WateReuse California
ANNUAL CONFERENCE
2022

DEVELOPMENT AND TRACER STUDY VALIDATION OF A 3D MODEL OF MIRAMAR RESERVOIR FOR INDIRECT POTABLE REUSE

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ADDITIONAL COLLABORATORS

Public Utilities

- Sarah Brower
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water Quality Solutions

- Imad Hannoun
- Ira Rackley

Pure Water San Diego

Tracer Study

Model Setup and Calibration

Model Validation

Results and Lessons Learned

The City of SAN DIEGO

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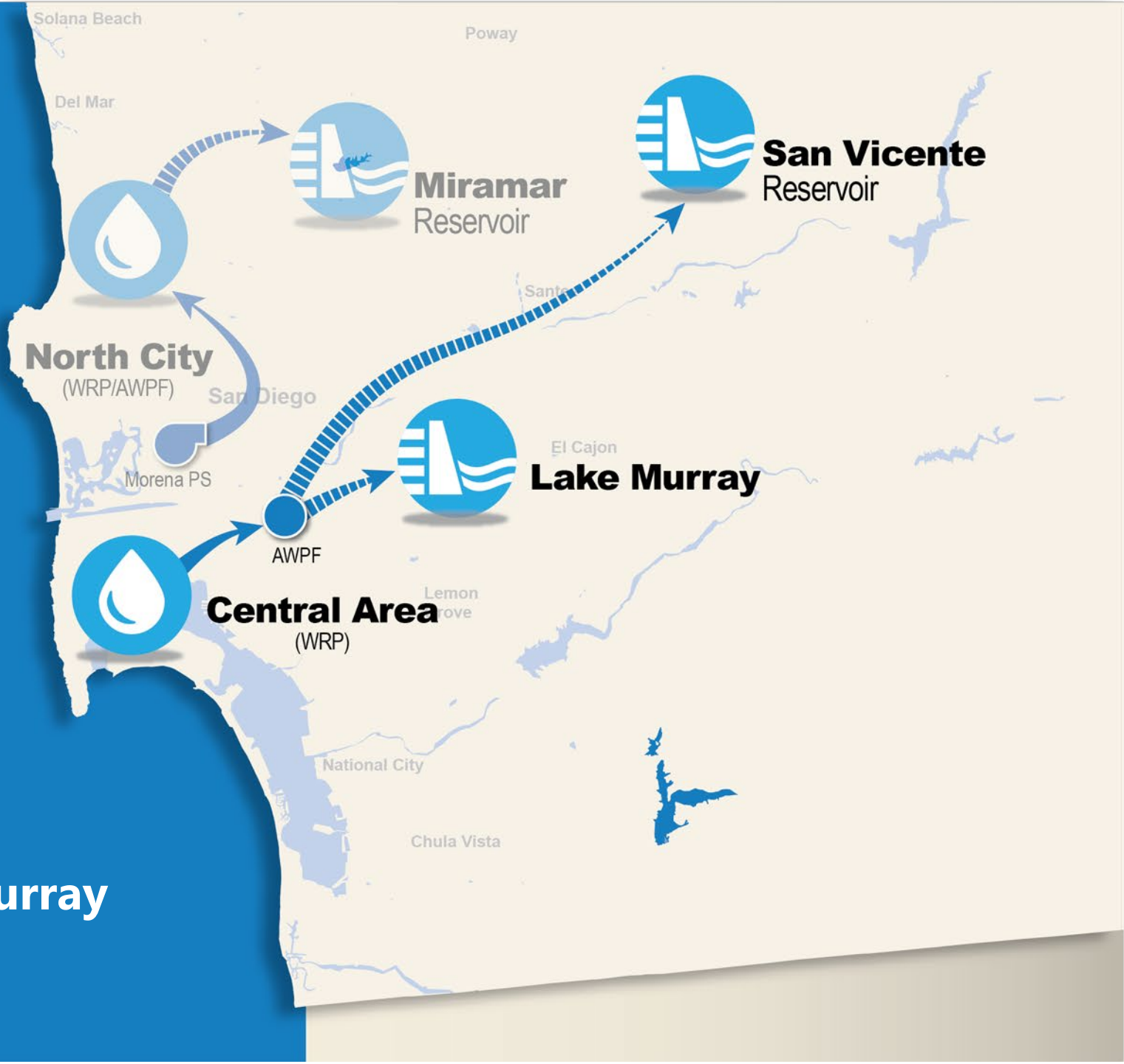
The City of SAN DIEGO

Pure Water
will produce

1/2
of San Diego's water
locally

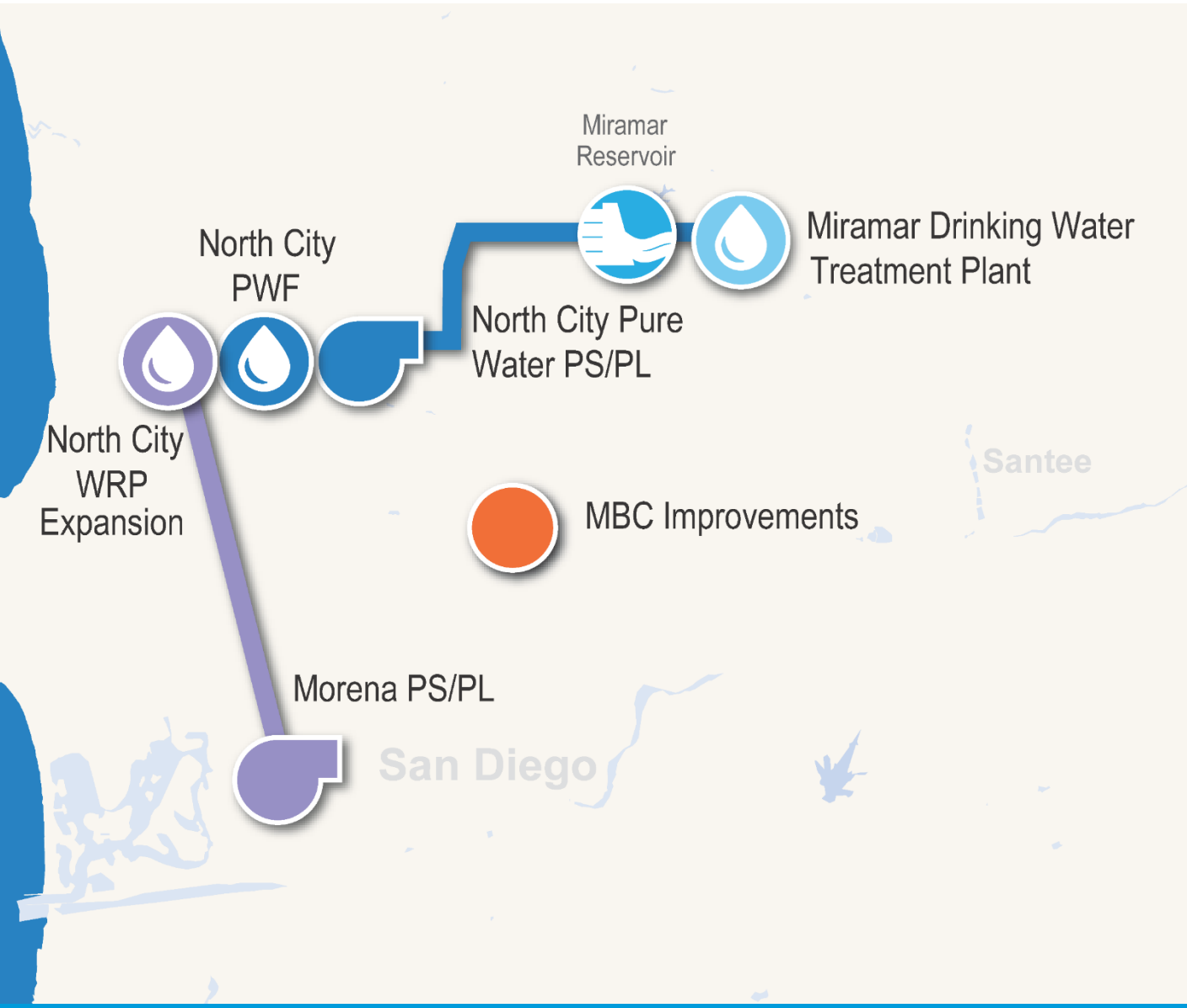


Phase 2
Central Area Project

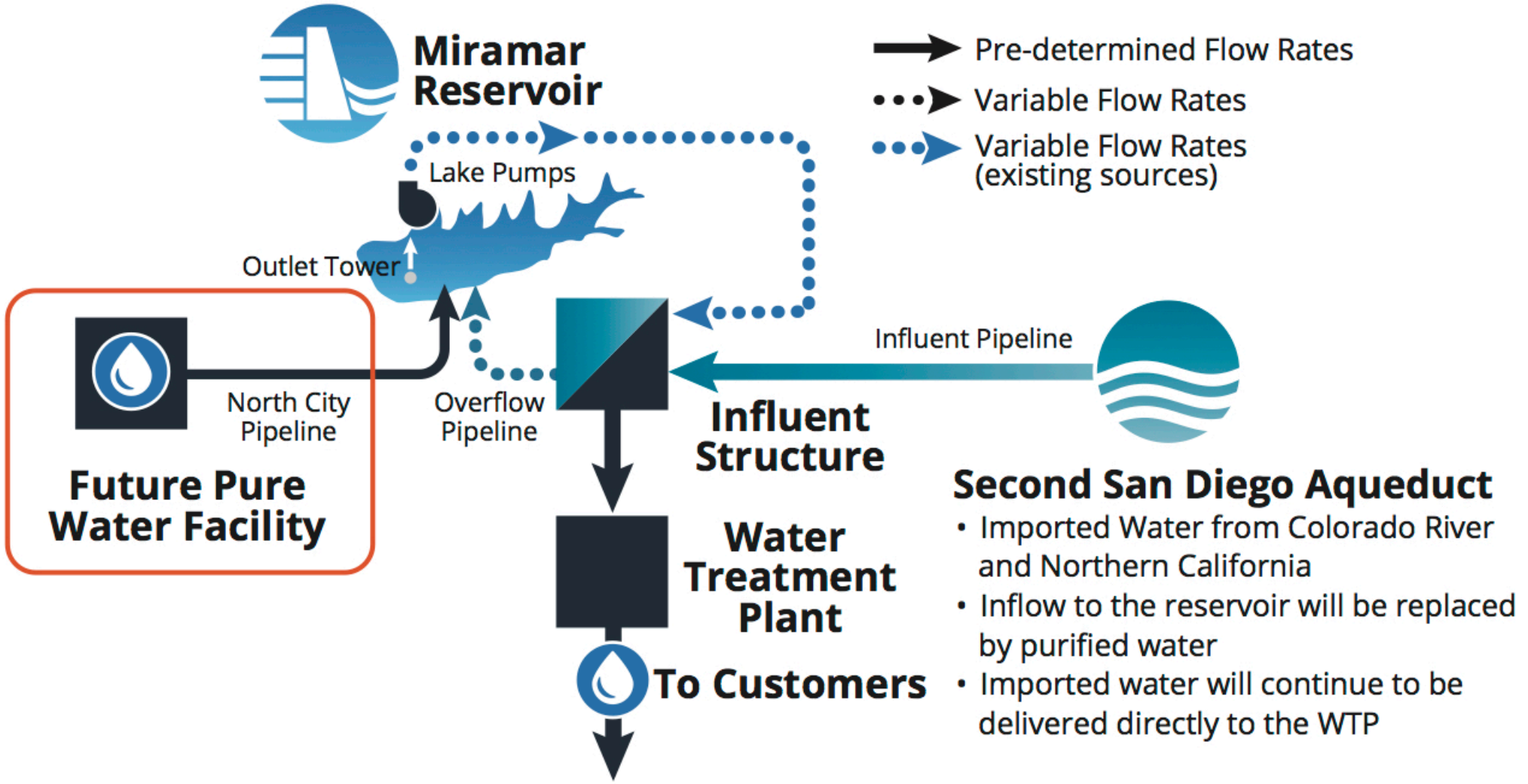
- **2035 Completion**
- **53 mgd**
- **Central Area PWF to San Vicente or Lake Murray**

North City (Phase 1) Project Components

- Sewer pumps station and conveyance pipeline
- Water Reclamation Plant expansion
- North City Pure Water Facility
- Purified water pump station and pipeline
- Miramar Reservoir and Drinking Water Treatment Plant
- Metro Biosolids Center improvements



Pure Water North City Project



Miramar Reservoir Storage

- 6,700 acre-feet max storage (2200 MG)
- 650 acre catchment area

Miramar Reservoir

Dilution Criteria

- >100:1 dilution of all 24-hour purified water inflows
  - ***>10:1 dilution with additional treatment***
  - *Tracer study and modeling to demonstrate compliance*

Prior to augmentation,…the [Surface Water Source Augmentation Project Public Water System (SWSAP PWS)] shall demonstrate to the State Board, utilizing tracer studies and hydrodynamic modeling, that at all times under all operating conditions, the volume of water withdrawn from the augmented reservoir …contains no more than…ten percent, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period…

Panel Advises on Validity

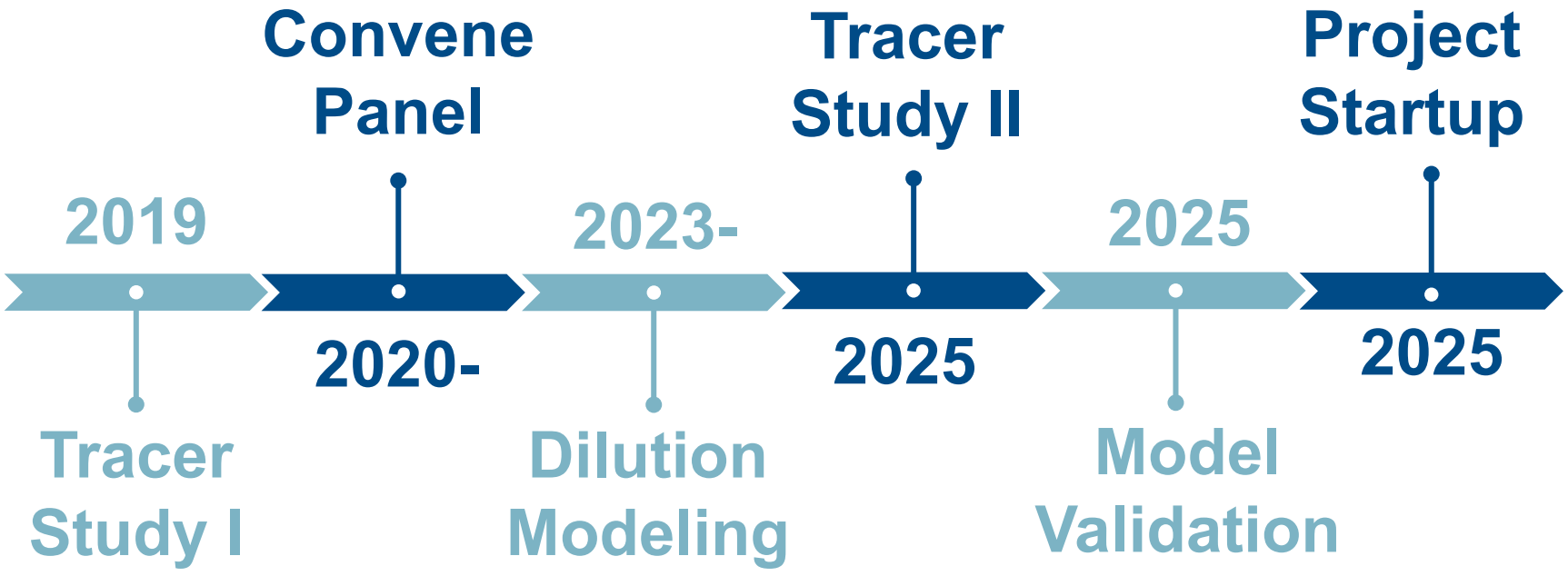
- No criteria given by regulators for model validity
- Independent Advisory Panel advises regulators on validity of model

…the SWSAP PWS shall initiate a tracer study utilizing an added tracer. The results of the tracer study shall be used to validate the hydrodynamic modeling required in subsection (c).

a SWSAP PWS shall utilize an independent scientific advisory panel to meet the requirements of this section pertaining to the hydraulic characterization of the reservoir, including tracer study verifications and hydraulic modeling used to demonstrate compliance with subsection (c)

Project Goals

- Complete tracer study and modeling
- Develop criteria on model validity with Panel
- Distill “Lessons Learned” for Tracer Study II



Pure Water San Diego

Tracer Study

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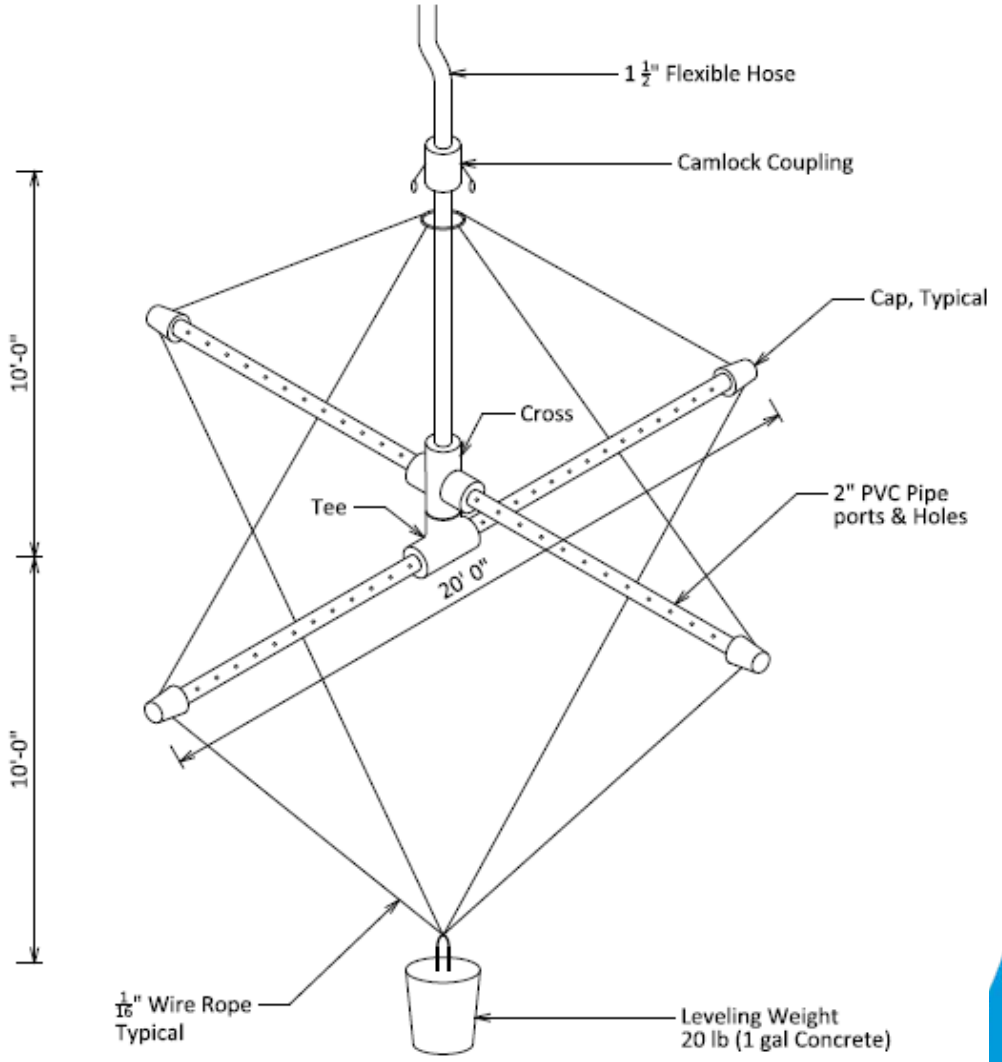
Model Validation

Results and Lessons Learned

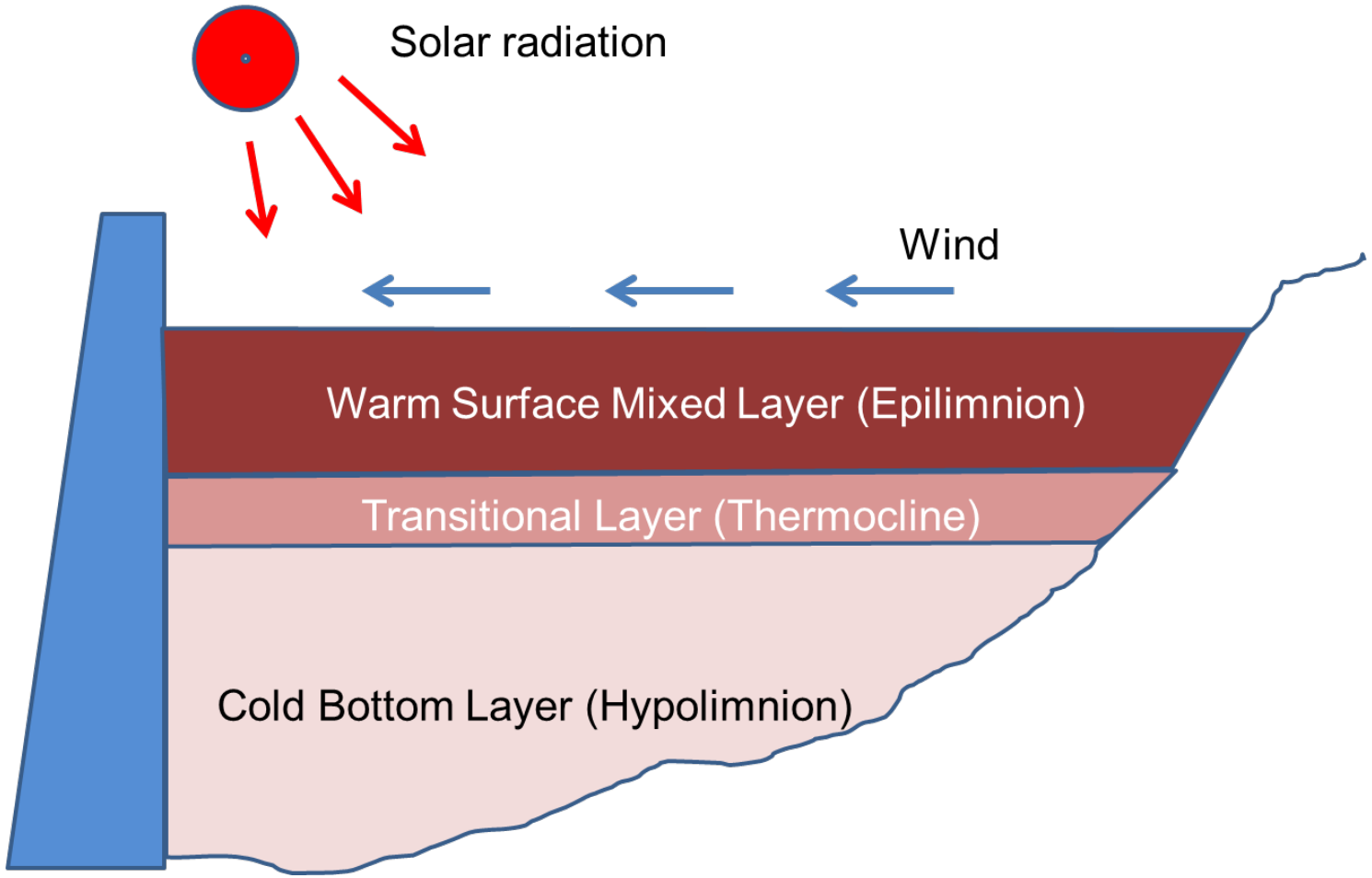
The City of SAN DIEGO

Tracer Study

- Tracer Study in July-Oct 2019
- Rhodamine WT tracer
  - *Injected through small diffuser*



