Closed Cycle Cooling Tower Feasibility Assessment for Turkey Point Nuclear Units 3 and 4

July 11, 2016

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I. Executive Summary

Retrofit mechanical draft wet cooling towers for Turkey Point Units 3 and 4 are feasible and cost effective, even if they operate for as little as ten years. The annualized cost of the wet cooling towers would be approximately \$59 to \$79 million per year over a ten-year cost recovery term, depending on the type of cooling tower configuration selected. This compares to a gross annual revenue generated by Units 3 and 4 of approximately \$500 million. The cost of electricity production for the FPL system as a whole, of which Units 3 and 4 provide about 10 percent of the annual delivered electricity, would increase about 1.5 to 2 percent with the addition of retrofit cooling towers on Units 3 and 4. The cooling tower investment would ensure the reliability of the Units 3 and 4 cooling systems through 2032 and 2033, the respective end dates of the current Units 3 and 4 operating licenses.

Wet cooling towers for Units 3 and 4 can be operational within four years of submittal of applications for the necessary permits and approvals to proceed with Units 3 and 4 cooling tower retrofits, based on actual retrofits at operational large U.S. nuclear and fossil power plants.

The design parameters of the wet inline cooling tower in use on 1,060 MW Turkey Point Unit 5, and the proposed round wet cooling towers on proposed nuclear units Units 6 and 7, serve as the basis for the retrofit cooling towers for Units 3 and 4 evaluated in this report. A 24-cell inline mechanical draft wet cooling tower is in operation at Turkey Point Unit 5. In addition, FPL has included round mechanical draft wet cooling towers in the design of proposed nuclear Units 6 and 7 at Turkey Point.

The approximate capital cost of wet cooling towers for both Units 3 and 4 would be in the range of \$220 to \$310 million in 2016 dollars, depending on the size and design details of the towers selected. The cooling towers would be designed to reduce discharge (cold water) temperature 2 ^{o}F to 6 ^{o}F below the average maximum cooling canal system (CCS) discharge temperature of 93 ^{o}F. This would have the practical benefit of increasing the gross power output of Units 3 and 4.

The proposed source of makeup water for the Units 3 and 4 cooling towers would be reclaimed water from the Miami-Dade Water and Sewer Department (MDWASD). The MDWASD treatment plant closest to Turkey Point, the South District Wastewater Treatment Plant (SDWWTP), currently injects approximately 101 million gallons per day (mgd) of treated wastewater to the Lower Floridan Aquifer. MDWASD by law must reduce its treated wastewater ocean outfall discharges by 60 percent, equivalent to 117.5 mgd, by 2025. MDWASD had intended to largely address this requirement by supplying 90 mgd to the proposed Turkey Point 6 and 7 nuclear project and the existing Unit 5 gas-fired power plant. However, FPL has postponed the start dates for proposed Units 6 and 7 to 2031 and 2032, eliminating this alternative as a viable compliance option for 2025.

Reclaimed water would be the sole source of makeup water supply to Units 3 and 4 cooling towers. Onsite treated reclaimed water reservoirs at Turkey Point would assure the reliability of reclaimed water supply even if supply disruptions occurred at the SDWWTP. The largest nuclear plant in the country, 3,900 MW Palo Verde Nuclear near Phoenix, Arizona, has operated reliably for 30 years using reclaimed water alone as the makeup water supply, combined with onsite reclaimed water reservoirs to assure supply reliability in the event of temporary supply interruptions. This successful application of reclaimed water as the exclusive makeup water supply for a nuclear plant is the model for makeup water supply to the Units 3 and 4 cooling towers.

The current net loss of approximately 29 mgd of surface water in the CCS attributable to the removal of heat from the Units 3 and 4 circulating cooling water would no longer occur if reclaimed water is the source of makeup water supply.

A certain level of continuous discharge from the circulating cooling water, known as "blowdown," is necessary to prevent the build-up of scaling deposits in the cooling towers. A zero liquid discharge (ZLD) system would be utilized to treat blowdown from the Units 3 and 4 cooling towers to eliminate wastewater discharges.

Use of reclaimed water as the makeup water source will allow for a highly concentrated, relatively low flow blowdown stream, as is done in actual practice at the Palo Verde Nuclear Plant in Arizona. This in turn will allow for a ZLD system of reasonable capital and operating cost to treat blowdown from the Units 3 and 4 cooling towers. The purified water produced by the ZLD system would be re-utilized as makeup water. Solid residue will be landfilled.

Additional practical benefits of cooling towers for Units 3 and 4 would be the elimination of: 1) up to 100 mgd of fresh water pumping from the L-31E Canal to the CCS to reduce water temperature in the CCS, and 2) 14 mgd of Upper Floridan Aquifer pumping for salinity control in the CCS.

Net power output of Units 3 and 4 may also increase if these units shift from the CCS to cooling towers, especially under summertime conditions, as cooling tower fan and water pumping demand may be more than offset by higher gross unit output from Units 3 and 4.

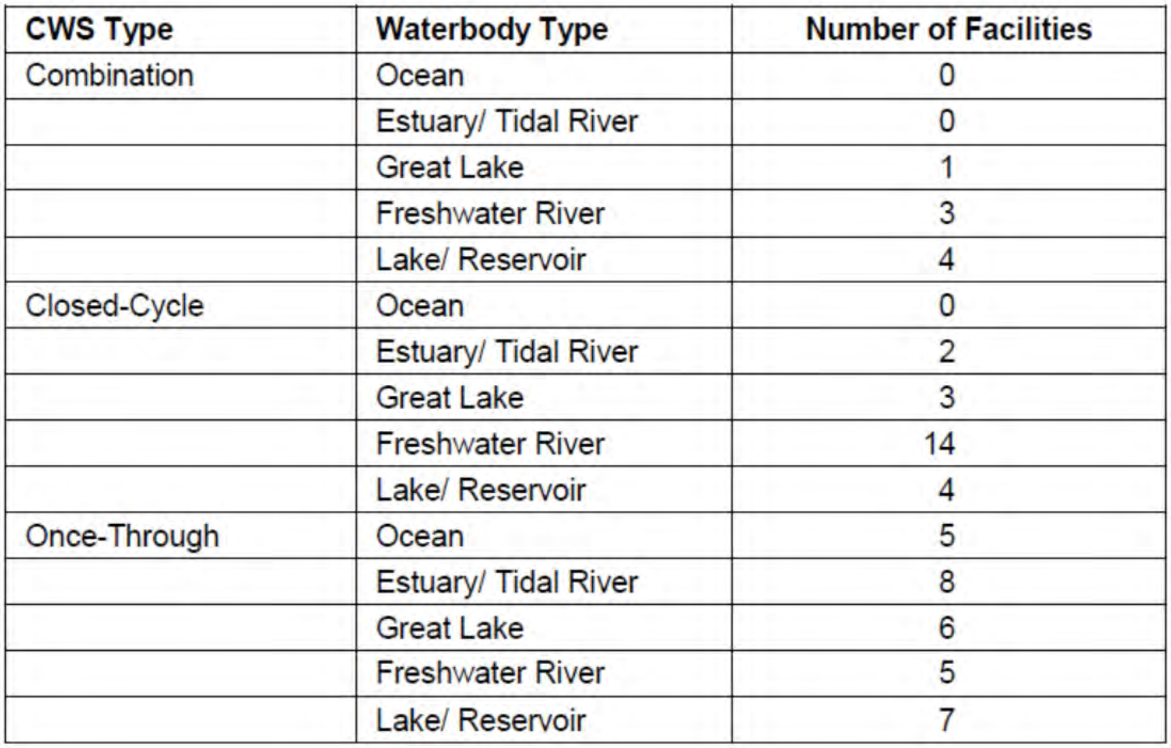
In conclusion, the use of mechanical draft closed-cycle cooling towers on Turkey Point Units 3 and 4, combined with ZLD technology to eliminate cooling tower blowdown discharges, represents the best available technology for eliminating surface water thermal discharge impacts and hypersalinity impacts on the aquifer underlying the CCS.

II. Cooling Systems at U.S. Nuclear Power Plants

A. Overview

The U.S. EPA documented the distribution of combination (can operate as closed-cycle or once-through), closed-cycle, and once-through cooling systems at nuclear plants in the May 2014 316(b) Technical Development Document (TDD). The distribution of cooling system types in use at U.S. nuclear plants is shown in Table 1.

Table 1. Distribution of Cooling Systems at U.S. Nuclear Plants[1]



CWS Type	Waterbody Type	Number of Facilities
Combination	Ocean	0
	Estuary/ Tidal River	0
	Great Lake	1
	Freshwater River	3
	Lake/ Reservoir	4
Closed-Cycle	Ocean	0
	Estuary/ Tidal River	2
	Great Lake	3
	Freshwater River	14
	Lake/ Reservoir	4
Once-Through	Ocean	5
	Estuary/ Tidal River	8
	Great Lake	6
	Freshwater River	5
	Lake/ Reservoir	7

Combination cooling systems can operate as closed-cycle or once-through cooling systems depending on the position of the isolation valves and sluice gates. Examples of U.S. nuclear power plants utilizing a combination cooling system are Xcel Energy's 1,100 MW Prairie Island Nuclear Generating Station (MN) and Entergy's 605 MW Vermont Yankee Nuclear Power Plant (VT).[2] The cooling towers at these two nuclear plants are shown in Figure 1.

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[1] EPA, *Technical Development Document for the Final Section 316(b) Existing Facilities Rule*, May 2014, Exhibit 4-10, p. 4-9.

[2] ASA, Inc., *Hydrothermal Modeling of the Cooling Water Discharge from the Vermont Yankee Power Plant to the Connecticut River – Final Report*, ASA Report 02-088, prepared for Normandeau Associates, Inc., April 2004 (revision), p. 1.

Figure 1. Cooling Towers at Prairie Island Nuclear and Vermont Yankee

a. Prairie Island Nuclear Generating Plant[3]

b. Vermont Yankee Nuclear Power Plant[4]

B. Closed Cycle Canal Cooling System in Use on Turkey Point Nuclear Units 3 and 4

Circulating cooling water used at Turkey Point Units 3 and 4 is cooled in a closed cycle canal cooling system (CCS) that covers approximately 5,900 acres.[5] The CCS is shown in Figure 2. Two thermal units that formerly relied on the CCS, Turkey Point Units 1 and 2, have been converted to synchronous condensers and no longer utilize the CCS.[6]

The heat load on the CCS from Units 3 and 4 has increased in recent years. The U.S. Nuclear Regulatory Commission (NRC) approved a 15 percent power uprate for Units 3 and 4 that was

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[3] Xcel Energy – Prairie Island Nuclear Generating Plant webpage: https://www.xcelenergy.com/energy_portfolio/electricity/nuclear/prairie_island.

[4] Google Earth photograph of Vernon, VT and Vermont Yankee Nuclear.

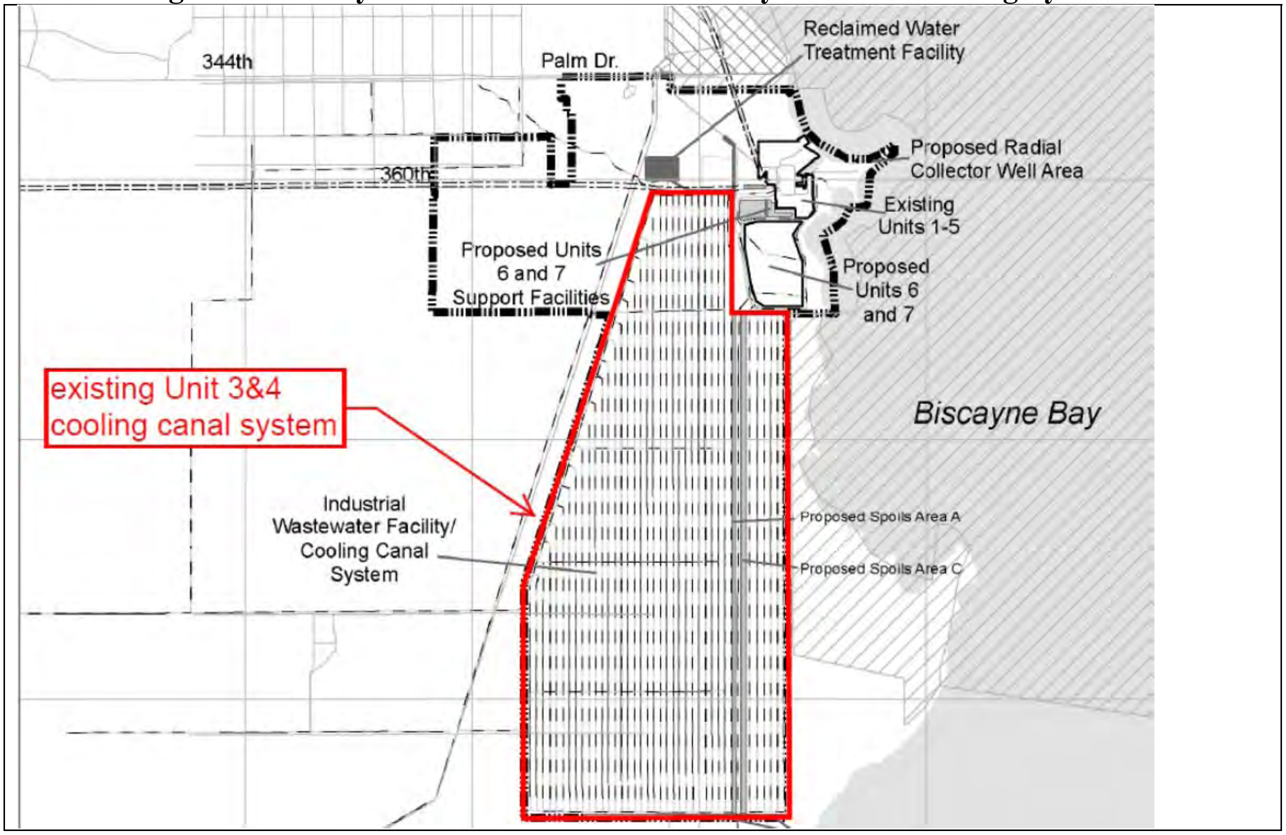
[5] NRC, Draft NUREG-2176, Volume I, February 2015, p. 2-7.

[6] Ibid, p. 3-1.

completed by FPL in 2013, from 2,300 megawatt thermal (MWt) to 2,644 MWt.[7,8] Net electric power output was increased from approximately 700 MW per unit to 816 MW per unit.[9] The amount of heat that must be rejected in the cooling system is the difference between these two values, or 1,828 MWt. This is equivalent to 6,240 million Btu per hour (MMBtu/hr) that must be removed by the cooling system in the Unit 3 and the Unit 4 cooling towers.[10]

The current average gross evaporation rate from the CCS is 44.20 mgd.[11] However, on average 15.52 mgd is replenished by rainfall.[12] The net average CCS evaporation rate, when rainfall replenishment is accounted for, is 28.68 mgd.[13]

Figure 2. Turkey Point Unit 3 and 4 Closed Cycle Canal Cooling System[14]



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[7] NRC, Turkey Point Units 3 and 4 Issuance of Amendments Regarding Extended Power Uprate (TAC NOS. ME4907 and ME4908) – cover letter, June 15, 2012, p. 1. "The amendments increase the licensed core power level for Turkey Point Units 3 and 4 from 2,300 megawatts thermal (MWt) to 2,644 MWt."

[8] Ibid, p. 3-1.

[9] Ibid, p. 3-1. "The net power output of Units 3 and 4 together increased from a nominal 1,400 MW(e) to 1,632 MW(e) as a result of the uprate."

[10] 1,828 MW × (1,000 kW/MW) × (3,412 Btu/kW) = 6,240 MMBtu/hr.

[11] D. Chin – University of Miami, *The Cooling Canal System at FPL Turkey Point Power Station – Final Report*, May 2016, p. 39. Available at: http://www.miamidade.gov/mayor/library/memos-and-reports/2016/05/05.12.16-Final-Report-on-the-Cooling-Canal-Study-at-the-Florida-Power-and-Light-Turkey-Point-Power-Plant-Directive-151025.pdf.

[12] Ibid, p. 39.

[13] Ibid, p. 39.

[14] NRC, Draft NUREG-2176, February 2015, p. 3-3.

