    - Used for smaller dropshafts/lower flow rate
    - Sloped de-aeration chamber with divider wall separating the active flow portion from the ventilation portion of the dropshaft
- D4 – “Bucket” dropshaft used for larger dropshafts/higher flow rates
    - Has a de-aeration chamber with a horizontal roof and a separate ventilation shaft
- 13 bucket dropshafts (small minority) – though 3 of 5 geysers observed at these locations

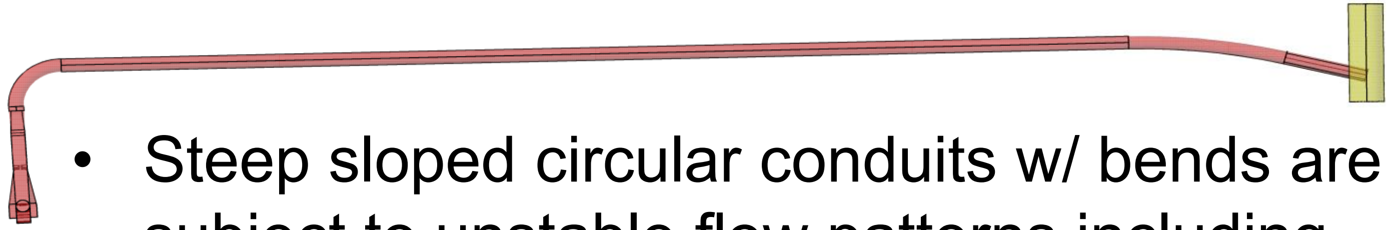




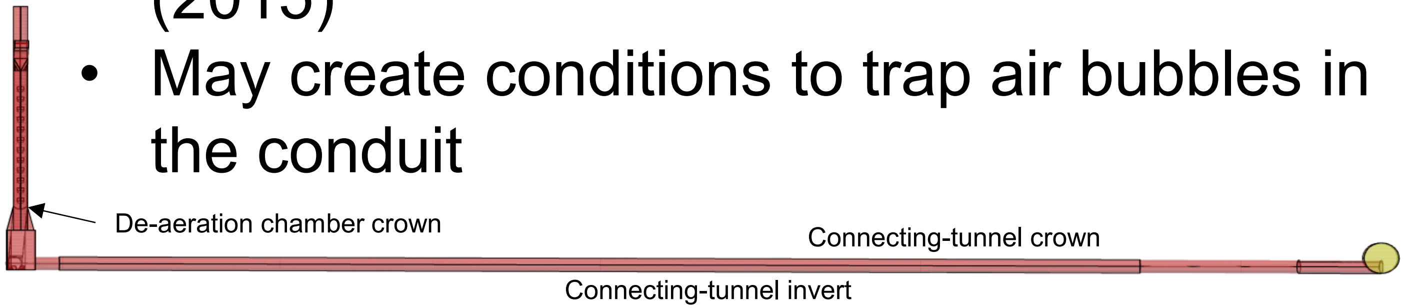
DS-84

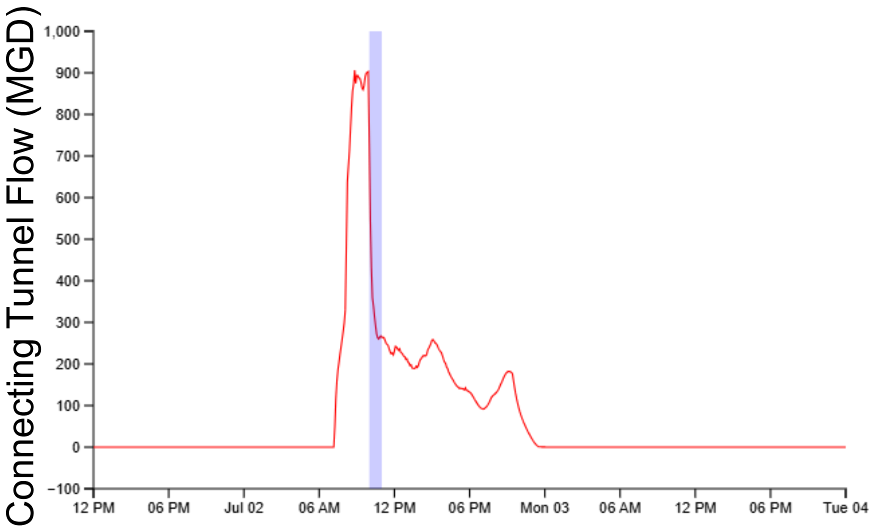

Connecting Tunnel Flow (MGD)
900
800
700
600
500
400
300
200
100
0
Tue 03
12 PM
Wed 04
12 PM
Thu 05
12 PM
Fri 06
12 PM
Sat 07
Main tunnel stage (ft-CCD)
0
−20
−40
−60
−80
−100
−120
−140
−160
−180
−200
De-aeration chamber crown
Connecting-tunnel crown
Connecting-tunnel invert
Tue 03
12 PM
Wed 04
12 PM
Thu 05
12 PM
Fri 06
12 PM
Sat 07
De-aeration chamber crown
Connecting-tunnel crown
Connecting-tunnel invert

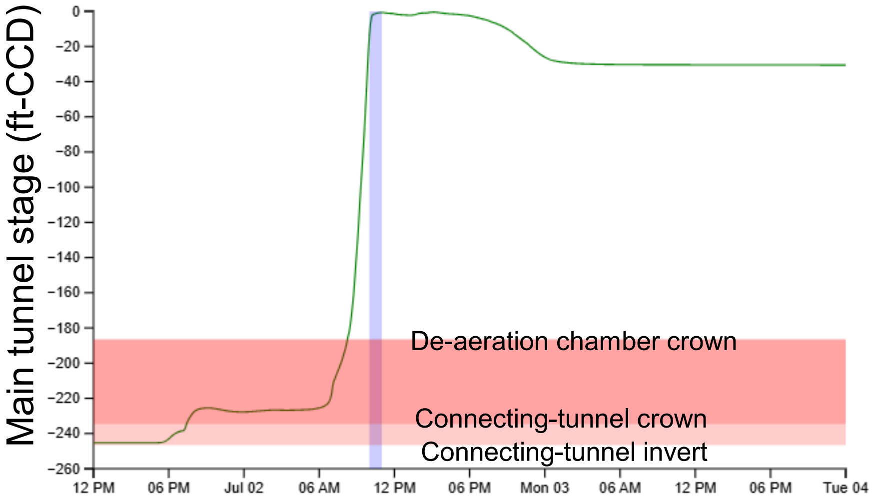
DS-53



- Steep sloped circular conduits w/ bends are subject to unstable flow patterns including “helical choking flow” (Supercritical Flow in Circular Conduit Bends – Kolarevic, et.al (2015)
- May create conditions to trap air bubbles in the conduit







