REUSE OF INTERNAL OR EXTERNAL WASTEWATERS IN THE COOLING SYSTEMS OF COAL-BASED THERMOELECTRIC POWER PLANTS

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OVERVIEW

- Project goal
- Background and regulatory information
- Materials and methods
  - Lab-scale studies
  - Pilot-scale studies
- Project accomplishments
  - Lab-scale studies
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- Summary

PROJECT GOAL

- Assess potential of three different impaired waters for use in recirculating cooling water systems
  - secondary-treated municipal wastewater
  - passively-treated coal mine drainage
  - ash pond effluent

NONTRADITIONAL SOURCES OF COOLING WATER: TREATED MUNICIPAL WASTEWATER

- 11.4 trillion gallons of municipal wastewater collected and treated annually in U.S.
- Experience with use of treated municipal water for power plant cooling in arid west; e.g., Burbank, Las Vegas, Phoenix
- Significant additional treatment beyond secondary treatment (e.g., clarification, filtration, N and P removal)

NONTRADITIONAL SOURCES OF COOLING WATER: PASSIVELY-TREATED AMD

- Significant flows of abandoned mine drainage (AMD) in coal mining regions
- NETL has confirmed magnitude and reliability of AMD as source of cooling water
- Adequate treatment (to raise pH, remove dissolved solids and metals) prior to use is largest concern
- Passive treatment systems offer potential for inexpensive source of cooling water

NONTRADITIONAL SOURCES OF COOLING WATER: ASH POND EFFLUENT

- Water-ash slurry systems used commonly to remove bottom ash and fly ash
- Slurry is directed to ponds where settling of ash particles occurs
- Slurry water is often discharged
- Potential to reuse the slurry water in the slurry system and as cooling system makeup water

PROBLEMS WITH USE OF IMPAIRED WATERS

- Precipitation and scaling
- Accelerated corrosion
- Biomass growth

Review of Regulations Relevant to Reuse of Impaired Waters

- The basis of reusing water.
- Cooling tower blowdown discharge.
- Air emissions when using impaired waters.
- Transporting wastewater across boundaries (interstate or intrastate).

Franklin Township Municipal Sanity Authority, Murrysville, PA.

Basis for Water Reuse

- None of the current regulations directly prohibit the use of reclaimed water as power plant cooling water.

In the "Guidelines of U.S. Water Reuse" (2004), USEPA suggested the treatment requirements and standards for reclaimed water reutilized as cooling water in thermoelectric systems.

Cooling Tower Blowdown Discharge

- Clean Water Act (CWA) §402, EPA establishes the National Pollutant Discharge Elimination System (NPDES), which requires that all point source discharges of pollutants to surface waters must be authorized by NPDES discharge permits. Limits in NPDES permits can be technology-based or water quality based.

Depending on technologies adapted in cooling tower design, the concentrations of available chlorine, chromium, and zinc are likely to be confining factors.

Control of Air Emissions

- Aerosols are the major concern for cooling tower emissions
- In National Ambient Air Quality Standards (NAAQS) and Regional Haze Regulations," (EPA, 2005), cooling towers are categorized as potential point sources of pollutants emission with volatile organic compounds, PM10, PM2.5, and NH_3
- Possible issues with emissions of concentrated metal and chemicals

Transporting Wastewater Across Boundaries

- One potential approach that may alleviate severe water shortages in drought areas, such as Arizona, Texas, and Florida, is to transfer natural or treated water from other regions where it may be available in larger quantities

- Most transfer events between states were evaluated on a case-by-case basis and records indicate few prohibitions against water transfer

SUMMARY – Task 1

- Existing regulations do not prohibit the use of impaired waters for cooling purposes. Regular monitoring and evaluation is required to meet the discharge and air emission regulations.

- Cases of interbasin transfer showed that most transfer events were evaluated on a case-by-case basis without explicit prohibition.

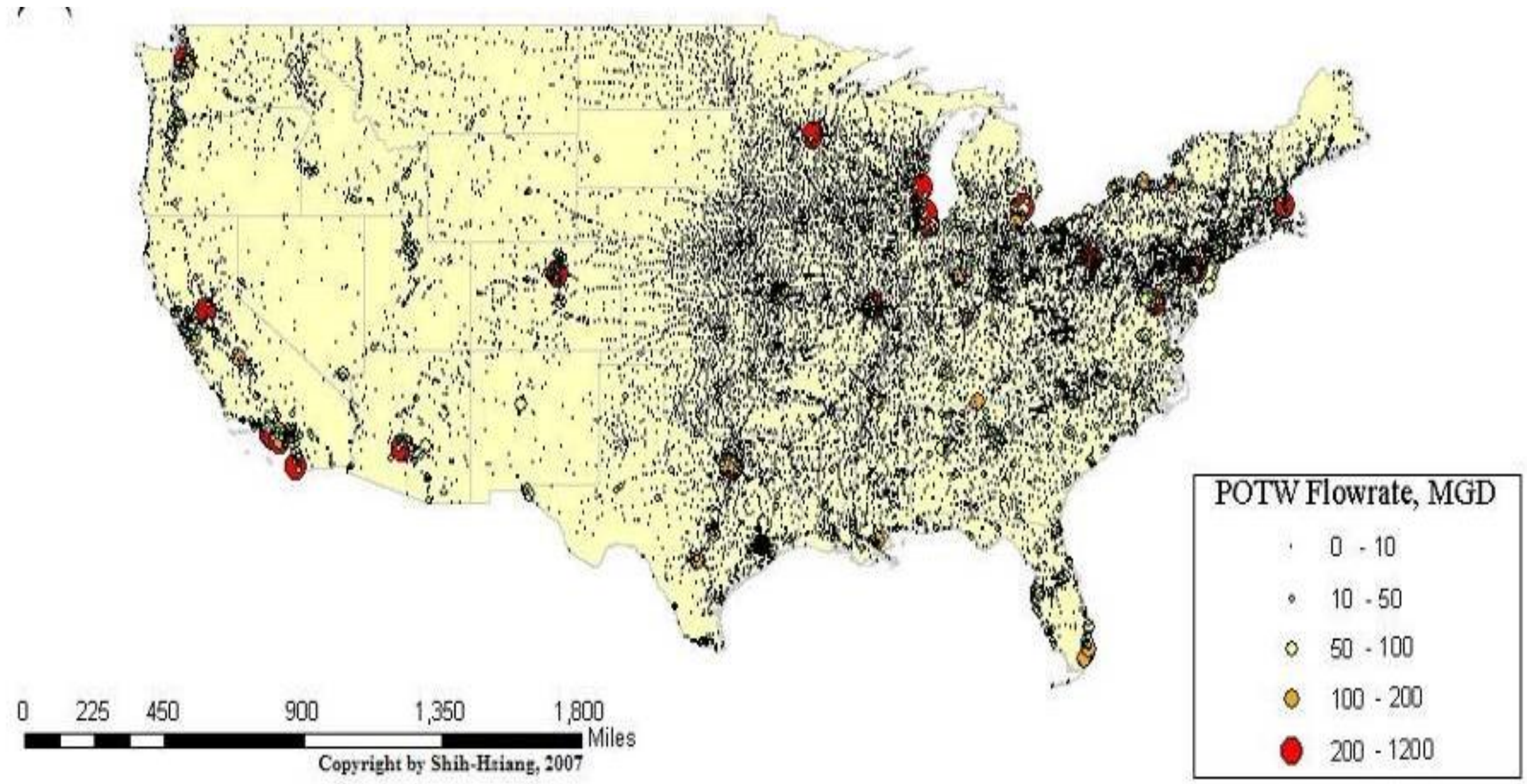
Feasibility Analysis of Using Wastewater in Cooling Towers

Assess availability of impaired waters (quantity and proximity) to meet cooling needs of coal-based thermoelectric power plants:

- Build a scenario of water supply: Construct a map of publicly owned treatment plants on GIS.
- Build a scenario of water demand: Develop an equation to estimate the water demand for a proposed power plant.
- Spatial analysis: Use the GIS map to evaluate the potential wastewater flowrate within a specific range of each proposed power plant.
- Compare available wastewater flowrate and estimated water needed for proposed power plants.

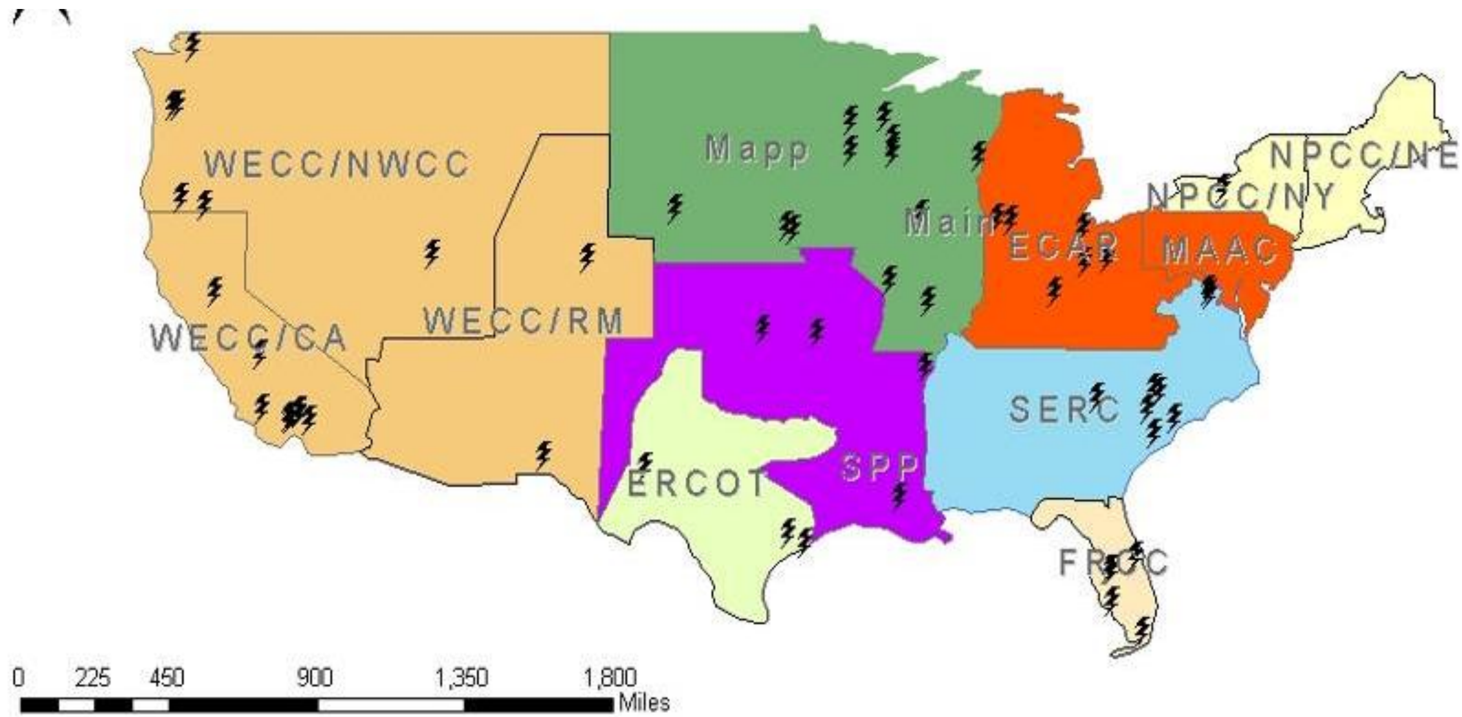
Inventory of Available Wastewater

A GIS-based tool is developed to assess the availability of secondary effluent from publicly owned treatment works in the continental U.S. Digital geographic map containing 17864 publicly owned treatment works in the lower 48 states is developed as potential water supply.

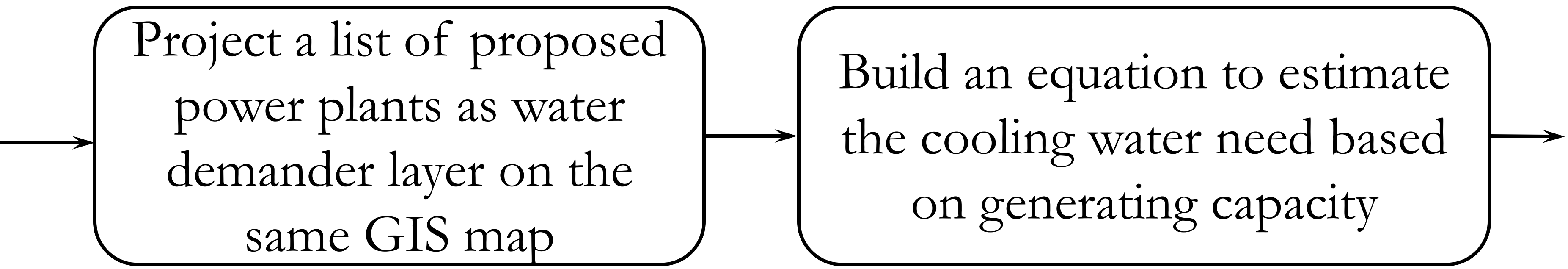


Inventory of Water Needs

- The 110 proposed power plants are from EIA annual report 2007.
- U.S. is divided into 8 major NERC regions (shown in color) and 13 minor regions.



