Ultraviolet Disinfection and Other New Water Treatment Technologies

Lawrence K. Wang, PE, PhD
Water Facilities Manager
City of Albany, NY 12204
Tel: (518) 767-2667; Fax: (518) 767-9265
LarryKWang@juno.com
LarryKWang@gmail.com

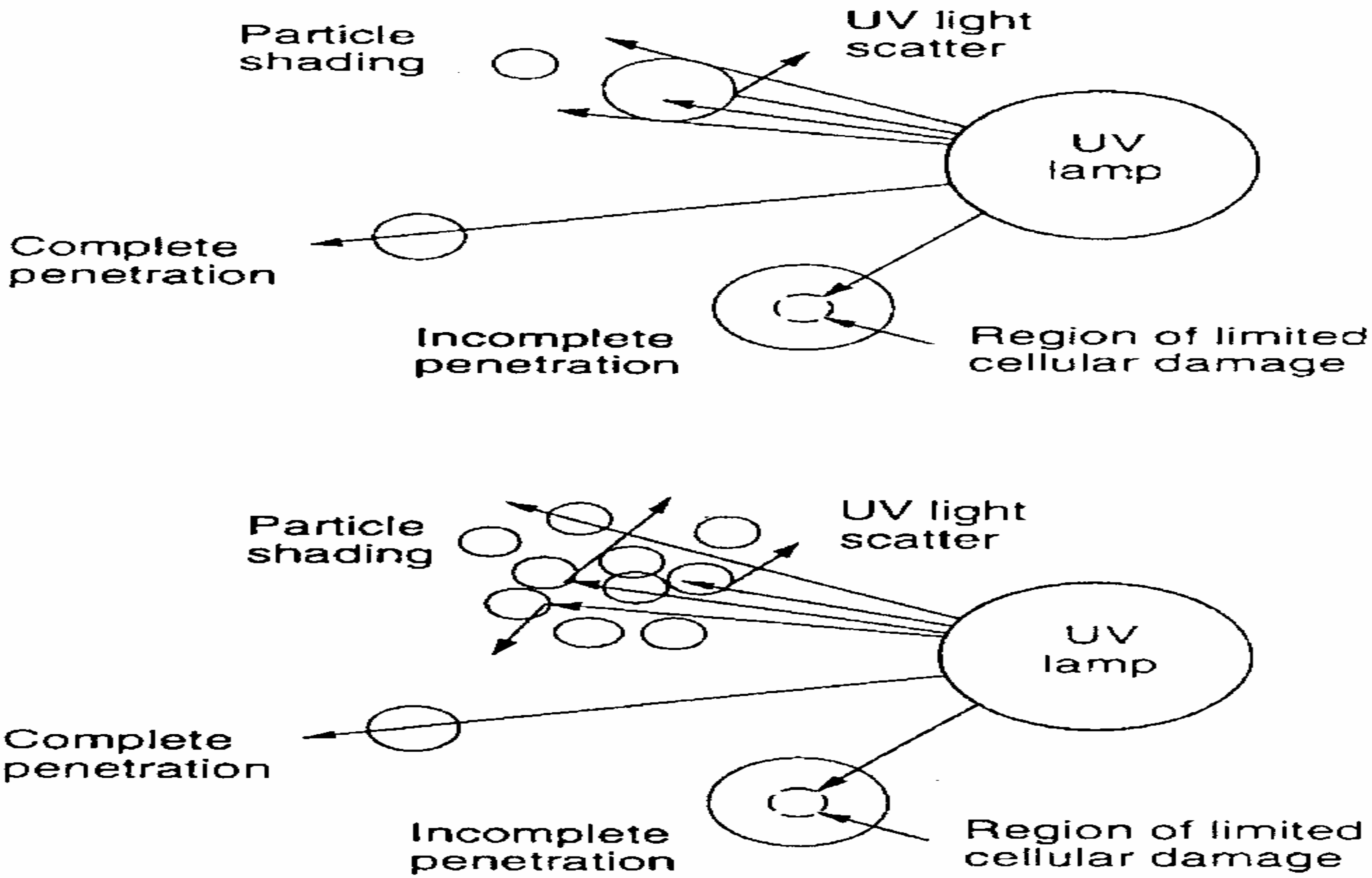
UV Disinfection

- Inactivates microorganism by UV light absorption and DNA/RNA destruction
- Exceptional for disinfection of small bacteria and viruses
- Technically feasible for disinfection of large Giardia and Cryptosporidium at very high UV doses and/or long contact time, or in conjunction with oxidants (ozone, peroxide, chlorine)
- Well established disinfection technology

UV for Potable Water Treatment

- UV alone for treatment of uncontaminated groundwater where Giardia and Cryptosporidium are not expected to occur
- UV + ozone (or hydrogen peroxide) (or chlorine) , known as AOP, for treatment of surface water
- Applied prior to distribution system
- No residual, or DBP, is produced
- Secondary chemical disinfection is required

UV Effectiveness vs. Particles



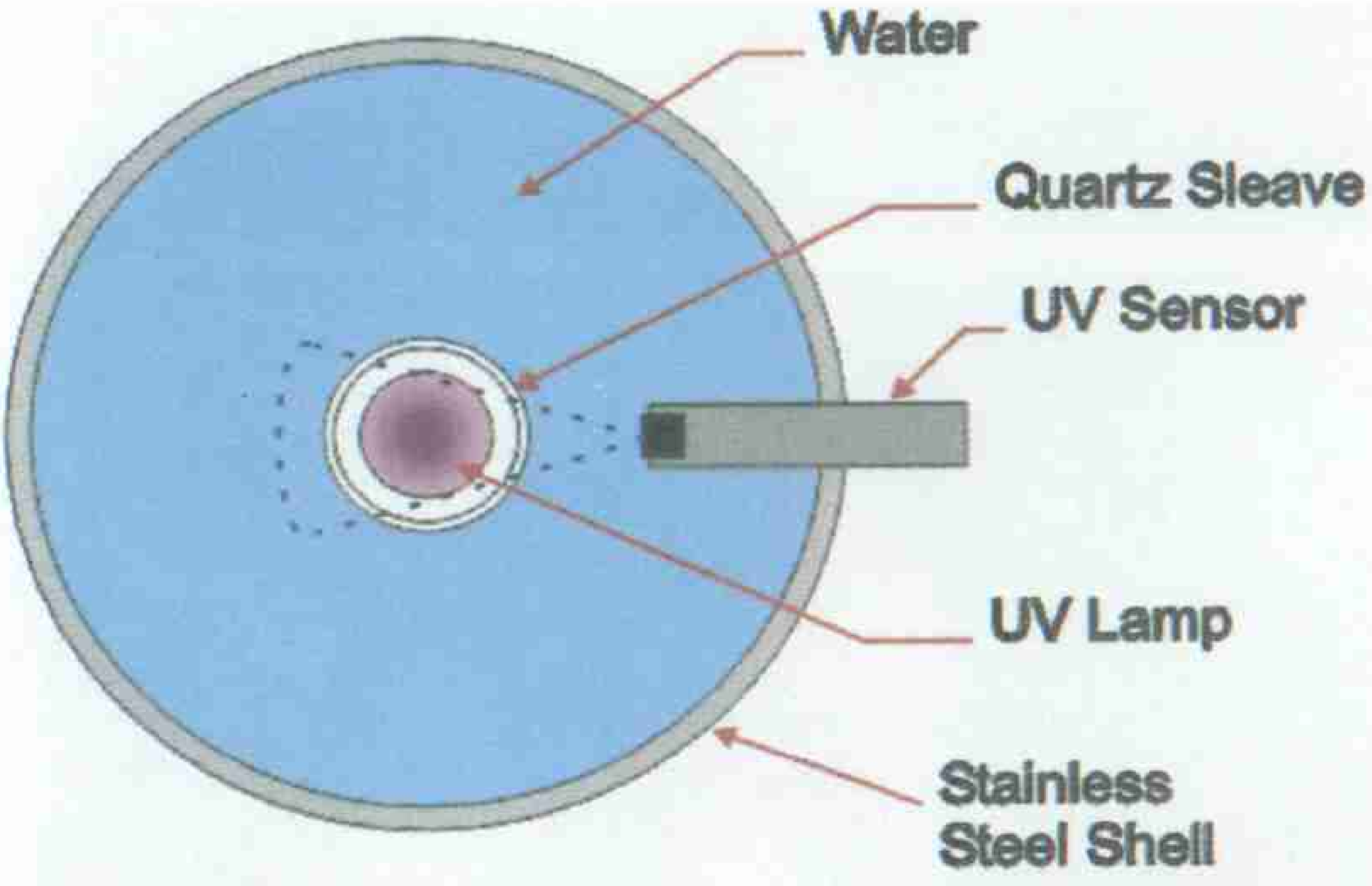
UV Eelectromagnetic Waves

- 100-400 nm (between X-rays & visible light spectrums)
- Vacuum UV (100-200 nm)
- UV-B (280-315 nm)
- UV-A (315 nm)
- Optimum UV range for water disinfection (245 & 285 nm)