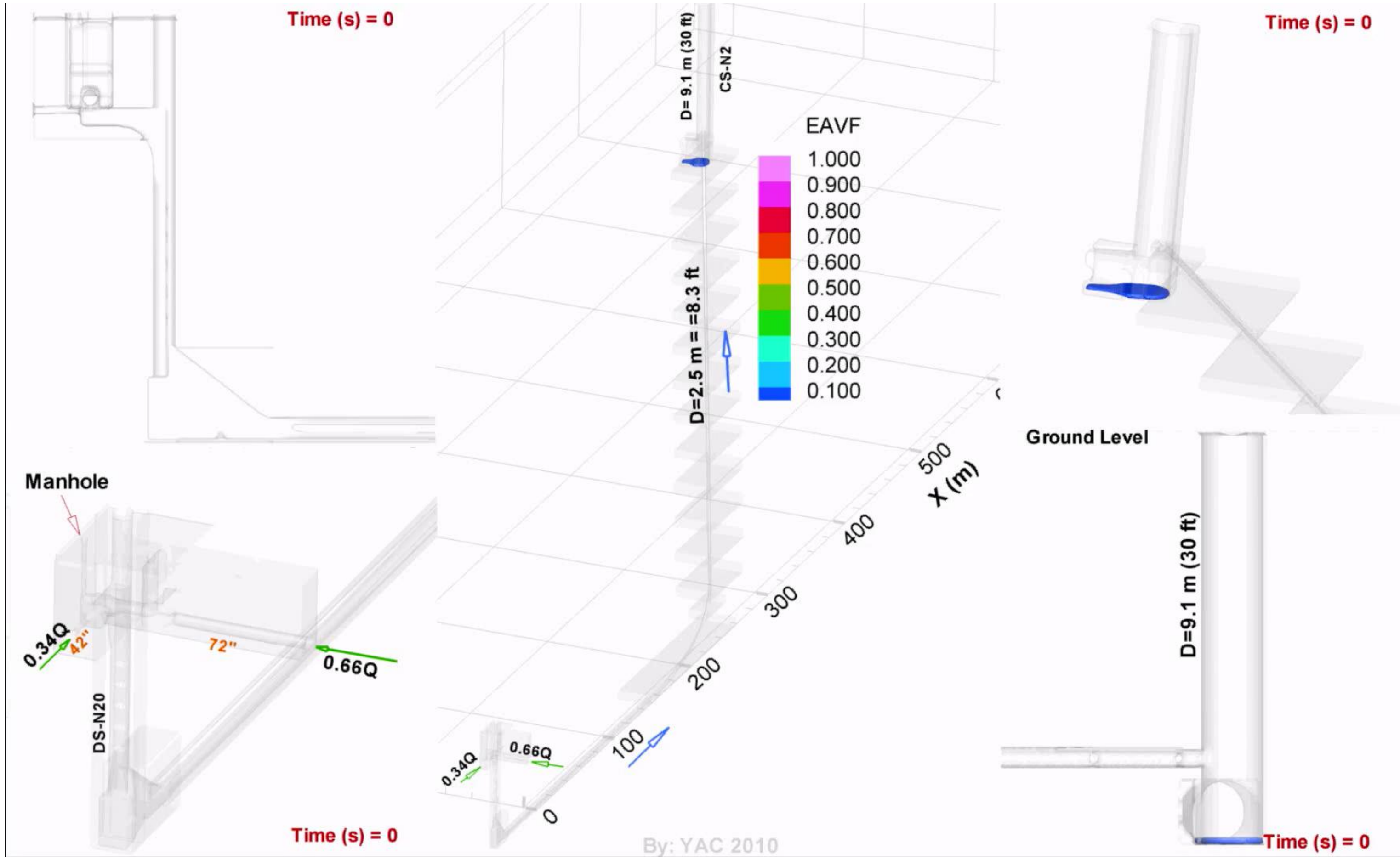
DS Geometry Observations for Geysers

- Documented geysering generally associated with rapid changes in drop-shaft inflow or tunnel stage (exception is DS-M111)
- Most geysers occur for drop-shafts that have flows at or near the design discharge
- Unique geometry for several dropshafts:
  - DS-M84 – Approx. 15.5-ft between tunnel crown and invert of the drop-shaft/de-aeration chamber
  - DS-M53 – Approx. 1200-ft long connecting tunnel with a 90-degree bend

DROPSHAFT	DIAMETER	DESIGN-Q (CFS)	MAX-Q (CFS)	% DESIGN
DS-M111	4’6”	84	13	16%
DS-M84	13’	1530	1270	83%
DS-M79	13’	1530	2090	137%
DS-M53	12’	1240	1390	113%
DS-M13	13’	1530	1680	110%

Detailed Modeling – CFD and Surge

- Can be used to examine details of air/water flow interaction within a dropshaft and connecting tunnel
- Has been used previously to examine geysering at DS-N20



Future Enhancements

- Improved representation of gate positions for system inflows
- Evaluate “non-geyser” events as a control
  - Goal: identify a metric that is indicative of geysering risk that distinguishes geyser/non-geyser events
  - May not be possible 1D model
- Use Chicago All-Pipe Model – more detailed routing into TARP
- Consider antecedent moisture conditions, especially for 7/2/2023 event
- Identify other sources of monitoring comparison (Racine Avenue Pumping Station and/or North Branch Pumping Station)

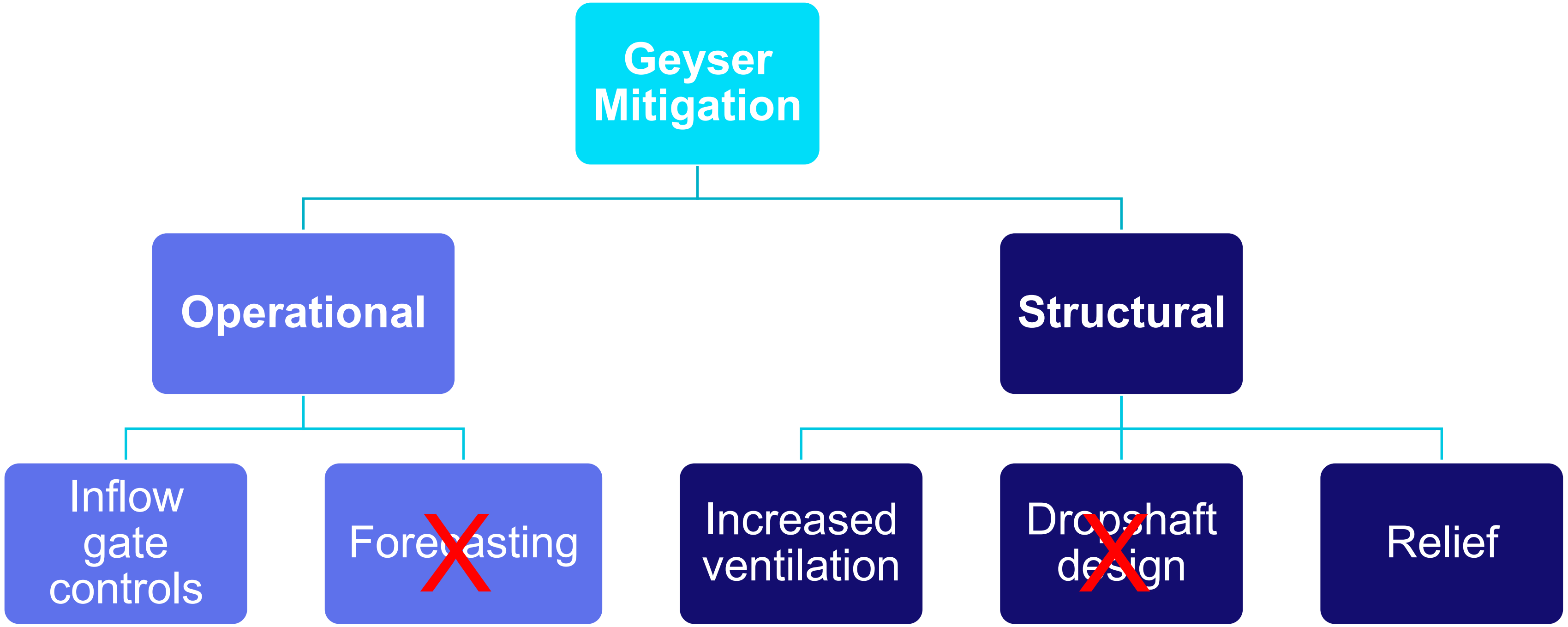
Alternatives Analysis

Reducing or eliminating the occurrence of geysers

Overview of Approaches

Key factors for geyser formation

- Rate of tunnel pressurization
- Interconnection of regional-scale tunnel-filling and local dropshaft

