TROJAN UV

REUSO POTAVEL DE AGUAS RESIDUAIS: O MERCADO GLOBAL ATUAL E O PAPEL DOS PROCESSOS DE OXIDAÇÃO AVANÇADA

Jose C Fragoso

10 Dezembro 2015

Empresa

SOLUÇÕES INOVADORAS PARA TRATAMENTO DE ÁGUA

- > 500 colaboradores, operando a partir de 25 localidades em 12 paises
- $200M em vendas anuais
- 5.0% investidos em pesquiza e desenvolvimento
- Mais de 8,000 instalações municipais em 6 continentes
- Representantes: mais de 200 escritórios em 90 paises nos 6 continentes
- Manufatura no Canada, USA, Europa e China

Unidades de Negócios

Através de aquisições e parcerias estratégicas, a empresa tem diversificado seu portfolio de produtos e aplicações. Trojan Technologies é composta por seis unidades de negócios:

Aquafine

UV disinfection systems for industrial and commercial water and wastewater treatment

salsnes Filter

Solids separation for municipal, commercial and industrial wastewater

TROJAN UV

UV disinfection and UV-oxidation systems for municipal water and wastewater treatment

TROJAN marinex

Filtration + UV treatment systems for ballast water

USP technologies

Environmental hydrogen peroxide-based treatment programs to purify water, wastewater, soil and air

VIQUA

UV disinfection systems for homes and businesses

DANAHER

Environmental	Test & Measurement	Dental	Life Sciences & Diagnostics	Industrial Technologies
Water Quality HACH ChemTreat, Inc. TROJAN technologies	**Communications** FLUKE networks Tektronix communications ARBOR NETWORKS	**Dental** KaVo. Dental Excellence. Kerr Nobel Biocare Ormco DEXIS	**Diagnostics** BECKMAN COULTER Leica BIOSYSTEMS RADIOMETER	**Product ID** VIDEOJET ESKO x-rite PANTONE
Gilbarco Veeder-Root GILBARCO VEEDER-ROOT NAVMAN WIRELESS teletrac	**Instruments** FLUKE Tektronix		**Life Sciences** AB SCIEX BECKMAN COULTER Life Sciences Leica MICROSYSTEMS Molecular Devices	**Automation** KOLLMORGEN THOMSON

Building a Global Science and Technology Company

WATER QUALITY – GLOBAL TRENDS

- Contaminants are being detected regularly in the water supply
- Many regulators are now requiring routine testing of chemicals that were virtually unknown just a few years ago (e.g. nitrosamines by California DPH & UCMR 2)
- Supplies are tightening as population increases and water sources are more heavily tapped
- Unintentional water reuse is occurring

"One city's wastewater is another city's drinking water"

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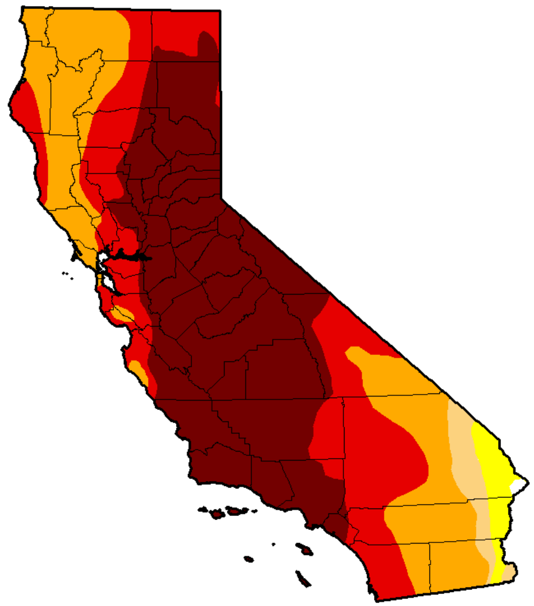
WATER STRESS IN THE UNITED STATES

California

- Southern cities (e.g. Los Angeles and San Diego) receive the bulk of their water from the Colorado river and from the northern part of the state
  - Extreme costs associated with transportation
  - 20% of energy used in state is used to move water
- Title 22 provides guidelines on non-potable reuse treatment requirements
- Guidelines on potable reuse expected in 2016.

As of August 6, 2015



Source: U.S. Drought Monitor (University of Nebraska, Lincoln), 2015

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As of July 26, 2005

Source: U.S. Drought Monitor (University of Nebraska, Lincoln), 2015

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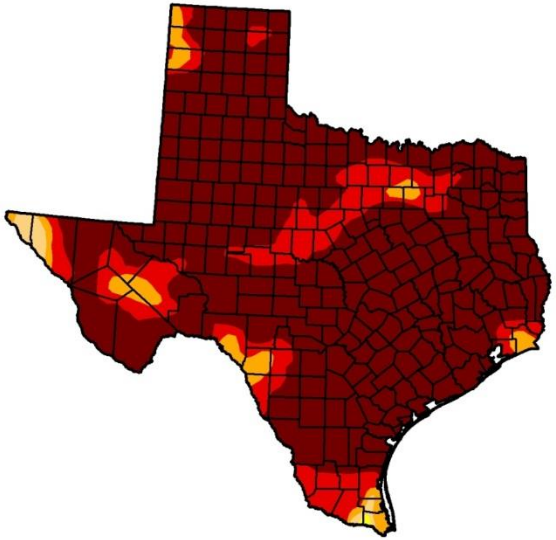
WATER STRESS IN THE UNITED STATES

Texas

- Extreme drought conditions caused strain on drinking water sources

As of February 28, 2012



Source: U.S. Drought Monitor (University of Nebraska, Lincoln), 2012

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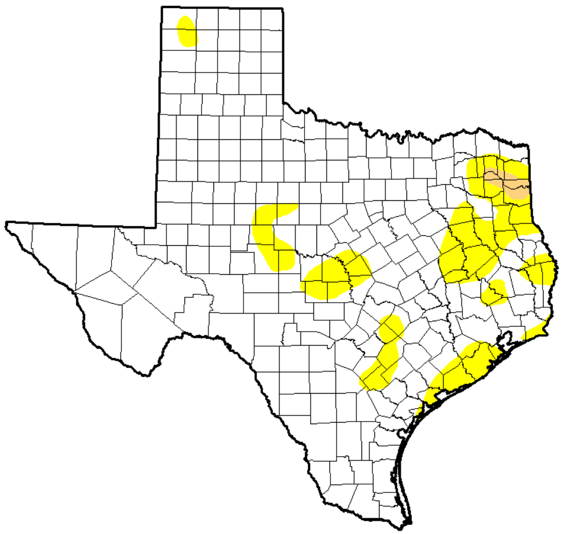
WATER STRESS IN THE UNITED STATES

Texas

- Most recent State Water Plan released in 2012
- Composed of 16 individual water planning regions which submit long-term water plans to the Texas Water Development Board (TWDB) in advance of State Water Plan developments.

As of July 28, 2015



Source: U.S. Drought Monitor (University of Nebraska, Lincoln), 2012

WATER STRESS: WHAT ARE THE OPTIONS?

- Reduce Growth
- Conserve
- Develop New Water Sources
- Water Transfer
- Desalination
  - Seawater
  - Brackish Water
- Non-potable Reuse to Offset DW
- Indirect or Direct Potable Reuse (IPR/DPR)

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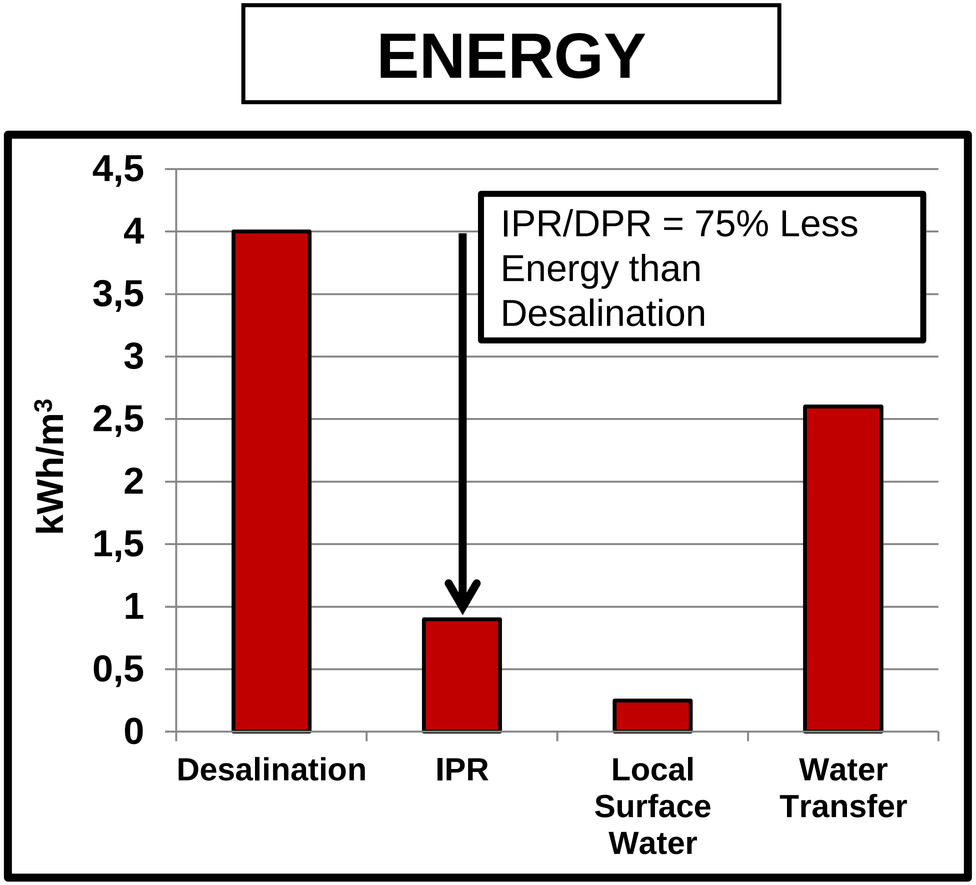
WATER SHORTAGE: WHAT ARE THE OPTIONS?

- IPR is also less energy intensive than other water shortage solutions

- IPR is an Attractive Option Both in Terms of:

  1. Costs

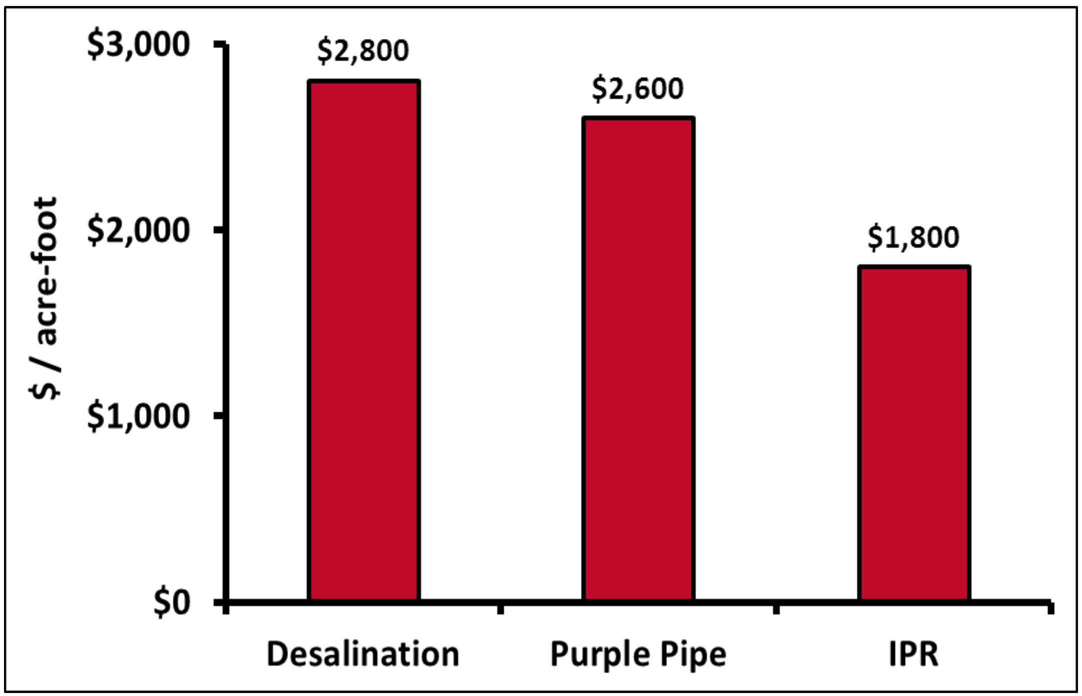
  2. Energy Use



WATER STRESS: WHAT ARE THE OPTIONS?

