

Table of Contents

PREFACE.....	I
1 INTRODUCTION	1
1.1 Purpose and Scope.....	1
1.2 Background on Water for Power Plant Cooling	6
1.2.1 Water “Use” Definitions	6
1.2.2 Configurations that Characterize Water “Use” of Power Plant Cooling Systems	8
1.2.3 Trends in Power Plant and Cooling System Installations (United States).....	17
1.2.4 Measuring and Estimating Thermal Power Plant Cooling Water Consumption and Withdrawal.....	21
1.3 Nomenclature.....	26
1.4 References.....	27
2 THE CONTEXT OF THERMAL POWER PLANT WATER USAGE.....	1
2.1 Power Plant Cooling as Part of a Larger Whole System	1
2.2 Environmental Considerations for Power Plant Water Usage	11
2.2.1 Environmental Effects of Thermal Power Plants	12
2.2.2 Regulatory Context	15
2.2.3 EPA Analysis of Costs and Benefits of Retrofitting From Once-Through Cooling to Cooling Towers.....	21
2.3 Balancing Thermoelectric Power Production and Thermal Pollution... 	22
2.4 Energy Information Administration Collection and Dissemination of Cooling System Data.....	28
2.4.1 EIA and Its Relevant Forms	28
2.4.2 Ensuring Accuracy of EIA Data	29
2.4.3 Maintaining Relevance of EIA Data.....	30
2.4.4 Cooling System Data Collected by EIA	31

2.5	Nomenclature.....	32
2.6	References.....	32
3	ENGINEERING AND PHYSICAL MODELING OF POWER PLANT COOLING SYSTEMS	1
3.1	Heat and Water Balance of Power Plant Cooling Systems	1
3.1.1	Introduction to Cooling System Types	1
3.1.2	Once-Through Cooling	2
3.1.3	Wet-Cooling Towers	4
3.1.4	Heat Balance of a Cooling Tower.....	6
3.1.5	Water Balance for Wet-Cooling Towers	9
3.1.6	Wet-Cooling Tower Materials and Design	13
3.1.7	Dry-Cooling Towers.....	18
3.1.8	Parallel Condensing Systems	24
3.1.9	Hybrid (Wet-Dry) Cooling Towers.....	25
3.1.10	Wind Impacts on Dry-Cooling Towers	28
3.2	Summary of S-GEM: System-Level Generic Model of Thermal Cooling Systems	31
3.2.1	Sensitivity of S-GEM.....	35
3.2.2	Effects of Ambient Conditions: Once-Through Cooling	38
3.2.3	Effects of Ambient Conditions: Wet-Cooling Tower	39
3.3	Cooling of Natural Gas Combustion and Combined Cycle Power Plants	42
3.3.1	Inlet Air Cooling in Gas Turbines.....	43
3.3.2	Water for DeNOx System in Gas Turbines	43
3.3.3	Natural Gas Combined Cycle Cooling Requirements.....	44
3.4	Extraction of Water From Power Plant Exhaust Gas	45
3.4.1	Condensing Heat Exchanger	45
3.4.2	Flue-Gas Water Recovery Calculation—NGCC Example	45
3.4.3	Flue-Gas Water Recovery Calculation—Coal Example	47
3.5	Specific Cooling Water Requirements in Commercial Nuclear Power	48
3.5.1	Introduction	48
3.5.2	Water needs during normal operation.....	50
3.5.3	Handling of Spent Reactor Fuel	54
3.5.4	Discharge of Cooling Water	56
3.5.5	Cooling After Shutdown and During Emergencies.....	57

3.5.6	Advanced Light Water Reactor Designs.....	60
3.5.7	Summary.....	63
3.6	USGS Estimation of Water Consumption and Withdrawal—Including Forced Evaporation	64
3.6.1	Introduction	66
3.6.2	Background	66
3.6.3	Forced-Evaporation Model.....	69
3.6.4	Discussion	74
3.6.5	Conclusion.....	75
3.7	Evaporation Suppression From Reservoirs	76
3.8	Considerations for Water Quality and Treatment for Power Plant Cooling Water	79
3.9	Nomenclature.....	83
3.10	References.....	83
4	ECONOMIC CONSIDERATIONS AND DRIVERS	1
4.1	Introduction.....	1
4.2	Cooling System Alternatives.....	1
4.2.1	Once-Through Cooling	1
4.2.2	Closed-Cycle Wet Cooling	2
4.2.3	Dry Cooling.....	2
4.2.4	Hybrid Cooling	3
4.3	Cooling System Selection Methodology and Trade-offs.....	4
4.3.1	Costs Specific to Cooling System.....	5
4.3.2	Plant Costs Affected by Cooling System Choice.....	5
4.3.3	Other Plant Equipment	6
4.3.4	Cooling System Related “Penalty” Costs.....	6
4.3.5	System Optimization.....	7
4.4	Cost and Performance Comparisons of Cooling Systems for New Thermal Power Plants	7
4.4.1	Cost of Water Conservation.....	11
4.5	System Economic Studies of Cooling System Retrofits	11
4.5.1	Retrofit Cost Methodology	14

4.5.2	Degrees of Difficulty of Once-Through to Wet-Cooling Tower	
Retrofits		16
4.5.3	Cost Ranges for Cooling System Retrofits.....	18
4.5.4	Nuclear-Specific Issues.....	20
4.5.5	Examples of Thermal Power Plants That Have Retrofitted Once-Through Cooling Systems	20
4.6	Economic Benefits of Alternative Cooling Technologies	22
4.6.1	Value of Resiliency Against Water Constraints	22
4.6.2	Insurance Against Water Constraints	23
4.6.3	Applicability to Retrofit and New Construction	24
4.7	Nomenclature.....	24
4.8	References	25
5	COOLING SYSTEM CASE STUDIES	1
5.1	Various Case Studies	1
5.1.1	Argentina—ACC Instead of Once-Through Sea Water to Avoid Disturbed Habitat for Coastal Tourism	1
5.1.2	ACC to Avoid Visible Plumes	2
5.1.3	North Africa—ACC Instead of Nearby Brackish or Sea Water ...	3
5.2	Drought and Water for Energy in Australia	4
5.2.1	Air-Cooling Kogan Creek Power Station.....	6
5.2.2	Kogan Creek Solar Boost Project.....	7
5.2.3	Conclusion: Australia Case Study	7
5.3	Regulatory Frameworks and Incentives for Australian Power Plants to Adopt Water Efficiency Measures.....	8
5.4	Municipal Water Reuse for Power Plant Cooling.....	10
5.4.1	Introduction	10
5.4.2	CPS Energy	11
5.4.3	History of Braunig and Calaveras Lake Power Stations	11
5.4.4	Braunig and Calaveras Power Stations	14
5.4.5	Water Chemistry	18
5.4.6	Challenges of Reclaimed Water Use	20
5.4.7	Water Supply Management Strategies	22
5.4.8	Conclusions	23
5.4.9	Acknowledgements	23

5.5 Case Study of Dry Cooling in South Africa	24
5.5.1 Introduction	24
5.5.2 History and Plant Configurations	25
5.5.3 General Operational Experience With Dry-Cooling Systems ...	29
5.6 Power Plant Cooling Systems in Spain	31
5.6.1 Introduction	31
5.6.2 Iberian Climate Atlas.....	31
5.6.3 Spanish Power Plants.....	34
5.6.4 Cooling Tendency.....	37
5.7 References.....	39
GLOSSARY.....	1