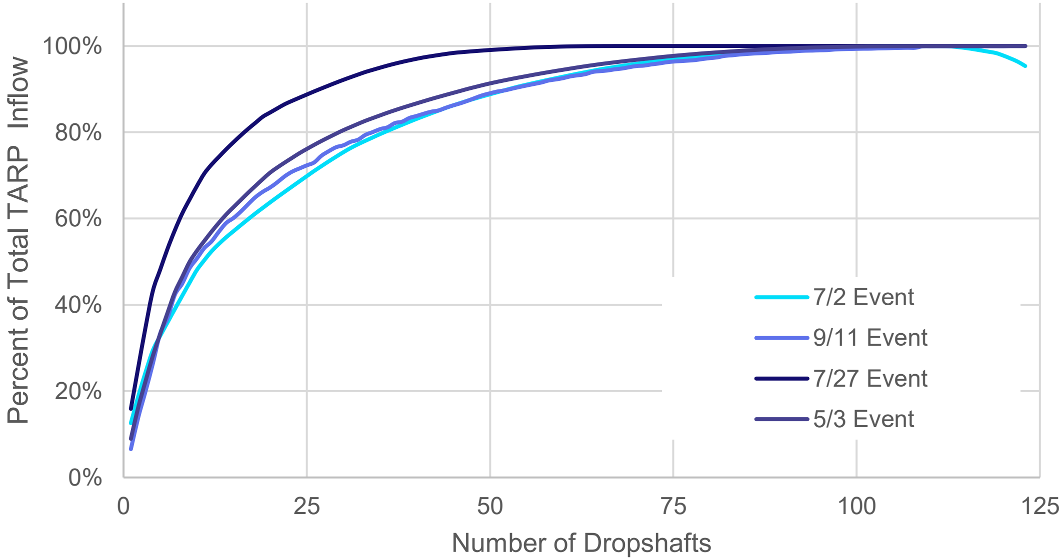


- **Geyser Mitigation**
  - **Operational**
    - Inflow gate controls
    - ~~Forecasting~~
  - **Structural**
    - Increased ventilation
    - ~~Dropshaft design~~
    - Relief

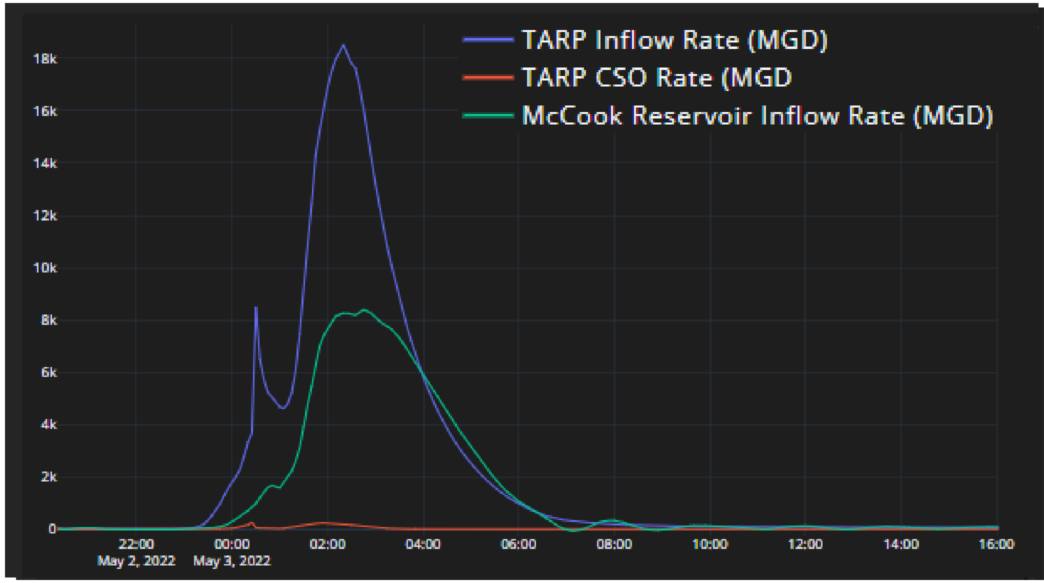
Baseline Inflow Summary

- Informs potential locations for gate control and relief
- Considerations
  - Location – System, By Reach, By DS
  - Metrics - Timing, Total Volume, Peak Rate
  - Variation by Event

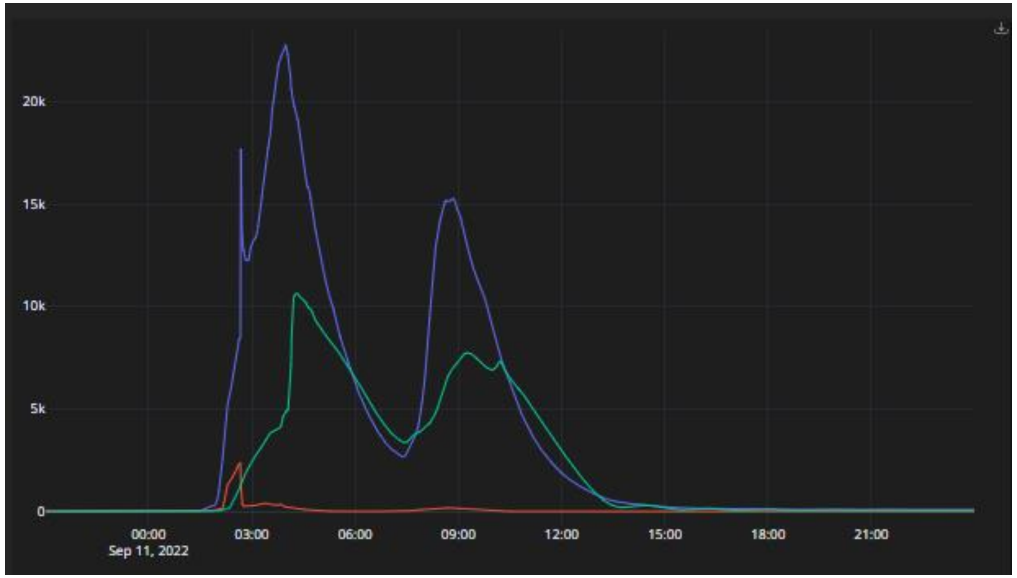
Less than 40 Dropshafts contribute Over 80% Total TARP Inflow