IPR is cheaper than desalination and non-potable water reuse

- Desal: Higher energy costs
- Non-potable (Purple Pipe): Install new distribution system



Fermian Business and Economic Institute, 2011

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UV for Disinfection

METHODS OF DISINFECTION

- Chlorine
  - Chlorine Gas
  - Sodium Hypochlorite (Bleach)
  - Chlorine Dioxide
- Ozone (O_3)
- Membrane filtration
- **UV Disinfection**

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WHY DISINFECT? *CRYPTOSPORIDIUM*

- Milwaukee, WI 1993 – 403,000 sick, 104 deaths
  - largest documented waterborne disease outbreak in US history
  - There was contamination present and a high turbidity event at the Howard Avenue Water Purification Plant
  - Source of Crypto according to CDC: a **wastewater plant** 2 miles upstream in Lake Michigan

Cryptosporidium Oocyst

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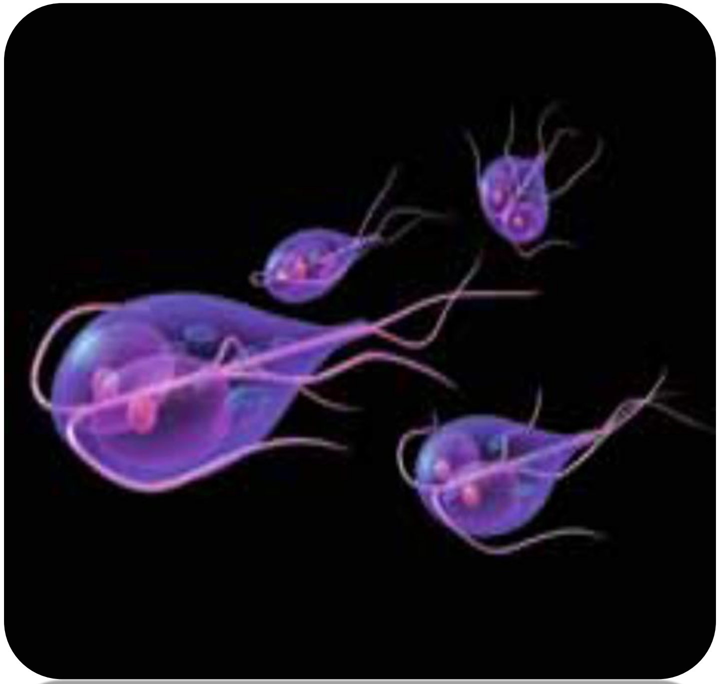
WHY DISINFECT? *CRYPTOSPORIDIUM*

- *Cryptosporidium* – parasite that can live inside the intestines of humans/farm and wild animals/pets
  - Forms protective shell (an oocyst) that enables it to live in harsh conditions
- Cryptosporidiosis symptoms: stomach cramps, fever, diarrhea, dehydration
- Resistant to chlorine



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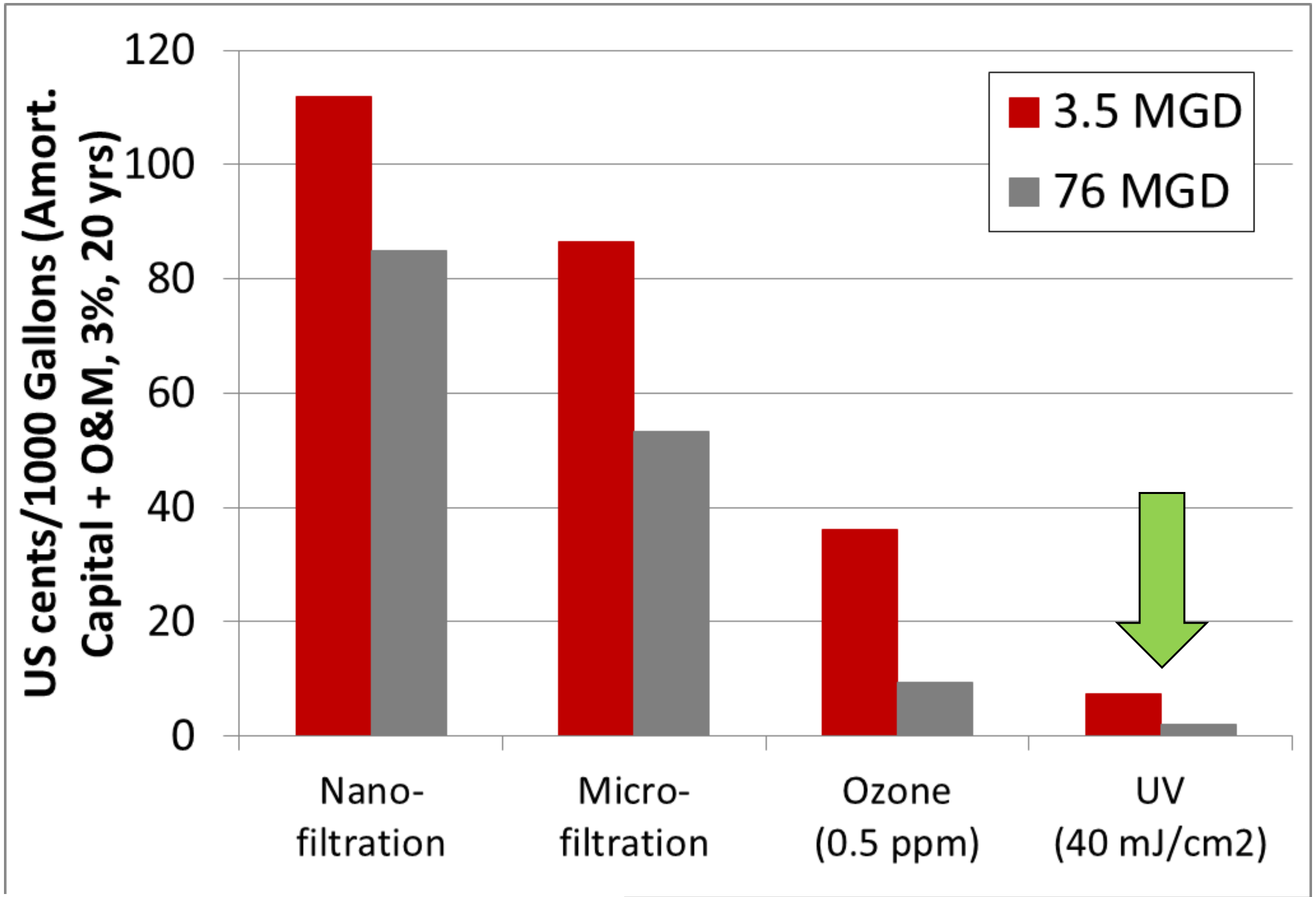
DISINFECTION COSTS – UV IS HIGHLY COST-EFFECTIVE



- UV is 1/5th cost of ozone
- UV is 1/10th the cost of membranes
- Implementation of log-reduction treatment leading to even lower UV costs

Technologies and Costs Document for the Final Long Term 2 Enhanced Surface Water Treatment Rule

Office of Water (4606-M) EPA 815-R-05-013 December 2005

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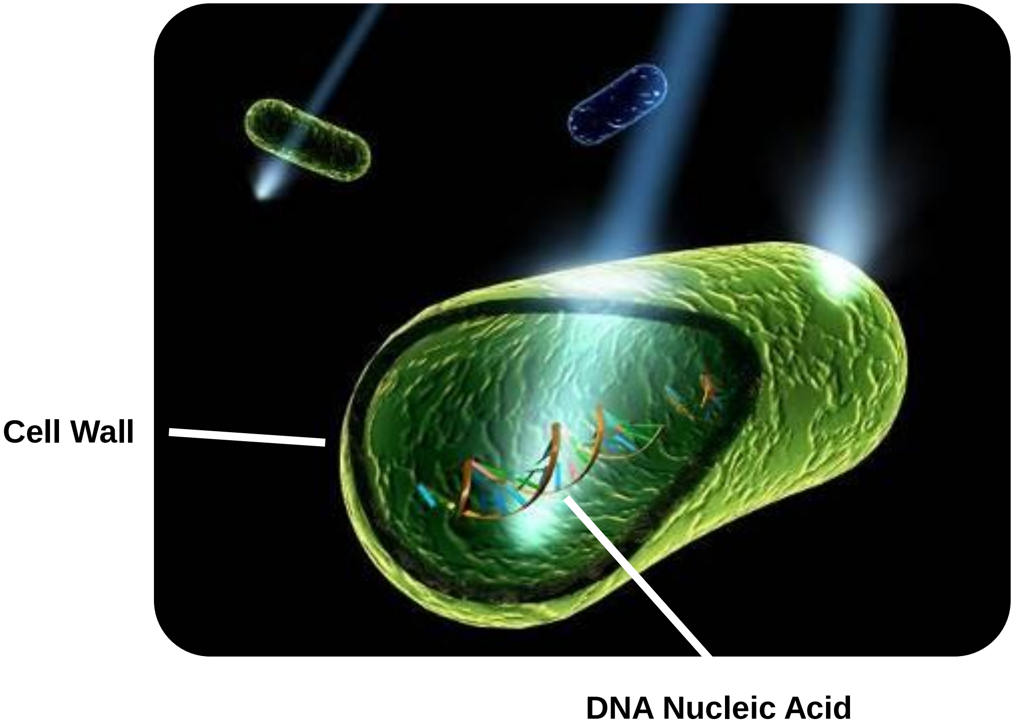
HOW DOES UV DISINFECT?

- UV light penetrates the cell wall
- The UV energy permanently alters the DNA structure of the microorganism
- The microorganism is "inactivated" and unable to reproduce or infect



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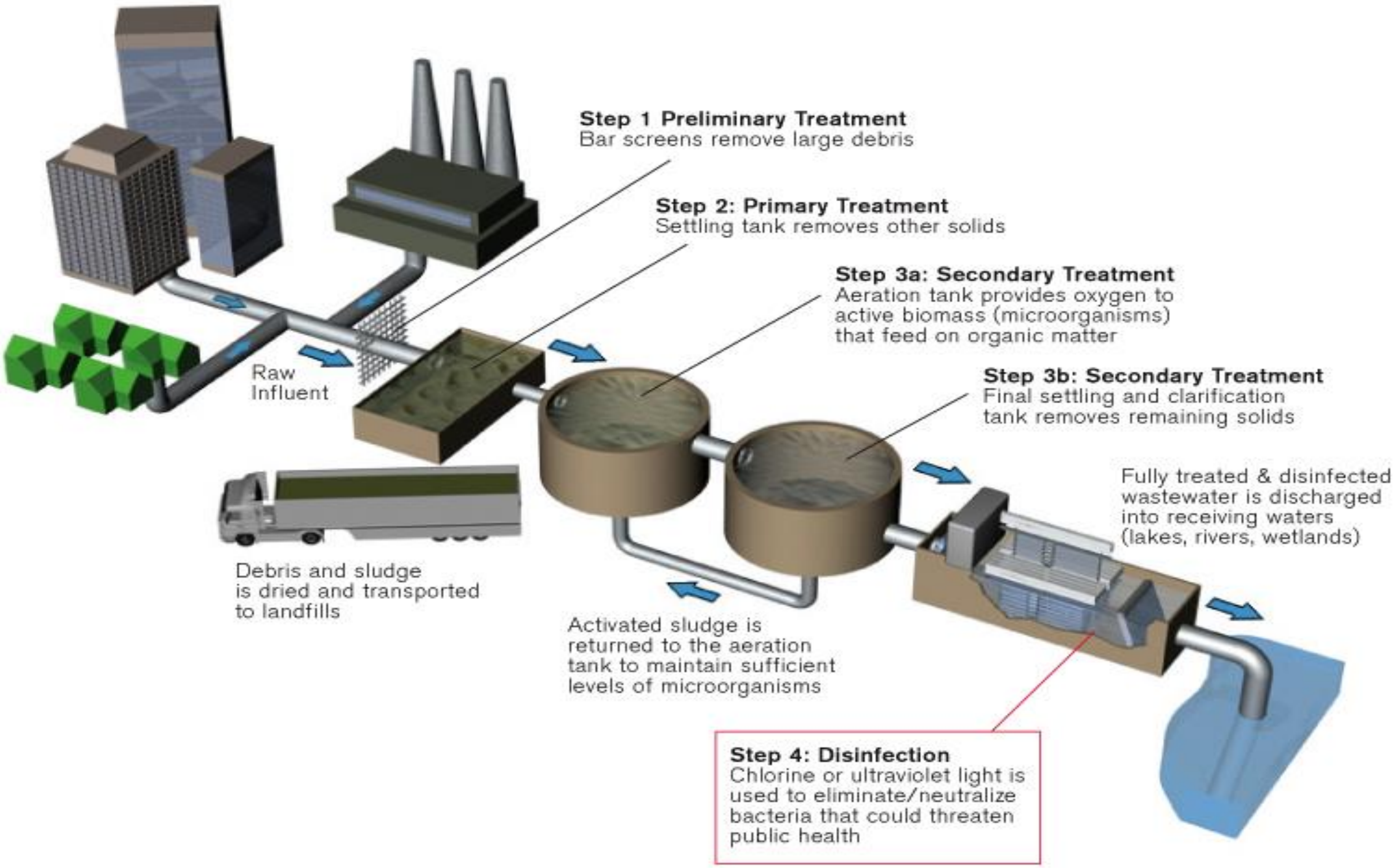
WASTEWATER DISINFECTION