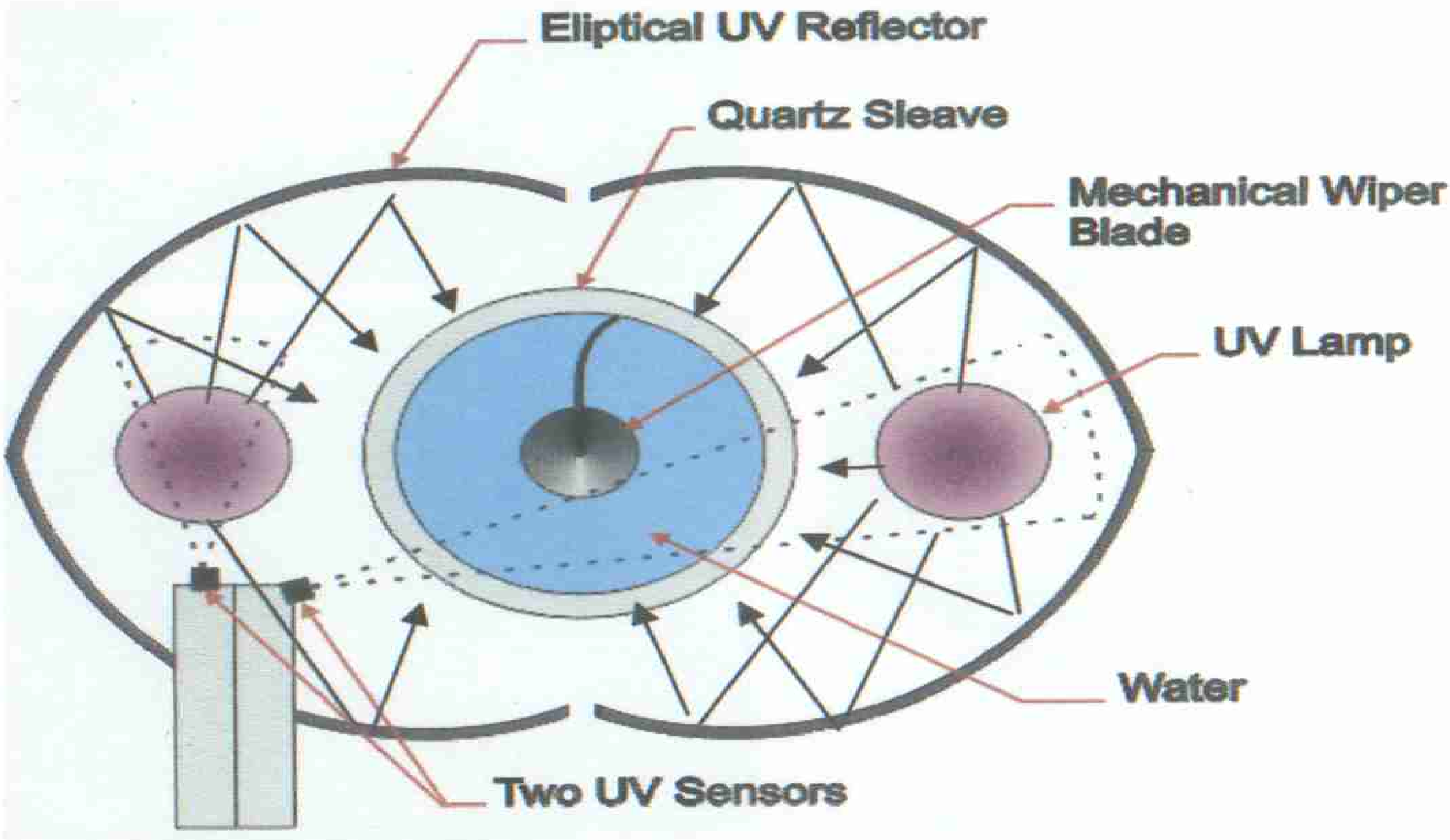
UV Radiation System

- UV lamps emitting max energy output at low pressure (253.7 nm) for small water systems, and at medium pressure (180-1370 nm) for large water systems
- Quartz sleeves arranged in banks
- Closed reactor chambers
- Sensors and controls

Conventional UV System



Innovative UV System



UV Reaction Parameters

- Dose (mW-sec/sq.cm.) = Intensity (mW/sq cm) x contact time (sec)
- UV intensity = 3 to 12 mW/sq cm
- Contact time = 6 to 40 sec (note: 10 min for Giardia and Cryptosporidium)
- Dose = 20 to 40 mW-sec/sq cm (extremely high dose for Giardia and Cryptosporidium)
- Transmittance for water = 85 to 100 %
- Oxidants (ozone, peroxide, chlorine) for ADP

UV Transmittance

- % transmittance T = the ability of water to transmit UV light at 253.7 nm through a path length of 1 cm (A = absorbance unit/ cm)
- Water quality = excellent (A = 0.022, T = 95%); good (A = 0.071; T = 85%); fair (A = 0.125; T = 75%)

$$\text{Percent Transmittance} = 100 \times 10^{-A}$$

Commercial UV Systems

Description	Low Pressure Low Intensity	Low Pressure High Intensity	Medium Pressure High Intensity
Operating Temp. (°C)	40-60	180-200	600-800
Operating Press. (mm Hg)	10^{-2}-10^{-3}	N/A	10^{2}-10^{3}
Arc Length (inch)	30-58	5-16	12
Output Characteristics	Monochromatic	Monochromatic	Polychromatic
Input Power (W)	70-90	1600	2800
Output Energy (W/in)	0.46	30	23-36
% Input Energy to Germicidal Output	30-35	30-35	7-10
Expected Lamp Life (hrs)	8,000-12,000	8,000-12,000	4,000-6,000
Automatic Quartz Sleeve Cleaning	No	Yes	Yes
Variable Output Lamps	No	Yes	Yes
On-Line UV Trans-mission Analyzer	No	No	Yes
No. of Full Scale Installations Operating	2000	<5	150
Lamp Costs	$28-$130	N/A	$170-$200

UV Operational Experience 1

- Quartz sleeve cleaning frequency = low pressure & low intensity (manual, once a week); medium/low pressure & high intensity (automatic, several times/day)
- Lamp age = low pressure & low/high intensity (8000-12000 hours); medium pressure & high intensity (400-6000 hours)
- Lamp aging = intensity decreases with lamp age rapidly in early stages, but slowly in late stage.

UV Operational Experience 2

- Lamp replacement = (a) dead; (b) preset expected life; (c) below present intensity or dose.
- Sensors detect any drop in output intensity
- Alarms and shutdown systems
- Automatic/manual cleaning cycles
- Telemetry system for remote control

UV Operational Experience 3

- Reliable and adequate disinfection
- No need to transport or store chemicals
- Elimination of toxic residual DBP
- Sensible to water quality variations
- Operational simplicity
- No need to comply with costly safety requirements.
- Potentially higher equipment & O&M costs
- UV dechlorination & deozonation
- Requirement of standby power

UV Operational Experience 4

- UV disinfection efficiency decreases due to (a) chemical and biological films; (b) dissolved organics and inorganics; (c) aggregation of microorganisms; (d) color & turbidity; & (e) flow short-circuiting.
- Scaling of quartz sleeves is likely to occur when (a) iron greater than 0.1 mg/L; (b) hardness greater than 140 mg/L; and hydrogen sulfide greater than 0.2 mg/L. Any raw water with the problems of iron, hardness and hydrogen sulfide will limit the UV application.

UV Safety Issues

- Burning burn skin, eyes, etc. by UV radiation
- Submerging UV lamps in water to keep exposure minimum
- Wearing safety goggles when working near an operating UV
- Avoiding electrical hazard of the high-voltage ballasts (transforms)
- Disposing spent UV lamps (universal wastes) which contains mercury.

UV Summary 1

Consideration	Description
Generation	Low pressure and medium pressure UV lamps available.
Primary uses	Primary physical disinfectant; requires secondary chemical disinfectant for residual in distribution system.
Inactivation efficiency	Very effective against bacteria and viruses at low dosages (5-25 mW•s/cm^2 for 2-log removal and 90-140 mW•s/cm^2 for 4-log removal). Much higher dosage required for *Cryptosporidium* and *Giardia* (100-8,000 mW•s/cm^2 for 2-log removal).
Byproduct formation	Minimal disinfection byproducts produced.
Limitations	Limited experience and data with flows greater than 200 GPM. Water with high concentrations of iron, calcium, turbidity, and phenols may not be applicable to UV disinfection.
Point of application	Prior to distribution system.
Special considerations	Extremely high UV dosages for *Cryptosporidium* and *Giardia* may make surface water treatment impractical.

