Designing Reuse Ultraviolet Disinfection Systems by the Book!

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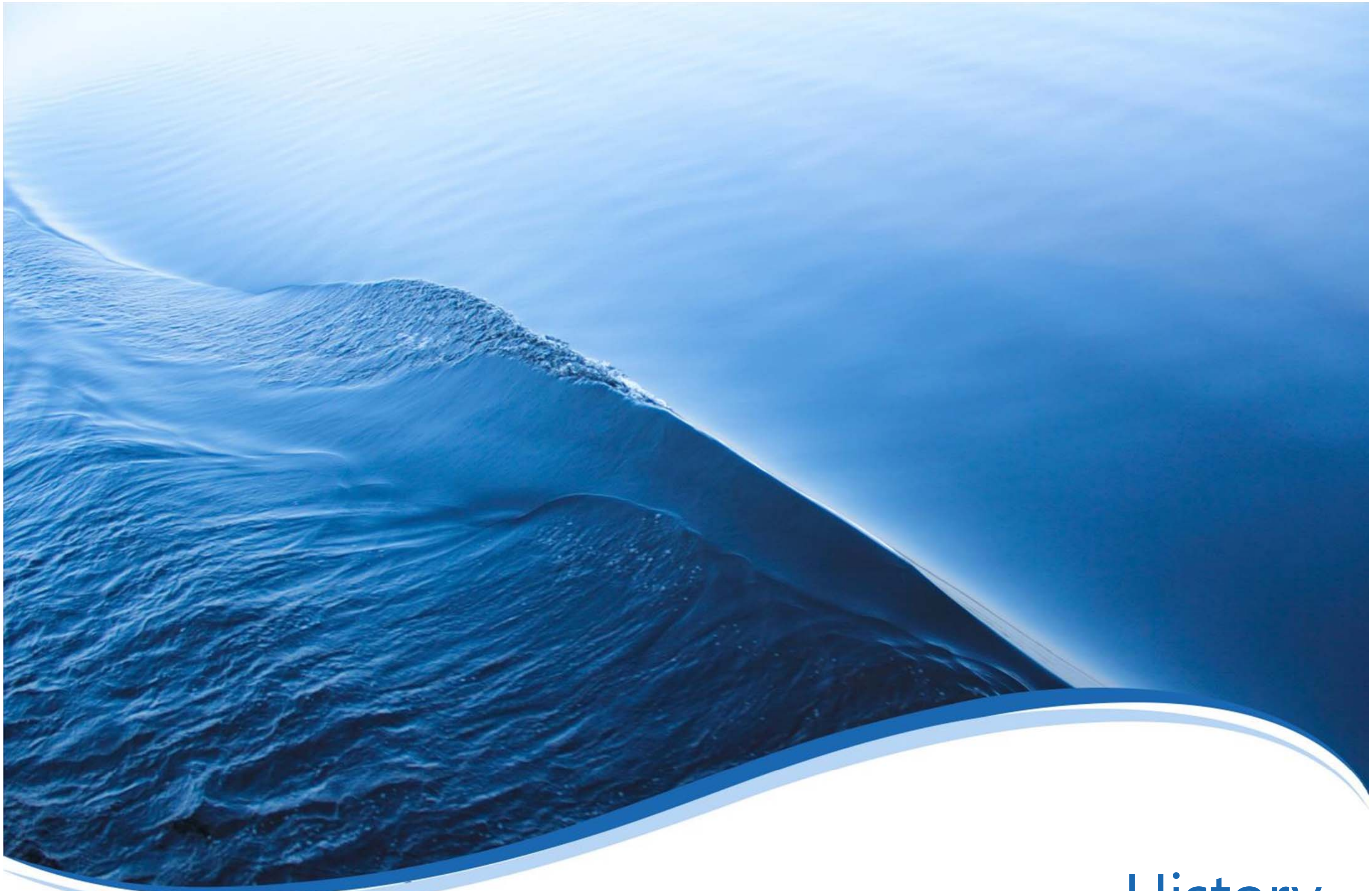
Outline

- History
- Validation Protocols
- Reclaimed Permit Limits
- Case Studies
- Hydraulic Concerns
- Design Summary



History

History

In 1981 the USEPA published the extensive work of Johnson and Qualls on the use of a bioassay, collimated beam, and tracer studies for characterizing a flow through UV system. The referenced bioassay used *B. subtilis* spores.

UV systems introduced into the marketplace in the early 1990's, such as the Trojan Technologies UV3000 and the Fischer & Porter 70UV6000, utilized electronic ballasts and had the same lamp and lamp spacing.

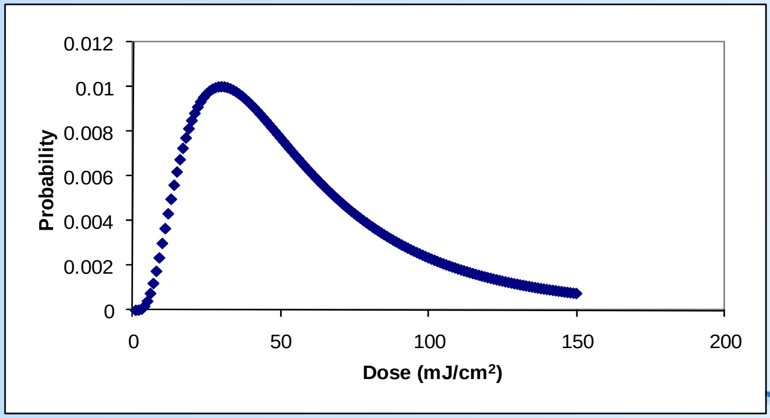
Bioassay testing with *B. subtilis* spores provided a Reduction Equivalent Dose (RED) for each system for the same design parameters allowing for a fair performance comparison.