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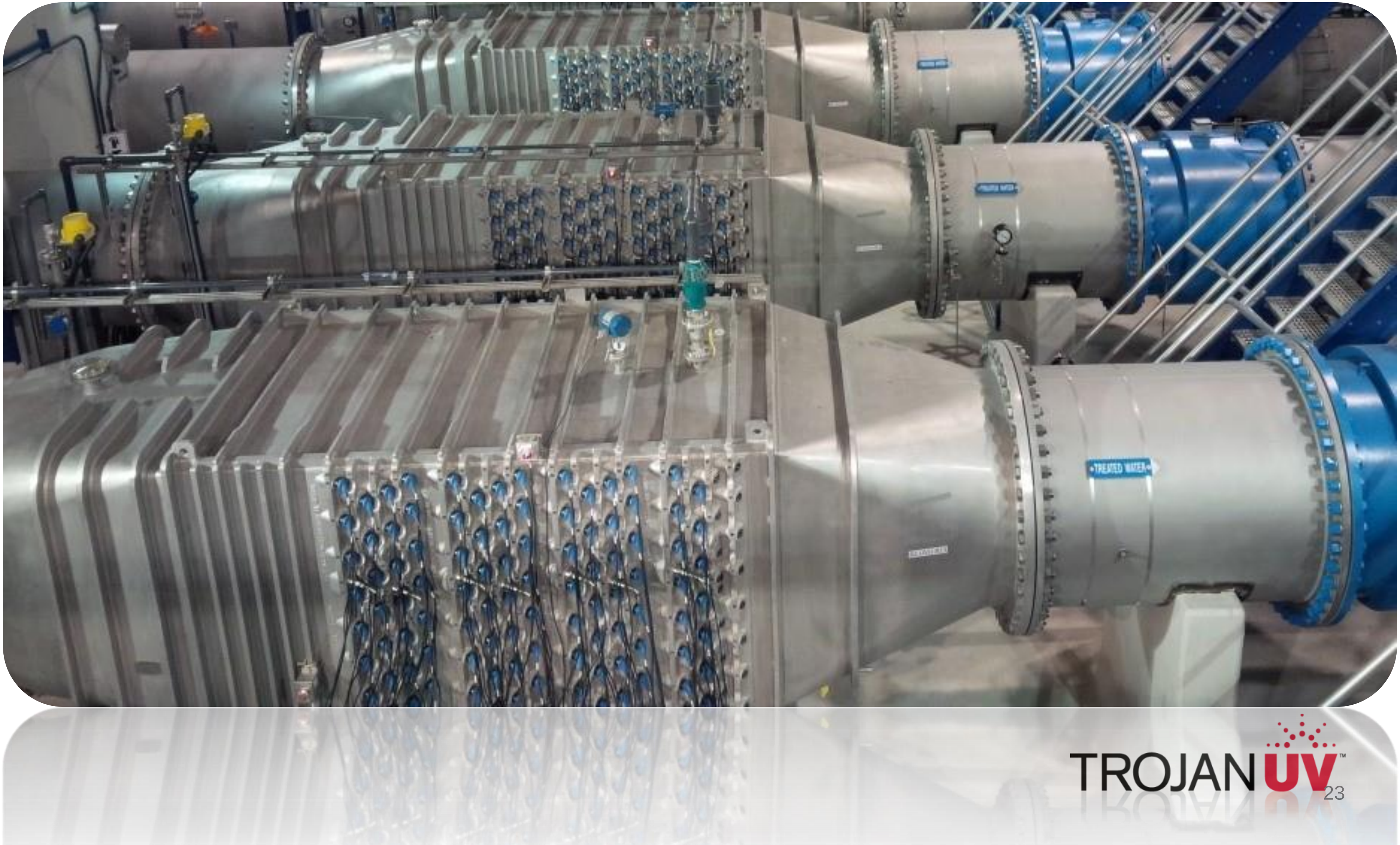
Examples of UV Installations
Large and Small

NEUSTADT, ONTARIO CANADA – TROJANUV SWIFT™ SC

NEW YORK CITY - TROJANUVTORRENT™

NEW YORK CITY – ONE QUADRANT, 14 REACTORS



ALBANY, NEW YORK – TROJANUVSWIFT™

VANCOUVER, BRITISH COLUMBIA

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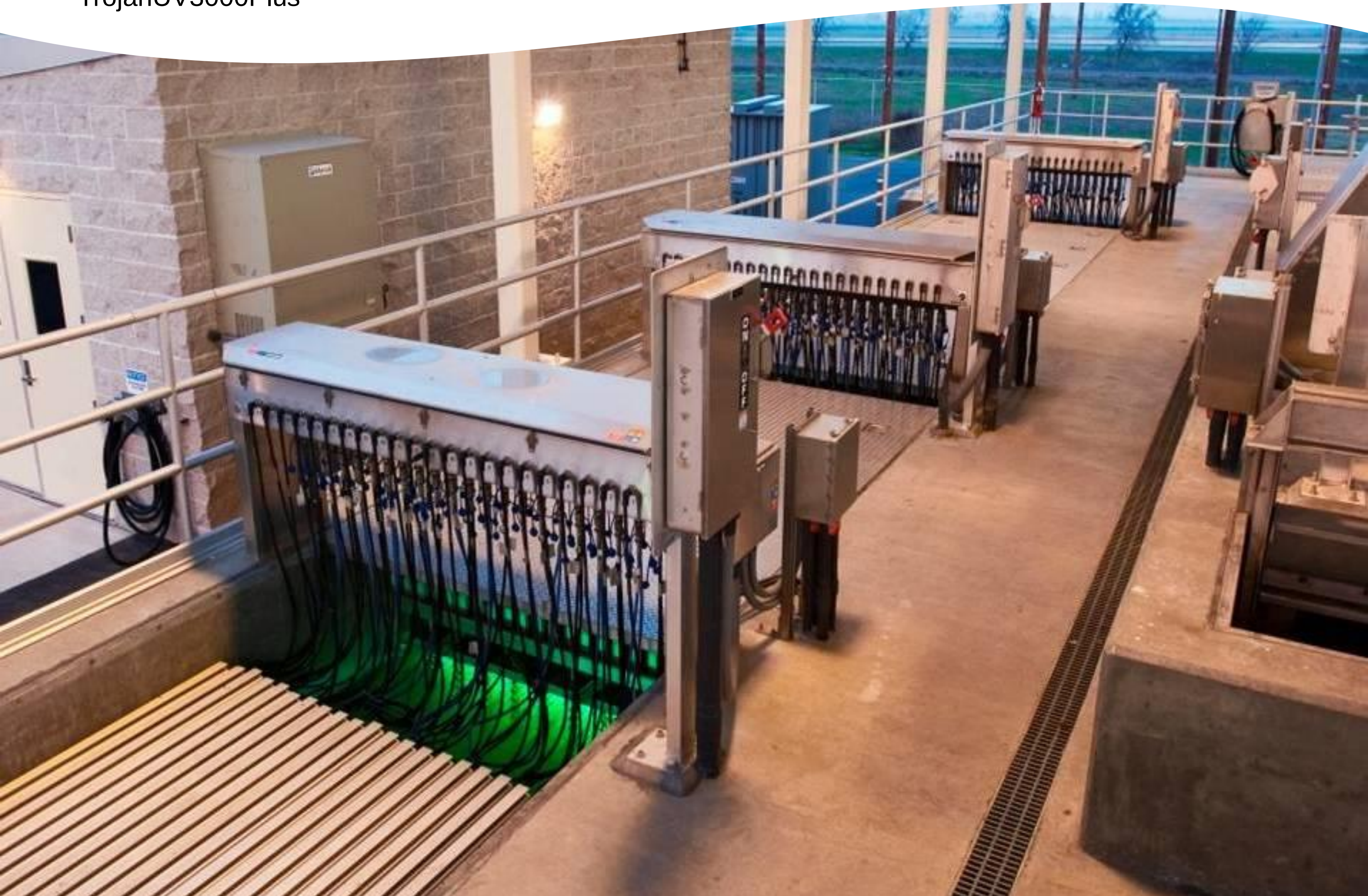
TIANJIN, CHINA – TROJANUVSWIFT

Lodi, California – 714 L/s (16.3 MGD)

TrojanUV3000Plus™



Peoria, Arizona – 900 L/s (20.5 MGD)

TrojanUVFit™

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UV for Contaminant Treatment

EXAMPLES OF CONTAMINANTS

N-nitrosodimethylamine (NDMA)
Industrial additive & disinfection byproduct

1,4-Dioxane
Industrial solvent

Pesticides & Herbicides
Agricultural crop protection products

Taste & Odor Compounds
Seasonal occurrences of MIB, geosmin and others

Pharmaceuticals & Personal Care Products
Includes potential endocrine disruptors

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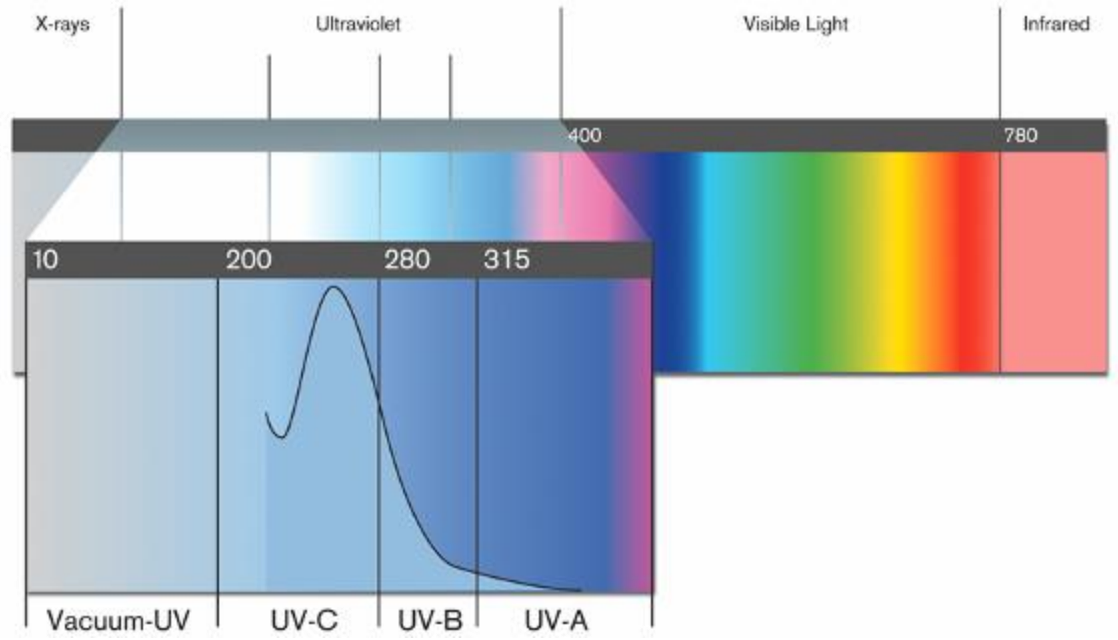
ENVIRONMENTAL CONTAMINANT TREATMENT

Using UV and hydrogen peroxide to destroy trace organic contaminants in water by:

UV-Photolysis

UV-Oxidation



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GROWING APPLICATIONS OF UV-OXIDATION FOR ECT

- Drinking Water
  Contaminated groundwater or surface water sources
- Indirect/Direct Potable Reuse (IPR)
  Wastewater treated to drinking water quality
- Groundwater Remediation
  Plume containment, site cleanup

