DESALINATION TECHNOLOGIES RESEARCH INSTITUTE (DTRI)
SALINE WATER CONVERSION CORPORATION (SWCC)

PAPER TITLE: The Effect of Source Water Quality and Chlorination on Biofouling in SWCC Seawater Reverse Osmosis Plants

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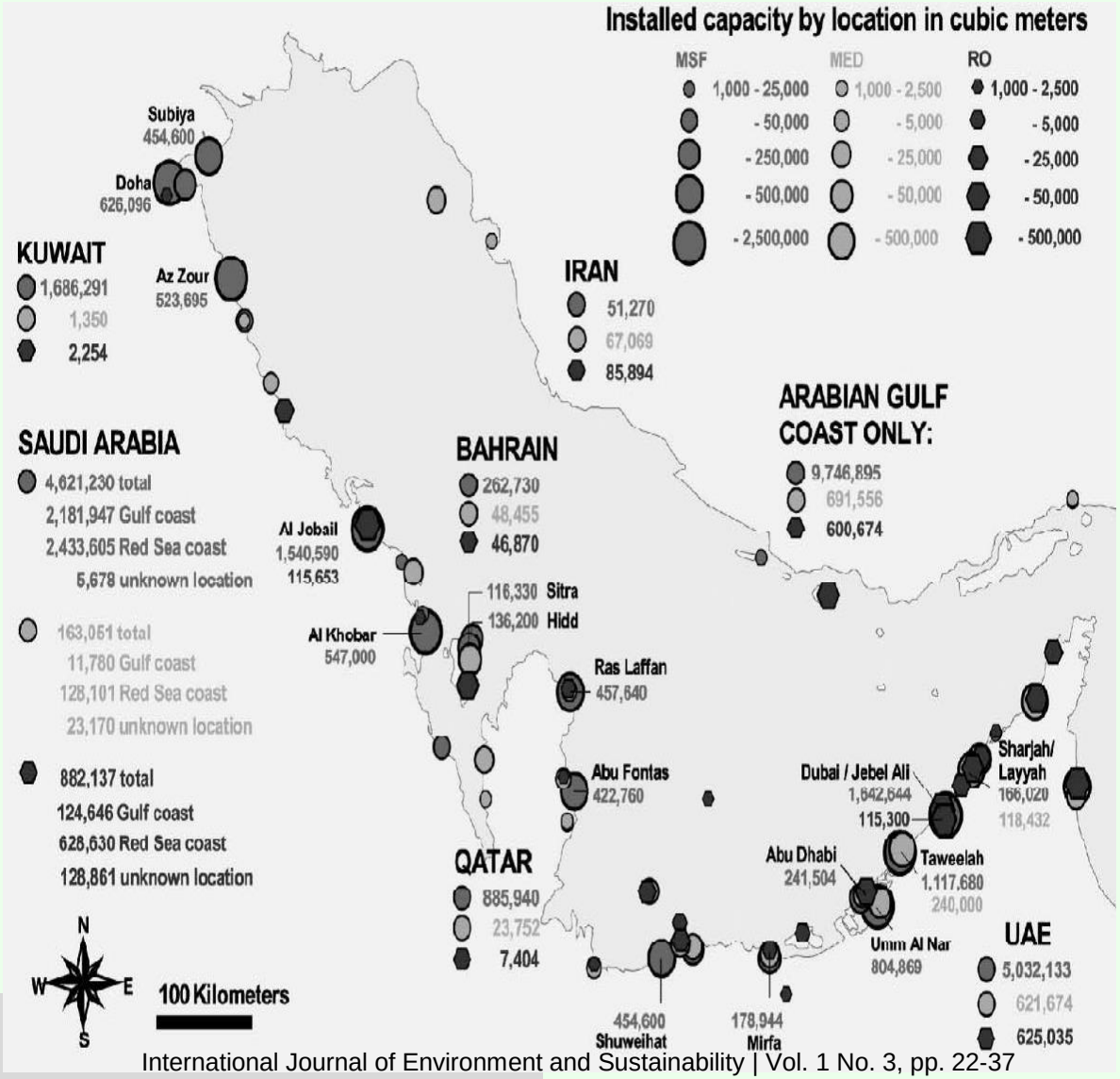
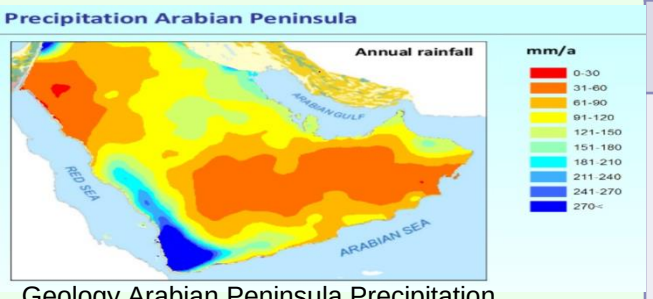
DESALINATION IN GCC NATIONS