Trojan UV3000

F&P 70UV6000

History

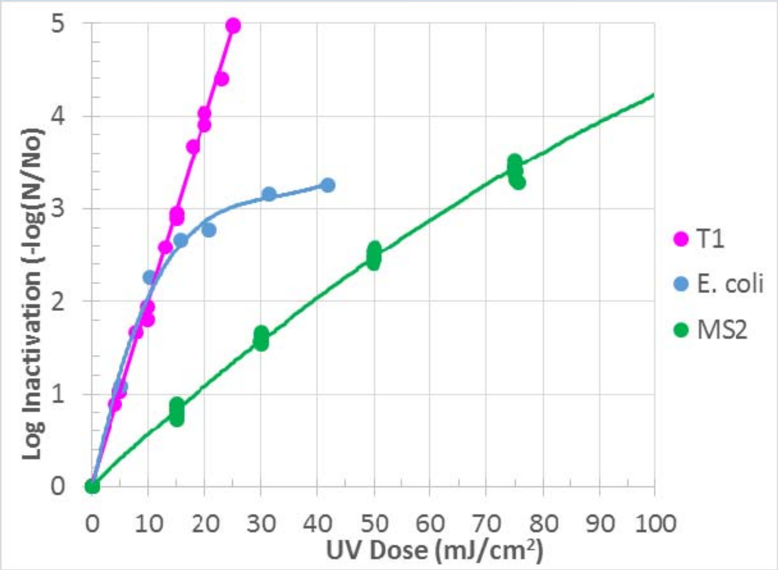
- The majority of the UV systems were sized to deliver a calculated UV dose defined as the product of the average UV intensity within the UV reactor, determined using Point Source Summation (PSS), multiplied by a theoretical residence time.
- This approach assumed ideal hydraulics and that each microbe passing through the UV reactor was exposed to the same UV dose.
- Each microbe passing through a reactor will follow a different trajectory, each with a unique residence time and exposed to a unique UV intensity – different UV dose level.
- UV dose delivered by a UV reactor is best described using a dose distribution, a probability plot that a microbe passing through a UV reactor will receive a given UV dose.



Validation Protocols

Validation Protocols

- In the 1990's, *B. subtilis* spores were supplanted by MS2 coliphage for bioassays of UV disinfection equipment.
- MS2 has a UV sensitivity of approximately 20 mJ/cm^2/log I which makes it a suitable surrogate for virus inactivation.
- Sizing a wastewater UV system based on MS2 RED can lead to inefficient and poor inactivation of bacterial indicator organisms such as *E. coli* and Fecal Coliform.
- T1 is an excellent surrogate for bacterial indicator organism inactivation since they have a similar sensitivity to UV light.



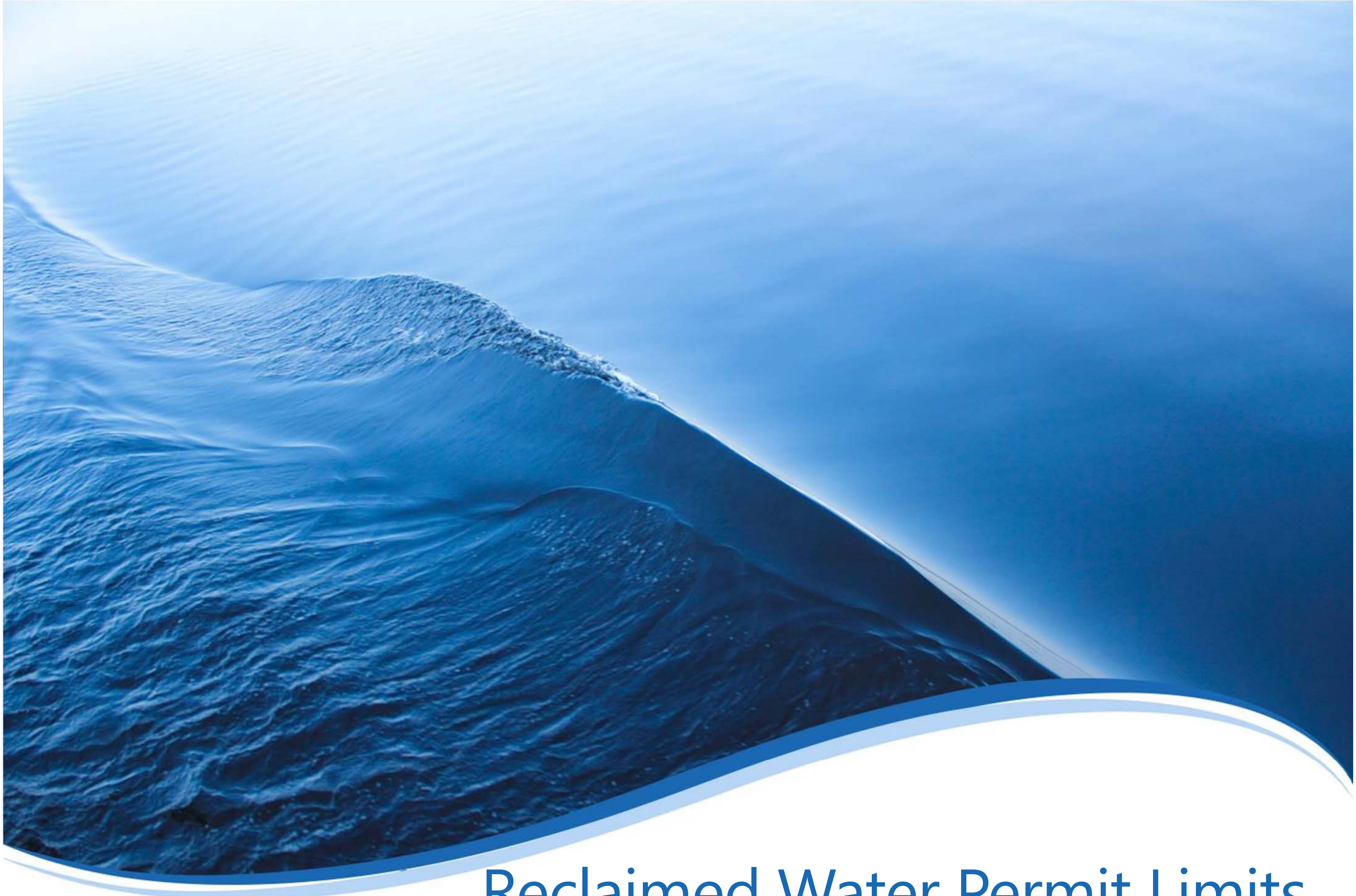
Dose Response Curves of *E. coli*, T1 and MS2

Validation Protocols

- As guidelines evolve, design engineers struggle to create a level playing field for all UV manufacturers with validations using different surrogate organisms following different protocols.