*Total Flow Rate for Trojan **Municipal** UV-Oxidation Projects in*

2000: <10 MGD (38 MLD)

2015: >650 MGD (2.5 BLD)

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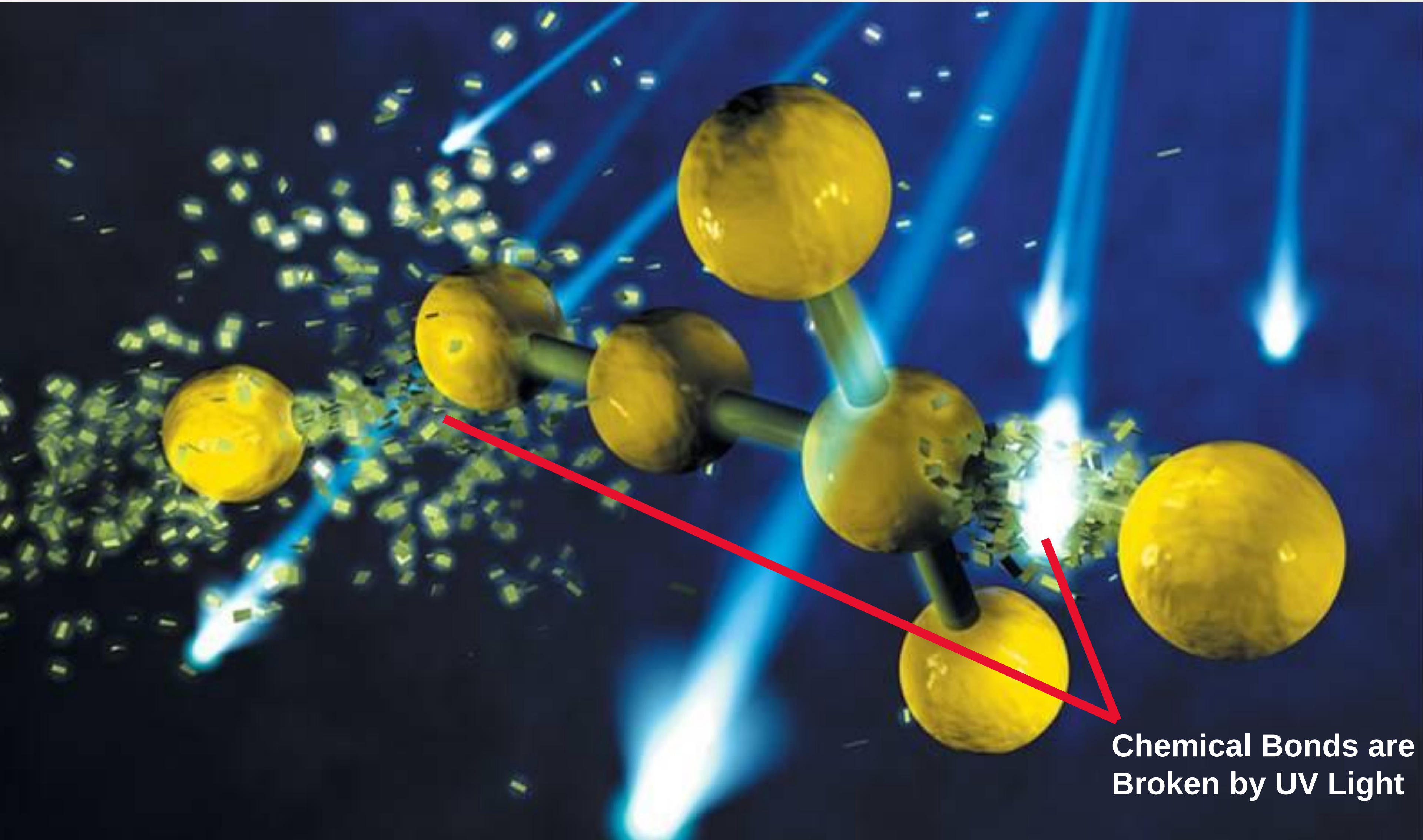
UV-PHOTOLYSIS



UV-PHOTOLYSIS

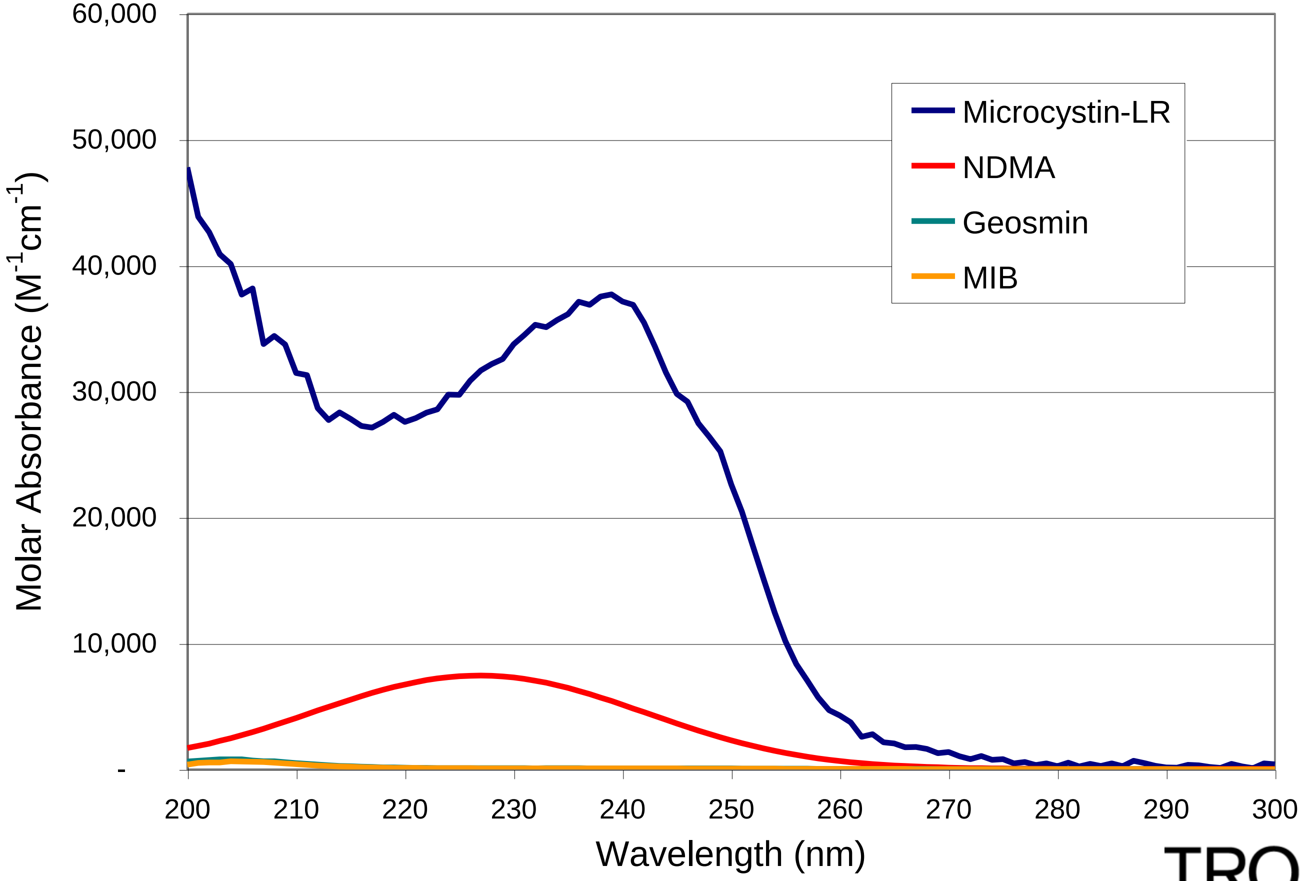
UV light is absorbed by the contaminant “C”:

$$C \xrightarrow{h\nu\ \text{(energy)}} \text{[radical species]} \xrightarrow{O_2} \text{Products}$$

- Degradation rate depends on:
  - Quantum yield
  - Molar absorption coefficients of C in the UV range
  - Intensity and spectral distribution of the light source (i.e. lamp type, UV system design)
  - Absorption of water background (UVT)

UV ABSORPTION SPECTRA

- UV-Photolysis is highly dependent on a contaminant molecule's ability to absorb UV light at a certain wavelength



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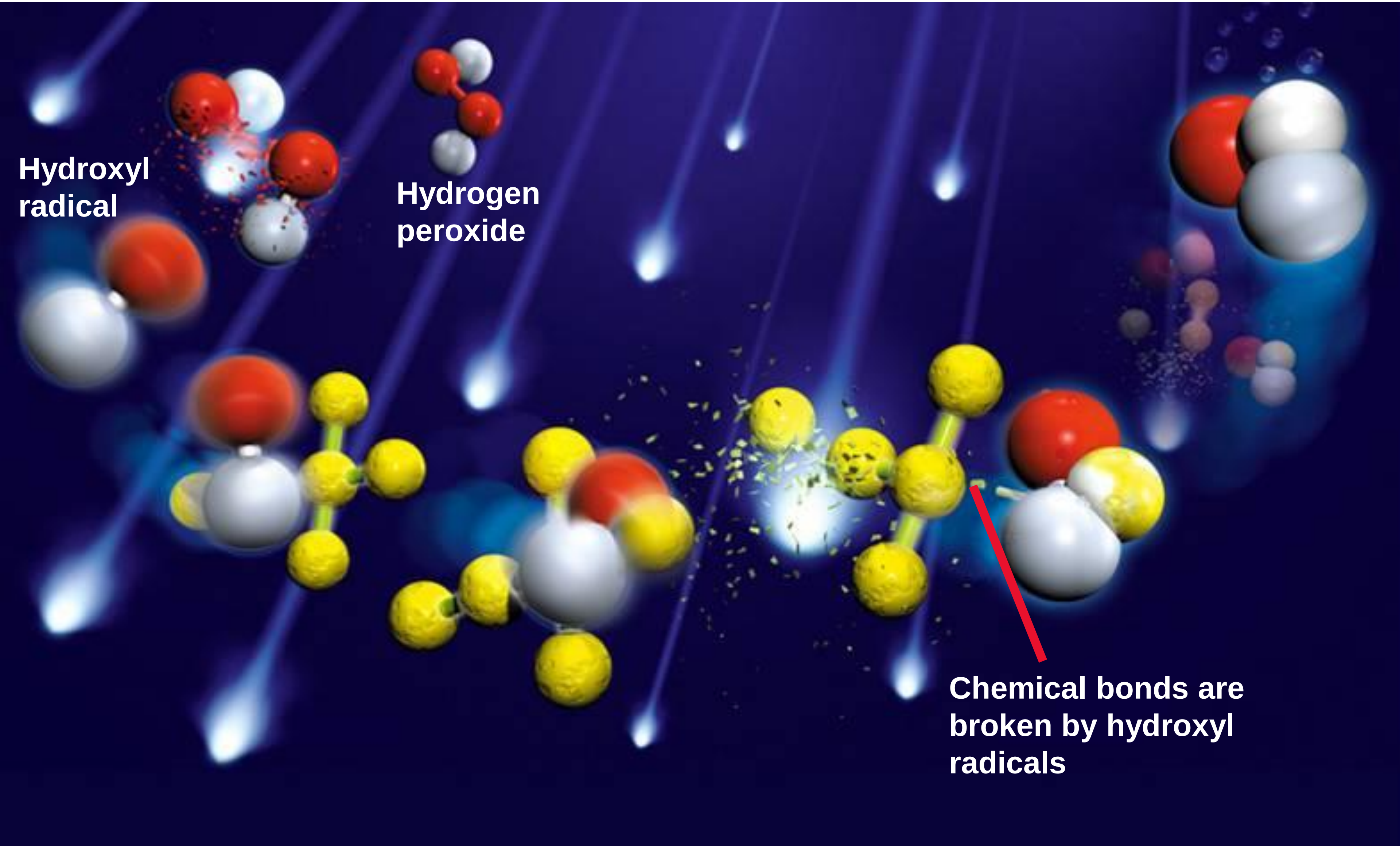
UV-OXIDATION



UV-OXIDATION REACTION MECHANISMS

- UV light is absorbed by hydrogen peroxide:

$$H_2O_2 \xrightarrow{h\nu \text{ (energy)}} 2 \bullet OH$$

$$C + \bullet OH \xrightarrow{k_{OH,P}} \text{[radical species]} \xrightarrow{O_2} \text{Products}$$