UV Summary 2

Characteristics /Criteria	Chlorination/ dechlorination	UV	Ozone	MF	UF	NF
Safety	+	+ + +	+ +	+ + +	+ + +	+ + +
Bacteria removal	+ +	+ +	+ +	+ +	+ + +	+ + +
Virus removal	+	+	+ +	+	+ + +	+ + +
Protozoa removal	-	-	+ +	+ + +	+ + +	+ + +
Bacterial regrowth	+	+	+	-	-	-
Residual toxicity	+ + +	-	+	-	-	-
By-products	+ + +	-	+	-	-	-
Operating costs	+	+	+ +	+ + +	+ + +	+ + +
Investment costs	+ +	+ +	+ + +	+ + +	+ + +	+ + +

-: none; +: low; ++: middle; +++: high

UV Summary 3

- Normal UV feed point for cost saving = prior to post chlorination and prior to distribution system; UV serves as an extra disinfection; and chlorine dosage remains the same.
- UV feed point for AOP effect = before post chlorination for killing Giardia and Cryptosporidium; more chlorine is required.
- UV is an effective dechlorination process.

City of Albany UV Reactor

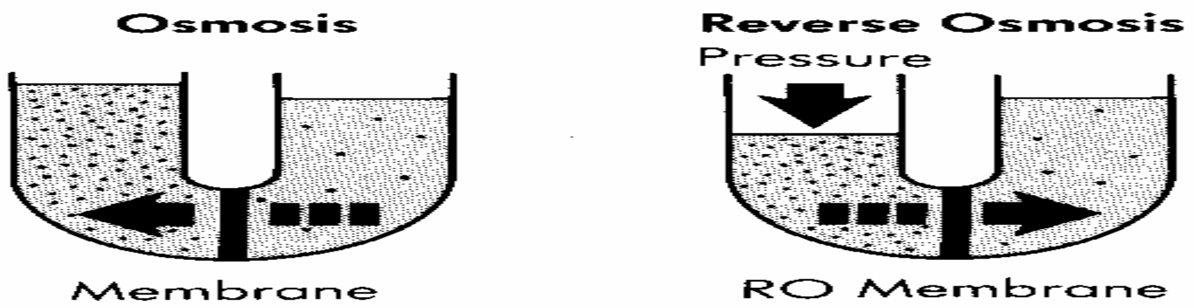
City of Albany UV Valves

New Water Technologies

- Membrane filtration technologies
- Ballasted coagulation, sedimentation & filtration
- Magnetic ion exchange, coagulation, sedimentation and filtration
- Pre-ozonation, dissolved air flotation and filtration/GAC

Membrane Filtration

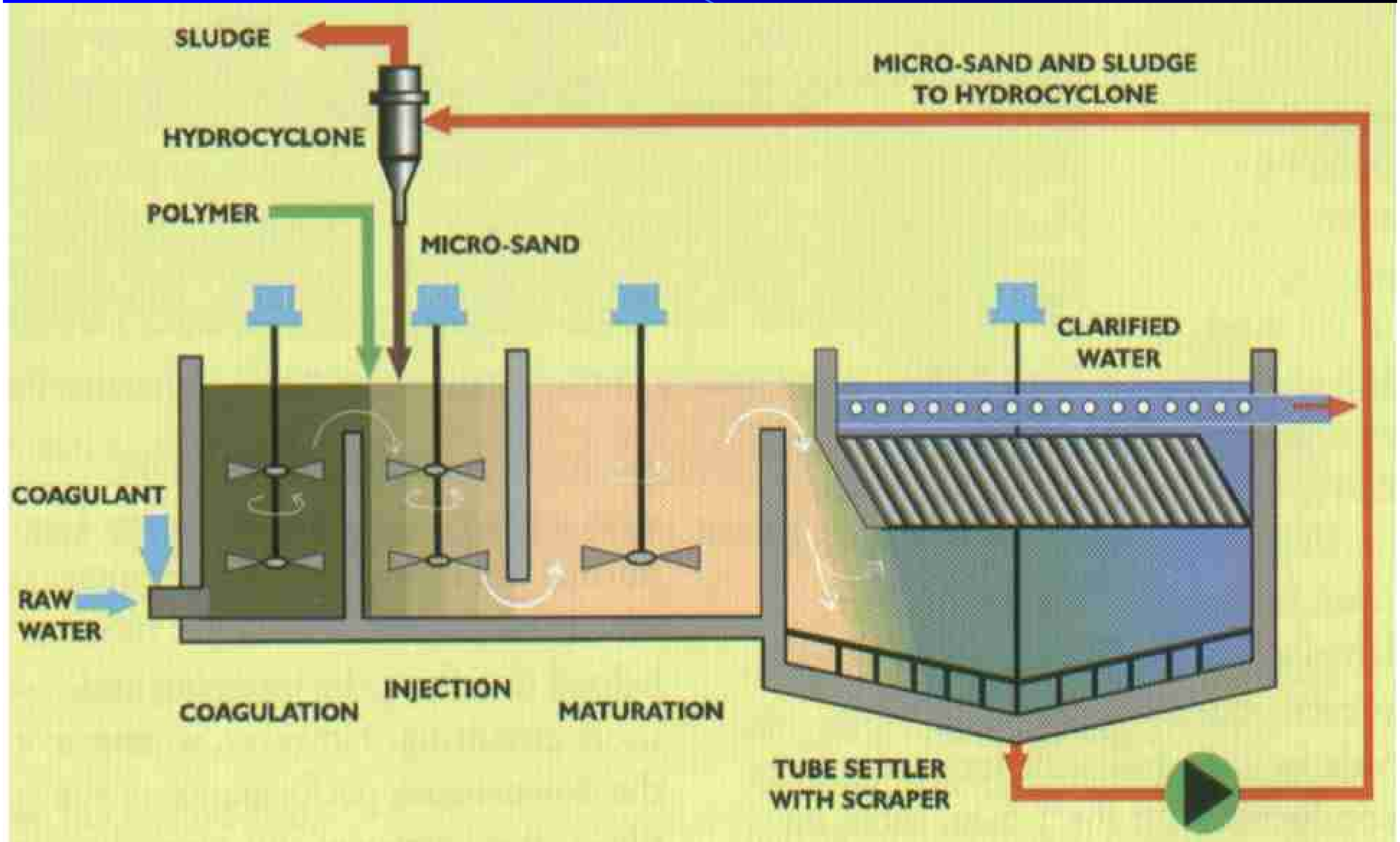
- Reverse osmosis (RO) removes 90-99% of all types contaminants in raw water
- High pressure pumps force water through semipermeable membranes for treatment
- It is time to consider adoption of RO for WTP near oceans



Planning for Membrane WTP

- Future planning = (a) ocean will be the future water supply sources; (b) more emerging contaminants are found and require treatment; (c) the prices of membrane processes are decreasing. (d) membrane WTP may be the best redundancy WTP.
- Membrane filtration will be the WTP of the future for all cities near the coastlines
- For long-time planning, the land spaces must be reserved or created for membrane WTP and pump stations construction

Ballasted Sedimentation



Ballasted Sedimentation Special Features

- Using microsands to enhance flocculation
- Using Lamella plates to enhance settling
- Overflow rate = 16-25 gpm/sq ft (40-6-m/h)
- Mixing/flocculation DT = 8 min
- Effluent turbidity = less than 1 NTU
- Effluent TSS = less than 5 mg/L

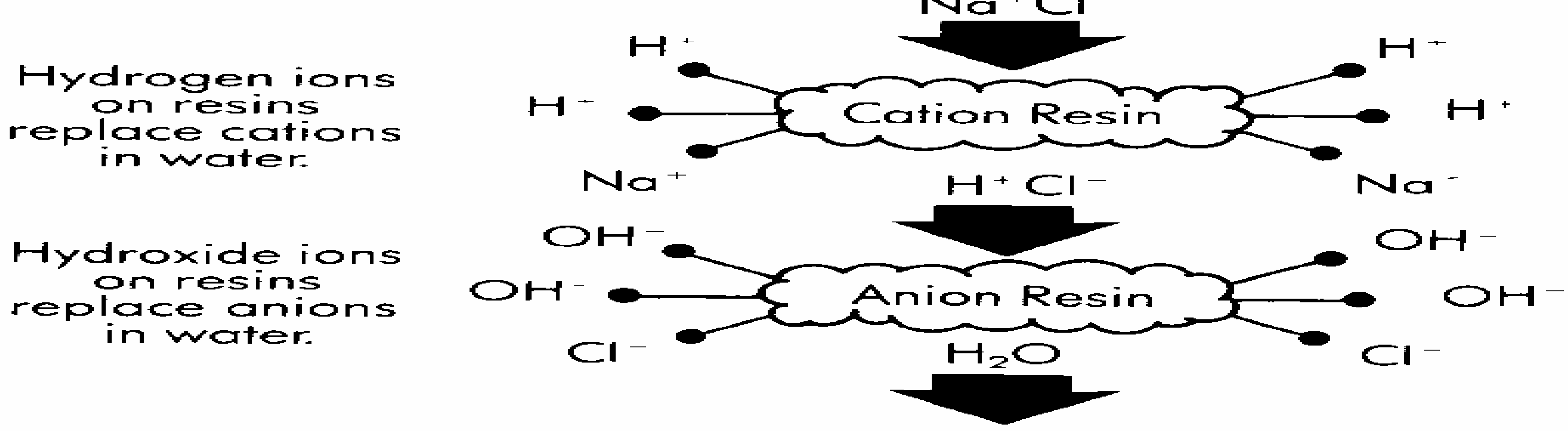
Ballasted Sedimentation Raw Water Quality

