



Water Treatment for Power Plant Cooling Towers:

A supplement to the EPRI 2012 [RFI](#) for those unfamiliar with the power industry

This slide deck is meant to serve as a brief guide through the [resources](#) available for the EPRI 2012 “**Development of Innovative Water Treatment and Cooling Technologies for Power Plant Water Consumption Reduction**” Request for Information ([RFI](#))
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Motivation for Advanced Water Treatment Technology

Limited Freshwater Resources

To meet current and future constraints on new plant siting and long term operations, it is necessary to develop advanced technologies to bolster our ability to expand the electric industry's water resources. Due to ever-increasing competing demands, it is critical to prioritize our water resources, delegating different grades of water to appropriate usages. Current alternative sources of degraded water for use in power plant cooling are limited and must be expanded to keep up with energy generation needs.

Most Rewarding Areas for Energy Efficient Water Treatment Technology Development:

Water Loss Reduction Technology and Water Resource Expansion

1) Minimize water loss and waste in power plant cooling operations

■ Process cooling applications:

- Moisture recovery from cooling tower (more than 20%) or boiler flue gas
- Post treatment of blowdown water from evaporative cooling tower operations to enable reuse on site, preferably for cooling system make-up water.
- Pre-treatment and side stream treatment in order to increase the cycles of concentration in the cooling system.
- Technologies which leverage existing processes and infrastructure – such as waste heat.

2) Expand current sources of water used for power plant cooling

Degraded and nontraditional water sources:

- Technologies which enable cost effective utilization of municipal wastewater effluent and brackish water.

Overview

1. [Overview of Power Plant Cooling Tower Operations¹](#)
2. [Water Tower Chemistry Criteria¹](#)
3. [Sources of Degraded Water¹](#)
4. [Source Water Evaluation: Operational Concerns and Environmental Constituents of Interest^{1,2}](#)
5. [Power Plant Cooling Water Treatment Technologies^{1,3,4}](#)



1. Overview of Power Plant Cooling Tower Operations

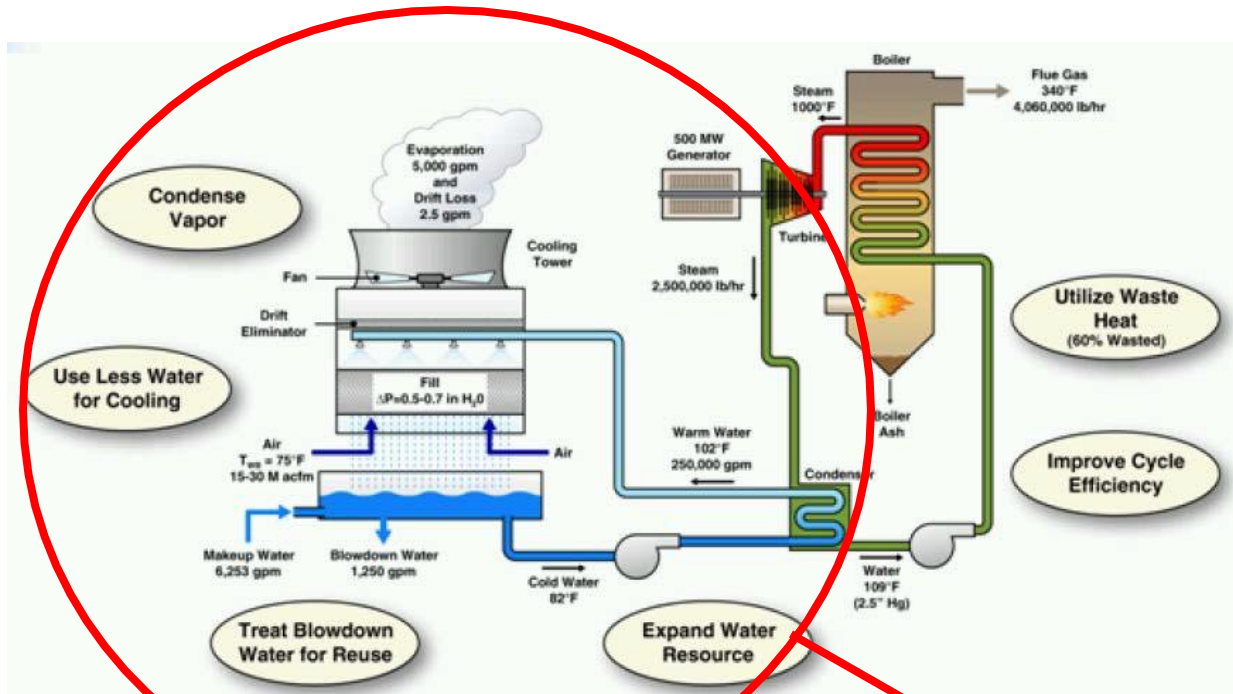
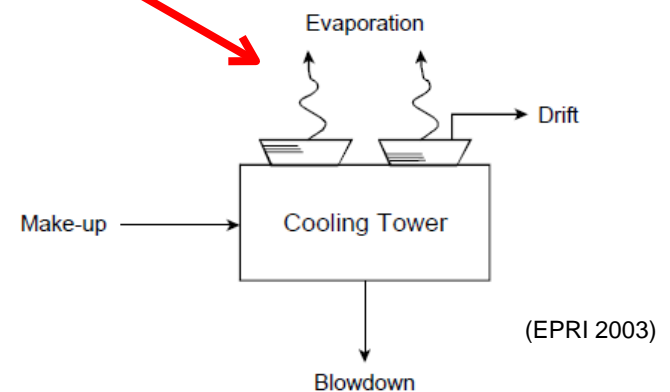


Diagram of an Open, Re-Circulating Cooling Tower

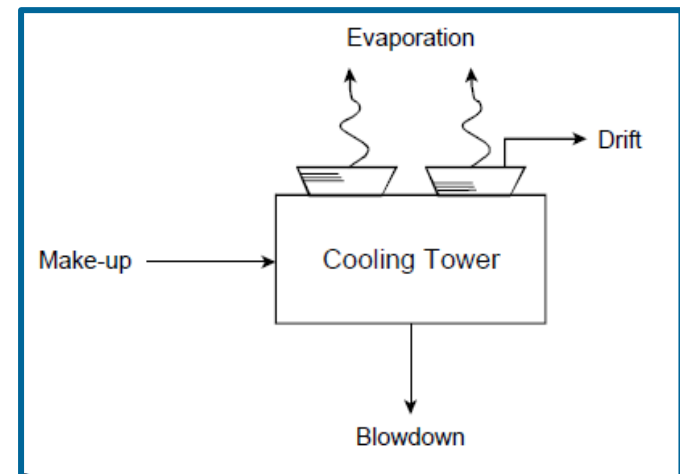


Open Re-circulating Cooling Towers Operation

- 1) After accepting heat from turbine steam, the heated cooling water is showered down the cooling tower for heat rejection.
- 2) Heat from the steam is rejected mainly from evaporation as air is forced past falling droplets and films of circulating cooling water
- 3) Water leaves the tower through evaporation and drift (small water droplets), increasing the concentration of minerals and contaminants in the cooling water
- 4) To decrease concentration, a portion of cooling water is removed as blowdown
- 5) Make-up water is added to the cooling stream to compensate for water lost to blowdown, evaporation, and drift
- 6) Cooling is re-circulated through the condenser

SimpleWaterBalance

$$\text{Make-Up} = \text{Evaporation} + \text{Blowdown} + \text{Drift}$$



(EPRI 2003)

Water Treatment: General Background on Water Treatment Applications for Cooling Effluents and Inputs

Effluent Pathways	Potential Treatment Targets
Drift	Can contain heavy metals and organic compounds, and biological pathogens (ex. Legionella)
Evaporation	Can contain gaseous contaminants
Blowdown	Can contain heavy metals and organic compounds
Waste streams from treatment processes associated with the cooling circuit	Can contain heavy metals and organic compounds
Sludge generated from cooling system maintenance	Contains inorganic, organic and biological sediments generated by day to day operations. The waste must be analyzed for toxicity and hazards and disposed of appropriately.

Degraded water (potential input for cooling water): “Non-potable- groundwater or surface water impacted by naturally occurring minerals or human impacts and wastewater generated by human, industrial or agricultural activities” (EPRI 2003)



2. Water Tower Chemistry Criteria

Water Quality Parameters for Cooling Towers

Table 2-1
Cooling Tower - Water Quality Parameters

Degraded Water TC				Current EPRI ⁽¹³⁾ Standards 1998	Refinery Cooling System ⁽¹³⁾ 1993 ⁽⁵⁾
Parameter	Units	Kunz ⁽¹³⁾ 1977	EPRI ⁽¹³⁾ 1982		
Ca	mg/l CaCO ₃	300	900 (max)	(Note 6)	1,500 (max)
Ca x SO ₄	(mg/l) ²	500,000	---	500,000 ⁽⁵⁾	(Note 10)
Mg x SiO ₂	mg/l CaCO ₃ x mg/l SiO ₂	---	35,000 ⁽²⁾ 75,000 ⁽³⁾	35,000 ⁽⁵⁾	---
M Alkalinity	mg/l CaCO ₃	---	30-50 ⁽²⁾ 200-250 ⁽³⁾	(Note 6)	---
SO ₄	mg/l	---	---	(Note 6)	5,000 (max)
SiO ₂	mg/l	150	150	150 ⁽⁵⁾	300 (max)
PO ₄	mg/l	---	<5 (Note 4)	(Note 6)	50 (max)
Fe (Total)	mg/l	0.5	---	<0.5 ⁽⁵⁾	10 (max)
Mn	mg/l	0.5	---	<0.5	1
Cu	mg/l	0.08	---	<0.1	0.5
Al	mg/l	1	---	<1	1
S	mg/l	5	---	5	10
NH ₃	mg/l	---	---	<2 ⁽¹²⁾	40 (max)
pH		8.0 (max)	6.8-7.2 ⁽²⁾ 7.8-8.4 ⁽³⁾	(Note 6)	7-9
TDS	mg/l	2,500	70,000	---	---
TSS	mg/l	100-150	---	<100 ⁽⁷⁾ - <300 ⁽⁸⁾	200
BOD	mg/l	---	---	---	200 (max)
COD	mg/l	---	---	---	200 (max)
Langlier SI ⁽¹¹⁾		+1.5 (max)	---	<0	---
Ryznar SI ⁽¹¹⁾		+7.5 (max)	---	>6	---
Puckorius SI ⁽¹¹⁾		---	---	>6	---

Notes.....

1. M Alkalinity = HCO₃ + CO₃, expressed as mg/l CaCO₃.
2. Without scale inhibitor.
3. With scale inhibitor.
4. No recommendation given because of insufficient data.
5. Conservative value - reference is made to EPRI's SEQUIL RS for predicting case-specific limits. SEQUIL RS takes into account parameters such as ionic associations, ionic strength (measure of background salt and ionic charge), pH and temperature to predict the solubility of certain salts.
6. No value given - reference is made to EPRI's SEQUIL RS for predicting case-specific limits.
7. <100 mg/l TSS with film fill.
8. <300 mg/l TSS with open fill.
9. Water quality parameters were prepared by Betz for refinery cooling towers accepting in-plant wastewater as a means of conserving water. Refineries typically experience more severe operating conditions than power plants, e.g. higher temperatures, organic contamination, heavy metals, etc.
10. No inference was made by the authors to the product of the Ca and SO₄ maximum operating values to be used to set a Ca x SO₄ limit (reference Kunz and EPRI values).
11. Refer to Appendix B for a discussion of the Langlier, Ryznar and Puckorius calcium carbonate saturation indices.
12. <2 mg/l NH₃ applies when copper bearing alloys are present in the cooling system. This does not apply to 70-30 or 90-10 copper nickel.
13. Refer to citations 4, 5, 6 and 7 found in Appendix A.

Cooling water quality can affect power plant performance. Therefore, the criteria for power plants cooling water are stricter than those for refineries, which do not have this concern. Water sources must be evaluated for their chemical constituents. Each constituent or constituent pair should be analyzed individually to determine the maximum allowable concentration.

The concentration limit is typically defined by the solubility thresholds of one or more constituents. The first three criteria are applicable to power plants. EPRI developed standards are circled.

(EPRI 2003)

Types of Constituents Effecting Cooling Tower Operations

1. General mineral constituents, found in all sources of water, which have direct effects on cooling tower operation and performance.
- Constituents that are regulated due to environmental concerns and also effect cooling tower operation
 - Regulated constituents that do not impact cooling water operation but are regulated for environmental issues
 - Biological Activity Promoters

Cycles of Concentration (N)

In order to evaluate source water feasibility and treatment strategy, each constituent or constituent pair of concern should be analyzed.

N can:

- 1) Provide insight on the limiting parameters
- Provide guidance on make-up and blowdown rates necessary to maintain acceptable concentration levels.