5/3 Event – System Inflow

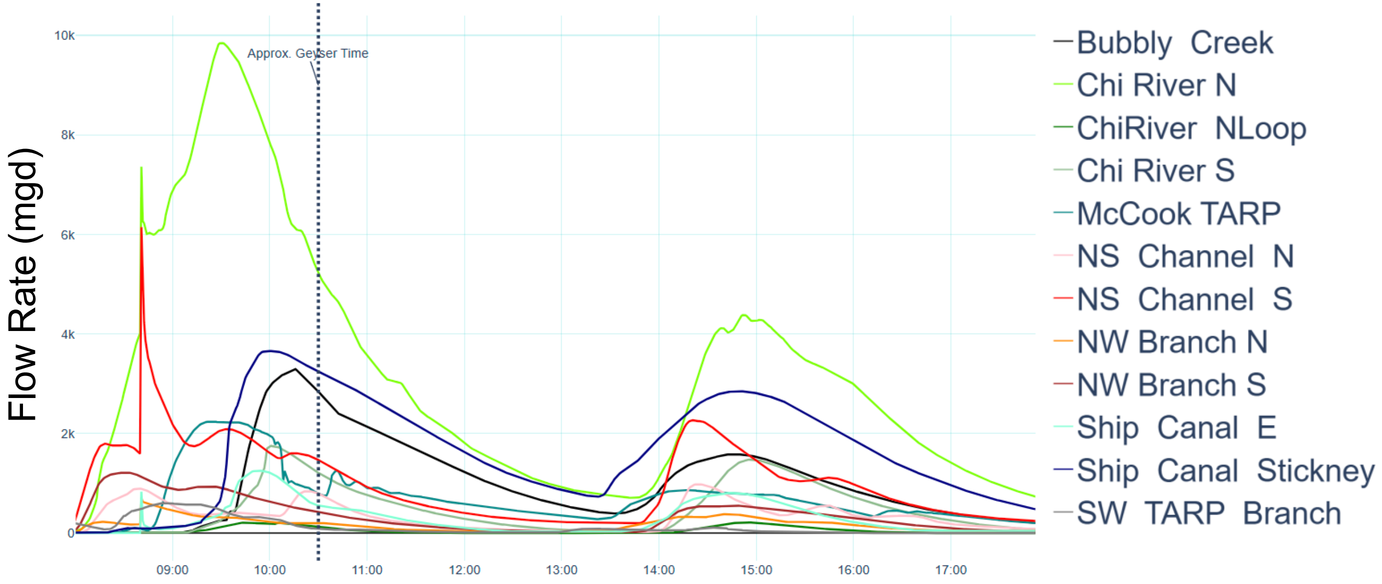


9/11 Event – System Inflow

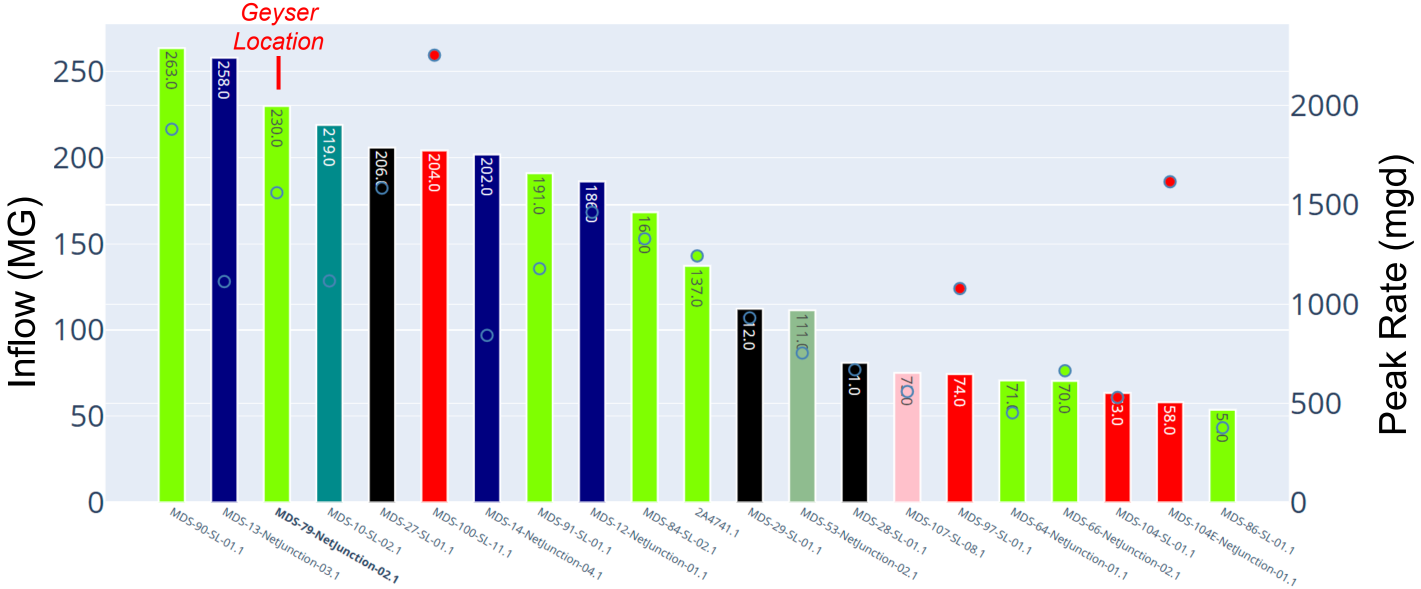


Inflow Details - 09/11/2022

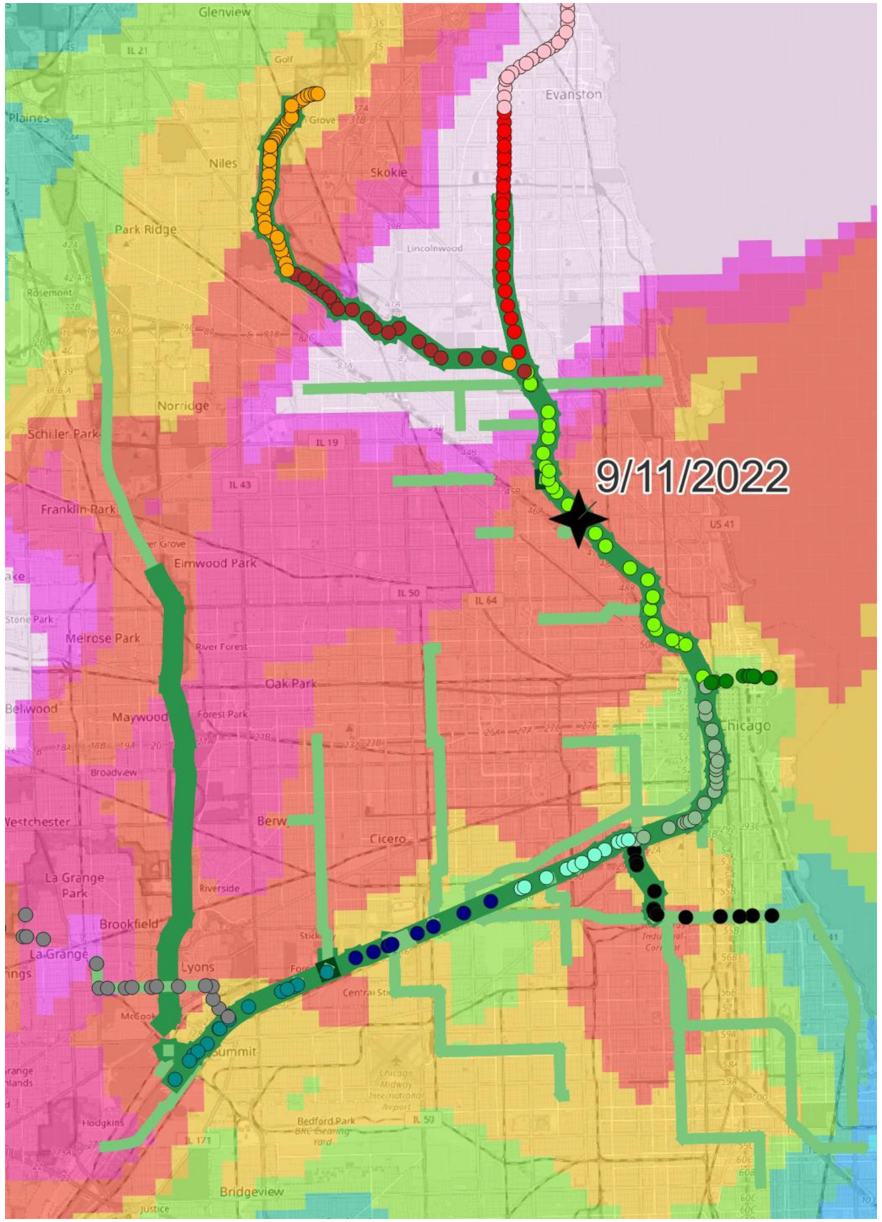
Inflow By Reach



Highest Inflow Dropshafts



Rainfall Accumulation



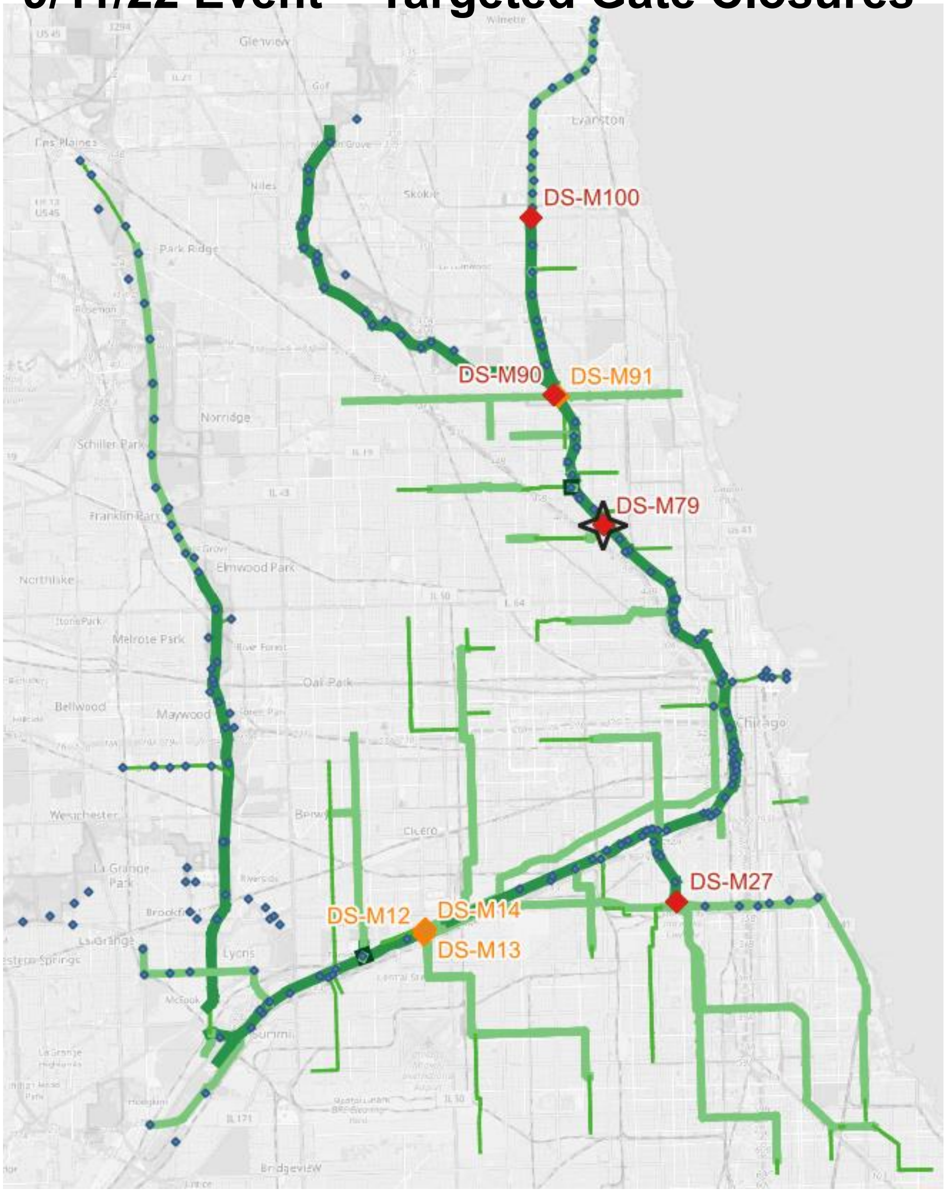
Controlling TARP Inflow Gates

- Two approaches considered
  - 1) System wide reductions
  - 2) Targeted gate reductions
    - 25% & 50% Total TARP Inflow