C. Effect of Units 3 and 4 Uprates on Cooling Canal System Performance

Maximum circulating water temperature at the Units 3 and 4 discharge outfalls is 108 °F. Maximum water temperature near the intakes is typically about 93 °F.[15] The NRC granted FPL's 2014 request to increase the maximum intake water temperature for Unit 3 and 4 from 100 °F to 104 °F.[16] The maximum daily average temperature at the discharge of the CCS and upstream of the Units 3 and 4 cooling water intakes was 101 °F on August 22, 2014.[17] Temperatures in the CCS in the summer of 2014 were sufficiently elevated to prompt concern regarding the sustainability of the CCS as an adequate source of cooling water for Unit 3 and 4.[18] Units 3 and 4 operated continuously through the summer of 2015 with a maximum intake temperature of 98.5 °F.[19]

The Unit 3 and 4 cold water intake temperature has increased by 4 °F on average since the uprate took place.[20] Supplementary cooling was necessary in 2014 to stay within the allowable maximum intake water temperature.[21] FPL is permitted to pump up to 100 million gallons per day (mgd) of fresh water from the L-31E Canal into the CCS to reduce temperature in the June 1 – November 30 period.[22] The permit authorizes pumping from June 1 to November 30 in 2015 and 2016.[23] FPL pumped an average of 30 mgd from the L-31E Canal over 94 days in 2015, from August 27 to November 30, 2015.[24]

There has been a steady increase in cooling canal system salinity since operation of the system began in 1973.[25] Seepage from the cooling canal system into the Biscayne aquifer has increased the salinity of the aquifer for several miles inland.[26] FPL has reached an agreement with Miami-Dade County to install a system of up to six wells to pump low salinity water at a rate of 14 mgd from the Upper Floridan Aquifer into the CCS in order to reduce the salinity in the CCS.[27]

III. Alternative Cooling System for Units 3 and 4

A. Cooling Tower Already in Use at Turkey Point – Unit 5

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[15] D. Chin – University of Miami, *The Cooling Canal System at FPL Turkey Point Power Station – Final Report*, May 2016, p. 10.
[16] Ibid, p. 18.
[17] Ibid, p. 20.
[18] Ibid, p. 19.
[19] Ibid, p. 65.
[20] Ibid, p. 1.
[21] Ibid, p. 1.
[22] Ibid, p. 3.
[23] Ibid, p. 43.
[24] Ibid, p. 66.
[25] Ibid, p. 2.
[26] Ibid, p. 2.
[27] Ibid, p. 3.

Turkey Point Unit 5 is a 1,150 MW gas turbine combined cycle unit consisting of four gas turbines and one steam turbine generator that began operation in 2007. The cooling system is a wet cooling tower consisting of 24 cells in a back-to-back configuration as shown in Figure 3. The dimensions of the Unit 5 cooling tower are 96 feet width by 648 feet length.

Figure 3. Turkey Point Unit 5 24-Cell, Back-to-Back Wet Cooling Tower[28]

The initial design performance specifications for the Unit 5 cooling tower are provided in Table 2. The initial design specification called for a 22-cell cooling tower with width x length dimensions of 114 feet by 661 feet. The Unit 5 cooling tower that was built is a 24-cell cooling tower, as shown in Figure 3, with dimensions of 96 feet by 648 feet.

Table 2. Initial Design Performance Specifications for the Unit 5 Cooling Tower[29]

Parameter	Value
Number of cells	22
Length, feet	661
Width, feet	114
Deck height, feet	51
Stack height, feet	65
Circulating water flow rate, gallons per minute	306,000
Design hot water temperature, °F	105.2
Design cold water temperature, °F	86.9
Range (difference between hot and cold water temperatures), °F	18.3
Approach temperature, °F[30]	6.9
Heat rejected, million Btu per hour	2,600

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[28] Google Earth photograph, downloaded by B. Powers.

[29] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Table 3.4-3, p. 3-24; Figure 3.5-1, p. 3-34.

[30] The design 1 percent summer wet bulb temperature for Miami, FL is 80 °F. See Ecodyne, *Weather Data Handbook*, 1980, p. 6-9. Therefore, the approach temperature, assuming no recirculation at the cooling tower, would be: cold water temperature – 1 percent summer design wet bulb temperature = 86.9 °F – 80 °F = 6.9 °F.

Evaporative loss in cooling tower, gallons per minute (gpm)	4,214 (6.1 mgd)
Blowdown flowrate, gpm	1,987 (2.9 mgd)

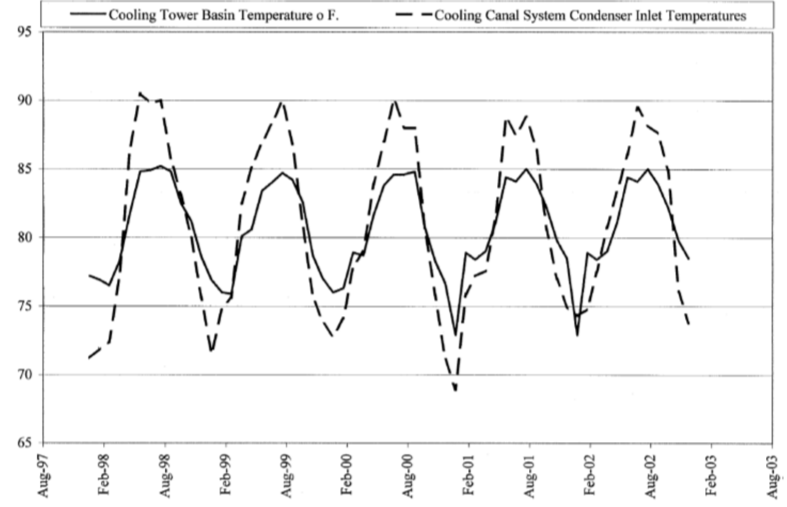
The total design makeup water flowrate for Unit 5 is 12.6 mgd.[31] Makeup water for the Unit 5 cooling tower is well water pumped from the Upper Floridan Aquifer.[32] However, FPL indicated at the permitting stage of the Unit 5 project that reclaimed water from the Miami-Dade Water and Sewer Department's (MDWASD) South District Wastewater Treatment Plant would potentially become the source of makeup water for the Unit 5 cooling tower in the future.[33]

The design Unit 5 "range" for the circulating cooling water is 18.3 °F. Range is the increase in cooling water temperature as it passes through the surface condenser located below the steam turbine. The purpose of the surface condenser is to condense the low pressure steam exiting the steam turbine back to water for return to the steam generators in a closed-loop system.

"Approach temperature" is a measure of how close the cooling tower gets the cold water to the 1 percent summer design ambient wet bulb temperature.

The conservative design of the Unit 5 cooling tower results in a design cold water temperature significantly lower than the cold water temperature achieved by the CCS.[34] This phenomenon is shown in Figure 4. The significance of this lower cold water temperature at peak conditions is that higher gross MW output can be achieved.

Figure 4. Comparison of Peak Cold Water Temperatures – Unit 5 Cooling Tower and CCS



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[31] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Figure 3.5-1, p. 3-34. Design makeup water flowrate is 8,752 gpm (12.6 mgd).

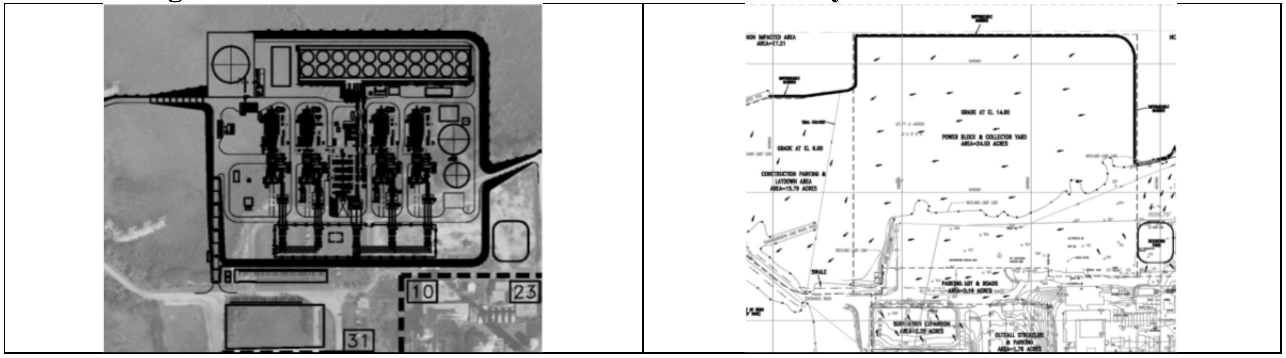
[32] Ibid, p. 3-11.

[33] Ibid, p. 3-11.

[34] The design cold water temperature is the 1 percent summer wet bulb temperature + the design approach temperature. In the case of the Unit 5 cooling tower, the 1 percent summer wet bulb temperature = 80 °F and the design approach temperature is 6.9 °F. Therefore the design cold water temperature for the Unit 5 cooling tower is: 80 °F + 6.9°F = 86.9 °F.

Most of the area covered by Unit 5 was marsh land prior to construction of the project, as shown in Figure 5a. Fill was added to increase the elevation of the area where the power block (gas turbines, steam turbine) and the cooling tower are located to an elevation of 14 feet, as shown in Figure 5b. The fill for the site was reclaimed from the limerock that was stockpiled along the CCS berms when the CCS was built.[35]

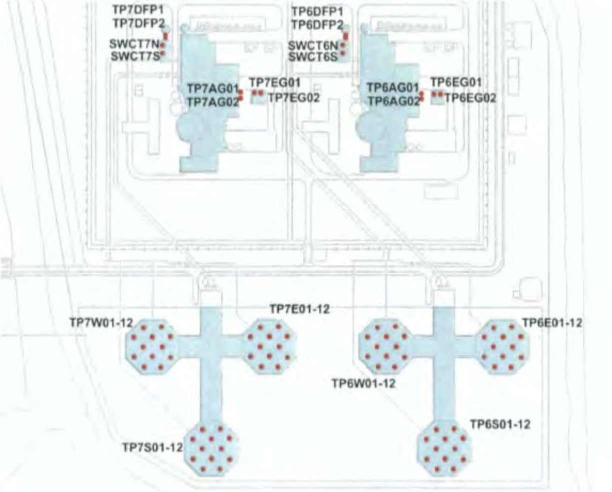
Figures 5a and 5b. Construction of Unit 5 Primarily Over Marsh Area[36,37]



B. Cooling Towers Included with Proposed Units 6 and 7

FPL has also proposed a mechanical draft wet cooling towers for proposed nuclear Units 6 and 7. These round mechanical draft cooling towers, three 12-cell round towers per unit, are shown in Figure 6, along with the general layout of the proposed Units 6 and 7 expansion project.

Figure 6. Round Mechanical Draft Cooling Towers Proposed for Units 6 and 7 (three each per unit)[38]



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[35] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, p. 3-18. "Fill material will include materials such as limerock stockpiled along the existing cooling canal berms at the Turkey Point Power Plant. The existing stockpiles are the result of the construction and maintenance of the existing cooling canal system."

[36] Ibid, Table 3.4-3, pdf p. 166.

[37] Ibid, pdf p. 172.

[38] FPL, PSD Application to Florida DEP, 2009, pdf p. 63.

The design performance specifications for the proposed Units 6 and 7 cooling towers are provided in Table 3. The specifications shown in Table 3a are for one round tower of the three round towers that collectively serve as the circulating water cooling system for each nuclear unit.

Table 3a. Design Specifications for the Units 6 and 7 Cooling Towers (three per unit)[39]

Parameter	Value
Number of round cooling towers per unit	3
Number of cells per round tower	12
Diameter, feet	246
Height, feet	67
Circulating water flow rate per round tower, gallons per minute	210,367
Design wet bulb temperature, °F[40]	83.9
Range (difference between hot and cold water temperatures), °F	24.4
Approach temperature, °F[41]	7.1
Design hot water temperature, °F	108.3
Design cold water temperature, °F	91.0
Heat rejected, million Btu per hour[42]	2,510

According to FPL's current plans, the proposed Units 6 and 7 cooling towers may use either reclaimed water delivered by pipeline from MDWASD, or saltwater from radial wells on the Turkey Point site, or a combination of the two sources, as the cooling tower makeup water supply. The normal makeup water flow rates for reclaimed water and saltwater for the Units 6 and 7 cooling towers are shown in Table 3b.

Table 3b. Total Cooling Tower Evaporative Losses and Blowdown Rates for Proposed Units 6 and 7 Cooling Towers[43]

Reclaimed water, evaporative loss in cooling tower, gpm	28,800 (41.5 mgd)
Reclaimed water, blowdown flowrate, gpm	9,714 (14.0 mgd)
Saltwater, evaporative loss in cooling tower, gpm	28,800 (41.5 mgd)
Saltwater, blowdown flowrate, gpm	57,714 (83.1 mgd)

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[39] FPL, *Turkey Point Units 6 & 7 COL Application Part 3 — Environmental Report – Revision 6,* Table 3.4-2, p. 3.4-10. Note: Revision 7 was issued October 14, 2015 but did not include any changes to the Revision 6 Part 3 — Environmental Report.

[40] Includes 3.3 °F (recirculating air) interference allowance.

[41] The design 1 percent summer wet bulb temperature for Miami, FL is 80 °F. See Ecodyne, *Weather Data Handbook*, 1980, p. 6-9. Therefore, the approach temperature, assuming no recirculation at the cooling tower, would be: cold water temperature – 1 percent summer design wet bulb temperature = 86.9 °F – 80 °F = 6.9 °F.

[42] FPL, *Turkey Point Units 6 & 7 COL Application Part 3 — Environmental Report – Revision 6,* p. 3.2-4. "The condenser rejects approximately 7.54E9 Btu/hour of waste heat to the circulating water system." 7,540 million Btu per unit = 7,540 million Btu per hour ÷ 3 cooling towers = 2,510 million Btu per hour per cooling tower.

[43] Ibid, p. 3.3-6, p.3.3-8.

The cooling towers for the proposed Units 6 and 7 are less conservatively designed than the cooling tower on Unit 5. The design cold water temperature for the proposed Units 6 and 7 cooling towers is 91 °F. In contrast, the design cold water temperature of the Unit 5 cooling tower is 87 °F. These two mechanical draft cooling tower designs represent the range of mechanical draft cooling tower performance that FPL has already employed at Turkey Point (Unit 5) or has proposed to employ (Units 6 and 7).

C. Most Recent Large-Scale Cooling Tower Retrofit at U.S. Power Plant

Two retrofit natural draft hyperbolic cooling towers were completed in May 2012 at the 1,500 MW Brayton Point Station coal- and gas-fired power plant near Fall River, Massachusetts and are shown in Figure 6.[44] These cooling towers each have a design circulating water flow rate of 400,000 gpm.[45]

Figure 6. Natural Draft Hyperbolic Cooling Towers at Brayton Point Station[46]

D. Cooling Tower Energy Penalty

A mechanical draft cooling tower retrofit, compared to continued operation of the CCS, would introduce both a net energy gain in the form of higher gross output under design conditions, and a small energy penalty in the form of: 1) extra pumping power needed to pump cooling water through the cooling tower, and 2) electricity demand of large diameter fans in each cooling tower cell.

The U.S. EPA has evaluated these energy penalties as part of the process of establishing national regulations for cooling water intake structures. Both the EPA 316(b) 2001 Phase I Technical Development Document (TDD) for new plants and the 2002 Phase II TDD for existing plants include the average heat rate penalty, fan penalty, and pump penalty for nuclear, fossil fuel, and combined cycle plants.

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[44] Telephone communication between K. Rahe, Kiewit Infrastructure (Chicago office) and B. Powers, Powers Engineering, July 11, 2016 (Kiewit Infrastructure built the Brayton Point Station cooling towers.)

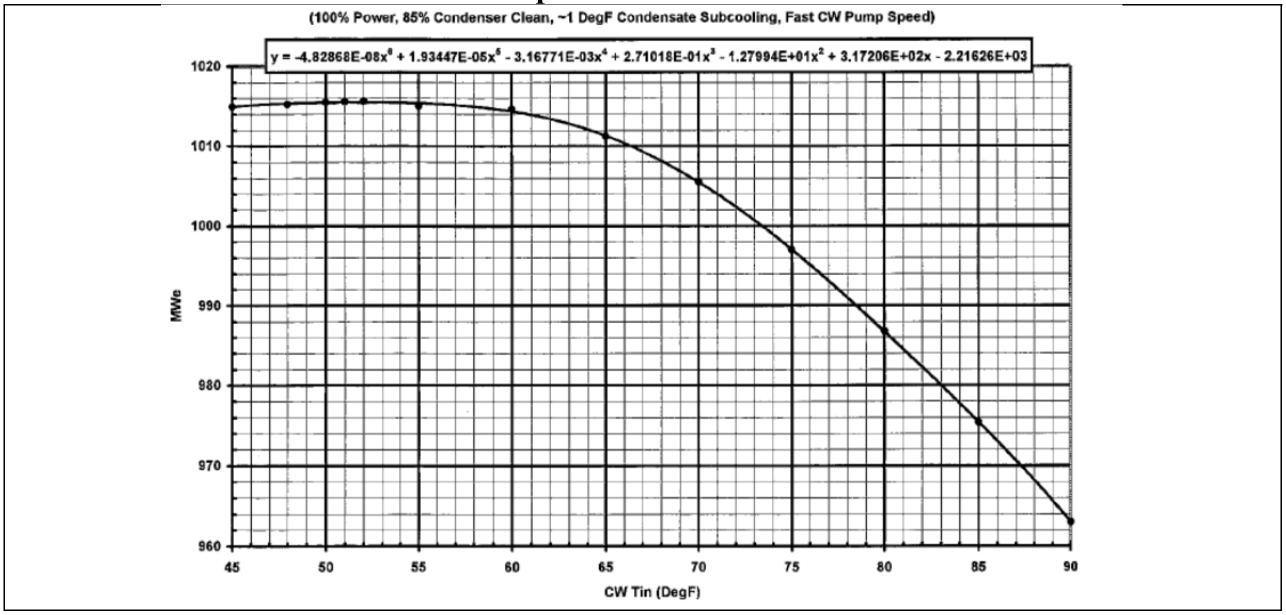
[45] U.S. EPA Fact Sheet, *Dominion Energy Brayton Point, LLC Closed Cycle Cooling Tower and Unit 3 Dry Scrubber/Fabric Filter Projects*, p. 6. See: https://www.epa.gov/sites/production/files/2015-08/documents/debp-fact-sheet.pdf.