The three current, most prevalent validation protocols for water reuse and wastewater applications are as follows:

- *Ultraviolet Disinfection Guidelines for Drinking Water and Water Reuse*, 3rd edition, published by the National Water Research Institute (NWRI) in collaboration with the Water Research Foundation (NWRI and WRF, 2012);
- *Ultraviolet Disinfection Guidance Manual for the Final Long Term 2 Enhanced Surface Water Treatment Rule* published by the U.S. Environmental Protection Agency (U.S. EPA, 2006) (UVDGM); and
- *Uniform Protocol for Wastewater UV Validation Applications* (Whitby et al., 2011) published by the International Ultraviolet Association (IUVA).



Reclaimed Water Permit Limits

Reclaimed Water Permit Limits

- For States like California and Florida that follow the NWRI UV Guidelines, UV system sizing has been simplified for the design engineer.
- As long as the design parameters are within the validation envelope and the system complies with the required dose, the system is deemed to be appropriately sized.
- For other States that are implementing water reuse, such as Arizona, South Carolina and Texas, UV system design methodologies are not well defined.

State	Classification	Organism	Limit	Maximum
AZ	Class A+	Fecal Coliform	Non-Detect, 4 out of the last 7 daily samples taken	23 CFU/100 mL
SC	Land Application	*E. coli*	2 CFU/100 mL, at least 75% of the values obtained on a separate day during a period of 30 consecutive days shall be below the detection limit	25 CFU/100 mL
TX	Type I	Fecal Coliform or *E. coli*	20 CFU/100 mL, 30-day geometric mean	75 CFU/100 mL
		Enterococci	4 CFU/100 mL, 30-day geometric mean	9 CFU/100 mL

Case Studies

Case Studies

California Utility

- In 1997, the Utility installed a Trojan UV4000 system that had a disinfection capacity of 67 mgd at 60% UV transmittance (UVT) based on the original 1993 NWRI UV Guidelines.
- In 2013, the Division of Drinking Water (DDW) required a re-evaluation of the disinfection capacity. Based on DDW criteria, the UV system was re-rated to a capacity of 48.5 mgd at a UVT of 64%. Based on current UVT data, the lower 10th percentile is now 61% which results in a disinfection capacity of 43 mgd.
- Given the age of the UV system and the capacity deficiency, the Utility decided to replace the existing medium-pressure UV system with a low-pressure, high-output UV system.
- Since this project is in California the design parameters are straight forward, they are: **peak flow of 67 mgd, UVT of 55% and a design MS2 RED of 100 mJ/cm^2**.

Case Studies

California Utility

Parameters	Trojan UVSigna 2-Row	WEDECO Duron	Calgon Carbon C³500D	Ozonia Aquaray 3X
Configuration:				
Number of Channels	4	5	5	5
Number of Banks/Channel	12	17	5	8
Number of Modules/Bank	1	2	13	2
Number of Lamps/Module	24	12	8	36
Total Number of Lamps	**1152**	**2040**	**2600**	**2880**
Number of UV Sensors	48	85	25	40
Number of Power Distribution Centers	16	45	25	10
Number of System Control Centers	1	1	6	1
Total Power Consumption (kW)	**1374.6**	**1436.0**	**1660.8**	**1220.0**

- Third-party validation of the different UV systems allows for a straight-forward comparison that included monetary (equipment and annual O&M costs) and non-monetary (experience, operational and maintenance ease, footprint, headloss, etc.) factors.