- Degradation rate depends on:
  - Intensity and spectral distribution of the light source (i.e. lamp type, UV system design)
  - Absorption of water background (UVT)
  - Hydroxyl radical (●OH) rate constant $k_{OH,C}$
  - H_2O_2 concentration
  - Hydroxyl radical scavenging demand

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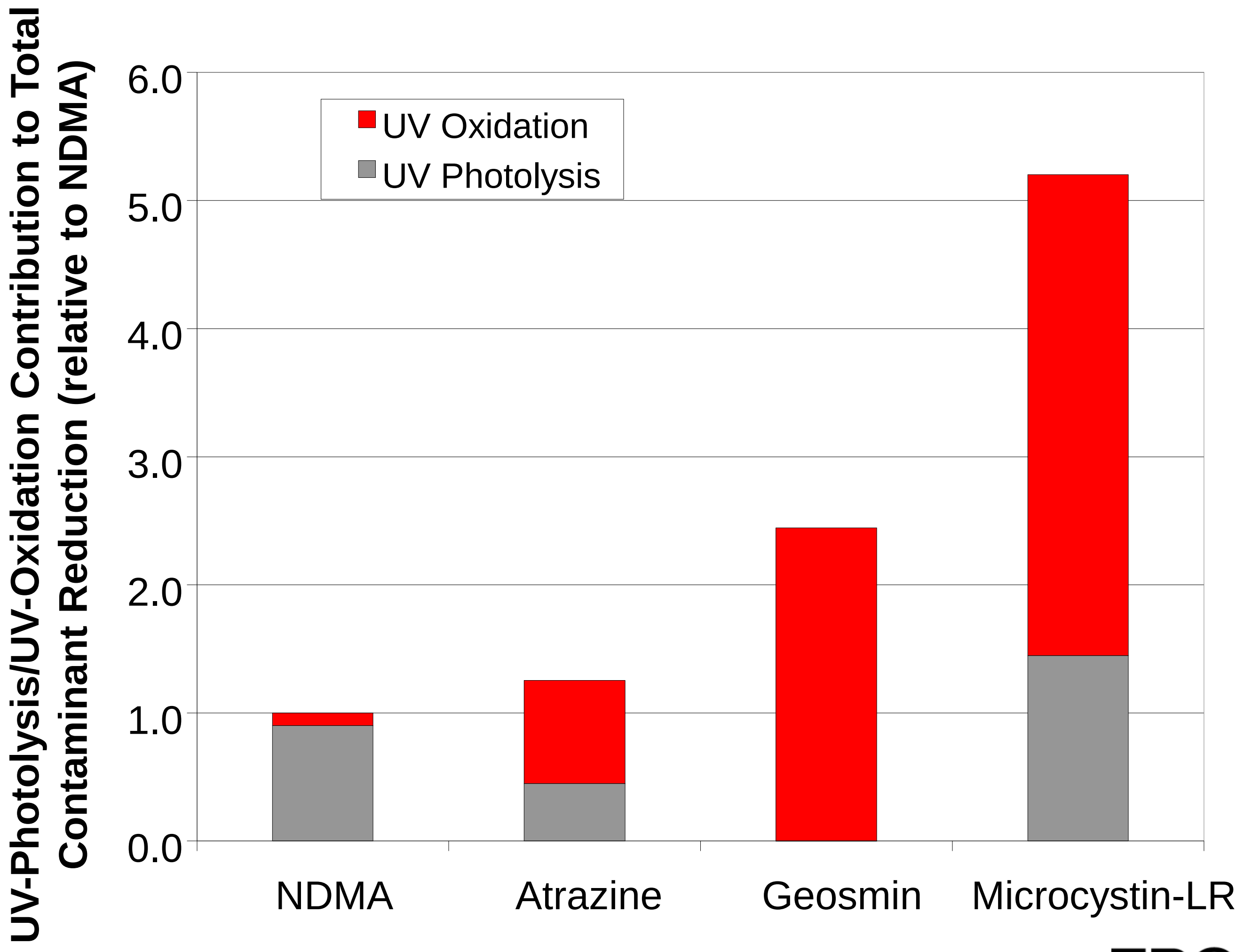
PHOTOLYSIS + OXIDATION - CONTAMINANT DESTRUCTION BALANCE



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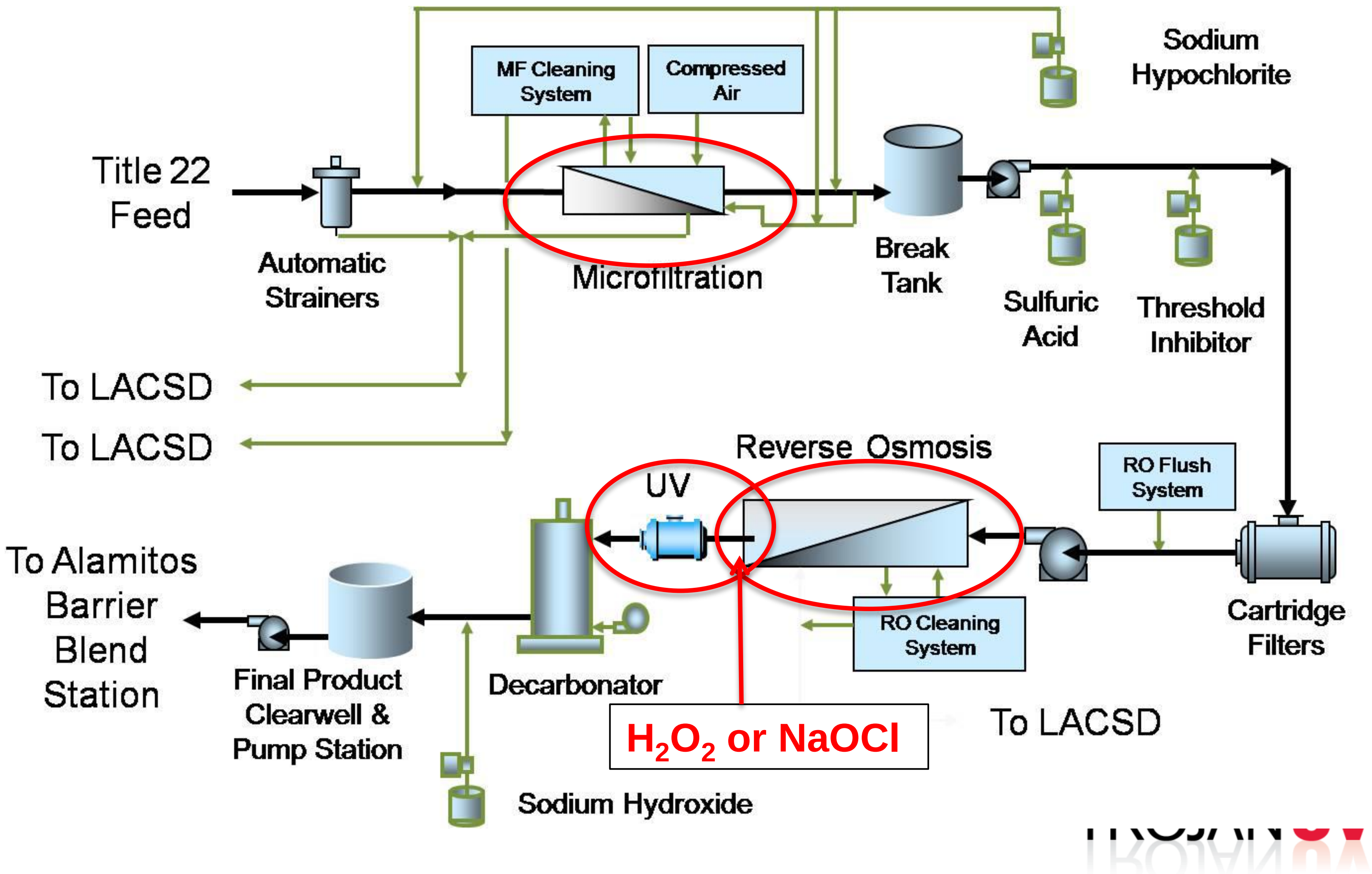
ECT APPLICATIONS:
POTABLE WATER REUSE

INDIRECT POTABLE REUSE SYSTEMS GLOBALLY

Name of Project	Location	Start-Up Date
Orange County Water District Factory 21	Fountain Valley, CA	1975
Orange County Water District Groundwater Replenishment System	Fountain Valley, CA	2004
Leo J. Vander Lans Advanced Treatment Facility	Long Beach, CA	2003
West Basin Water Recycling Facility	Los Angeles, CA	2006
Bundamba Advanced Water Purification Facility	Brisbane, AUS	2007
Luggage Point Advanced Water Purification Facility	Brisbane, AUS	2008
Gibson Island Advanced Water Purification Facility	Brisbane, AUS	2008
Joint Water Purification Project	Cottonwood, CO	2010
San Diego Water Purification Demonstration Project	San Diego, CA	2011
Big Spring Water Reclamation Facility	Big Spring, TX	2012
Oxnard Advanced Water Purification Facility	Oxnard, CA	2012

Process Flow Diagram



Regulatory Framework

- Why oxidation?
  - Removal of contaminants that pass through MF and RO
  - Up to 6-log virus disinfection
- **California** requires an oxidation step post-RO
  - Demonstrated by removing a basket of contaminants or 0.5-log 1,4-dioxane
- **Texas** requires 4-log removal of virus, removal of contaminants

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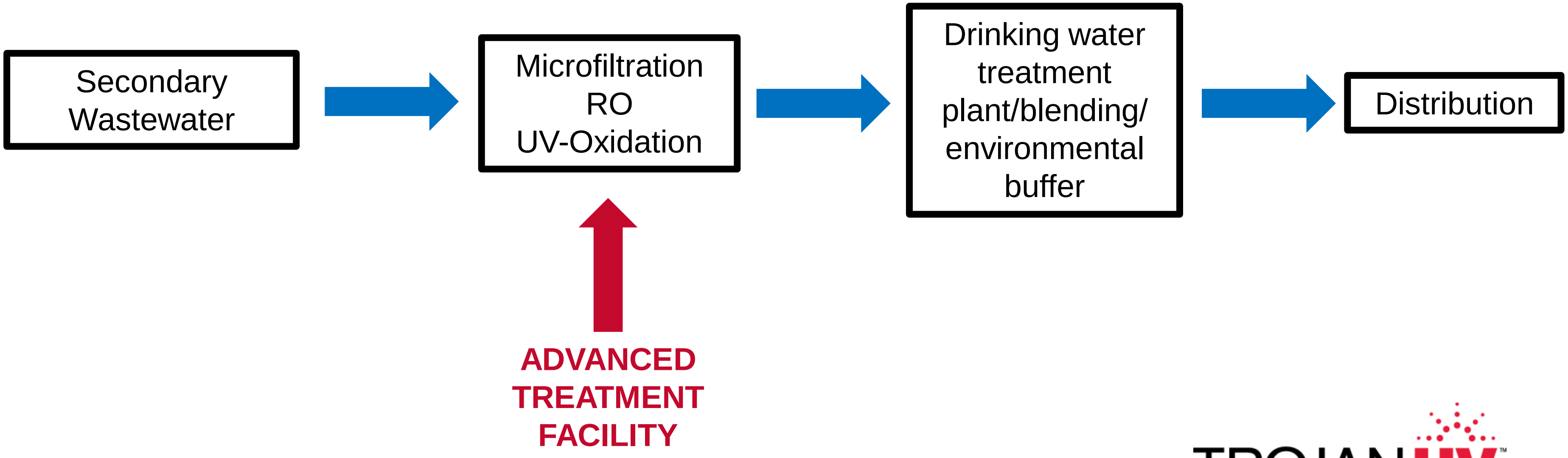
MAKING POTABLE WATER FROM "WASTEWATER"

- Water collected from wastewater treatment plants is "advanced" treated to higher standard allowing this water to be treated again back into drinkable water

- Advanced treatment includes three different treatment technologies:
  1. Microfiltration
  2. Reverse osmosis
  3. UV-oxidation



WHY USE UV-OXIDATION FOR IPR?