[46] Photo downloaded from Dominion Brayton Point Power Station webpage in 2012 (the power plant was sold to Dynegy, Inc. in 2015 and the Dominion Brayton Point Power Station webpage is no longer operational).

1. Steam Turbine Efficiency Potential Improvement by Conversion to Mechanical Draft Closed-Cycle Cooling Tower

The design cold water temperature for the Unit 5 cooling tower is 87 °F. The typical average maximum cold water temperature produced by the CCS is 93 °F. The higher temperature means higher backpressure on the Units 3 and 4 steam turbines and less gross power output under design conditions. This phenomenon is shown in Figure 7 for Unit 2 of the Indian Point Energy Center in New York.[47] The output of Indian Point Unit 2 drops from 976 MW at a cold water temperature of 85 ºF to 963 MW at a cold water temperature of 90 ºF. This is a 13 MW reduction in gross output, greater than 1 percent, due to the turbine efficiency penalty experienced as the cold water temperature rises.

Figure 7. Reduction in MW Output from Indian Point Unit 2 as Hudson River Temperature Increases[48]



2. Closed-Cycle Cooling Pump and Fan Power Demand

The 2002 Phase II TDD includes the average cooling tower fan energy penalty and pump energy penalty for nuclear, fossil fuel, and combined cycle plants.[49] These energy penalties are shown in Table 4.

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[47] Powers Engineering does not have access to a similar curve for either Turkey Point Units 3 or 4.

[48] Enercon, *Conversion of Indian Point Units 2 & 3 to a Closed-Loop Cooling Water Configuration, Attachment 1-Economic and Environmental Impacts Associated with Conversion of Indian Point Units 2 and 3 to a Closed-Loop Condenser Cooling Water Configuration*, June 2003, p. 21.

[49] Ibid, Table 5-12, p. 5-23. The fan power energy penalties shown in Table 4 are for Plant #3 in (EPA TDD) Table 5-12 for a cooling tower with an approach temperature of 10 °F and a flowrate of 243,000 gpm. This is the one larger cooling tower example in Table 5-12. None of the other three cooling towers in Table 5-12 have circulating water flowrates above 30,000 gpm.

Table 4. EPA Estimates of Cooling Tower Pump and Fan Power Penalty

Plant type	Pump power energy (%)	Fan power energy (%)	Total pump and fan power energy (%)
Nuclear	0.57	0.56	1.13
Fossil fuel	0.45	0.45	0.90
Combined cycle	0.15	0.15	0.30

Mechanical draft cooling towers, either back-to-back or round, would have both booster pumps and fans, and associated pump and fan energy penalties. The average nuclear plant mechanical draft cooling tower pump and fan energy penalty would be 1.13 percent based on EPA data.

A natural draft hyperbolic cooling tower, such as the natural draft cooling towers shown in Figure 4, would have no fan energy penalty, only a pump energy penalty. The cooling tower pump energy penalty estimated by the EPA for nuclear units is 0.57 percent.[50]

The advantages of a mechanical draft cooling tower is lower capital cost and lower height than a hyperbolic tower. The advantage of the hyperbolic tower is lower operating cost, as no fan power is required.

E. Cooling Tower Installed Cost

The installed cost of the only cooling tower retrofit conducted to date on a U.S. nuclear unit, the 800 MW Palisades Nuclear in Michigan, was $68/kW in 1999 U.S. dollars. This is equivalent to approximately $98/kW in 2015 dollars.[51] This retrofit project included the installation of higher head pumps to overcome the hydraulic resistance of the cooling tower(s).[52] The two inline mechanical draft cooling towers at Palisades Nuclear are shown in Figure 8a and 8b.

Applied to the 816 MW (each) Units 3 and 4 at Turkey Point, which are effectively the same capacity as the Palisades Nuclear unit, the equivalent cost in 2015 dollars would be about $80 million per unit for conventional inline mechanical draft cooling towers, or $160 million for both

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[50] EPA 2002 Phase II TDD, Table 5-15, *Summary of Fan and Pumping Energy Requirements as a Percent of Power Output*.

[51] Chemical Engineering, *Chemical Engineering Plant Cost Index*, January 2008 and August 2015 editions. Annual index in 1999 = 390.6; annual index in 2015 = 560.7. Therefore, unit cooling tower retrofit price, adjusted from 1999 to 2015 = (560.7 ÷ 390.6) × $68/kW = $98/kW.

[52] U.S. EPA, 2002 Phase II TDD, p. 4-5 ("The final installed cost of the project was $18.8 million (in 1973-1974 dollars), as paid by Consumers Energy. The key items for this project capital cost included the following: two wood cooling towers (including splash fill, drift eliminators, and 36-200 hp fans with 28 ft blades); two circulating water pumps; two dilution water pumps; startup transformers; yard piping for extension of the plant's fire protection system; modifications to the plant screenhouse to eliminate travelling screens and prepare for installation of the dilution pumps; a new discharge pump structure with pump pits; a new pumphouse to enclose the new cooling tower pumps; yard piping for the circulating water system to connect the new pumphouse and towers; switchgear cubicles for the fans; roads, parking lots, drains, fencing, and landscaping; and a chemical additive and control system.").

units.[53] This $160 million capital expense, when amortized over ten years at standard investor-owned utility cost recovery rates, equates to an annual cost of $41 million for both units.[54]

By way of comparison, the annual revenue generated by Units 3 and 4 is approximately $500 million per year.[55] The annual electricity output of Units 3 and 4, at approximately 13,296 gigwatt-hours per year (GWh/yr),[56] represents about 10 percent of FPL's electricity sales in 2015 of 122,756 GWh/yr.[57] Assuming an annual FPL revenue stream from energy sales of approximately $5 billion, the energy charge component of a FPL residential customer's bill would increase about four-fifths of 1 percent with the addition of a $41 million per year capital recovery charge for retrofit cooling towers for Units 3 and 4.

Mechanical draft cooling tower retrofit costs at non-nuclear plants are in general agreement with the cost of the Palisades Nuclear cooling tower retrofit. The estimated cost of Georgia Power's Plant Yates cooling tower retrofit in 2003, a 40-cell back-to-back conventional mechanical draft tower with a design circulating water flowrate of 460,000 gpm, was $75 million.[58,59] This project included the addition of a booster pump station. The total cost of the Plant Yates retrofit would be about $105 million adjusted to 2015 dollars.[60] Plant Yates is located in Georgia and the plant site has a similar 1 percent summer design wet bulb temperature, 79 °F, to Miami at 80 °F.[61] The Plant Yates back-to-back cooling tower is shown in Figures 9a and 9b.

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[53] $98/kW × 2 × 816,000 kW = $160 million.

[54] Energy, Economics, and Environment, Inc. (E3), 33% Renewable Portfolio Standard Calculator 2009 Public Version, "Resource Characterizations" worksheet, cell V71, annualized IOU capital cost factor over 10-year = 0.256. Therefore the annualized cost of the $160 million cooling tower investment would be: $160 million × 0.256 = $41 million per year.

[55] 2 × 816 MW × 0.93 × 8,760 hr/yr × $37.50/MW-hr [average NERC-reported 2011-2015 FL on-peak day-ahead spot electricity price, Florida (2011-2013) and Southern (2014-2015) regions] = $499 million/yr. Source of 0.93 capacity factor: capacity factor assumed by FPL for proposed Units 6 and 7. Source of 2010-2015 FL average wholesale electricity price: NERC "state of the market" PowerPoint summaries, 2011 through 2015. Note – NERC transitioned to reporting annual average Florida and Southern regional spot electricity prices to Southern regional spot prices only in the 2014 state of the market report.

[56] 2 × 816 MW × 0.93 × 8,760 hr/yr = 13,295,578 MWh/yr (13,296 GWh/yr)

[57] FPL, *Ten Year Power Plant Site Plan, 2016-2025*, April 2016, p. 29. "Net Energy for Load (NEL) is projected to reach 125,062 GWh in 2025, an increase of 2,306 GWh from the actual 2015 value." Therefore, FPL supplied: 125,062 GWh – 2,306 GWh = 122,756 GWh in 2015.

[58] EPA Region 1, *Memorandums on conversion of Yates Plant Units 1-5 to closed-cycle cooling*, January and February 2003. The original cost estimate for the Plant Yates cooling tower was $75 million. The estimate was revised to $87 million to address wetland remediation, remediation of old asbestos landfill where towers were to be constructed, and reinforcement of concrete cooling water conduits.

[59] T. Cheek - Geosyntec Consultants, Inc. and B. Evans – Georgia Power Company, *Thermal Load, Dissolved Oxygen, and Assimilative Capacity: Is 316(a) Becoming Irrelevant? – The Georgia Power Experience*, presentation to the Electric Power Research Institute Workshop on Advanced Thermal Electric Cooling Technologies, July 8, 2008, p. 18. Plant Yates cooling tower retrofit cost was $83 million, operational in 2004.

[60] Chemical Engineering, *Chemical Engineering Plant Cost Index*, January 2008 and August 2015 editions. Annual index in 2004 = 444.2; May 2015 index = 560.7. Therefore, unit cooling tower retrofit price, adjusted from 2004 to 2015 = (560.7 ÷ 444.2) × $83 million = $105 million (2015 dollars).

[61] Ecodyne, *Weather Data Handbook*, 1980, p. 6-10 (Newnan, GA).

Figure 8a. Mechanical Draft Cooling Towers at Palisades Nuclear – Perspective View[62]

Figure 8b. Mechanical Draft Cooling Towers at Palisades Nuclear – Plan View[63]

Figure 9a. Plant Yates 40-Cell Back-to-Back Cooling Tower – Perspective View[64]

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[62] Palisades Nuclear webpage: http://palisadespowerplant.com/.

[63] Google Earth photograph, overlays by B. Powers.

[64] T. Cheek – Geosyntec, Inc., *Thermal Load, Dissolved Oxygen, and Assimilative Capacity; Is 316(a) Becoming Irrelevant? – The Georgia Power Experience*, presentation to the Electric Power Research Institute Workshop on Advanced Thermal Electric Cooling Technologies, May 8, 2008, p. 18.

Figure 9b. Plant Yates 40-Cell Back-to-Back Cooling Tower – Plan View[65]

The original design of the Turkey Point Unit 5 cooling tower was a 22-cell tower designed to reject 2,600 MMBtu of heat from the circulating cooling water at design conditions.[66] The design specifications for this cooling tower were provided in the 2003 site certification application for Unit 5. FPL ultimately built a 24-cell cooling tower, as shown in Figure 3.[67]

Approximately 6,240 MMBtu of heat must be rejected from the circulating cooling water of Units 3 and 4 (each).[68] A linear scale-up of the original 22-cell Unit 5 cooling tower design, to maintain the same design performance while rejecting 6,240 MMBtu/hr of heat, would require a 54-cell back-to-back cooling tower.[69]

The round mechanical draft cooling towers for the proposed Units 6 and 7 are less conservatively designed than the Unit 5 cooling tower. There is proportionately less circulating water flowing through the Unit 6 and 7 cooling towers. This is reflected in the 24.4 °F design range of the Units 6 and 7 cooling towers, compared to the design range of the Unit 5 cooling tower of 18.3 °F. An increase in the design range of retrofit cooling towers for Units 3 and 4 from 18.3 °F to 24.4 °F, to achieve cooling tower performance similar to the design performance of the proposed Units 6 and 7 cooling towers, would reduce the size of the Units 3 and 4 cooling towers from 54 cells to 40 cells each.[70] The design approach temperature would increase incrementally from approximately 7 °F to 8 or 9 °F with the 40-cell back-to-back cooling tower, an increase in approach temperature of 1 to 2 °F.[71]

SPX Thermal Equipment and Services (SPX), the principal manufacturer of utility-scale cooling towers in North America, provided Powers Engineering with a cost estimate for back-to-back conventional and plume-abated cooling towers for nuclear applications. The generic SPX Thermal Equipment and Services cost estimate is provided in **Attachment A**. The cost estimate

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[65] Google Earth photograph, June 12, 2016 download.

[66] See Table 2.

[67] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Table 3.4-3, p. 3-24; Figure 3.5-1, p. 3-34.

[68] See p. 6, footnote 10.

[69] (6,240 MMBtu/hr ÷ 2,600 MMBtu/hr) × 22 cells = 53 cells. The total number of cells is rounded to the nearest even number, 54 cells, for consistency with the back-to-back cooling tower design.

[70] 53 cells ÷ (24.4 °F/18.3 °F) = 39.8 cells.

[71] SPX Cooling Technologies, *Cooling Tower Information Index*, 1986, Figure 5 (tower size factor vs range variance) and Figure 6 [tower size factor vs approach (°F)], pp. 3-4.

is based on a circulating cooling water flowrate of 830,000 gpm and heat rejection of 8,300 million Btu per hour (MMBtu/hr) at a West Coast location. The cost estimate assumes premium hardware and California seismic requirements.

The SPX-estimated capital cost for a fresh water 54-cell back-to-back mechanical draft cooling tower, composed of three tower sections of 18-cells each and based on the design specifications of the Unit 5 cooling tower, is $145 million (in 2009 dollars).[72] The capital cost of this cooling tower in 2015 dollars would be $156 million.[73] The cost of two of these cooling towers, for Units 3 and 4, would be approximately $310 million (in 2015 dollars). The annualized cost over ten years of this capital investment would be about $79 million per year.[74]

The cost of energy production from Units 3 and 4, assuming use of the 54-cell cooling towers, would increase about $5.90/MWh ($0.0059/kWh), with the addition of retrofit cooling towers, or about 16 percent assuming a base case wholesale electricity price of $37.50/MWh.[75] The cost of electricity production for the FPL system as whole, of which Units 3 and 4 provide about 10 percent of the annual delivered electricity, would increase about 2 percent with the addition of retrofit cooling towers on Units 3 and 4.[76]

The interpolated SPX cost estimate for a 40-cell back-to-back cooling tower, assuming a linear cost relationship, is approximately $108 million (in 2009 dollars). The capital cost of this cooling tower in 2015 dollars would be $116 million.[77] The 40-cell cooling tower design for Units 3 and 4 is based on the performance specifications for the proposed Units 6 and 7 cooling towers. The cost of two of these cooling towers, for Units 3 and 4, would be approximately $230 million (in 2015 dollars). The annualized cost over ten years of this capital investment would be about $59 million per year.[78]

The cost of energy production from Units 3 and 4, assuming use of the 40-cell cooling towers, would increase about $4.40/MWh ($0.0044/kWh), with the addition of retrofit cooling towers, or about 12 percent assuming a base case wholesale electricity price of $37.50/MWh.[79] The cost of electricity production for the FPL system as whole, of which Units 3 and 4 provide about 12

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[72] SPX estimates that the non-cooling tower infrastructure cost is approximately three times the cost of the wet cooling tower. These costs include: site preparation, basins, piping, electrical wiring and controls. The cost of a 54-cell wet back-to-back cooling tower is estimated by SPX at $36.4 million. The associated infrastructure cost = 3 x $36.4 million = $109.2 million. Therefore, the total project cost would be: $36.4 million + 109.2 million = $145.6 million.

[73] Chemical Engineering, *Chemical Engineering Plant Cost Index*, January 2008 and August 2015 editions. Annual index in 2009 = 521.9; May 2015 index = 560.7. Therefore, unit cooling tower retrofit price, adjusted from 2009 to 2015 = (560.7 ÷ 521.9) × $145 million = $156 million (2015 dollars).

[74] $310 million × 0.256 = $79 million per year.

[75] $79 million per year ÷ 13,296,000 MWh per year = $5.94/MWh. This is approximately 16 percent of $37.50/MWh.

[76] The primary charges on the customer bill are: 1) transmission and distribution charge, and 2) energy charge. The energy charge is typically the lesser of these two primary charges.

[77] Ibid. The unit cooling tower retrofit price, adjusted from 2009 to 2015 = (560.7 ÷ 521.9) × $108 million = $116 million (2015 dollars).

[78] $230 million × 0.256 = $59 million per year.

[79] $59 million per year ÷ 13,296,000 MWh per year = $4.44/MWh. This is approximately 12 percent of $37.50/MWh.