Estimation of Water Needs



- A total of 110 power plants proposed in 2007 was used to assess water demand.
- Water needed for power generation is 1.2 gallon per kWh.
- The equation for estimating cooling water need:

Water needed =

Capacity (kW)*1.2 (gal/kWh)* 24 (hr)*0.75 (Load factor)

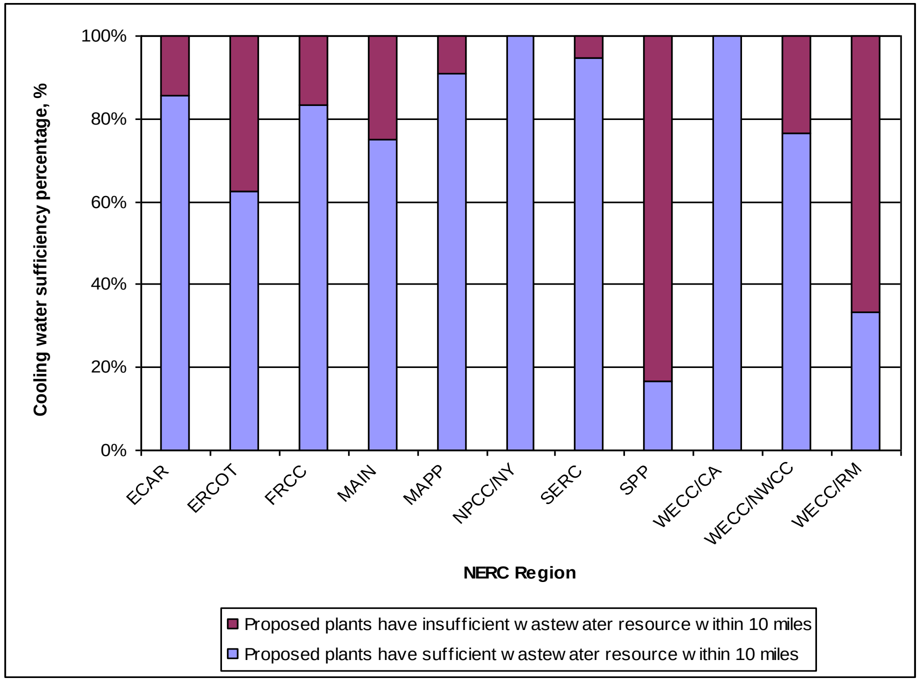
Supply vs. Demand

Region	Total Daily Cooling Water Need, MGD	Total Daily Wastewater Flow rate, MGD	Percentage of Available Wastewater needed for cooling, %
ECAR	27.5	4873	0.56
ERCOT	15.0	1993	0.76
FRCC	42.9	1374	3.12
MAIN	1.6	3318	0.05
MAPP	25.7	1167	2.20
NPCC/NY	0.1	1112	0.01
SERC	28.2	3915	0.72
SPP	17.5	2077	0.84
WECC/CA	22.5	3636	0.62
WECC/NWCC	44.9	1910	2.35
WECC/RM	9.3	1061	0.88

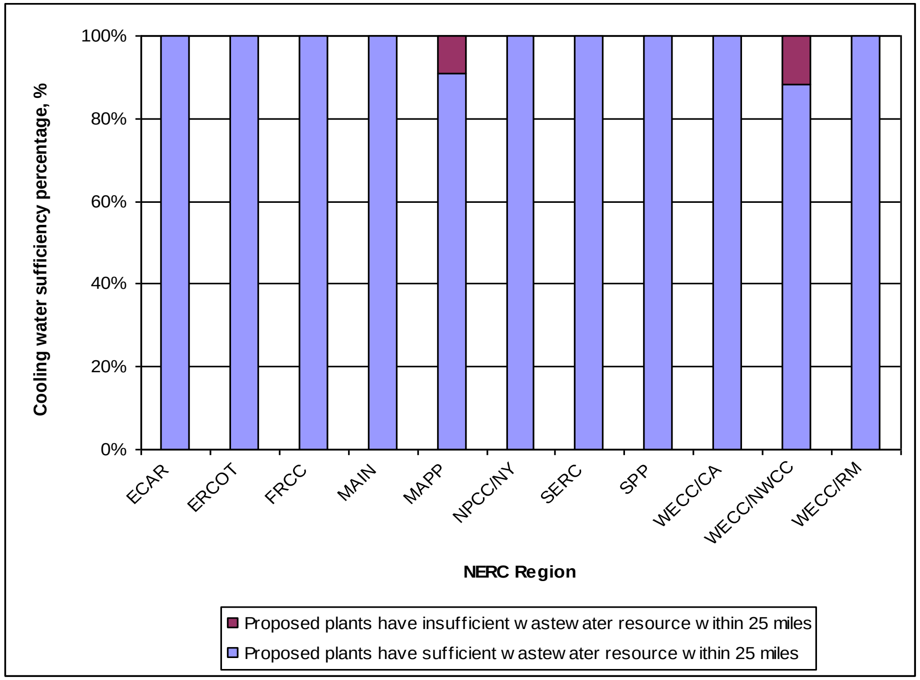
How many POTWs are needed to satisfy the cooling water demand?

Region	Proposed power plants that have sufficient wastewater within 10 mi to satisfy their cooling water needs, %	Average number of POTWs within a 10 mile radius of a proposed power plant	POTWs needed to satisfy cooling water needs within a 10 mile radius
ECAR	86	2.9	1.1
ERCOT	63	3.0	1.2
FRCC	83	4.6	1.4
MAIN	75	7.0	1.0
MAPP	91	3.1	1.0
NPCC/NY	100	4.0	1.0
SERC	95	2.1	1.0
SPP	17	2.0	2.0
WECC/CA	100	4.9	1.0
WECC/NWCC	76	2.8	1.0
WECC/RM	33	2.0	1.0

How many POTWs are needed to satisfy the cooling water demand?



Percentage of proposed plants which have sufficient wastewater within 10 mi



Percentage of proposed plants which have sufficient wastewater within 25 mi

Summary – Task 2

- POTWs located within 10 and 25 mile radius from the proposed power plants can satisfy 81% and 97% of power plant cooling water needs, respectively.
- On average, one fairly large POTW can completely satisfy the cooling water demand for each of these power plants.

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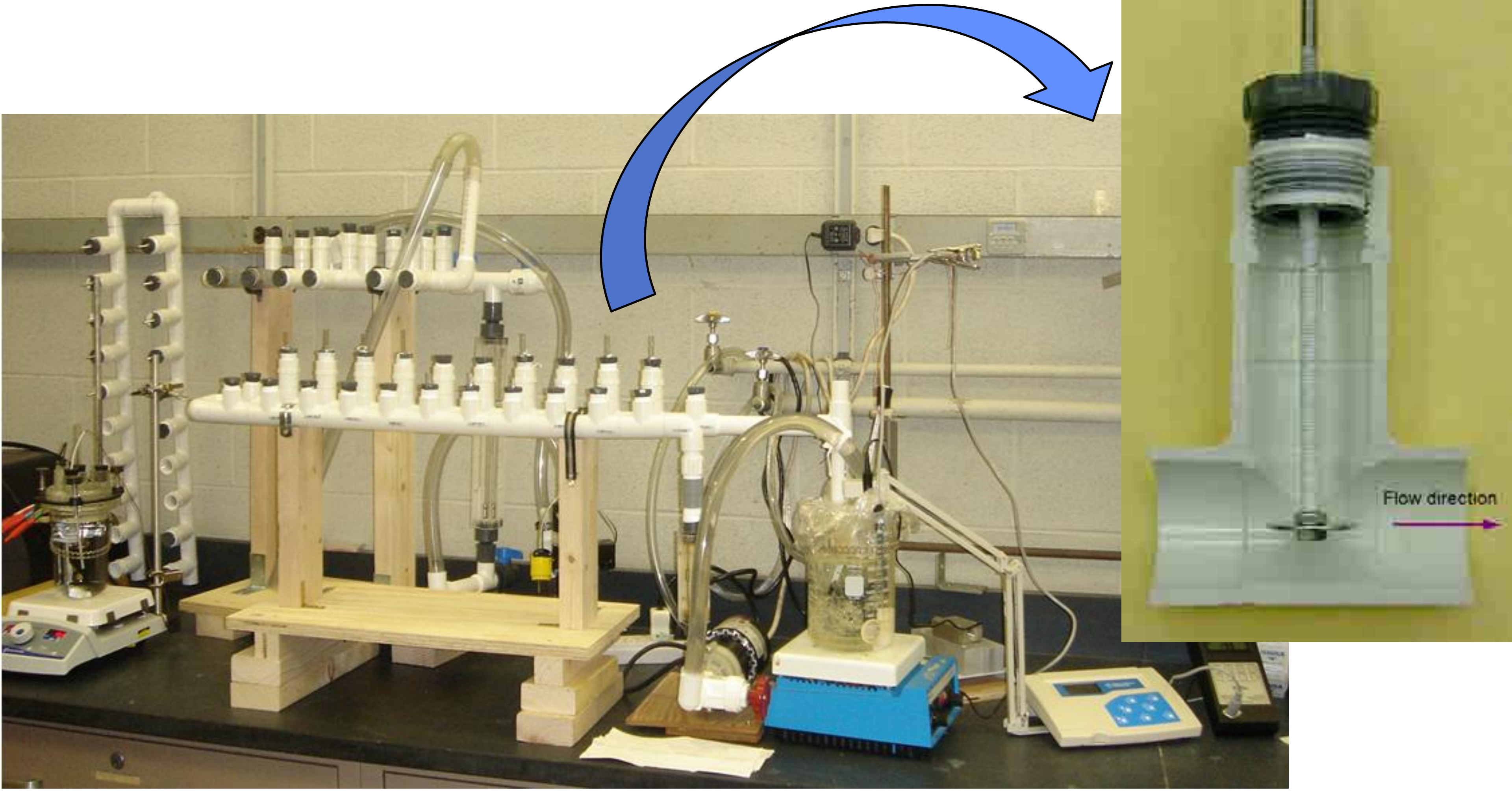
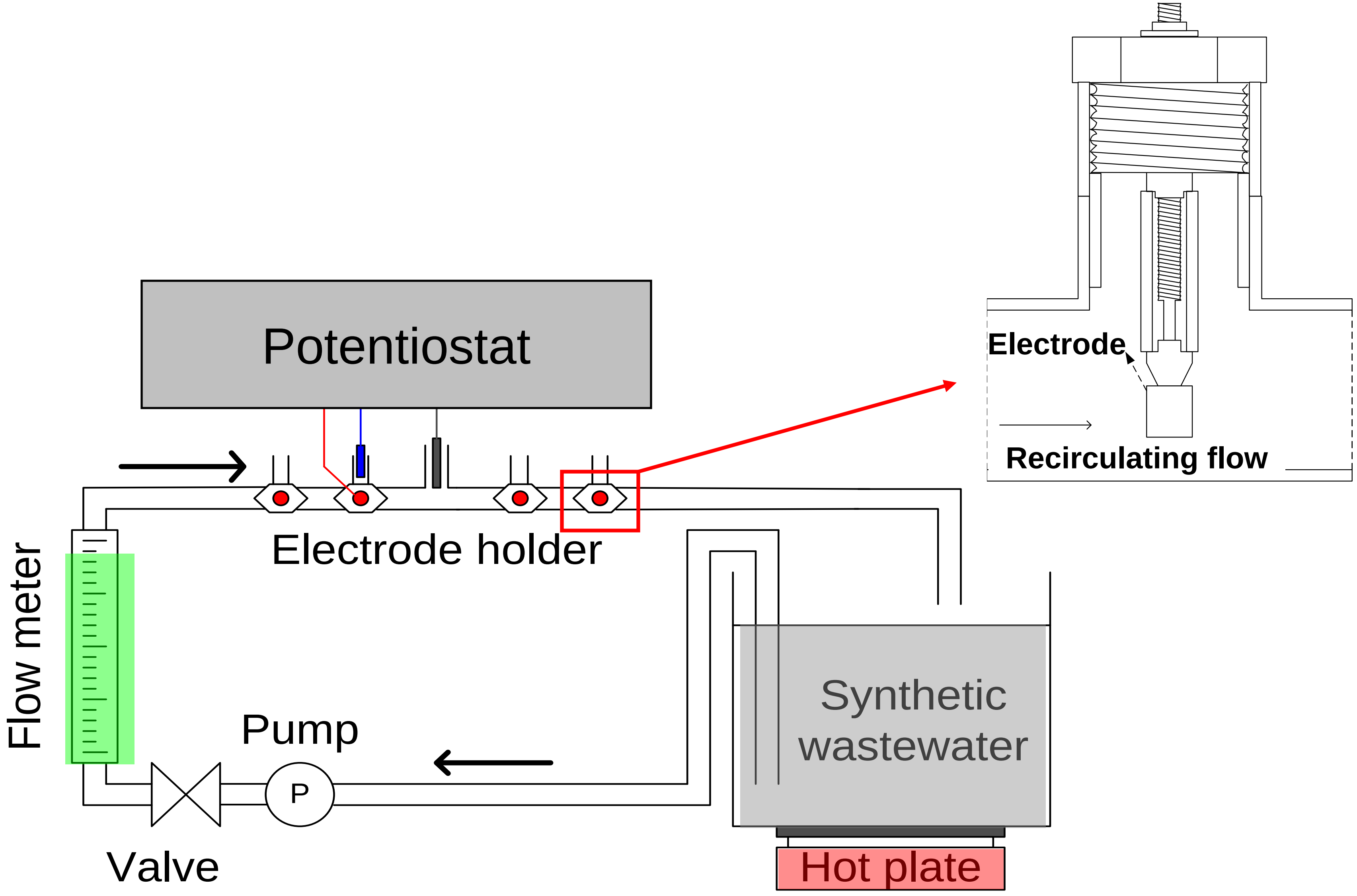
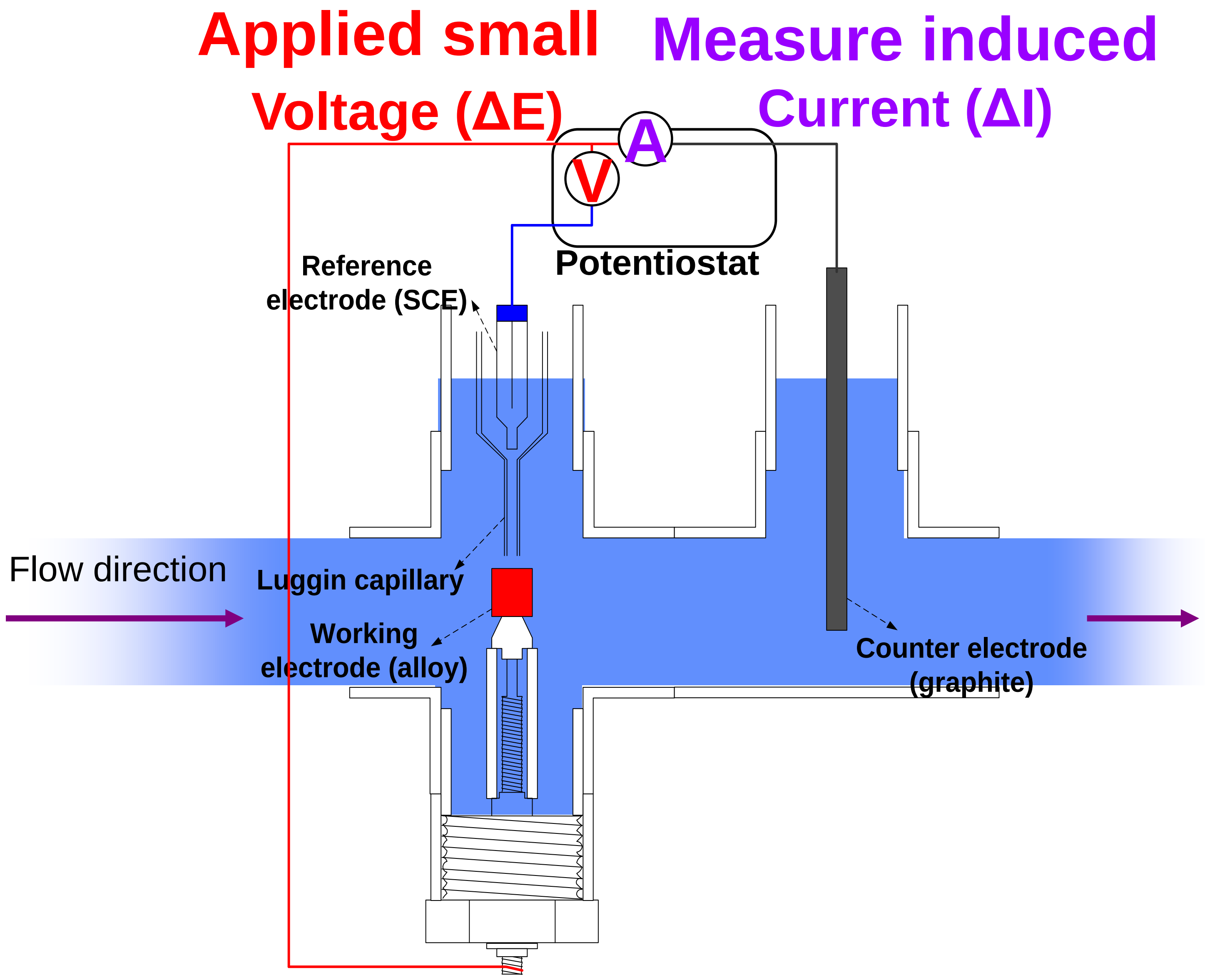
Bench-scale Water Recirculating System: Scaling Kinetics