N: Insight on Limiting Parameters

Maximum Cycles of Concentration (N):

The comparison of the make-up water concentration of each constituent to the corresponding water quality limit will determine the limiting parameters (lowest maximum)

$$N = \frac{C_{Limit}}{C_{MU,i}} \quad (1)$$

Where:

N	Cycles of concentration
$C_{Limit,i}$	Water quality limit for constituent i
$C_{MU,i}$	Concentration of constituent i in the make-up water

For ion pair limits such as magnesium and silica, calculate the maximum cycles of concentration as follows:

$$N = \sqrt{\frac{C_{Limit,ij}}{C_{MU,i}C_{MU,j}}} \quad (2)$$

Where:

$C_{Limit,ij}$	Water quality limit for constituents i and j
$C_{MU,i}$	Concentration of constituent i in source water
$C_{MU,j}$	Concentration of constituent j in source water

(EPRI 2003)

N: Guidance on Blowdown Rates and Make-Up Water Rates

Cycles of Concentration of Each Constituent:

As a consequence of evaporative water loss, the concentration of constituents in the cooling water increases after cycling through the cooling tower. After circulation, constituent concentration in the cooling water becomes greater than the concentration in the original make up water. The cycles of concentration (N) of each constituent can be determined from a comparison of the circulating water concentration to the concentration of the makeup water. N can subsequently be used to determine blowdown and make-up rates.

$$MU = E + BD + D \quad (\text{flow balance}) \quad (3)$$

where: MU make-up rate, gpm
E Evaporation rate, gpm
BD Blowdown rate, gpm
D Drift rate, gpm

$$MU \times C_{MU,i} = E \times C_{E,i} + BD \times C_{BD,i} + D \times C_{D,i} \quad (\text{mass balance}) \quad (4)$$

where: $C_{BD,i}$ Concentration of chemical constituent "i" in the circulating water

$$C_{E,i} = 0 \quad (\text{evaporation only consists of water vapor}) \quad (5)$$

$$C_{D,i} = C_{BD,i} \quad (\text{drift is comprised of circulating water}) \quad (6)$$

Substituting (5) and (6) into (4) yields:

$$MU \times C_{MU,i} = C_{BD,i} \times (BD + D) \quad (7)$$

$$N_i = \frac{C_{BD,i}}{C_{MU,i}} \quad (8)$$

where: N_i Cycles of concentration of constituent "i"

Substituting (8) into (2) and (7) and solving for BD yields:

$$BD = \frac{E}{N - 1} - D \quad (9)$$

(EPRI 2003)

Other Water Quality Criteria

Langelier Saturation (LSI): Predicts scaling and corrosion tendencies in cooling water. It determines the pHs – CaCO_3 saturation pH, which is dependent on the calcium hardness, alkalinity, temperature and TDS of the cooling water. Positive values indicate a scaling tendency, due to CaCO_3 precipitation.

Ryznar Stability (RSI): Built upon LSI calculations to offer better predictability of scaling and corrosion. The ideal range of RSI is 6-7. Values higher than 7 indicate a corrosion tendency and values lower than 6 indicate a scaling tendency.

Puckorius Scaling Indices (PSI): Similar to the RSI system, but calculates the system pH instead of the actual pH. This modified system provides better predictive capabilities of scaling and corrosion tendencies of the cooling water by reflecting actual water alkalinity.

Make-up and Blowdown vs. Cycles of Concentration (N)

$$BD = \frac{E}{N-1} - D$$

Where:

BD = Blowdown rate, gpm

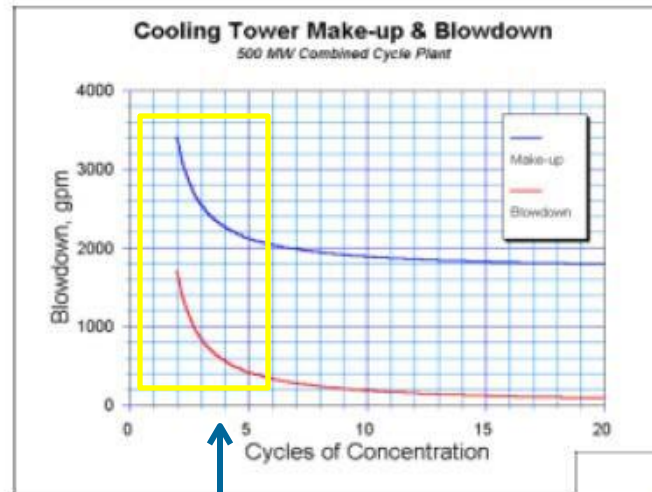
E = Evaporation rate, gpm

D = Drift rate, gpm

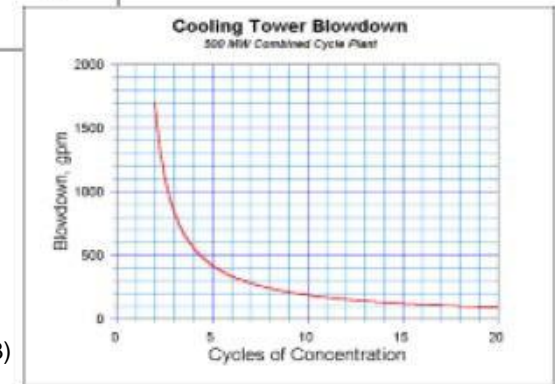
N = Cycles of Concentration

An inverse relationship exists between N and BD values. Lower values of N correspond with higher blowdown values and subsequently, higher make-up values as well.

For lower values of N, small decreases in N results in large increases in BD rates.



(EPRI 2003)





3. Sources of Degraded Water

Degraded Water Categories

Water Quality Requirements for Cooling Systems

Table 2-2
Degraded Water Categories

	General Minerals (Note 3)	Biological (Note 4)	Organic Compounds (Note 5)	Metals (Note 6)	Other (Note 7)
Fresh water ⁽⁸⁾	+		(Note 10)	(Note 10)	
Reclaimed water	+	+	(Note 10)	(Note 10)	+
Industrial process water ⁽⁹⁾	+	+	+	+	+
Degraded water					
↳ Agricultural return water ⁽¹⁾	+	+	+	+	+
↳ Dairy or feed-lot runoff	+	+	+		+
↳ Brackish water ⁽²⁾	+			+	+
↳ Contaminated groundwater	+		+	+	+

Notes.....

1. Selenium has been identified as a heavy-metal contaminant in some agricultural tailwaters.
2. Surface or groundwater with TDS >1,500 mg/l.
3. General Minerals Na, K, Ca, Mg, HCO₃, CO₃, Cl, SO₄ and SiO₂
4. Biological BOD, COD, NH₃, PO₄, etc. Typically found in reclaimed wastewater as well as pharmaceutical, biotech, livestock/dairy and food processing waste streams.
5. Organics Volatile, non-volatile or pesticide compounds.
6. Metals Ba, Sr, Fe, Mn, Cu, Zn, Se, As, Cr, Hg, etc.
7. Other NO₃, PO₄, ClO₄, S, F, etc.
8. Can be surface water or groundwater. Many supplies contain trace levels of organic compounds and metals.
9. Examples are produced water (oil production), micro-electronics wastewater, mine sluice water, electroplating rinse water, etc.
10. Trace concentrations of organics and metals (within regulatory limits) are found in many fresh water supplies.

(EPRI 2003)

This table contains key chemical constituents found in sources of degraded water. These are constituents found in typical situations, though the actual constituent make up may vary for each source of water.

Case Studies: Screening Results of Different Source Water, not including Regulated Constituents

Table 2-5
Source Water Screening

	Produced Water mg/l	Ag Return Water mg/l	Reclaimed Water mg/l	Fresh Water mg/l
Na (by difference)	982	2,182	76	41
K	22	6	5	0.72
Ca	40	554	76	18
Mg	13	270	43	0.76
HCO ₃	1,100	239	396	92
Cl	920	1,480	102	22
SO ₄	110	4,730	68	31
NO ₃	NR	48	NR	ND
Total PO ₄	NR	2	6	ND
S	6	NR	NR	ND
SiO ₂	120	37	17	16
B (5)	21	14	3	0.17
NH ₃	5	NR	5	ND
TDS	3,879	9,723	869	297
TSS	<1	11	8	<1
BOD	30	3	8	NA
COD	80	32	5	NA

Operating Cooling Tower Assumptions....

Cooling Tower Alkalinity, mg/l CaCO ₃	200	50	50	200
Calculated pH (SI)	7.9	7.0	7.0	7.9

Screening-Level Cycles of Concentration - N- without Pre-Treatment

(Refer to Tables 2-1a and 3b for control criteria and Table B-2 for calculation procedures)

Ca	9.0	<1	4.7	20.0
Ca x SO ₄ (7)	3.6	<1	4.2	16.4
Mg x SiO ₂	3.4	1.3	5.0	38.7
SiO ₂	1.3	4.1	8.8	9.4
Ca (in presence of PO ₄)	NA	<1	1.3	NA
TDS	18	7	80	235

Notes.....

1. Produced water from oil production in the Central Valley.
2. Agricultural return water from the San Luis Drain.
3. Secondary-treated reclaimed water from the Bay Area. t-PO 4, B, NH₃ and COD were estimated.
4. West Kern water. Silica concentration was modified for this analysis.
5. B exists as H₂BO₃ (non-dissociated boric acid) in water at this pH.
6. NR = not reported, ND = non-detectable and NA = not applicable.
7. H₂SO₄ used for pH control is accounted for when calculating the impact of additional SO₄ on CaSO₄ solubility.
8. Assume pH = 7.0 when PO₄ present.

(EPRI2003)

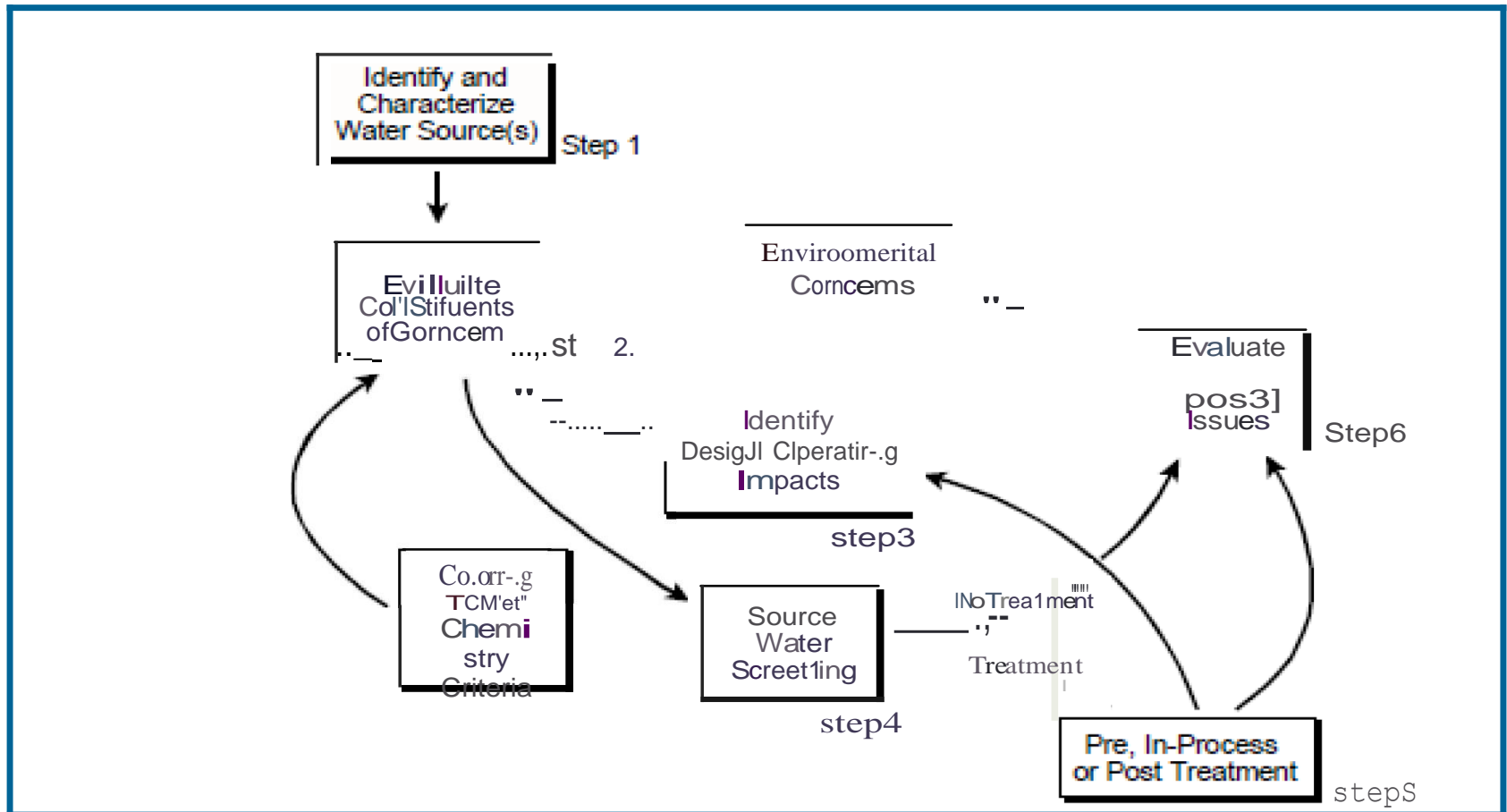


4. Source Water Evaluation: Operational Concerns and Environmental Constituents of Interest

Water Treatment Analysis and Methodology

STEPS	DESCRIPTION
Step 1: Identify and Characterize the Source Water(s)	Chemical analysis of constituents of concern should be conducted to determine the feasibility of using the water source(s) for cooling tower operations. Flow profiles are especially useful for water from multiple sources, which may require further analysis and calculations
Step 2: Evaluate Constituents of Concern	Each constituent must be evaluated to ensure compliance to operational quality criteria and environmental regulations. The maximum cycles of concentration (N) should be calculated for each constituent. The limiting parameter is the one with the lowest calculated N.
Step 3: Identify Cooling Tower Design and Operating Impacts	Based on the constituent make-up and evaluation of limiting parameters, the cooling tower design and operating impacts should be identified. Capital and operating costs will be affected by the design
Step 4: Determine the Need for Treatment	Treatment scenarios and alternate options will be determined based on calculated N values of constituents, source water, limiting parameters of, situational limitations, and regulation limitations of the constituents.
Step 5: Evaluate Treatment Requirements	Pre, side and post treatment plans will be developed based on previous calculations and evaluations of constituents present in the source water. Treatment technologies will be chosen and analyzed.
Step 6: Evaluate Disposal Issues	Cooling tower blowdown and treatment waste streams give rise to disposal issues, which must be evaluated. Wastes must be analyzed for toxicity and hazards and disposed of accordingly.

Source Water Evaluation Methodology



(EPRI2003)

Water Quality for Cooling Towers: Operational Issues

Areas of Water Quality Concern: Operating problems that may result from each area of concern are noted in the figure.