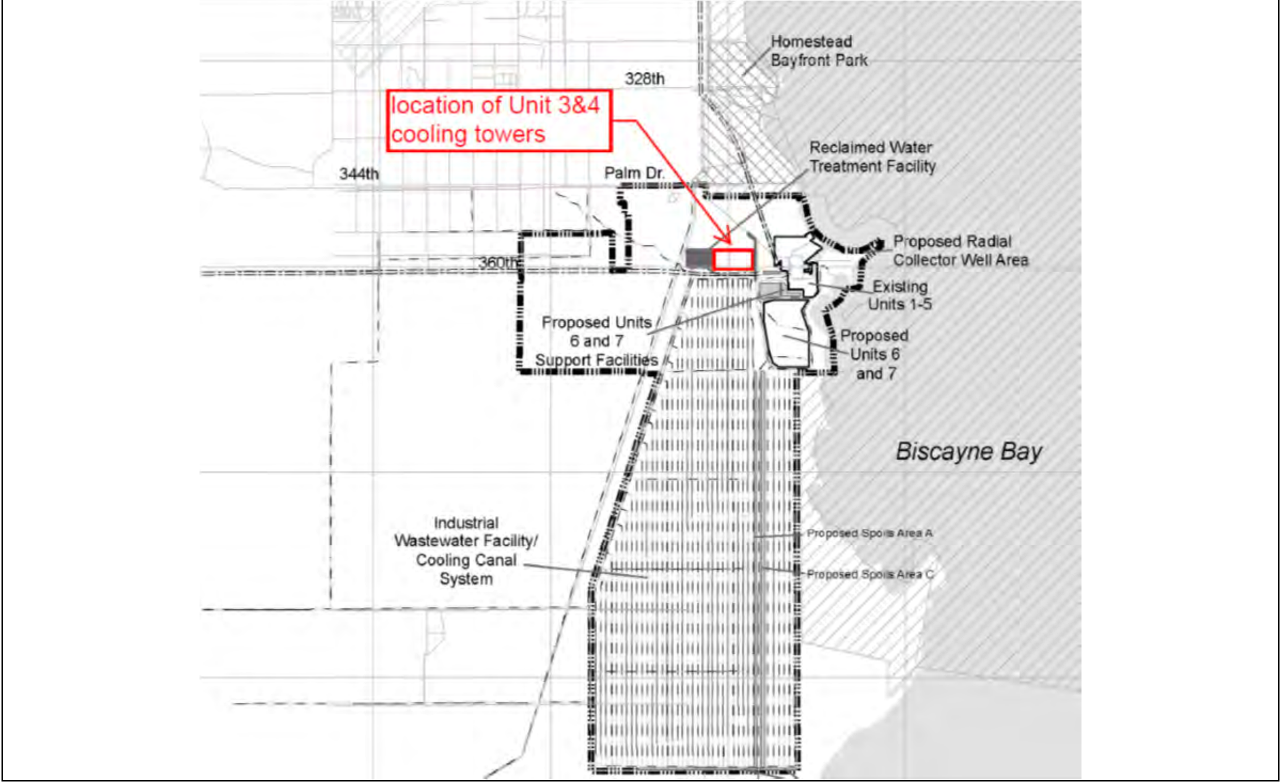
percent of the annual delivered electricity, would increase about 1.5 percent with the addition of retrofit cooling towers on Units 3 and 4.

IV. Retrofit Cooling Tower Configurations for Units 3 and 4

A. General Location of Retrofit Cooling Towers

The one area on the Turkey Point site that has ample space for the Units 3 and 4 mechanical draft cooling towers is adjacent to the Units 3 and 4 discharge canal and is not designated for potential use in the proposed Units 6 and 7 project. This area is shown as a red rectangle in Figure 10. This area is to the immediate east of the site designated as the reclaimed water treatment facility for the Units 6 and 7 cooling towers.[80]

Figure 10. Proposed Location of Units 3 and 4 Mechanical Draft Cooling Towers[81]



A more detailed view of the proposed location of the Units 3 and 4 cooling towers, as well as existing and proposed infrastructure, is shown in Figure 11.

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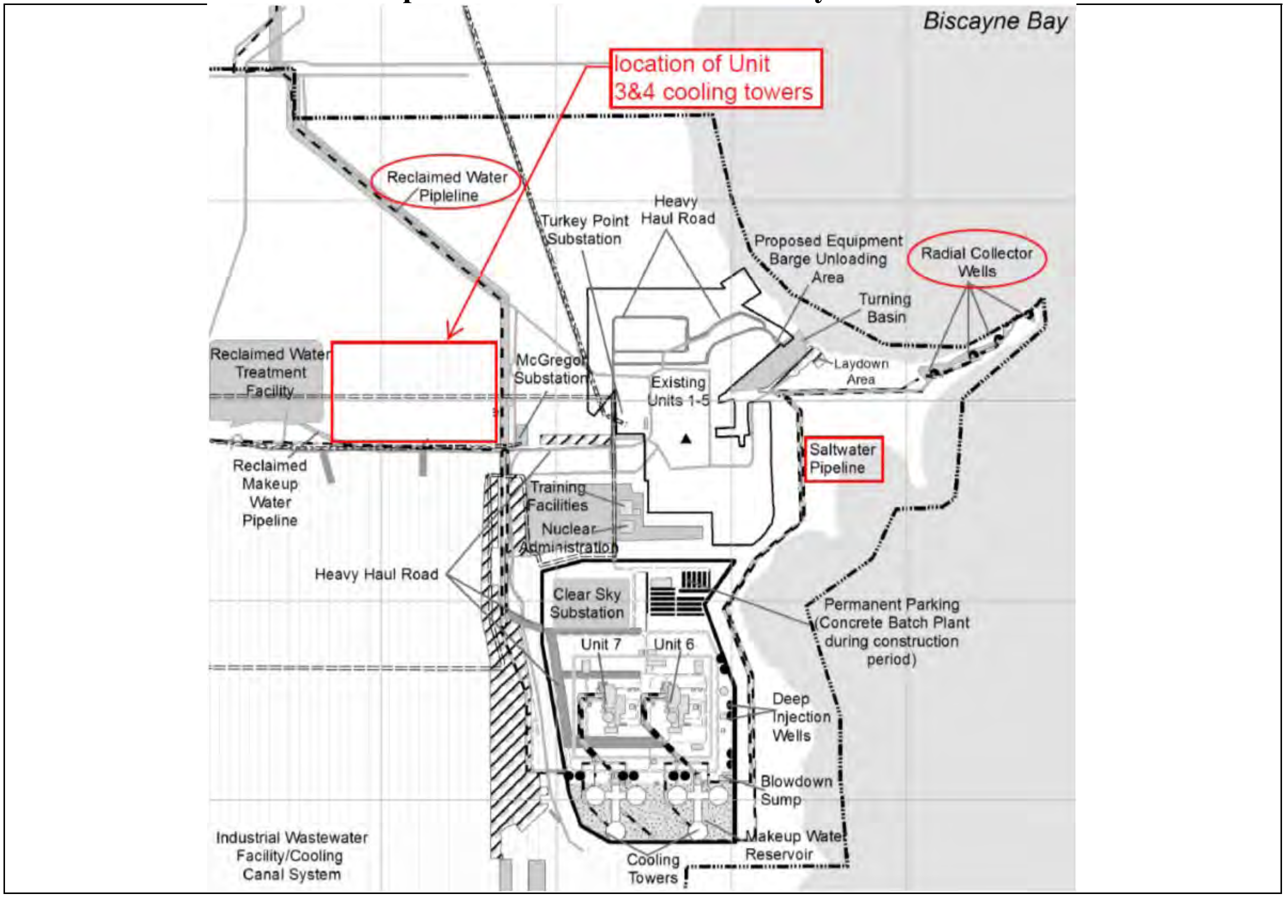
[80] The water supply being treated would be treated wastewater from the Miami-Dade Water and Sewer Department delivered by pipeline to the location. The proposed pipeline is shown in Figure 11.

[81] NRC, Draft NUREG-2176, Volume I, February 2015, p. 3-3.

Figure 11. General Location of Proposed Units 3 and 4 Cooling Towers and Existing and Proposed Infrastructure at Turkey Point[82]



B. 54-Cell Back-to-Back Mechanical Draft Cooling Towers - Layout

One potential layout for 54-cell cooling towers for Units 3 and 4 is provided in Figure 12. The cooling towers would be composed of three 18-cell sections. The cool water collected in the cooling tower cold water basin under the cooling tower would flow by gravity back to the return canal leading to the Units 3 and 4 intakes. The source of makeup water currently for the CCS is natural seepage from the surrounding aquifer.[83] Reclaimed water from the MDWASD would serve as makeup water for the Units 3 and 4 cooling towers.

The cooling tower sections shown in Figure 12 have sufficient spacing to avoid recirculation of warm, moisture-laden exhaust air from one cooling tower section being entrained in the inlet of an adjacent cooling tower section. Appropriate minimum spacing between cooling tower sections to avoid the effects of interference is shown in **Attachment B**.

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[82] Ibid, p. 3-7.

[83] D. Chin – University of Miami, *The Cooling Canal System at FPL Turkey Point Power Station – Final Report*, May 2016, p. 37.

Figure 12. 54-Cell Back-to-Back Mechanical Draft Cooling Towers

C. 40-Cell Back-to-Back Mechanical Draft Cooling Towers - Layout

A potential layout for 40-cell cooling towers for Units 3 and 4 is provided in Figure 13. The cooling towers would each be composed of one 40-cell cooling tower in a 2×20 back-to-back configuration. This would be the same cooling tower design used at Plant Yates and shown in Figures 9a and 9b.

Figure 13. 40-Cell Back-to-Back Mechanical Draft Cooling Towers[84]

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[84] Google Earth photograph, overlays added by B. Powers.

D. Additional Infrastructure Necessary for Units 3 and 4 Closed-Cycle Cooling Retrofits

1. Makeup Water Source – Reclaimed Water from MDWASD

Cooling tower makeup water supply would come from reclaimed wastewater provided by the MDWASD. Makeup water is necessary to replace water evaporated in the cooling tower(s) and removed from the circulating water system as blowdown. The reliability of the reclaimed water supply would be assured by constructing treated reclaimed water reservoirs at Turkey Point to assure two-to-three weeks of onsite reclaimed water supply in case of outages at the SDWWTP. This is the reclaimed water supply model that has been used successfully at the 3,900 MW Palo Verde Nuclear plant in Arizona for 30 years. See **Attachment C** for a detailed description of the Palo Verde Nuclear reclaimed water system.

The MDWASD treatment plant closest to Turkey Point, the South District Wastewater Treatment Plant (SDWWTP)about 9 miles north, injects approximately 101 mgd of treated wastewater into the Lower Floridan Aquifer.[85,86] The SDWWTP would be the source of reclaimed water supply to Turkey Point.

The concept of using MDWASD reclaimed water as cooling tower makeup water supply at Turkey Point is well established. Reclaimed water is the sole source of makeup water supply at Palo Verde Nuclear. Reclaimed water is identified by FPL as the primary source of makeup water for the proposed Units 6 and 7 cooling towers.[87] FPL also identified its intention to potentially transition its Unit 5 cooling tower makeup water supply from the Upper Floridan Aquifer to reclaimed water at some point in the future.[88]

Use of MDWASD reclaimed water as the makeup water supply for the proposed Units 3 and 4 cooling towers would contribute to the resolution of a regional treated wastewater discharge disposal challenge and eliminate evaporative losses of surface water in the CCS due to heated discharge water from Units 3 and 4. MDWASD is required by Florida statute to reuse 60 percent of its ocean outfall discharge by 2025.[89] This is equivalent to 117.5 mgd of reuse.[90] The 2013

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[85] Ecology & Environment, Inc., *MDWASD Reuse Feasibility Update – Chapter 3: Future Conditions, April 2007*, p. 3-6. "The SDWWTP is required to upgrade their treatment to produce effluent meeting FDEP HLD (High Level Disinfection) requirements. The upgrades were deemed necessary following an indication that the deeper Floridan Aquifer (Boulder Zone), where the SDWWTP effluent is injected, is possibly leaking upwards into the Upper Floridan. Since the Upper Floridan is defined as a USDW (Underground Source of Drinking Water) by the EPA, FDEP requires that the SDWWTP effluent meets HLD standards to ensure that any migration of the injected fluid into the Upper Floridan will not have negative impacts on the water quality of the USDW."

[86] E-mail communication between Bertha Goldberg, Assistant Director MDWASD, and Laura Reynolds, Conservation Concepts, LLC, July 7, 2016.

[87] FPL, Turkey Point Units 6 & 7 COL Application Part 3 — Environmental Report – Revision 6, p. 3.2-6.

[88] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, p. 3-11.

[89] Chapter 403.086(9)(c)(1), F.S. "(c)1. Each utility that had a permit for a domestic wastewater facility that discharged through an ocean outfall on July 1, 2008, must install, or cause to be installed, a functioning reuse system within the utility's service area or, by contract with another utility, within Miami-Dade County, Broward County, or Palm Beach County by December 31, 2025. For purposes of this subsection, a "functioning reuse system" means an environmentally, economically, and technically feasible system that provides a minimum of 60 percent of a facility's

MDWASD compliance plan proposed that 90 mgd would be utilized by FPL at Turkey Point for proposed Units 6 and 7.[91] However, FPL has officially delayed the Units 6 and 7 project until 2031-2032.[92] Therefore the primary MDWASD reuse strategy for 2025 compliance, directing the treated wastewater for use in the Units 6 and 7 cooling towers, is no longer an alternative. An advantage of using MDWASD reclaimed water as Units 3 and 4 cooling tower makeup water is its low salinity. The low salinity of this water supply allows the cooling tower blowdown flowrate to be minimized. This in turn would reduce the quantity of cooling tower wastewater requiring disposal.[93]

FPL has proposed constructing a reclaimed water treatment facility at Turkey Point to prepare the reclaimed water for use as circulating water system cooling tower makeup for proposed Units 6 and 7.[94] The estimated cost of the reclaimed water treatment plant to treat 90 mgd, and the dedicated reclaimed water pipeline from the SDWWTP that would be paid for by Miami-Dade County, is about $400 million.[95] The 90 mgd includes reclaimed water supply for the existing Unit 5 cooling tower. The pipeline cost is about $80 million of the $400 million total capital cost.[96]

This treatment facility could also be constructed, at smaller scale, to treat reclaimed water for use in the Units 3, 4, and 5 cooling towers. The capital cost of the reclaimed water plant, if sized to serve Units 3, 4, and 5 cooling towers, would be in the range of $140 million.[97] It would continue

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baseline flow on an annual basis for irrigation of public access areas, residential properties, or agricultural crops; aquifer recharge; groundwater recharge; industrial cooling; or other acceptable reuse purposes authorized by the department."

[90] Telephone communication between Bertha Goldberg, P.E., Assistant Director MDWASD, and Laura Reynolds, Conservation Concepts, LLC, July 7, 2016.

[91] Ibid.

[92] Ibid.

[93] FPL, Turkey Point Units 6 & 7 COL Application Part 3 — Environmental Report – Revision 6, p. 3.3-1.

[94] Ibid, p. 3.3-3. "The makeup water for the circulating water cooling towers would be treated to prevent biofouling in the raw water supply piping to the circulating water cooling towers. Additional treatment for biofouling, scaling, and suspended matter, with biocides, antiscalants, and dispersants would be performed as needed for the circulating water system and service water system. . . Cooling water chemistry would be controlled by the addition of chemicals and maintaining the proper cycles of concentration."

[95] Miami-Dade County Memorandum, *Resolution Authorizing Execution of a Joint Participation Agreement with Florida Power & Light Company to Develop a Reclaimed Water System to Serve the Company's Turkey Point Facility*, R-813-10, July 20, 2010, pp. 1-2. "This agreement represents a significant cost savings to the County within the overall context of reuse mandates. It should be noted that FP&L costs to design, procure and manage the construction of the pipeline plus construction of the additional treatment facilities to reduce nutrient content of the reclaimed water before it is used for cooling are estimated to exceed $400 million for this project. Other options for the County to satisfy WUP requirements, such as ground water replenishment could cost the County at least $300 million more than the option to provide reclaimed water to FP&L . . . The amount payable by the County (for the pipeline) is capped at $78 million (in January 2010) with maximum escalation of 4% per year . . . The attached JPA allocates up to 90 mgd of reclaimed water . . . to cool FP&L's existing gas powered plant (Unit 5) and the two proposed nuclear power units (Units 6 and 7)."

[96] Ibid.

[97] Unit 5 cooling tower average evaporative loss = 4,214 gpm (6.1 mgd). See footnote 106. Projected Units 3 and 4 cooling towers evaporative loss (combined) = 20,250 gpm (29.2 mgd). Total evaporative loss in Units 3, 4, and 5 cooling towers = 6.1 mgd + 29.2 mgd = 35.3 mgd . Assume all blowdown water is recycled to makeup water. Therefore approximate reclaimed water average need = 35 mgd. Assume 15 percent additional makeup water needed to meet peak demand, or a peak makeup water demand of 40 mgd. Assuming linear relationship between

to be available for use or expansion if proposed Units 6 and 7, or some other steam turbine generator technology, is built at the site to replace Units 3 and 4 when the operating licenses for these units expire in 2032 and 2033.[98]

MDWASD currently disposes of the treated wastewater by deep well injection at the SDWWTP,[99] with the associated high operations and maintenance costs of deep well injection. The cost of treatment of the reclaimed water to the level needed for use in the Units 3 and 4 cooling towers would in part be offset by eliminating the cost of deep well injection of this wastewater.

Treated reclaimed water storage reservoirs would also be needed if reclaimed water is the sole source of makeup water for the Units 3 and 4 cooling towers. At Palo Verde Nuclear a reserve reclaimed water supply is maintained in two onsite storage reservoirs. The total storage volume of the two reservoirs is 1.16 billion gallons.[100] Makeup water consumption is 43,000 gpm on average (61.9 mgd).[101] The storage reservoirs hold about 19 days of makeup water supply at average usage conditions.[102] The two storage reservoirs cover 45 acres and 65 acres respectively.[103]

Turkey Point would require about 665 million gallons of reclaimed water storage to provide 19 days of makeup water supply to Units 3, 4, and 5 cooling towers at average makeup water demand conditions.[104] Figure 13 shows two potential locations for reclaimed water storage reservoirs near the proposed Units 3 and 4 cooling tower locations. These two reservoirs, at approximately 40 acres and 60 acres respectively, would provide about 650 million gallons of reclaimed water storage if dredged to a uniform depth of 20 feet.[105] This would be sufficient storage to approximately equal the 19 days of stored reclaimed water supply maintained in the two storage reservoirs at Palo Verde Nuclear.