    - Vary depending on Event, but fair amount of overlap→ 10 unique DS
- Impacts
  - Reduced rate of inflows
  - Reduced rate of HGL change at pressurization
  - Increased CSO

Number of DS Impacted for Targeted Gate Closures

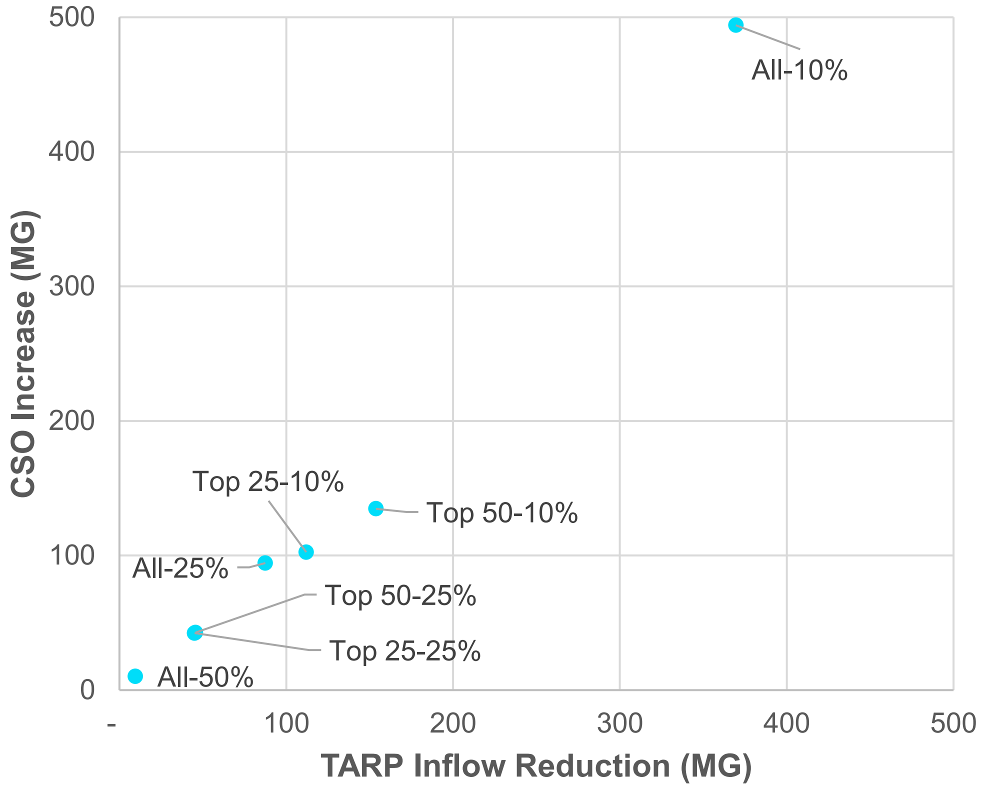
		9/11/22	5/3/22	7/2/23
♦	Top 25% Inflows	4	4	3
🔶	Top 50% Inflow	6	7	8

9/11/22 Event – Targeted Gate Closures



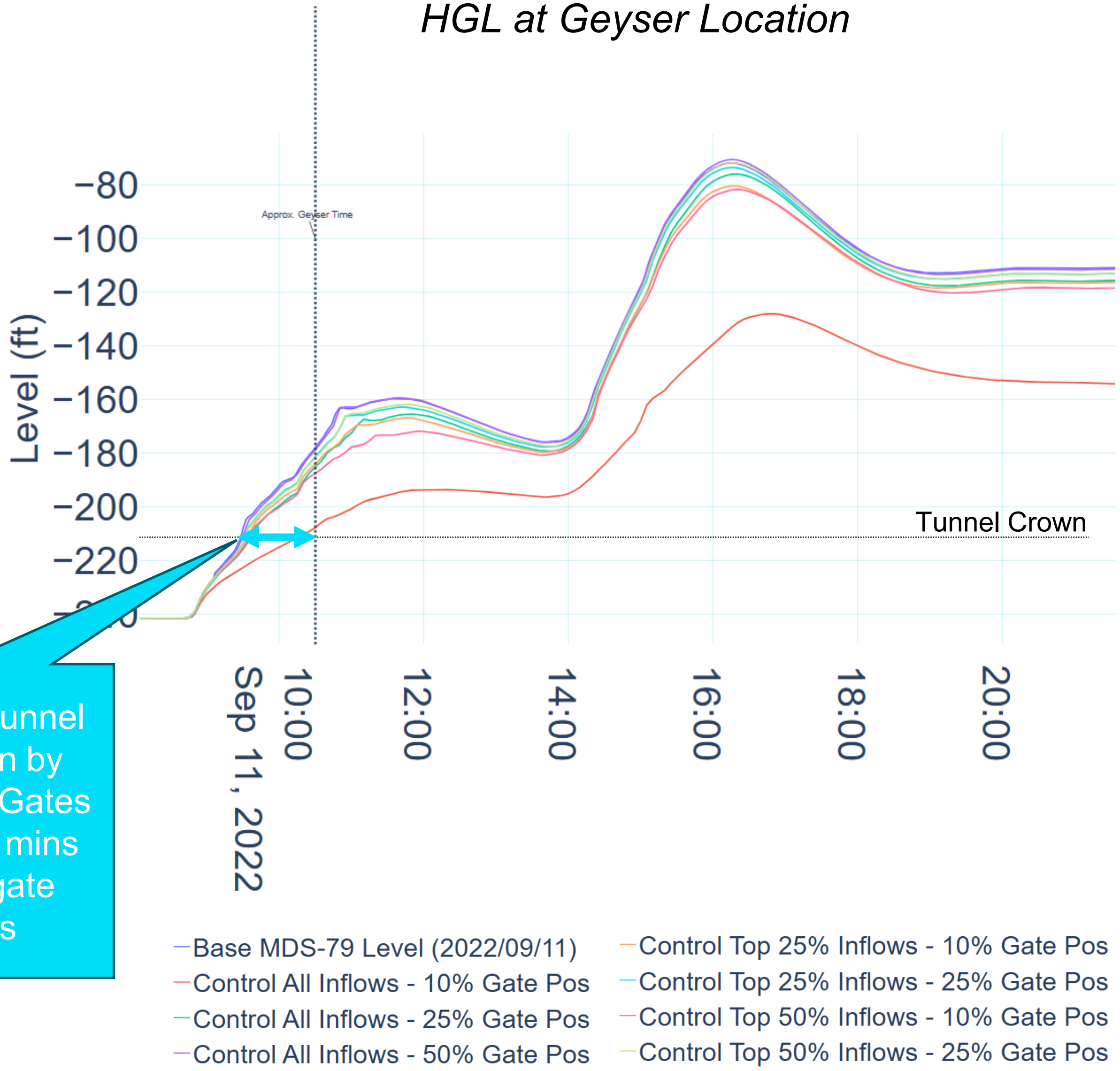
9/11 Event – Alternative Gate Closure Details