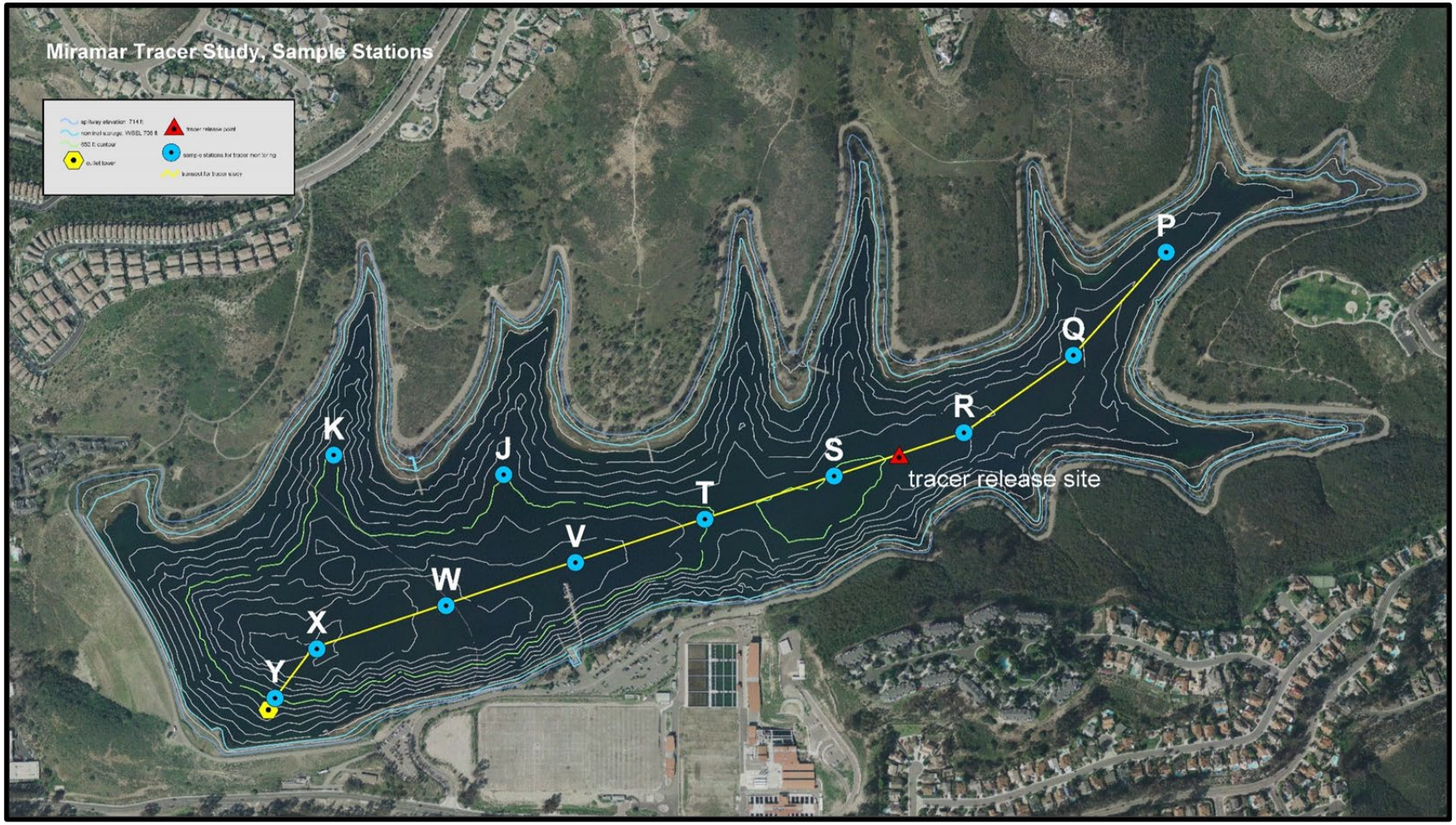
Miramar Reservoir Thermal Structure



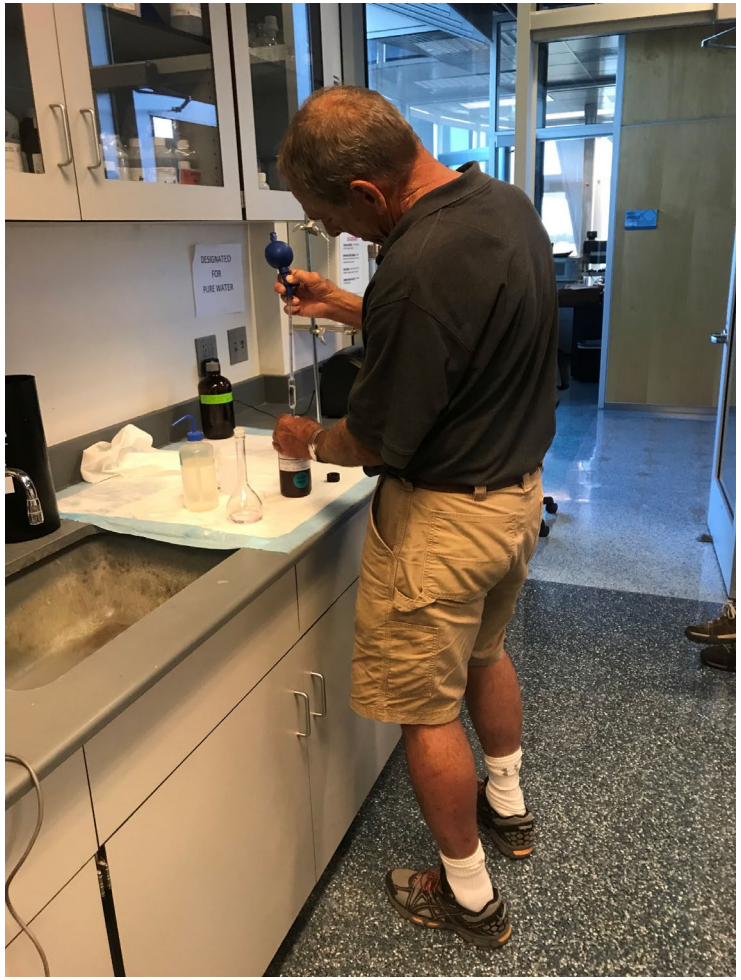
Tracer Study: Sampling Plan

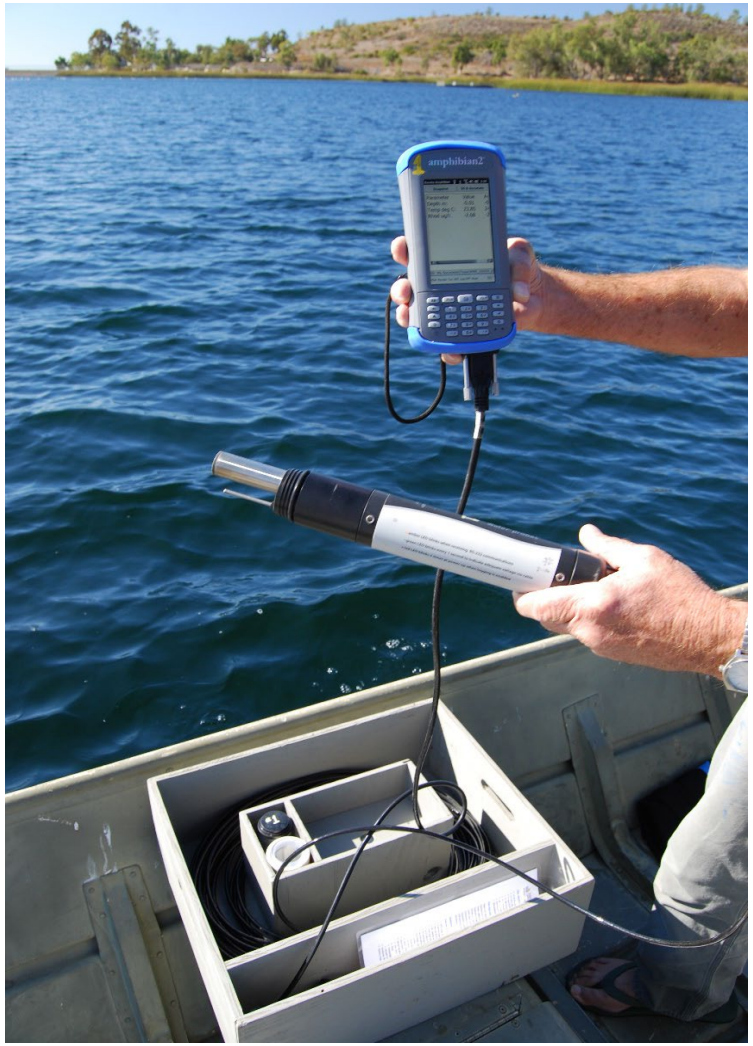
- Sample frequently, then occasionally
- Sample only at predetermined locations
  - *Do not "chase" tracer around reservoir*
  - *Sample stations where tracer may occur*

Tracer Study: Sampling Stations

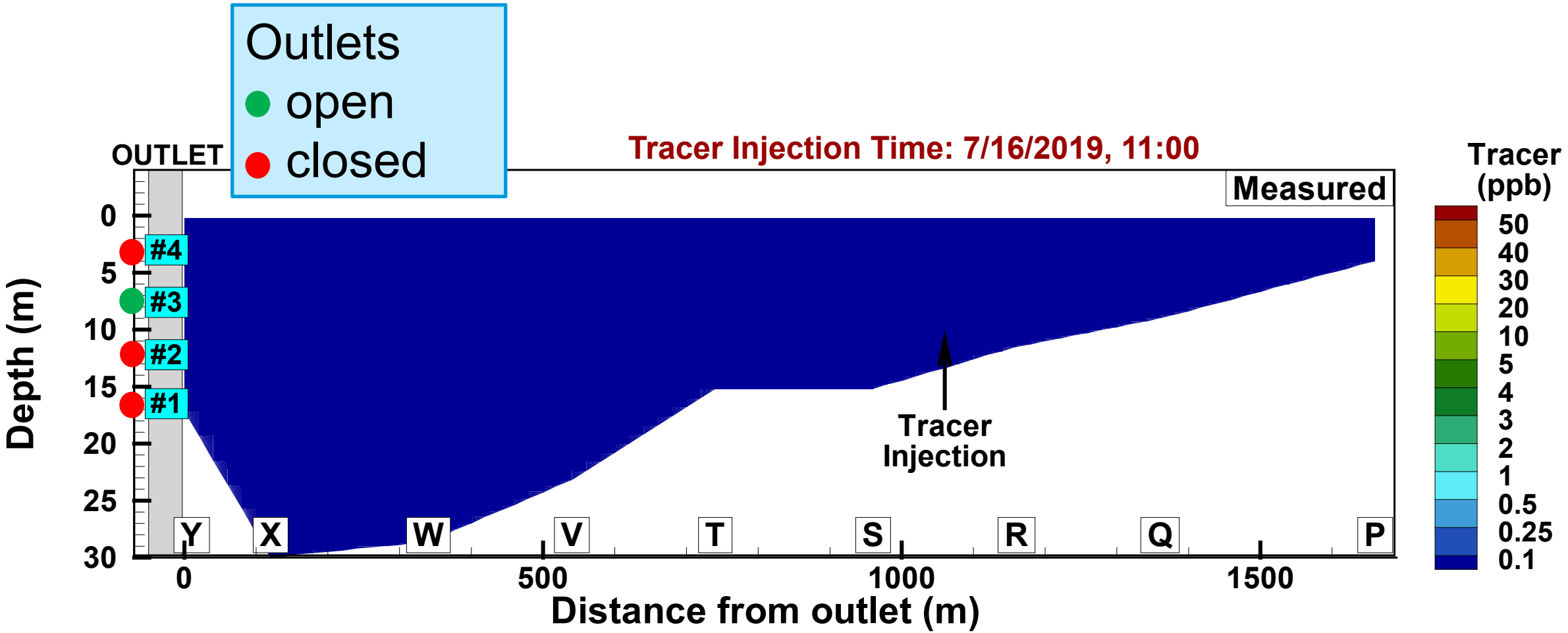


Tracer Study: Calibration and Background



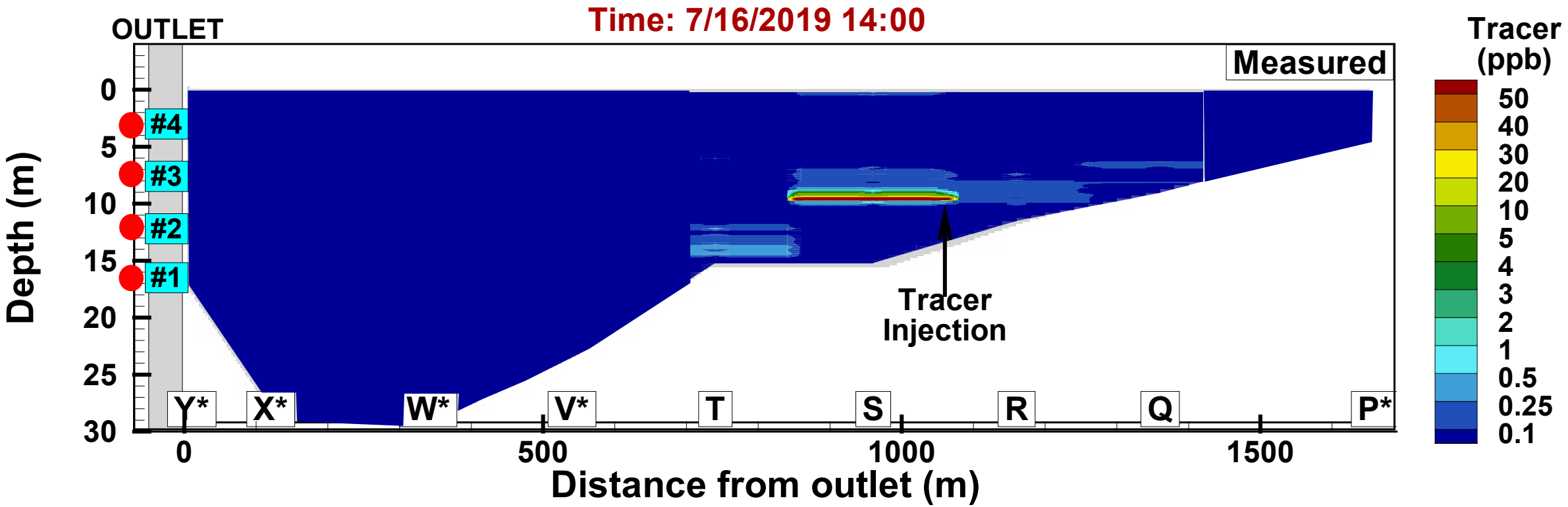


Tracer Study: Measured Tracer



Tracer Study: Measured Tracer

Time: 07/16/2019 14:00 (+3 hours)

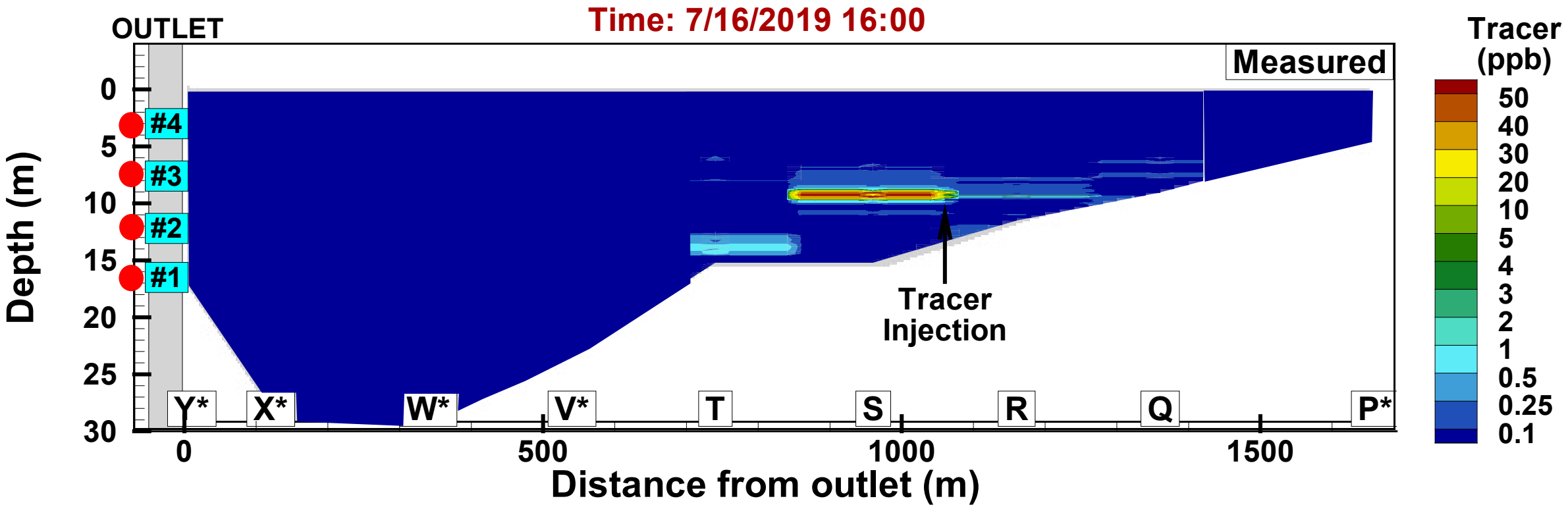


All ports closed

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/16/2019 16:00 (+5 hours)

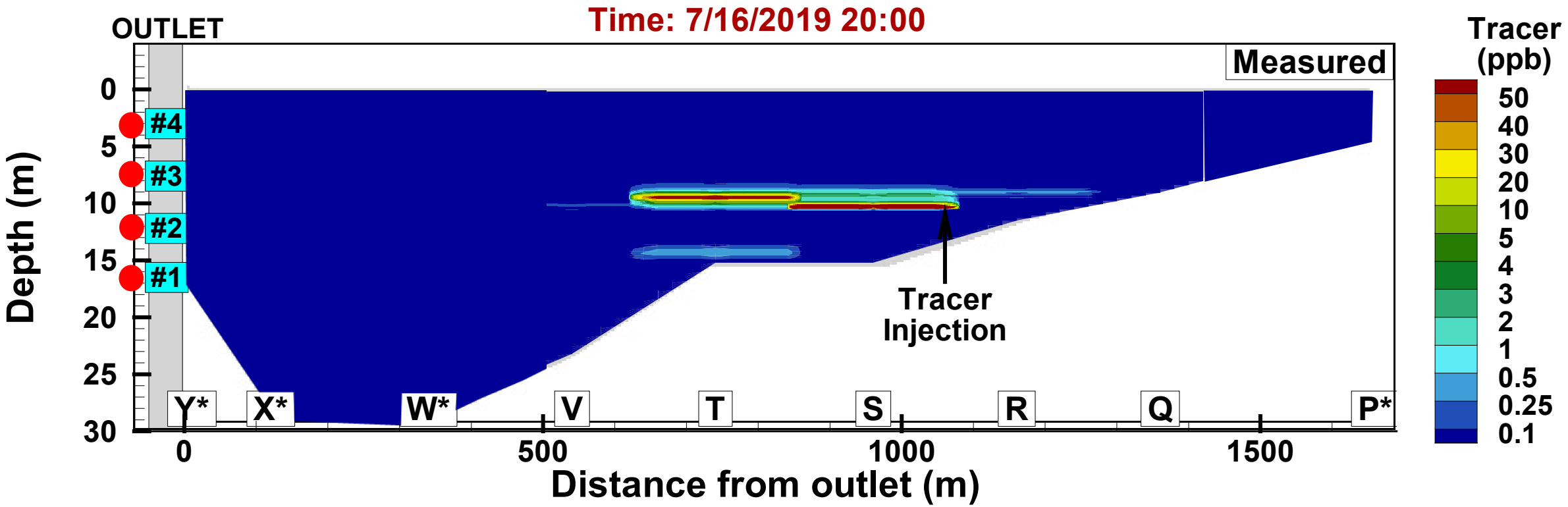


All ports closed

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/16/2019 20:00 (+9 hours)