- WORLD DESALINATION CAPACITY IS OVER 5,000 MILLION m^3/YEAR.
- SAUDI ARABIA ALONG WITH ITS GCC NEIGHBOORS, LEADS THE FIELD OF DESALINATION WTH A COMBINED POTABLE WATER PRODUCTION CAPACITY OF MORE THAN 1,800 million m^3/YEAR (2013)
- PROJECT TO NEARLY DOULE TO 3,000 million m^3/YEAR BY 2020.
- THE ARID GULF REGION MAKES DESALINATION A STREATIC OPTION FOR GCC COUNTRIES.

DRIVING FACTORS FOR DESALINATION IN THE GCC

1 Scarce Sources of Water Resource

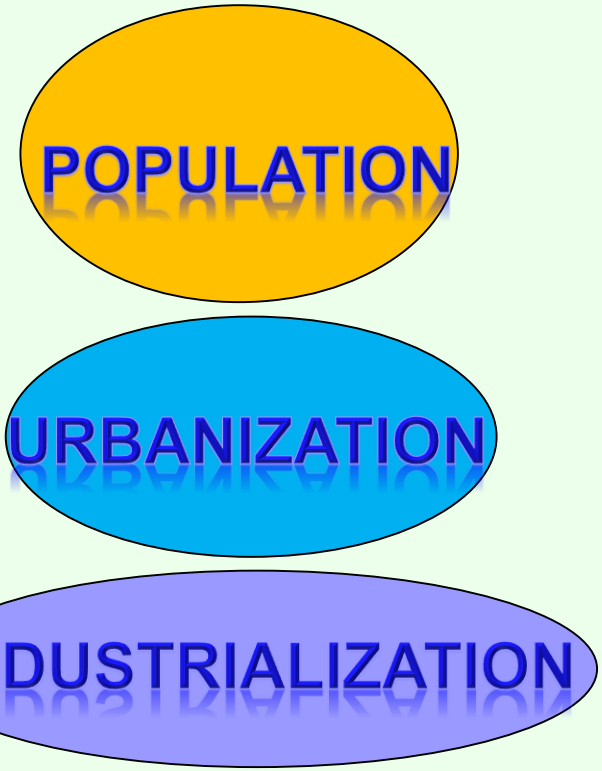


Geology Arabian Peninsula Precipitation

Sources	Assets
Rainfall	100 mm/year
Rivers Wadis	None -260 dams that can capture .6 billion m^3/year -Water from wadis used for irrigation
Aquifers	-Estimated recharge rate of 3.86 billion m^3/year (plentiful but deep [hard to extract]) TDS range from 300 to above 10,000 ppm. -Estimates that 15% of Euphrates drain basin in KSA and a small part in Kuwait.

DRIVING FACTORS FOR DESALINATION IN THE GCC

2 Human Drivers



3 Water and Power Resources

PLENTIFUL SOURCES OF SEAWATER AND ENERGY

Environmental Impact on Plants

- Much publicity is devoted to the negative effects of desalination plants on the environment.