Impact on CSO



Impact on Timing

HGL at Geyser Location



Slow Rate of Tunnel Pressurization by ~30 min for All Gates 10%, and <10 mins for all other gate closure alts

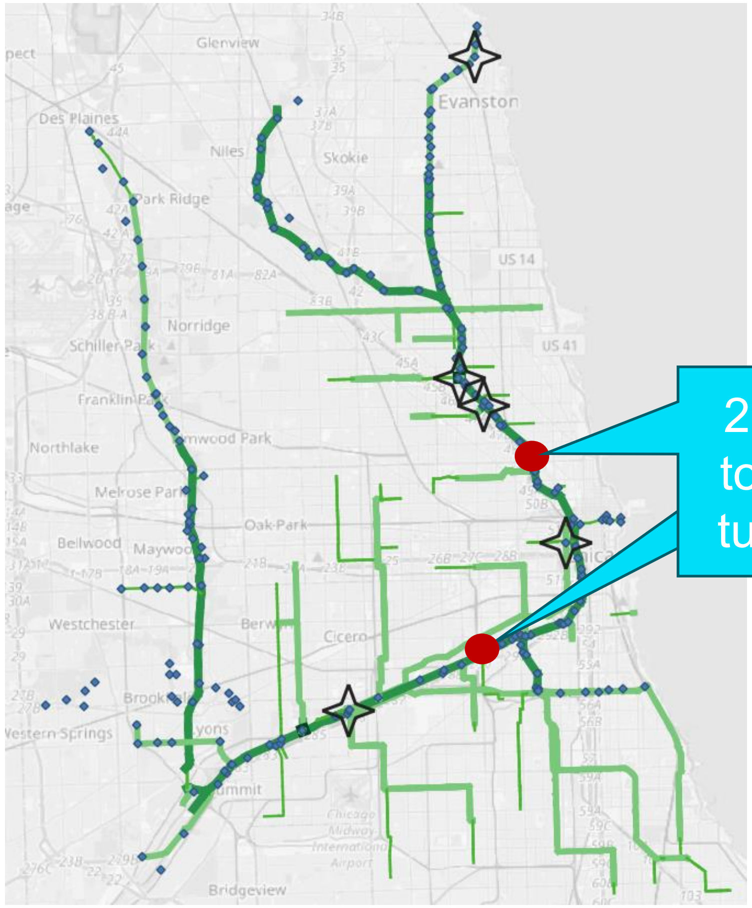
Next Steps:

- Additional Gate Closure Alternatives
- Identify common high-inflow dropshafts across events (non-geyser and geyser)

Relief at Time of Pressurization

Set-up

Modeling exercise to understand volume necessary to delay rate of filling and tunnel pressurization

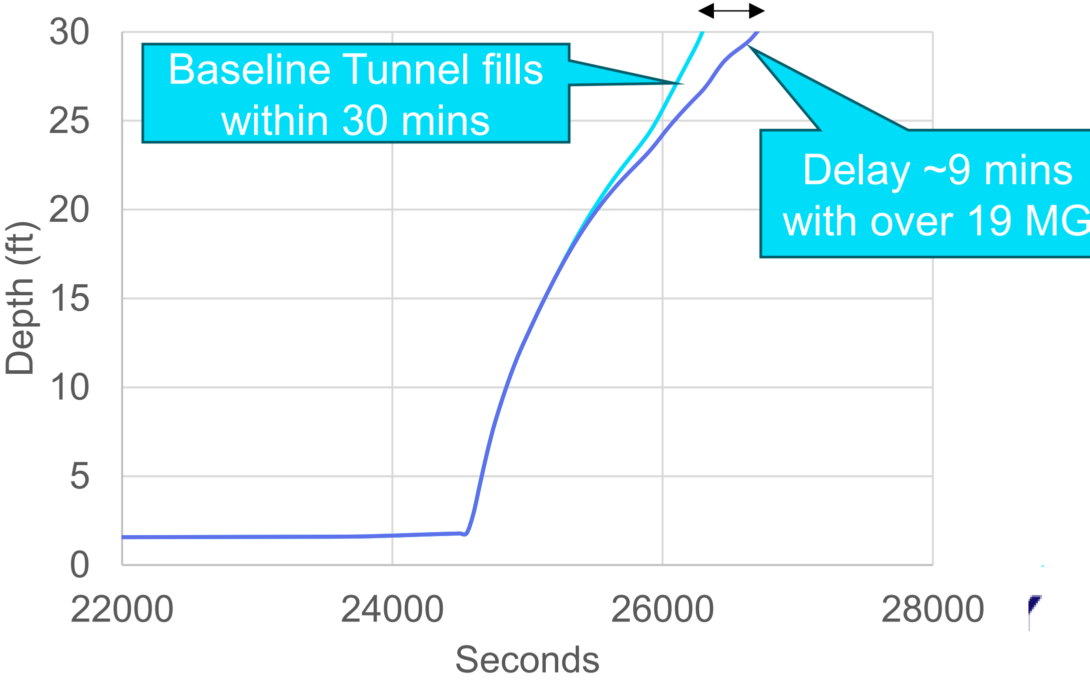


2 locations set to 50% or 75% tunnel capacity

Findings

- Potential to delay filling up to 15 minutes
- Relief requires large volumes and conveyance capacity
  - High flow rates within tunnel (up to 6,500 MGD) → Over 1,500 MGD required to provide any relief