Bench-scale Water Recirculating System: Corrosion Studies

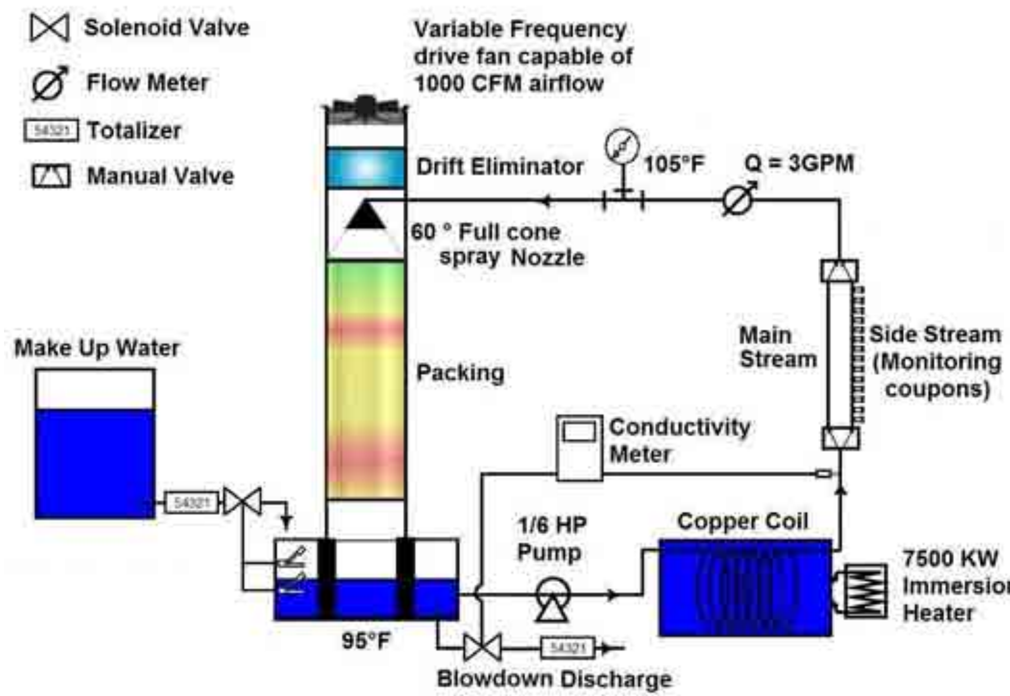


Design of T-section for Electrochemical Study

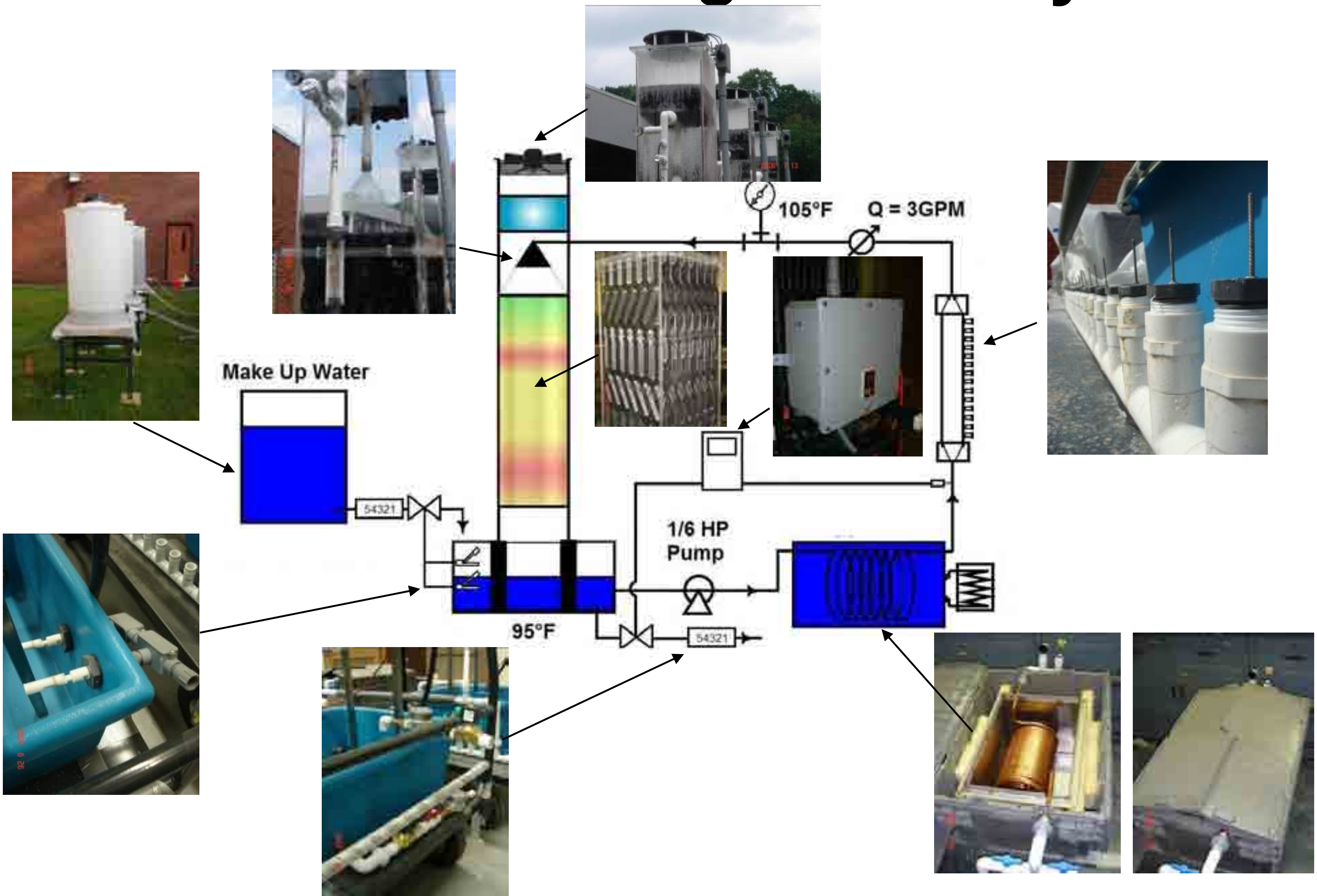


Pilot Scale Cooling Tower System Design

Design Criteria	
Flowrate	3GPM
Water Temperature	105ºF
Cooling capacity	10ºF
Airflow rate	150 CFM
Cycle of Concentration	4 COC
Blowdown Control	Conductivity of water



Pilot Scale Cooling Tower System



Pilot Scale Cooling Tower System

Pilot Scale Cooling Tower System

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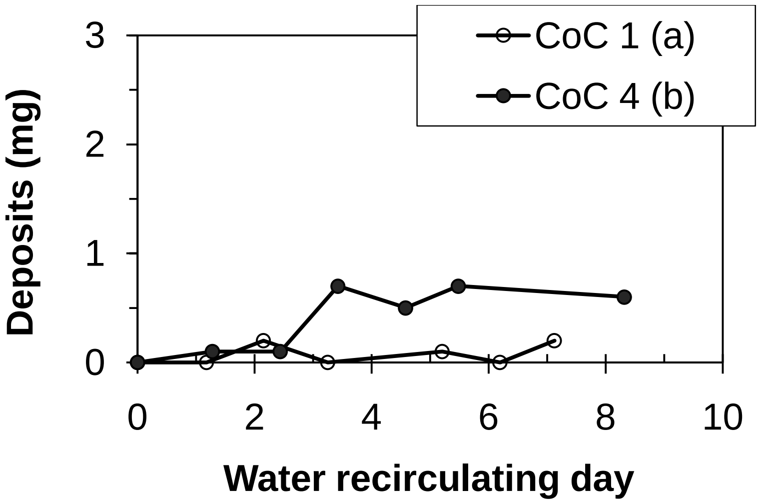
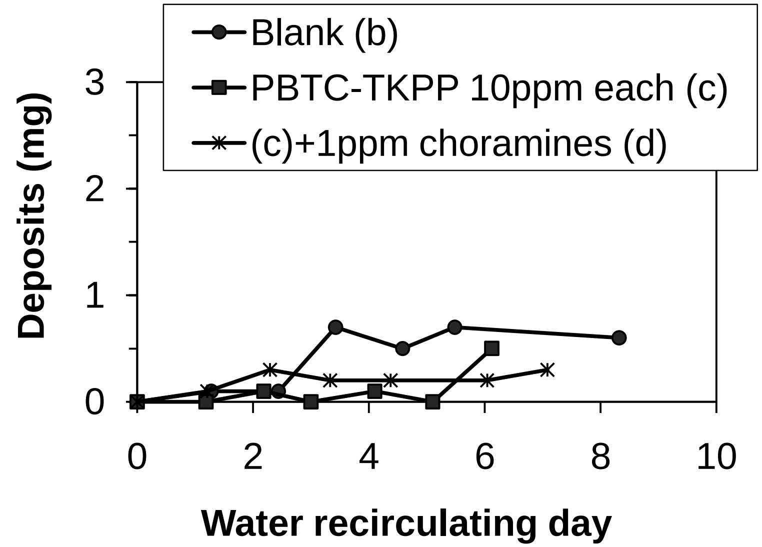
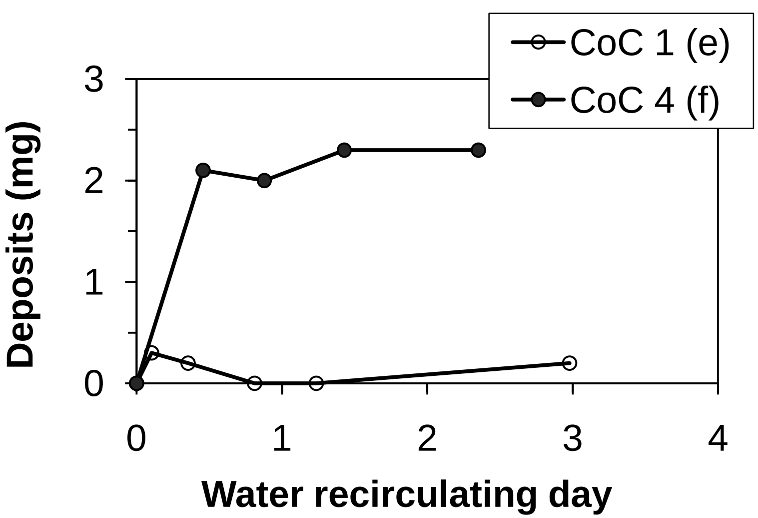
Experimental Matrix for Scaling Study with Secondary Wastewater