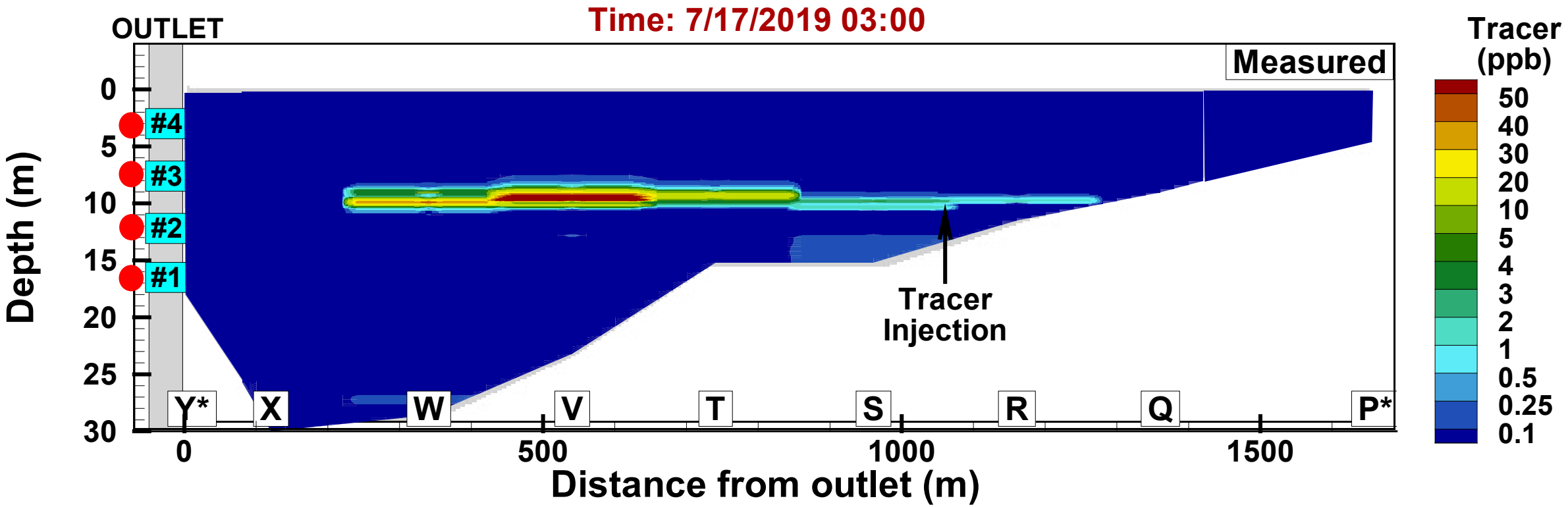


All ports closed

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/17/2019 03:00 (+16 hours)

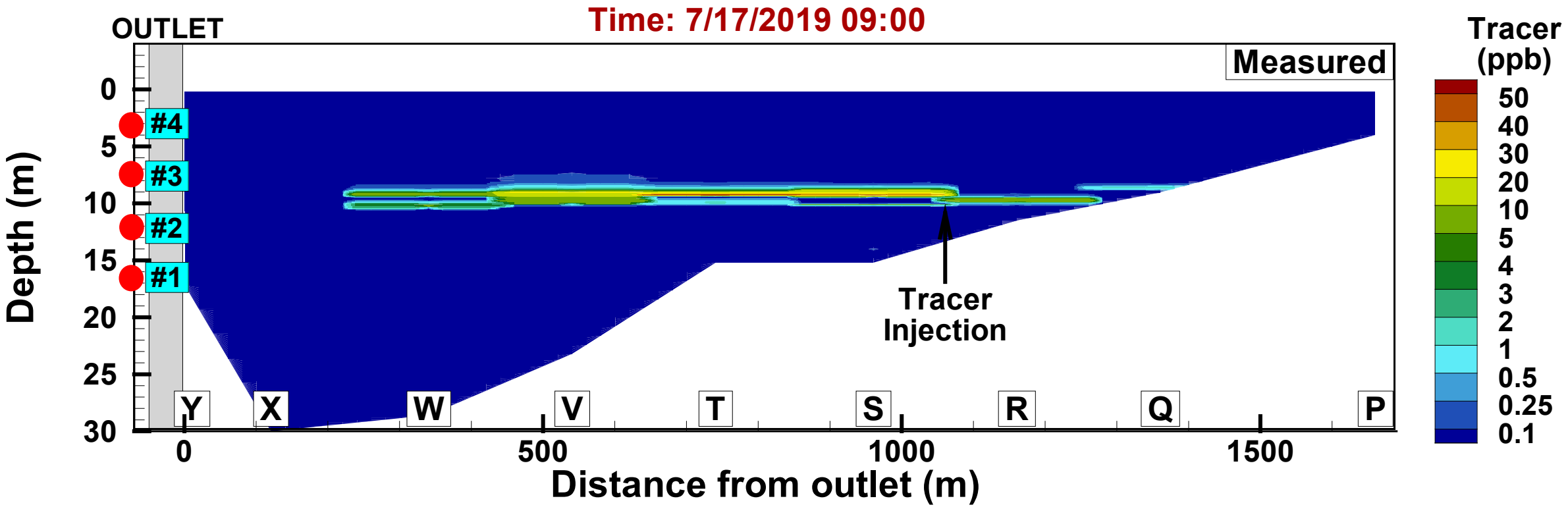


All ports closed

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/17/2019 09:00 (+22 hours)



All ports closed

Tracer Study: Measured Tracer

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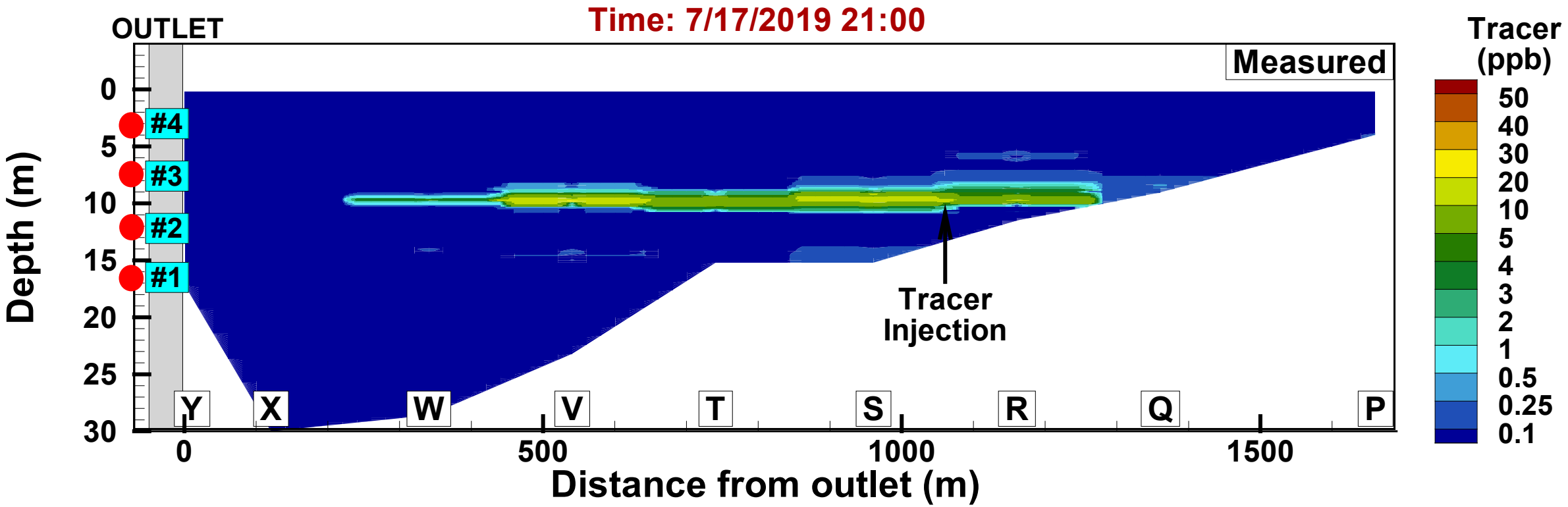
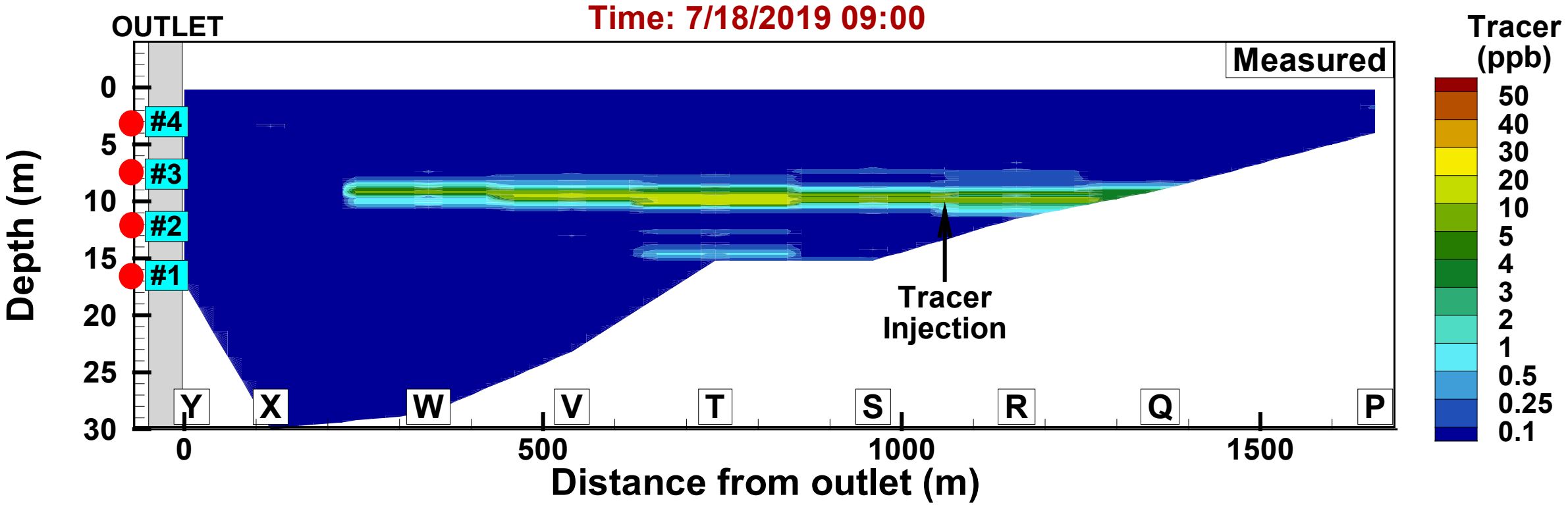


All ports closed

Tracer Study: Measured Tracer

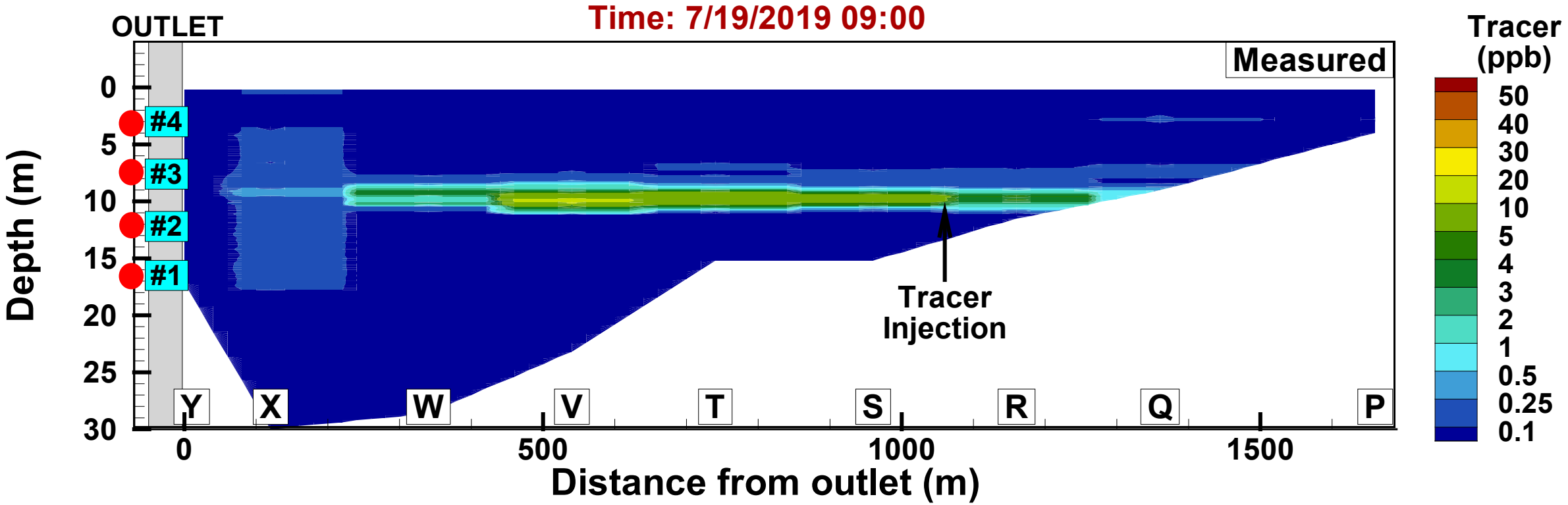
Time: 07/18/2019 09:00 (+46 hours)



All ports closed

Tracer Study: Measured Tracer

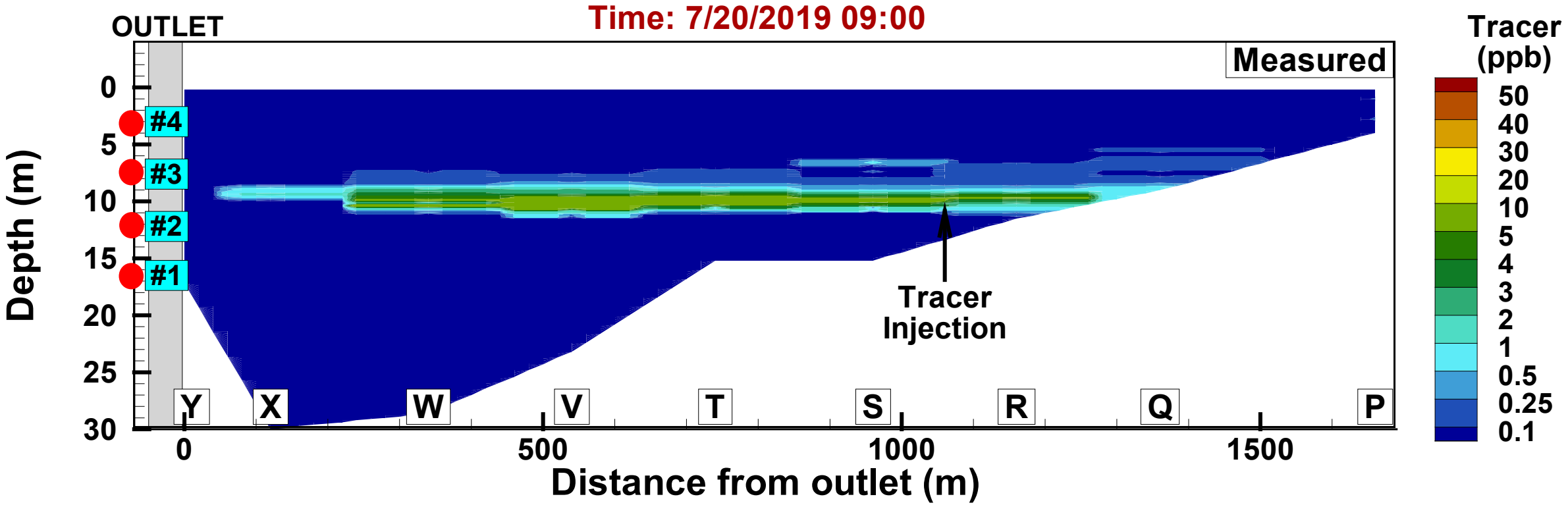
Time: 07/19/2019 09:00 (+3 days)



All ports closed

Tracer Study: Measured Tracer

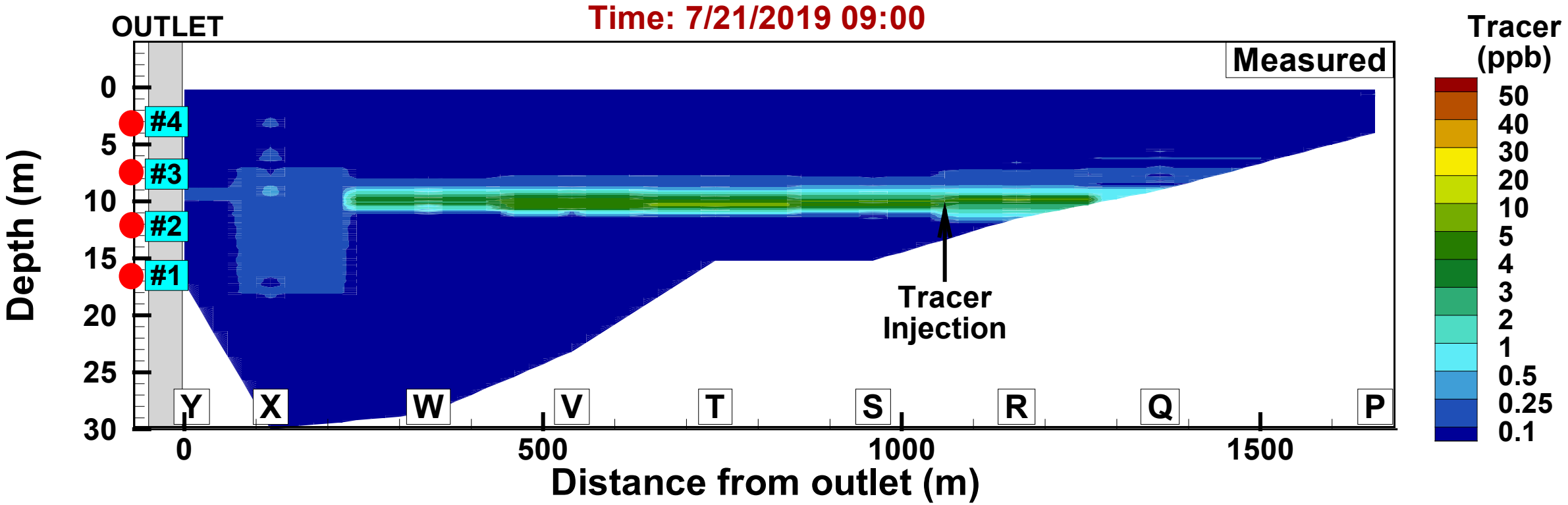
Time: 07/20/2019 09:00 (+4 days)



All ports closed

Tracer Study: Measured Tracer

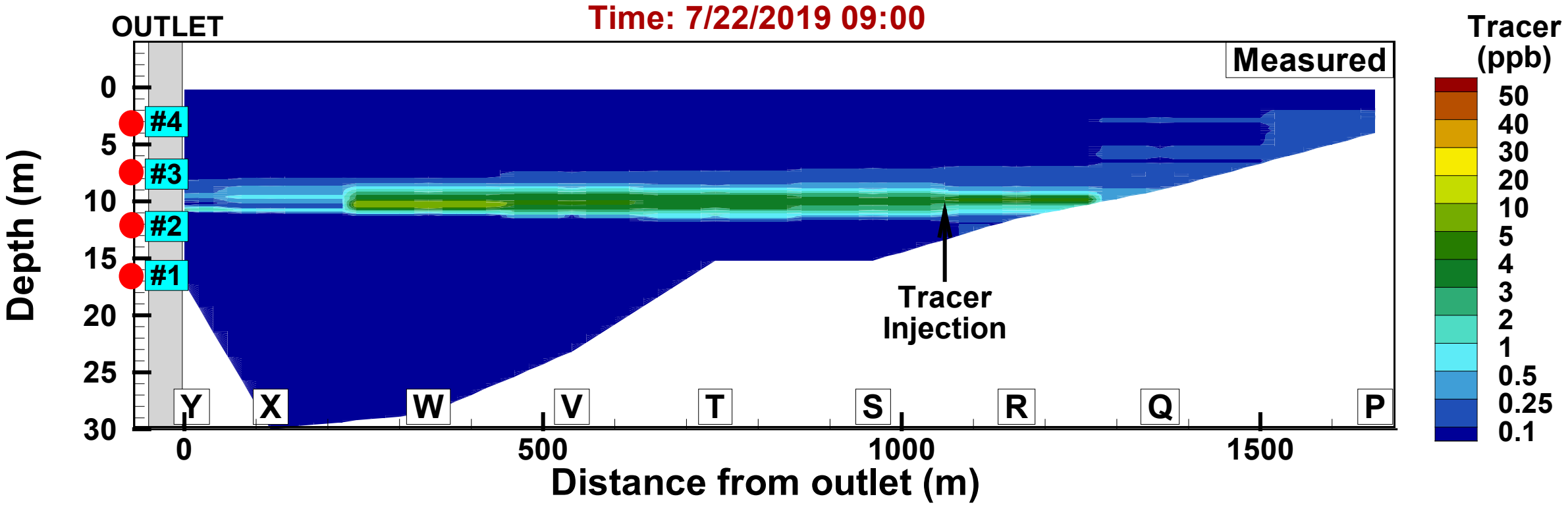
Time: 07/21/2019 09:00 (+5 days)