Tunnel Level for 9/11 Event near Geyser



Baseline Tunnel fills within 30 mins

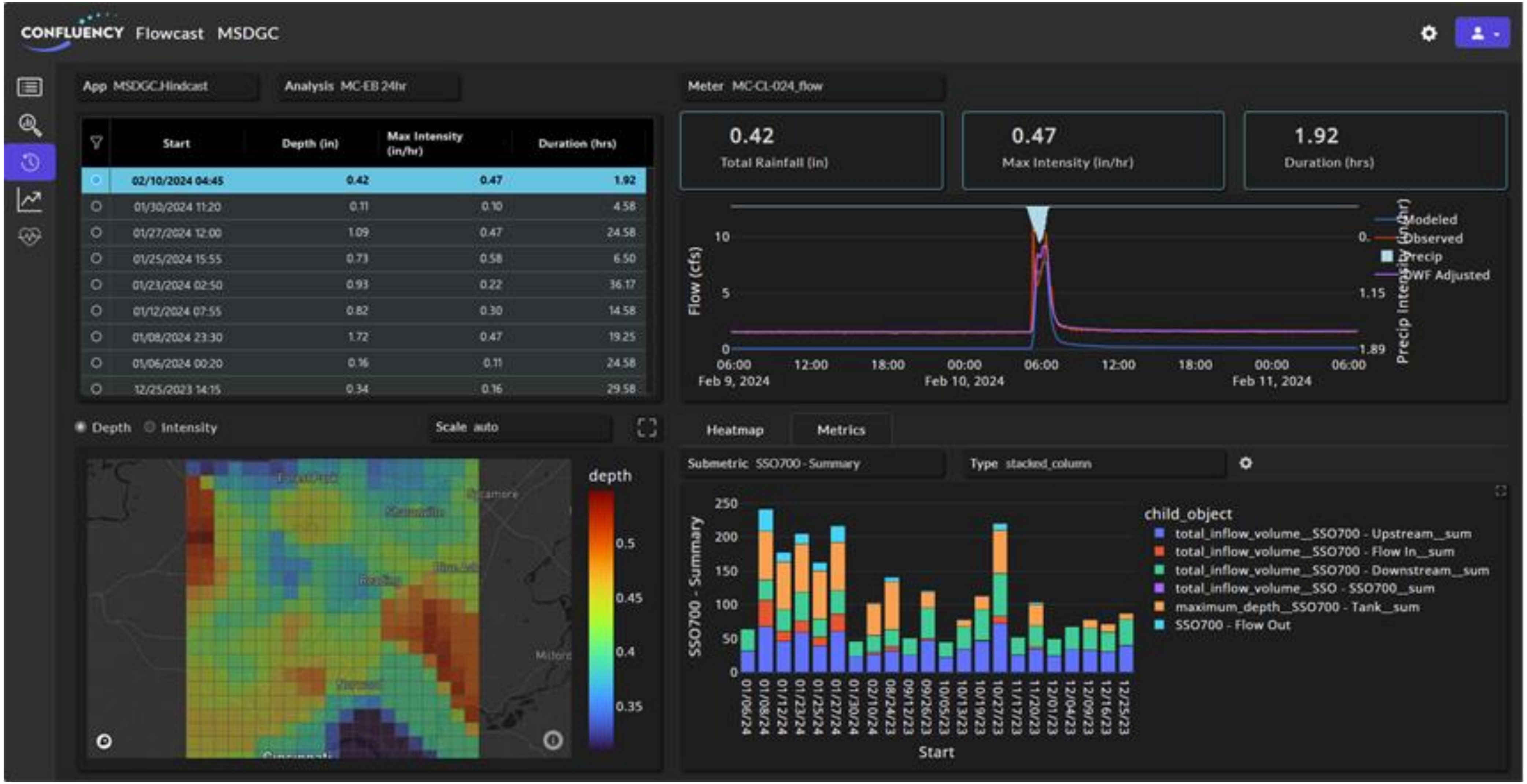
Delay ~9 mins with over 19 MG

Increased Ventilation Capacity
Future Analysis Informed by CFD

- Estimating ventilation capacity across the system
  - limitations – based on dropshaft location or design
  - aggregate ventilation capacity per reach
- CFD analysis may inform this
- Mitigation measures – very early stage of consideration; potential for enhanced ventilation that releases energy below ground?

Hindcasting – Learning from Every Storm

MSDGC example of automated modeling evaluation



App MSDGC.Hindcast

Analysis MC-EB 24hr

Meter MC-CL-024_flow

	Start	Depth (in)	Max Intensity (in/hr)	Duration (hrs)
●	02/10/2024 04:45	0.42	0.47	1.92
○	01/30/2024 11:20	0.11	0.10	4.58
○	01/27/2024 12:00	1.09	0.47	24.58
○	01/25/2024 15:55	0.73	0.58	6.50
○	01/23/2024 02:50	0.93	0.22	36.17
○	01/12/2024 07:55	0.82	0.30	14.58
○	01/08/2024 23:30	1.72	0.47	19.25
○	01/06/2024 00:20	0.16	0.11	24.58
○	12/25/2023 14:15	0.34	0.16	29.58

0.42 Total Rainfall (in)

0.47 Max Intensity (in/hr)

1.92 Duration (hrs)

● Depth ○ Intensity

Scale auto

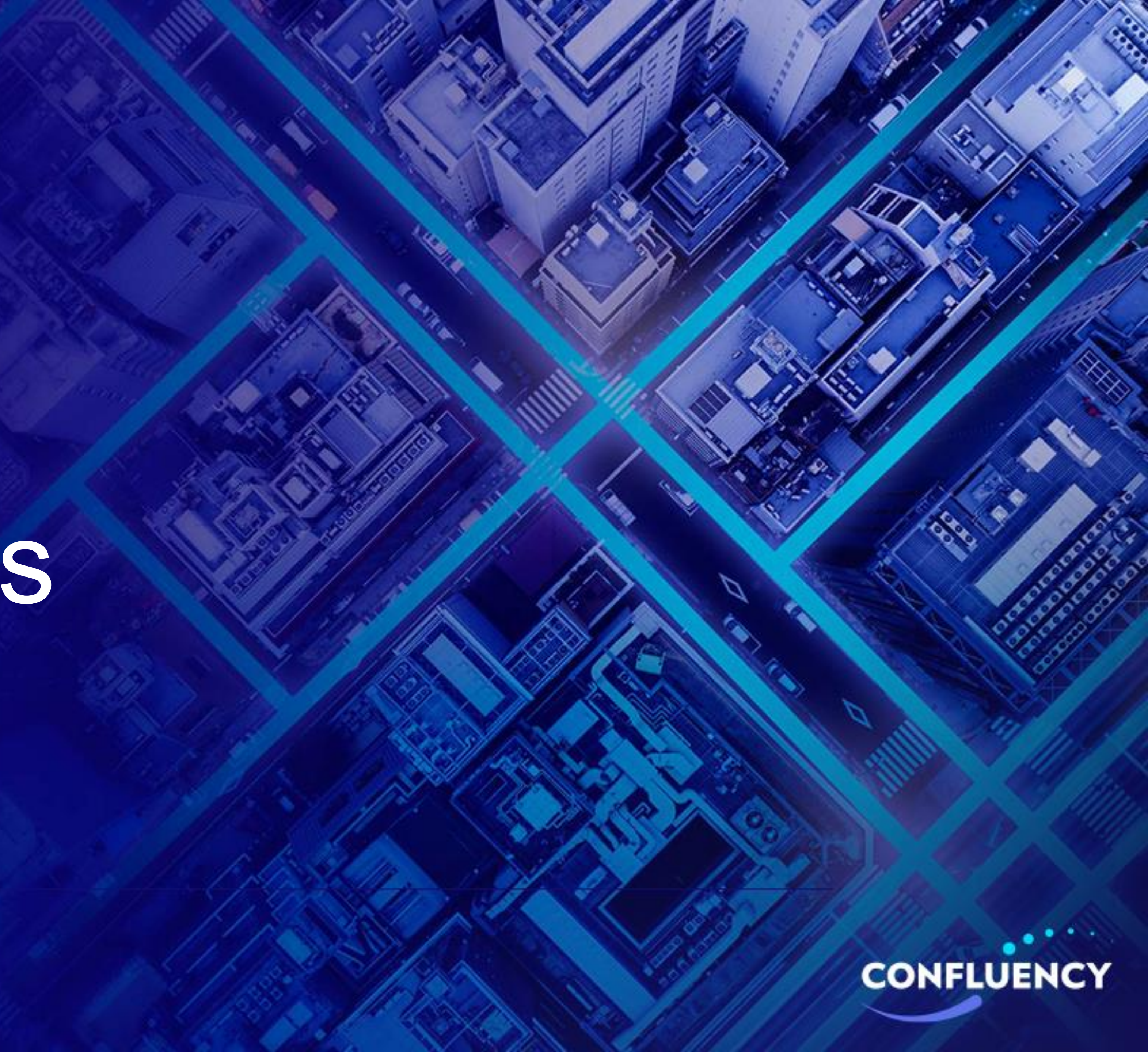
Submetric SSO700 - Summary

Type stacked_column

Benefit of Continuous Assessment for Understanding Geyser Risk

- Enhanced visibility of monitoring
- Standardize radar-rainfall processing techniques
- Continuous feedback on H&H model accuracy issues
- Faster insight and responsiveness to geyser events
- Technical hurdles
  - Orchestrating inter-related models (e.g., IUHM, CS-TARP, potentially ITM)
  - Rainfall pre-processing
  - Limited observational data available dynamically from API call