- The fact is forgotten that operation of plants is often jeopardized by problems arising from the environment.

Two Sources of Problems from the Environment

1. **Anthropogenic**

2. **Environmental Changes**

1. Anthropogenic Problems

Anthropogenic problems arise from:

- **Discharges into the sea from human sources (waste/industrial pollutants/ heat., etc).**

- **From a fouling point of view, these sources of pollutants can charge the sea with micro-nutrients spurring microbial and macro-biological growth and metabolism (organically enriching the sea water column).**

Anthropogenic Impacts on Plants Include :

Fouling of:

- **Intake structures, plant process lines, seawater cooling systems, opened and closed DMF systems, UF, NF, Cartridge Filters and SWRO membranes.**

  These impacts can increase operational costs due to: chemicial additions (disinfectants, antifoaming agents, flocculants), flux declines and increases membrane cleaning frequencies and/or replacements.

2. Plant Problems from Environmental Changes

Environmental Changes Include:

- **Changes in temperature, salinity, pH etc., which can favor microbes that have a more selective advantages for survival (such as thermophiles, halotrophs, acidophils etc).**
- **Sand Storms promoting iron fortification that can promote plankton blooms and associated die offs (increasing organic load and viscosity of the sea [-Red Tide Effect of the Arabian 2008- early 2009]).**

Sources of Environmental Impact on Plants

2. Environmental Changes (continued)

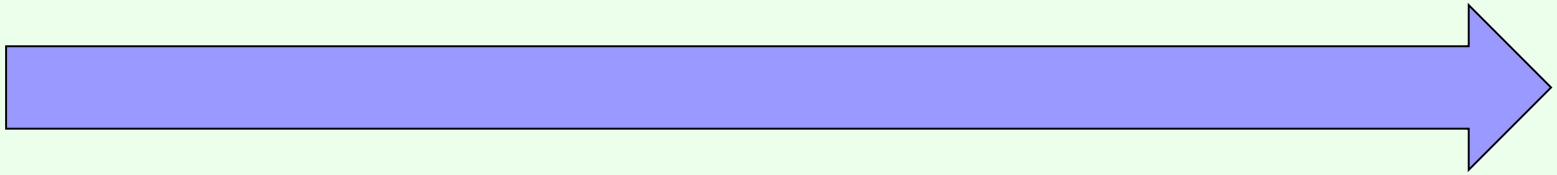
- Seasonal water currents and tides that bring silt from the benthos with biological and or other organic particles that create SDI Turbidity, TOC and TSS effects and sieving /filtration problems.

Dust storms over Riyadh, Saudi Arabia, March 2009

Red Tide: Fujairah, UAE (November 2008)

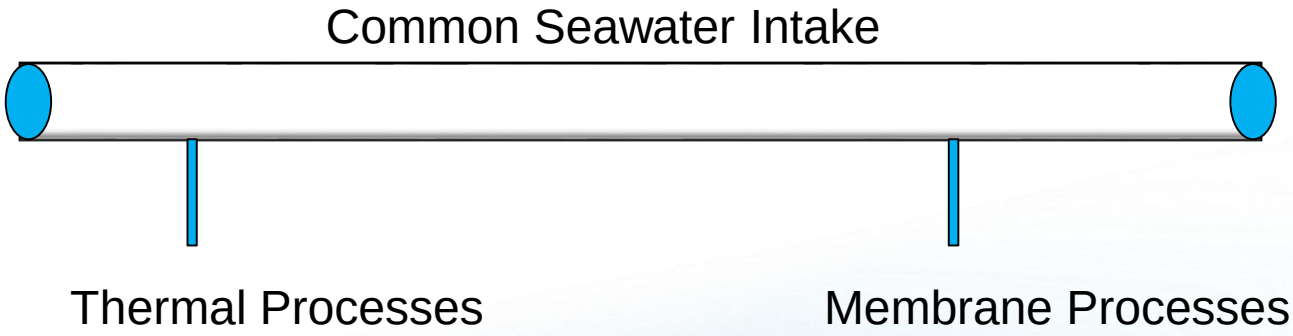
Morphology of Material and Process Fouling

- Surfactant Attachment
- Microbe Attachment (Growth and Metabolism)
- Biofilm Extracellular Polymeric Substances (EPS) Production
- Macrobial Attachment



To manage the problem of fouling, the object is to control or manipulate any of these factors (to slow down or prevent process fouling).