All ports closed

Tracer Study: Measured Tracer

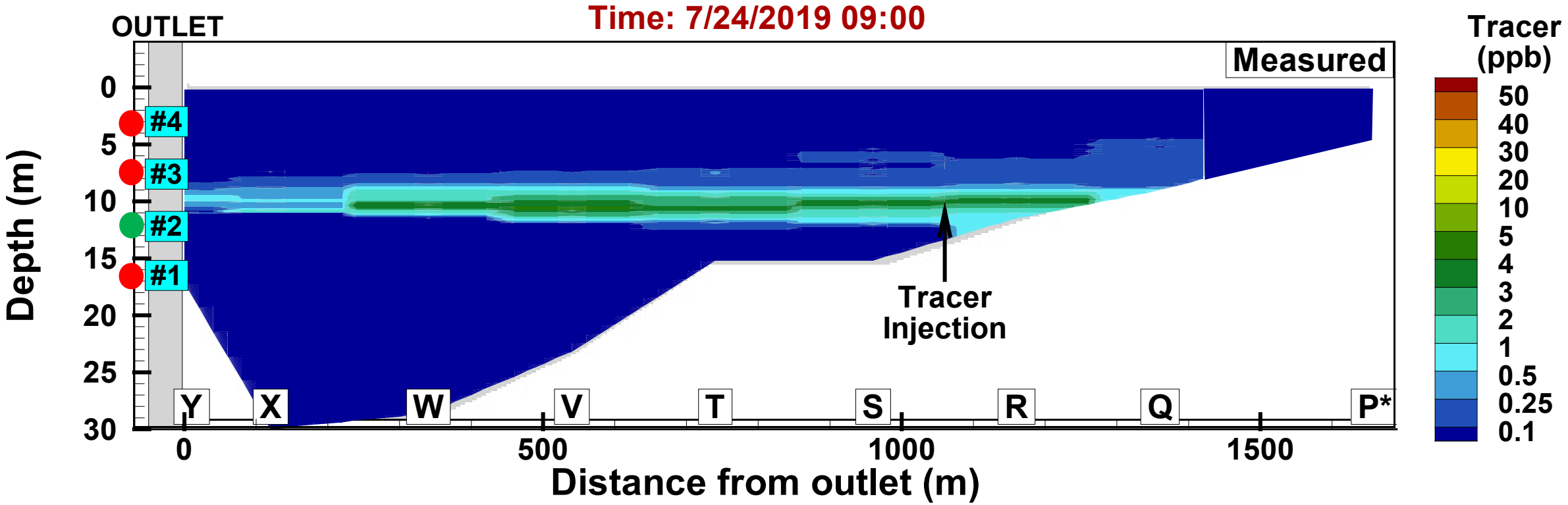
Time: 07/22/2019 09:00 (+6 days)



All ports closed

Tracer Study: Measured Tracer

Time: 07/24/2019 09:00 (+8 days)

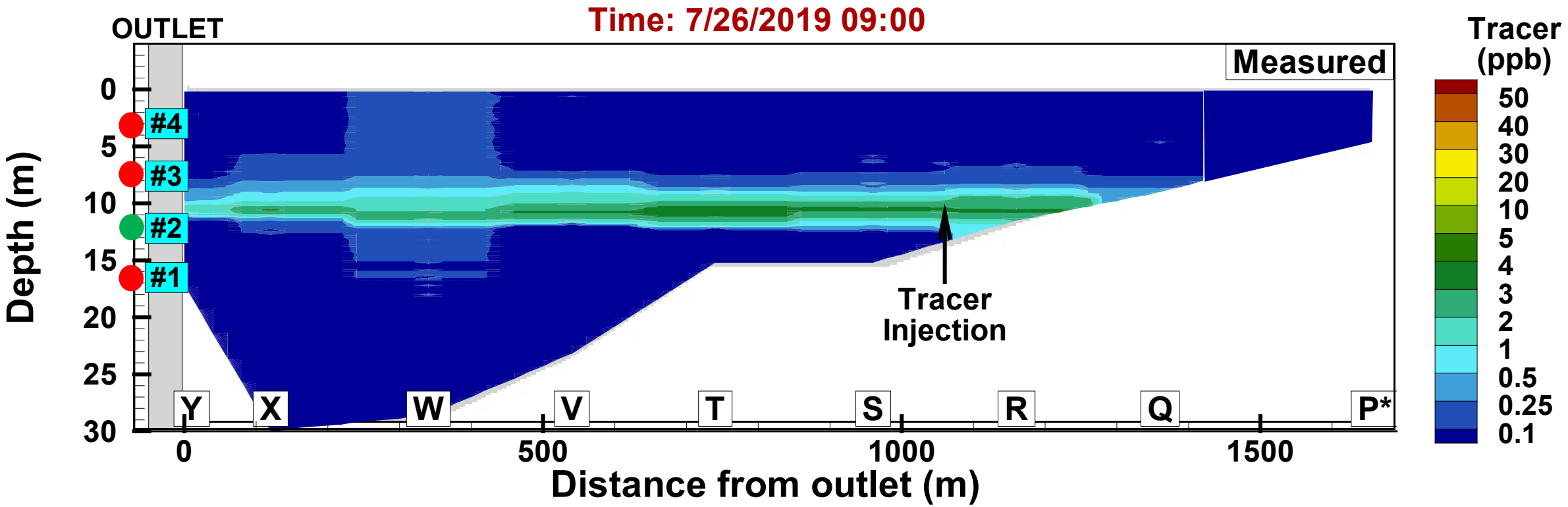


Port #2 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/26/2019 09:00 (+10 days)

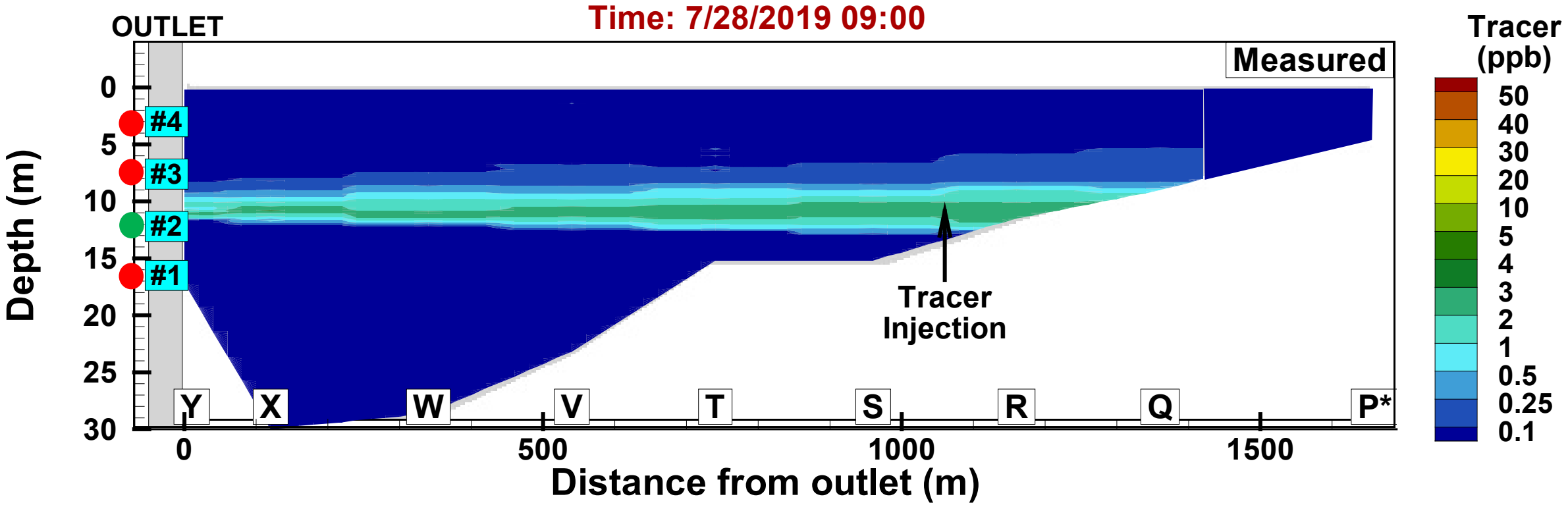


Port #2 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 07/28/2019 09:00 (+12 days)

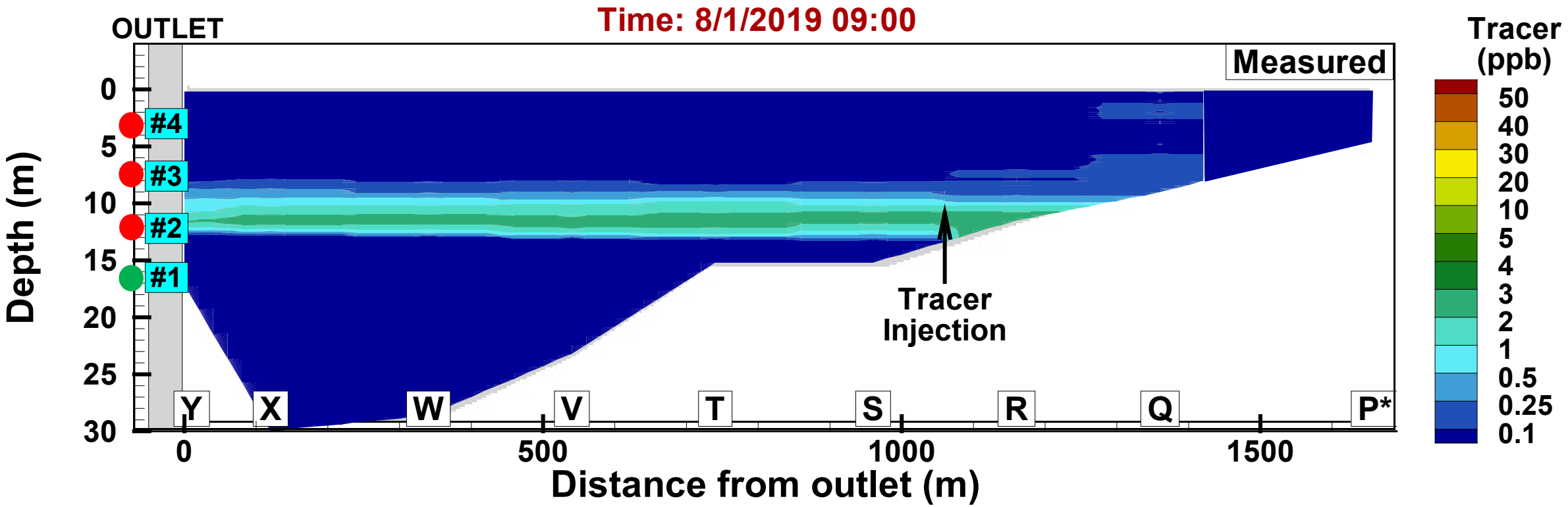


Port #2 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 08/01/2019 09:00 (+16 days)

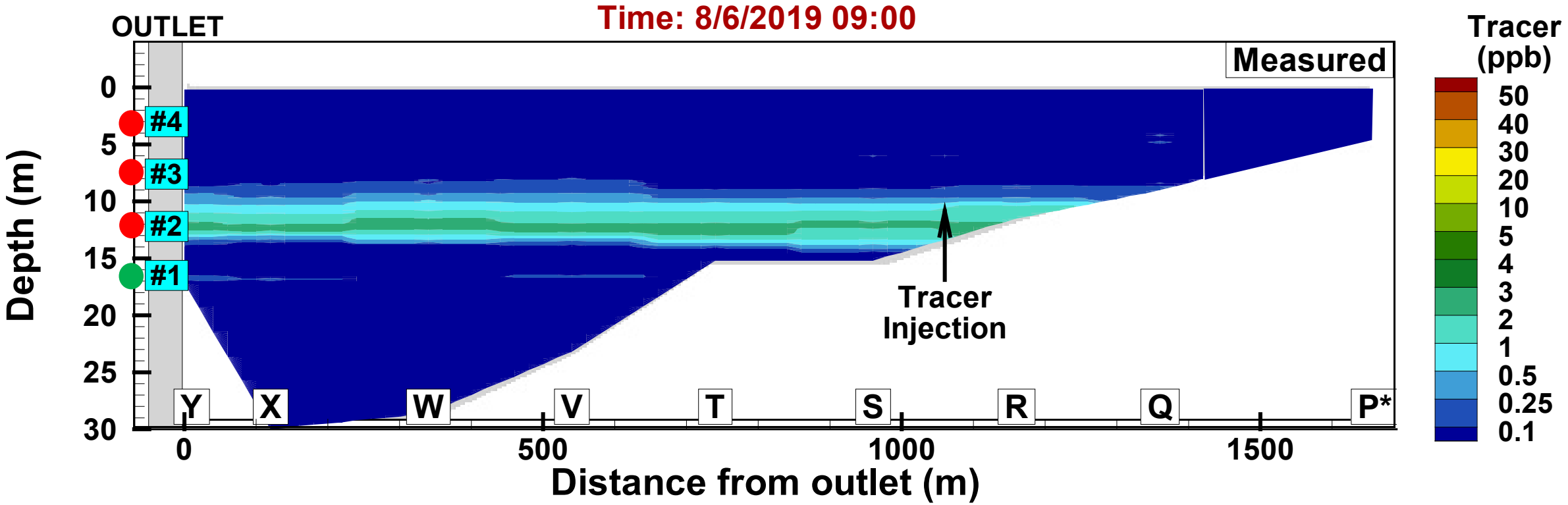


Port #1 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 08/06/2019 09:00 (+21 days)

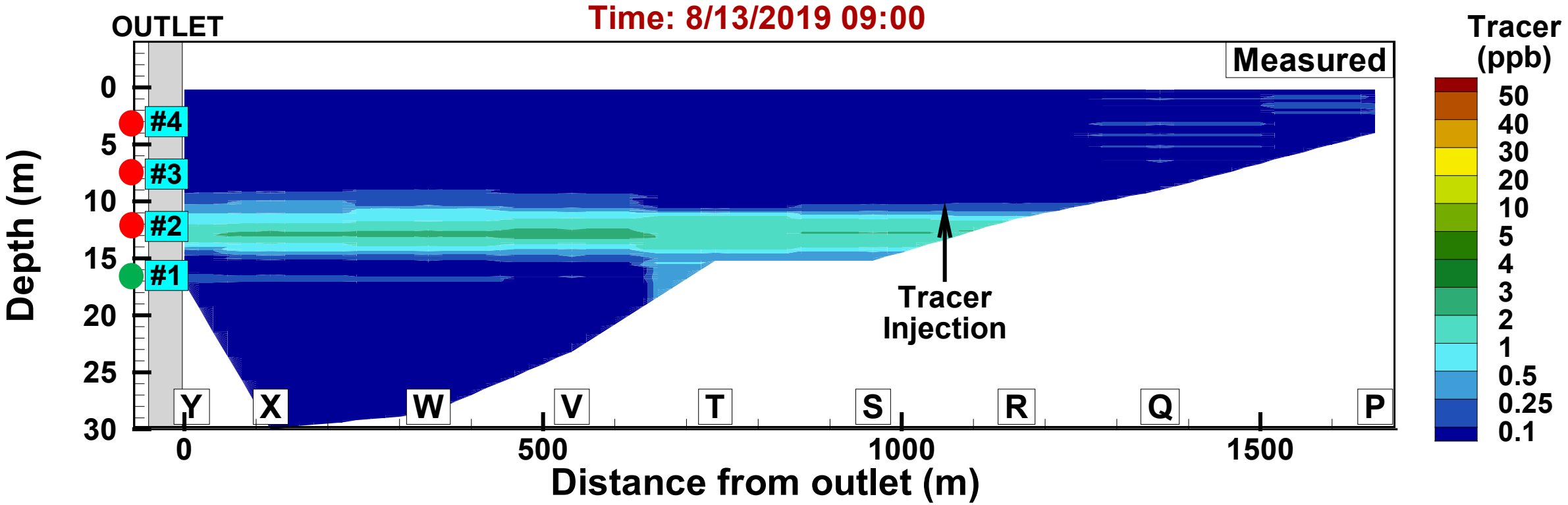


Port #1 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

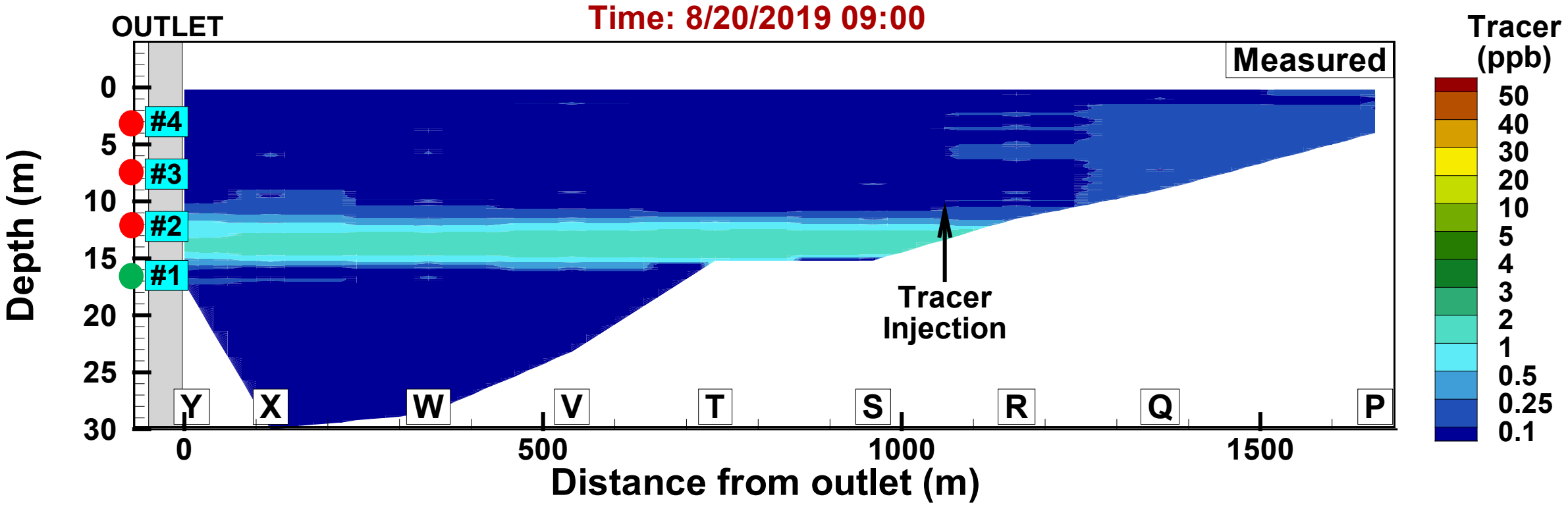
Time: 08/13/2019 09:00 (+28 days)



Port #1 open

Tracer Study: Measured Tracer

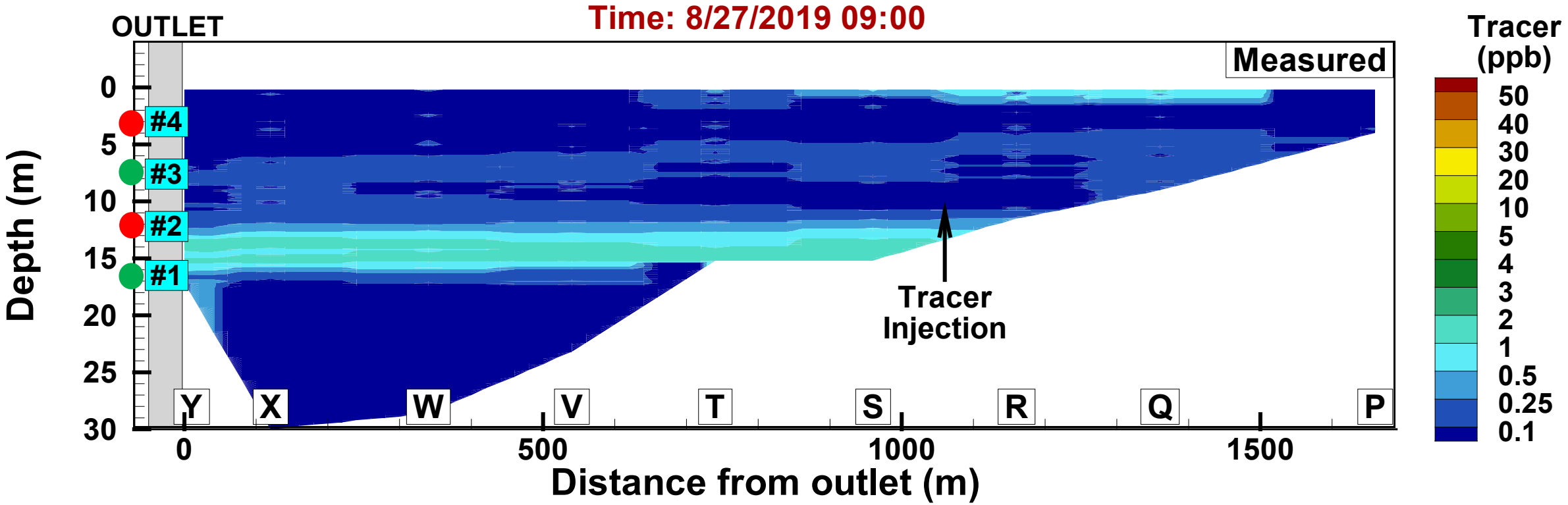
Time: 08/20/2019 09:00 (+35 days)



Port #1 open

Tracer Study: Measured Tracer

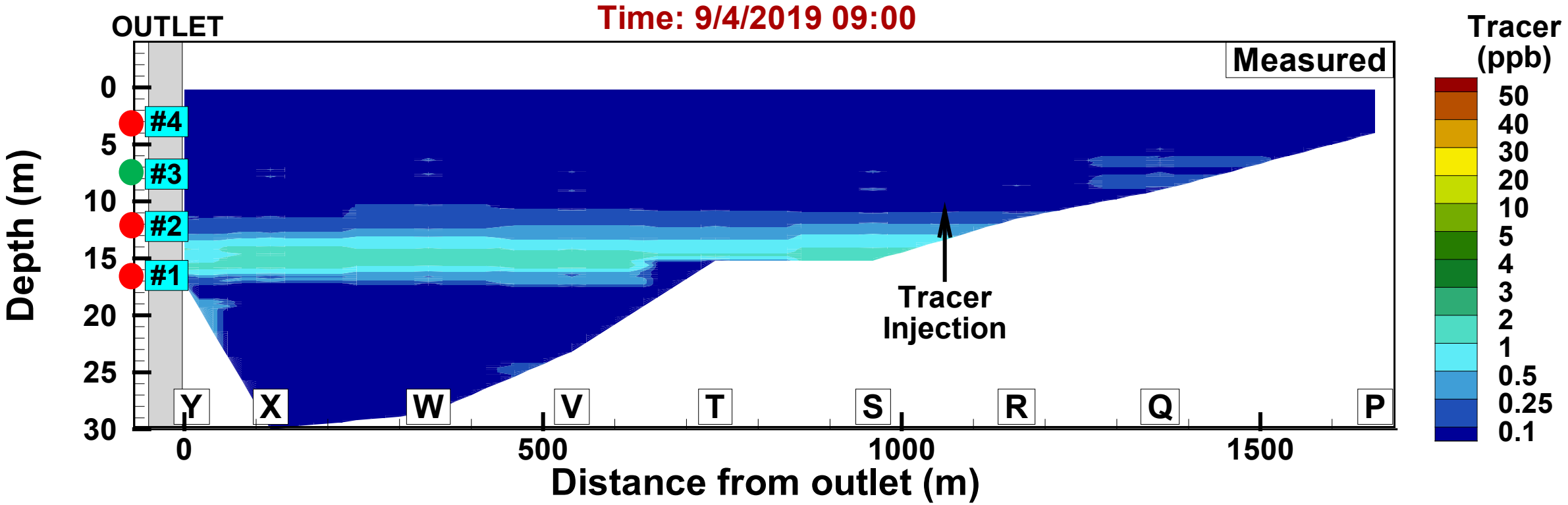
Time: 08/27/2019 09:00 (+42 days)