Water Quality Ranges	Color PCU	TOC	pH	Alkalinity mg/L, $CaCO_3$	Hardness mg/L, $CaCO_3$	Temp °C
Dry Season	25-50	3-6	7.4-8.4	110-135	150-185	15
Wet Season	200-320	25-38	6.2-6.6	25-60	60-80	30
Seasonal Average	100-150	15-20	6.8-7.2	90-110	120-150	18-26

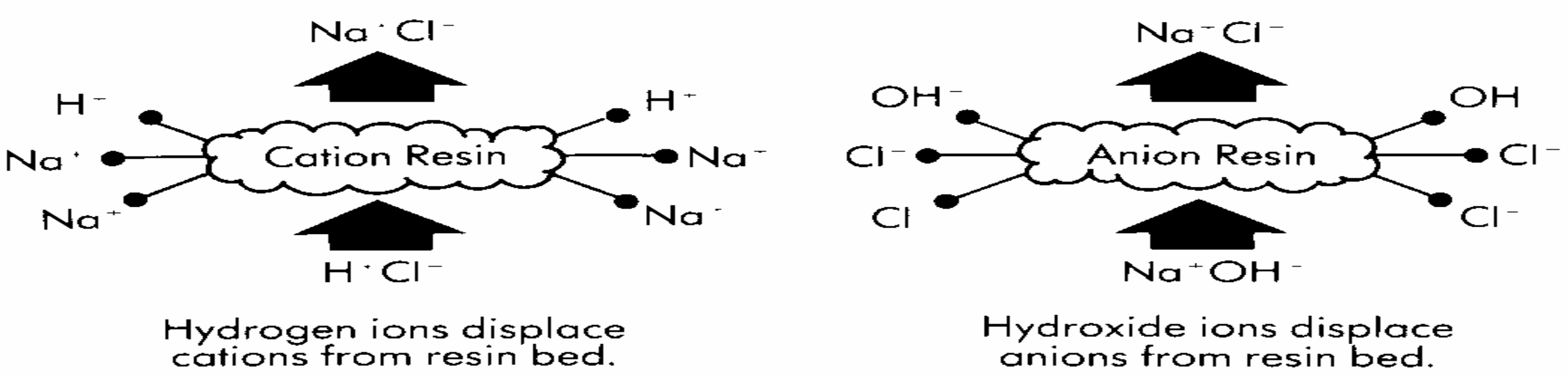
Raw water quality of the Hillsborough River, source for Tippin plant.