Conclusions

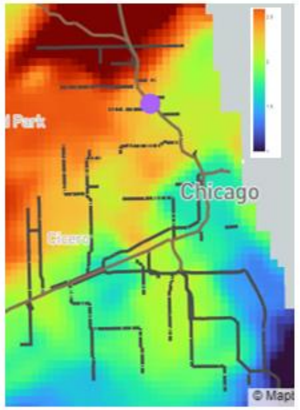


Geyser Event Characteristics

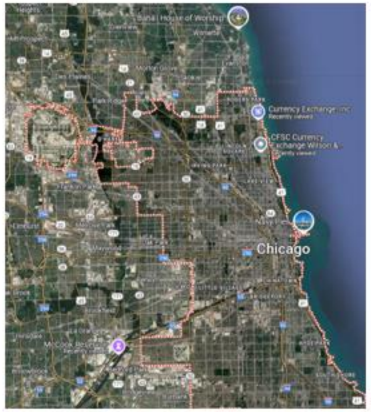
- Geysers occur for very different storm typologies
  - No single storm type offender
  - → Causal factors vary across storms
  - → Suite of mitigation measures likely to be important
- Specific factors contributing to geyser occurrence still partially understood
  - Interaction between regional tunnel hydraulics and local dropshaft geometry seems to be important
  - Geyser risk metrics - inconclusive

    → Additional modeling of “non-geyser” events

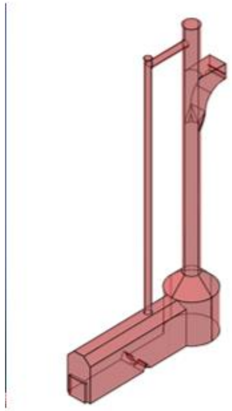
Rainfall Variability



System Scale



Local Factors



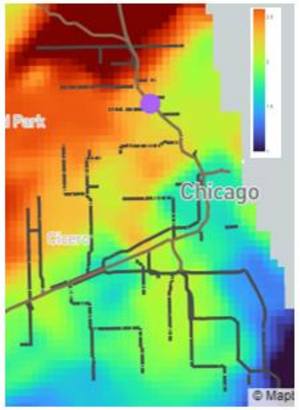
Mixed Phase

Siberia. From Wright et al, 2009

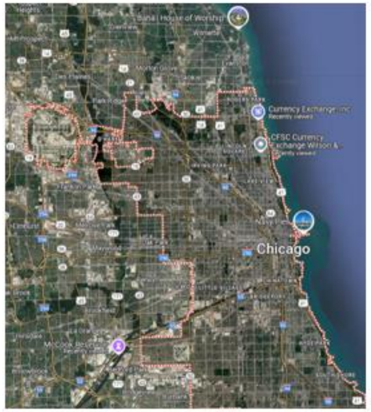
Modeling Tools – Insights and Opportunities

- CS-TARP Integrated Model (1D Dynamic model)
  - useful for defining overall system response
  - replicates the “macro-hydraulic” conditions in most-cases
  - opportunity for improved accuracy and/or confidence
    - Increased monitoring locations comparison
    - Evaluate for more storm events
- CFD required for modeling mixed-phase air/water interaction
  - Work is underway – but is dropshaft specific
- ITM for surge hydraulics – also underway
- Suite of models is necessary for complex geyser dynamics

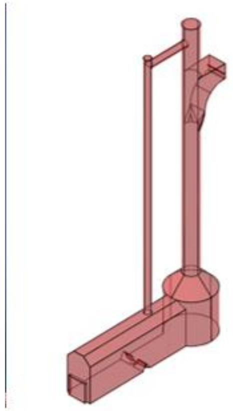
Rainfall Variability



System Scale



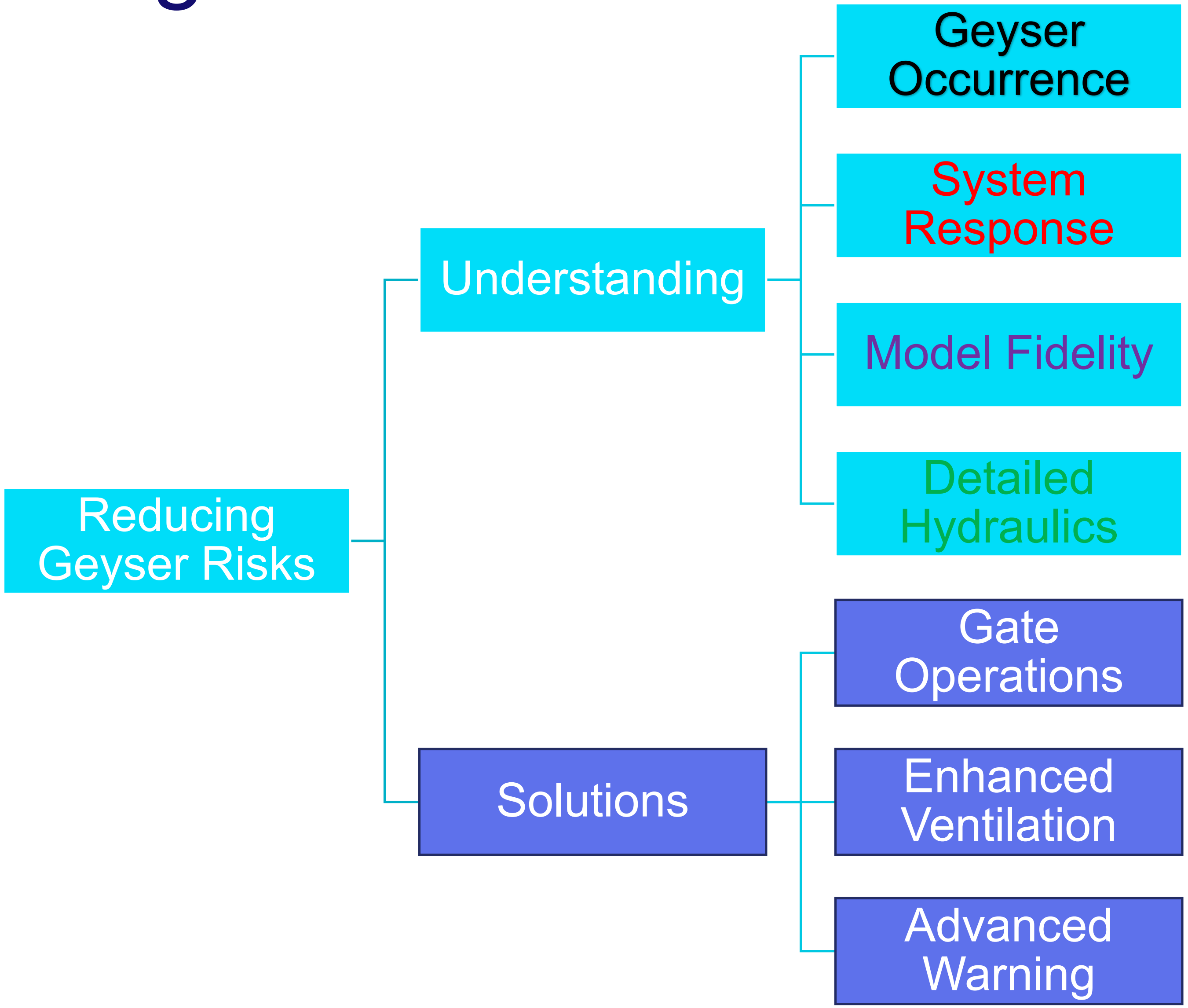
Local Factors



Mixed Phase

Siberia. From Wright et al, 2009

Gaining Confidence in Geyser Causes and Mitigation Measures



- Reducing Geyser Risks
  - Understanding
    - Geyser Occurrence
    - System Response
    - Model Fidelity
    - Detailed Hydraulics
  - Solutions
    - Gate Operations
    - Enhanced Ventilation
    - Advanced Warning

Geyser Occurrence	Process for Documentation	Post-Event Recon ?
System Response	Sensors on Key Dropshafts	Permanent Flow & Level Sensors
Model Fidelity	H&H Model Assessment	Antecedent Conditions
Detailed Hydraulics	Ongoing CFD Analysis	Integrated Modeling Analysis

1. Complete analysis focusing on control events
2. Alternatives analysis – input on "scale of impact" required
3. Complete study: Document degree of confidence in causal factors leading to individual geysers

Thank you!

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