Ports #1 and #3 open

Tracer Study: Measured Tracer

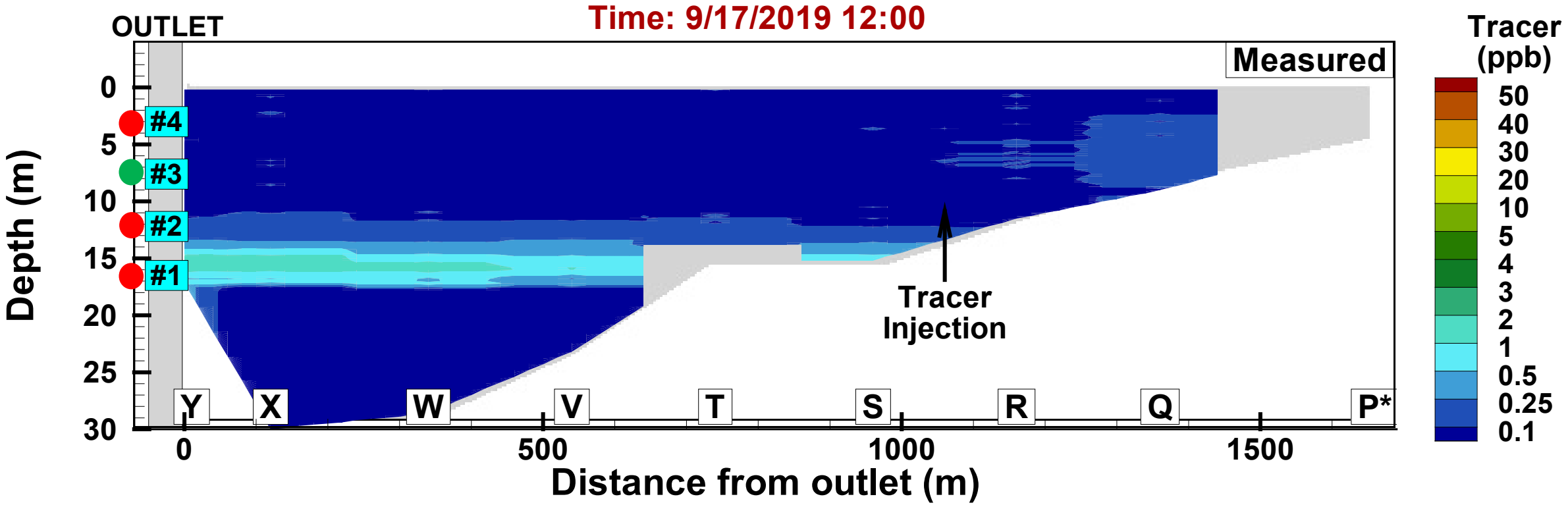
Time: 09/04/2019 09:00 (+50 days)



Port #3 open

Tracer Study: Measured Tracer

Time: 09/17/2019 12:00 (+63 days)

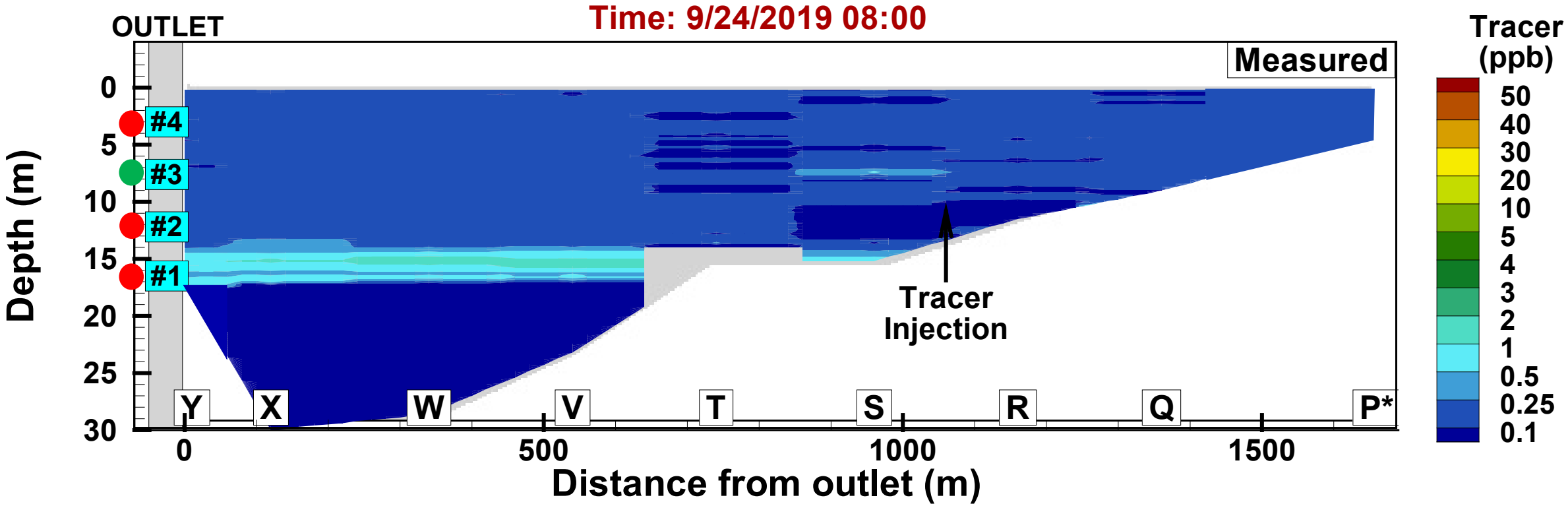


Port #3 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 09/24/2019 08:00 (+70 days)

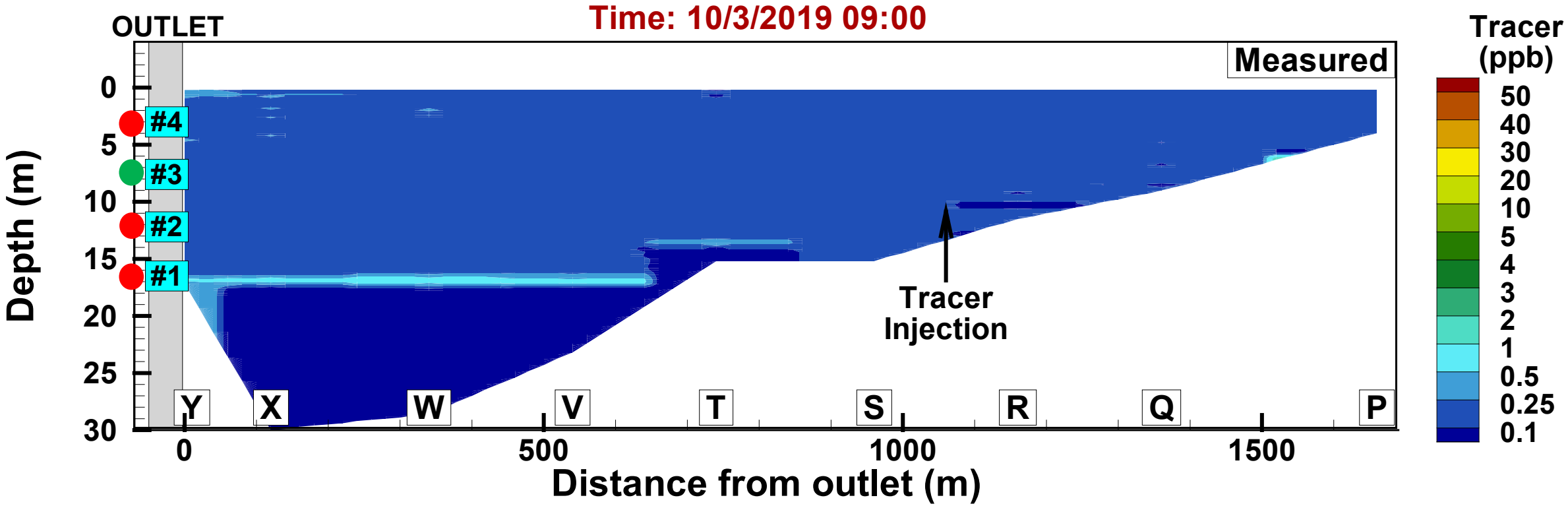


Port #3 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

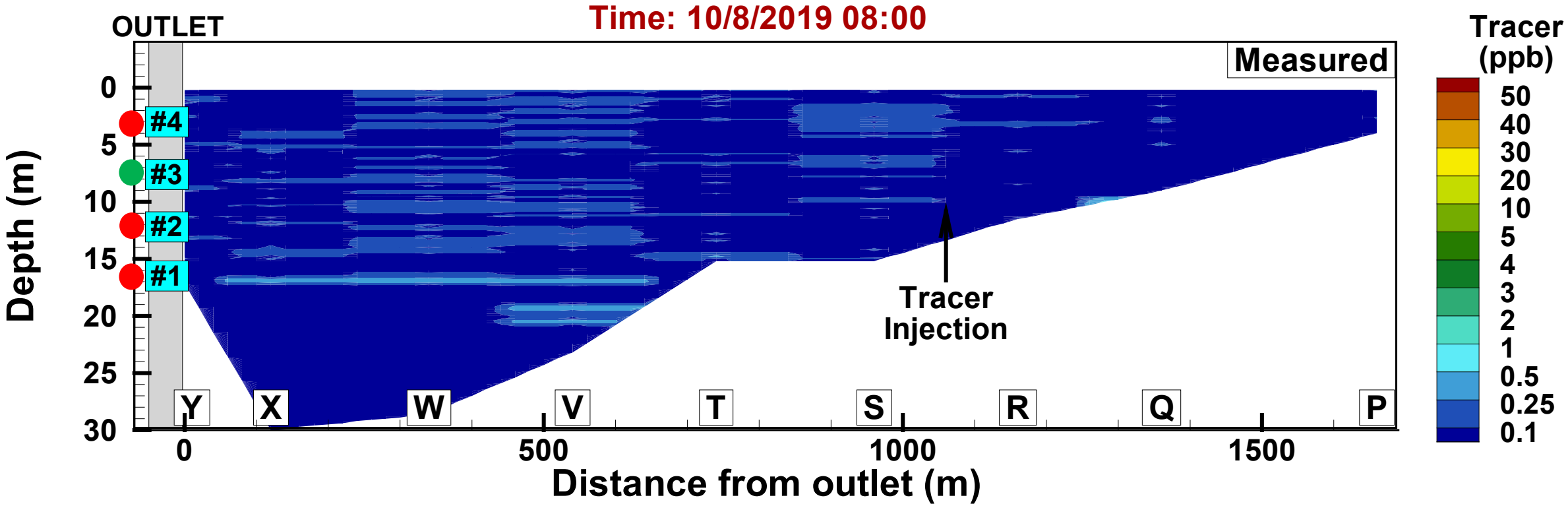
Time: 10/03/2019 09:00 (+79 days)



Port #3 open

Tracer Study: Measured Tracer

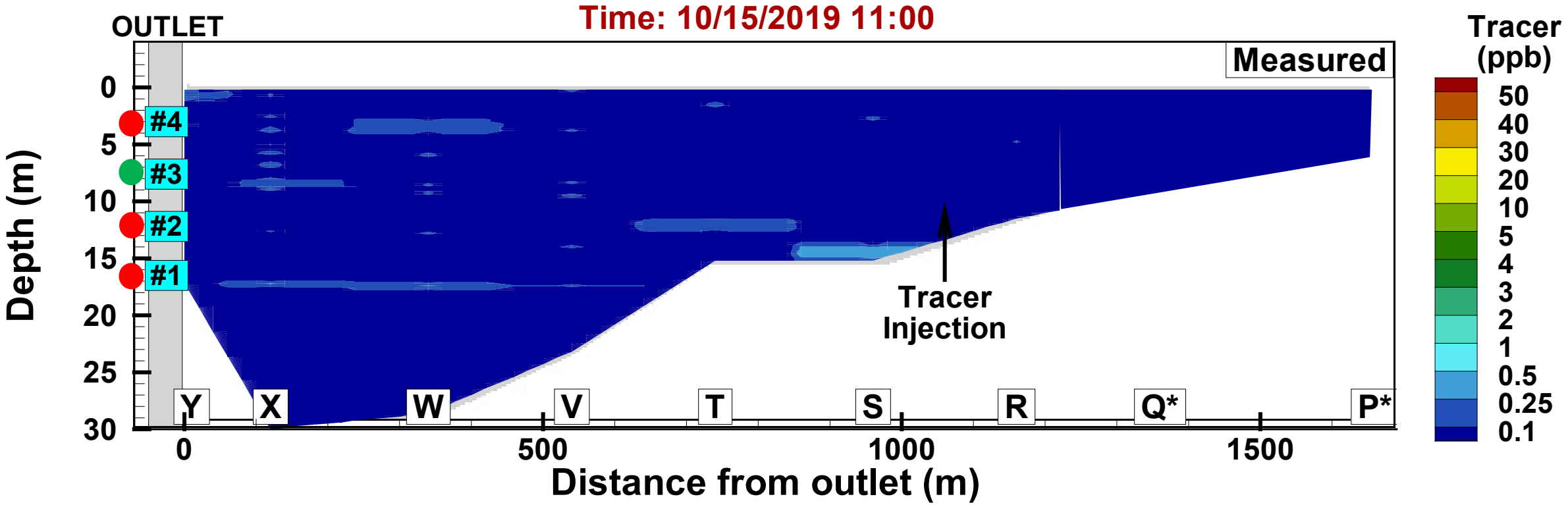
Time: 10/08/2019 08:00 (+84 days)



Port #3 open

Tracer Study: Measured Tracer

Time: 10/15/2019 11:00 (+91 days)

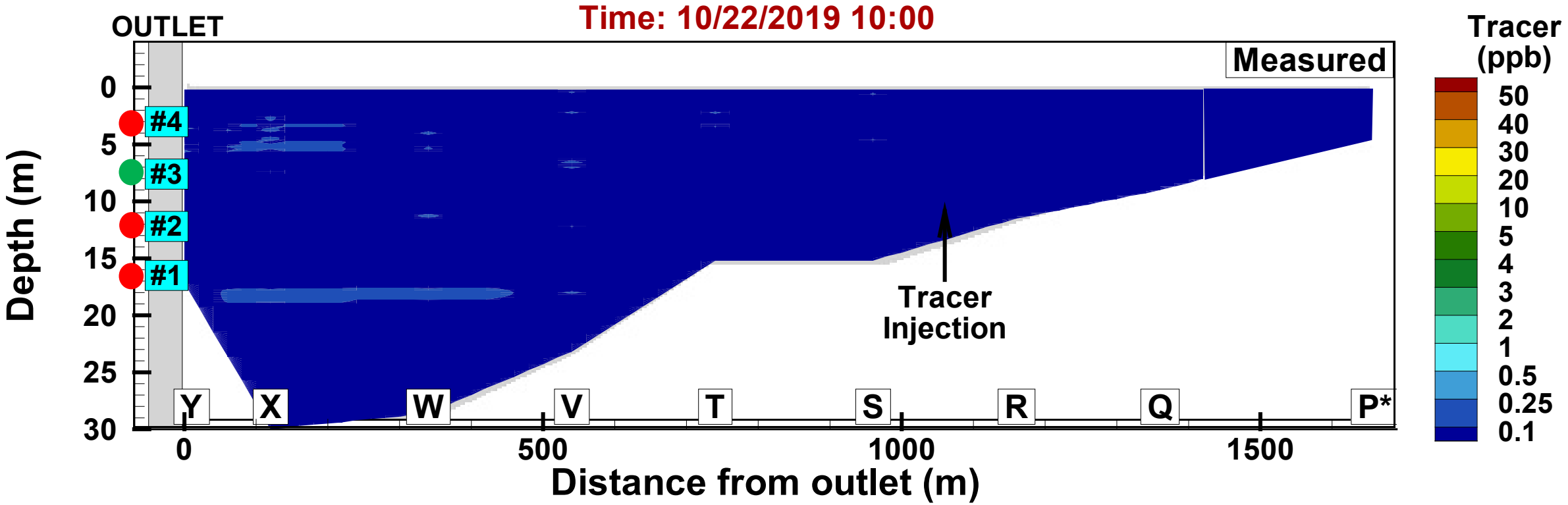


Port #3 open

*Stations not sampled, shown as gray

Tracer Study: Measured Tracer

Time: 10/22/2019 09:00 (+98 days)



Port #3 open

*Stations not sampled, shown as gray

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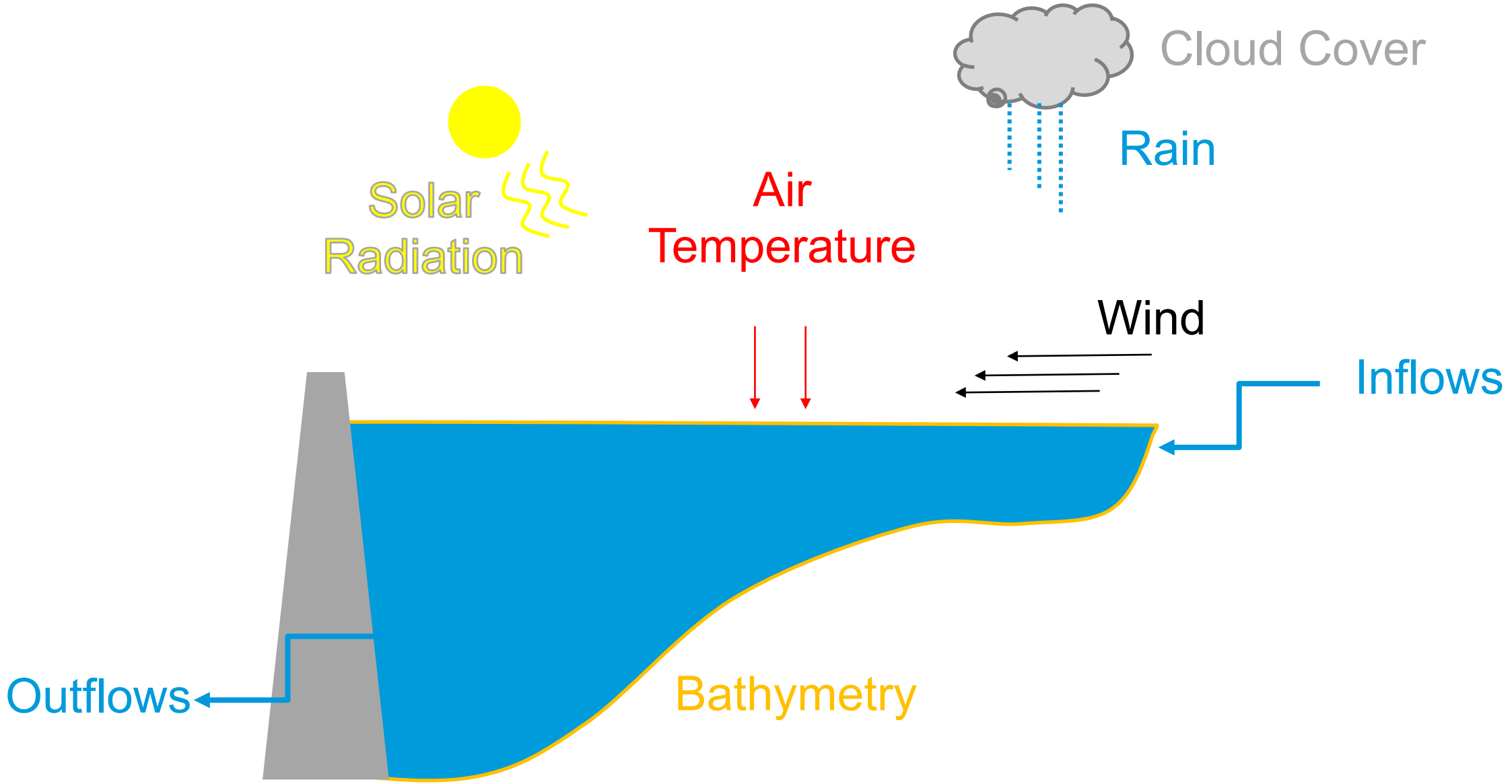
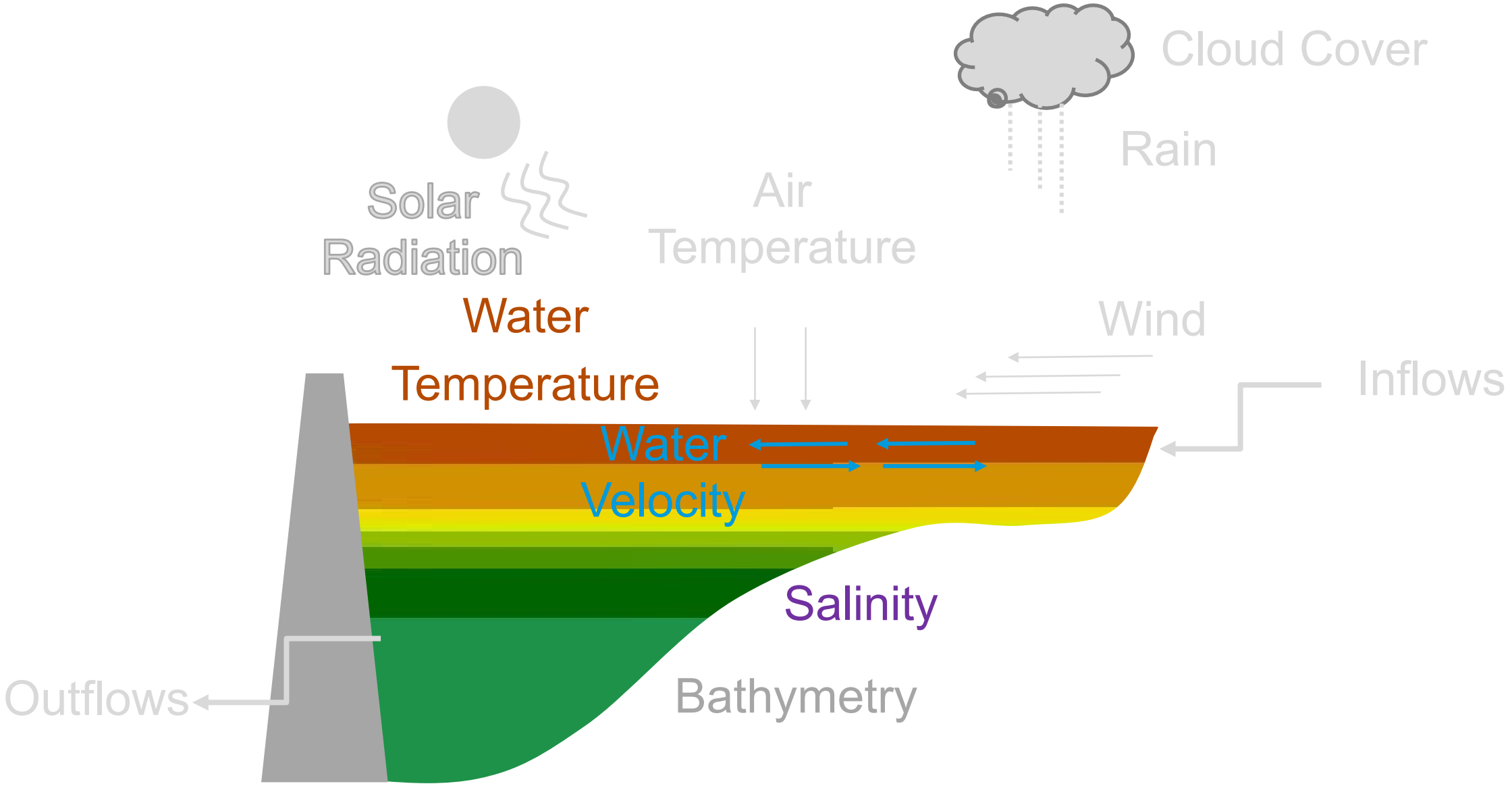
AEM3D Hydrodynamics: Inputs