Case Studies

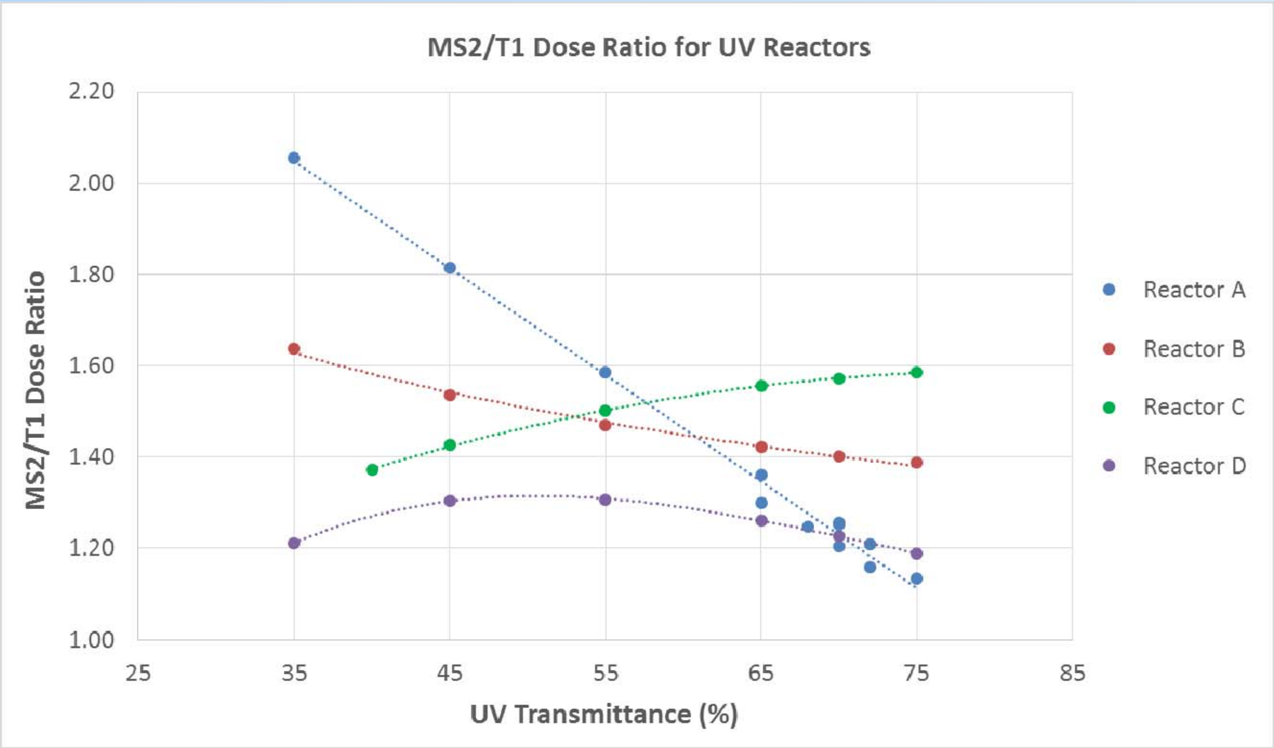
South Carolina Utility District

- The District is currently disinfecting with chlorine gas prior to being delivered to the irrigation reuse system or wetlands.
- The District typically discharges to the irrigation system where the land application permit applies (*E. coli* limit of 2 CFU/100 mL). During the winter, the disinfected effluent is discharged to the wetlands where NPDES permit limits apply. The land application permit will be used to determine the size of the UV system since it is more stringent than the NPDES permit.
- Third-party validated closed-vessel reactors were considered for this project. However, not all UV reactors have used the T1 surrogate during validation; therefore, MS2 was used for the design RED to provide a level playing field.

Case Studies

South Carolina Utility District

- Based on Carollo bioassay validation testing of different type of UV reactors with different lamp configurations and lamp power levels, the MS2/T1 RED ratios are detailed below. The ratio is dependent on the design UVT. It is recommended that the highest ratio be used to equate the different dose levels.



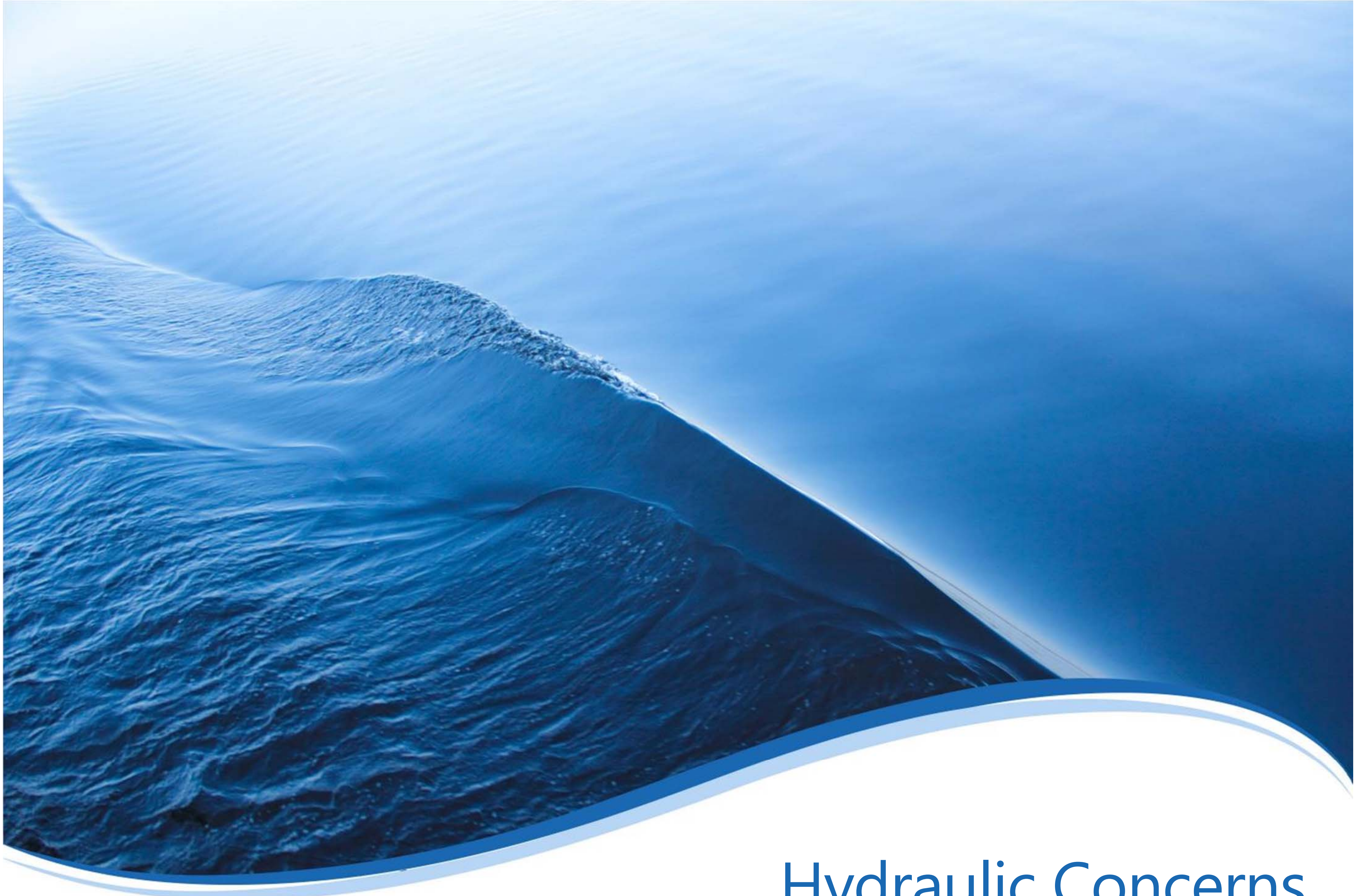
Case Studies

South Carolina Utility District

- Based on collimated beam analyses, a T1 RED of 27 mJ/cm^2 is required to comply with the land application permit limit.
- Based on the design UVT of 55% and a MS2/T1 ratio of 1.60, the design MS2 RED is 48 mJ/cm^2 which includes a safety factor given the limited number of collimated beam analyses performed.
- The design MS2 RED may require one or two manufacturers to oversize their UV system but whomever is selected for the project will provide the required dose to ensure that UV disinfection is properly sized for the design parameters.