Unit 5 draws about 12.6 mgd on average from the Upper Floridian Aquifer for use as makeup water for the Unit 5 cooling tower.[106] Another 14 mgd of Upper Floridian Aquifer water is also supplied to the CCS for salinity control.[107] This water is brackish, with an average total dissolved

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reclaimed water treatment plant size and capital cost, a 40 mgd treatment plant would cost: (40 mgd/90 mgd) × $320 million = $142 million (2010 dollars).

[98] Turkey Point Unit 3 NRC webpage, license expires 07/19/2032: http://www.nrc.gov/info-finder/reactors/tp3.html; Turkey Point Unit 4 NRC webpage, license expires 04/10/2033: http://www.nrc.gov/info-finder/reactors/tp4.html.

[99] Ecology & Environment, Inc., *MDWASD Reuse Feasibility Update – Chapter 3: Future Conditions, April 2007*, p. 3-6.

[100] B. Lotts – APS, *Water and Energy in Arizona - Palo Verde Water Reclamation Facility*, PowerPoint presented at 2011 Ground Water Protection Council Annual Forum, Atlanta, September 24-28, 2011, p. 11.

[101] Ibid. 43,000 gpm × 60min/hr × 24 hr/day = 61.9 mgd.

[102] 1,160 million gallons ÷ 61.9 million gallons/day = 18.7 days.

[103] B. Lotts, p. 21.

[104] 35 million gallons/day × 19 days = 665 million gallons.

[105] $[100 \text{ acres}/(640 \text{ acres/mile}^2)] \times (27{,}878{,}400 \text{ feet}^2/\text{mile}^2) \times 20 \text{ feet} \times (7.5 \text{ gallons/ft}^3) = 653.4$ million gallons.

[106] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Figure 3.5-1, p. 3-34. Design makeup water flowrate is 8,752 gpm (12.6 mgd).

[107] Ibid, p. 3.

solids (TDS) content of 1,911 ppm.[108] The pumping of 14 mgd from the Upper Floridan Aquifer for CCS salinity control can be discontinued when the Units 3 and 4 cooling towers are operational, as makeup water for these cooling towers will be MDWASD reclaimed water and the CCS will no longer be used for cooling.

<u>54-cell cooling tower alternative</u>: A supply of 8,752 gpm from the Upper Floridian Aquifer is the makeup water demand for the designed 309,000 gpm circulating water flowrate of the Unit 5 cooling tower.[109] Of this amount, 8.9 mgd (6,201 gpm) is required to make up cooling tower evaporative and blowdown losses.[110] The design heat rejection of the Unit 5 cooling tower is 2,600 MMBtu/hr. The design heat rejection of each 54-cell cooling tower for Units 3 and 4 would be 6,240 MMBtu/hr. Therefore the design circulating water flowrate for the Unit 3 and Unit 4 cooling towers assuming a linear scale-up in flowrate, to achieve the Unit 5 cooling tower performance specifications, would be 742,000 gpm each.[111]

The makeup water flowrate for the Unit 3 and Unit 4 cooling towers to replace evaporation and blowdown losses would be 14,890 gpm each if scaled-up directly from Unit 5 cooling tower design flowrates.[112] Of this makeup water flowrate, 68 percent (10,125 gpm per unit) evaporates in the cooling towers and 32 percent (4,765 gpm per unit) is blowdown.[113] About 20,250 gpm (29 mgd) of the total makeup water supply for the Units 3 and 4 cooling towers would be lost to evaporation in the towers.[114] By way of comparison, the net average evaporation rate of the CCS is approximately 28.7 mgd.[115] The Units 3 and 4 cooling tower(s) evaporation rate would be about the same as the net evaporation rate in the CCS.

The amount of makeup water is driven by the evaporation rate in the cooling tower(s) and the blowdown rate. The use of low salinity reclaimed water as makeup water supply instead of brackish well water supply can substantially reduce the rate of blowdown necessary to avoid excessive scale buildup in the cooling towers. The amount of blowdown would depend on the "cycles of concentration" maintained in the circulating cooling water.[116] Maximizing the cycles of concentration in the circulating cooling water would reduce the makeup water needed to

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[108] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Table 3.5-1, p. 3-26.

[109] Ibid, Figure 3.5-1, p. 3-34. Note that the Unit 5 cooling tower circulating water flowrate is identified as both 306,000 gpm and 309,000 gpm in the source document.

[110] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Figure 3.5-1, p. 3-34. The average "evaporation and drift" (4,214 gpm) and blowdown (1,987 gpm) rates for the Unit 5 cooling tower sum to 6,201 gpm. 6,201 gpm = 6,201 gpm × 60 min/hr × 24 hr/day × (1 mgd/10^6 gallons-day) = 8.9 mgd.

[111] (6,240 MMBtu/hr ÷ 2,600 MMBtu/hr) × 309,000 gpm = 742,000 gpm.

[112] (742,000 gpm ÷ 309,000 gpm) × 6,201 gpm = 14,890 gpm. 14,890 gpm × 60 min/hr × 24 hr/day = 21.4 mgd.

[113] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Figure 3.5-1, p. 3-34. Percentages are derived from the design makeup water evaporation and drift (4,214 gpm), and blowdown (1,987 gpm) average rates for the Unit 5 cooling tower. Evaporation and drift loss replacement is 68 percent of the total (10,125 gpm), and blowdown is 32 percent of the total (4,765 gpm).

[114] 10,125 gpm × 2 = 20,250 gpm. 20,250 gpm × 60 min/hr × 24 hr/day= 29.2 mgd.

[115] D. Chin – University of Miami, *The Cooling Canal System at FPL Turkey Point Power Station – Final Report*, May 2016, p. 39.

[116] Water Technology Report, Cycles of Concentration, March 30, 2015: https://watertechnologyreport.wordpress.com/tag/cycles-of-concentration/. "Cycles of concentration (COC) is defined by the ratio of the dissolved solids in the tower water to the dissolved solids in the makeup."

replace blowdown. This would also minimize the blowdown flowrate. This is discussed in more detail in the discussion of the blowdown treatment system.

FPL is currently permitted to pump up to 100 mgd of fresh water from the L-31E Canal into the CCS to reduce temperature in the June 1 – November 30 period.[117] Fresh water pumping from the L-31E Canal to the CCS would no longer be needed if use of the CCS for heat rejection is discontinued in favor of retrofit Units 3 and 4 cooling towers.

40-cell tower alternative: Cooling towers for Units 3 and 4 that are sized based on the Units 6 and 7 cooling tower performance specifications would require 25 percent less makeup water. Total circulating water flowrate per cooling tower would be reduced from 742,000 gpm to 557,000 gpm.[118] However the makeup water flowrate to replace evaporative loss in the Units 3 and 4 cooling towers would remain approximately 29 mgd, as the same amount of heat would need to be rejected via evaporation as in the 54-cell cooling tower alternative. The makeup water needed to replace blowdown would be minimized by maximizing the cycles of concentration in the circulating cooling water.

2. Blowdown Discharge System – Zero Liquid Discharge

The circulating cooling water will have to be continuously blown down to prevent a build-up of solids in the cooling towers. The precipitation of solids degrades the thermal efficiency of the cooling system.

Use of reclaimed water as the makeup water source will allow for production of a highly concentrated, relatively low-flow blowdown stream. This has been done in actual practice for thirty years at the 3,900 MW Palo Verde Nuclear in Arizona.[119] Secondary treated municipal wastewater is from the City of Phoenix is utilized as cooling tower makeup water.[120]

The cooling towers are operated on average at 24 cycles of concentration at Palo Verde.[121] Lime soda softening and soda ash softening are used to remove scaling agents such as hardness, alkalinity, ortho-phosphate, and silica.[122] Average makeup water total dissolved solids (TDS) concentration is about 1,000 parts per million (ppm).[123,124] In contrast, the TDS of MDWASD treated wastewater is substantially lower at approximately 375 ppm.[125] Circulating cooling water TDS at Palo Verde is about 24,000 ppm.[126]

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[117] Ibid, p. 3.

[118] 742,000 gpm × (18.3 °F/24.4 °F) = 557,000 gpm.

[119] J. Maulbetsch, M. DiFilippo, *Performance, Cost, and Environmental Effects of Saltwater Cooling Towers*, CEC-500-2008-043, prepared for California Energy Commission - Public Interest Energy Research Program, January 2010, pp. 39-40 (C.6 Palo Verde Nuclear Generating Station).

[120] Ibid, p. 39.

[121] Ibid, p. 40.

[122] Ibid, p. 39.

[123] Ibid, p. 40.

[124] ppm = milligram per liter (mg/l).

[125] V. Walsh – MDWASD, *Tracing Vertical and Horizontal Migration of Injected Fresh Wastewater into a Deep Saline Aquifer using Natural Chemical Tracers*, 20th Salt Water Intrusion Meeting, June 2008, p. 2.

[126] J. Maulbetsch, p. 40. The 24,000 ppm TDS concentration in the Palo Verde cooling tower(s) blowdown is about 70 percent of the TDS concentration in seawater (~35,000 ppm).

This high degree of concentration will allow for a zero liquid discharge (ZLD) system of reasonable capital and operating cost to treat the blowdown from the Units 3 and 4 cooling towers. Almost all the water in the blowdown, greater than 95 percent, is recycled in the ZLD system as purified water and available for reuse.[127] The purified water produced by the ZLD system would be re-utilized as makeup water to the Units 3 and 4 cooling towers. Solid residue produced by the ZLD process would be landfilled.

ZLD technology can be used to treat cooling system blowdown discharges from Units 3 and 4 cooling towers as an alternative to deep well injection. ZLD uses reverse osmosis and crystallizers to recycle cooling tower blowdown to produce clean water and a solid salt cake residue as end products.[128] A brief primer on ZLD technology and cost is presented in **Attachment D**. A description of the ZLD system in use on the Arizona Public Service 1,060 MW Redhawk combined-cycle power plant is provided in **Attachment E**.

Units 3 and 4 cooling towers will produce a total of about 900 gpm (1.3 mgd) of cooling tower blowdown at 24 cycles of concentration, using the same design ratio of blowdown flowrate to total makeup water flowrate as is used in the Palo Verde Nuclear cooling towers.[129] The installed capital cost of a ZLD treatment system capable of treating 900 gpm of cooling tower blowdown is approximately $32 million in 2016 dollars, based on an extrapolation of the capital cost of the ZLD system in use at the 1,100 MW APS Redhawk power plant.[130]

The primary operating cost of the ZLD system is electric power. A 900 gpm system would have an electric power demand of approximately 5,500 kW,[131] equivalent to an annual power cost of about $2 million per year.[132] Round-the-clock operator costs and maintenance costs would add another $1 million per year in annual operating costs.[133] As noted, more than 95 percent of the blowdown water processed in the ZLD system could be reused as makeup water.

In addition, the Unit 5 cooling tower blowdown, averaging 1,987 gpm, is directed to the existing Units 3 and 4 discharge canal.[134] The circulating water in the discharge canal would pass through the Units 3 and 4 cooling towers. As a result, the design of the ZLD system must take into account the additional TDS burden imposed by the Unit 5 cooling tower blowdown. The additional TDS burden from the Unit 5 blowdown would result in a "composite" makeup water

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[127] E-mail from Stephen Heal - Vice President Sales & Marketing, Veolia Water Technologies, to B. Powers, Powers Engineering, July 5, 2016.

[128] Global Water Intelligence, *From zero to hero – the rise of ZLD*, December 2009. See also **Attachment D**.

[129] (volumetric flow of total makeup water)/(volumetric flow of blowdown) = cycles of concentration (CoC). Therefore, (evaporative loss + blowdown flow)/(blowdown flow) = CoC. (20,250 gpm + 900 gpm)/900 gpm = 23.5. And 900 gpm × 60 min/hr × 24 hr/day= 1.27 mgd.

[130] E-mail from Stephen Heal - Vice President Sales & Marketing, Veolia Water Technologies, to B. Powers, Powers Engineering, July 4, 2016.

[131] Ibid.

[132] 5,500 kW × (1 MW/1,000 kW) × $37.50/MW-hr × 8,760 hr/yr = $1.81 million/yr.

[133] Stephen Heal, July 4, 2016.

[134] GeoTrans, Inc., Draft Feasibility Study to Assess Engineering Options for Stopping Western Migration of Saline Water and Decreasing Cooling Canal System Concentrations, Turkey Point Plant, Florida – Attachment 1, August 11, 2010, , pdf p. 33.

TDS to the Units 3 and 4 cooling towers of less than 1,000 ppm.[135] As a result, it is reasonable to assume 24 cycles of concentration are achievable in the Units 3 and 4 circulating cooling water, based on the 24 cycles of concentration achieved at Palo Verde with a makeup water TDS concentration of about 1,000 ppm.

ZLD technology is cost-effective and would eliminate cooling tower blowdown discharges from the Units 3 and 4 cooling towers. Use of ZLD would also reduce makeup water demand proportionate to the amount of water recycled onsite by use of the ZLD system. In the case of a 900 gpm ZLD system to treat blowdown from Units 3 and 4 cooling towers, almost all of the 900 gpm of purified water produced by the ZLD process, about 1.3 mgd,[136] could be reused as makeup water for the cooling towers.

3. Chemical Treatment of Circulating Cooling Water

The chemical treatment applied to circulating cooling water serving the Units 3 and 4 cooling towers will follow the protocol used by FPL on Unit 5 circulating cooling water:[137]

> Intermittent shock chlorination or other oxidizing or non-oxidizing biocides will be used to prevent biofouling of the heat rejection system. A chlorine solution will be feed into the cooling water.
>
> A scale inhibitor will be fed to the circulating water system to control the formation of calcium carbonate scales. These scales can adhere to heat transfer surfaces and impair cooling condenser performance. Sulfuric acid will be added to the circulating water system to reduce alkalinity in the circulating water makeup, thus reducing the likelihood of scale formation. In addition, a polymer may be added to the circulating water system to help hold suspended solids in suspension.
>
> Cooling tower makeup water will be pretreated by chemical softening prior to addition to the cooling tower basin.

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[135] Total reclaimed water makeup for evaporative loss in Units 3 and 4 cooling towers = 20,250 gpm @ TDS of 375 ppm. Design blowdown discharge from Unit 5 = 1,987 gpm @ ~5,700 ppm (3 cycles of concentration. *See* FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, Figure 3.5-1, p. 3-34). The additional TDS in the Unit 5 blowdown would add in effect a maximum of about 560 ppm per gpm to the reclaimed water makeup supply: 1,987 gpm/20,250 gpm = x ppm/ 5,700 ppm. 5,700 ppm × (1,987 gpm/20,250 gpm) = 559 ppm. Therefore, the maximum TDS concentration in Units 3 and 4 makeup water supply, accounting for the Unit 5 cooling tower blowdown TDS contribution, is: 375 ppm + 559 ppm = 934 ppm. This composite Units 3 and 4 makeup water TDS concentration of 934 ppm is approximately equivalent to the Palo Verde makeup water TDS concentration of about 1,000 ppm.

[136] 900 gpm × 60 min/hr × 24 hr/day = 1.29 mgd.

[137] FPL, *Site Certification Application – Turkey Point Expansion Project, Volume 1 of 3*, November 8, 2003, p. 3-14.

V. Closed-Cycle Cooling Retrofits Have Been Performed on a Number of U.S. Power Plants

The U.S. EPA reviewed closed-cycle cooling retrofits performed at a number of U.S. power plants in the technical development document the agency prepared for the 316(b) existing facilities rule in 2002. The results of the EPA review are summarized in Table 5.[138]

Table 5. U.S. Closed-Cycle Retrofits: Site, MW Rating, and Cooling Water Flowrate

Site	MW	Flowrate (gpm)
Palisades Nuclear	800	410,000
Brayton Point Station	1,500	800,000
Pittsburg Unit 7	751	352,000
Yates Units 1-5	550	460,000
Canadys Station	490	not reported
Jeffries Station	346	not reported

Entergy's Palisades Nuclear Power Plant began commercial operation on December 31, 1971.[139] Palisades operated as a once through cooled nuclear plant in 1972 and 1973 before conversion to closed-cycle cooling during an outage from August 1973 to April 1975.[140] The electricity production of Palisades Nuclear in its first ten years of commercial operation is shown in Table 6. The electricity production rate in 1973, when Palisades operated with a once-through cooling system, was comparable to the electricity production rates in 1975, 1978, and 1980 after Palisades converted to a closed-cycle cooling system.

Table 6. Palisades Nuclear Electricity Production – First Ten Years of Operation[141]

Year	Electricity Production (MWh)	Cooling System Type
1972	1,899,100	once through
1973	2,411,300	once through
1974	93,300	unknown
1975	2,427,800	closed cycle
1976	2,846,900	closed cycle
1977	5,084,600	closed cycle
1978	2,624,200	closed cycle
1979	3,433,400	closed cycle
1980	2,379,100	closed cycle
1981	3,462,700	closed cycle

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[138] U.S. EPA, 2002 Phase II TDD' Chapter 4, *Cooling System Conversions at Existing Facilities*. Note - The Brayton Point Station (Massachusetts) and Plant Yates (Georgia) cooling tower retrofits occurred after the U.S. EPA review included in the 2002 Phase II TDD.

[139] Entergy Palisades Power Plant webpage: http://www.entergy-nuclear.com/plant_information/palisades.aspx.