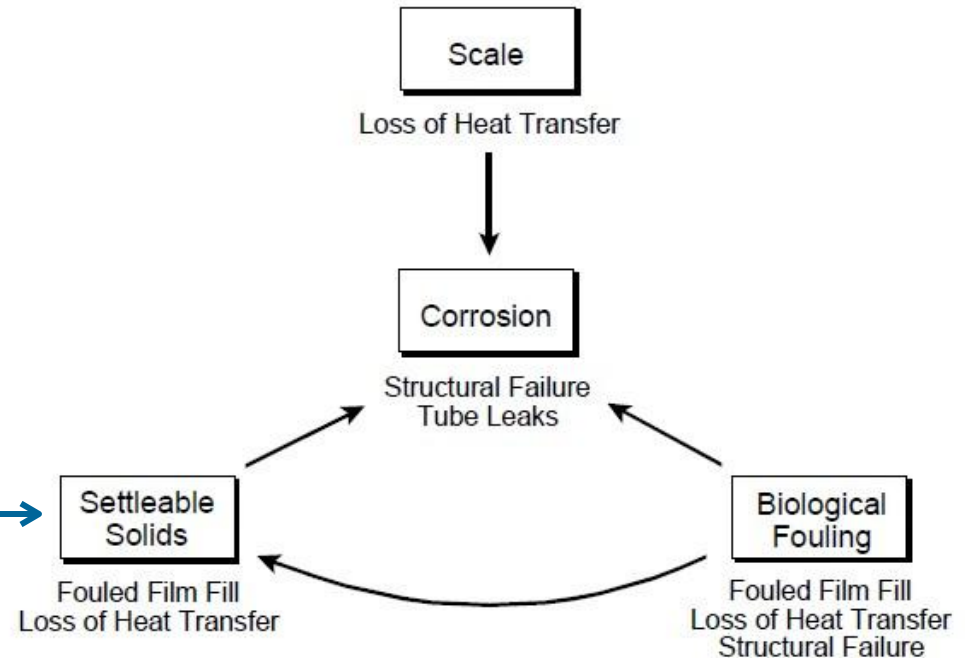


Figure 2-3
Cooling Tower Issues of Concern

(EPRI 2003)

Operation Objectives of Water Quality Criteria :

1. Minimize mineral Scaling and Biological fouling of heat transfer surfaces
2. Minimize corrosion of heat transfer and structural metal
3. Minimize fouling loads on cooling tower fill

Operational Concern Mitigation: Typical Treatment Requirements

Degraded Water Source	Typical Limitations	Treatment Options
Produced Water	CaSO ₄ , Mg/silica, silica	<ul style="list-style-type: none"> • High silica concentrations can be reduced with side stream lime/soda softening. • pH control: high alkalinity requires sulfuric acid additions • Due to high ammonia levels, non copper bearing alloys should be utilized.
Agricultural Return Water	Ca, Mg/silica, CaPO ₄ , CaSO ₄ ,	<ul style="list-style-type: none"> • High silica concentrations can be reduced with side stream lime/soda softening. • pH control: high alkalinity requires sulfuric acid additions • Ca. Mg. PO₄³⁻ concentrations also can be reduced with the above treatment
Reclaimed Water	Ca, CaSO ₄ , CaPO ₄	<ul style="list-style-type: none"> • Ca removal by make-up or side-stream softening • Due to high ammonia levels, non copper bearing alloys should be utilized. • To avoid formation of chloramine, bromine should be used instead of chlorine.

Environmental Issues: Constituents of Concern

Environmental constituents of concern may present environmental hazards and are subject to state or federal regulations but have no affect on cooling tower performance. These chemical constituents will need to be removed from feedwater prior to use in cooling tower.

Examples of constituents of environmental concern: Volatile organic solvents, pesticides, heavy metals

Water Policy Compliance

Regulations and guidelines on federal and state levels exist regarding water reuse and environmental release of chemical constituents. Many states have developed individual policies addressing cooling system water use in power plants.

Water Reuse Regulations and Guidelines by States

Table 3.5. Summary of water reuse regulations and guidelines by states*

State	Regulations	Guidelines	No regulation/Guideline	Unrestricted Urban Reuse	Restricted Urban Reuse	Agricultural Reuse Food Crops	Agricultural Reuse Non-Food Crops	Unrestricted Recreational Reuse	Restricted Recreational Reuse	Environmental Reuse	Industrial Reuse	Groundwater Recharge	Indirect Potable Reuse
Alabama		•			•		•						
Alaska	•						•						
Arizona	•					•	•		•				
Arkansas		•		•	•	•	•						
California (3)	•			•	•	•	•	•	•		•	•	•
Colorado	•			•	•	•	•	•	•				
Connecticut			•	•	•		•						
Delaware	•			•	•		•						
Florida	•			•	•	•	•			•	•	•	•
Georgia		•		•	•		•				•	•	•
Hawaii		•		•	•	•	•		•		•	•	•
Idaho	•			•	•	•	•						
Illinois	•			•	•		•						
Indiana	•			•	•	•	•						
Iowa	•			•	•		•						
Kansas		•		•	•	•	•						
Kentucky			•										
Louisiana			•										
Maine			•										
Maryland		•			•		•						
Massachusetts	•	•		•	•		•					•	•
Michigan	•		•			•	•						
Minnesota			•										
Mississippi			•										
Missouri	•				•		•						
Montana	•			•	•	•	•						
Nebraska	•			•	•		•		•				
Nevada	•			•	•	•	•	•	•				
New Hampshire			•										
New Jersey		•		•	•	•	•				•		
New Mexico		•		•	•	•	•						
New York		•		•	•		•						
North Carolina	•			•							•		
North Dakota		•		•	•		•						
Ohio		•		•	•		•						
Oklahoma	•				•	•	•						
Oregon	•			•	•	•	•	•	•		•		
Pennsylvania		•			•		•						
Rhode Island			•										
South Carolina	•			•	•		•						
South Dakota		•		•	•		•						
Tennessee	•			•	•		•						
Texas	•			•	•	•	•	•	•		•		
Utah				•	•	•	•	•	•		•		
Vermont	•						•						
Virginia			•										
Washington		•		•	•	•	•	•	•	•	•	•	•
West Virginia	•				•	•	•						
Wisconsin	•												
Wyoming	•			•	•	•	•						

*Adapted from "Guidelines of Water Reuse", USEPA, 2004.

**States reviewed in this study are those that are shaded in this table.

Please see
(NETL/DOE 2009) for
further details on state
regulations

(NETL/DOE 2009)

Regulations and Guidelines of Selected States

Table 3.6. Summary of regulations and guidelines reviewed in the twelve selected states.

	Water Reuse Regulations	Water Discharge Regulations	Air Emission
	'AAC, R18-9, Article 7	• AAC, R18-9 Article 9	
	• State Water Resources Control Board, Resolution No. 75-58	• State Water Resources Control Board, Resolution No. 75-58	* 22CCR60306
	• Warren-Alquist Act, Section 25602		• 17CCR93103
	• Water Code, Section 462		
	* 22CCR60306		
	* FAC 62-610-668	• FAC 62-302-520	* FAC 62-610 668
		• FAC 62-660.400	
	• Guidelines for the Treatment and Use of Recycled Water, III, C (Dep. of Health, 2002)		• Guidelines for the Treatment and Use of Recycled Water, III, C (Dep. of Health, 2002)
		• COMAR26 08.03.06	
New Jersey	• Reclaimed Water for Beneficial Reuse (Dep. of Env. Pro., 2005)		
	* 15A NCAC 02T.0906	• 15A NCAC 02B.0208	
	* 15A NCAC 02T.0910	• 15A NCAC 02B.0211	
		• Thermal (Temperature) Variances to North Carolina Water Quality Standards (USEPA, 2006)	
	'OAR 340-550.0012		* OAR 340-550-0012
	'TAC 30-210.32		* TAC 30-210.32
	* TAC 30-210.33	• TAC 30-307.8	* TAC 30-210.33
			• TAC 30-113.220
	• Water Reuse in Utah (Division of Water Resource, 2005)		* UAC R317-3-11
	'UAC R317-3-11		
	'RCW 90.46		• Water Reclamation of Reuse Standards (Dep. of Health & Dep. of Ecology, 1997)
	• Water Reclamation of Reuse Standards (Dep. of Health & Dep. of Ecology, 1997)		
Wyoming	• WORS Chapter 21	• WORS Chapter 2	

Notation: • Related to reuse of reclaimed water in power plant cooling water system.
 Related to power plant cooling water system.

(NETL/DOE 2009)

California Regulations on Power Plant Cooling Systems

Table 2.8
Power Plant Cooling Systems Requirements for Approval

California Code of Regulations, title 20, Division 2, Chapter 5 §2012, Article 8			
Subsection (of App. B)	Subject	Requirement	Relevant Code > Regulation
(a)(1)(A)	Executive Summary	General description of water supply, pollution control systems, etc.	None cited
(b)(1)(C)	Project Description	Design, construction, operation of cooling systems	None cited
(b)(1)(D)	Site/Facility Selection	How selection made and consideration given to env. impacts, water and—	None cited
(f)(1)&(2)	Alternatives	Discussion of other choices and economic/Environmental merits	Public Resources Code, Section 25640.6(b)/Policy 75-58
(g)(4)	Noise		None cited
(g)(6)(F)	Visual Resources	Assessment of impact of visible plumes	None cited
(g)(8)(A)	Air Quality	Info necessary for air pollution control district to complete Determination of Compliance	None cited
(g)(9)	Public Health		Health and Safety Code, Section 25264.8
(g)(10)	Hazardous Materials Handling		Cal Code, title 22, §66261.20 et seq. Also, Health and Safety Code, Section 25531.
(g)(12)	Waste Management		Cal Code, title 22, §66261.20 et seq.
(g)(13)	Biological Resources		Cal Code, title 20, Sects. 1702 (q) and (v)
(g)(14)	Water Resources		Waste Discharge Requirements; NPDES; Policy 75-58
(g)(15)	Agriculture and Soils	Effect of emissions on surrounding soil-vegetation	None cited

(EPRI2003)



5. Power Plant Cooling Water Treatment Technologies

Treatment Options and Objectives

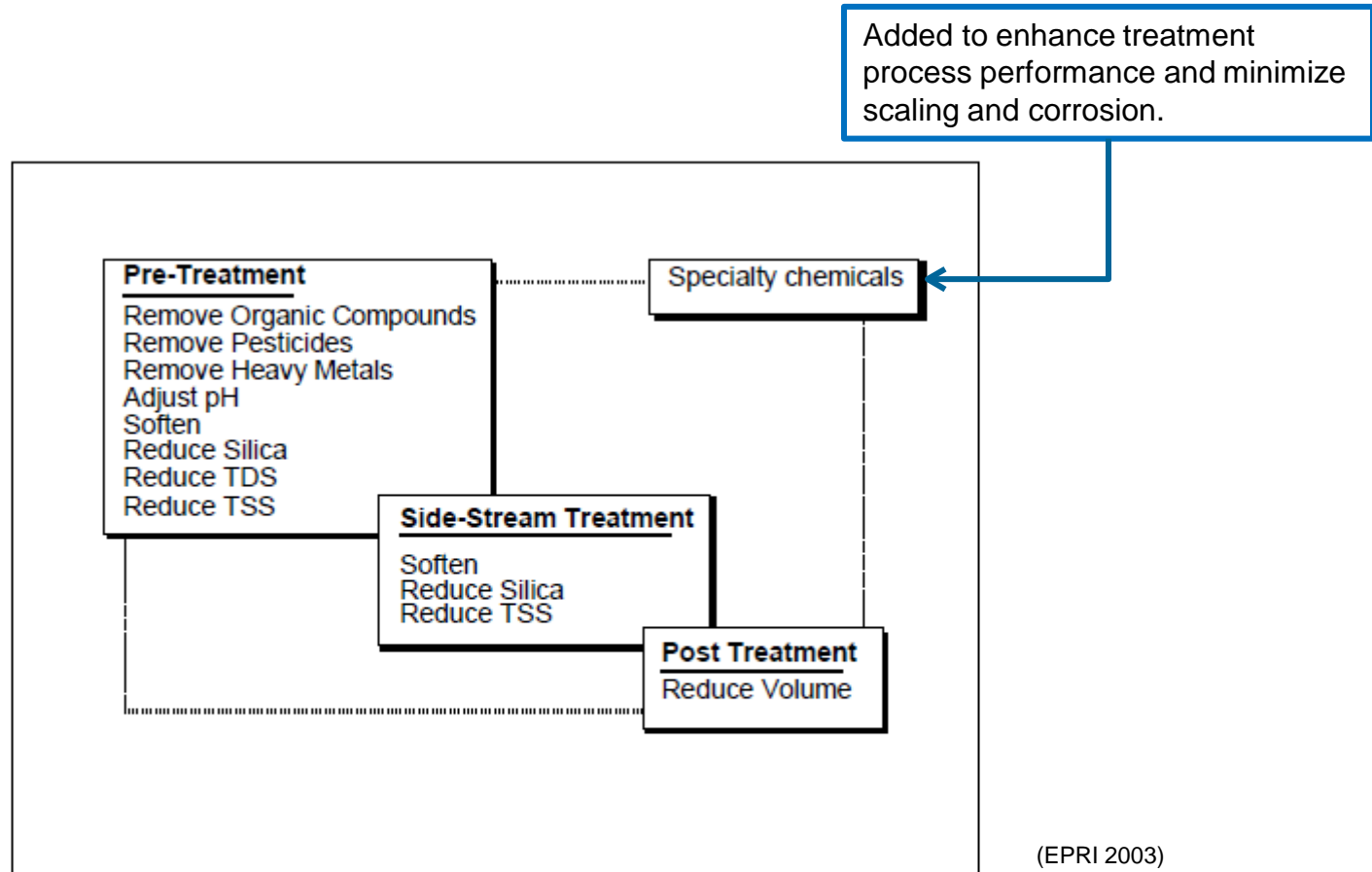


Figure 2-5
Cooling Water Treatment

Mainstream/Common Treatments and Technologies

Waste Reduction

Post-Treatment

Common Technologies

Evaporative Brine Concentrators

Evaporative Crystallizers

Reverse Osmosis

Evaporation Ponds

Spray Dryers

Environmental Concerns

Pre-Treatment

Common Technologies

Air Stripping followed with vapor phase granular activated carbon (GAC)