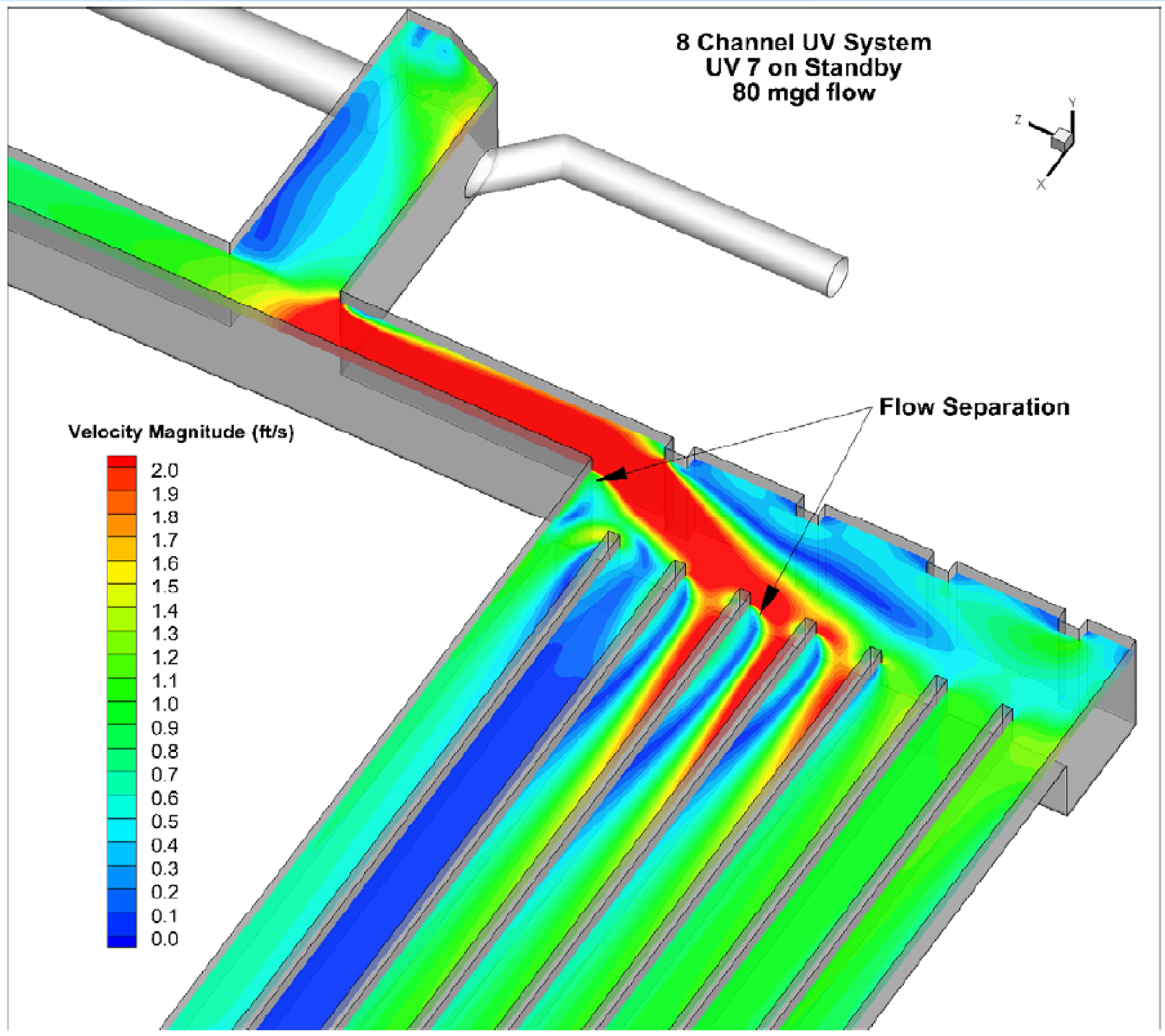
Design Parameters	
Peak Flow Rate (mgd)	5.26
Design UV Transmittance (%)	55
Number of Trains (Preferred)	3 duty
Minimum MS2 RED (mJ/cm^2), per NWRI 2012	48.0
Redundancy	N + 1 Train

Parameters	**Trojan UVFit**	**WEDECO LBX**	**ETS UVLW**
Configuration:			
Number of Duty Trains	3	3	3
Number of Standby Trains	1	1	1
Total Number of Trains	4	4	4
Number of Reactors/Train	1	1	1
Number of Lamps/Reactor	72	60	30
Total Number of Lamps	**288**	**240**	**120**
Total Power Consumption (kW)	**74.3**	**80.0**	**102.0**