Ion Exchange & Regeneration

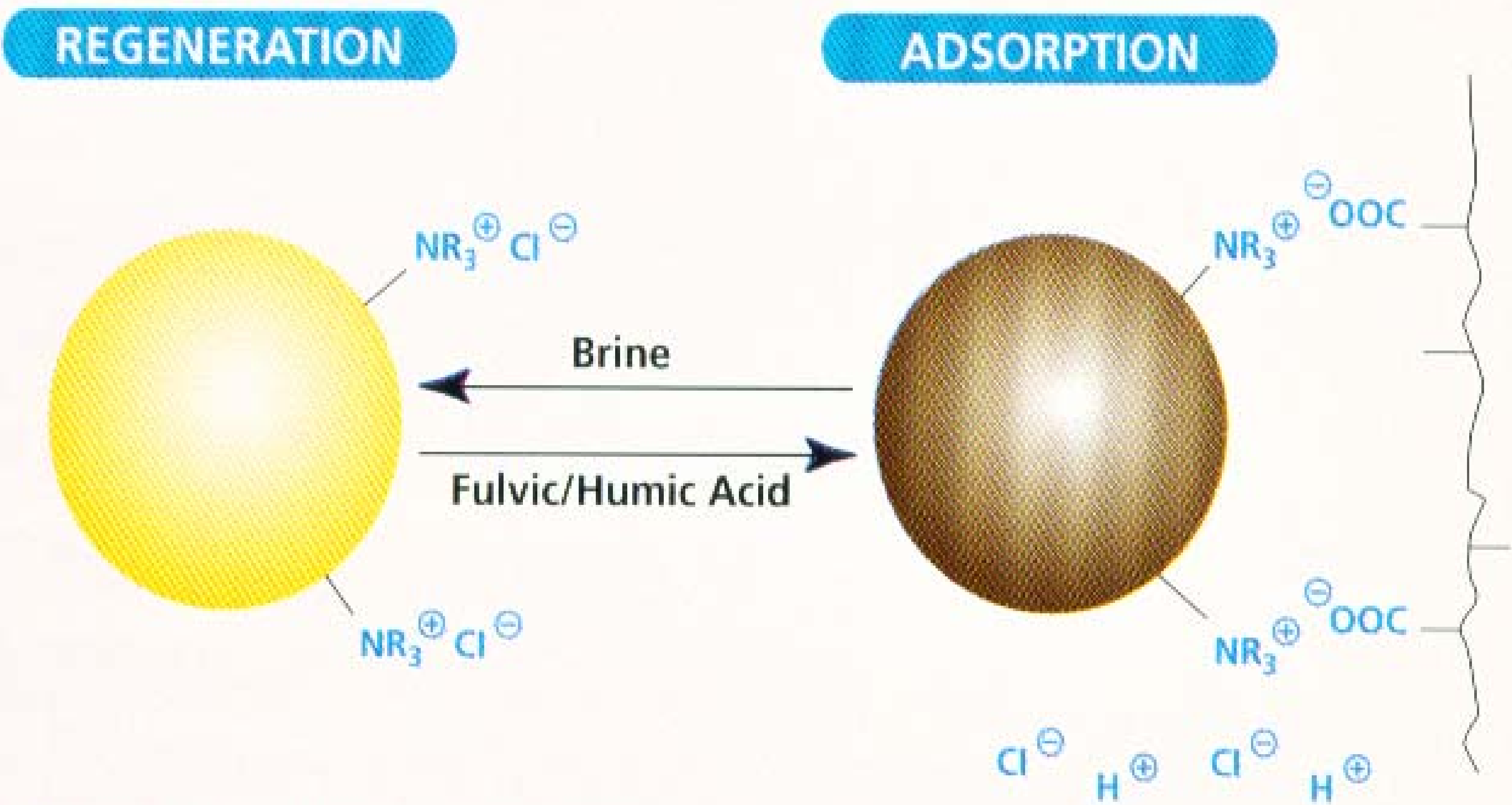
Deionization



Regeneration

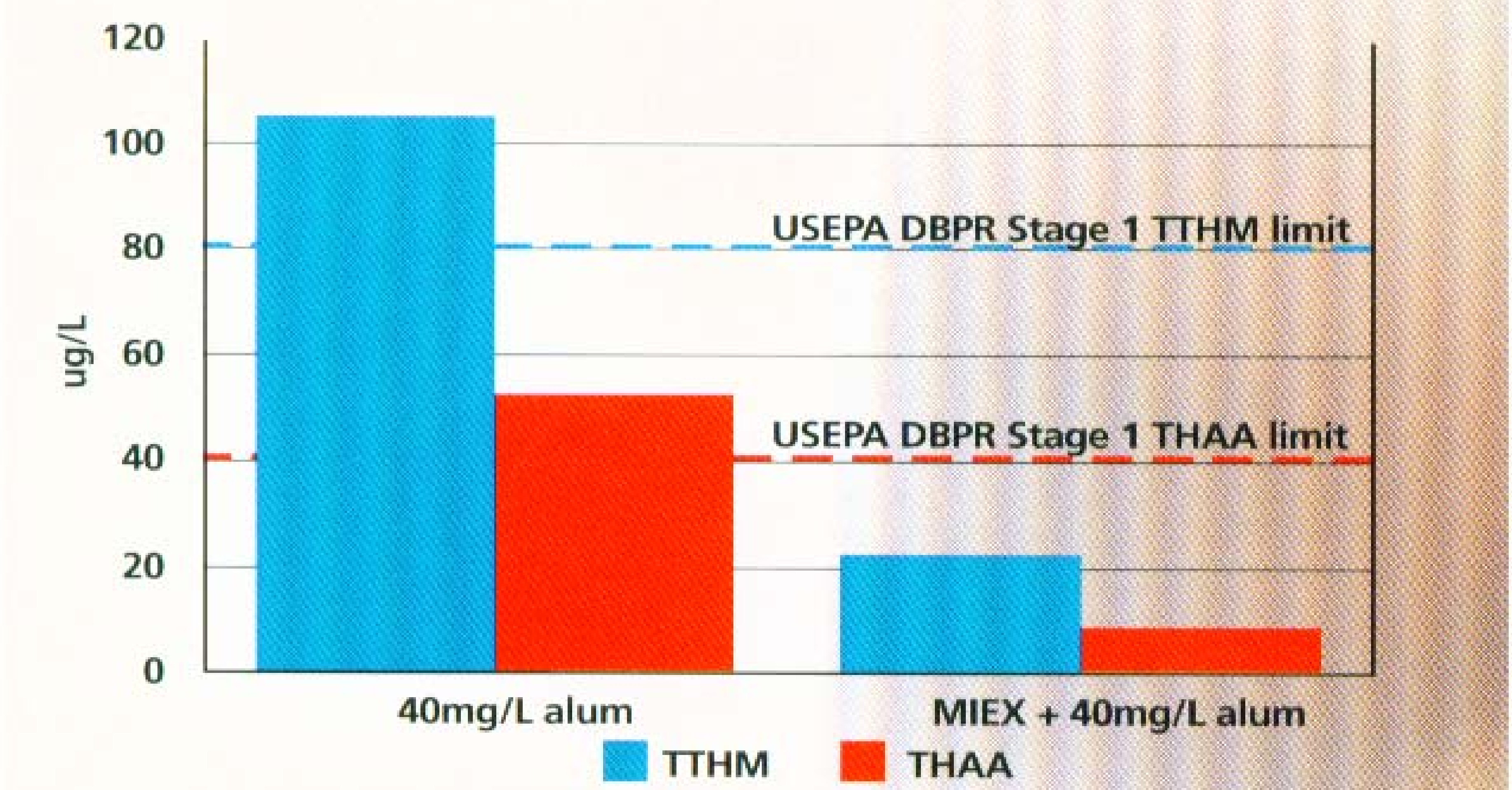


Magnetic Ion Exchange (MIEX)



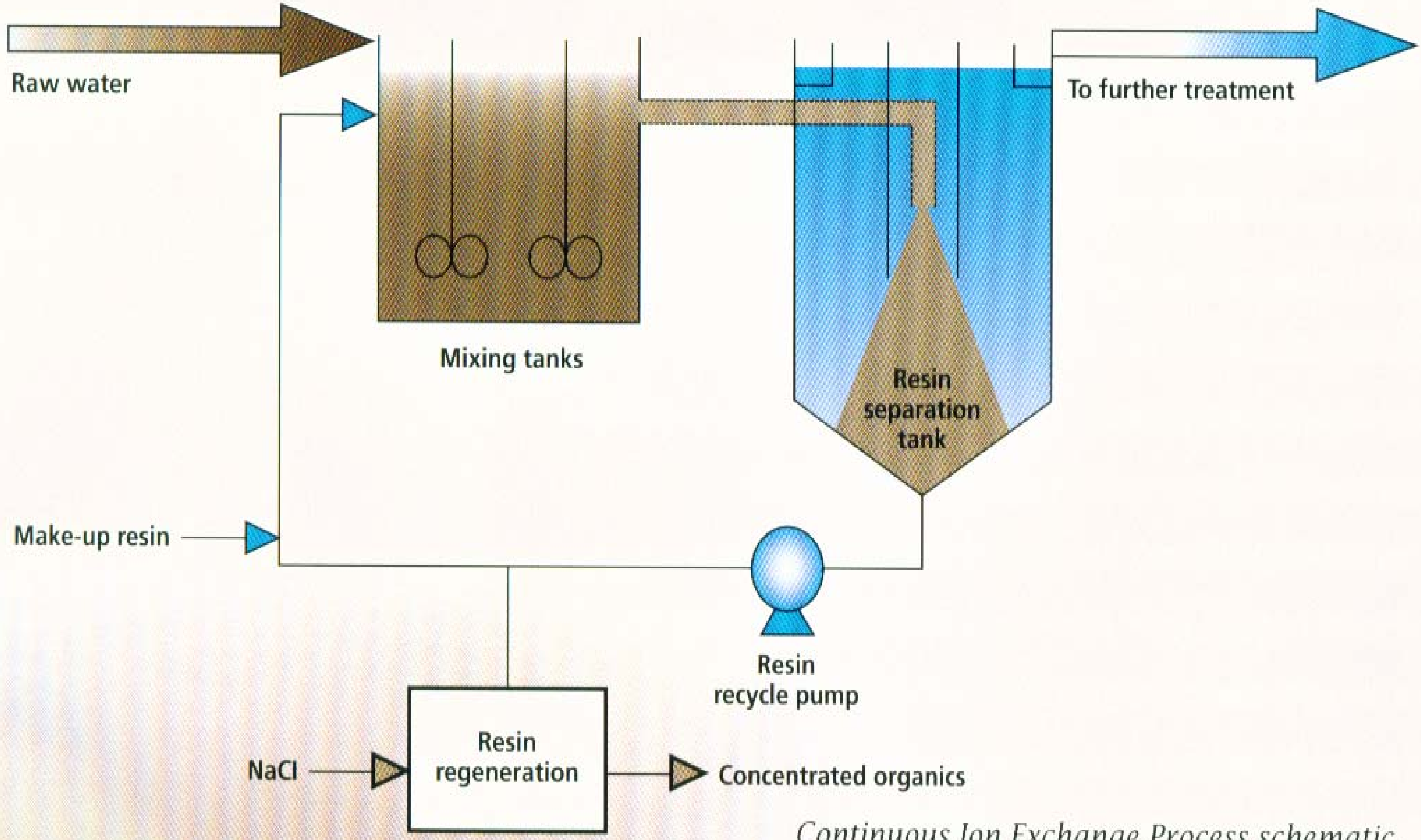
MIEX® DOC Resin chemistry.

MIEX for TTHM & THAA Removal



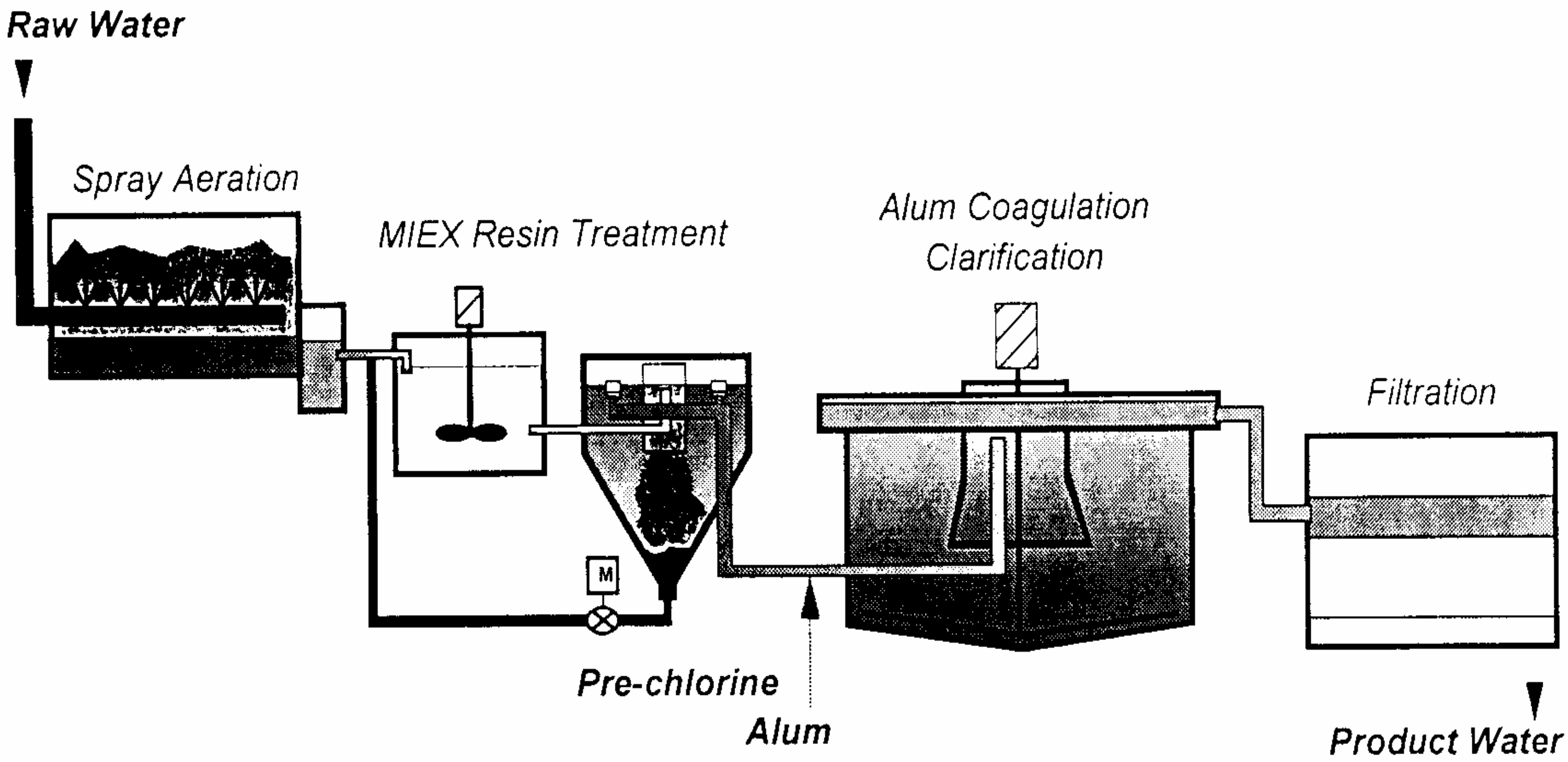
Tests on raw water at Wade G. Brown WTP, Durham NC

MIEX Unit Process



Continuous Ion Exchange Process schematic.