PROCESS FOULING ISSUES



-At SWCC several of our high capacity plants are co-generation producing both power and water.
-Several of our plants share (Thermal/SWRO) share common intakes and common fouling issues.

PROCESS FOULING ISSUES

THERMAL SYSTEMS

- **FOAMING**
- **SCALING**
- **MATERIAL DEGREDATION (CORROSION/BIOCORROSION)**
- **BIOLOGICAL FOULING (COOLING WATER SYSTEMS AND HEAT EXCHANGERS WHERE LOW TEMPERATURES ARE PRESENT)**
- **SLUDGE BUILDUP IN DEAIRATORS**
- **TRANSMISSION LINE FOULING**

PROCESS FOULING ISSUES

IN MEMBRANE SYSTEMS:

- **FOAMING**
- **SCALING**
- **MATERIAL DEGREDATION (CORROSION/BIOCORROSION)**
- **BIOLOGICAL FOULING (PROCESS LINES, DMF, UF, NF, SWRO MEMBRANES)**
- **TRANSMISSION LINE FOULING**

❑ **TO HELP CONTROL BIOLOGICAL FOUIING SWCC MAINLY CHLORINATES.**

METHODS OF CHLORINATION IN SWCC DESALINATION PLANTS

- **Commercial Purchase and Use (NaOCl/CaOCl)**
  Sodium and Calcium Hypochlorites

- **Chlorine Gas Injection (Cl_2)**

❑ **Electrolysis (NaOCl):**
Electrochemically on-line generation from sodium chloride of seawater

METHODS OF CHLORINATION USED

INJECTION OF:

- **Sodium and Calcium Hypochlorites**

$$\mathbf{NaOCl} + H_2O \rightarrow \mathbf{HOCl} + NaOH-$$

[CaOCl]

- **Chlorine Gas**

$$\mathit{Cl_2(g)} + 2NaOH + \rightarrow \mathbf{NaOCl} + NaCl + H_2O$$

- **Chlorine from Electrolysis**

$$\mathit{Na^+} \quad \mathit{2Cl^-} \rightarrow \mathit{Cl_2(g)} + \mathit{2e-}\ \mathit{2H_2O} + \mathit{2e-} \rightarrow \mathit{H_2} + \mathit{2OH^-}$$