Hydraulic Concerns

Hydraulics – *Flow Split*



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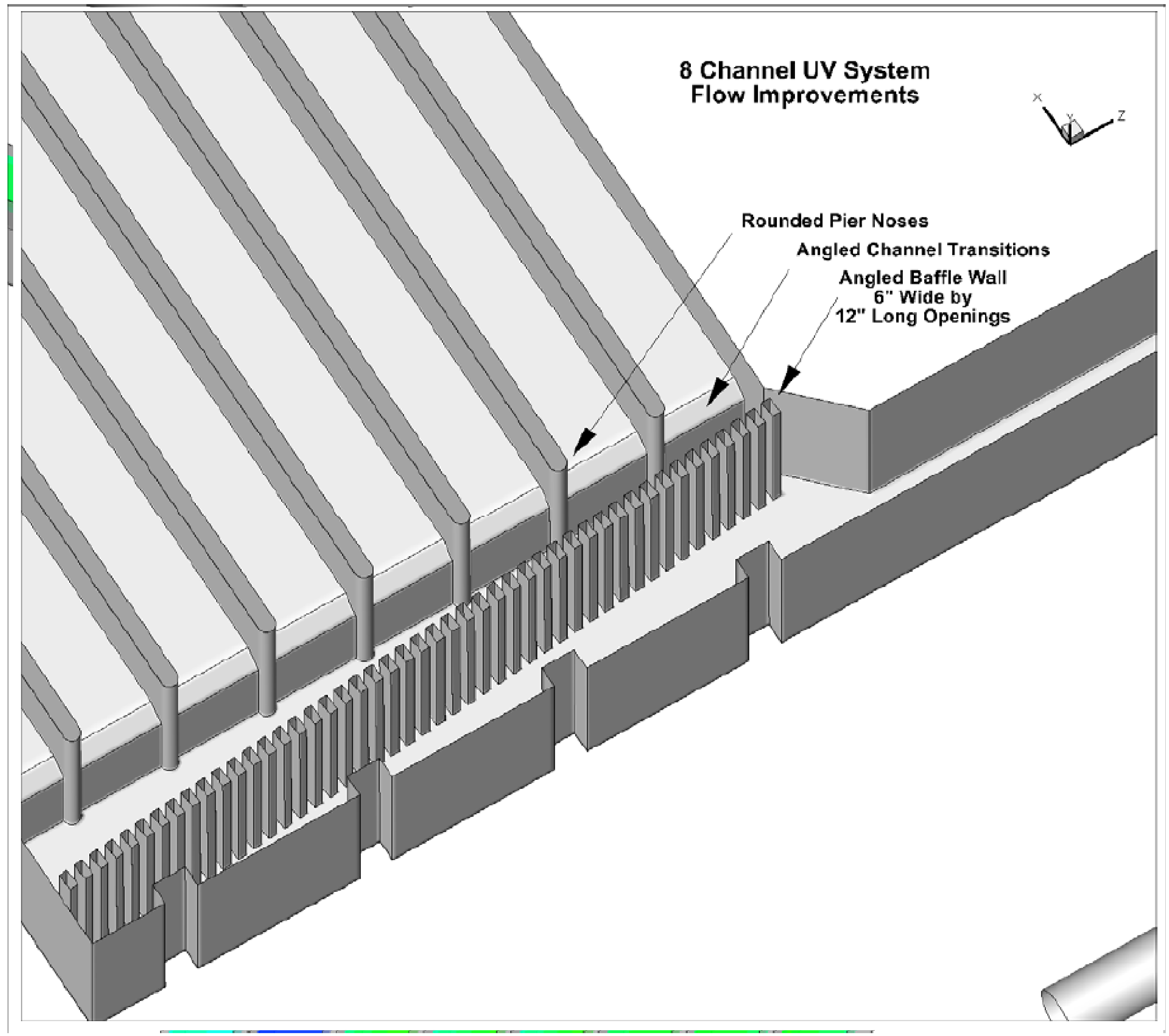
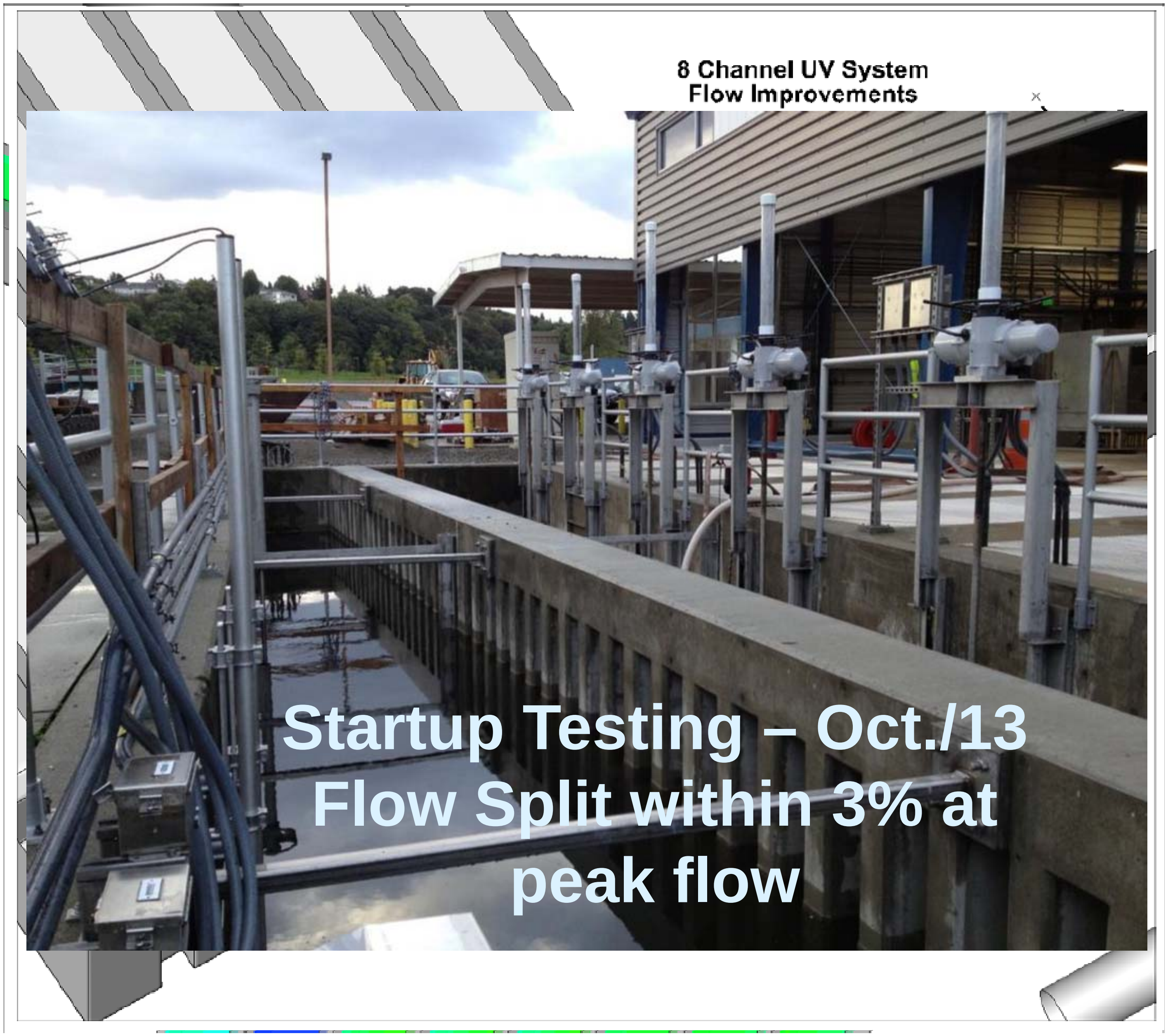
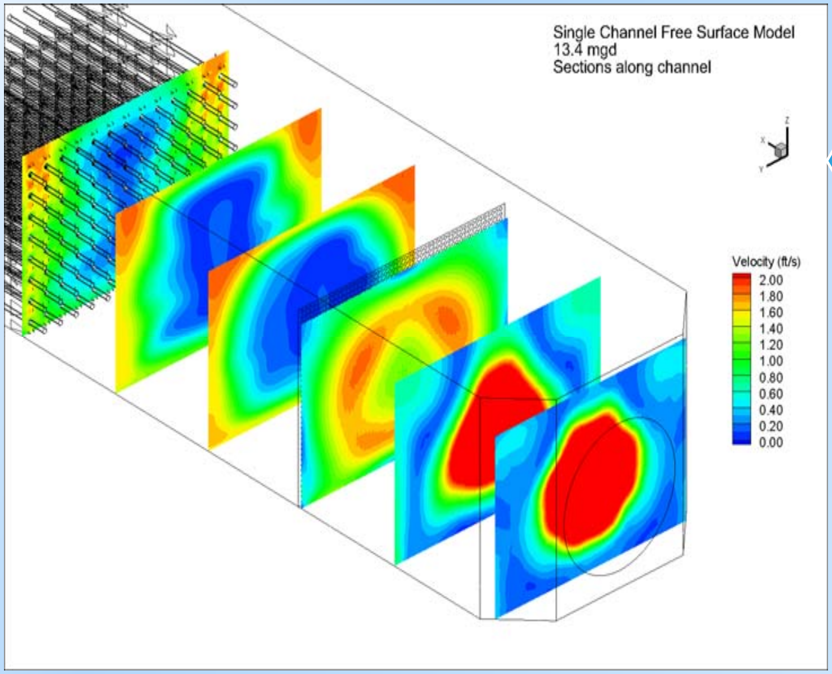