MIEX Process System 59-MGD Wanneroo Groundwater Treatment Plant, Australia

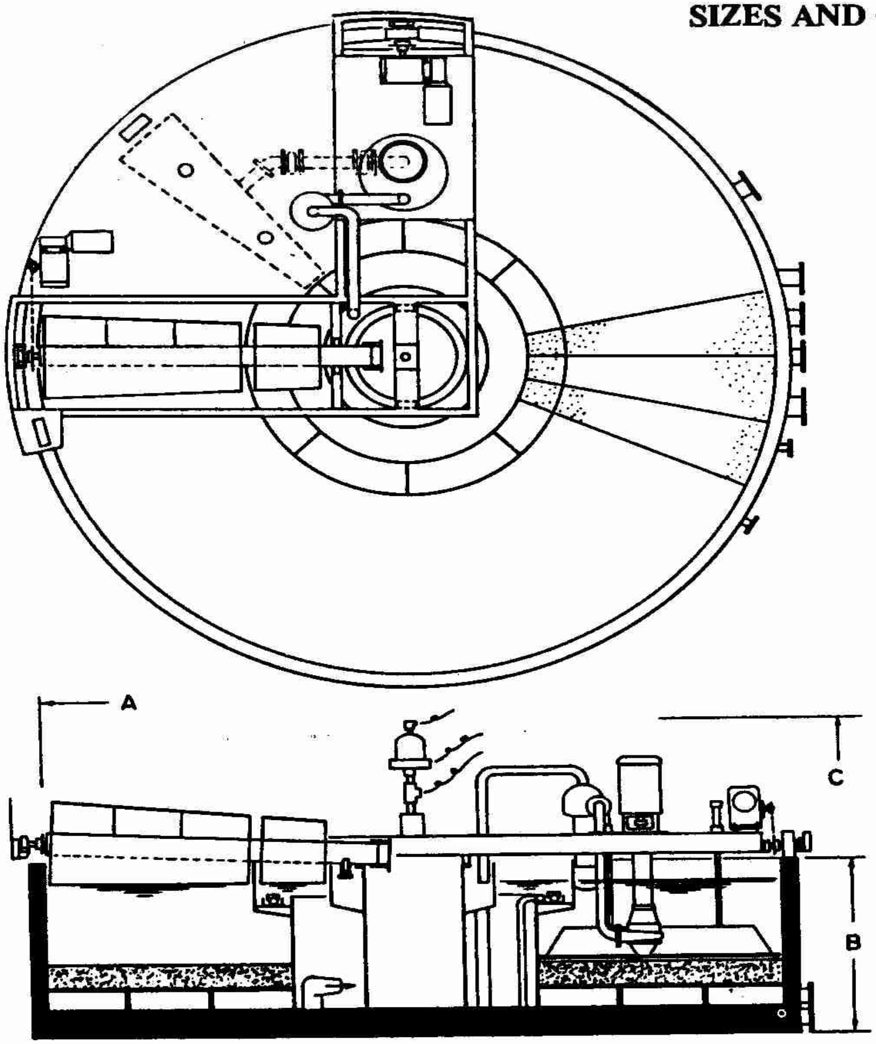


Dissolved Air Flotation – Bubbles

First Flotation WTP in America
Lenox WTP, MA, USA. 1.2 MGD

Flotation Water Treatment Plant Pittefield, MA, USA. 37.5 MGD

Flotation-Filtration WTP Sizing

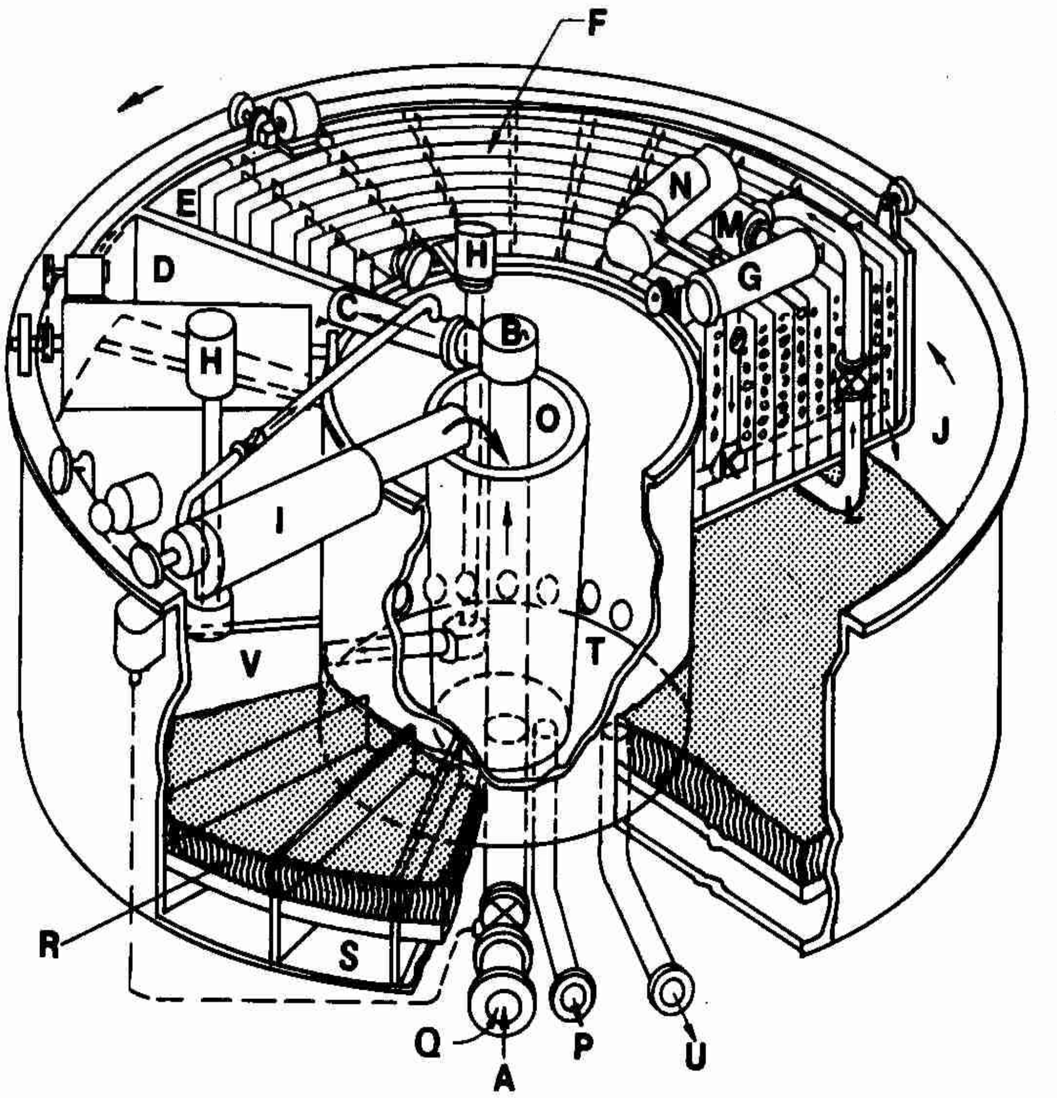


SIZES AND CAPACITIES

TYPE		FLOW			
A ft	AØ mm	US MGD	US GPM	m^3/min.	m^3/h
8	2400	0.16	110	0.42	25.2
10	3200	0.25	174	0.66	39.6
12	3900	0.36	250	0.95	57.0
15	4500	0.56	390	1.48	88.8
18	5500	0.81	562	2.14	128.4
20	6100	1.00	694	2.64	158.4
22	6700	1.21	840	3.19	191.4
24	7200	1.44	1000	3.80	228.0
27	8100	1.82	1270	4.81	288.6
30	9000	2.25	1560	5.93	355.8
33	10000	2.72	1890	7.18	430.8
36	11000	3.24	2250	8.55	513.0
40	12200	4.00	2780	10.55	633.0
44	13400	4.84	3360	12.77	766.2
49	14800	6.00	4170	15.83	949.8
55	16800	7.56	5250	19.95	1197.0
62	18800	9.61	6670	25.35	1521.0