Air stripping followed with vapor phase thermal oxidation

Liquid phase GAC

Aerobic biological treatment

Anaerobic biological treatment

Strong base anion ion exchange

Chelating ion exchange

Precipitation

Operational Concerns

Pre-Treatment and Sidestream Treatment

Common Technologies

Make-Up Softening

Sidestream Filtration and softening

Please see Chapter 5 of (EPRI 2003) for process descriptions of technologies

Cooling Tower Performance and Operation Related Treatment Technologies

Technology	Targeted Constituents	Description of Technology
Pre-Treatment: Softening	Removes hardness: Ca^{2+} and Mg^{2+} carbonate alkalinity: CO_2 , HCO_3^{1+} , and CO_3^{2+} Incident removal of silica	lime or lime/soda softening is used to treat make-up water. $\text{Ca}(\text{OH})_2$ and Na_2CO_3 are fed into the softener which is mixed with the make-up water. Waste sludge is separated from treated water.
Side-Treatment: Softening and Filtration	Removes hardness: Ca^{2+} and Mg^{2+} carbonate alkalinity: CO_2 , HCO_3^{1+} , and CO_3^{2+} Incident removal of silica	<p>If make up softening does not offer adequate treatment, side stream treatment may be necessary.</p> <p>Filtration is used to limit suspended matter in the cooling water. Water is directed from the return line on the hot side of the cooling circuit, fed through filters.</p> <p>From the condenser, the hot cooling water is fed into a reactor clarifier, where softening by $\text{Ca}(\text{OH})_2$ and Na_2CO_3 occurs.</p> <p>Sludge is also generated as a waste product</p>

General Summary of Treatment of Constituents of Operational/Performance Concern

Table 2-6
Pre-, Side-Stream Treatment for Cooling Towers

Cooling Tower Chemical Criteria (Note 3)	<i>Pre-Treatment</i>		<i>Side-Stream Treatment</i>	
	pH Adjustment	Lime or Lime/Soda Softening	Filtration	Warm Lime or Lime/Soda Softening
Ca		Pri		Pri
Ca x SO ₄		Pri via Ca		Pri via Ca
Mg x SiO ₂		Pri via Mg		Pri
M Alkalinity	Pri	Sec		Sec
SO ₄		Pri via Ca		Pri via Ca
SiO ₂		(Note 5)		Pri
PO ₄		Sec		Sec
pH	Pri			
TSS		Sec	Pri	Sec

Notes.....

1. Pri = primary means of reduction - intention of process.
2. Sec = secondary means - incidental reduction in process.
3. Chemical criteria found in Table 2-1.
4. Refer to Table 2-6 for removal of contaminants from degraded water for cooling tower make-up.
5. There is some removal of SiO₂.

(EPRI 2003)

Waste Minimization: ZLD Systems

Zero Liquid Discharge (ZLD)

ZLD systems aim for complete recovery of cooling water, where no wastewater should leave the site and all waste should be converted to dry form for ultimate disposal. ZLD systems offer the potential for sustainable cooling and a viable waste treatment option for areas where evaporation ponds are infeasible or prohibited. Though ZLD is ideal, not all power plants can achieve these systems, but waste minimization technologies are nonetheless desirable.

These systems are currently limited by high costs, but can be alleviated by development of higher recovery technologies, such as advanced RO membranes.

Conventional ZLD systems commonly utilize evaporative technologies, which are highly energy intensive. Increased recovery with increased pre-treatments can reduce water volume and thereby, lower evaporative costs. However, higher solid waste disposal and chemical costs will increase may offset any cost benefits of reduced wastewater volume. With power plant water treatment systems, recovery benefits are often difficult to balance with costs.

Typical ZLD Schemes:

1. Pre-Treatment Steps: Wastewaters undergo pre-treatment processes (i.e. ion exchange) to concentrate constituents of concern into smaller volumes
- Desalinization Steps: Excess water must subsequently be recovered from water treatment waste

Please see Chapter 3 of (WaterReUse 2008) for further details on ZLD systems

Current Common Technologies Used in US Non-Municipal ZLD Systems

Water Recovery Technology	Description
Evaporative Brine Concentrators	A energy intensive process utilized to concentrate waste water to minimize volume. Evaporator concentrate (also known as brine) undergoes further drying in evaporation ponds to produce dry waste. Distillate collected from the evaporation process can be recycled into the cooling system.
Evaporative Crystallizers	Instead of disposal in brine ponds after evaporative treatment, the condensate is sent through a crystallizer. The crystallizer dries excess water to form dry salt cake. This process is useful for situations in which evaporative ponds are not a feasible option.
Reverse Osmosis	High Pressure pumps force water through membranes without allowing dissolved salts through. Pre-treatment steps are required to optimize membrane performance. Softening steps to remove minerals (silica, calcium, magnesium) are removed via a softening step, and filtration steps to remove particulate matter are commonly conducted prior to the RO filtration.
Evaporation Ponds	Wastewater in warmer climates can be sent to evaporation ponds on-site, where the water can slowly evaporate from the waste.
Spray Dryers	Used to treat smaller volumes of water.

Environmental Constituents of Concern Related Treatment Technologies

Chemical constituents that are regulated under state and federal law should be removed prior to cooling tower circulation

Technology	Targeted Constituents for removal	Description of Technology
Air Stripping followed with vapor phase granular activated carbon (GAC)	Volatile organic compounds, THM, and some pesticides	When volatile organic concentrations are high, air stripping is more economical than liquid phase carbon removal. Counter-flowing airstream is flowed through droplets of water which allows for volatile compounds to evaporate and be removed from the cooling water. The exhaust air is fed through porous carbon media, trapping organic compounds. Spent media must be regenerated on site with steam, or disposed of.
Air stripping followed with vapor phase thermal oxidation	Volatile organic compounds, THS, and some pesticides	Using controlled combustion, air stripped organic compounds are converted into combustion byproducts through thermal oxidation. Oxidation of certain compounds may require a scrubber (ex. Chlorinated organic compounds). Spent media must be regenerated on site with steam, or disposed of.
Liquid phase GAC	Volatile and non-volatile organic compounds and pesticides, incidental removal of some BOD and COD	Liquid phase GAC is used to treat water with non-volatile organic compounds or low concentrations of volatile organic compounds. Water is directed through media intended to filter and remove particulates or organic constituents. Spent media must be regenerated, and the waste disposed of, or completely disposed of without regeneration

Continued

Technology	Targeted Constituents for removal	Description of Technology
Aerobic biological treatment	Organic compounds, ammonia, and incidental removal of BOD and COD	Converts targeted constituents into carbon dioxide and water, or ammonia into NO_3^{-1} . Organic constituents are metabolized by aerobic bacteria. Waste products in the form of sludge is produced.
Anaerobic biological treatment	Organic compounds, ASO_4^{-3} , CrO_4^{-2} , SeO_4^{-2} , SeO_3^{-2} , and ClO_4^{-1} , and incidental removal of BOD, COD, and possibly NO_3^{-1}	Anaerobic bacteria may metabolize chemically bound oxygen from chemical constituents. Compounds are reduced to elemental forms and leaves as waste sludge.
Ion Exchange		Water is passed through cation exchange resins, which contain functional groups targeted at certain constituents of concern. By exchanging hazardous ions with non-hazardous replacements, ion exchange treatment removes them from the cooling water. Ion exchange media will need to be regenerated periodically. Post treatment of concentrated constituent fluid will be required.
• Strong base anion ion exchange	ASO_4^{-3} , CrO_4^{-2} , SeO_4^{-2} , SeO_3^{-2} , and ClO_4^{-1} and incidental removal of PO_4^{-3} , NO_3^{-1} , and F^{-1}	In ion exchange, an ionic bond is formed between the media and the targeted constituents.
• Chelating ion exchange	High affinity for transition metals (Cu, Ni, Cd, Cr^{+3} , etc)	Chelating resin beads are used to creates covalent bonds with divalent ions.

General Summary: Treatment Options for Constituents of Environmental Concern

Table 2-7

Pre-Treatment of Contaminated Water for Cooling Water Make-Up

Chemical Parameter	Stripping Vapor-Phase GAC	Stripping Vapor-Phase Thermal	Liquid Phase GAC	Biological Treatment	Strong Base IX	Chelating IX	Recipitation Co-P
Organic Compounds	Pri - Volatile	Pri - Volatile	Pri	Ali	Sec		
Pesticides			Pri	(!)	Sec		
Cationic Heavy Metals						Ari	Pri
Anionic Heavy Metals				Pri [P - NO ₃], Ali	Pri		Pri (11)
Biological			See m	Ali	Pri		

Notes:

1. Pri = primary means of reduction - initial step of process
2. Sec = secondary means - secondary reduction process
3. GAC is granular activated carbon.
4. There are a variety of biological processes, e.g. constructed wetlands, moving bed biofilter, fixed film aerobics, etc.
5. Refer to Table 2-2 for chemical treatment of contaminated groundwater and surface water treatment.
6. Biological waste components include BOD, COD, NH₃, PO₄, etc. They are found in reclaimed water as well as pharmaceutical, bio and livestock and food processing wastewaters.
7. There will be some reduction of BOD and COD.
8. Pesticides can be detrimental to biological processes because of their toxicity.
9. Anaerobic biological treatment is required for NO₃ and NO₂ - Anaerobic treatment is necessary for NO₃.
10. Depending on treatment conditions NO₃ removal may not be completely achievable.
11. Applies to ASO₄ and SeO₄.
12. Cationic heavy metals include Cu, Ni, Co, Cr (+3), etc.
13. Anionic heavy metals include As, Se, CrO₄, SeO₄, etc.
14. Anaerobic biological treatment is sometimes used for anionic heavy metals.

References

1. *Use of Degraded Water Sources as Cooling Water in Power Plants*, EPRI, Palo Alto, CA and California Energy Commission, Sacramento, CA: 2003, 1005359.
2. *Reuse of Treated Internal and External Wastewaters in the Cooling Systems of Coal-Based Thermoelectric Power Plants*, DOE/NETL: September 2009, DE-FC26-06NT42722.
3. *Survey of High Recovery and Zero Liquid Discharge Technologies for Water Utilities*, WaterReuse Foundation: 2008, 02-006a-01.
4. *Water Use for Electric Power Generation*, EPRI, Palo Alto, CA : 2008, 1014026.

Motivation for Advanced Water Treatment Technology

Limited Freshwater Resources

To meet current and future constraints on new plant siting and long term operations, it is necessary to develop advanced technologies to bolster our ability to expand the electric industry's water resources. Due to ever-increasing competing demands, it is critical to prioritize our water resources, delegating different grades of water to appropriate usages. Current alternative sources of degraded water for use in power plant cooling are limited and must be expanded to keep up with energy generation needs.

Most Rewarding Areas for Energy Efficient Water Treatment Technology Development:

Water Loss Reduction Technology and Water Resource Expansion

1) Minimize water loss and waste in power plant cooling operations

Process cooling applications:

- Moisture recovery from cooling tower (more than 20%) or boiler flue gas
- Post treatment of blowdown water from evaporative cooling tower operations to enable reuse on site, preferably for cooling system make-up water.
- Pre-treatment and side stream treatment in order to increase the cycles of concentration in the cooling system.
- Technologies which leverage existing processes and infrastructure – such as waste heat.

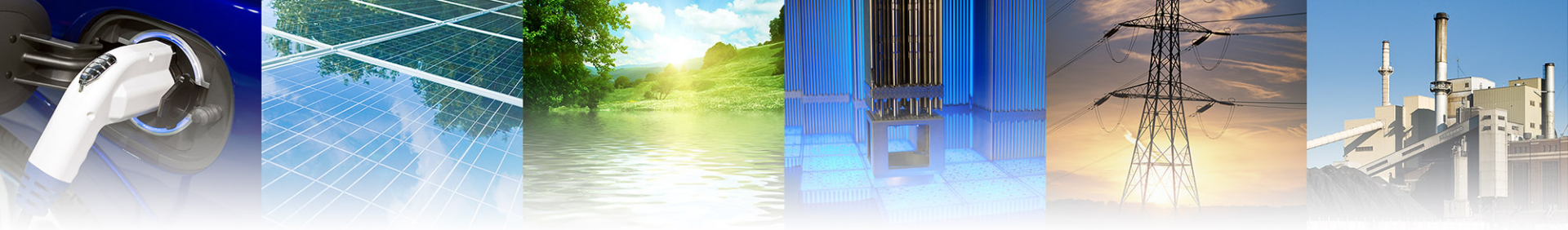
2) Expand current sources of water used for power plant cooling

Degraded and nontraditional water sources:

- Technologies which enable cost effective utilization of municipal wastewater effluent and brackish water.