Hydraulics – *Flow Split*

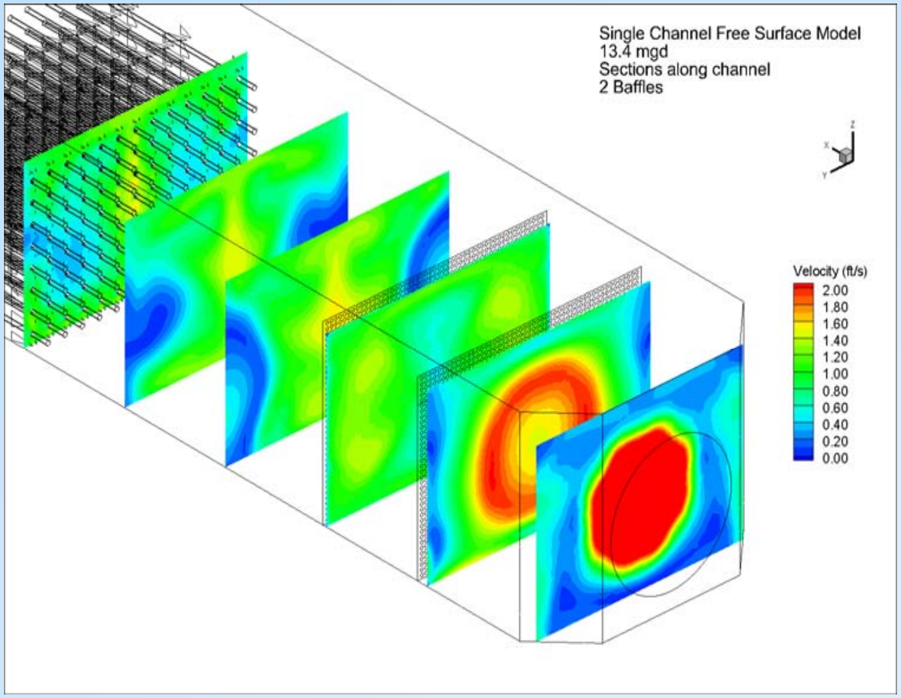


Hydraulics – *Channel Inlet Approach*

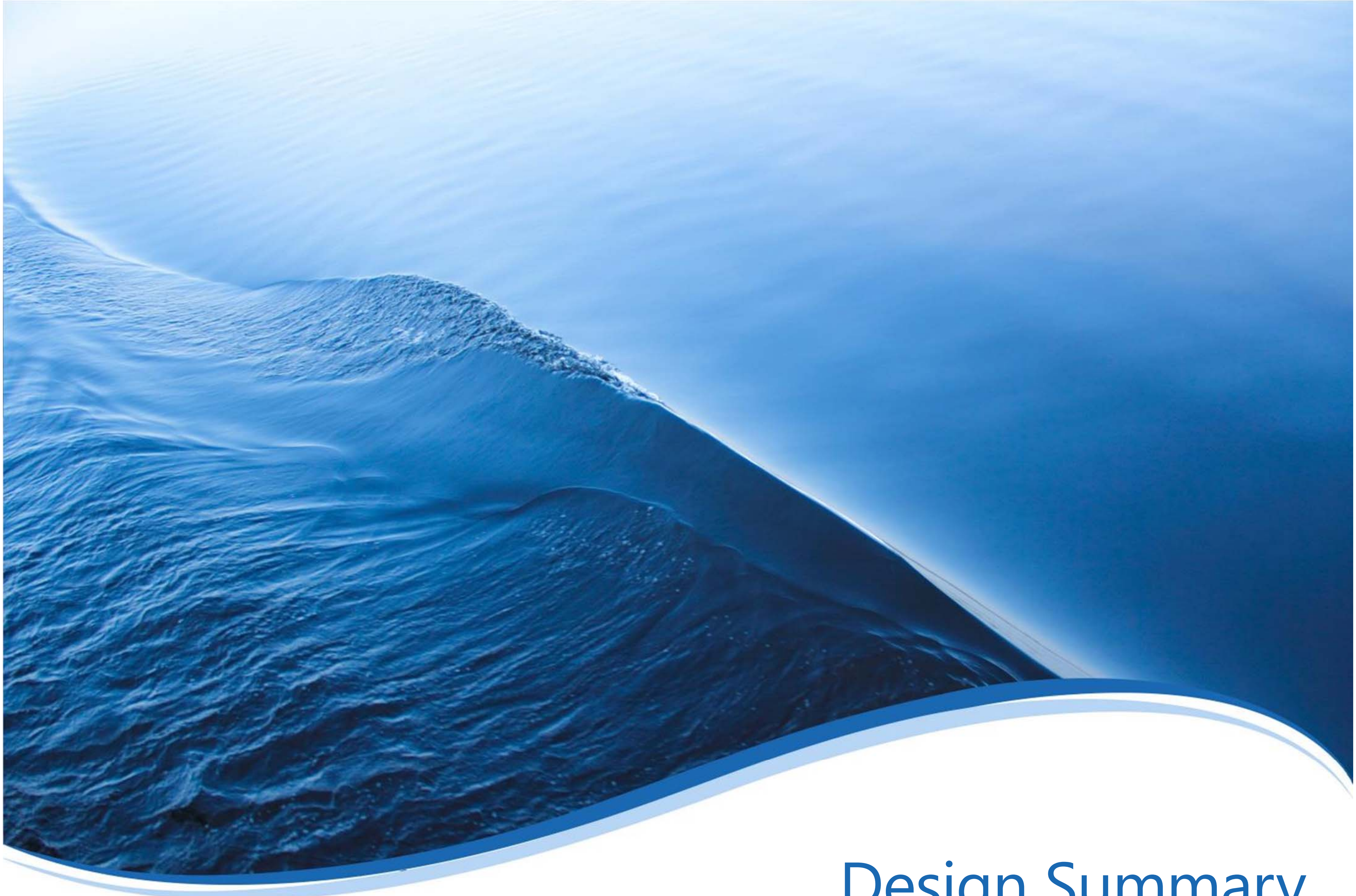


Approach velocities approaching first bank of lamp with 1 baffle plate and …

… with 2 baffle plates.



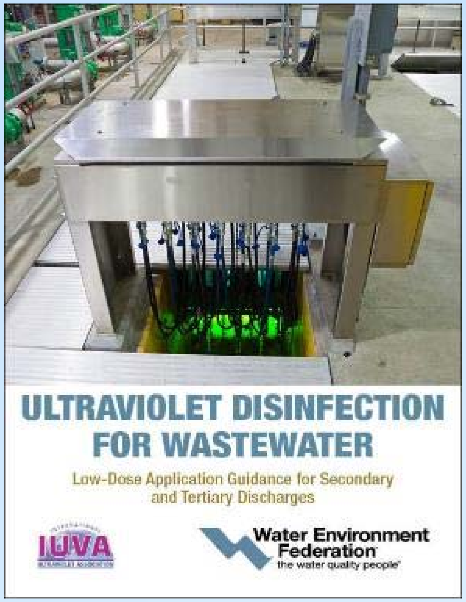
Up-front CFD modelling is a small investment relative to the potential lifetime performance gains from a good flow-split and approach velocity. After construction, issues are expensive to fix.

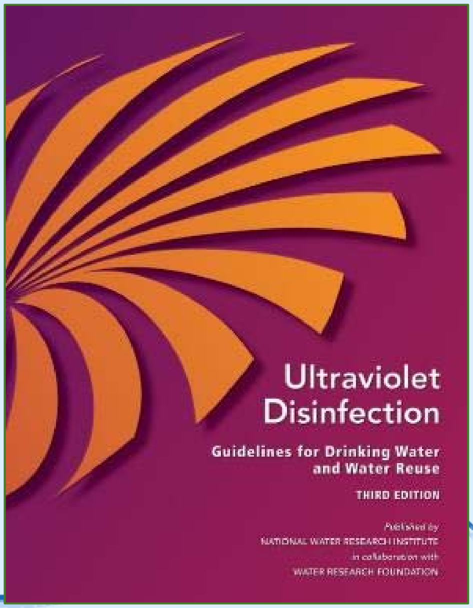


Design Summary

Design Summary

- Collect as much flow, UVT and TSS data as possible.
- Perform collimated beam analysis for non-California reuse applications.
- Follow the guidelines and procedures detailed in the IUVA/WEF book and NWRI UV Guidelines.
- Evaluation of wet weather flows establishes capacity and redundancy criteria.
- CFD analysis to eliminate/minimize flow split and channel inlet hydraulic issues.





Design Summary

- For reactors that have not been validated with the *IUVA Uniform Protocol*, disinfection can be jeopardized by not properly equating the design MS2 and T1 REDs.
- Recommend that the method shown in the South Carolina Utility District case study be used to determine the MS2/T1 ratio depending on the design UV transmittance.
- By following these steps, you are **Designing UV Systems by the Book!**

QUESTIONS

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Thank You