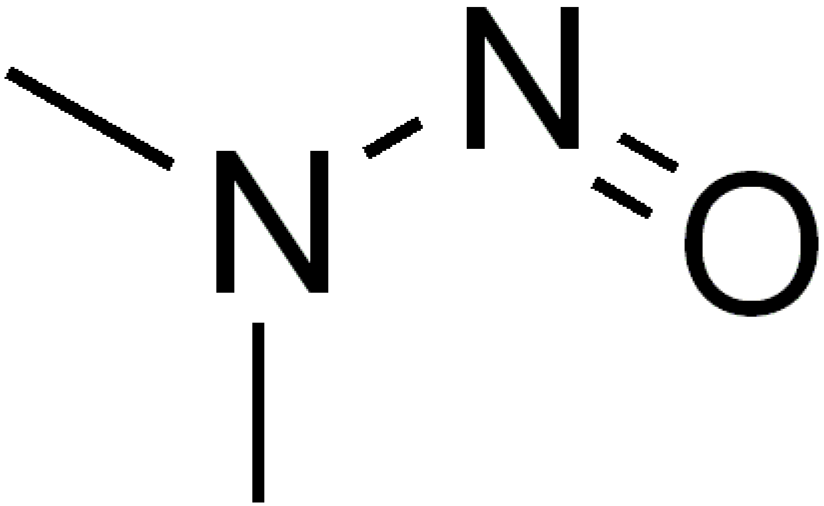
It has been documented that molecules less than 100 atomic mass units in size and those with high hydrophobicity can pass through microfiltration and RO without being treated

Contaminants with these characteristics include:

NDMA	**1,4-Dioxane**
Bisphenol-A	Carbamazepine
DEET	Estradiol
Ibuprofen	Acetaminophen
Clofibric acid	Diclofenac
Meprobamate	Oxybenzone

N-NITROSODIMETHYLAMINE (NDMA)

- NDMA is a disinfection by-product
- It can be generated in both wastewater and drinking water
- It is a probable human carcinogen with a 1 in 1,000,000 cancer risk concentration of 0.7 ng/L (ppt) in drinking water
  - **Source:** USEPA Integrated Risk Information System (IRIS) Database



NDMA

NDMA – TREATMENT

Ozone

- Ineffective for NDMA treatment
- Can eliminate the precursors of NDMA in wastewater but…
- Can also generate NDMA

UV-Oxidation

- Highly effective for NDMA treatment
- NDMA absorbs UV light at 254 nm
- NDMA destruction occurs through photolysis

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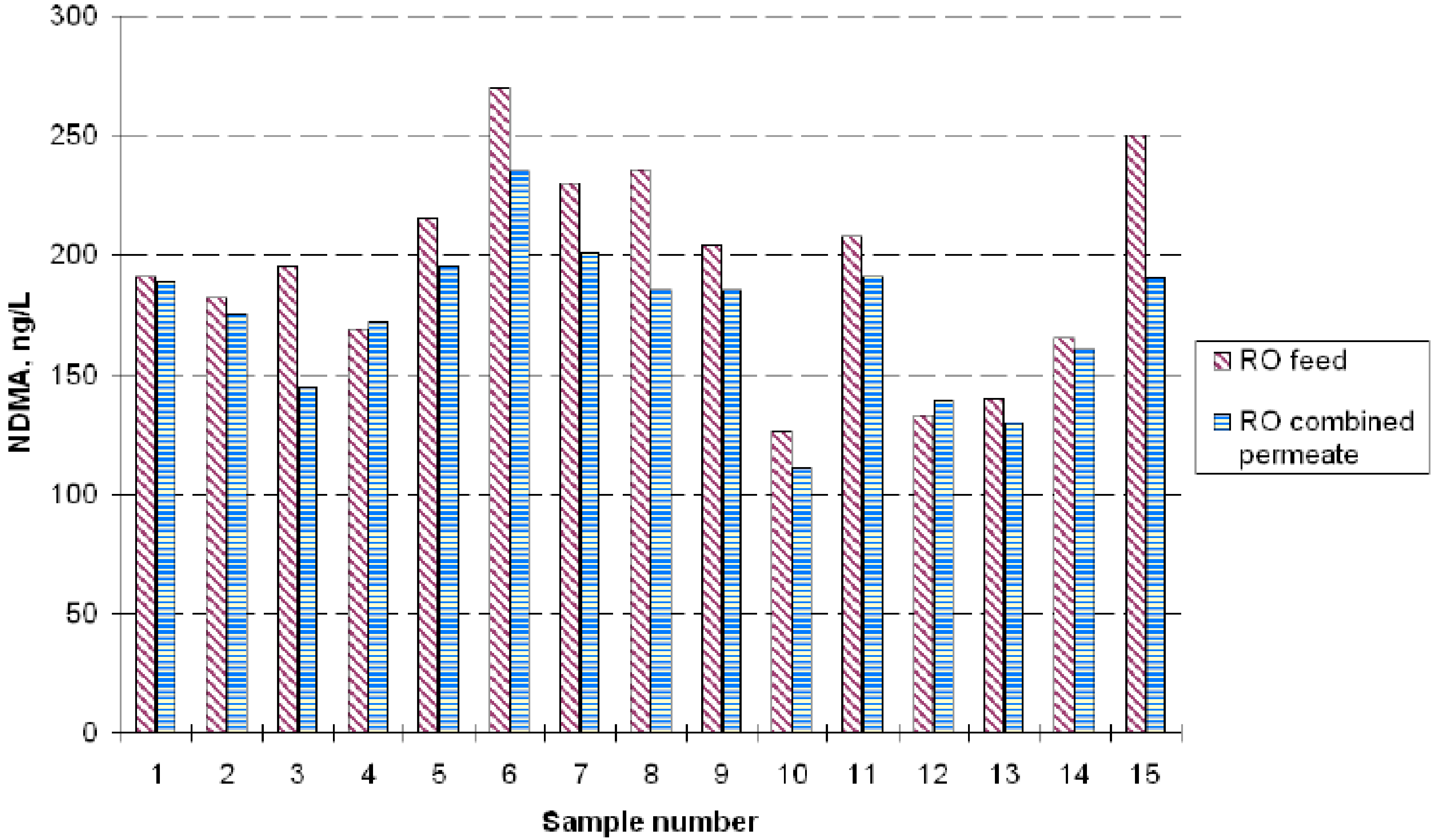
NDMA – MEASURED POST REVERSE OSMOSIS IN AUSTRALIA



* Poussade, Y; A. Roux, T. Walker and V. Zavlanos. Advanced Oxidation for Indirect Potable Reuse – A Practical Application in Australia. Presented at OzWater 2009.

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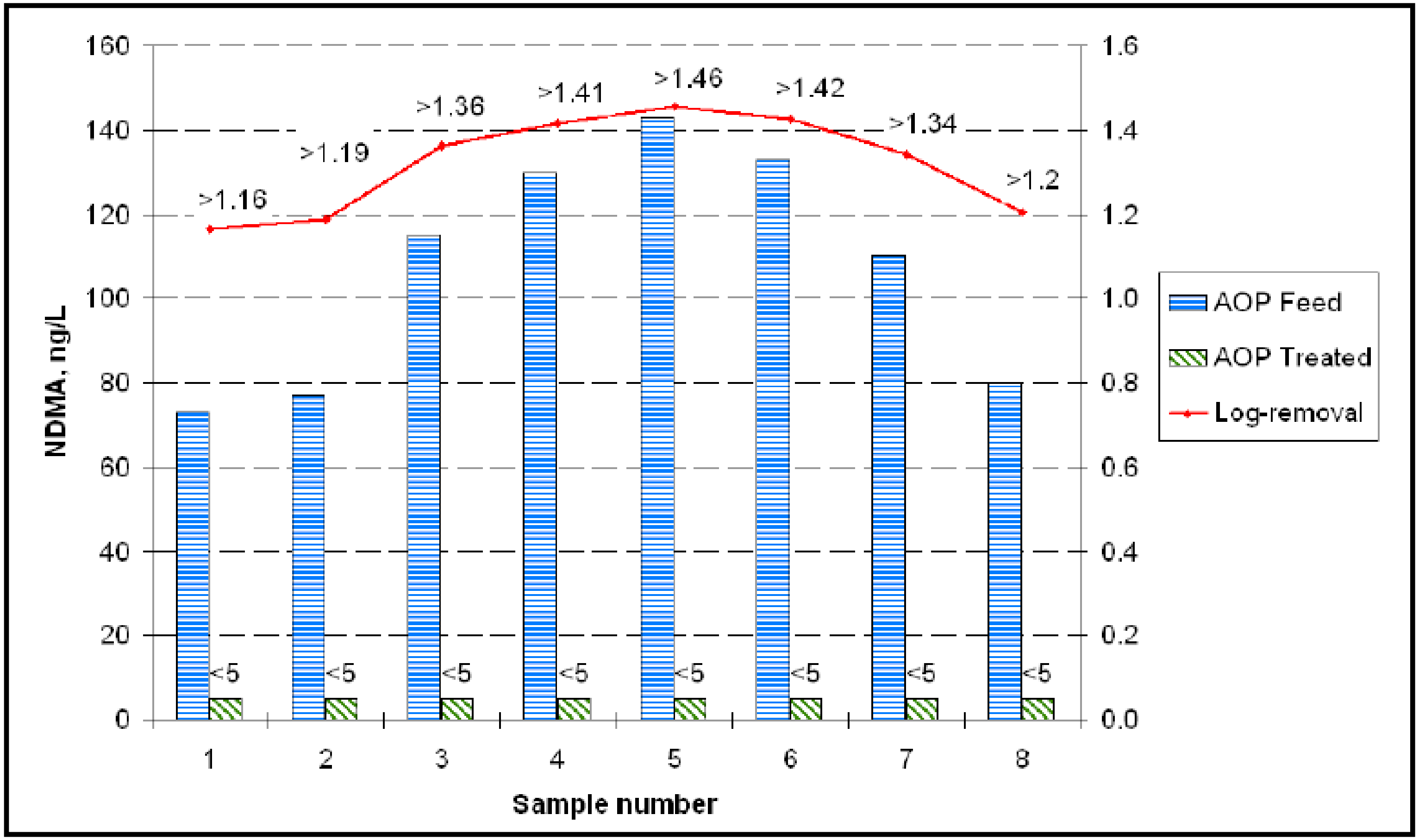
NDMA – MEASURED POST UV-OXIDATION IN AUSTRALIA (RO EFFLUENT)



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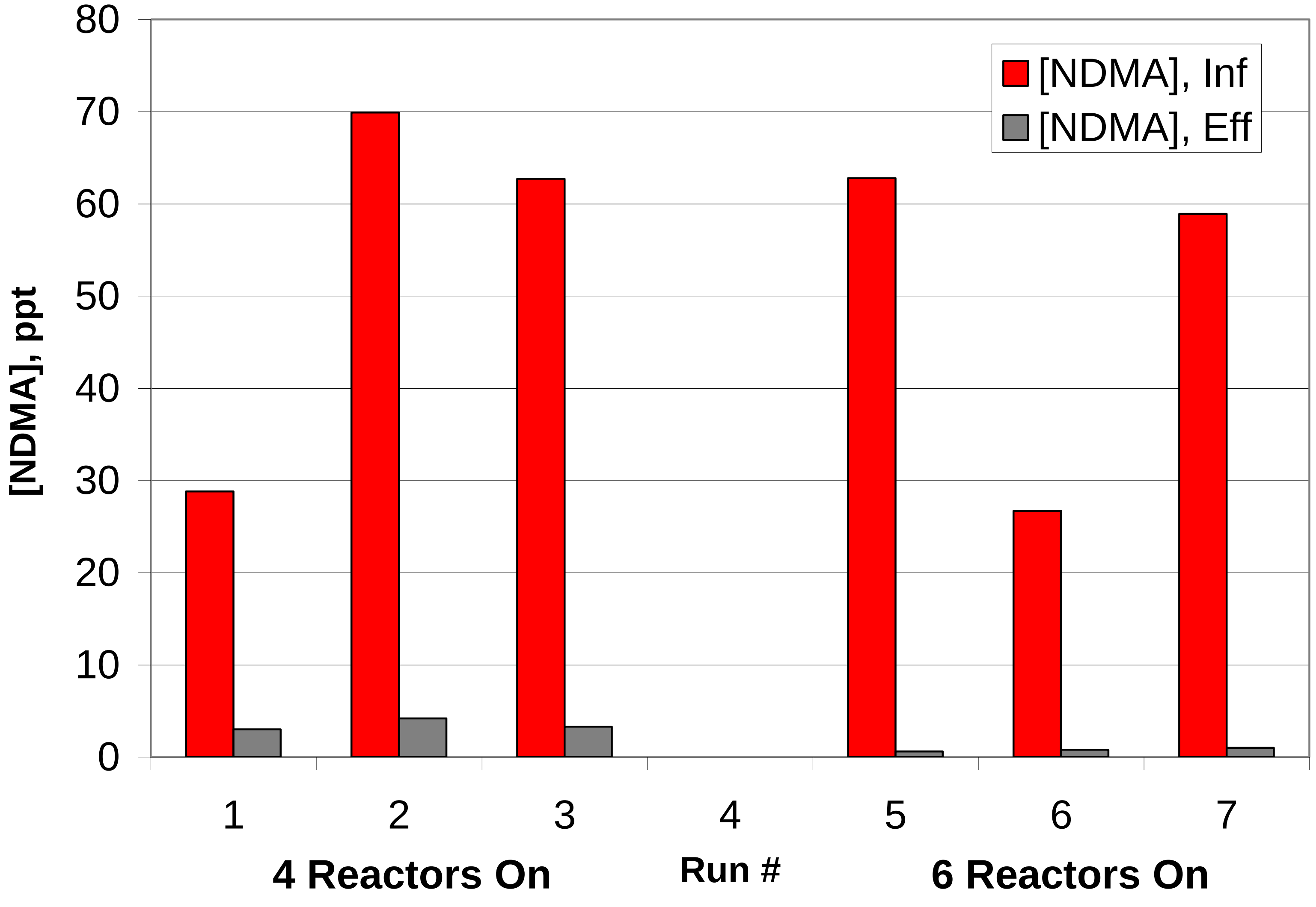
ORANGE COUNTY, CA – INDIRECT POTABLE REUSE (IPR)