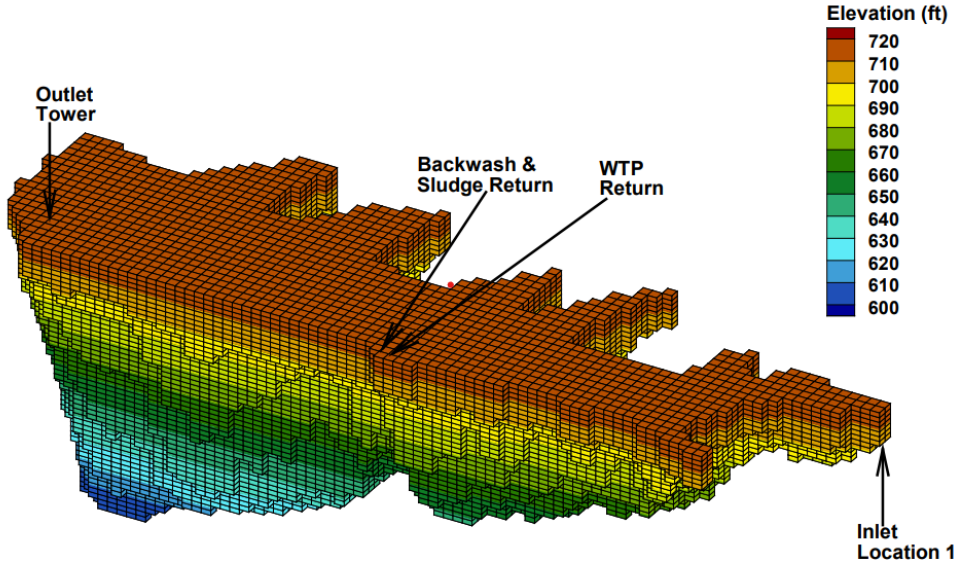


AEM3D Hydrodynamics: Outputs



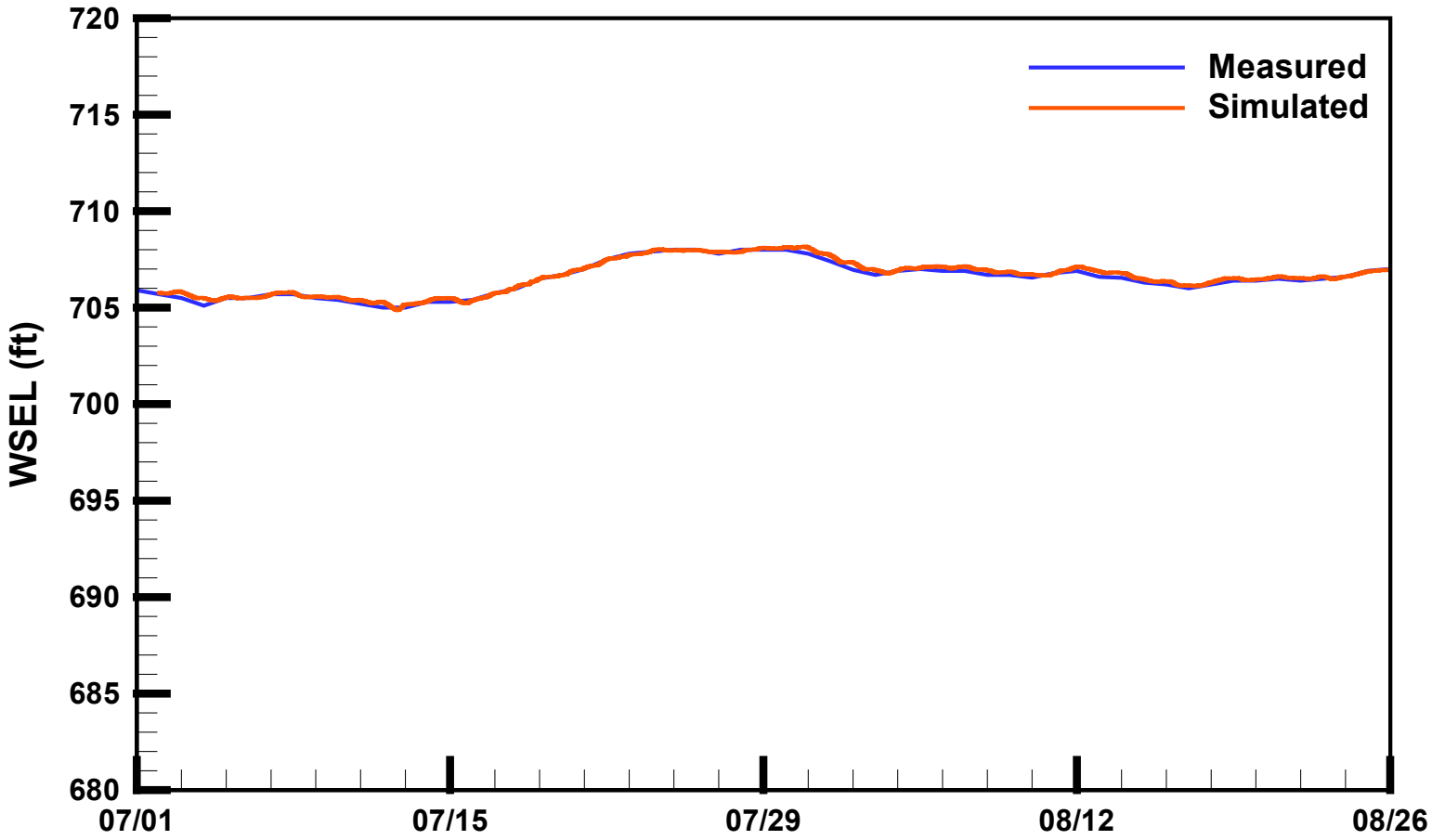
Model Setup

- AEM3D simulates reservoir hydrodynamics
  - *Grid generated*
  - *Flows obtained from City*
  - *Meteorological data obtained nearby*
    - Wind measured at dam

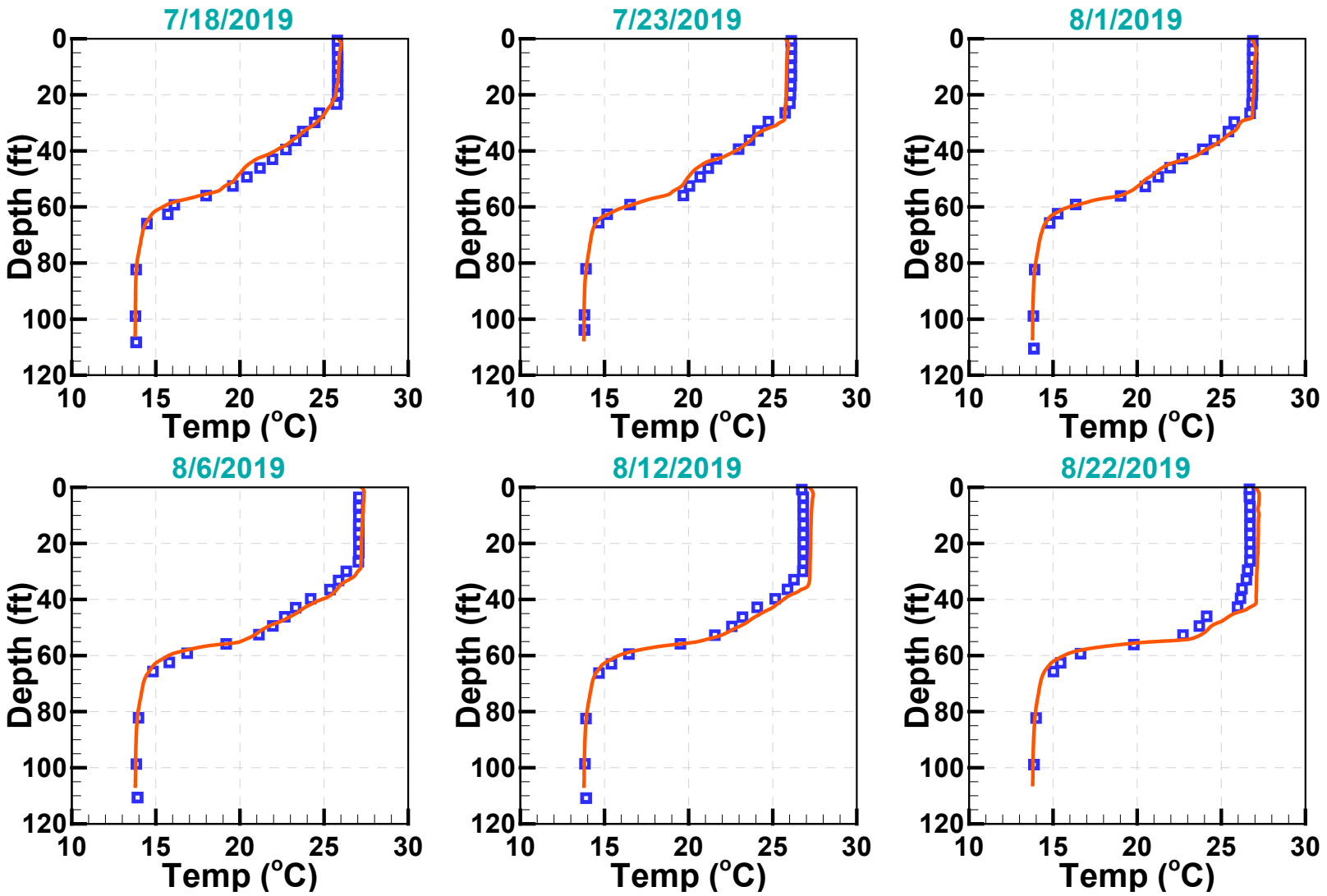


20 m x 20 m x 0.05 m grid

Model Calibration: WSEL



Model Calibration: Temperature Profiles



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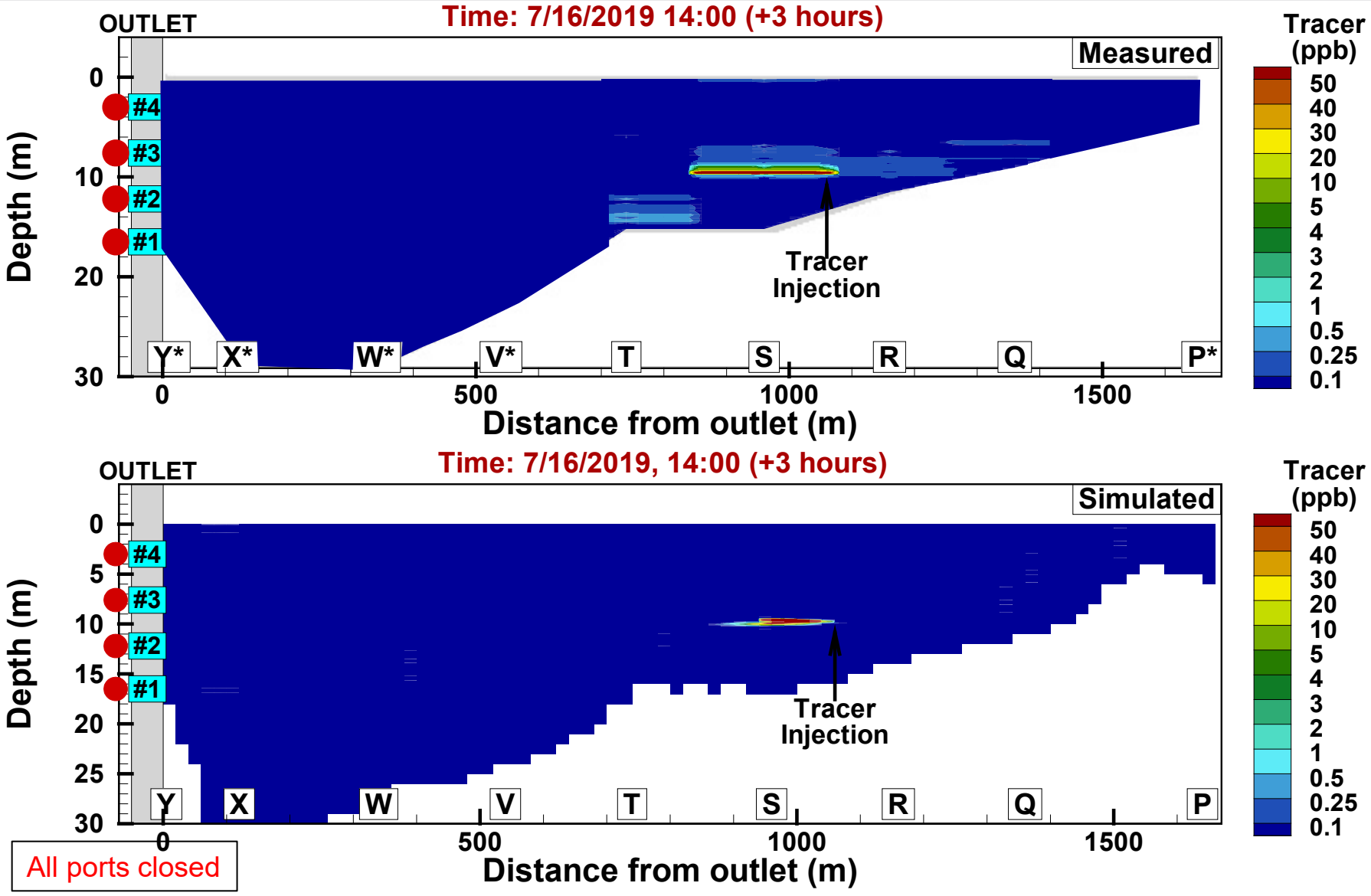
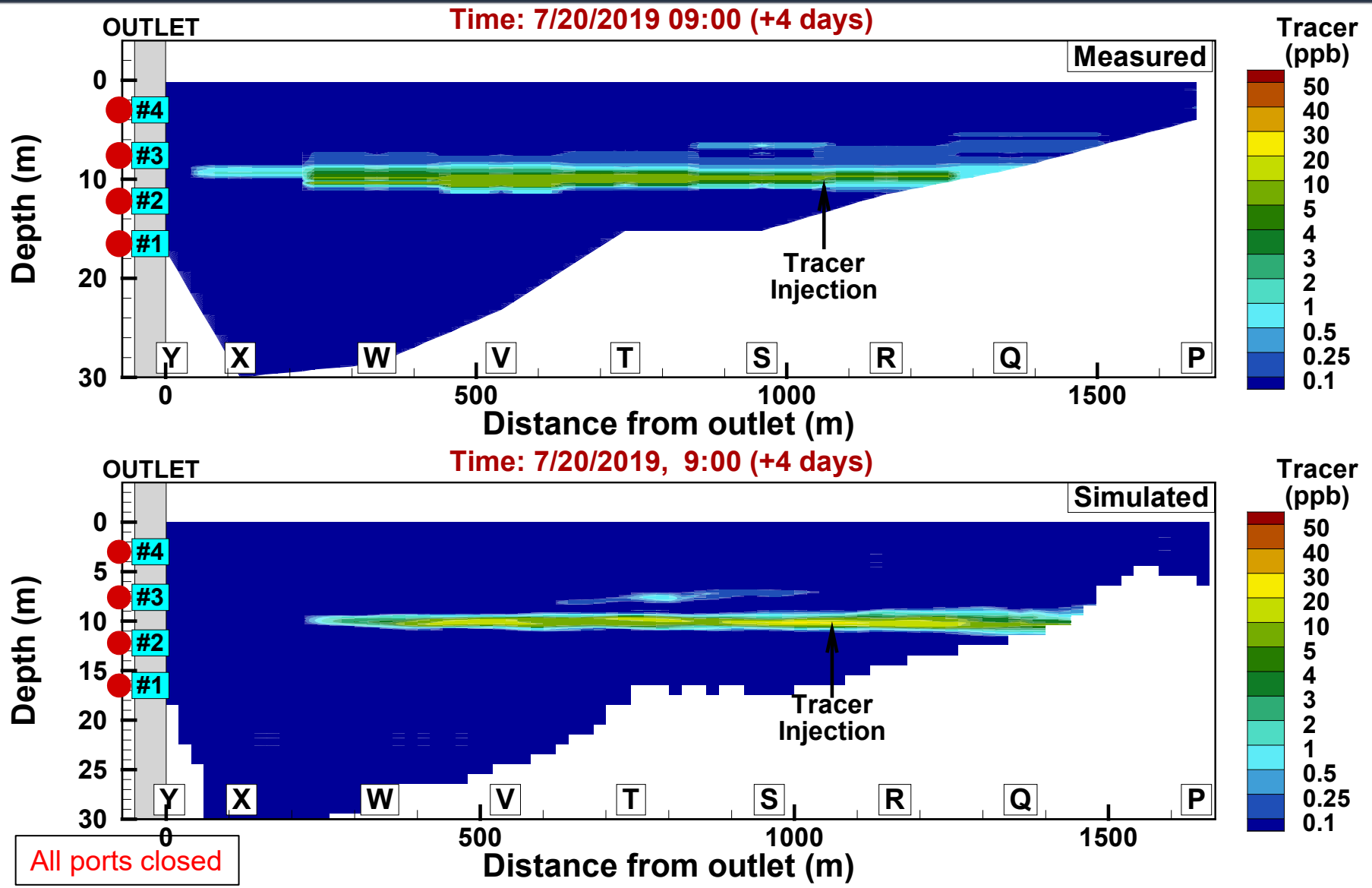
Comparison of Tracer Contours