Salt Ion + Current

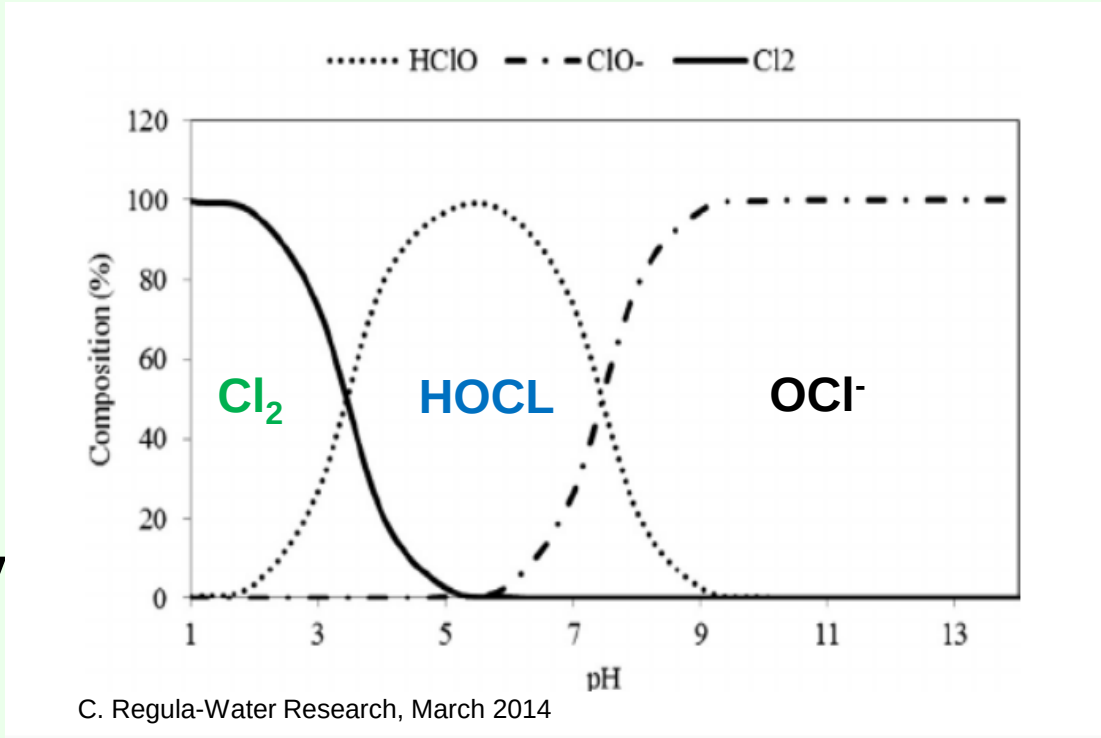
$$\mathit{Cl_2(g)} + \mathit{2OH^-} \rightarrow \mathbf{HOCl} + \mathit{Cl-}$$

Chlorine Reservoir Effect

Reservoir Effect

Cl_2<>**HOCl**<>OCl^-

- **pH dependant**
- **Chlorine species determines disinfection potency based on cellular permeability and free radical activity**
- **Biocide activity is non-selective**
- **Organic degradation results in increased micronutrients and THM production.**



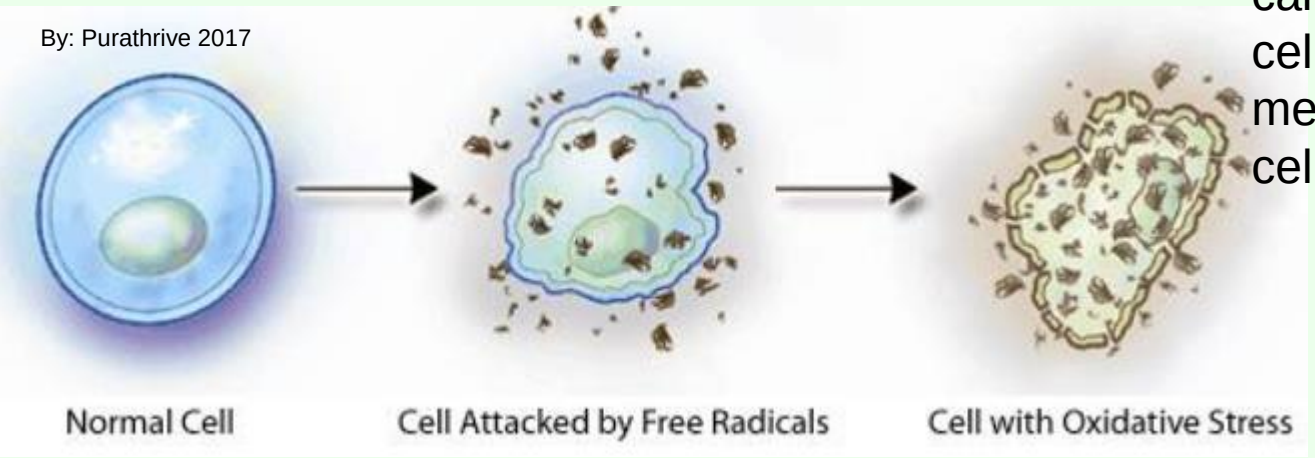
C. Regula-Water Research, March 2014

Mechanism of Chlorine Biocide Kill and Destruction (Bacteria, Fungi, Viruses)

- Free Radical Degradation

Cl_2 – Gaseous Cl_2 dissolves in water and freely diffuses into the cell reacting with external and internal cellular structures.