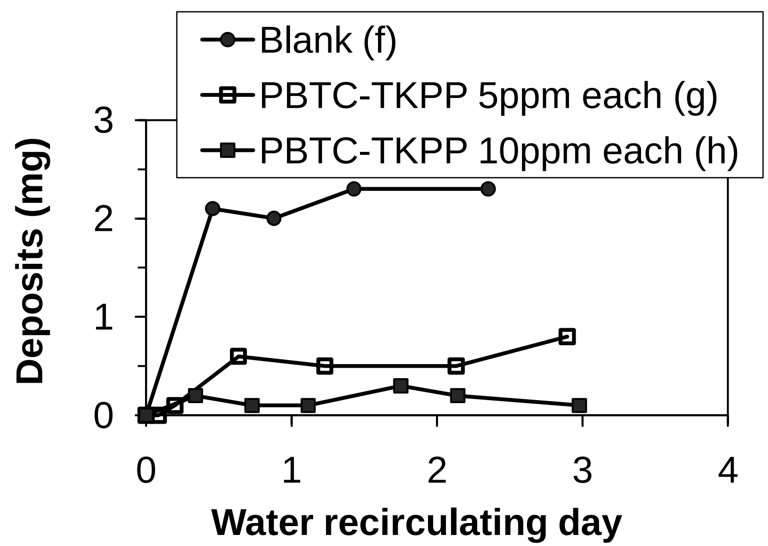
	Source Water				Concentration of antiscalant (mg/L)		
Exp. #	Actual	Synthetic	CoC	Chlorine addition [α]	PMA	PBTC	TKPP
a	√		1	-	-	-	-
b	√		4	-	-	-	-
c	√		4	-	-	10	10
d	√		4	1ppm chloramines	-	10	10
e		√	1	-	-	-	-
f		√	4	-	-	-	-
g		√	4	-	-	5	5
h		√	4	-	-	10	10
i		√	4	1ppm chlorine [β]	-	10	10
j		√	4	1ppm chloramines	-	10	10
k		√	4	1ppm chloramines	10	5	-
l		√	4	1ppm chloramines	20	10	-
m		√	4	w/o ammonia	-	10	10
n		√	4	w/o phosphate	-	10	10

Scaling behavior of secondary wastewater: actual vs. synthetic

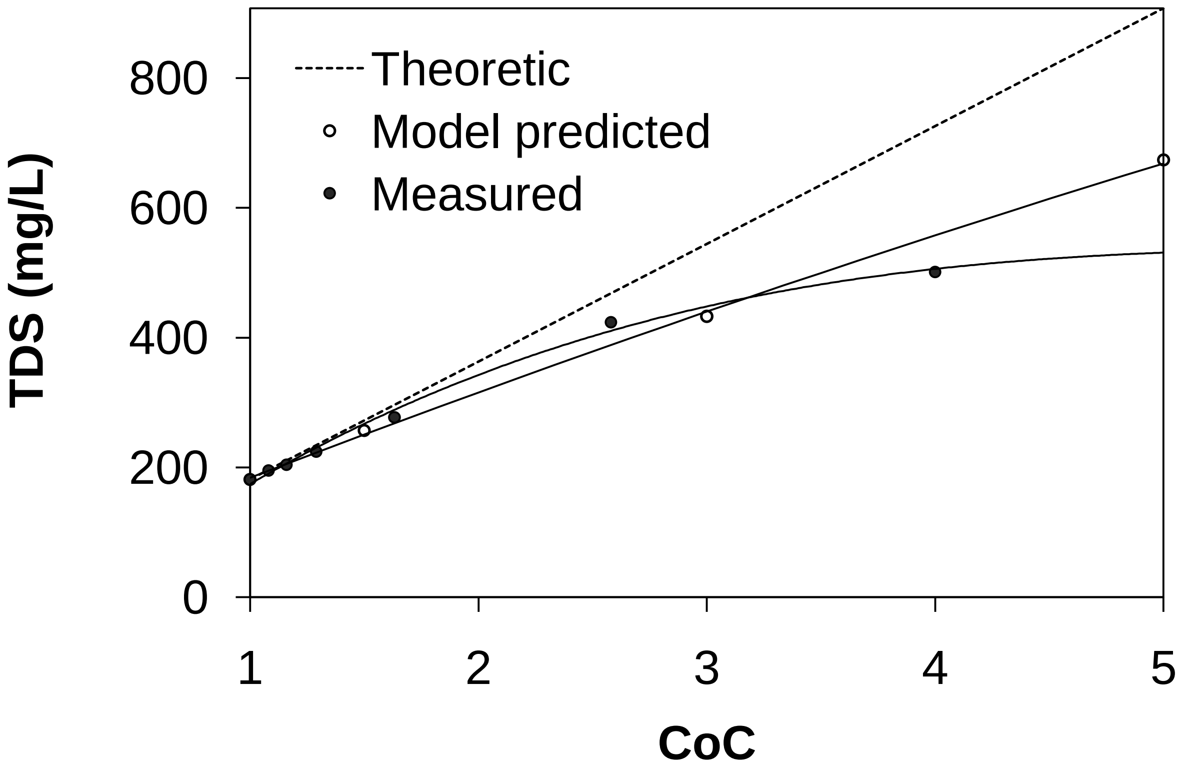




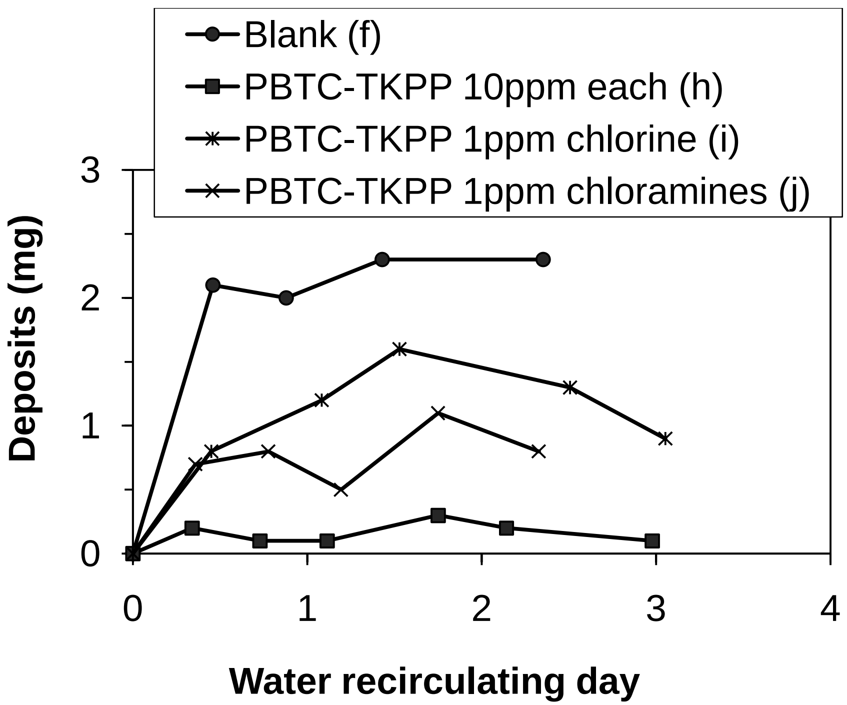


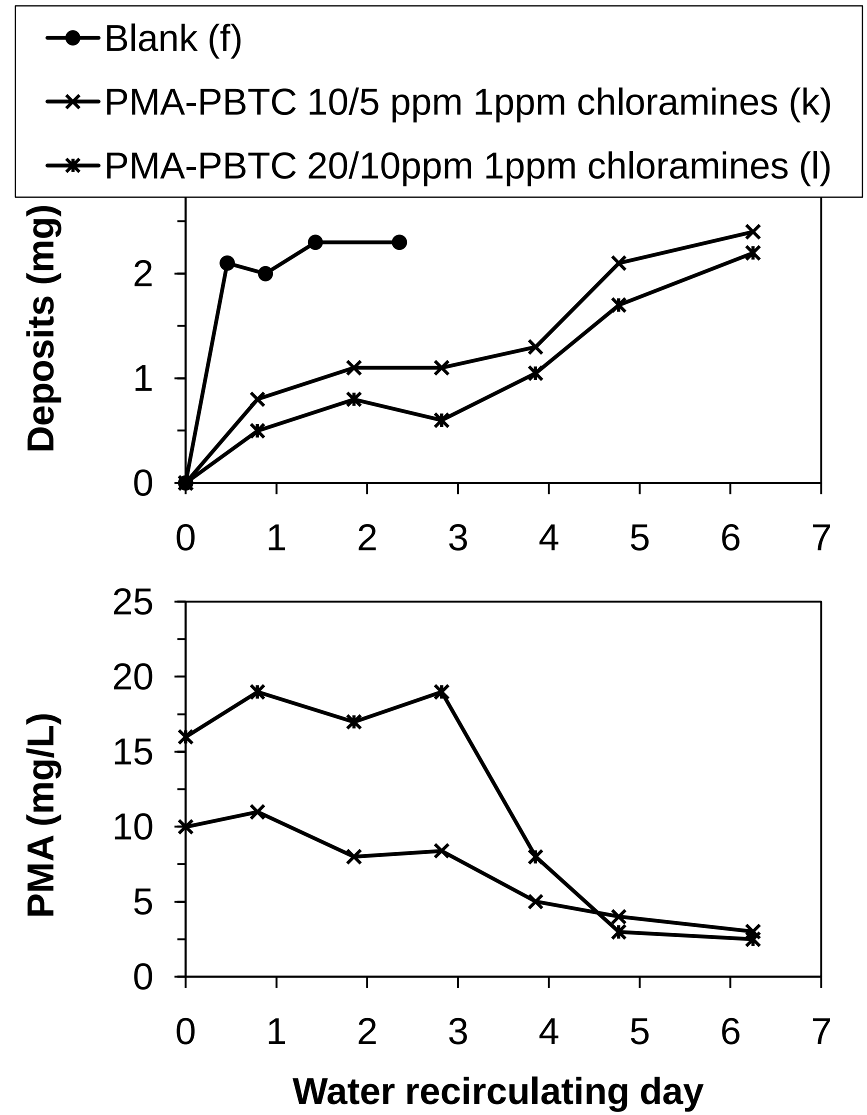


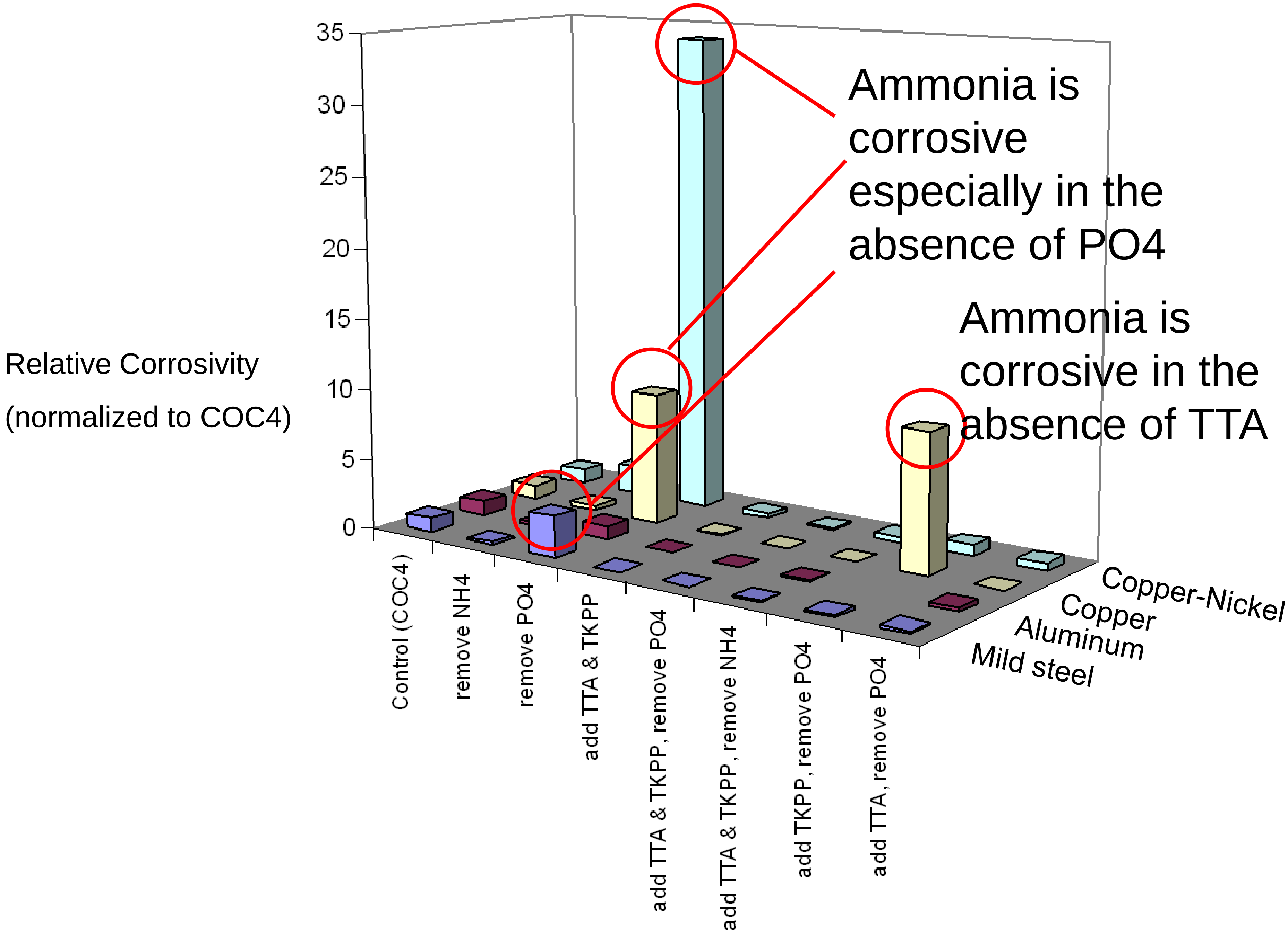
Actual waters concentrated by evaporation are not suitable for scaling studies because a significant amount of dissolved solids precipitates during the evaporation process