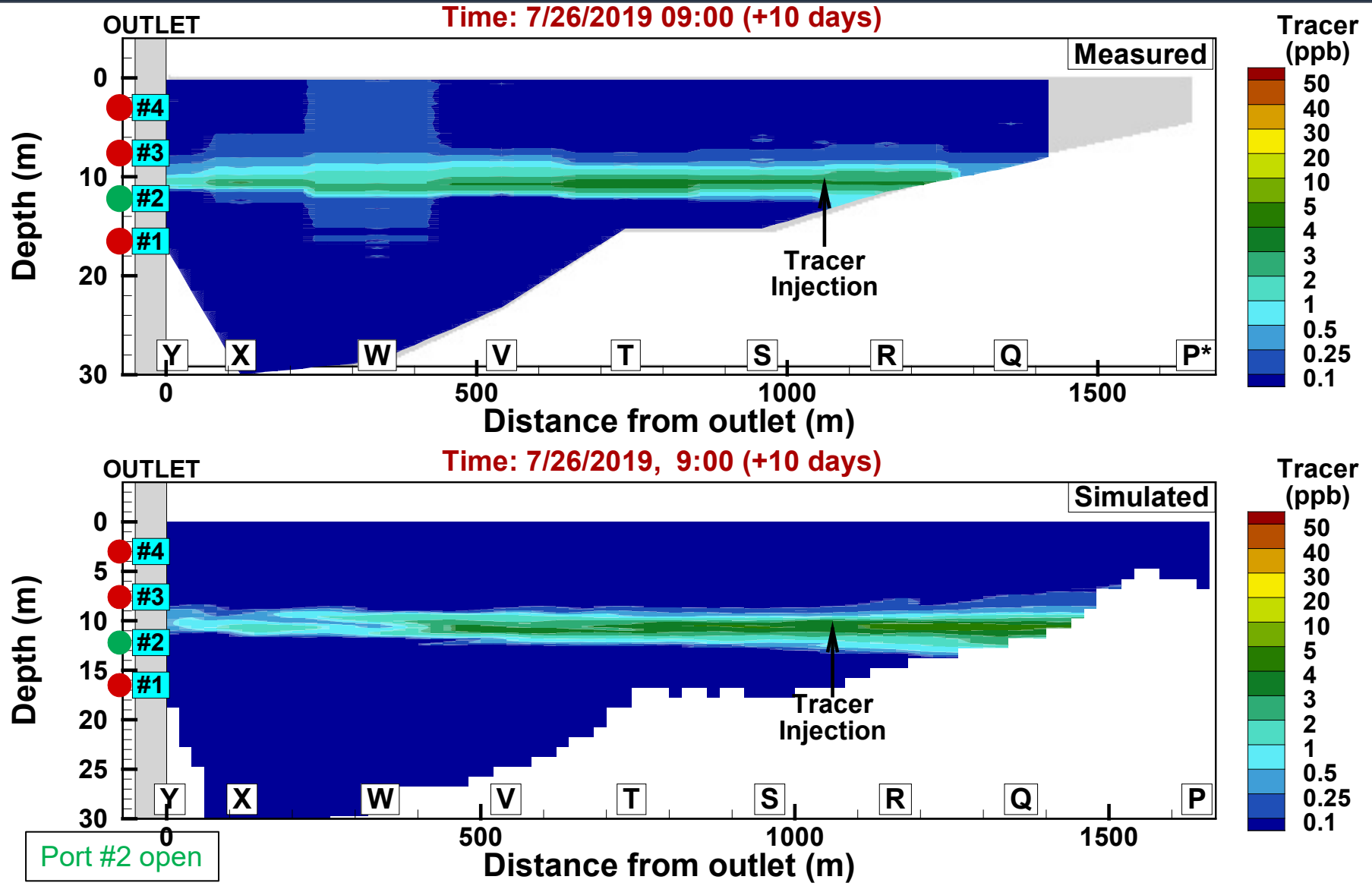


*Stations not sampled, shown as gray

Comparison of Tracer Contours



Comparison of Tracer Contours



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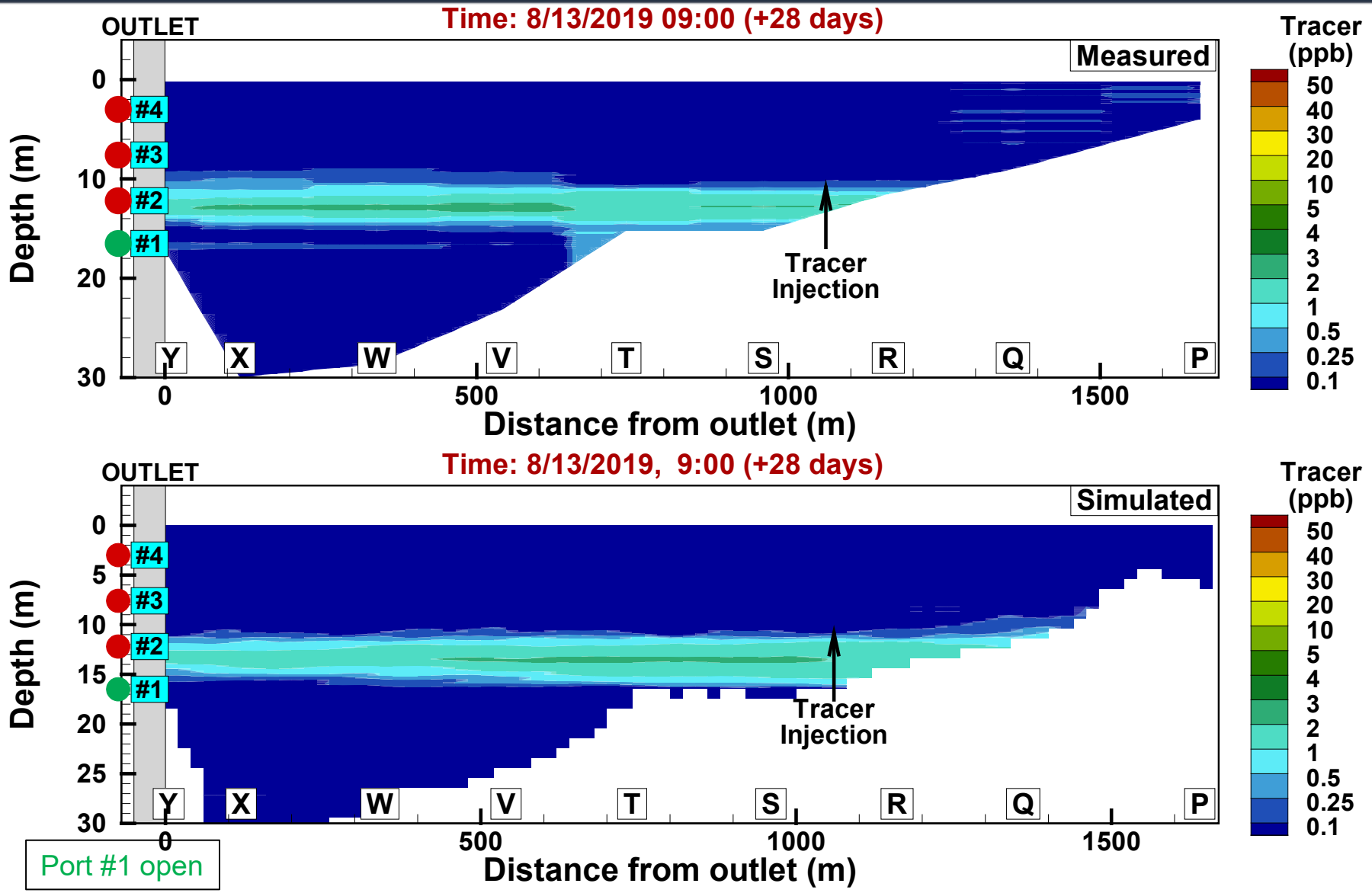
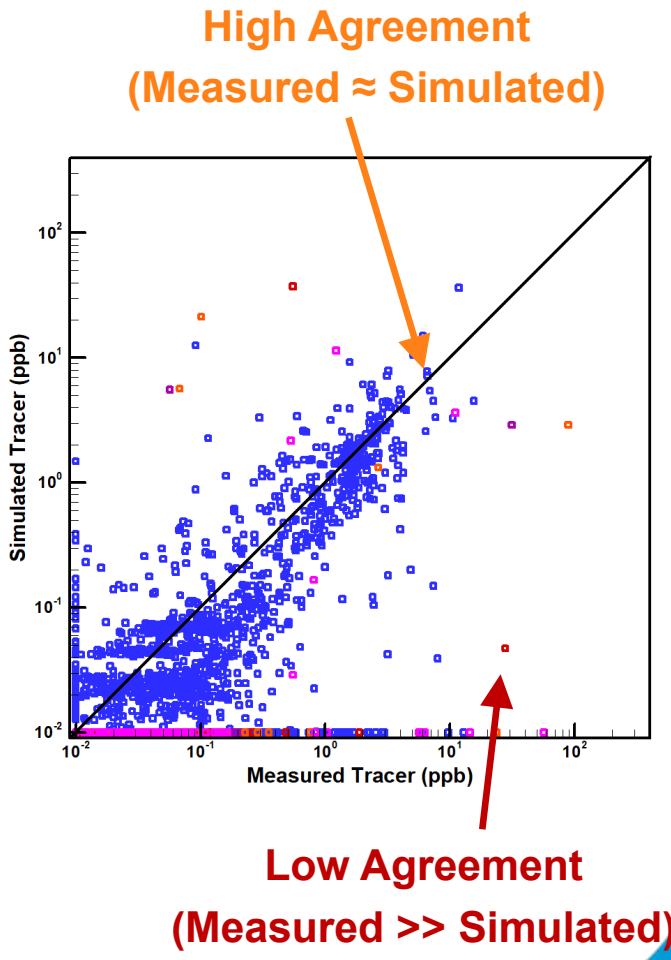
Comparison of Tracer Contours

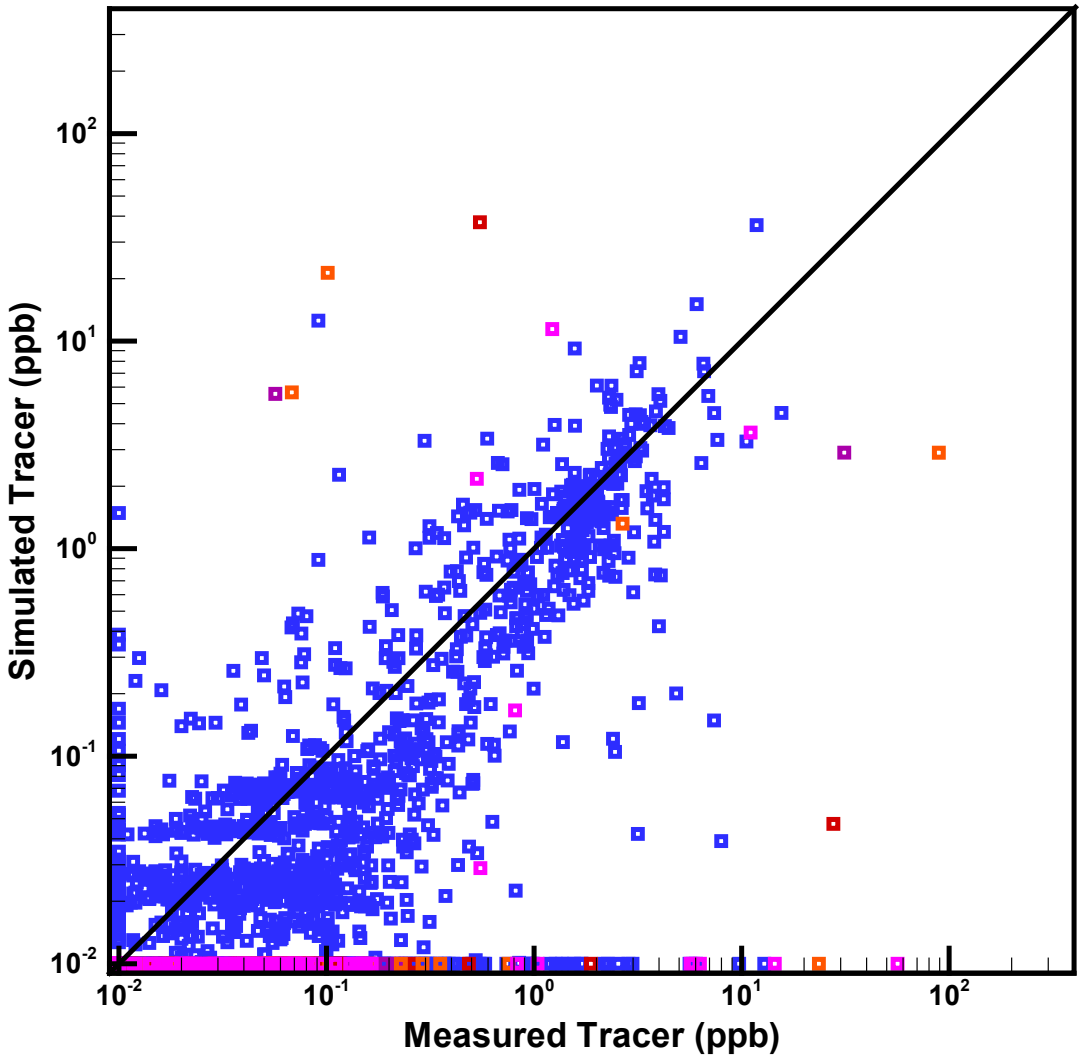


Tracer Study Vs Model

- For each sampling event, the measured RWT data were compared to the simulated tracer concentration
- Data spans four orders of magnitude
- Data not randomly distributed
- Thin tracer layer emphasizes differences



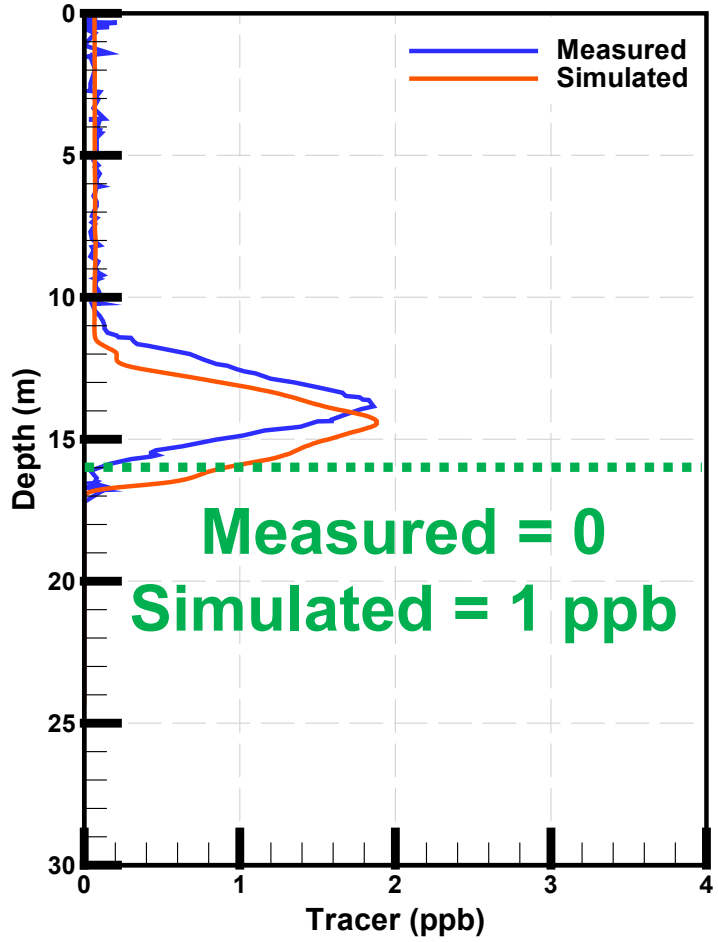
Tracer Study Vs Model



- 14:00, 7/16 (+3 hours)
- 16:00, 7/16 (+5 hours)
- 20:00, 7/16 (+9 hours)
- 03:00, 7/17 (+16 hours)
- All Later Sampling Events

Small Offset Gives Low Agreement

- Even when model performance is excellent visually, statistical results may be low



Tracer Study Statistics

	Total Number of Data Points	r	R^2	Relative RMSE
All sampling events	3241	-0.27	-0.07	2.6%

RRMSE low (high agreement),
but R^2 also low (low agreement)

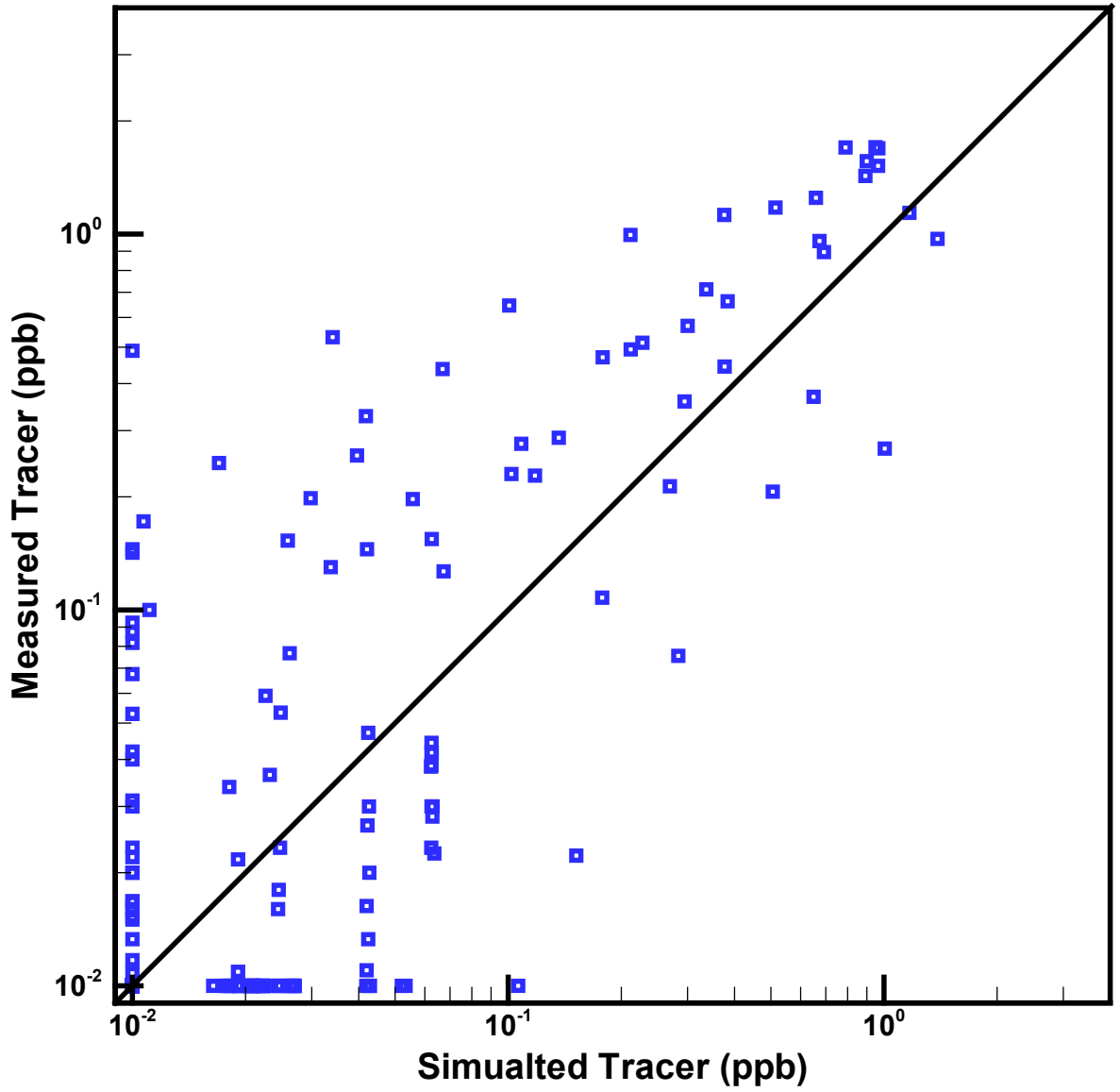
Data range makes statistics difficult

Tracer Study Statistics

	Total Number of Data Points	r	R^2	Relative RMSE
All sampling events	3241	-0.27	-0.07	2.6%
Excluding initial 4 sampling events	2885	0.32	0.10	5.4%

Statistics improve after 1 day

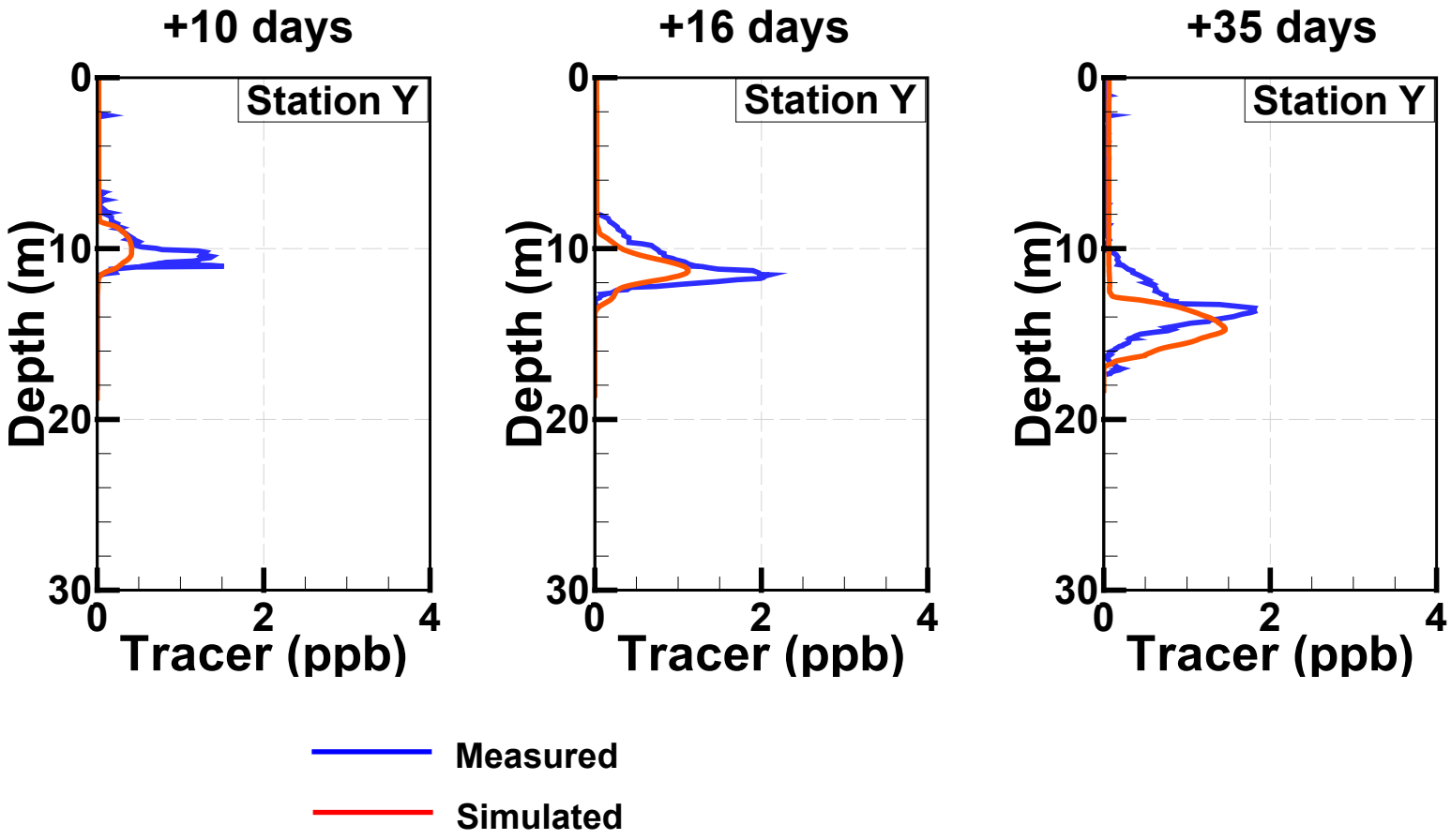
Statistics at Outlet



Tracer measured at outlet matches well with simulated concentrations

Prior to augmentation,…the SWSAP PWS shall demonstrate to the State Board, utilizing tracer studies and hydrodynamic modeling, that at all times under all operating conditions, the volume of water withdrawn from the augmented reservoir …contains no more than…ten percent, by volume, of recycled municipal wastewater that was delivered to the surface water reservoir during any 24-hour period…