NDMA FULL SCALE TESTING - ORANGE COUNTY, CA



Flow: >8.5 MGD

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WEST BASIN MUNICIPAL WATER DISTRICT, CA

- 12.5 MGD California facility also treating wastewater to drinking water standards for groundwater replenishment
- MF/RO/UV-Oxidation treatment train (UV system uses monochromatic amalgam lamps)
- 1.3-log reduction of NDMA, disinfection

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WEST BASIN MUNICIPAL WATER DISTRICT, CA

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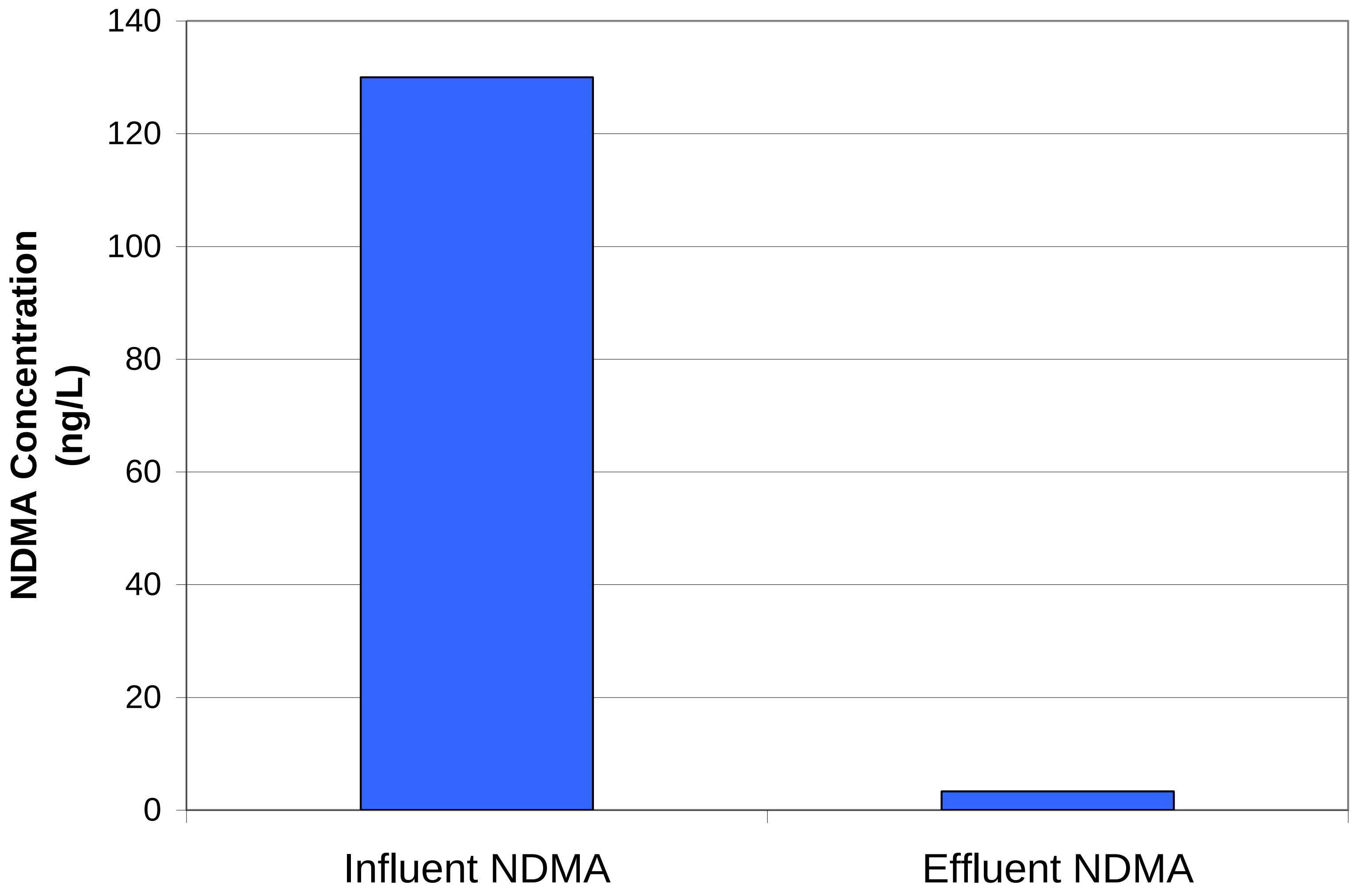
WEST BASIN MUNICIPAL WATER DISTRICT, CA – NDMA TREATMENT



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Leo J. Vander Lans Advanced Water Treatment Facility

- LJVWTF began operation in 2005
- Treating 3 million gallons/day (MGD)
- UV design basis: 1.6-log reduction of NDMA

LVLWTF Expansion

- Plant expansion to 8 MGD was completed in ‘14
- 2 new trains of UV added
- Hydrogen peroxide injection system was added
- **Design: 2.1-log reduction of NDMA and 0.5-log reduction of 1,4-dioxane**
- Site acceptance testing required
- UV/Cl_2 study performed in parallel

LVLWTF UV-Oxidation System

COLORADO RIVER MUNICIPAL WATER DISTRICT

- Provides a privatized drinking water supply to municipalities in West Texas
  - Odessa
  - Snyder
  - Big Spring
- Population of service area = ~150,000
- Traditional Sources of Raw Water:
  - E.V. Spence Reservoir = 1.4 % FULL AS OF SEPT 8, 2014
  - Lake J.B. Thomas= 0.9 % FULL AS OF SEPT 8, 2014
  - O.H. Ivie Reservoir= 16.9 % FULL AS OF SEPT 8, 2014

COLORADO RIVER MUNICIPAL WATER DISTRICT

- In 2004, the traditional reservoirs used to supply drinking water were at only 10% of their capacity

- In response to this as well as state mandated legislation to develop a long-term regional plan for drinking water supply, the CRMWD evaluated possible approaches to conserving or augmenting declining drinking water supplies.

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COLORADO RIVER MUNICIPAL WATER DISTRICT

Evaluated options in the study included:

1. Use of other water catchments

2. Non-potable reuse of reclaimed wastewater
   – Irrigation, Recreation, Agriculture

3. Potable reuse of reclaimed wastewater
   – Drinking water
   – Re-supply local reservoirs with high-purity treated wastewater

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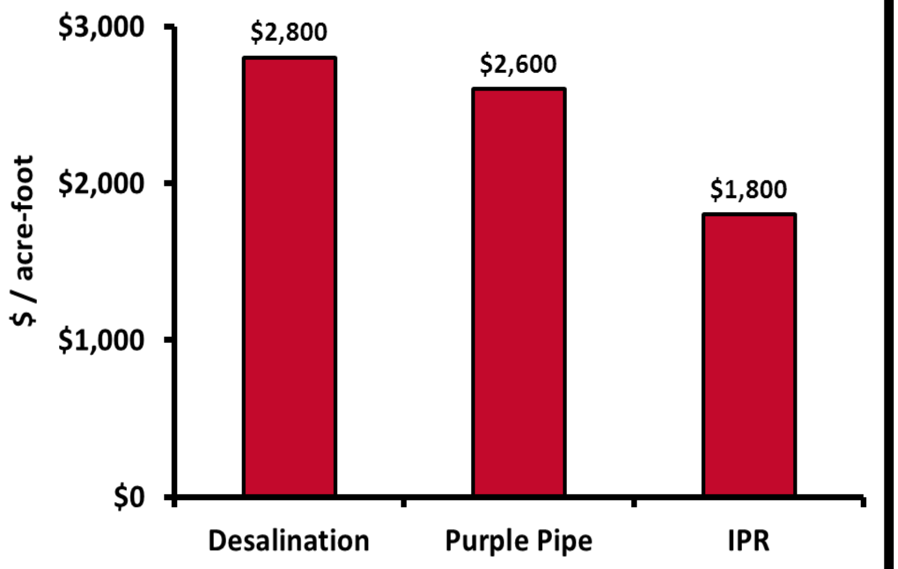
WHAT HAD BEEN DONE: OTHER EXTERNAL STUDIES

- Evaluating alternatives to address water shortages in San Diego County

  - Desal: Higher energy costs
  - Non-potable reuse (Purple Pipe)
    - Install new distribution system
  - IPR: Low cost option



Fermian Business and Economic Institute, 2011

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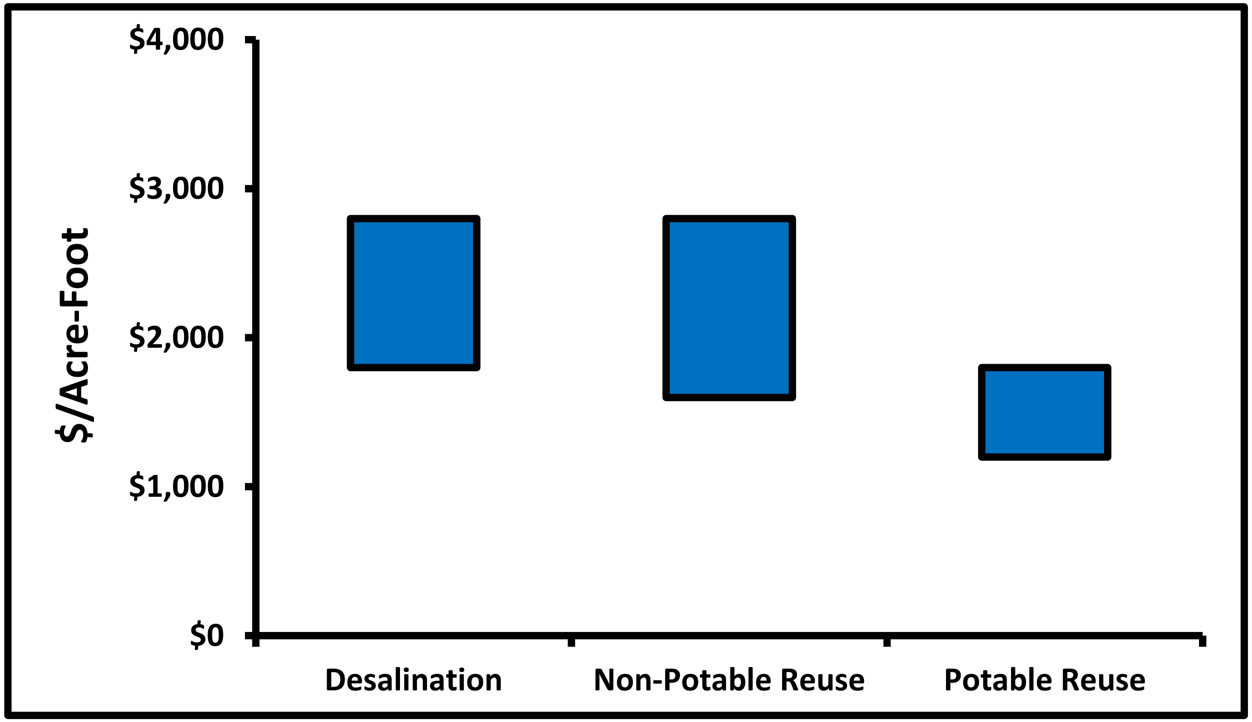
SELECTING POTABLE vs. NON-POTABLE REUSE