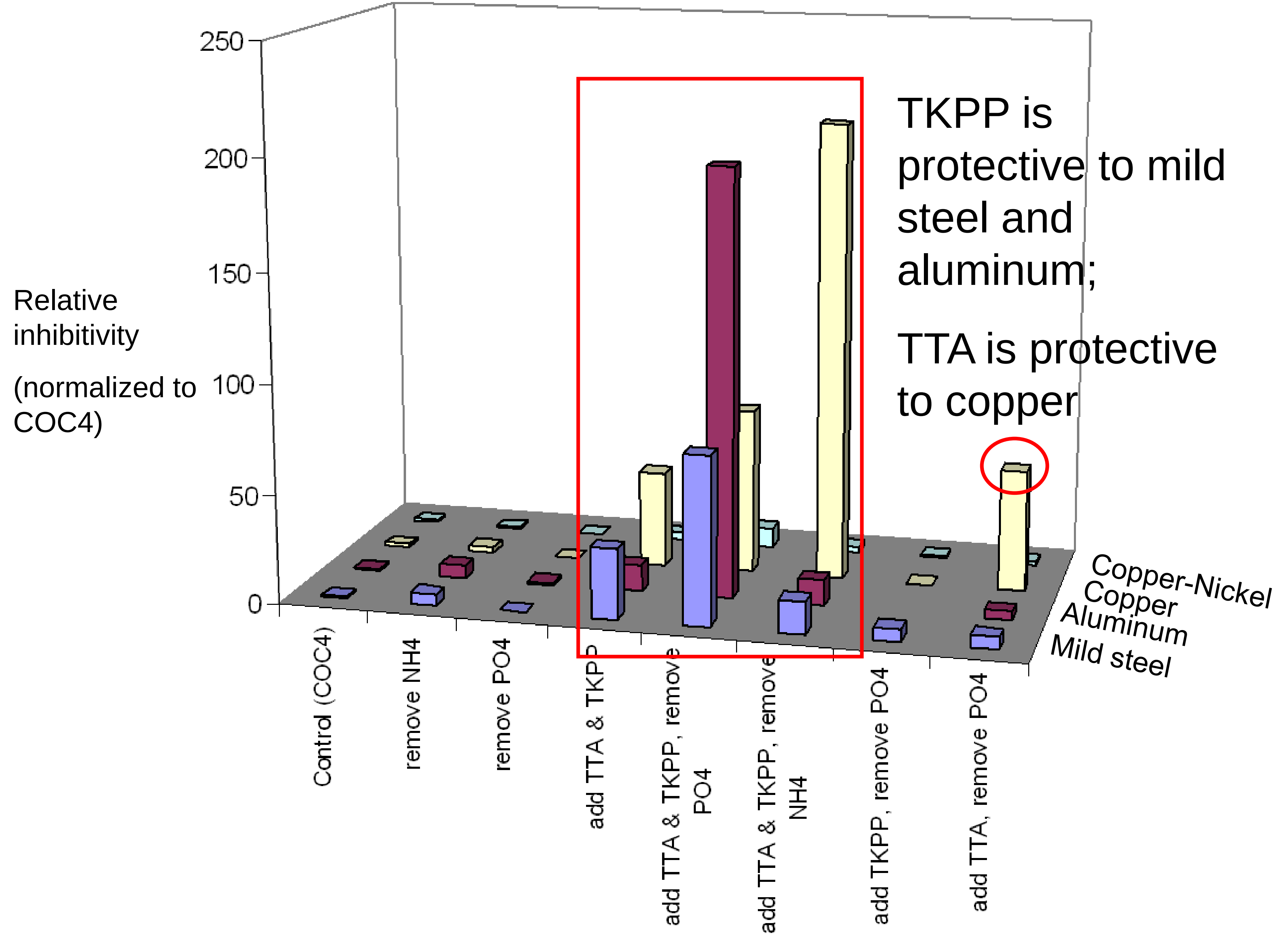


Impact of disinfection by chlorine and chloramines on scaling control effectiveness






Relative Corrosivity
(normalized to COC4)
35
30
25
20
15
10
5
0
Control (COC4)
remove NH4
remove PO4
add TTA & TKPP
add TTA & TKPP, remove PO4
add TTA & TKPP, remove NH4
add TKPP, remove PO4
add TTA, remove PO4
Copper-Nickel
Copper
Aluminum
Mild steel
Ammonia is corrosive especially in the absence of PO4
Ammonia is corrosive in the absence of TTA



TKPP is protective to mild steel and aluminum;

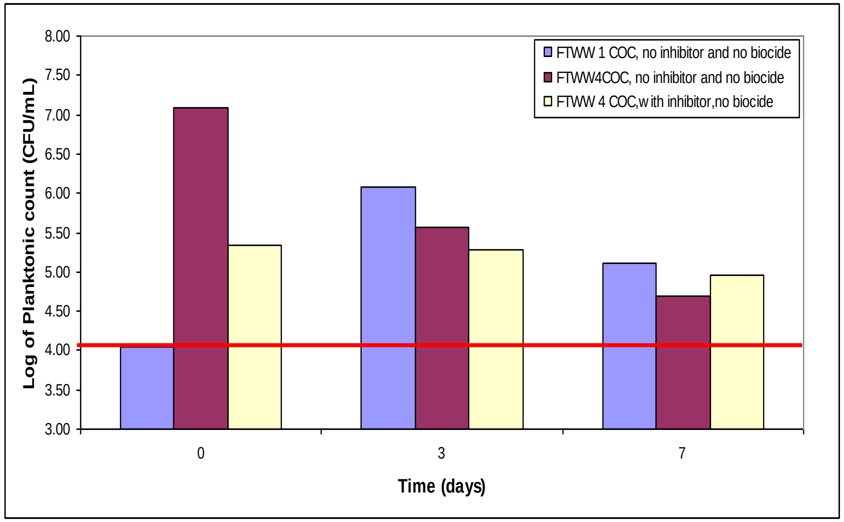
TTA is protective to copper

Influence of Key Parameters on Corrosion

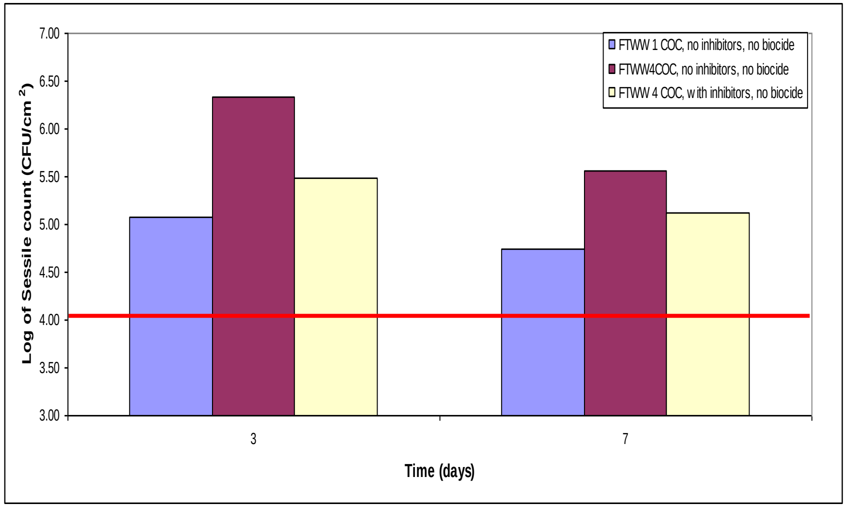
	Mild steel	Aluminum	Copper	Copper-nickel
Ammonia (100 ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TKPP (10ppm)	-Very aggressive -Negligible w/ TKPP (10ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TTA (2-4ppm)	-Very aggressive (esp. w/o PO_4) -Negligible w/ TTA (2-4ppm)
Free Cl2 (1ppm)	Aggressive	NC	Very aggressive	Very aggressive
Monochloramine (1ppm)	Aggressive	Aggressive	Not aggressive in the presence of TTA (2-4ppm)	Some aggressive in the presence of TTA (2-4ppm)
Phosphate (20ppm)	Some protective	Aggressive	NC	NC
TKPP (10ppm)	Very protective (esp. w/o PO_4 because of co-precipitation)	Very protective (esp. w/o PO_4 because of co-precipitation)	NC	NC
TTA (2-4ppm)	NC	NC	Very protective even w/ NH_3	Protective only w/ NH_3

Biofouling potential of Secondary Treated Municipal Wastewater in Bench-Scale Experiments

- Heterotrophic bacteria count in both COC1 and COC4 exceeded the target criteria of 10^4 CFU / ml (CTI, 2006)
- As the cycles of concentration increase, wastewater may be more susceptible to biofouling, due to increase in organic loading and nutrients



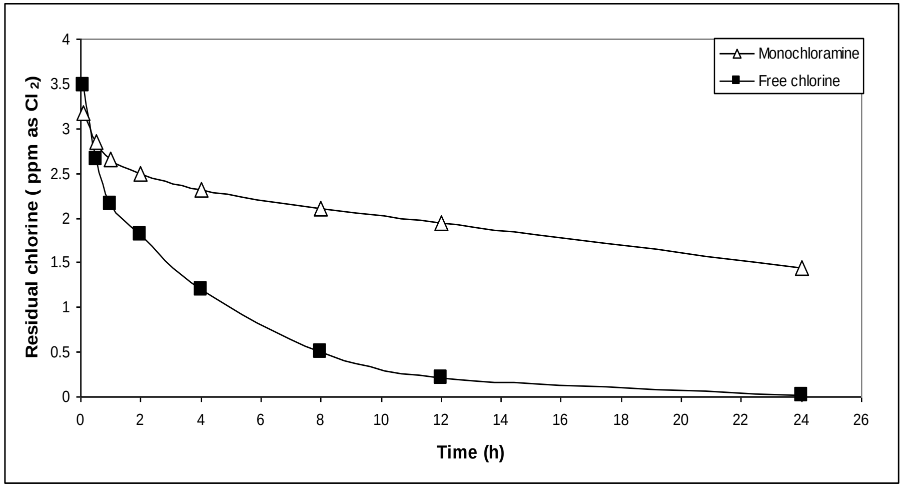
Planktonic HPC



Sessile HPC

Comparison of Chlorine Dose Requirements for Free Chlorine and Chloramine

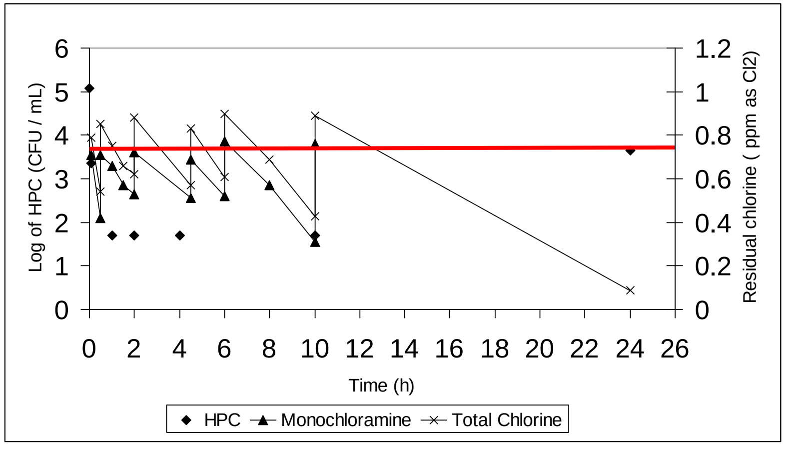
- The decay rate of monochloramine is much slower than that of free chlorine.
- Chlorine dose required to maintain certain monochloramine level may be much lower than for maintaining free chlorine.
- Chloramination may reduce chlorine requirements and be more cost-effective.



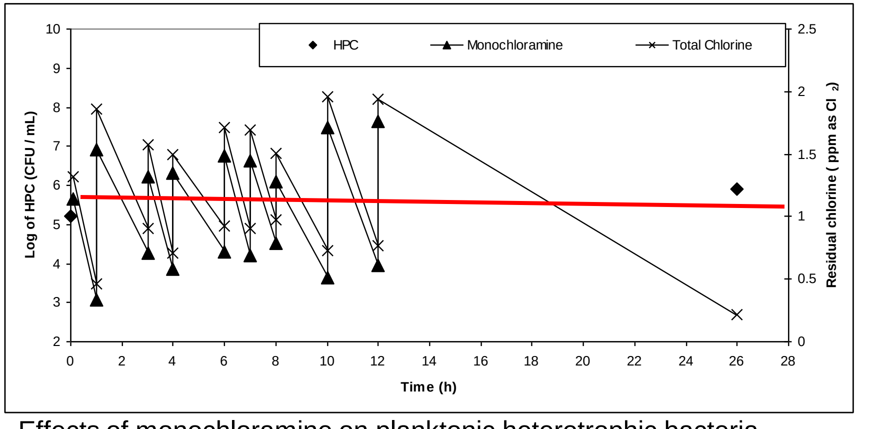
Monochloramine and free chlorine decomposition at 4 COC and pH 8

Bench-Scale Experiments for Biofouling Control by Chloramination

- In FTWW 4 COC, the planktonic HPC was 1.2 x 10^5 CFU / mL before adding chloramine.
- For both dosage, 0.5 -1 ppm as Cl_2 and 1-2 ppm as Cl_2, monochloramine seems very effective and can keep plantonic HPC under detection limit for 10 hours.