Overview

1. [Overview of Power Plant Cooling Tower Operations¹](#)
2. [Water Tower Chemistry Criteria¹](#)
3. [Sources of Degraded Water¹](#)
4. [Source Water Evaluation: Operational Concerns and Environmental Constituents of Interest^{1,2}](#)
5. [Power Plant Cooling Water Treatment Technologies^{1,3,4}](#)



1. Overview of Power Plant Cooling Tower Operations

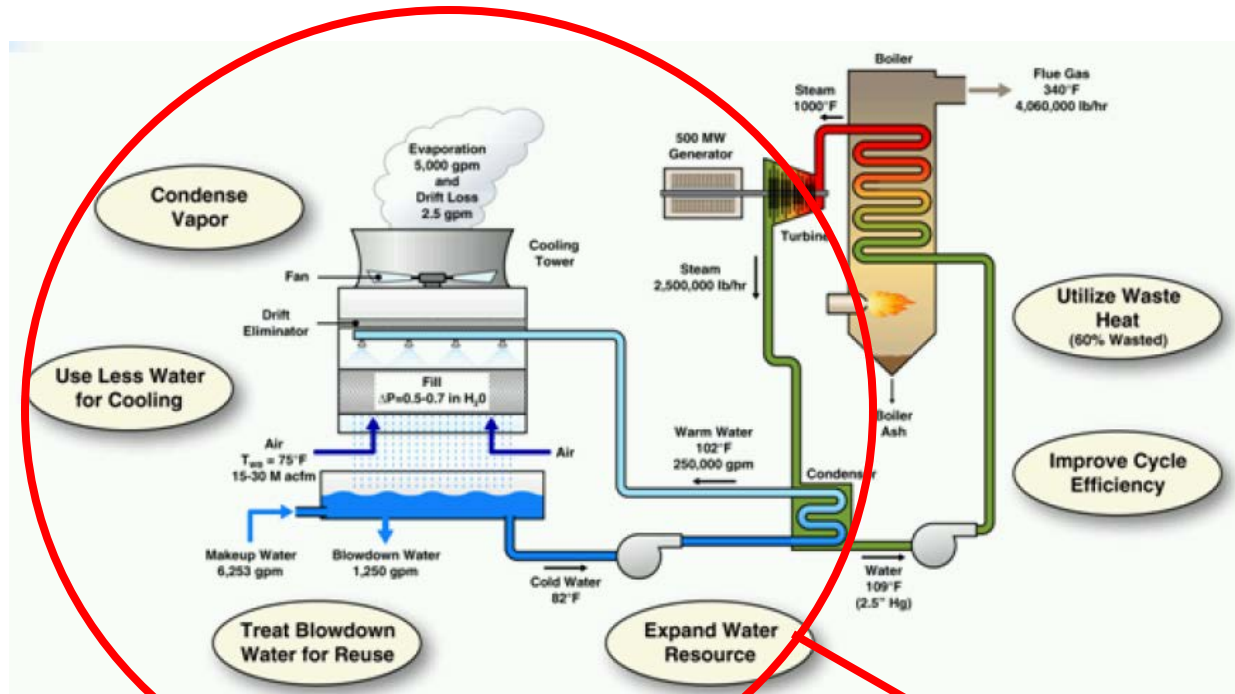
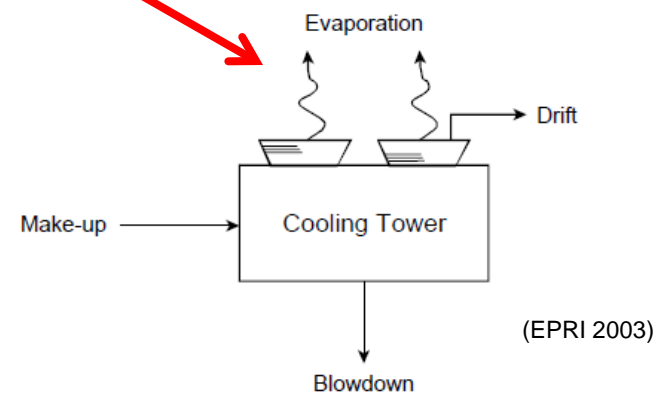


Diagram of an Open, Re-Circulating Cooling Tower

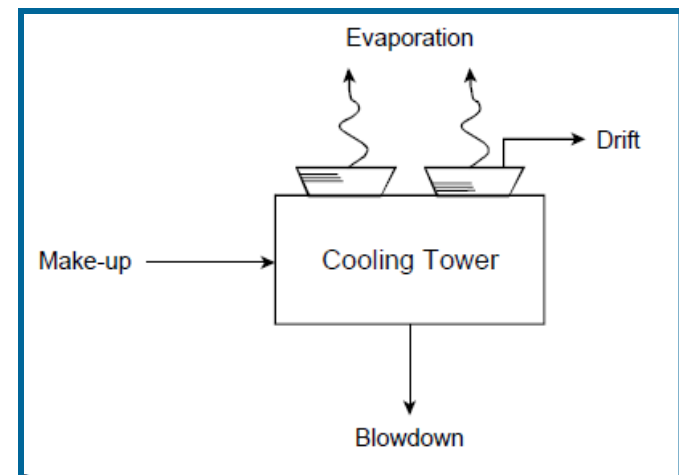


Open Re-circulating Cooling Towers Operation

- 1) After accepting heat from turbine steam, the heated cooling water is showered down the cooling tower for heat rejection.
- 2) Heat from the steam is rejected mainly from evaporation as air is forced past falling droplets and films of circulating cooling water
- 3) Water leaves the tower through evaporation and drift (small water droplets), increasing the concentration of minerals and contaminants in the cooling water
- 4) To decrease concentration, a portion of cooling water is removed as blowdown
- 5) Make-up water is added to the cooling stream to compensate for water lost to blowdown, evaporation, and drift
- 6) Cooling is re-circulated through the condenser

Simple Water Balance

$$\text{Make-Up} = \text{Evaporation} + \text{Blowdown} + \text{Drift}$$

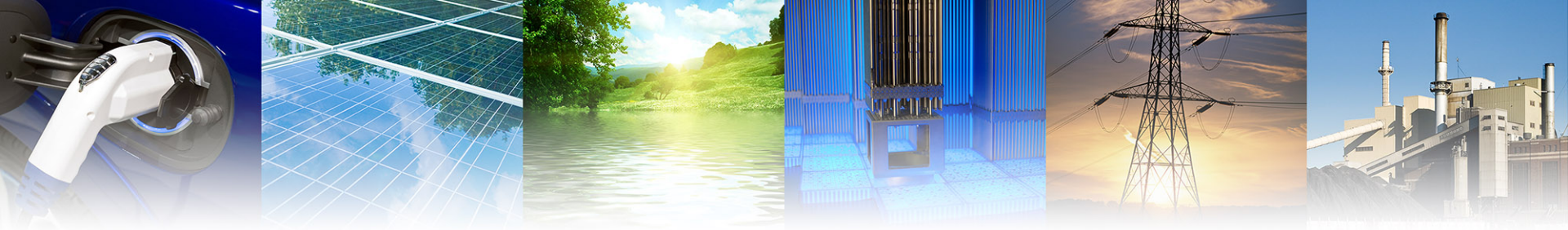


(EPRI 2003)

Water Treatment: General Background on Water Treatment Applications for Cooling Effluents and Inputs

Effluent Pathways	Potential Treatment Targets
Drift	Can contain heavy metals and organic compounds, and biological pathogens (ex. Legionella)
Evaporation	Can contain gaseous contaminants
Blowdown	Can contain heavy metals and organic compounds
Waste streams from treatment processes associated with the cooling circuit	Can contain heavy metals and organic compounds
Sludge generated from cooling system maintenance	Contains inorganic, organic and biological sediments generated by day to day operations. The waste must be analyzed for toxicity and hazards and disposed of appropriately.

Degraded water (potential input for cooling water): “Non-potable- groundwater or surface water impacted by naturally occurring minerals or human impacts and wastewater generated by human, industrial or agricultural activities” (EPRI 2003)



2. Water Tower Chemistry Criteria

Water Quality Parameters for Cooling Towers

Table 2-1
Cooling Tower - Water Quality Parameters

Degraded Water TC			Current EPRI (13) Standards 1998		Refinery Cooling System (13) 1993 (9)
Parameter	Units	Kunz (13) 1977	EPRI (13) 1982		
Ca	mg/l CaCO ₃	300	900 (max)	(Note 6)	1,500 (max)
Ca x SO ₄	(mg/l) ²	500,000	---	500,000 (5)	(Note 10)
Mg x SiO ₂	mg/l CaCO ₃ x mg/l SiO ₂	---	35,000 (2) 75,000 (3)	35,000 (5)	---
M Alkalinity	mg/l CaCO ₃	---	30-50 (2) 200-250 (3)	(Note 6)	---
SO ₄	mg/l	---	---	(Note 6)	5,000 (max)
SiO ₂	mg/l	150	150	150 (5)	300 (max)
PO ₄	mg/l	---	<5 (Note 4)	(Note 6)	50 (max)
Fe (Total)	mg/l	0.5	---	<0.5 (5)	10 (max)
Mn	mg/l	0.5	---	<0.5	1
Cu	mg/l	0.08	---	<0.1	0.5
Al	mg/l	1	---	<1	1
S	mg/l	5	---	5	10
NH ₃	mg/l	---	---	<2 (12)	40 (max)
pH		8.0 (max)	6.8-7.2 (2) 7.8-8.4 (3)	(Note 6)	7-9
TDS	mg/l	2,500	70,000	---	---
TSS	mg/l	100-150	---	<100 (7) - <300 (8)	200
BOD	mg/l	---	---	---	200 (max)
COD	mg/l	---	---	---	200 (max)
Langlier SI (11)		+1.5 (max)	---	<0	---
Ryznar SI (11)		+7.5 (max)	---	>6	---
Puckorius SI (11)		---	---	>6	---

Notes.....

1. M Alkalinity = HCO₃ + CO₃, expressed as mg/l CaCO₃.
2. Without scale inhibitor.
3. With scale inhibitor.
4. No recommendation given because of insufficient data.
5. Conservative value - reference is made to EPRI's SEQUIL RS for predicting case-specific limits. SEQUIL RS takes into account parameters such as ionic associations, ionic strength (measure of background salt and ionic charge), pH and temperature to predict the solubility of certain salts.
6. No value given - reference is made to EPRI's SEQUIL RS for predicting case-specific limits.
7. <100 mg/l TSS with film fill.
8. <300 mg/l TSS with open fill.
9. Water quality parameters were prepared by Betz for refinery cooling towers accepting in-plant wastewater as a means of conserving water. Refineries typically experience more severe operating conditions than power plants, e.g. higher temperatures, organic contamination, heavy metals, etc.
10. No inference was made by the authors to the product of the Ca and SO₄ maximum operating values to be used to set a Ca x SO₄ limit (reference Kunz and EPRI values).
11. Refer to Appendix B for a discussion of the Langlier, Ryznar and Puckorius calcium carbonate saturation indices.
12. <2 mg/l NH₃ applies when copper bearing alloys are present in the cooling system. This does not apply to 70-30 or 90-10 copper nickel.
13. Refer to citations 4, 5, 6 and 7 found in Appendix A.

Cooling water quality can affect power plant performance. Therefore, the criteria for power plants cooling water are stricter than those for refineries, which do not have this concern. Water sources must be evaluated for their chemical constituents. Each constituent or constituent pair should be analyzed individually to determine the maximum allowable concentration.

The concentration limit is typically defined by the solubility thresholds of one or more constituents. The first three criteria are applicable to power plants. EPRI developed standards are circled.

(EPRI 2003)

Types of Constituents Effecting Cooling Tower Operations

1. General mineral constituents, found in all sources of water, which have direct effects on cooling tower operation and performance.
2. Constituents that are regulated due to environmental concerns and also effect cooling tower operation
3. Regulated constituents that do not impact cooling water operation but are regulated for environmental issues
4. Biological Activity Promoters

Cycles of Concentration (N)

In order to evaluate source water feasibility and treatment strategy, each constituent or constituent pair of concern should be analyzed.

N can:

- 1) Provide insight on the limiting parameters
- 2) Provide guidance on make-up and blowdown rates necessary to maintain acceptable concentration levels.

N: Insight on Limiting Parameters

Maximum Cycles of Concentration (N):

The comparison of the make-up water concentration of each constituent to the corresponding water quality limit will determine the limiting parameters (lowest maximum)

$$N = \frac{C_{Limit}}{C_{MU,i}} \quad (1)$$

Where:

N	Cycles of concentration
$C_{Limit,i}$	Water quality limit for constituent i
$C_{MU,i}$	Concentration of constituent i in the make-up water

For ion pair limits such as magnesium and silica, calculate the maximum cycles of concentration as follows:

$$N = \sqrt{\frac{C_{Limit,ij}}{C_{MU,i}C_{MU,j}}} \quad (2)$$

Where:

$C_{Limit,ij}$	Water quality limit for constituents i and j
$C_{MU,i}$	Concentration of constituent i in source water
$C_{MU,j}$	Concentration of constituent j in source water

(EPRI 2003)

N: Guidance on Blowdown Rates and Make-Up Water Rates

Cycles of Concentration of Each Constituent:

As a consequence of evaporative water loss, the concentration of constituents in the cooling water increases after cycling through the cooling tower. After circulation, constituent concentration in the cooling water becomes greater than the concentration in the original make up water. The cycles of concentration (N) of each constituent can be determined from a comparison of the circulating water concentration to the concentration of the makeup water. N can subsequently be used to determine blowdown and make-up rates.

$$MU = E + BD + D \quad (\text{flow balance}) \quad (3)$$

where: MU make-up rate, gpm
E Evaporation rate, gpm
BD Blowdown rate, gpm
D Drift rate, gpm

$$MU \times C_{MU,i} = E \times C_{E,i} + BD \times C_{BD,i} + D \times C_{D,i} \quad (\text{mass balance}) \quad (4)$$

where: $C_{BD,i}$ Concentration of chemical constituent "i" in the circulating water

$$C_{E,i} = 0 \quad (\text{evaporation only consists of water vapor}) \quad (5)$$

$$C_{D,i} = C_{BD,i} \quad (\text{drift is comprised of circulating water}) \quad (6)$$

Substituting (5) and (6) into (4) yields:

$$MU \times C_{MU,i} = C_{BD,i} \times (BD + D) \quad (7)$$

$$N_i = \frac{C_{BD,i}}{C_{MU,i}} \quad (8)$$

where: N_i Cycles of concentration of constituent "i"

Substituting (8) into (2) and (7) and solving for BD yields:

$$BD = \frac{E}{N - 1} - D \quad (9)$$

(EPRI 2003)

Other Water Quality Criteria

Langelier Saturation (LSI): Predicts scaling and corrosion tendencies in cooling water. It determines the pHs – CaCO_3 saturation pH, which is dependent on the calcium hardness, alkalinity, temperature and TDS of the cooling water. Positive values indicate a scaling tendency, due to CaCO_3 precipitation.

Ryznar Stability (RSI): Built upon LSI calculations to offer better predictability of scaling and corrosion. The ideal range of RSI is 6-7. Values higher than 7 indicate a corrosion tendency and values lower than 6 indicate a scaling tendency.