A - Inside tank diameter (varies with TYPE)
B - Height of tank 6′ 0″ - 1830 mm
C - total max. height 13′ 4″ - 4060 mm

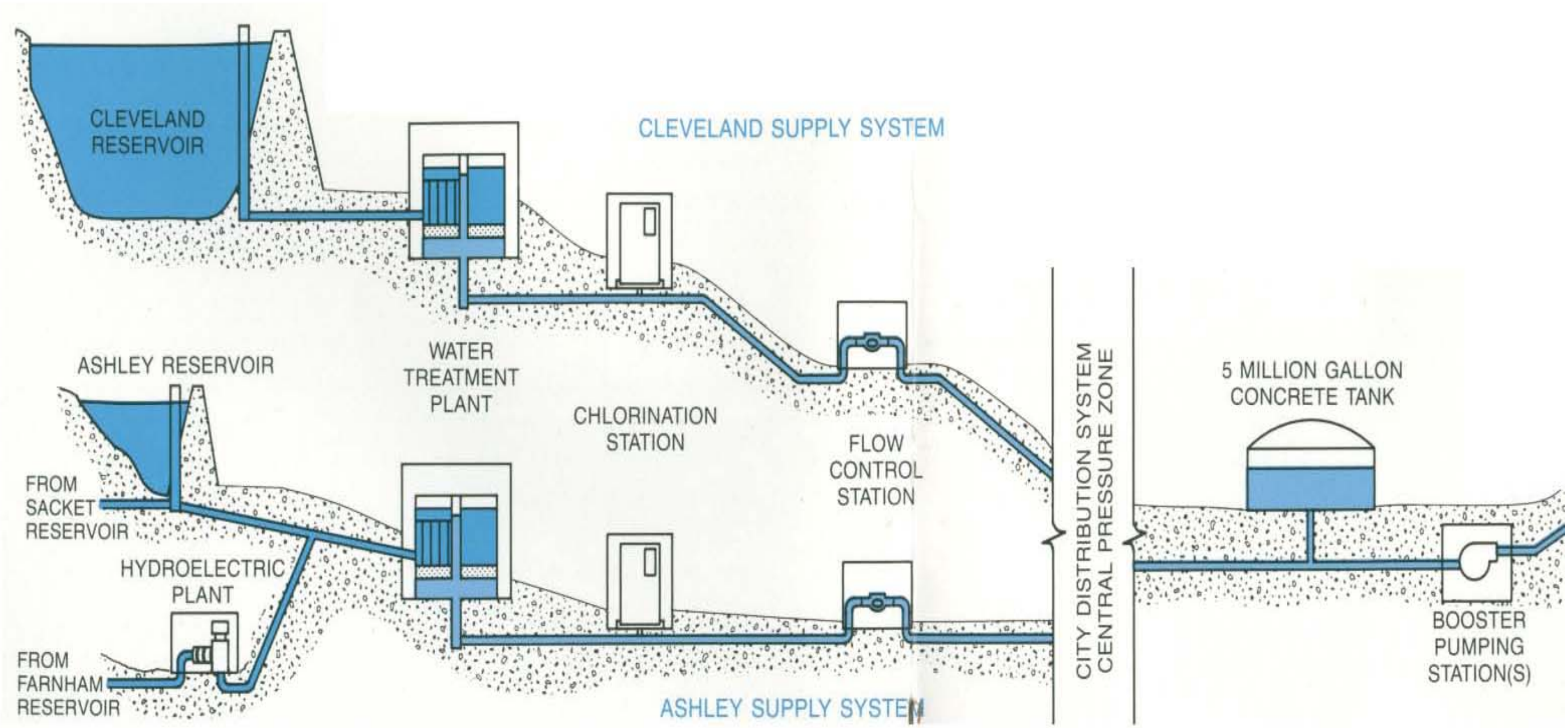
Flotation-Filtration WTP Bird's View



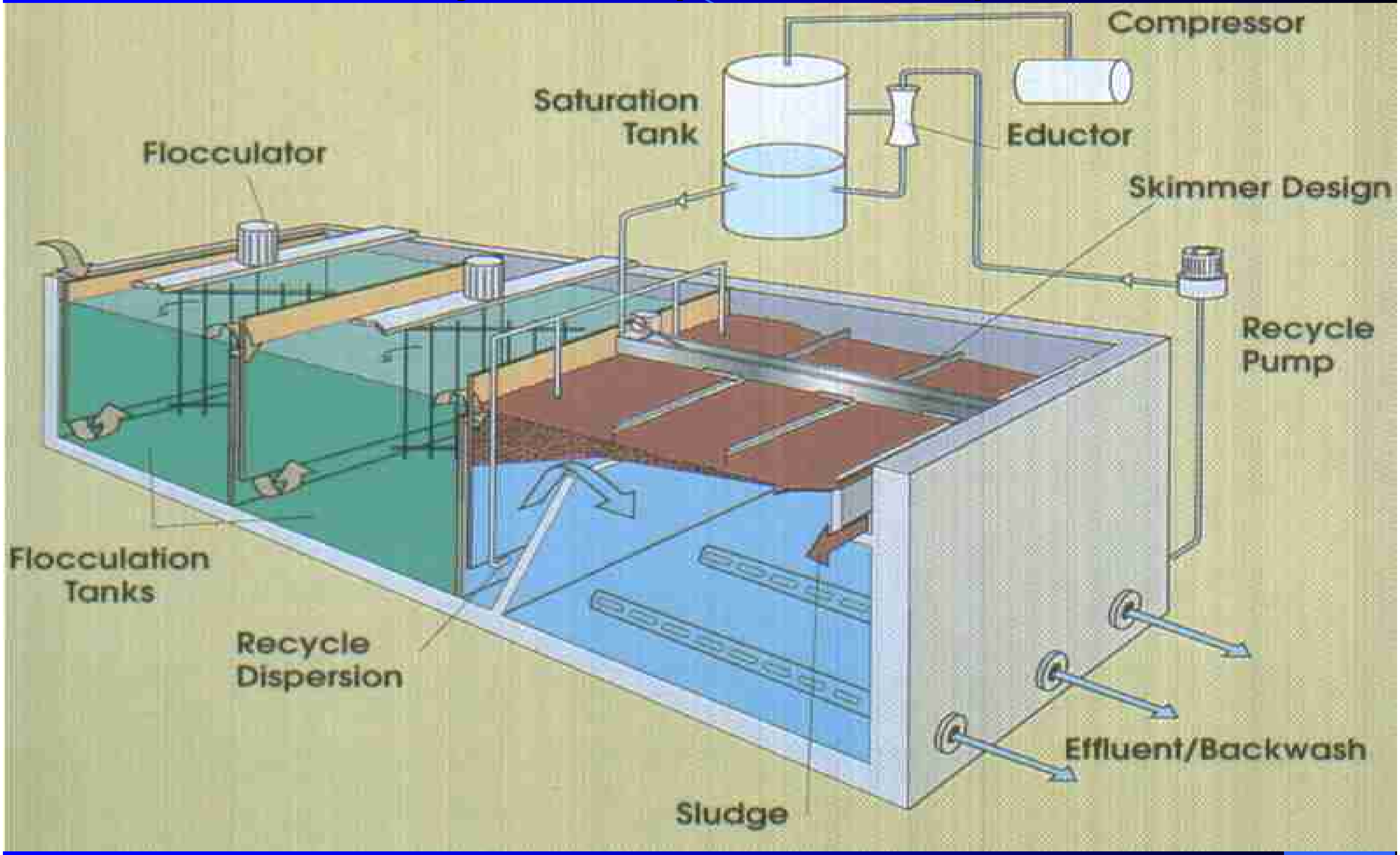
- A – RAW WATER INLET
- B – HYDRAULIC JOINT
- C – INLET DISTRIBUTOR
- D – RAPID MIXING
- E – MOVING SECTION
- F – STATIC HYDRAULIC FLOC
- G – AIR DISSOLVING TUBE
- H – BACKWASH PUMPS
- I – SPIRAL SCOOP
- J – FLOTATION TANK
- K – DISSOLVED AIR ADDITION
- L – BOTTOM CARRIAGE
- M – PRESSURE PUMP
- N – AIR COMPRESSOR
- O – CENTER SLUDGE COLLECTOR
- P – SLUDGE OUTLET
- Q – CHEMICAL ADDITION
- R – SAND FILTER BEDS
- S – INDIVIDUAL CLEAR WELLS
- T – CENTER CLEAR WELL
- U – CLEAR EFFLUENT OUTLET
- V – TRAVELING HOOD