Effects of monochloramine on planktonic heterotrophic bacteria maintaining total chlorine between 0.5-1 ppm as Cl2 at initial 100 ppm NH_3-N in FTWW 4 COC in bench-scale circulating system



Effects of monochloramine on planktonic heterotrophic bacteria maintaining total chlorine between 1-2 ppm as Cl2 in FTWW 4 COC in bench scale circulating system

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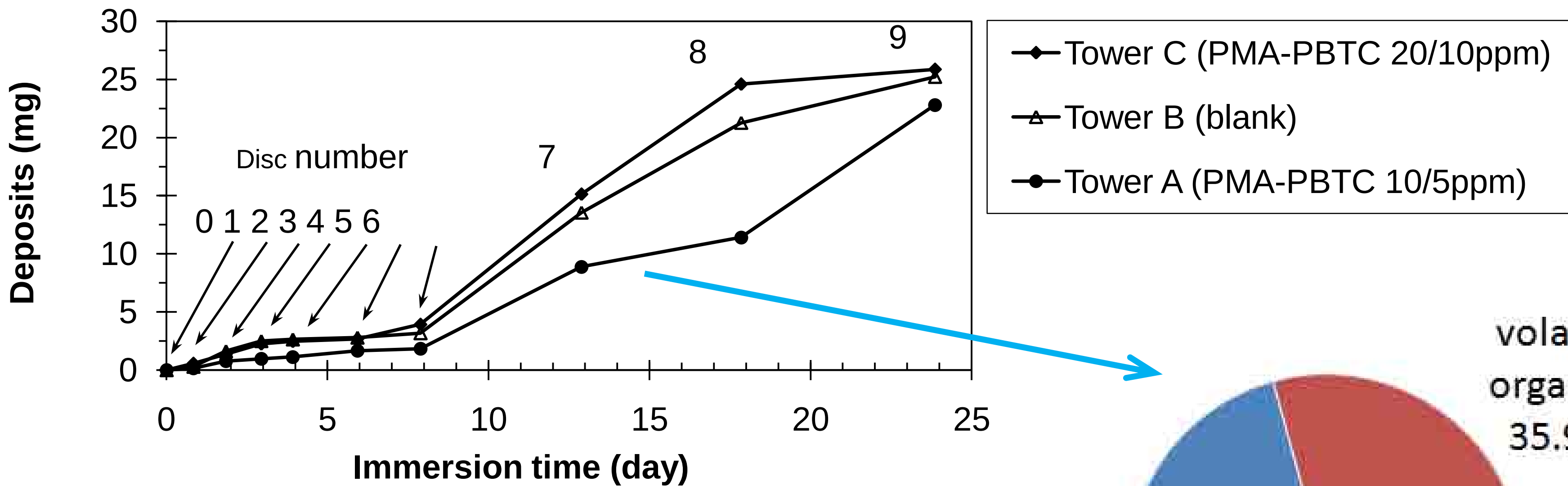
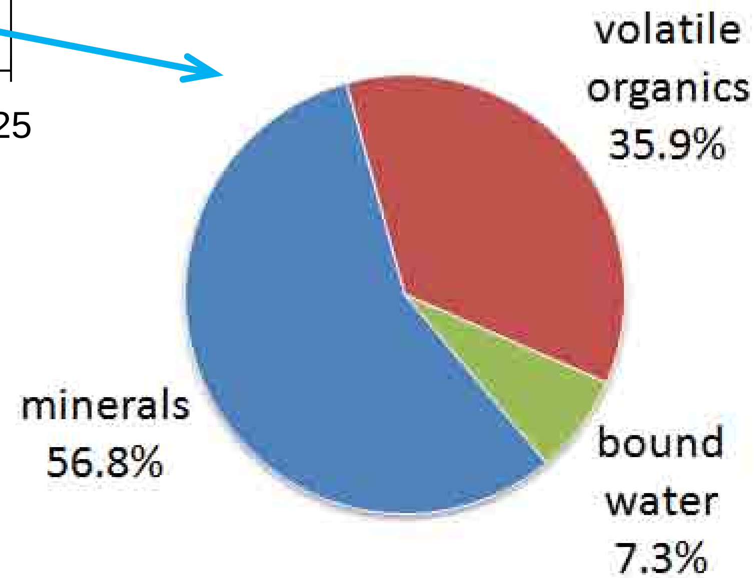
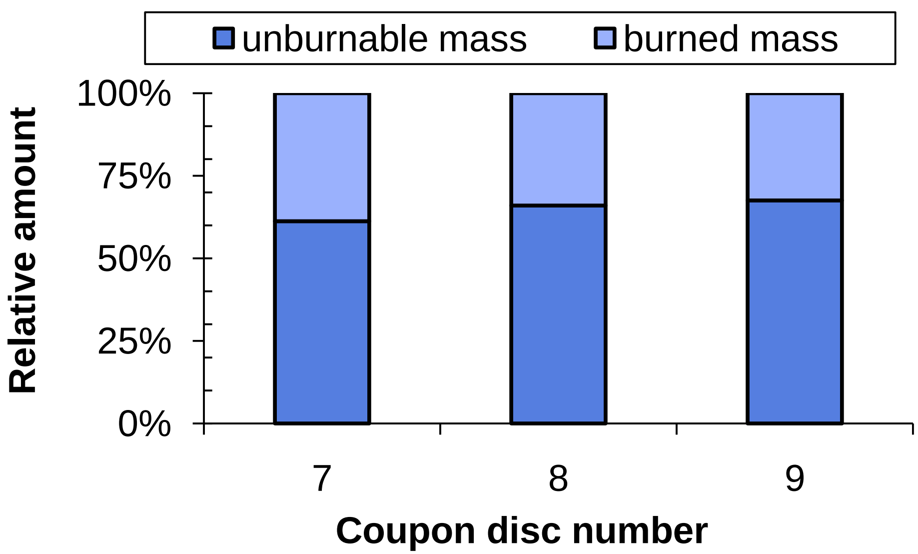
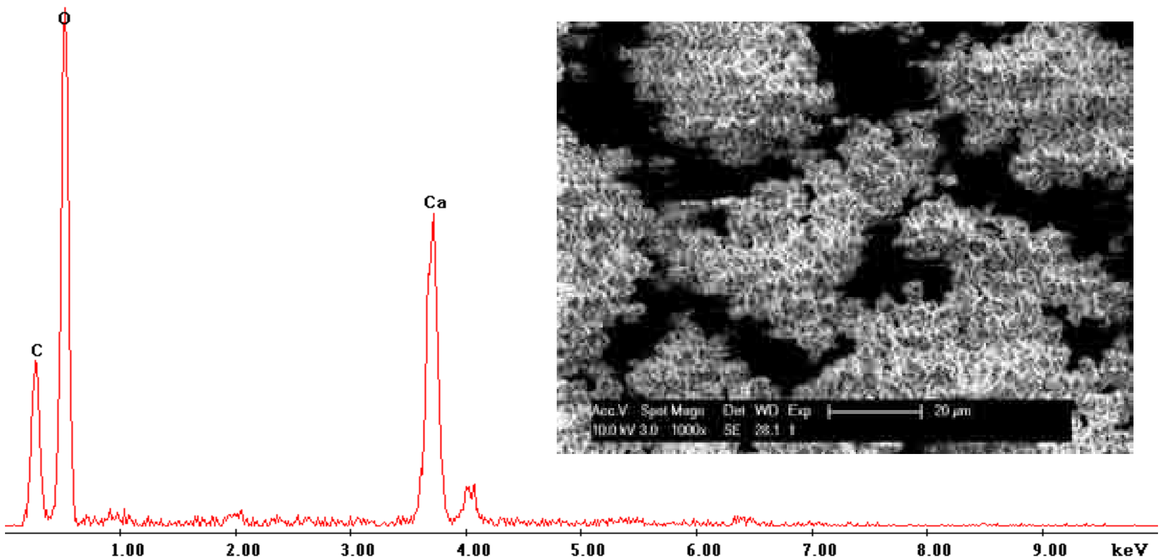
Cooling water scaling when using secondary treated MWW at Franklin Township



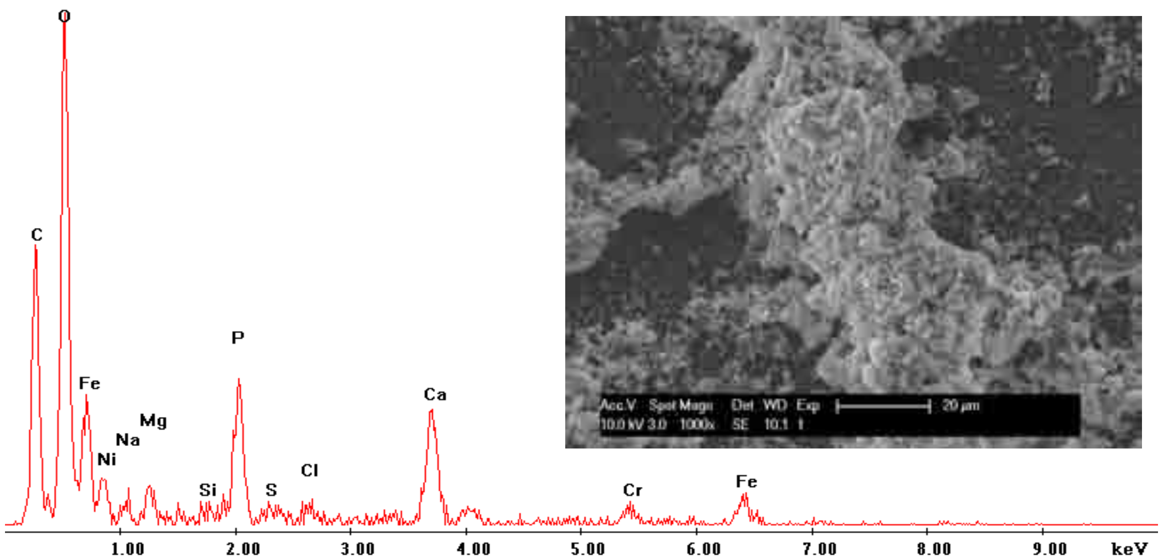




SEM-EDS examination of solids collected from coupon discs

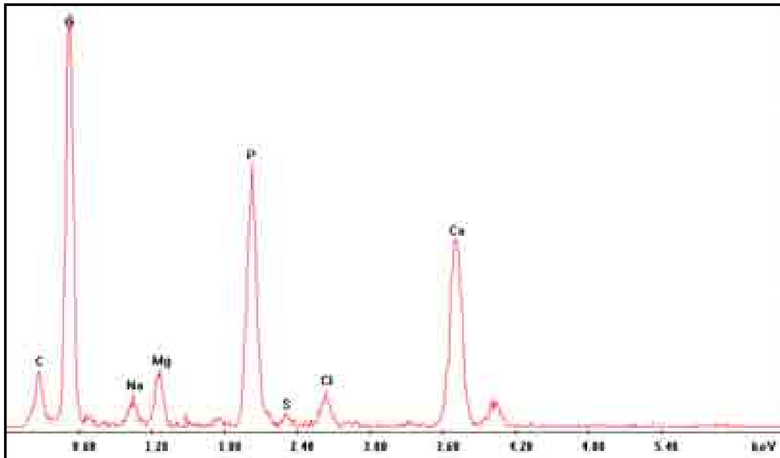


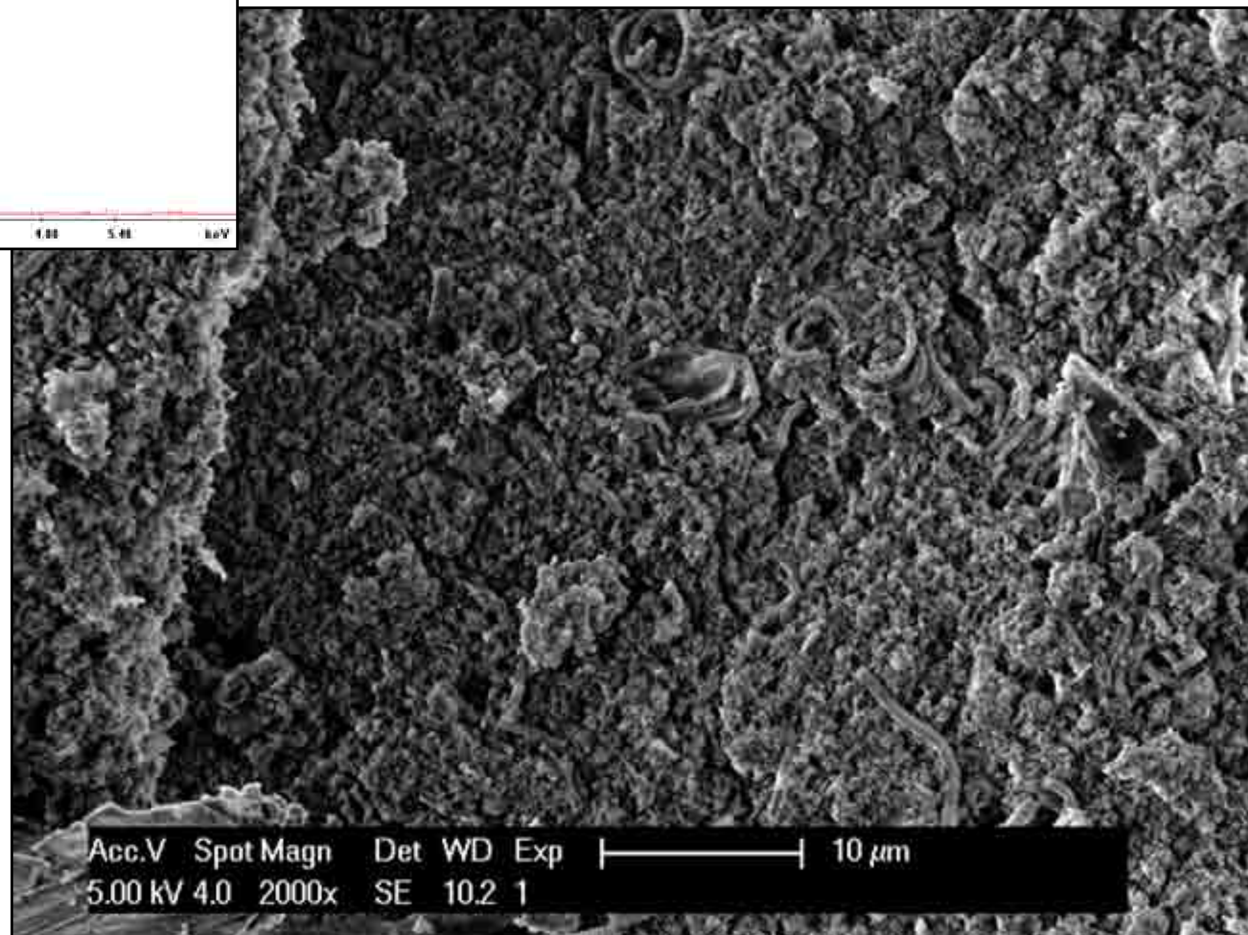
Coupon disc for synthetic wastewater



Coupon disc for actual wastewater

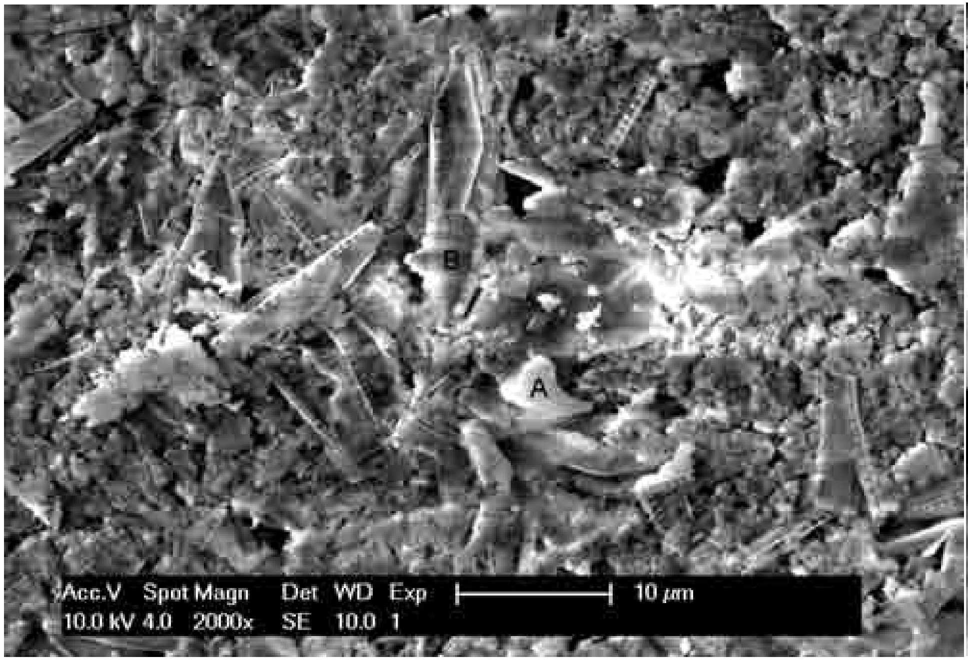
Bio-growth in the deposited solids of disc coupons