Puckorius Scaling Indices (PSI): Similar to the RSI system, but calculates the system pH instead of the actual pH. This modified system provides better predictive capabilities of scaling and corrosion tendencies of the cooling water by reflecting actual water alkalinity.

Make-up and Blowdown vs. Cycles of Concentration (N)

$$BD = \frac{E}{N-1} - D$$

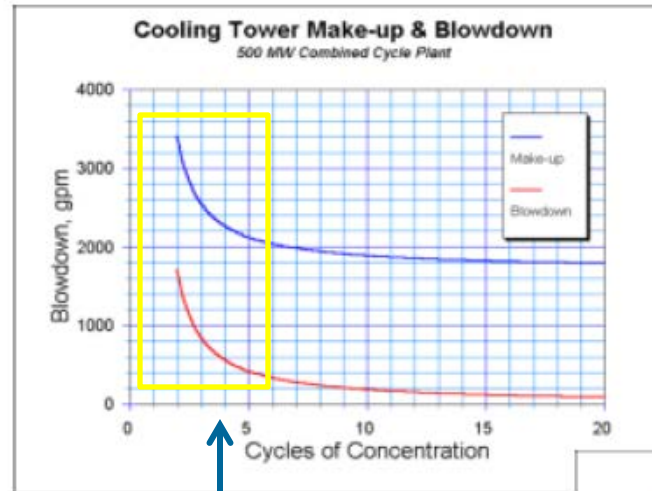
Where:

BD = Blowdown rate, gpm

E = Evaporation rate, gpm

D = Drift rate, gpm

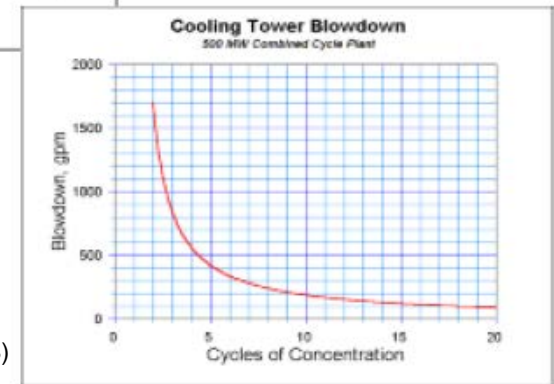
N = Cycles of Concentration

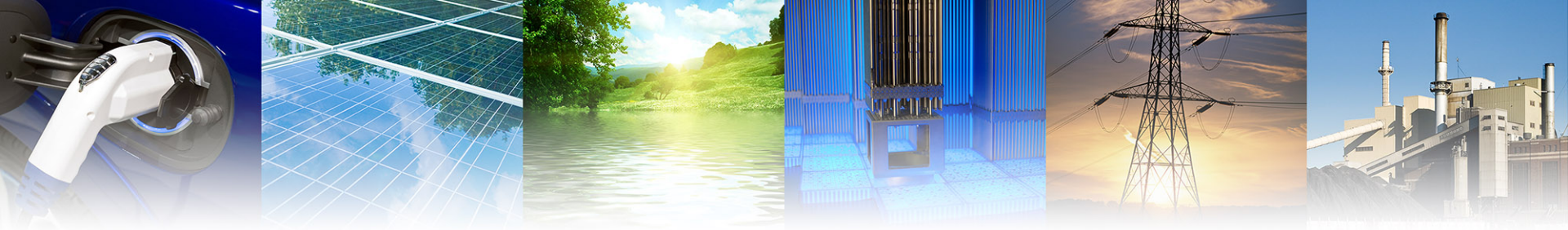


An inverse relationship exists between N and BD values. Lower values of N correspond with higher blowdown values and subsequently, higher make-up values as well.

For lower values of N, small decreases in N results in large increases in BD rates.

(EPRI 2003)





3. Sources of Degraded Water

Degraded Water Categories

Water Quality Requirements for Cooling Systems

Table 2-2
Degraded Water Categories

	General Minerals (Note 3)	Biological (Note 4)	Organic Compounds (Note 5)	Metals (Note 6)	Other (Note 7)
Fresh water ⁽⁸⁾	⊕		(Note 10)	(Note 10)	
Reclaimed water	⊕	⊕	(Note 10)	(Note 10)	⊕
Industrial process water ⁽⁹⁾	⊕	⊕	⊕	⊕	⊕
Degraded water					
↳ Agricultural return water ⁽¹⁾	⊕	⊕	⊕	⊕	⊕
↳ Dairy or feed-lot runoff	⊕	⊕	⊕		⊕
↳ Brackish water ⁽²⁾	⊕			⊕	⊕
↳ Contaminated groundwater	⊕		⊕	⊕	⊕

Notes.....

1. Selenium has been identified as a heavy-metal contaminant in some agricultural tailwaters.
2. Surface or groundwater with TDS >1,500 mg/l.
3. General Minerals Na, K, Ca, Mg, HCO₃, CO₃, Cl, SO₄ and SiO₂
4. Biological BOD, COD, NH₃, PO₄, etc. Typically found in reclaimed wastewater as well as pharmaceutical, biotech, livestock/dairy and food processing waste streams.
5. Organics Volatile, non-volatile or pesticide compounds.
6. Metals Ba, Sr, Fe, Mn, Cu, Zn, Se, As, Cr, Hg, etc.
7. Other NO₃, PO₄, ClO₄, S, F, etc.
8. Can be surface water or groundwater. Many supplies contain trace levels of organic compounds and metals.
9. Examples are produced water (oil production), micro-electronics wastewater, mine sluice water, electroplating rinse water, etc.
10. Trace concentrations of organics and metals (within regulatory limits) are found in many fresh water supplies.

(EPRI 2003)

This table contains key chemical constituents found in sources of degraded water. These are constituents found in typical situations, though the actual constituent make up may vary for each source of water.

Case Studies: Screening Results of Different Source Water, not including Regulated Constituents

Table 2-5
Source Water Screening

	Produced Water mg/l	Ag Return Water mg/l	Reclaimed Water mg/l	Fresh Water mg/l
Na (by difference)	982	2,182	76	41
K	22	6	5	0.72
Ca	40	554	76	18
Mg	13	270	43	0.76
HCO ₃	1,100	239	396	92
Cl	920	1,480	102	22
SO ₄	110	4,730	68	31
NO ₃	NR ⁽⁶⁾	48	NR	ND
Total PO ₄	NR	2	6	ND
S	6	NR	NR	ND
SiO ₂	120	37	17	16
B ⁽⁵⁾	21	14	3	0.17
NH ₃	5	NR	5	ND
TDS	3,879	9,723	869	297
TSS	<1	11	8	<1
BOD	30	3	8	NA
COD	80	32	5	NA

Operating Cooling Tower Assumptions.....

Cooling Tower Alkalinity, mg/l CaCO ₃	200	50	50	200
Calculated pH ⁽⁸⁾	7.9	7.0	7.0	7.9

Screening-Level Cycles of Concentration - N - without Pre-Treatment

(Refer to Tables 2-3a and 3b for control criteria and Table B-2 for calculation procedures)

Ca	9.0	<1	4.7	20.0
Ca x SO ₄ ⁽⁷⁾	3.6	<1	4.2	16.4
Mg x SiO ₂	3.4	1.3	5.0	38.7
SiO ₂	1.3	4.1	8.8	9.4
Ca (in presence of PO ₄)	NA	<1	1.3	NA
TDS	18	7	80	235

Notes.....

1. Produced water from oil production in the Central Valley.
2. Agricultural return water from the San Luis Drain.
3. Secondary-treated reclaimed water from the Bay Area. t-PO₄, B, NH₃ and COD were estimated.
4. West Kern water. Silica concentration was modified for this analysis.
5. B exists as H₃BO₃ (non-dissociated boric acid) in water at this pH.
6. NR = not reported, ND = non-detectable and NA = not applicable.
7. H₂SO₄ used for pH control is accounted for when calculating the impact of additional SO₄ on CaSO₄ solubility.
8. Assume pH = 7.0 when PO₄ present.

(EPRI 2003)

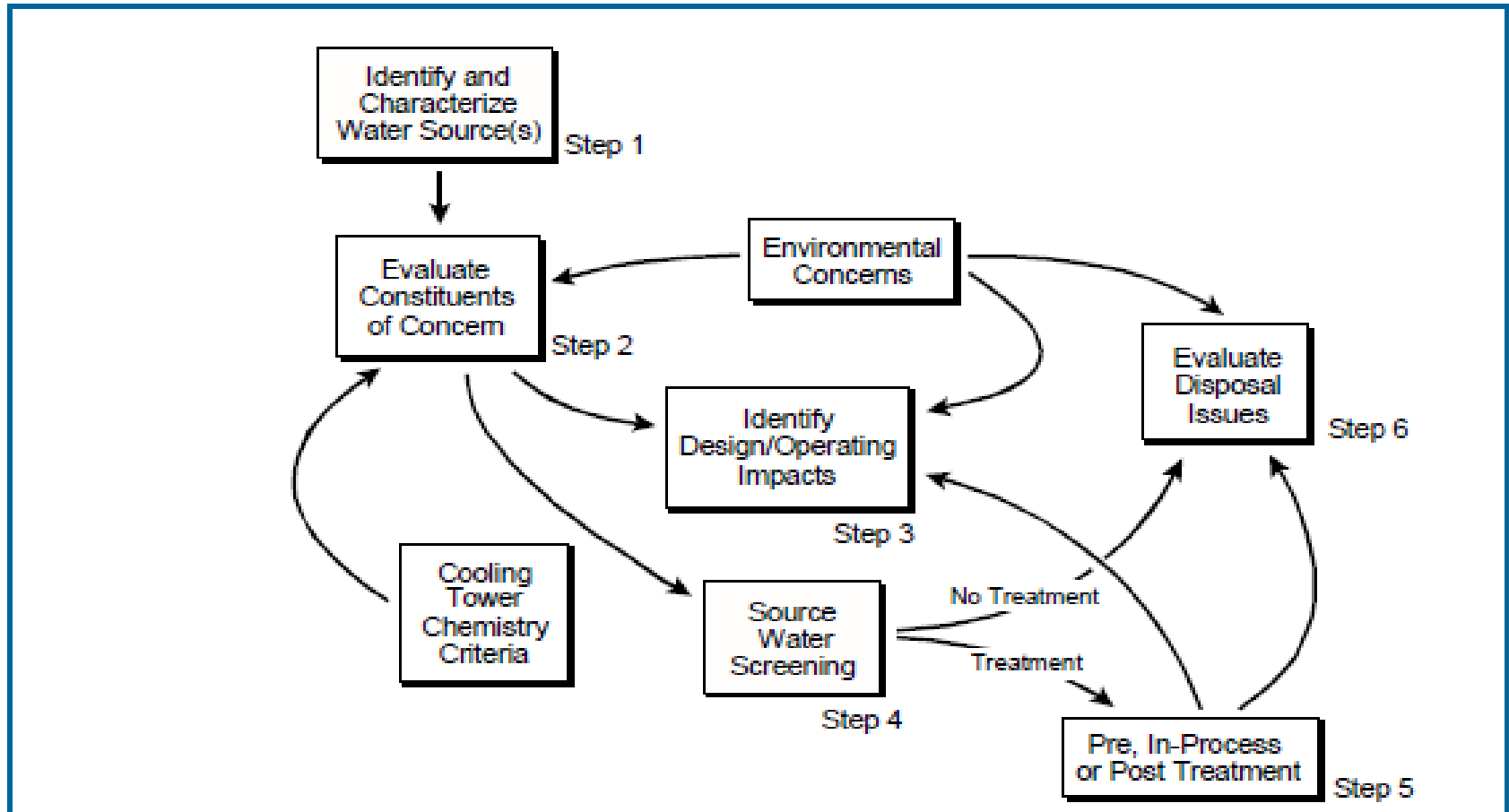


4. Source Water Evaluation: Operational Concerns and Environmental Constituents of Interest

Water Treatment Analysis and Methodology

STEPS	DESCRIPTION
Step 1: Identify and Characterize the Source Water(s)	Chemical analysis of constituents of concern should be conducted to determine the feasibility of using the water source(s) for cooling tower operations. Flow profiles are especially useful for water from multiple sources, which may require further analysis and calculations
Step 2: Evaluate Constituents of Concern	Each constituent must be evaluated to ensure compliance to operational quality criteria and environmental regulations. The maximum cycles of concentration (N) should be calculated for each constituent. The limiting parameter is the one with the lowest calculated N.
Step 3: Identify Cooling Tower Design and Operating Impacts	Based on the constituent make-up and evaluation of limiting parameters, the cooling tower design and operating impacts should be identified. Capital and operating costs will be affected by the design
Step 4: Determine the Need for Treatment	Treatment scenarios and alternate options will be determined based on calculated N values of constituents, source water, limiting parameters of, situational limitations, and regulation limitations of the constituents.
Step 5: Evaluate Treatment Requirements	Pre, side and post treatment plans will be developed based on previous calculations and evaluations of constituents present in the source water. Treatment technologies will be chosen and analyzed.
Step 6: Evaluate Disposal Issues	Cooling tower blowdown and treatment waste streams give rise to disposal issues, which must be evaluated. Wastes must be analyzed for toxicity and hazards and disposed of accordingly.

Source Water Evaluation Methodology



(EPRI 2003)

Water Quality for Cooling Towers: Operational Issues

Areas of Water Quality Concern:

Operating problems that may result from each area of concern are noted in the figure.