Profiles at Outlet



Profiles show visual match of measured and simulated tracer concentrations

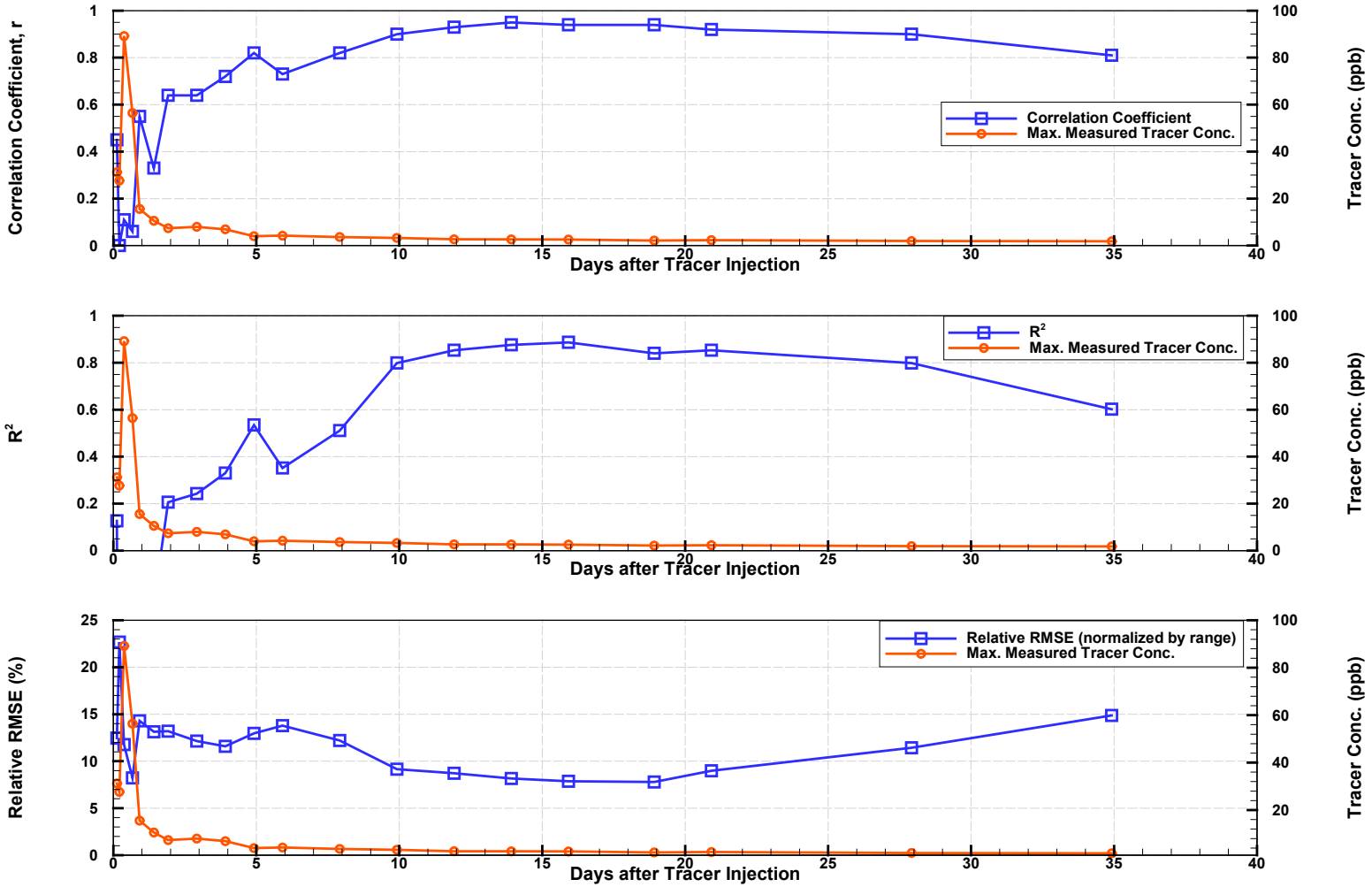
Tracer Study Statistics

Results at outlet most relevant to dilution

	Total Number of Data Points	r	R^2	Relative RMSE
Sampling at outlet	**284**	**0.86**	**0.69**	**9.8%**

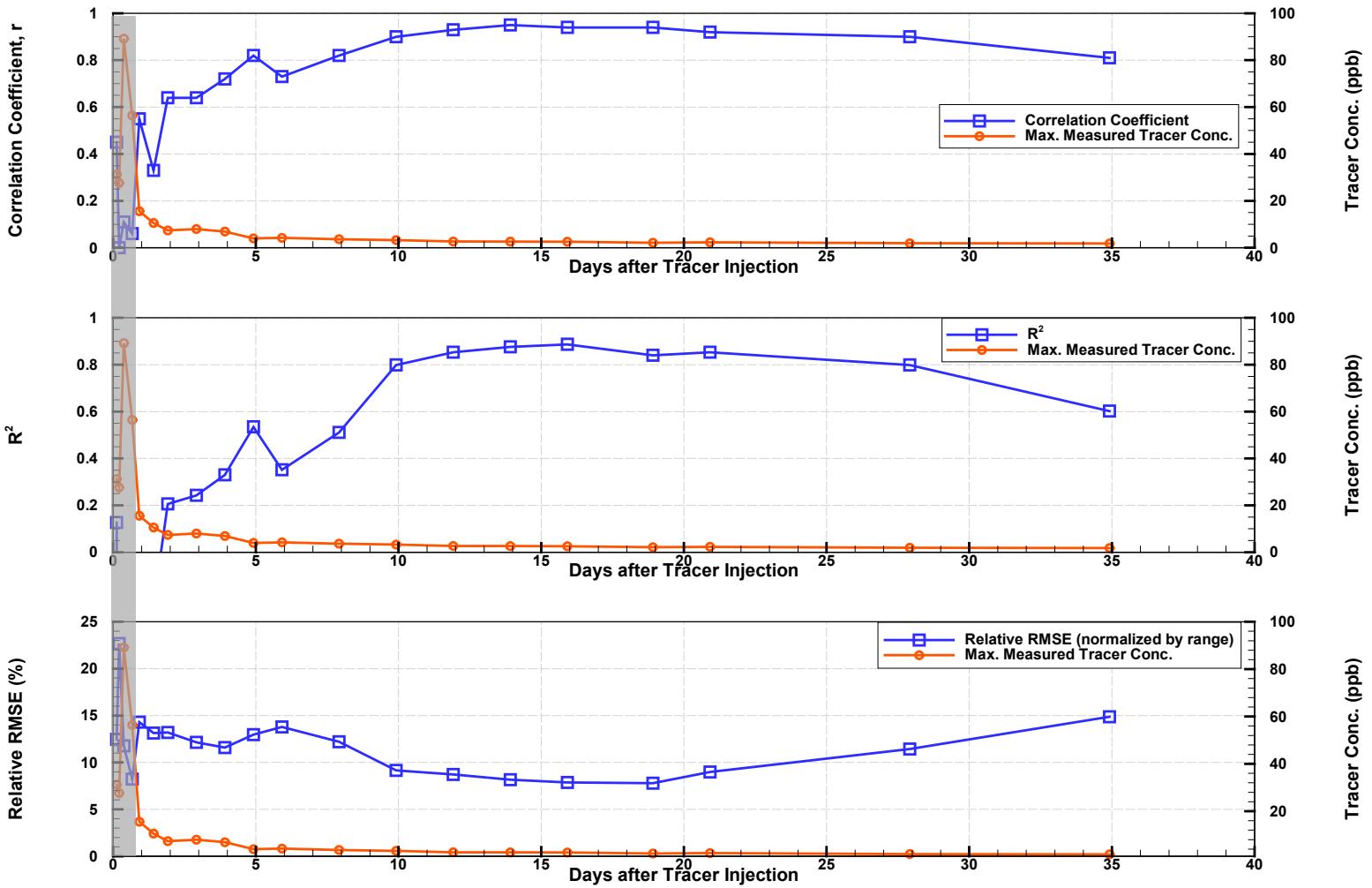
Panel suggests that metrics compare well to other modeling studies

Tracer Study Statistics Over Time



Statistics improve over first week

Tracer Study Statistics Over Time



	r	R^2	Relative RMSE
Excluding initial 4 sampling events	0.33-0.95	0.21-0.88	7-15%

Statistics improve over first week

Model Validation

- Statistics after initial samplings and at outlet better characterize model performance
- Combination of visual approach, statistics (r, R^2, RMSE) on entire dataset, and statistics at outlet
  - *Approach characterizes agreement more clearly*
- Provides framework for panel discussions on model validation

Pure Water San Diego

Tracer Study

Model Setup and Calibration

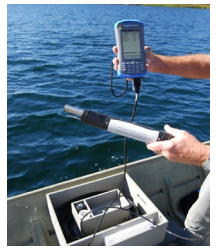
Model Validation

Results and Lessons Learned

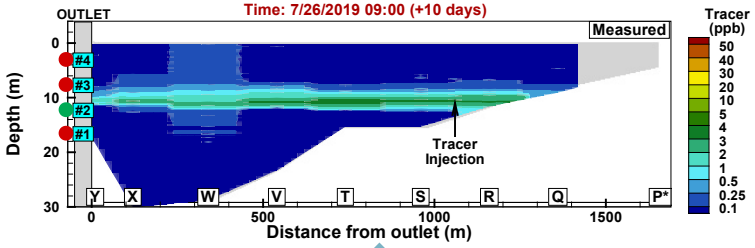
The City of SAN DIEGO

Summary

- Tracer study completed
- 3D model calibrated, applied to tracer study
- Model simulation compared to measured data

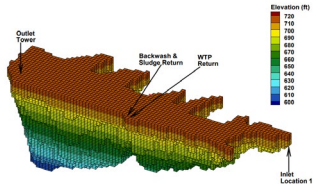


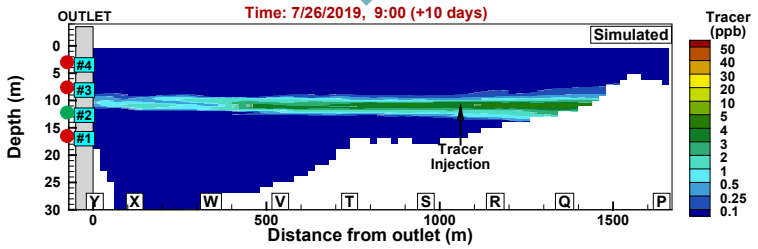
Tracer Study



Model Validation

3D Model





Lessons Learned

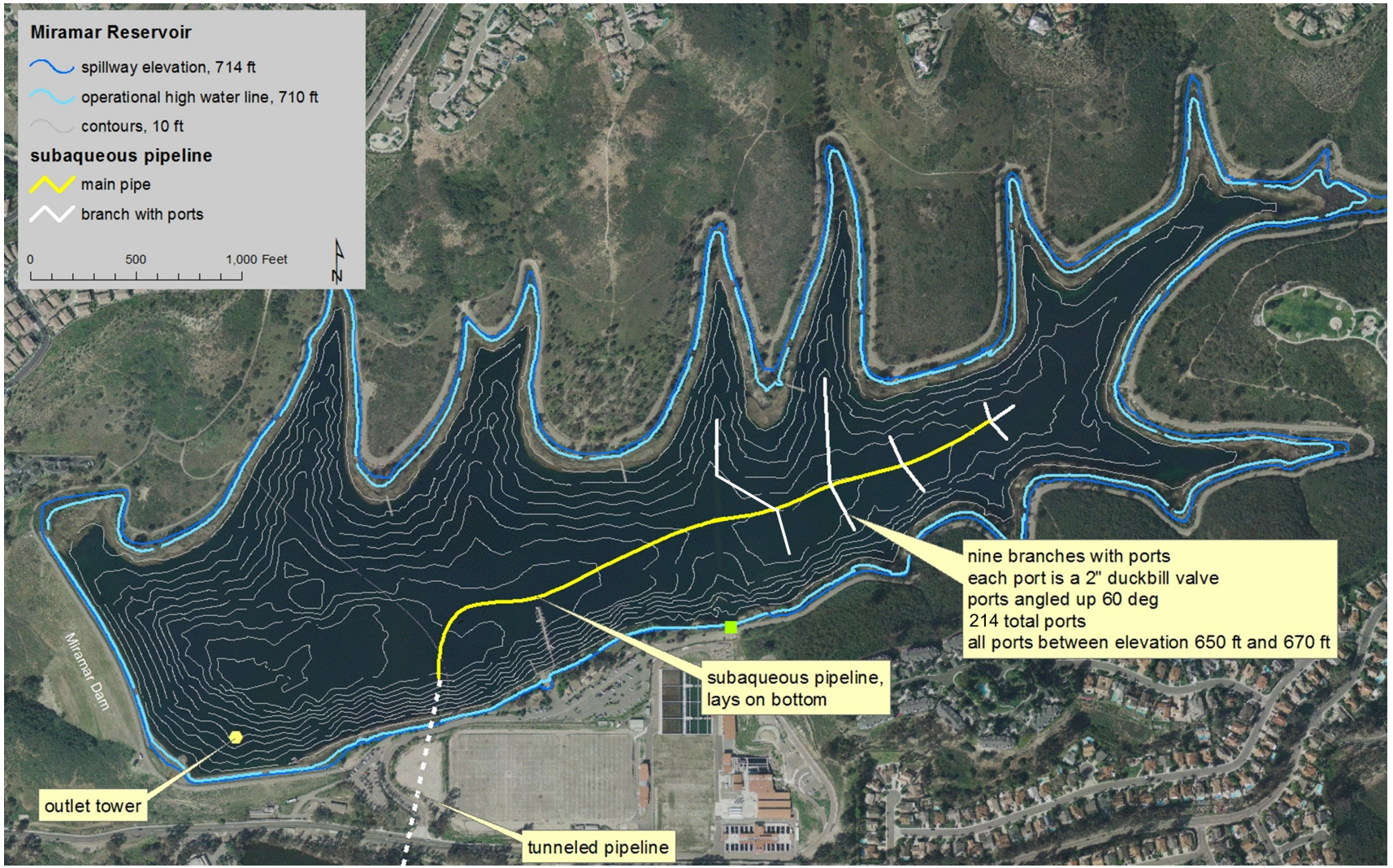
- Sampling plan effective
  - *Not intended to resolve early timepoints*
- AEM3D model effective for simulating tracer movement
  - *Well-calibrated model essential*
  - *Multi-faceted validation approach beneficial*

Preparation for Tracer Study Upon Startup

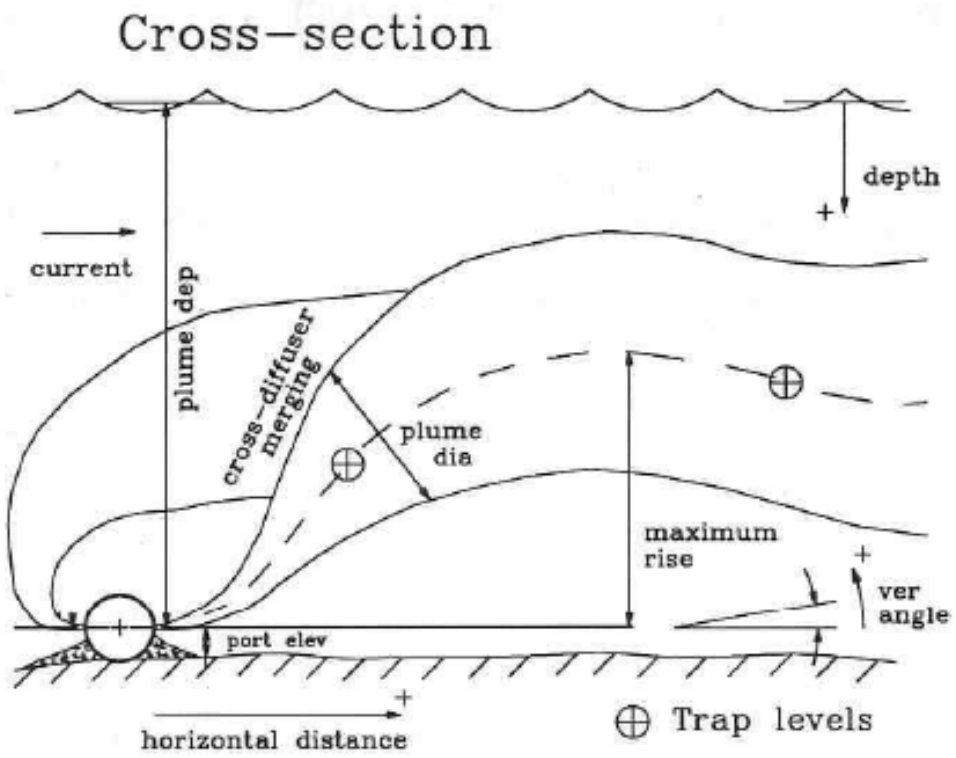
- Conduct tracer study similarly to 2019 tracer study
  - *Inject tracer through purified water inlet (2025)*
- Continue upgrading model and inputs
  - *New submodel for initial dilution of purified water*
  - *Meteorology, bathymetry and flow enhancements*
- Confirm approach to define validity

Backup Slides

Purified Water Diffuser



Modeling Initial Dilution



UM3 model (three-dimensional Updated Merge model) of the EPA PLUMES is embedded in the diffuser code;

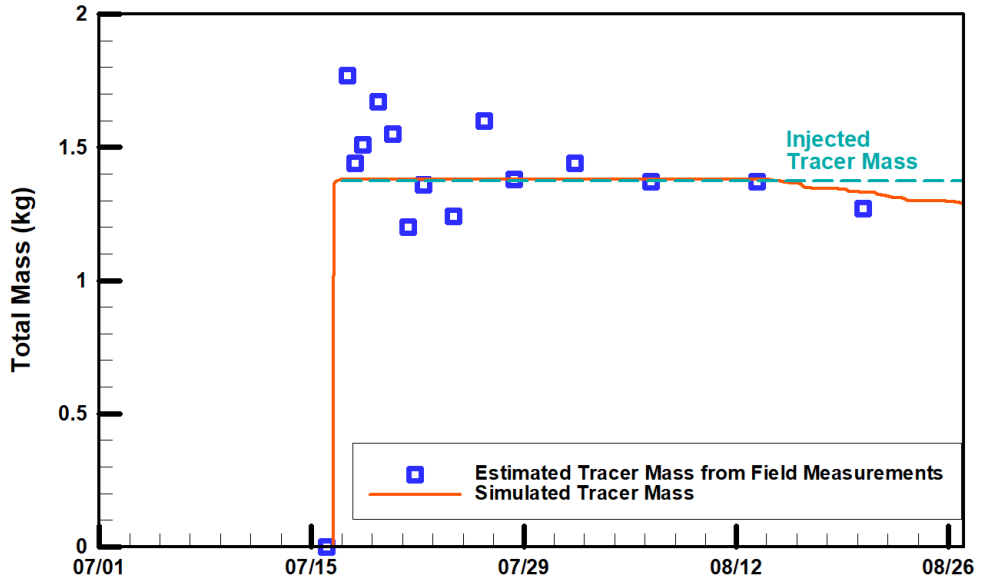
UM3 model, originally coded in Delphi Pascal, simulates single and multi-port submerged discharges;

Dilution (and entrainment) at different depths and the final insertion level are calculated by the UM3 model, then returned to the AEM3D program.

Source: Dilution Models for Effluent Discharges, EPA (1994)

Tracer Study: Measured Tracer

- **Simulation Period:** 7/2/2019 – 8/26/2019
- **Total Tracer Mass:** Simulation matched with the field measurements



*Note that this plot includes only those dates when at least 10 of 11 stations were sampled. Dates when fewer than ten stations were sampled are not included because it is not possible to calculate the mass of tracer in the reservoir when some data is absent. The sampling dates not included are 7/16 (14:00, 16:00, 20:00), 7/17 (3:00), 7/30, and 8/4.

Statistics

Metrics	Definition	
Mean Error	$Mean\ Error = \frac{\sum_{i=1}^{N}(C_{simulated} - C_{measured})}{N}$	
Root Mean Squared Error (RMSE)	$RMSE = \sqrt{\frac{\sum_{i=1}^{N}(C_{simulated} - C_{measured})^2}{N}}$	
Relative RMSE	(1) Based on the range of measured data	$Relative\ RMSE = \frac{RMSE}{\lvert C_{meansured,max} - C_{measured,min} \rvert}$
	(2) Based on the range of ($C_{95} - C_5$)	$Relative\ RMSE = \frac{RMSE}{\lvert C_{meansured,95\%} - C_{measured,5\%} \rvert}$
Relative Absolute Error (RAE)	$RAE = \frac{\sqrt{\sum_{i=1}^{N}(C_{simulated} - C_{measured})^2}}{\sqrt{\sum_{i=1}^{N} C_{measured}{}^2}}$	

C = Concentration
N = the number of paired predictions-observations.
*RAE and the two types of relative RMSE only differ in the denominator in the definitions.

Statistics

$$r = \frac{1}{n-1} \sum \left(\frac{x - \overline{x}}{s_x} \right) \left(\frac{y - \overline{y}}{s_y} \right)$$

$$R^2 = 1 - \frac{SS_{RES}}{SS_{TOT}} = 1 - \frac{\sum_i (y_i - \hat{y}_i)^2}{\sum_i (y_i - \overline{y})^2}$$