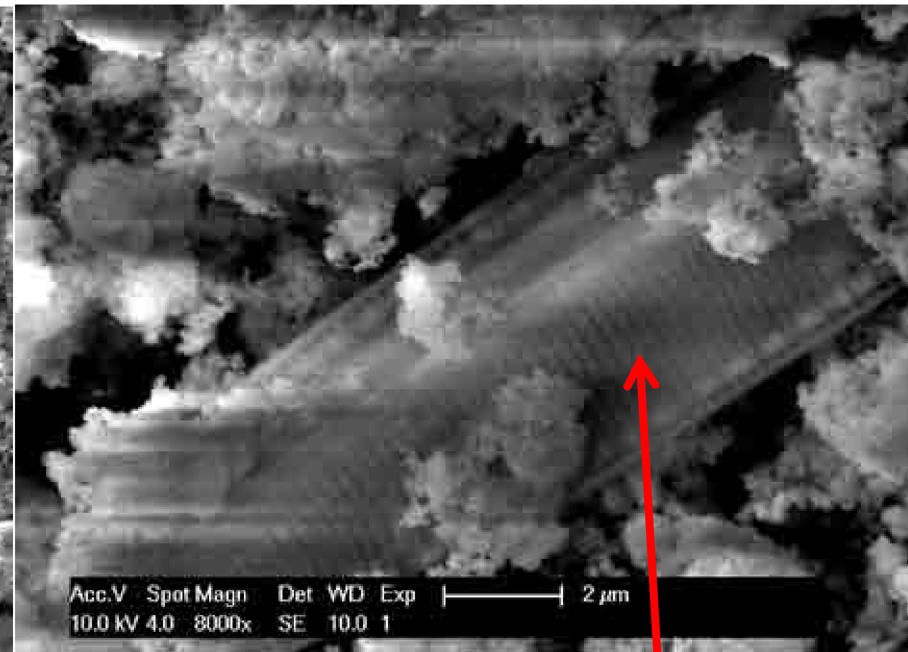


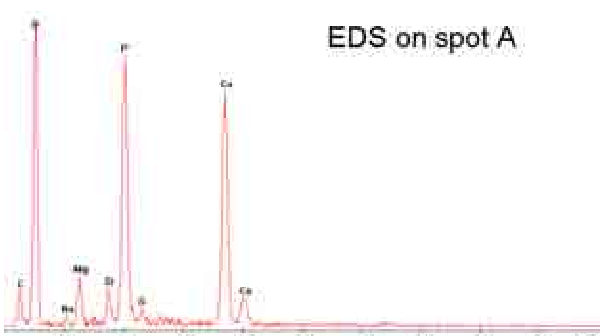


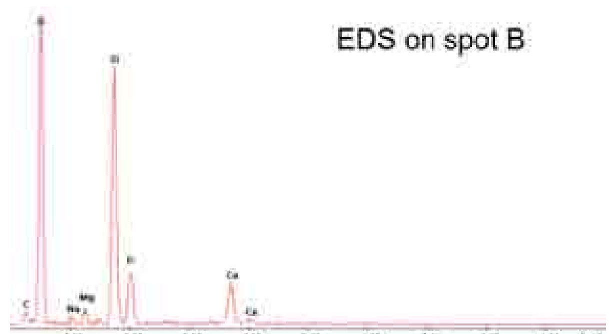
Settled solids at the bottom of recirculating water basin

Algal cells found inside the in-line flowmeter





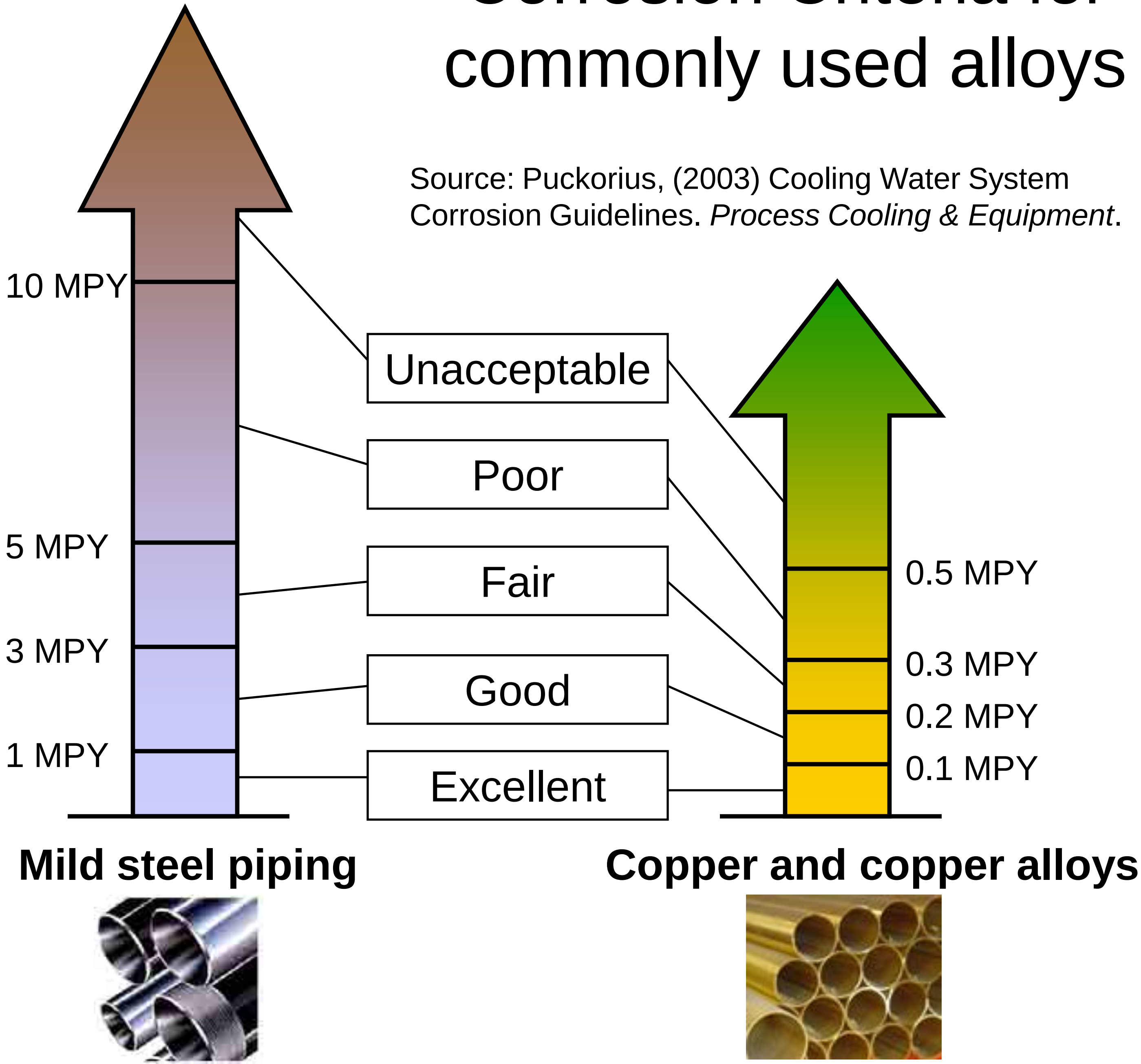


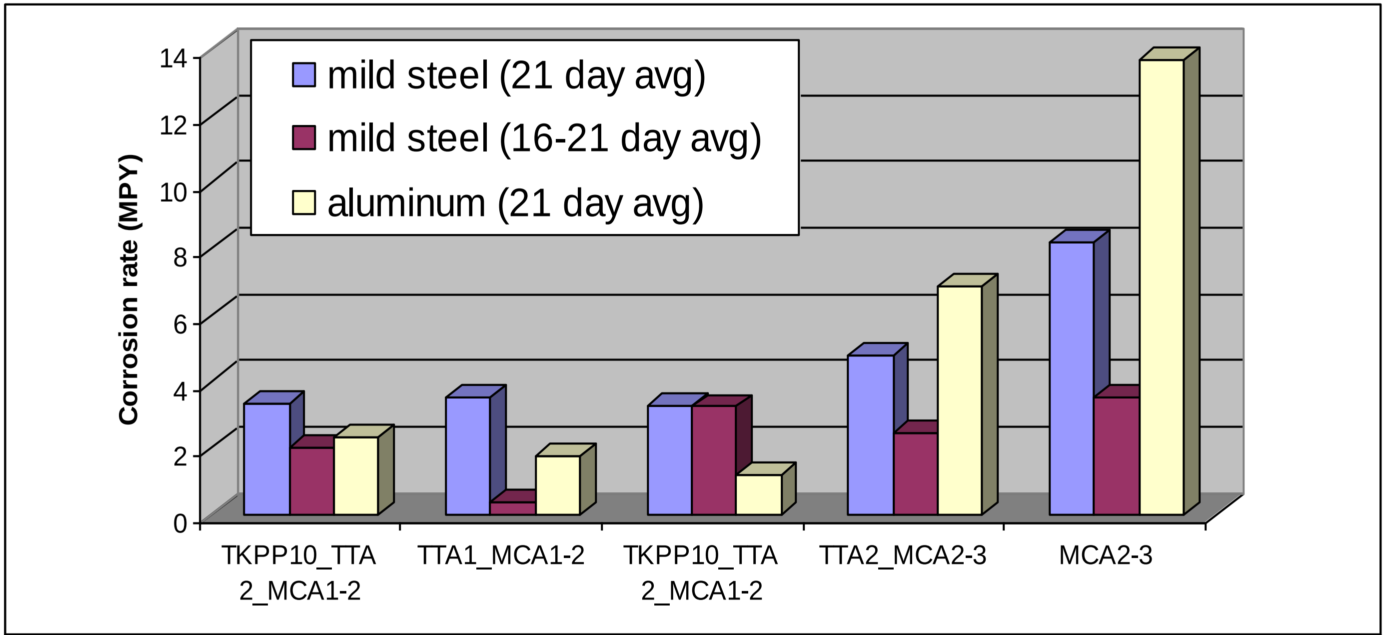


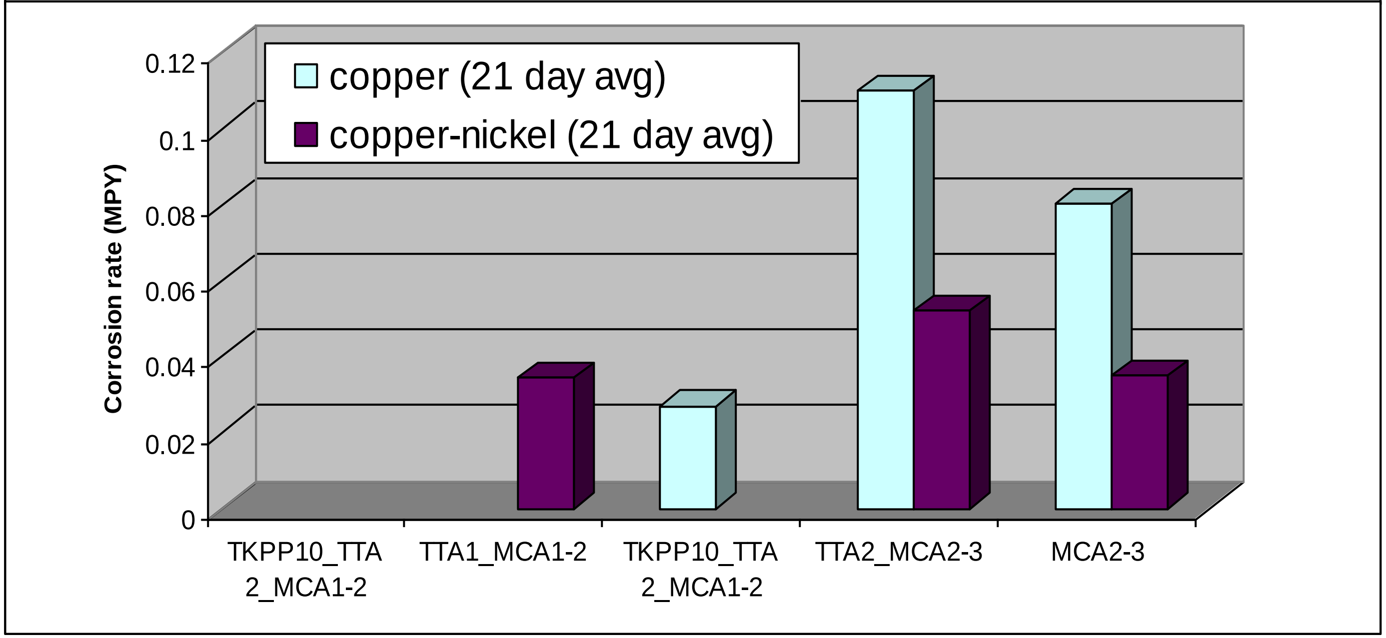
Nitzschia palea

Corrosion Criteria for commonly used alloys

Source: Puckorius, (2003) Cooling Water System Corrosion Guidelines. *Process Cooling & Equipment*.