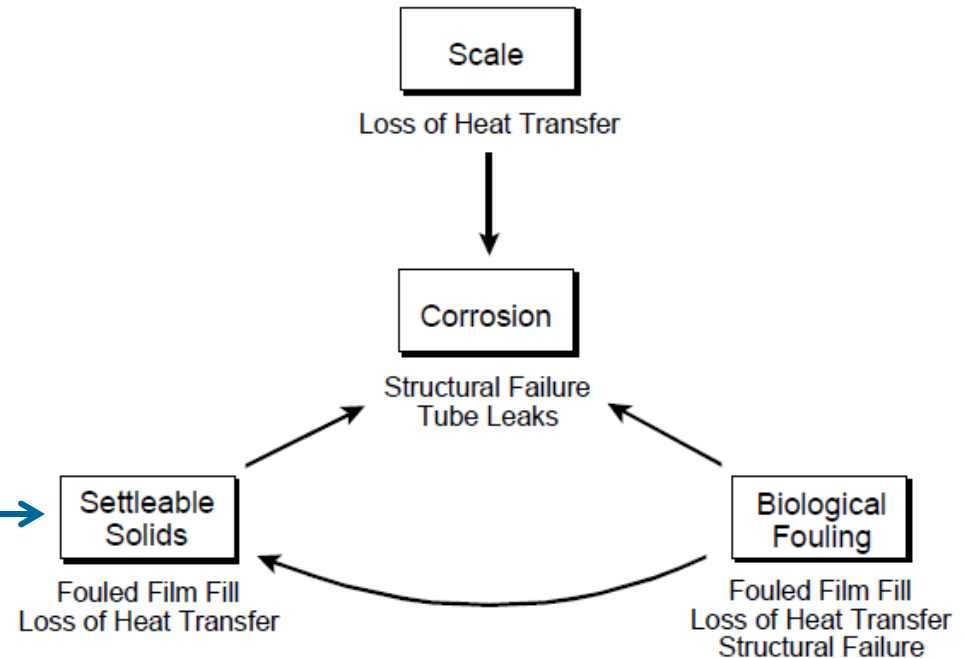


Figure 2-3
Cooling Tower Issues of Concern

(EPRI 2003)

Operation Objectives of Water Quality Criteria :

1. Minimize mineral Scaling and Biological fouling of heat transfer surfaces
2. Minimize corrosion of heat transfer and structural metal
3. Minimize fouling loads on cooling tower fill

Operational Concern Mitigation: Typical Treatment Requirements

Degraded Water Source	Typical Limitations	Treatment Options
Produced Water	CaSO ₄ , Mg/silica, silica	<ul style="list-style-type: none"> • High silica concentrations can be reduced with side stream lime/soda softening. • pH control: high alkalinity requires sulfuric acid additions • Due to high ammonia levels, non copper bearing alloys should be utilized.
Agricultural Return Water	Ca, Mg/silica, CaPO ₄ , CaSO ₄ ,	<ul style="list-style-type: none"> • High silica concentrations can be reduced with side stream lime/soda softening. • pH control: high alkalinity requires sulfuric acid additions • Ca, Mg, PO₄³⁻ concentrations also can be reduced with the above treatment
Reclaimed Water	Ca, CaSO ₄ , CaPO ₄	<ul style="list-style-type: none"> • Ca removal by make-up or side-stream softening • Due to high ammonia levels, non copper bearing alloys should be utilized. • To avoid formation of chloramine, bromine should be used instead of chlorine.

Environmental Issues: Constituents of Concern

Environmental constituents of concern may present environmental hazards and are subject to state or federal regulations but have no effect on cooling tower performance. These chemical constituents will need to be removed from feedwater prior to use in cooling tower.

Examples of constituents of environmental concern: Volatile organic solvents, pesticides, heavy metals

Water Policy Compliance

Regulations and guidelines on federal and state levels exist regarding water reuse and environmental release of chemical constituents. Many states have developed individual policies addressing cooling system water use in power plants.

Water Reuse Regulations and Guidelines by States

Table 3.5. Summary of water reuse regulations and guidelines by states*

State	Regulations	Guidelines	No regulation/Guideline	Unrestricted Urban Reuse	Restricted Urban Reuse	Agricultural Reuse Food Crops	Agricultural Reuse Non-Food Crops	Unrestricted Recreational Reuse	Restricted Recreational Reuse	Environmental Reuse	Industrial Reuse	Groundwater Recharge	Indirect Potable Reuse
Alabama		•			•		•						
Alaska	•						•						
Arizona	•					•	•		•				
Arkansas		•		•	•	•	•						
California (3)	•			•	•	•	•	•	•		•	•	•
Colorado	•			•	•	•	•	•	•				
Connecticut			•	•	•		•						
Delaware	•			•	•		•						
Florida	•			•	•	•	•			•	•	•	•
Georgia		•		•	•		•					•	•
Hawaii		•		•	•	•	•		•		•	•	•
Idaho	•			•	•	•	•						
Illinois	•			•	•		•						
Indiana	•			•	•	•	•						
Iowa	•			•	•	•	•						
Kansas		•		•	•	•	•						
Kentucky			•										
Louisiana			•										
Maine			•										
Maryland		•			•		•						
Massachusetts	•	•		•	•		•					•	•
Michigan	•					•	•						
Minnesota			•										
Mississippi			•										
Missouri	•				•		•						
Montana	•			•	•	•	•						
Nebraska	•				•		•						
Nevada	•			•	•	•	•	•	•				
New Hampshire			•										
New Jersey		•		•	•	•	•				•		
New Mexico		•		•	•	•	•						
New York		•			•		•						
North Carolina	•			•							•		
North Dakota		•		•	•		•						
Ohio		•		•	•		•						
Oklahoma	•				•	•	•						
Oregon	•			•	•	•	•	•	•		•		
Pennsylvania		•			•		•						
Rhode Island			•										
South Carolina	•			•	•		•						
South Dakota		•		•	•		•						
Tennessee	•			•	•		•						
Texas	•					•	•	•	•		•		
Utah				•	•	•	•	•	•		•		
Vermont	•						•						
Virginia			•										
Washington		•		•	•	•	•	•	•	•	•	•	•
West Virginia	•				•	•	•						
Wisconsin	•												
Wyoming	•			•	•	•	•						

*Adapted from "Guidelines of Water Reuse", USEPA, 2004.

**States reviewed in this study are those that are shaded in this table.

Please see
(NETL/DOE 2009) for
further details on state
regulations

(NETL/DOE 2009)

Regulations and Guidelines of Selected States

Table 3.6. Summary of regulations and guidelines reviewed in the twelve selected states.

	Water Reuse Regulations	Water Discharge Regulations	Air Emission
Arizona	*AAC, R18-9, Article 7	* AAC, R18-9 Article 9	
California	* State Water Resources Control Board, Resolution No.75-58 * Warren-Alquist Act, Section 25602 * Water Code, Section 462 * 22CCR60306	* State Water Resources Control Board, Resolution No. 75-58	* 22CCR60306 * 17CCR93103
Florida	* FAC 62-610-668	* FAC 62-302-520 * FAC 62-660.400	* FAC 62-610-668
Hawaii	* Guidelines for the Treatment and Use of Recycled Water, III, C (Dep. of Health, 2002)		* Guidelines for the Treatment and Use of Recycled Water, III, C (Dep. of Health, 2002)
Maryland		* COMAR26.08.03.06	
New Jersey	* Reclaimed Water for Beneficial Reuse (Dep. of Env. Pro., 2005)		
North Carolina	* 15A NCAC 02T.0906 * 15A NCAC 02T.0910	* 15A NCAC 02B.0208 * 15A NCAC 02B.0211 * Thermal (Temperature) Variances to North Carolina Water Quality Standards (USEPA, 2006)	
Oregon	* OAR 340-550-0012		* OAR 340-550-0012
Texas	* TAC 30-210.32 * TAC 30-210.33	* TAC 30-307.8	* TAC 30-210.32 * TAC 30-210.33 * TAC 30-113.220
Utah	* Water Reuse in Utah (Division of Water Resource, 2005) * UAC R317-3-11		* UAC R317-3-11
Washington	* RCW 90.46 * Water Reclamation of Reuse Standards (Dep. of Health & Dep. of Ecology, 1997)		* Water Reclamation of Reuse Standards (Dep. of Health & Dep. of Ecology, 1997)
Wyoming	* WQRS Chapter 21	* WQRS Chapter 2	

Notation: * Related to reuse of reclaimed water in power plant cooling water system.
 • Related to power plant cooling water system.

(NETL/DOE 2009)

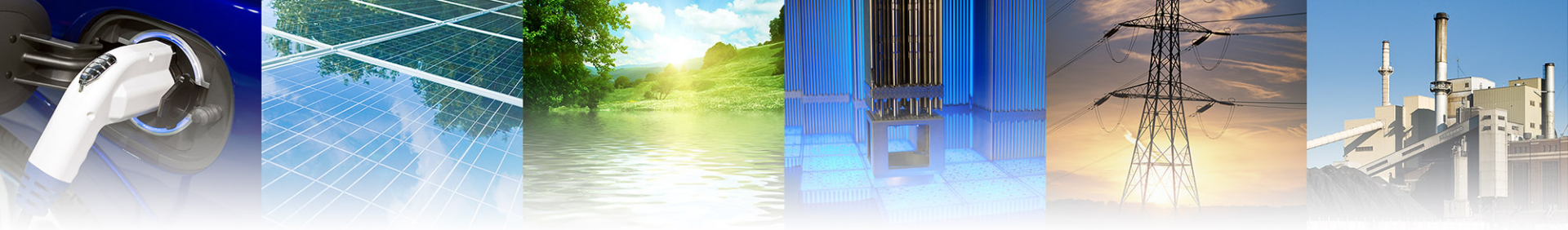
California Regulations on Power Plant Cooling Systems

Table 2-8
Power Plant Cooling Systems - Requirements for Approval

California Code of Regulations, Title 20, Div. 2, Chap. 5---§2012, App. B

Subsection (of App. B)	Subject	Requirement	Relevant Code/Regulation
(a)(1)(A)	Executive Summary	General description of....water supply, pollution control systems....	None cited
(b)(1)(C)	Project Description	Design, construction, operation of----cooling systems	None cited
(b)(1)(D)	Site/Facility Selection	How selection made and consideration given to env. impacts, water and---	None cited
(f)(1)&(2)	Alternatives	Discussion of other choices and economic/environmental merits	Public Resources Code, Section 25540.6(b)/Policy 75-58
(g)(4)	Noise		None cited
(g)(6)(F)	Visual Resources	Assessment of impact of visible plumes	None cited
(g)(8)(A)	Air Quality	Info necessary for air pollution control district to complete Determination of Compliance	None cited
(g)(9)	Public Health		Health and Safety Code, Section 25294.8
(g)(10)	Hazardous Materials Handling		Cal. Code, title 22, §86261.20 et seq. Also, Health and Safety Code, Section 25531.
(g)(12)	Waste Management		Cal. Code, title 22, §86261.20 et seq.
(g)(13)	Biological Resources		Cal. Code, title 20, Sects. 1702 (q) and (v)
(g)(14)	Water Resources		Waste Discharge Requirements; NPDES; Policy 75-58
(g)(15)	Agriculture and Soils	Effect of emissions on surrounding soil-vegetation	None cited

(EPRI 2003)