[140] U.S. EPA, 2002 Phase II TDD' Chapter 4, *Cooling System Conversions at Existing Facilities*, p. 4-4. The Palisades plant constructed the main portions of the tower system in 1972 and 1973, while the plant operated in once-through mode."

[141] International Atomic Energy Agency website, Power Reactor Information System (PRIS), Palisades Nuclear: http://www.iaea.org/PRIS/CountryStatistics/ReactorDetails.aspx?current=616.

The NRC reported the following causes for the Palisades August 1973 to April 1975 outage:[142]

> An outage was initially estimated for 3 months to repair [the plant's steam generators]. Internal reactor problems and a waste gas release investigation prolonged the outage into 1974. The new cooling towers were completed and placed in operation and the turbine-generator was overhauled.... [Consumers Power] filed a suit against several vendors for startup problems with the condenser, [steam generators], and core internals. Turbine repairs and condenser-retubing extended the outage even further.

According to an article in the October 1974 issue of Nuclear News, Consumers Power had said that the outage was "due principally to steam generator corrosion and damage caused by vibration of the reactor core internals, as well as defective main condenser design and tubing." As a result, Consumers Power sued Bechtel Corporation and four other companies who helped to build the Palisades nuclear plant because "equipment supplied [in 1966 and 1967] was defective" and that defective equipment had not been promptly and adequately repaired.[143]

VI. Other Closed Cycle Retrofits Have Encountered Space Limitations and Have Re-Utilized Existing Cooling System Equipment

Some of the cooling tower retrofits listed in Table 7 encountered space limitations and incorporated to a degree some components of the existing once-through cooling system. Space limitations are not an issue if the Units 3 and 4 cooling towers are located as shown in Figures 11 and 12. A brief description of the details of each of the closed-cycle retrofits examined by the EPA is provided in Table 7.[144]

Table 7. Issues Encountered on U.S. Closed-Cycle Cooling Retrofits

Site	Issues
Palisades Nuclear	New equipment, in addition to the two cooling towers, included two circulating water pumps, two dilution water pumps, startup transformers, a new discharge pump structure with pump pits, a new pump house to enclose the new cooling tower pumps, and yard piping for the circulating water system to connect the new pump house and towers.
Yates Units 1-5	Back-to-back 2×20 cell cooling tower. 1,050 feet long, 92 feet wide, 60 feet tall. Design approach is 6 °F. Cooling tower return pipes discharge into existing intake tunnels. Circulating pumps replaced with units capable of overcoming head loss in cooling tower. Condenser water boxes reinforced to withstand higher system hydraulic pressure. Existing discharge tunnels blocked. New concrete pipes connect to discharge tunnels and transport warm water to cooling tower.

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[142] NRC, *Nuclear Power Plant Operating Experience Summary*, NUREG/CR-6577, p. 243.

[143] D. Schlissel – Synapse Energy Economics, *letter report regarding closed-cycle cooling conversion outage duration re EPA's NODA for Phase II Cooling Water Intake Regulations*, submitted to Riverkeeper, Inc., May 30, 2003, p. 2.

[144] Ibid.

Pittsburg Unit 7	Cooling towers replaced spray canal system. Towers constructed on narrow strip of land between canals, no modifications to condenser. Hookup time not reported.
Canadys Station	Distance from condensers to towers ranges from 650 to 1,700 feet. No modifications to condensers. Hookup completed in 4 weeks.
Jefferies Station	Distance from condensers to wet towers is 1,700 feet. No modifications to condensers. Two small booster pumps added. Hookup completed in 1 week.

VII. The NRC Does Not Consider the Circulating Cooling Water System as a Nuclear Safety-Related System

Under the U.S. Nuclear Regulatory Commission (NRC) regulatory regime, the circulating water system at an operating nuclear plant is not considered a "safety related" system because it functions on the non-nuclear side of the facility, separate from the emergency core cooling system and other plant safety systems.[145] The NRC's review of the operability of a plant's circulating water system is generally focused on the question of whether a failure of this system could affect a safety-related component or system.[146]

For example, Bechtel determined in September 2014, at the request of the California State Water Resources Control Board and under contract to plant owner Pacific Gas & Electric, that no NRC license amendment process would be triggered by the conversion from once-through cooling to closed-cycle cooling at 2,200 MW Diablo Canyon nuclear plant on the California coast. Bechtel concluded that any NRC review process, if any was initiated by the NRC, would be conducted in parallel with state permit reviews and would not introduce additional delay in the project schedule:[147]

> Although we believe that the 10 CFR 50.59 process required to make any plant modification would not result in the need for a licensing amendment, it is likely that the U.S. Nuclear Regulatory Commission (USNRC) would be involved in reviewing this change, which may result in a detailed regulatory review process. It is assumed that any USNRC review would be conducted in parallel with the various state permit reviews.

In the case of Turkey Point Units 3 and 4, the modifications would be substantially less intrusive than the proposed cooling tower retrofit project at Diablo Canyon. In the case of Turkey Point, the conversion would be from one type of closed-cycle cooling, the CCS, to cooling towers. The

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[145] *See* NUREG-0800, Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants, Revision 3, March 2007, Section 10.4.5, available at http://www.nrc.gov/reading-rm/doc-collections/nuregs/staff/sr0800/, last accessed August 16, 2012.

[146] Ibid.

[147] Bechtel Power Corporation, *Addendum to the Independent Third-Party Final Technologies Assessment for the Alternative Cooling Technologies or Modifications to the Existing Once-Through Cooling System for Diablo Canyon Power Plant Addressing the Installation of Saltwater Cooling Towers in the South Parking Lot*, September 17, 2014, p. 5.

intake and discharge structures at Turkey Point Units 3 and 4 would not be modified, as shown in Figures 12 and 13.

VIII. Closed-Cycle Retrofits Do Not Require Extended Unscheduled Outages

Much of the work related to a closed-cycle retrofit can be carried out while the power generation units are online. Hook-up of the cooling tower requires an outage. The duration of the two retrofits for which detailed information is available, Canadys and Jefferies Station, was four weeks or less. The Yates Unit 1-5 conversion was accomplished without any additional outage time for the retrofit. However, the retrofit was apparently carried out during a time of low power demand when Units 1-5 could be offline for extended periods without impacting the dispatch schedule of the plant.[148] The EPA assessed the outage time required for a cooling tower retrofit at a nuclear plant in its 2002 TDD:[149]

> The Agency estimates for the flow-reduction regulatory options considered that the typical process of adjoining the recirculating system to the existing condenser unit and the refurbishment of the existing condenser (when necessary) would last approximately two months. Because the Agency analyzed flexible compliance dates (extended over a five-year compliance period), the Agency estimated that plants under the flow reduction regulatory options could plan the cooling system conversion to coincide with periodic scheduled outages, as was the case for the example cases. For the case of nuclear units, these outages can coincide with periodic inspections (ISIs) and refueling. For the case of fossil-fuel and combined-cycle units, the conversion can be planned to coincide with periodic maintenance. Even though ISIs for nuclear units last typically 2 to 4 months, which would extend equal to or beyond the time required to connect the converted system, the Agency estimates for all model plants one month of interrupted service due to the cooling system conversion.

All Units 3 and 4 cooling tower construction activities can proceed with Units 3 and 4 online.

IX. Achievable Timeline for Completing Units 3 and 4 Cooling Tower Project Is Four to Five Years

A. 1,500 MW Brayton Point Station Cooling Towers - Permitting and Construction Completed in Less Than 4.5 Years

Permitting and construction of the Units 3 and 4 cooling towers and associated infrastructure can occur in four to five years based on the actual permitting and construction timelines for the

---

[148] EPA Region 1, *Memorandums on conversion of Yates Plant Units 1-5 to closed-cycle cooling*, January and February 2003.

[149] 2002 TDD, p. 2-9. The EPA provided a longer nuclear plant outage estimate for cooling tower conversions in the 2011 TDD for the proposed 316(b) regulation. However, EPA provided no new substantive information in the 2011 TDD to support a longer outage estimate for nuclear plants.

cooling tower retrofit at 1,500 MW Brayton Point Station. The EPA Region 1 December 2007 order addressing the conversion of Brayton Point Station from once-through cooling to closed-cycle cooling towers established regulatory timelines for: 1) acquiring necessary permits and approvals, and 2) construction.[150] A maximum of 15 months was allocated in the order to acquire the permits and approvals and issue a notice to proceed with cooling tower engineering and procurement.[151] The order also stipulated that within 36 months of obtaining all permits and approvals, the cooling towers had to be fully operational.[152]

Dominion Energy was given 52 months by EPA Region 1 to complete the cooling tower conversion project, from January 2008 to May 2012. The two hyperbolic cooling towers at Brayton Point Station, shown in Figure 7, had to be operational by May 13, 2012.[153] The total project timeline, from initiating work on permits and approvals to operational cooling towers, was 53 months.

There is no technical or administrative reason that the permitting and construction of the Units 3 and 4 cooling tower project should take any longer than the permitting and construction of the Brayton Point Station cooling towers.

B. Permitting Can Be Completed in Approximately One Year

In addition to the Brayton Point Station cooling towers, other large-scale power projects with major environmental issues have been permitted in approximately one year. The California Energy Commission consistently completed combined National Environmental Policy Act/California Environmental Quality Act application reviews and approvals for construction of utility-scale solar thermal projects in the 2009-2010 timeframe in twelve to thirteen months.[154] These projects each covered thousands of acres of undeveloped public land with substantial endangered species issues.

In contrast, the proposed Units 3 and 4 cooling towers and associated infrastructure would largely be located on either previously developed land or land designated for development on the Turkey Point site. Also, the purpose of the project would be to reduce impacts on marine and subterranean ecosystems, by reducing MDWASD ocean outfall discharges and the impacts of

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[150] U.S. Environmental Protection Agency Region I - New England, Docket 08-007, In the matter of Dominion Energy Brayton Point, LLC, Brayton Point Power Station, Somerset, Massachusetts, NPDES Permit No. MA0003654Proceedings under Section 309(a)(3) of the Clean Water Act, as amended, *Findings and Order for Compliance*, December 17, 2007.

[151] Ibid, p. 5. "By January 2, 2008, commence the process to obtain all permits and approvals . . . Within five days of obtaining all permits and approvals or April 6, 2009, whichever is later, issue the Notice to Proceed with Engineering and Procurement for cooling tower construction to Dominion's contractor."

[152] Ibid, p. 6. "Within 36 months of obtaining all permits and approvals, (Dominion Energy must) complete tie-in of all condenser units such that all permit limits are met."

[153] EPA Region 1, NPDES Permit No. MA0003654 - Authorization (issued to Dominion Energy Brayton Point, LLC) to Discharge Under the National Pollutant Discharge Elimination System, February 29, 2012.

[154] 1,000 MW Blythe Solar Power Project, application filed August 24, 2009, approved September 15, 2010: http://www.energy.ca.gov/sitingcases/blythe_solar/index.html; 250 MW Genesis Solar Energy Project, application filed August 31, 2009, approved September 29, 2010: http://www.energy.ca.gov/sitingcases/genesis_solar/index.html; 250 MW Abengoa Mojave Solar Project Power Plant, application filed Aug. 10, 2009, approved Sept. 8, 2010: http://www.energy.ca.gov/sitingcases/abengoa/index.html.

hypersaline seepage from the CCS into the underlying aquifer. The permit to construct the Units 3 and 4 cooling towers can be obtained in one year if it is a state and county priority to issue the permit.

C. Construction Can Be Completed in Approximately Three Years

Other large-scale cooling tower retrofits in addition to Brayton Point Station have been constructed in approximately three years. Two examples are Palisades Nuclear and Plant Yates.

Palisades Nuclear began procurement and construction of retrofit cooling towers in mid-1971 and the cooling towers were operational in mid-1974.[155] These cooling towers are shown in Figures 8a and 8b.Georgia Power received regulatory approval to install the 40-cell back-to-back cooling tower at Plant Yates in August 2001 and the cooling tower was operational in 2004.[156,157] These cooling towers are shown in Figures 9a and 9b.

X. Conclusion

Closed-cycle mechanical draft cooling towers are a feasible and cost-effective alternative to the CCS, even if Units 3 and 4 operate for as little as ten years with the cooling towers in operation. A conversion to cooling towers would eliminate: 1) the transfer of up to 100 mgd of water from the L-31E Canal to the CCS for water temperature control purposes, and 2) the pumping of 14 mgd of Upper Floridan Aquifer supply for salinity control in the CCS. Use of MDWASD reclaimed wastewater as cooling tower makeup water would also reduce the environmental impacts of the current MDWASD of deep well injection at its SDWWTP, and provide Units 3 and 4 with a low salinity makeup water supply. This in turn would allow for a cost-effective ZLD system that would eliminate wastewater discharges from the Units 3 and 4 cooling towers. The use of mechanical draft cooling towers with ZLD technology at Turkey Point Units 3 and 4 represents the best available technology for eliminating surface water thermal discharge impacts and hypersalinity impacts on the aquifer underlying the CCS.

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[155] EPA, 2002 TDD, p. 4-3. Procurement and construction of the cooling tower system began in mid- to late-1971. The cooling towers became operational in May 1974.

[156] Georgia Department of Natural Resources, response letter re Georgia Power Company, Plant Yates Consent Order No. EPD-WQ-3742, NPDES Permit No. GA0001473, Coweta County, Georgia, August 16, 2001. “We (Georgia DNR) concur with your choice to construct an evaporative cooling tower.”

[157] T. Cheek - Geosyntec Consultants, Inc. and B. Evans – Georgia Power Company, *Thermal Load, Dissolved Oxygen, and Assimilative Capacity: Is 316(a) Becoming Irrelevant? – The Georgia Power Experience*, presentation to the Electric Power Research Institute Workshop on Advanced Thermal Electric Cooling Technologies, July 8, 2008, p. 18. Plant Yates cooling tower became operational in 2004.

Attachment A

Nuclear Plant Retrofit Comparison for Powers Engineering 9-June-2009

	Case 1A	Case 2A	Case 1B	Case 2B
Water	Salt	Salt	Fresh	Fresh
Type	ClearSky BTB	Wet BTB	ClearSky BTB	Wet BTB
Cells	3x22=66	3x18=54	3x20=60	3x18=54
Footprint	3@529x109	3@433x109	3@481x109	3@433x109
Rough Budget	$115.6 million	$38.6	$109.1	$36.4

Basis: 830,000 gpm at 108-88-76. Plume point is assumed at 50 DB/90% RH.

Low clog film type fill is used for all of the selections, assuming any fresh water used would likely be reclaimed water of some sort. Low clog fill has been used successfully in various sea water applications. Intake screens would be required for the make-up sea water to limit shells, etc. Make-up for the ClearSky tower would be approximately 80-85% of the wet tower make-up on an annual basis. Budget is tower only, not including basins. Infrastructure cost is estimated by some at 3 times the cost of the wet tower, including such things as site prep, basins, piping, electrical wiring and controls, etc. Sub-surface foundations such as piling can add significantly, and may be necessary for a seacoast location. The estimates above are adjusted for premium hardware and California seismic requirements, which are a factor in the taller back-to-back (BTB) designs both for wet and ClearSky. These are approximate comparisons. Both the wet towers and ClearSky towers could likely be optimized more than what has been estimated here, and may have to be tailored to actual site space in any event. ClearSky has pump head like a wet tower, is piped like a wet tower, and has higher fan power than a wet tower to accommodate the increased air flow and pressure drop.

Coil type wet dry towers would cost significantly more, with premium tube (titanium for sea water, and possibly for reclaimed water) and header materials. An appropriate plenum mixing design has yet to be developed, but would also require non-corrosive materials and high pressure drop on the air side. No coil type BTB wet dry towers are likely to be proposed.

Bill Powers

From: PAUL.LINDAHL@ct.spx.com
Sent: Tuesday, June 09, 2009 9:27 AM
To: bpowers@powersengineering.com
Subject: Nuclear Comparison

Bill,

A comparison of wet and ClearSky back to back towers for a reference duty is included in the attached summary.

Paul Lindahl, LEED AP
Director, Market Development
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Attachment B

Cooling Tower Fundamentals

Compiled from the knowledge and experience
of the entire SPX Cooling Technologies staff.