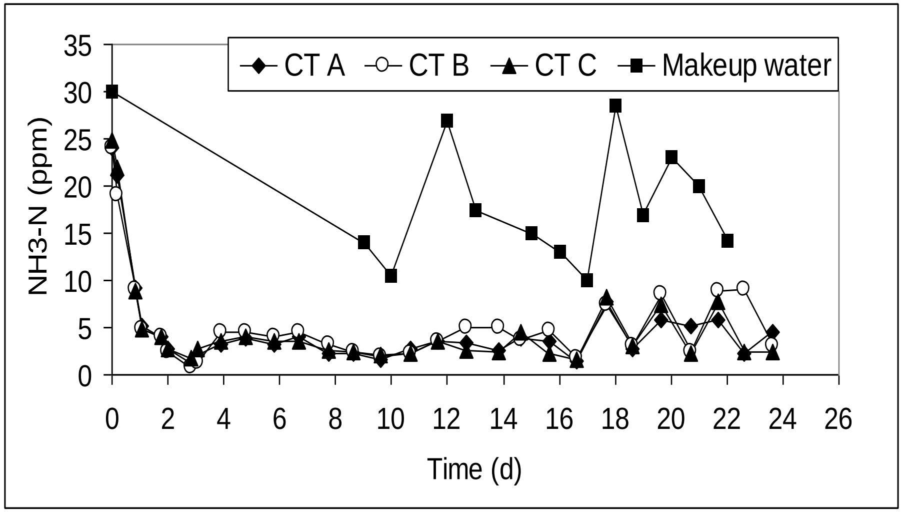



mild steel (21 day avg)
mild steel (16-21 day avg)
aluminum (21 day avg)
Corrosion rate (MPY)
0
2
4
6
8
10
12
14
TKPP10_TTA 2_MCA1-2
TTA1_MCA1-2
TKPP10_TTA 2_MCA1-2
TTA2_MCA2-3
MCA2-3


copper (21 day avg)
copper-nickel (21 day avg)
Corrosion rate (MPY)
0
0.02
0.04
0.06
0.08
0.1
0.12
TKPP10_TTA 2_MCA1-2
TTA1_MCA1-2
TKPP10_TTA 2_MCA1-2
TTA2_MCA2-3
MCA2-3

Ammonia Concentration in Pilot-Scale Cooling Towers

- All towers were dosed with sodium hypochlorite solution at rates intended to achieve 0.5-1.0 ppm as Cl2 monochloramine in the circulating water.
- The monochloramine was formed in situ through reaction with the ammonia present in the wastewater.
- Average ammonia concentration in the raw makeup water was 18.4±6.8 ppm NH_3-N but all towers have relatively low ammonia concentration.



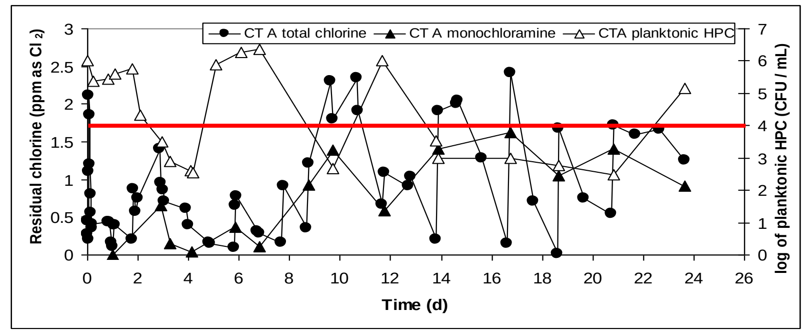
Ammonia concentration in makeup water and in three cooling towers in pilot scale tests at Franklin Township Municipal Sanitary Authority, Murrysville, PA, July-August, 2008

Results of Pilot-Scale Experiments for Biofouling Control by Chloramination

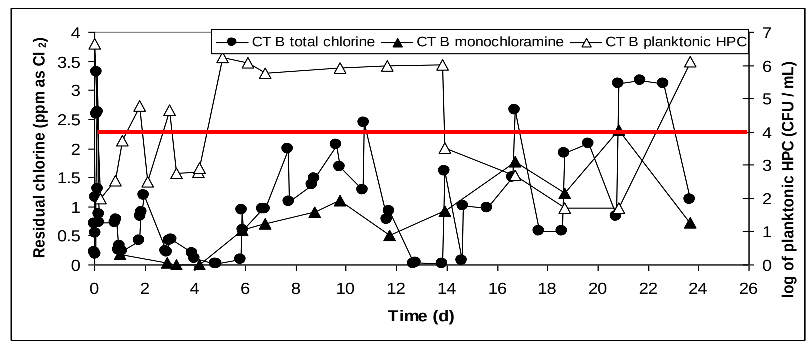
- Once the total chlorine and monochloramine were above 1 ppm as Cl_2, HPC were reduced below the target criteria of 10^4 CFU / ml (CTI, 2006)

- It appears that when total chlorine and mono-chloramine levels drop to non-detectable levels, biogrowth is established and it takes time to reverse.

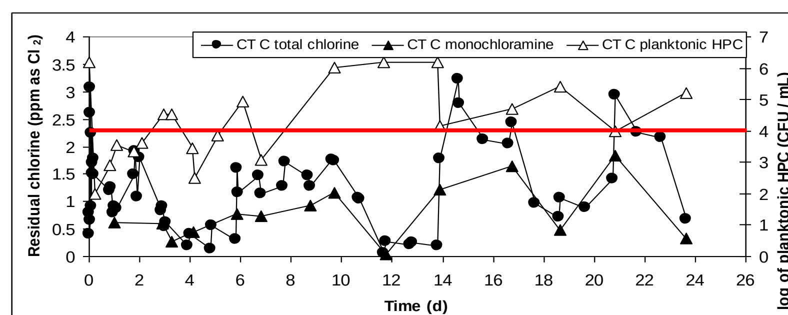
(A)



(B)



(C)



SUMMARY: Scaling (1)

- Water pre-concentrated by evaporation is not representative of higher COCs.
- Several scale inhibitors were effective in the absence of disinfectants.
- Addition of chlorine impaired the effectiveness of the antiscalants.
- Phosphate, either present in the makeup water or added as corrosion inhibitor, worsened scaling.
- Ammonia helped mitigate scaling.

SUMMARY: Scaling (3)

- Biomass significantly contributed to scaling; therefore, control of biogrowth in both the makeup tank and the recirculating system is required.
- Addition of phosphate-containing chemicals should be avoided or minimized.
- Less aggressive disinfectants, such as chloramines, worked better with scale control chemicals.
- The beneficial effect of ammonia observed in bench-scale studies could not be relied on as the ammonia was effectively stripped out in the pilot-scaling cooling towers.

SUMMARY: Corrosion (1)

- Methodology of instantaneous corrosion rate (ICR) is established.
- In terms of corrosion, feasibility of using impaired waters in cooling systems can be evaluated through ICR measurement
- From lab experiment, key parameters to corrosion have been identified:
  - Protective: phosphate, TKPP, TTA
  - Aggressive: ammonia, free Cl2 and monochloramine
  - Aggressivity of ammonia overcome by TKPP and TTA

SUMMARY: Corrosion (2)

- TKPP failed to reduce corrosion since it co-precipitated with PO_4
- MCA 2-3 was more corrosive than MCA 1-2 to all alloys, especially to copper.
- All alloys were covered by deposition, and thus were protected. The deposition also made TTA less effective.
- In general, except for aluminum (pitting in all situations), corrosion rate of alloys were within acceptable range

SUMMARY: Biofouling (1)

- Increase in cycles of concentration can increase the susceptibility of biofouling for secondary treated municipal wastewater
- Bench-scale recirculating system results show that chloramination can be an effective oxidizing biocide option for secondary treated municipal wastewater.

SUMMARY: Biofouling (2)

- Relatively high organic load in secondary treated municipal wastewater makes biofouling control a challenging task
- Ammonia stripping can significantly affect biocidal efficacy of monochloramine formed by adding chlorine directly into the wastewater
- Continuous supply of biocide may be required to control biogrowth in cooling tower using secondary treated municipal wastewater as makeup

USE OF TREATED MUNICIPAL WASTEWATER AS POWER PLANT COOLING SYSTEM MAKEUP WATER:

TERTIARY TREATMENT VS. EXPANDED CHEMICAL REGIMEN FOR RECIRCULATING WATER QUALITY MANAGEMENT

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October 27, 2008

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OVERVIEW

- Project goal
- Background
- Specific objectives
- Project tasks
- Project schedule
- Summary

PROJECT GOAL

- Evaluate benefits and costs of implementing tertiary treatment for secondary-treated municipal wastewater prior to use in cooling systems vs. expanded chemical management of cooling water chemistry

BACKGROUND

- Treated municipal wastewater is a common, abundant and widespread source of impaired water
- ~ 80% of US power plants have sufficient cooling water supply from 1-2 POTWs within 10 miles
- ~ 97% from 1-2 POTWs within 25 miles

PROBLEMS WITH USE OF IMPAIRED WATERS

- Precipitation and scaling
- Accelerated corrosion
- Biomass growth

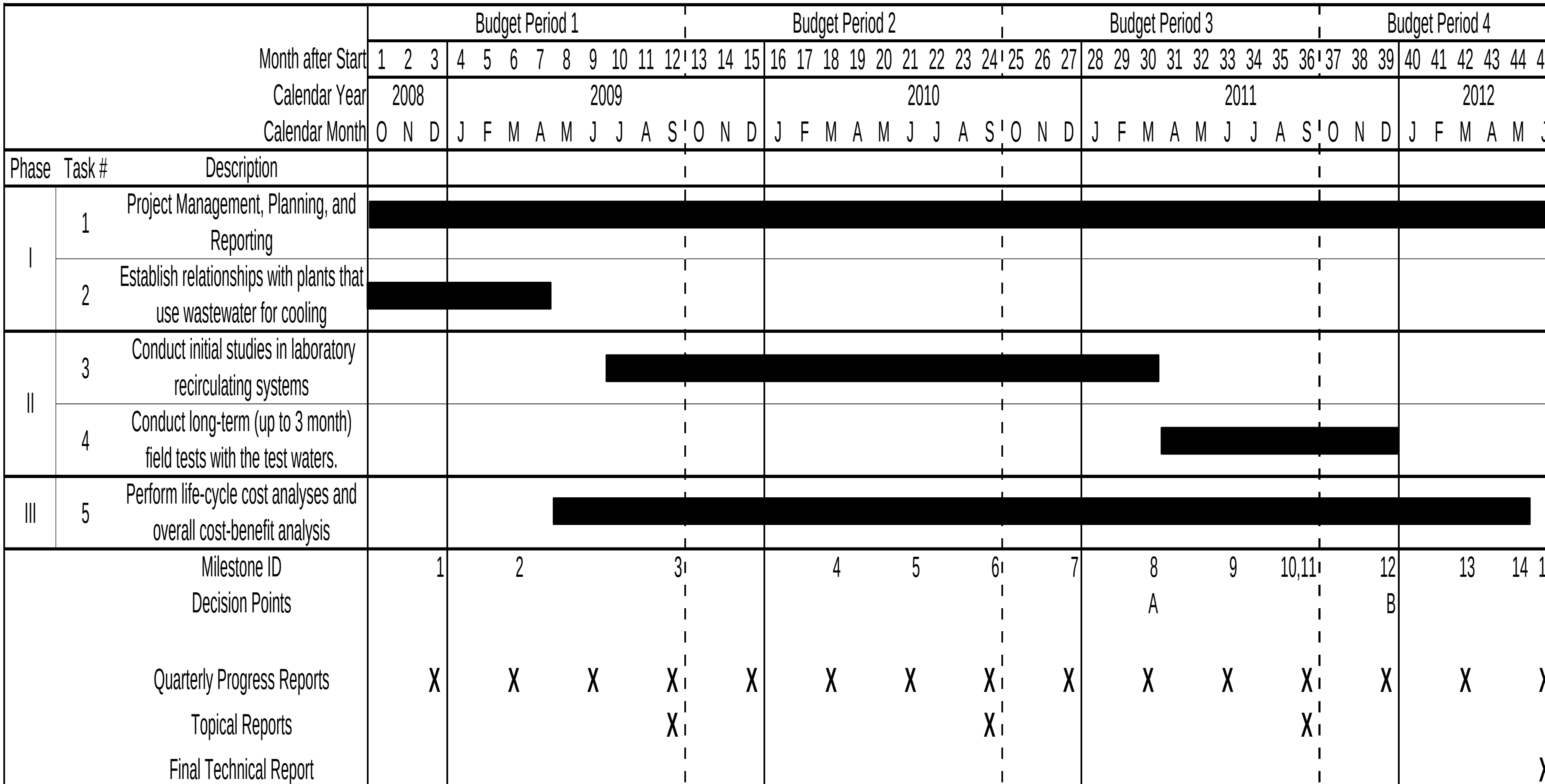
SPECIFIC OBJECTIVES

- Determine benefits and costs of different levels of additional treatment
- Determine different chemical treatment regimens required for waters with different levels of tertiary treatment
- Perform comparative life-cycle analyses
- Determine critical economic, technical and social factors

RESEARCH TASKS

- Task 1: Project management
- Task 2: Establish relationships with power plants that use treated ww as cooling makeup
- Task 3: Conduct initial lab studies
- Task 4: Conduct long-term field tests
- Task 5: Perform comparative life-cycle cost analyses and overall cost-benefit analysis

PROJECT SCHEDULE



SUMMARY

- Collaborative project: Carnegie Mellon and University of Pittsburgh
- Goal: evaluate benefits and costs of tertiary treatment for municipal wastewater prior to use in cooling systems vs. expanded cooling water chemical management
- Methods: Lab tests, field tests, economic analyses
- 45-month schedule