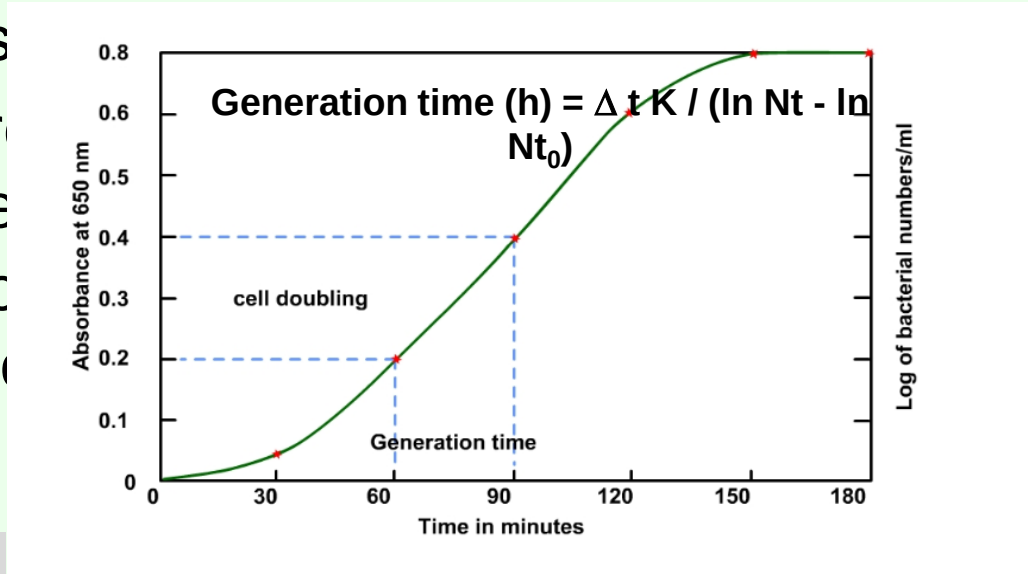
HOCl- Hypochlorous Acid Neutrally charged with a similar structure geometry to water. It can feely permeate inside of cells destroying interal metabolic processes and cellular structures.



OCl- Hypochlorite Ion is negatively charged with an effective repulsive effect for most organics. It enters cells by ion transport channels an is considered the least disinfectant.

LESSONS LEARNED FROM CHLORINATION PROCESS FOULING

- **Chlorination is not always effective at mitigating problems of fouling.**
  - Chlorination increases micronutrients
  - Chlorination decreases bacteriological generation time (increases bacterial proliferation)
  - Produces
  - Can hydr … ation processe
  - Non-spec … es residual



LESSONS LEARNED FROM CHLORINATION PROCESS FOULING

- Chlorination is not always effective in mitigating problems of fouling.

  -Some microbes express resistance to chlorination
  (H.F. Ridgway Chlorine resistance patterns of bacteria from two drinking water distribution systems)

  -Shell fish can detect toxins and protect themselves by closing and inducing slim production .



STEPS TAKEN BY SWCC IN LIGHT OF EXPERIENCE WITH CHLORINATION

- Introduction of Intermediate Chlorine Injection (ICI) 3 times/day

-Reduction in THM's production

-Cost savings from chlorine use (chemical and power for production)

-Better control of muscle attachment and growth

-Better membrane longevity and performance

STEPS TAKEN BY SWCC IN LIGHT OF EXPERIENCE WITH CHLORINATION

•Use a chlorine tolerant membrane with continuous or ICI dosing

Switched from polyamide to cellulose triacetate membranes.