Edited by
John C. Hensley

SECOND EDITION

Published by
SPX Cooling Technologies, Inc.
Overland Park, Kansas USA

SPX
COOLING TECHNOLOGIES

Printed in the United States of America

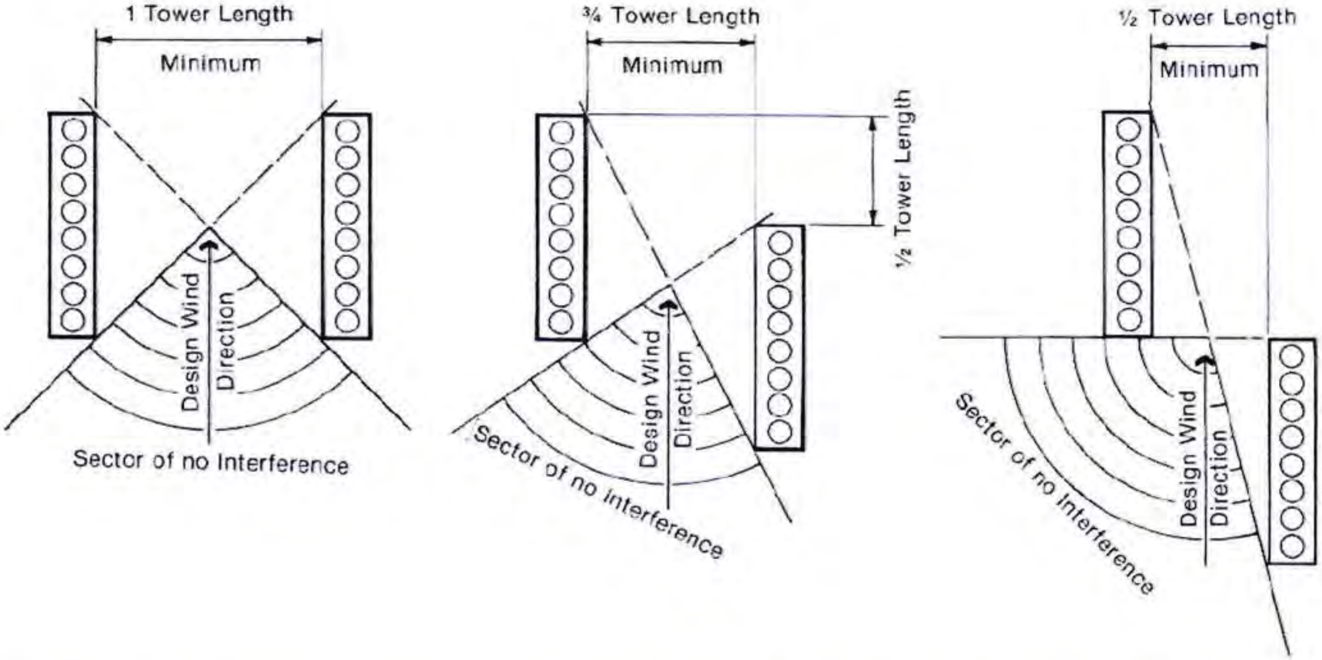
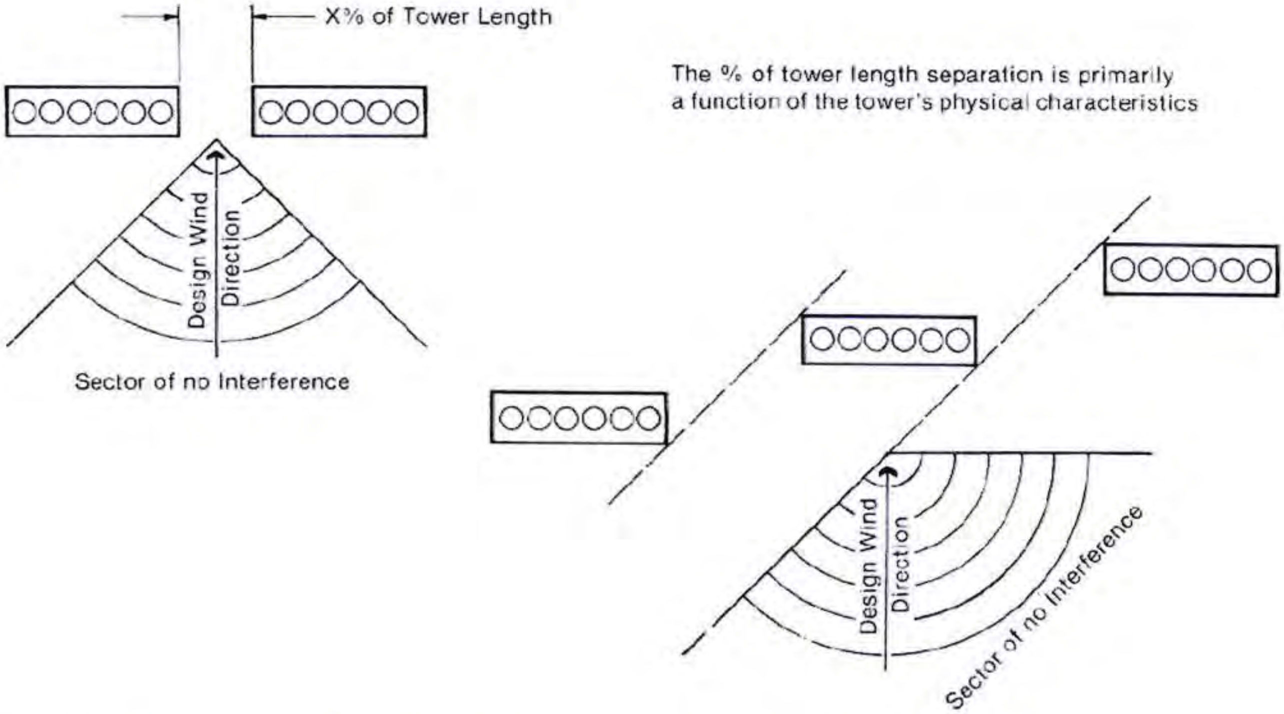


Figure 37 — Proper orientation of towers in a prevailing longitudinal wind. (Requires relatively minimal tower size adjustment to compensate for recirculation and interference effects.)



The % of tower length separation is primarily a function of the tower's physical characteristics

Figure 38 — Proper orientation of towers in a prevailing broadside wind. (Requires significantly greater tower size adjustment to compensate for recirculation and interference effects.)

Attachment C

http://www.gwpc.org/sites/default/files/event-sessions/9f_Lott_Bob_0.pdf
2011 Ground Water Protection Council Annual Forum, Atlanta, Sept 24-28, 2011

Water and Energy in Arizona

Bob Lotts
Arizona Public Service Company

Outline

- 91st Avenue Wastewater Treatment Plant
- Palo Verde Water Reclamation Facility (WRF)

91st Avenue WWTP

91st Avenue Statistics

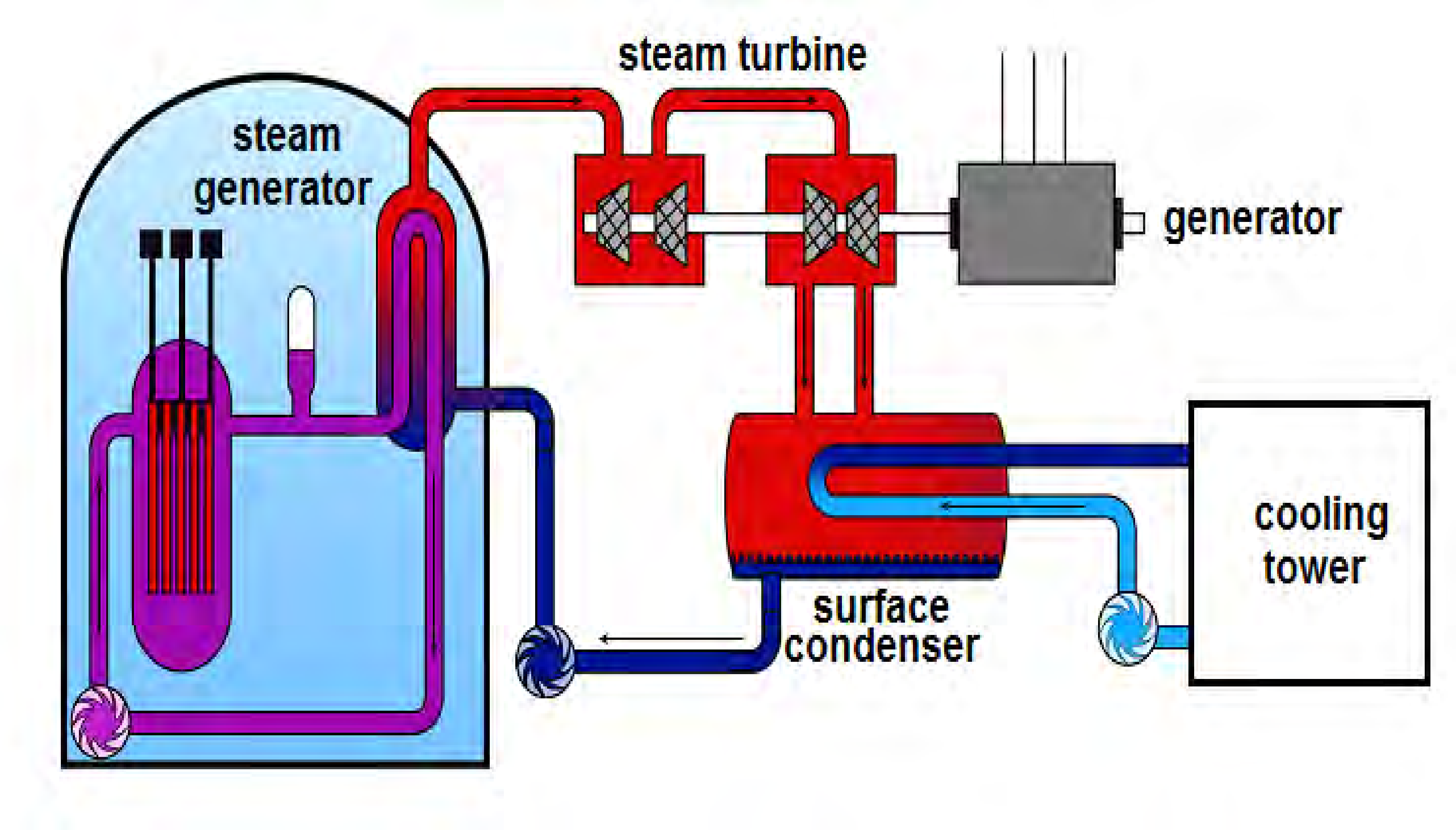
- **Capacity 204.5 MGD**
  - 229,000 AF/year
- **Treating 135 MGD**
  - 152,000 AF/year
- **65,000 AF/year to Palo Verde**
  - Palo Verde receives and additional 5,000 to 10,000 AF/year from the cities of Tolleson and Goodyear
- **30,000 AF/year to Buckeye Irrigation**
- **28,500 AF/year to Tres Rios Wetlands**

An acre foot of water = 325,851 gallons

Palo Verde Nuclear Generating Station Water Reclamation Facility

Nuclear Plant Water Use

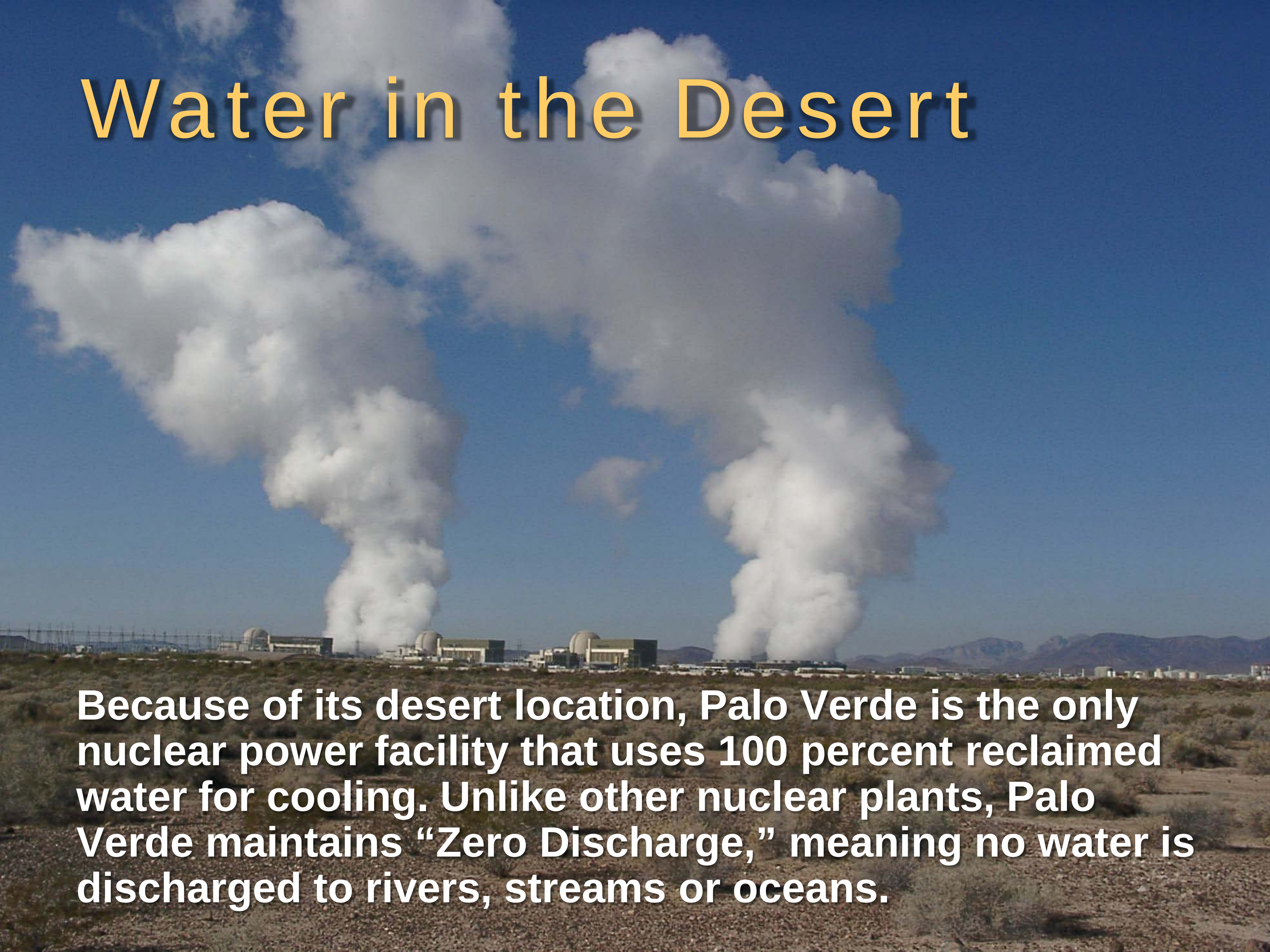
Secondary Loop



Primary Loop

Tertiary Cooling Loop

Water in the Desert



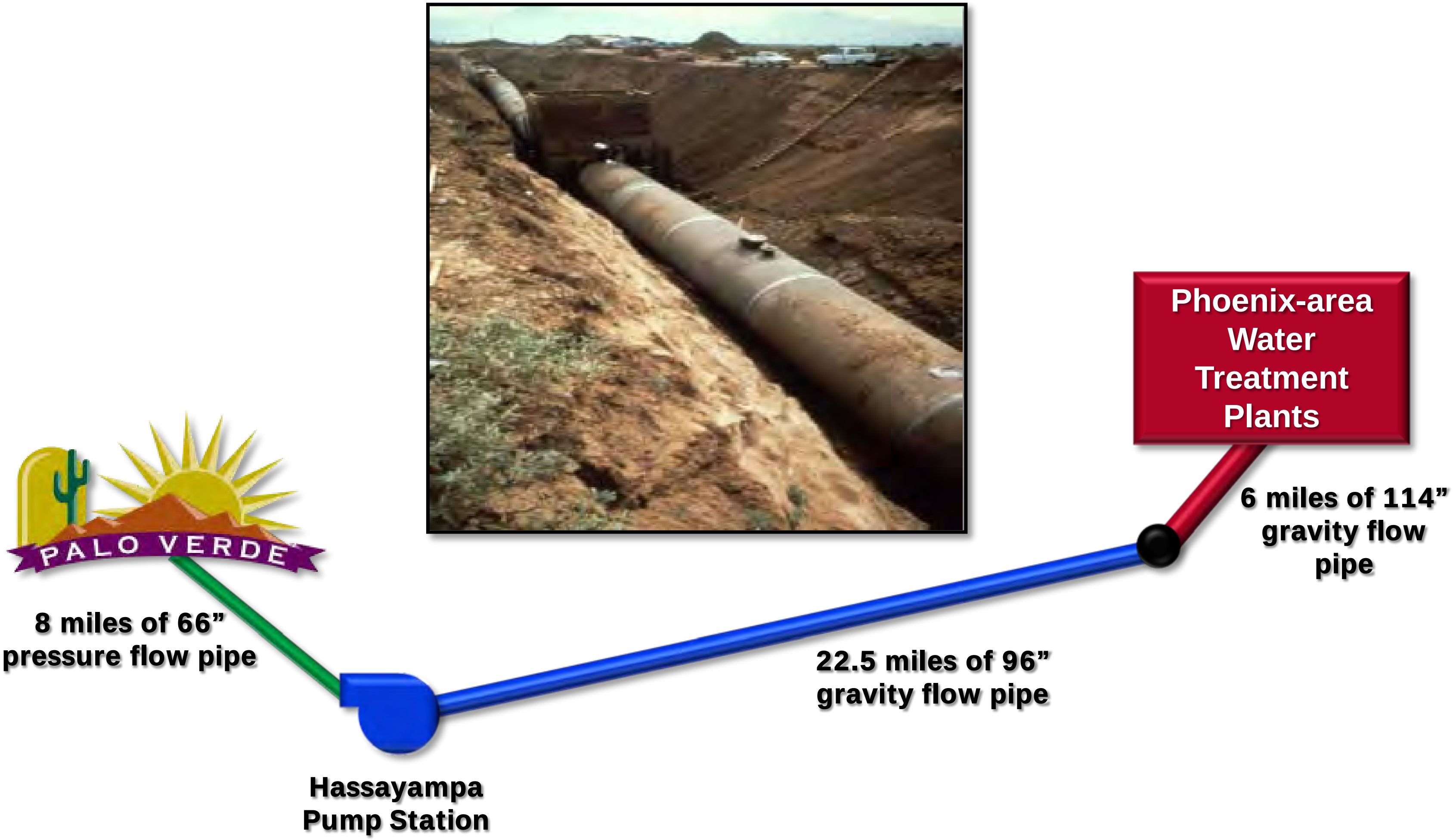
Because of its desert location, Palo Verde is the only nuclear power facility that uses 100 percent reclaimed water for cooling. Unlike other nuclear plants, Palo Verde maintains “Zero Discharge,” meaning no water is discharged to rivers, streams or oceans.