Pittsfield WTP Near Reservoirs

Pittsfield Water Supply System



Separate Flotation and Filtration System (Waterlink)



World's Largest Flotation WTP - 75 MGD

TABLE ROCK AND NORTH SALUDA WTP, GREENVILLE, S. CAROLINA

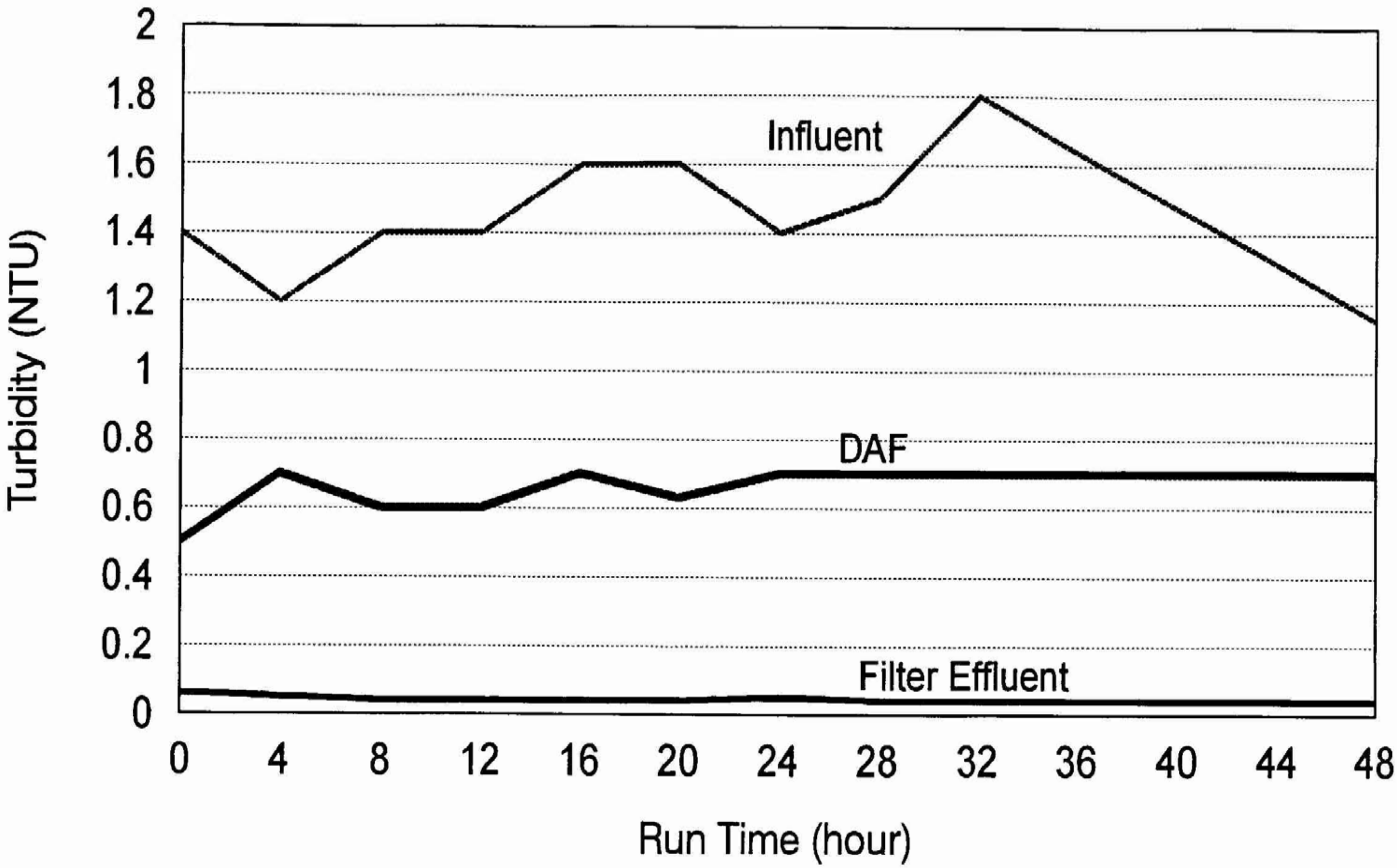
Plant Flow	75 MGD
Loading Rate	5 gpm/sqft
Basins	12 Concrete
Trains	3 x 4 Basin
Leopold Dual Media Filters	

Filter Run Times

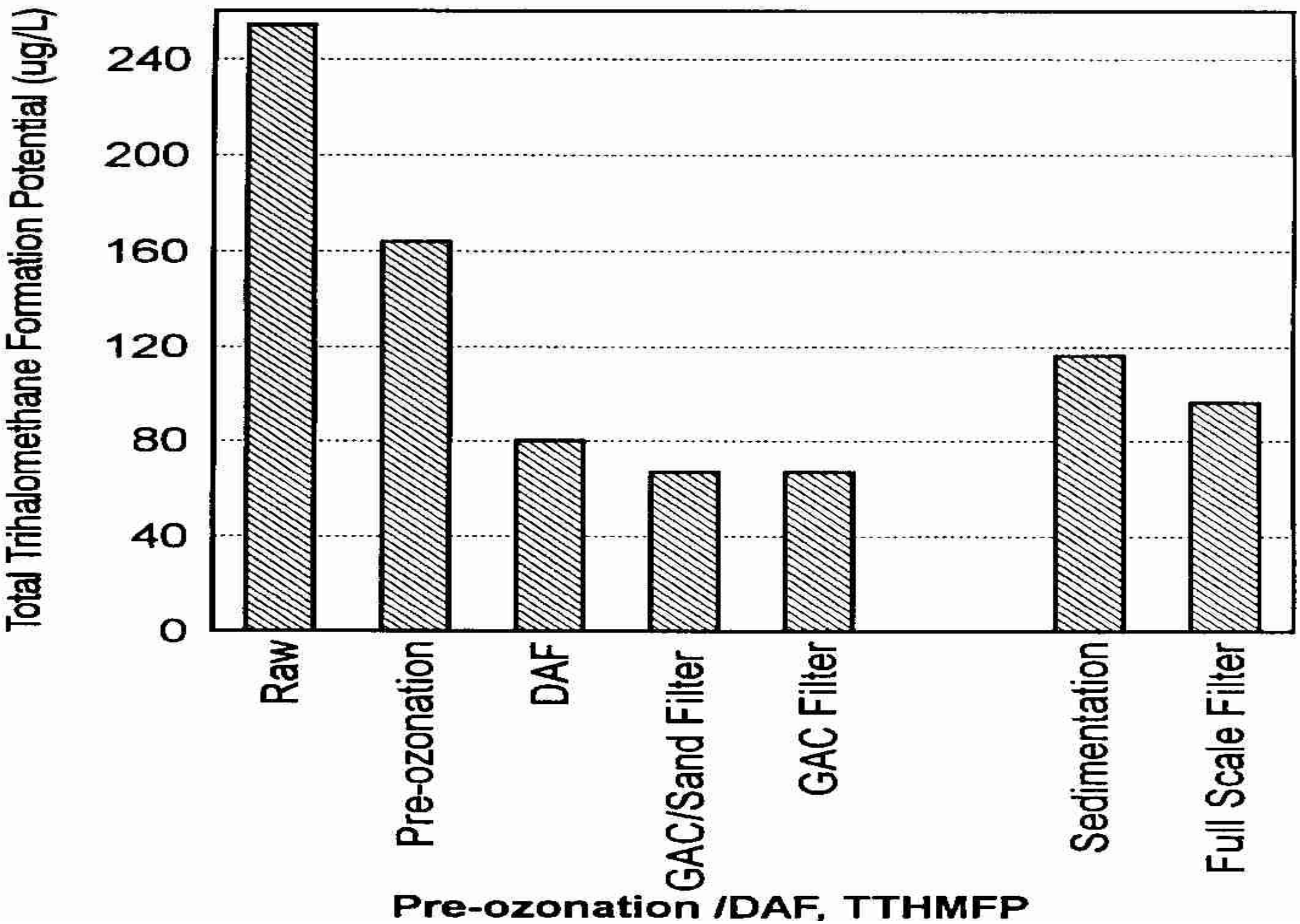
+ 144 Hours (6 days)

	Influent	DAF	Filtered
Turbidity	1.8 NTU	0.2 NTU	0.04 NTU
[illegible]	[illegible]	[illegible]	[illegible]

Flotation WTP Water Quality



Pre-ozonation & Flotation



Ultraviolet Disinfection and Other New Water Treatment Technologies

- Lawrence K. Wang, PE, PhD
- Water Facilities Manager
- City of Albany, New York 12204
- Tel: (518) 767-2667; Fax: (518) 767-9265
- LarryKWang@juno.com
- LarryKWang@gmail.com