Problems: -Limited pH operation range (3-5, 6-8).

-Temperature degradation above 35^{o}C).

•Operation of membrane systems without chlorination/ disinfection

STEPS TAKEN BY SWCC IN LIGHT OF EXPERIENCE WITH CHLORINATION

- STUDY OF PULSE CHLORINATION (Barnacles and Mollusks)

-Death induced by mechanical action shell fish on short term exposure/non-exposure to chlorine.

- Protects cooling water systems and their pumping structures (thermal systems) in addition to process transmission lines from shell fish that impede flow in open and closed Dual Media Filters (DMF).



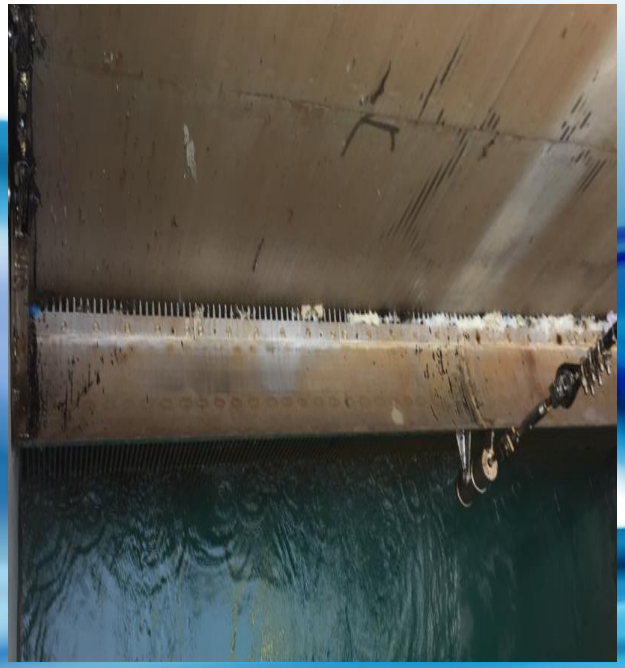

Summary

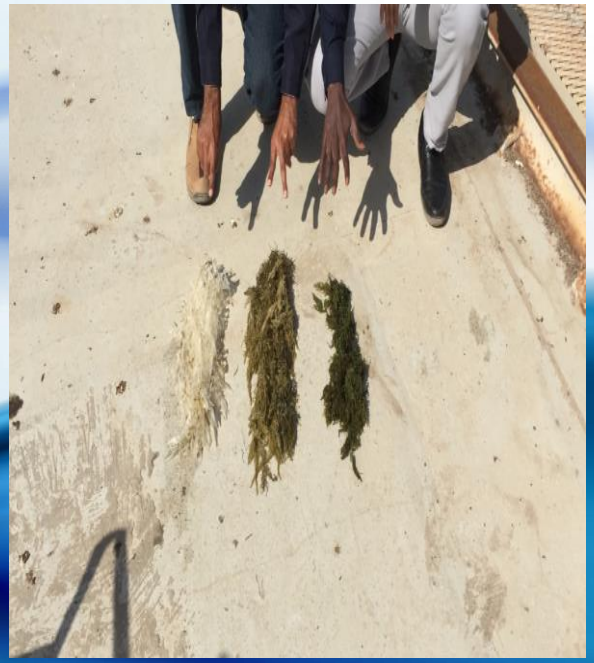
- Source Water Quality Has an Impact on Biological Fouling of Plant Structures and Operation.
- Chlorination does not arrest biological fouling but generates THM's and conversion of macro- into micro organics promoting biological fouling and operation problems.
- The effectiveness of chlorination depends on pH which can impact anti-scalants, anti-foaming agents and iron flocculants.
- ICI, Pulse chlorination, Non-Chlorination, membrane change and the use of chlorine dioxide (pH Independent and does not produce THM's) are promising experience based developments that are under evaluation.