5. Power Plant Cooling Water Treatment Technologies

Treatment Options and Objectives

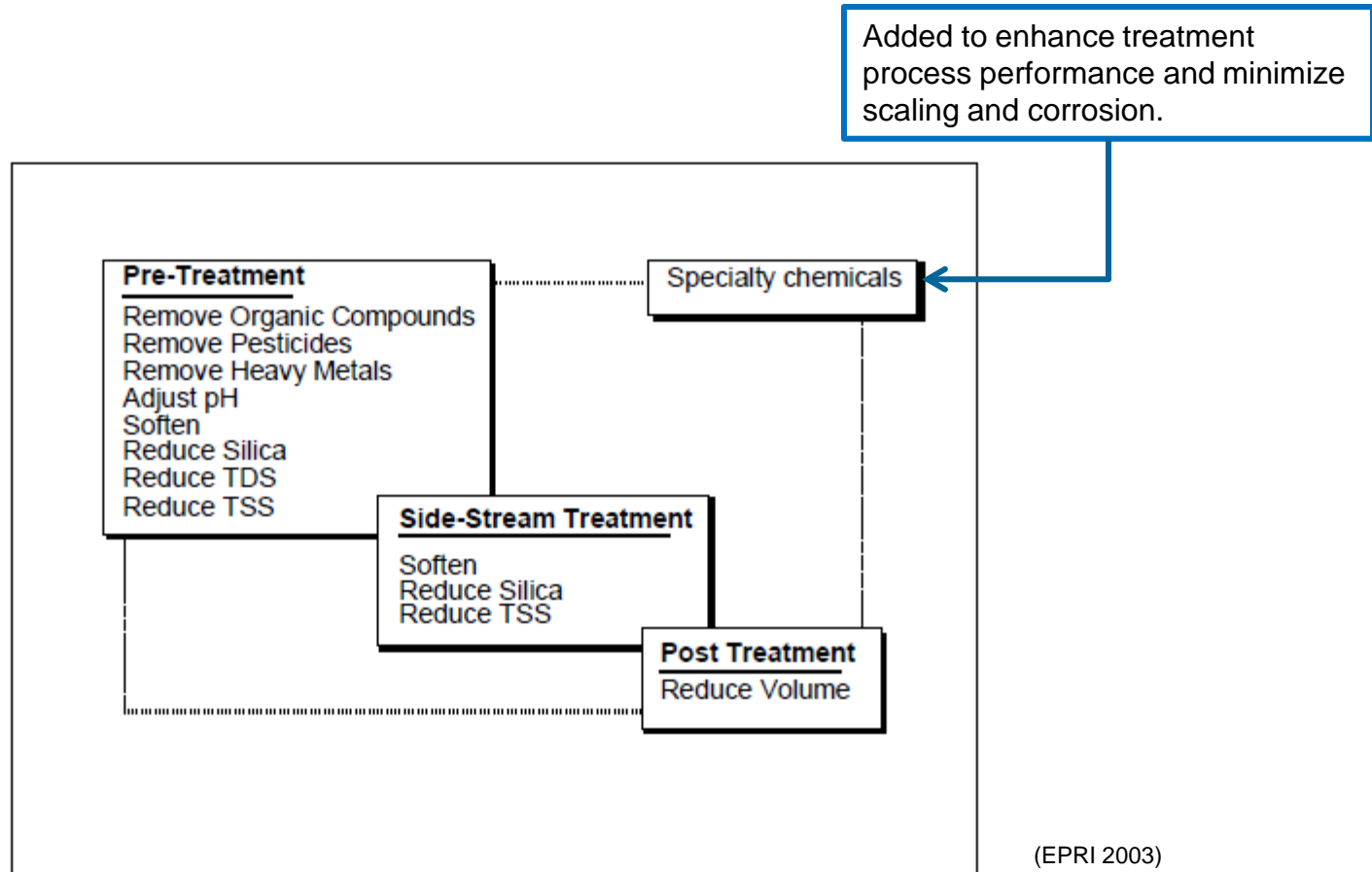
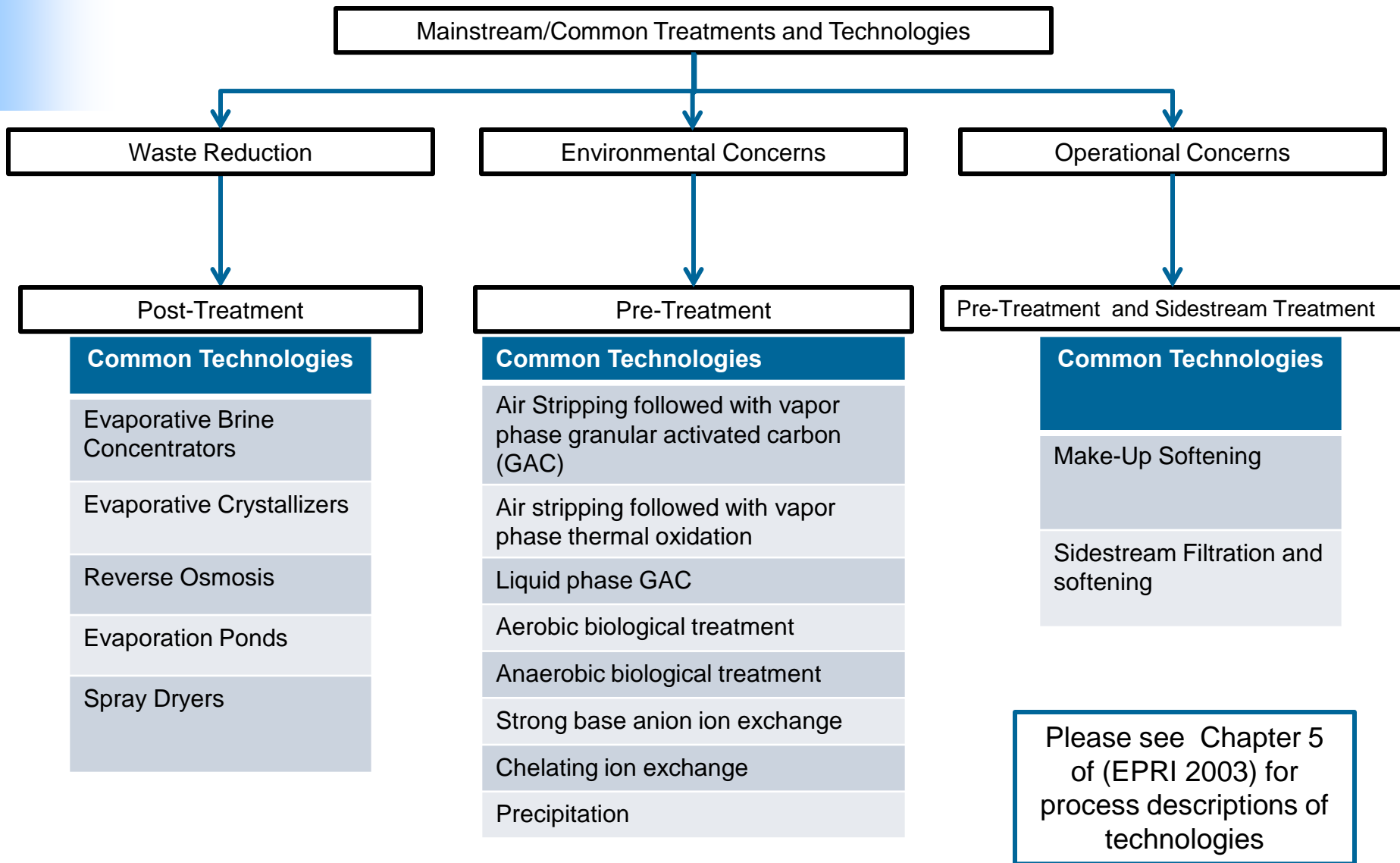


Figure 2-5
Cooling Water Treatment



Cooling Tower Performance and Operation Related Treatment Technologies

Technology	Targeted Constituents	Description of Technology
Pre-Treatment: Softening	Removes hardness: Ca^{2+} and Mg^{2+} carbonate alkalinity: CO_2 , HCO_3^{1+} , and CO_3^{2+} Incident removal of silica	lime or lime/soda softening is used to treat make-up water. $\text{Ca}(\text{OH})_2$ and Na_2CO_3 are fed into the softener which is mixed with the make-up water. Waste sludge is separated from treated water.
Side-Treatment: Softening and Filtration	Removes hardness: Ca^{2+} and Mg^{2+} carbonate alkalinity: CO_2 , HCO_3^{1+} , and CO_3^{2+} Incident removal of silica	<p>If make up softening does not offer adequate treatment, side stream treatment may be necessary.</p> <p>Filtration is used to limit suspended matter in the cooling water. Water is directed from the return line on the hot side of the cooling circuit, fed through filters.</p> <p>From the condenser, the hot cooling water is fed into a reactor clarifier, where softening by $\text{Ca}(\text{OH})_2$ and Na_2CO_3 occurs.</p> <p>Sludge is also generated as a waste product</p>

General Summary of Treatment of Constituents of Operational/Performance Concern

Table 2-6
Pre-, Side-Stream Treatment for Cooling Towers

Cooling Tower Chemical Criteria (Note 3)	<i>Pre-Treatment</i>		<i>Side-Stream Treatment</i>	
	pH Adjustment	Lime or Lime/Soda Softening	Filtration	Warm Lime or Lime/Soda Softening
Ca		Pri		Pri
Ca x SO ₄		Pri via Ca		Pri via Ca
Mg x SiO ₂		Pri via Mg		Pri
M Alkalinity	Pri	Sec		Sec
SO ₄		Pri via Ca		Pri via Ca
SiO ₂		(Note 5)		Pri
PO ₄		Sec		Sec
pH	Pri			
TSS		Sec	Pri	Sec

Notes.....

1. Pri = primary means of reduction - intention of process.
2. Sec = secondary means - incidental reduction in process.
3. Chemical criteria found in Table 2-1.
4. Refer to Table 2-6 for removal of contaminants from degraded water for cooling tower make-up.
5. There is some removal of SiO₂.

(EPRI 2003)

Waste Minimization: ZLD Systems

Zero Liquid Discharge (ZLD)

ZLD systems aim for complete recovery of cooling water, where no wastewater should leave the site and all waste should be converted to dry form for ultimate disposal. ZLD systems offer the potential for sustainable cooling and a viable waste treatment option for areas where evaporation ponds are infeasible or prohibited. Though ZLD is ideal, not all power plants can achieve these systems, but waste minimization technologies are nonetheless desirable.

These systems are currently limited by high costs, but can be alleviated by development of higher recovery technologies, such as advanced RO membranes.

Conventional ZLD systems commonly utilize evaporative technologies, which are highly energy intensive. Increased recovery with increased pre-treatments can reduce water volume and thereby, lower evaporative costs. However, higher solid waste disposal and chemical costs will increase may offset any cost benefits of reduced wastewater volume. With power plant water treatment systems, recovery benefits are often difficult to balance with costs.

Typical ZLD Schemes:

1. Pre-Treatment Steps: Wastewaters undergo pre-treatment processes (i.e. ion exchange) to concentrate constituents of concern into smaller volumes
2. Desalinization Steps: Excess water must subsequently be recovered from water treatment waste

Please see Chapter 3 of (WaterReUse 2008) for further details on ZLD systems

Current Common Technologies Used in US Non-Municipal ZLD Systems

Water Recovery Technology	Description
Evaporative Brine Concentrators	A energy intensive process utilized to concentrate waste water to minimize volume. Evaporator concentrate (also known as brine) undergoes further drying in evaporation ponds to produce dry waste. Distillate collected from the evaporation process can be recycled into the cooling system.
Evaporative Crystallizers	Instead of disposal in brine ponds after evaporative treatment, the condensate is sent through a crystallizer. The crystallizer dries excess water to form dry salt cake. This process is useful for situations in which evaporative ponds are not a feasible option.
Reverse Osmosis	High Pressure pumps force water through membranes without allowing dissolved salts through. Pre-treatment steps are required to optimize membrane performance. Softening steps to remove minerals (silica, calcium, magnesium) are removed via a softening step, and filtration steps to remove particulate matter are commonly conducted prior to the RO filtration.
Evaporation Ponds	Wastewater in warmer climates can be sent to evaporation ponds on-site, where the water can slowly evaporate from the waste.
Spray Dryers	Used to treat smaller volumes of water.

Environmental Constituents of Concern Related Treatment Technologies

Chemical constituents that are regulated under state and federal law should be removed prior to cooling tower circulation

Technology	Targeted Constituents for removal	Description of Technology
Air Stripping followed with vapor phase granular activated carbon (GAC)	Volatile organic compounds, THM, and some pesticides	When volatile organic concentrations are high, air stripping is more economical than liquid phase carbon removal. Counter-flowing airstream is flowed through droplets of water which allows for volatile compounds to evaporate and be removed from the cooling water. The exhaust air is fed through porous carbon media, trapping organic compounds. Spent media must be regenerated on site with steam, or disposed of.
Air stripping followed with vapor phase thermal oxidation	Volatile organic compounds, THS, and some pesticides	Using controlled combustion, air stripped organic compounds are converted into combustion byproducts through thermal oxidation. Oxidation of certain compounds may require a scrubber (ex. Chlorinated organic compounds). Spent media must be regenerated on site with steam, or disposed of.
Liquid phase GAC	Volatile and non-volatile organic compounds and pesticides, incidental removal of some BOD and COD	Liquid phase GAC is used to treat water with non-volatile organic compounds or low concentrations of volatile organic compounds. Water is directed through media intended to filter and remove particulates or organic constituents. Spent media must be regenerated, and the waste disposed of, or completely disposed of without regeneration

Continued

Technology	Targeted Constituents for removal	Description of Technology
Aerobic biological treatment	Organic compounds, ammonia, and incidental removal of BOD and COD	Converts targeted constituents into carbon dioxide and water, or ammonia into NO_3^{-1} . Organic constituents are metabolized by aerobic bacteria. Waste products in the form of sludge is produced.
Anaerobic biological treatment	Organic compounds, ASO_4^{-3} , CrO_4^{-2} , SeO_4^{-2} , SeO_3^{-2} , and ClO_4^{-1} , and incidental removal of BOD, COD, and possibly NO_3^{-1}	Anaerobic bacteria may metabolize chemically bound oxygen from chemical constituents. Compounds are reduced to elemental forms and leaves as waste sludge.
Ion Exchange		Water is passed through cation exchange resins, which contain functional groups targeted at certain constituents of concern. By exchanging hazardous ions with non-hazardous replacements, ion exchange treatment removes them from the cooling water. Ion exchange media will need to be regenerated periodically. Post treatment of concentrated constituent fluid will be required.
<ul style="list-style-type: none"> • Strong base anion ion exchange 	ASO_4^{-3} , CrO_4^{-2} , SeO_4^{-2} , SeO_3^{-2} , and ClO_4^{-1} and incidental removal of PO_4^{-3} , NO_3^{-1} , and F^{-1}	In ion exchange, an ionic bond is formed between the media and the targeted constituents.
<ul style="list-style-type: none"> • Chelating ion exchange 	High affinity for transition metals (Cu, Ni, Cd, Cr^{+3} , etc)	Chelating resin beads are used to creates covalent bonds with divalent ions.

General Summary: Treatment Options for Constituents of Environmental Concern

Table 2-7
Pre-Treatment of Contaminated Water for Cooling Tower Make-Up

Chemical Parameter (Note 5)	Air Stripping Vapor-Phase GAC (Note 3)	Air Stripping Vapor-Phase Thermal Oxidation	Liquid Phase GAC	Biological Treatment (Note 4)	Strong Base IX	Chelating IX	Precipitation Co-Precip
Organic Compounds	Pri - Volatile	Pri - Volatile	Pri	Pri	Sec		
Pesticides			Pri	Pri (8)	Sec		
Cationic Heavy Metals (12)						Pri	Pri
Anionic Heavy Metals (13)				Pri (14)	Pri		Pri (11)
NO ₃ , ClO ₄ , F (9)				Pri - NO ₃ , ClO ₄	Pri (10)		
Biological (6)			Sec (7)	Pri	Sec		

Notes.....

1. Pri = primary means of reduction - intention of process
2. Sec = secondary means - incidental reduction in process
3. GAC is granular activated carbon.
4. There are a variety of biological processes, e.g. constructed wetlands, trickling filter, fixed-film aerobic, etc.
5. Refer to Table 2-2 for chemical parameters of contaminated groundwater and surface water treatment.
6. Biological waste components include BOD, COD, NH₃, PO₄, etc. Typically found in reclaimed water as well as pharmaceutical, biotech, livestock/dairy and food processing waste streams.
7. There will be some incidental removal of BOD and COD.
8. Pesticides could be detrimental to biological processes because of its toxicity.
9. Anaerobic biological treatment is required for NO₃ and ClO₄. Anaerobic treatment is still considered experimental for ClO₄.
10. Depending on treatment conditions NO₃ removal may not be completely achievable.
11. Applies to AsO₄ and SeO₃.
12. Cationic heavy metals include Cu, Ni, Cd, Cr (+3), etc.
13. Anionic heavy metals include AsO₄, CrO₄, SeO₄, SeO₃, etc.
14. Anaerobic biologic treatment is still somewhat experimental for anionic heavy metals.

References

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