- Similar feasibility studies carried out in other areas
- Cost ranges for various approaches to drinking water augmentation



Source: Fermanian Business & Economic Institute, 2010

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SELECTING POTABLE vs. NON-POTABLE REUSE

- CRMWD decided to build a single treatment plant that would treat secondary wastewater from surrounding communities to an "advanced" level
- Known as the "Raw Water Production Facility" (RWPF)
- The RWPF will generate "synthesized" raw water that will be BLENDED with "natural" surface raw water of the E.V. Spence Reservoir upstream of the local drinking water treatment facilities
- Raw water will be re-treated as drinking water at existing drinking water treatment plants

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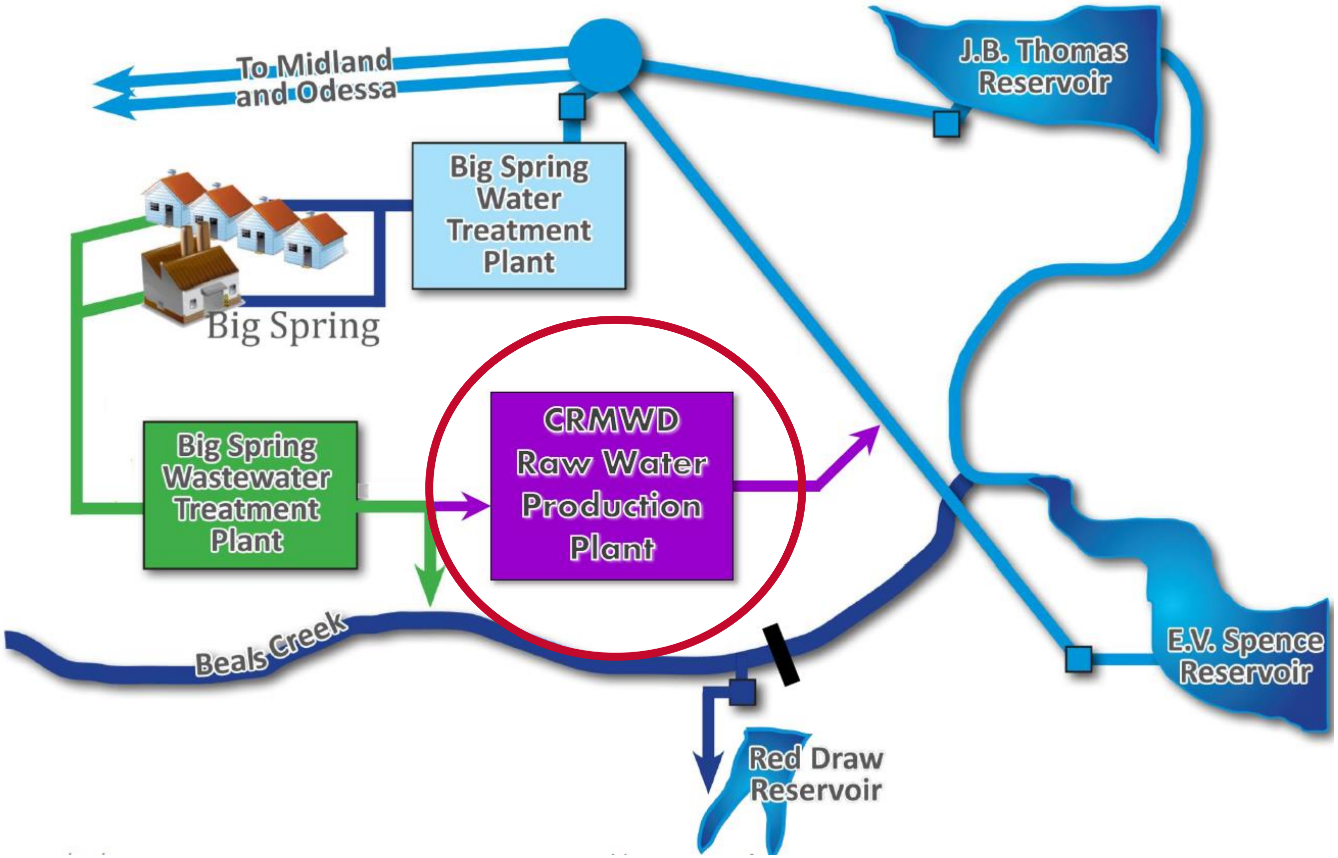
THE FINAL SOLUTION

CRMWD Big Spring Reclamation Project



RWPF PLANT DESIGN DETAILS AND CALIFORNIA PRECEDENT

- Advanced Treatment uses microfiltration, reverse osmosis and UV-oxidation similar to existing facilities in California; designed per CA regulations for Full Advanced Treatment
- CA and Orange County GWRS precedent aids in Public Acceptance
- UV-oxidation system sized based on treatment of NDMA and 1,4-Dioxane as surrogates
- UV-oxidation serves a number of unique purposes
  - Treatment of NDMA and 1,4-Dioxane
  - Treatment of pharmaceuticals and endocrine-disrupting chemicals not removed by MF or RO
  - Additional disinfection barrier of 4-log virus credit

Raw Water Production Facility Design Parameters	
Design Flow:	1.8 MGD
Target Contaminants:	NDMA 1,4-Dioxane
Design NDMA Reduction:	1.2 - Log
Design 1,4-Dioxane:	0.5 - Log
Oxidant:	H_2O_2
Disinfection Method:	UV Light

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THE FINAL SOLUTION – BIG SPRING

DRINKING WATER TREATMENT IN MDW AURORA, CO

190 MLD Colorado facility treating drinking water obtained from an effluent-dominated source

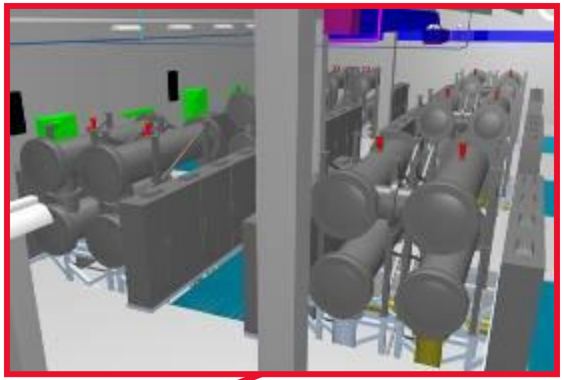
Platte River receives significant wastewater discharge

Treatment Process: Bank filtration, Precipitative softening, TrojanUVPhox™ UV-Oxidation, Biological filtration, Granular activated carbon

No membranes = no discharge, destruction technology

Use of LPHO technology significantly reduces energy vs. MP

MDW INSTALLATION - AURORA, CO



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MDW INSTALLATION - AURORA, CO

MULTI-BARRIER APPROACH – PWN: ANDIJK DRINKING WATER PLANT

- Water source is Lake IJssel in North Holland
- **Fed by Rhine River; significant amount of contaminants (from wastewater, agriculture, etc)**
- UV-Oxidation a barrier to micropollutants (pesticides, pharmaceuticals, seasonal algae-related contaminants, T&O compounds etc.)
- Disinfection objective to reduce Spores of Sulfur Reducing Clostridia (SSRC) and *Cryptosporidium & Giardia*
- Serves ~500,000 people (Peak flow ~95 MLD)

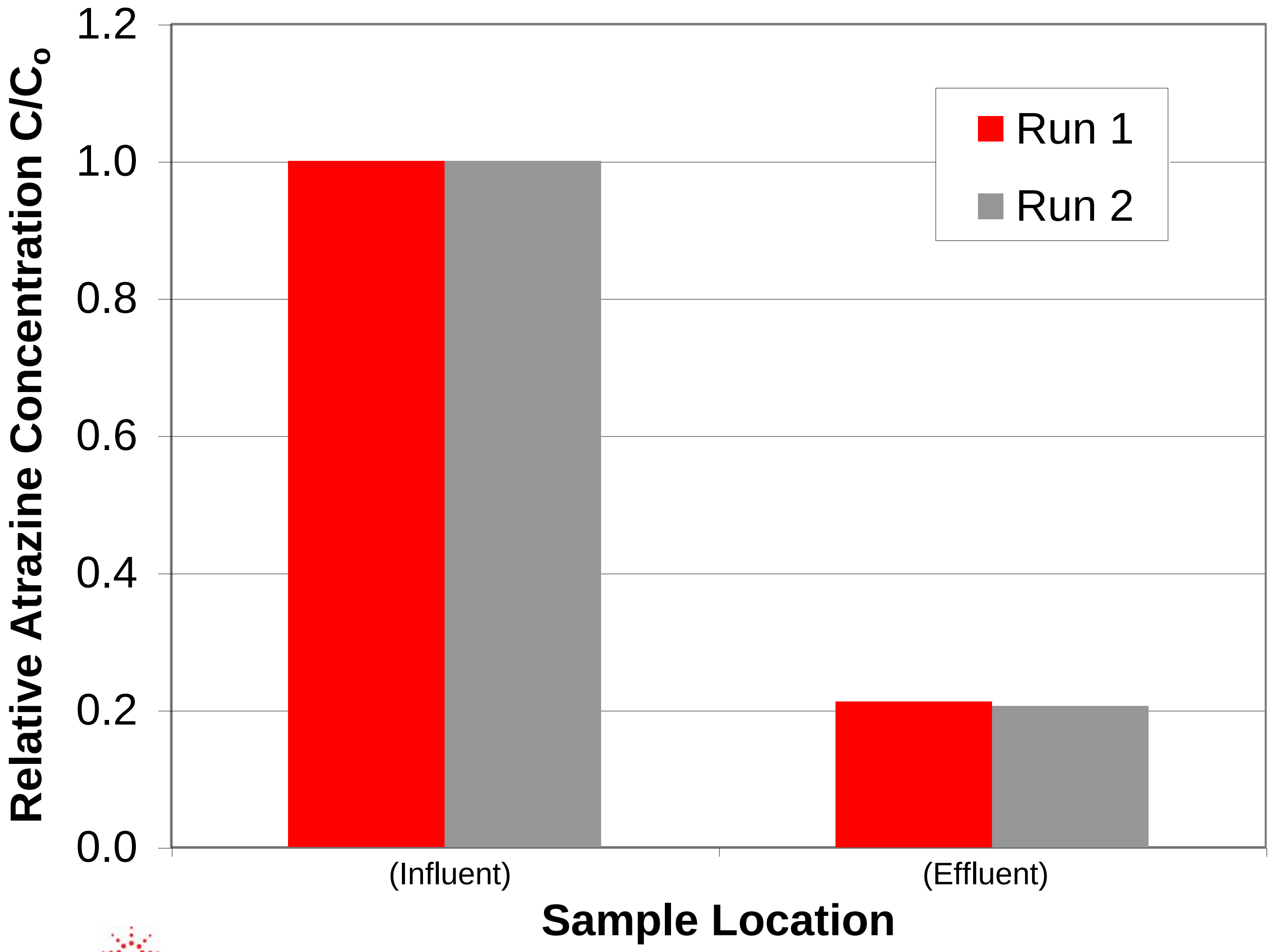
PWN ANDIJK – UV OXIDATION & DISINFECTION

- Ozone considered but rejected due to inability to treat targeted compounds and bromate DBP concerns
- UV-Oxidation does not create bromate
- Joint research project between Trojan & PWN investigated UV-oxidation and optimized reactor design
- Involved laboratory & pilot plant work
- Full scale UV-Oxidation plant installed October 2004.
- Heemskerk (another PWN Water Treatment Plant) with same treatment objectives constructed in 2008

FULL-SCALE INSTALLATION AT ANDIJK

TrojanUVSwift™ECT installation in Andijk (1 train of 3 trains)

PWN RESULTS FOR PESTICIDE TREATMENT



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CONCLUSIONS

- Potable reuse can be much less expensive than non-potable reuse
  - Year-round drinking water supply
  - Sustainable supply
  - Various economic and cost advantages over alternatives
- Advanced treatment of wastewater included MF-RO-UV-oxidation treatment train
  - Multi-barrier strategy
  - UV-Oxidation treats contaminants of concern not removed by RO (E.g.. NDMA)
  - Design based on extensive precedents in California, elsewhere

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Thank you

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