FOULING ISSUES THROUGHOUT PROCESS OF COMMERICAL SWRO PLANTS.

CLOGGING OF PRIMARY TRAVELING SCREENS (PLANT INTAKE ZONE)

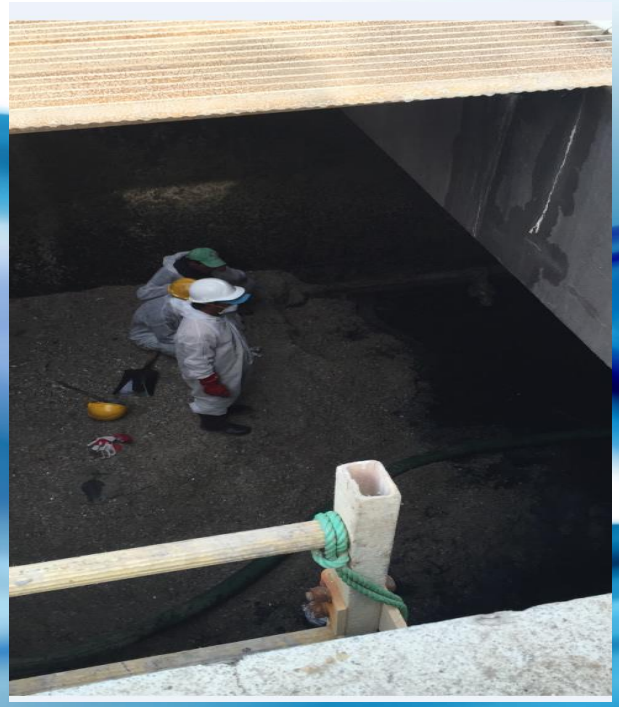
Fouled with mussels, barnacles, seaweed and hydroids.

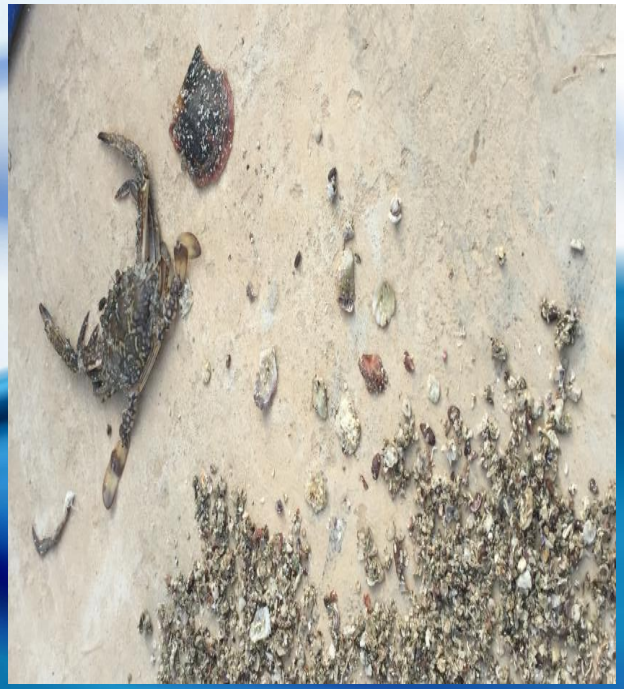




INTAKE (SUMP)

Various species of barnacle, mussels, cnidarians and hydroids with detritus and corrosive hydrogen sulfide from biological decomposition





FOULING: INTAKE SECONDARY TRAVELING SCREENS

- Secondary traveling screens experience blockage from jellyfish ingress, hydroids and various other shell fish.
- This can cause plant high pressure pumps to trip resulting in water stagnation and process line fouling.
- Corrosion and material damage from organic acids and other microbial/ macrobial metabolic byproducts (can also disrupt plant operation).

PROCESS LINE FOULING

Marine shell fouling of process lines due to low flow velocities from diameter widening of transmission lines.

THANK YOU