Water Reclamation Facility

The Palo Verde Water Reclamation Facility (WRF), is a 90 MGD tertiary treatment plant that reclaims treated secondary effluent from the cities of Phoenix, Scottsdale, Tempe, Mesa, Glendale and Tolleson.

Conveyance System

**28.5 miles of gravity flow with 100-foot elevation drop,
8 miles pumped flow with 150-foot elevation increase**



Phoenix-area Water Treatment Plants

6 miles of 114” gravity flow pipe

8 miles of 66” pressure flow pipe

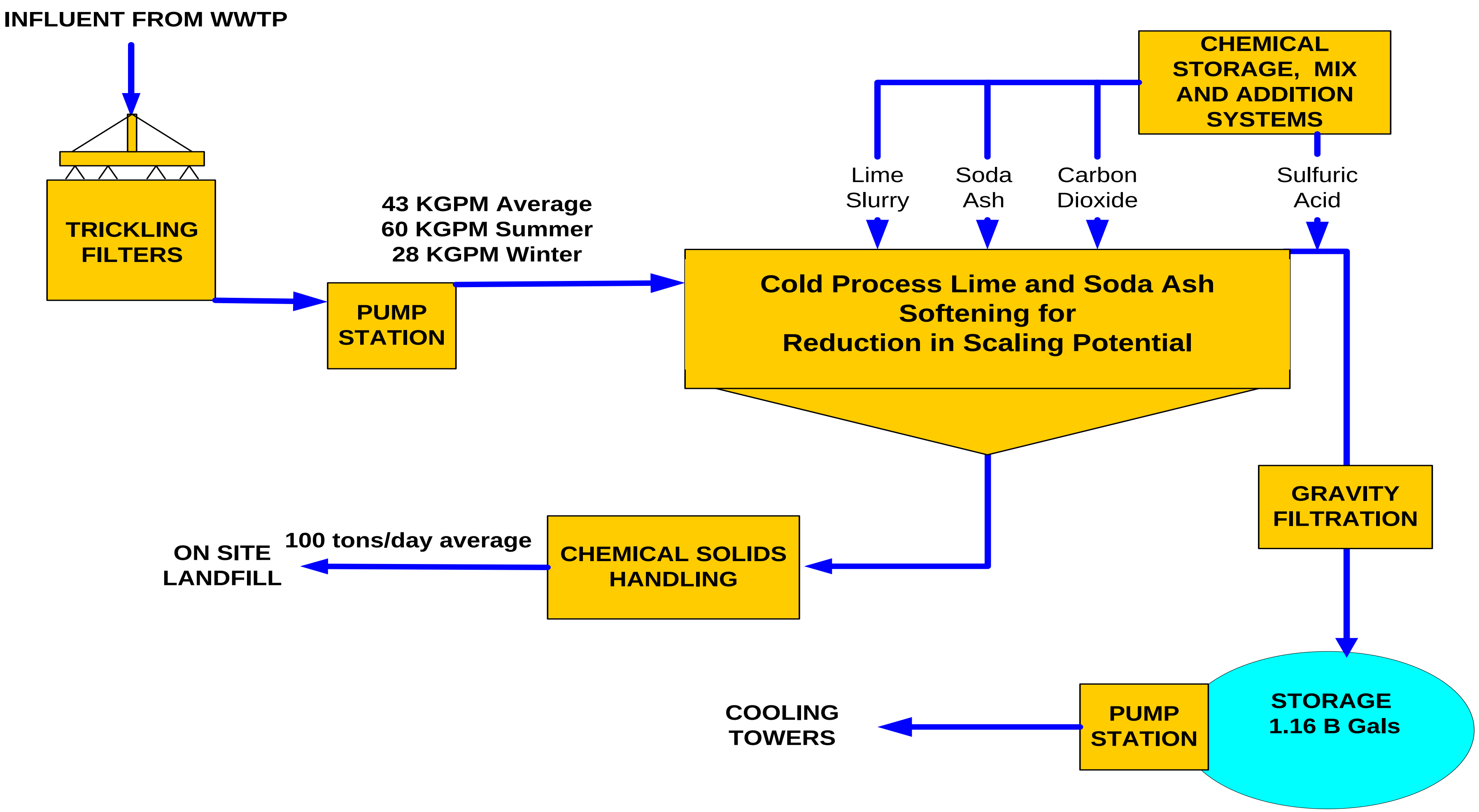
22.5 miles of 96” gravity flow pipe

Hassayampa Pump Station

Inspection and Maintenance of 36-mile Pipeline

Processing WWTP Effluent

Cooling Water Treatment Systems



INFLUENT FROM WWTP

TRICKLING FILTERS

PUMP STATION

43 KGPM Average
60 KGPM Summer
28 KGPM Winter

CHEMICAL STORAGE, MIX AND ADDITION SYSTEMS

Lime Slurry

Soda Ash

Carbon Dioxide

Sulfuric Acid

Cold Process Lime and Soda Ash Softening for Reduction in Scaling Potential

GRAVITY FILTRATION

CHEMICAL SOLIDS HANDLING

100 tons/day average

ON SITE LANDFILL

STORAGE
1.16 B Gals

PUMP STATION

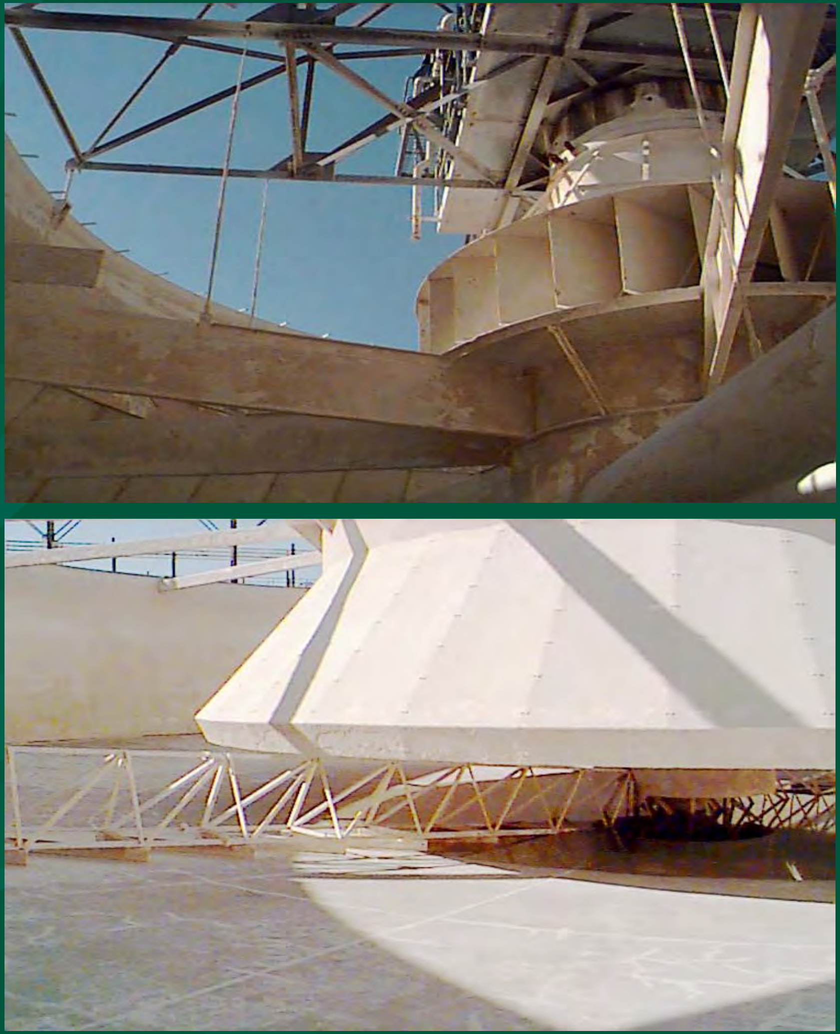
COOLING TOWERS

Trickling Filters

- Treatment of the secondary effluent begins with biological de-nitrification to remove ammonia, which takes place in the Trickling Filters.
- This process involves treated effluent trickling down over a biological growth maintained on plastic media.

1st Stage Solids Contact Clarifiers

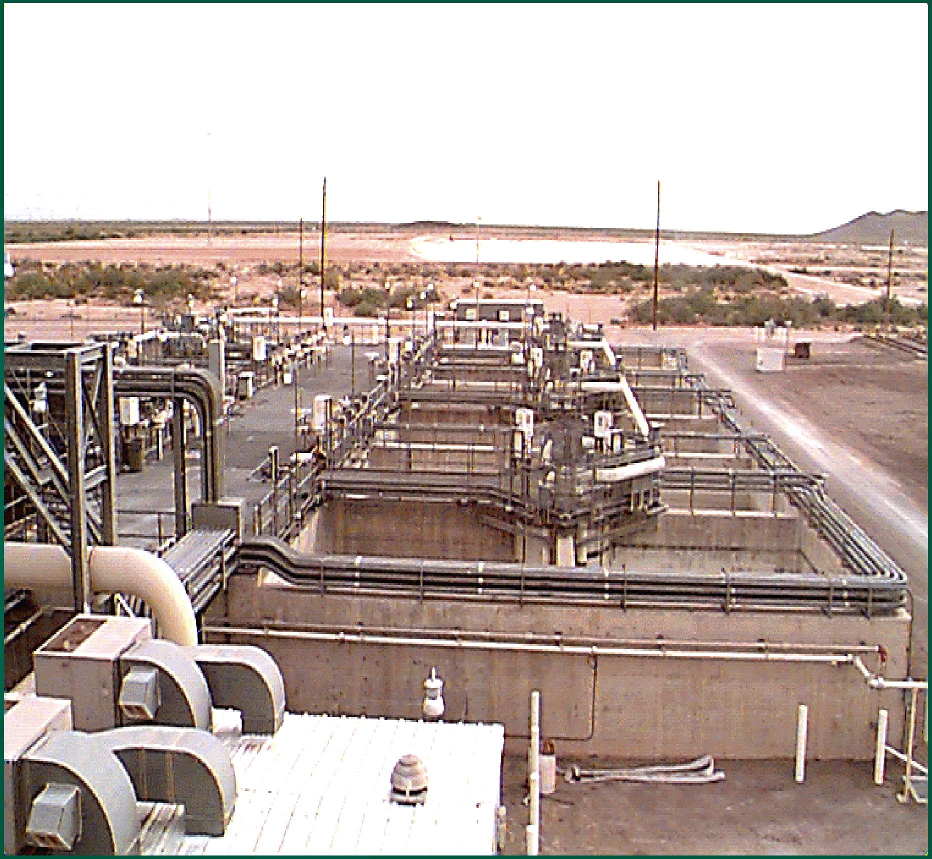
- After the addition of the Slaked Lime to the influent of the 1st Stage Solids Contact Clarifiers elevating the pH to 11.2, hardness causing minerals settle to the bottom of the Clarifier in the form of a heavy sludge.
- This sludge is raked to the middle of the Clarifier and pumped from the system for recycle and disposal.



2nd Stage Solids Contact Clarifiers

- In the Second Stage Clarifiers, the pH is lowered to 10.2 by the addition of Carbon Dioxide Gas.
- This pH drop and the addition of Soda Ash solution causes the precipitation of additional Calcium and further reduces hardness.

Gravity Filters

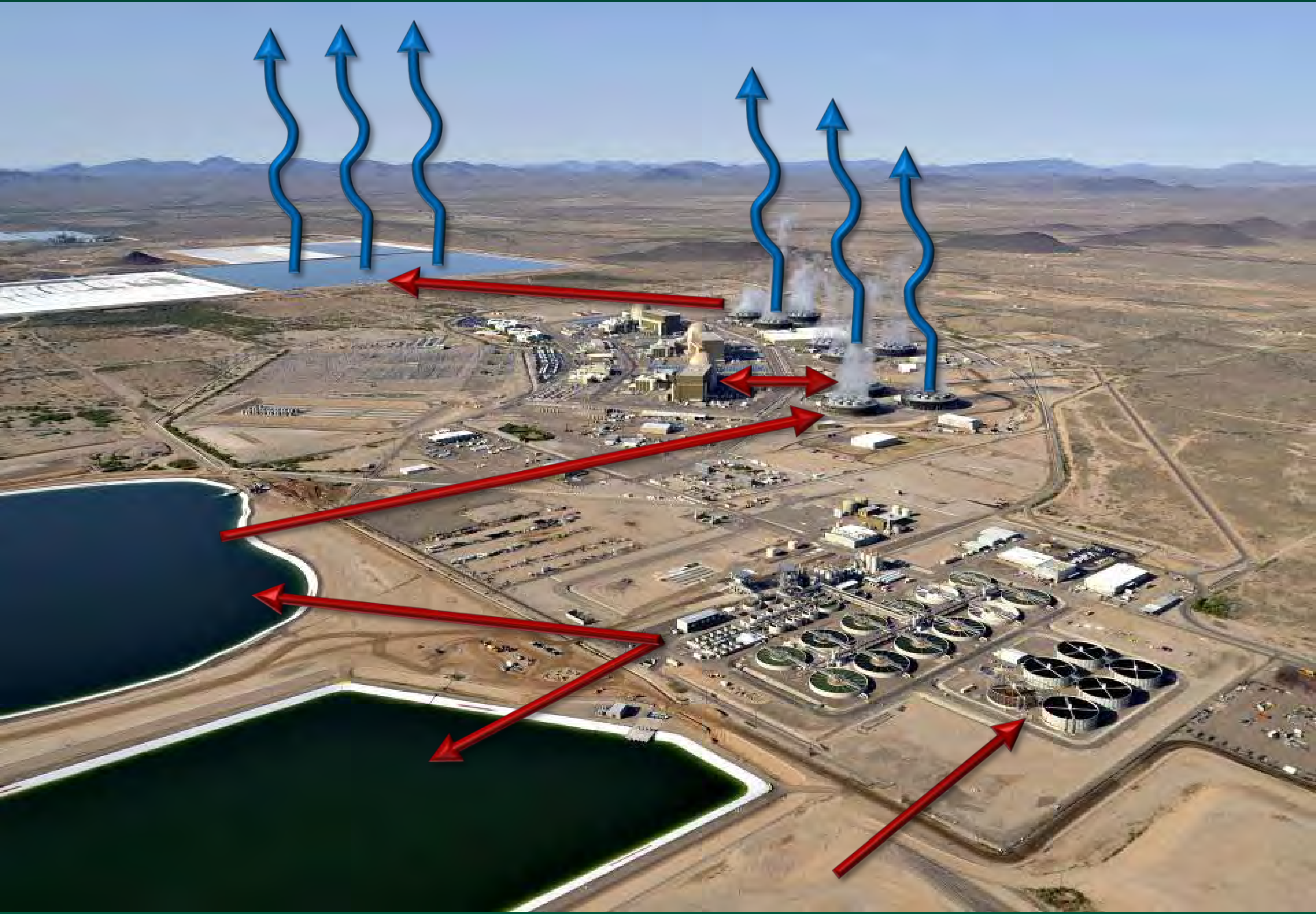


- **The effluent from the 2nd Stage SCC flows to a common header where the pH is adjusted to 9.2 and goes to the 24 Mixed Media Gravity Filters.**
- **These Mixed Media Filters contain a layer of Anthracite Coal over a layer of Sand.**
- **They serve as a final polishing process to remove particulate Calcium.**

Cooling Water Treatment

- **Softening of wastewater treatment plant (WWTP) effluent is a necessity. Softening is performed to:**
  - Minimize scaling potential
  - Maximize water use
  - Minimize quantity of water required

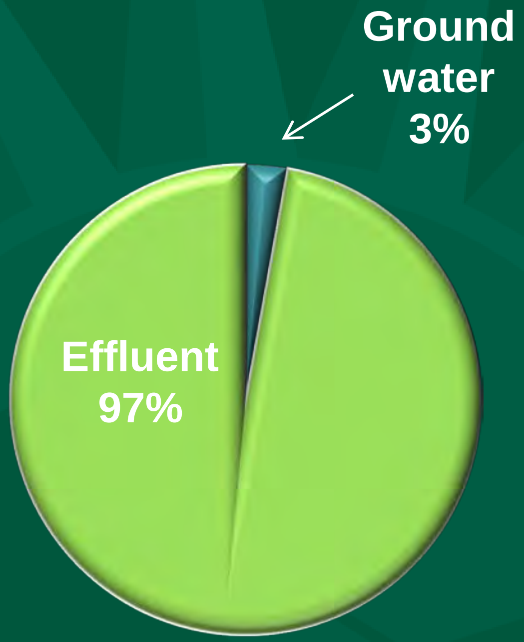
Scale Forming Constituents	Influent Quality (ppm)	Effluent Quality (ppm)
Alkalinity (as $CaCO_3$)	**189**	**27**
Calcium (as $CaCO_3$)	**183**	**73**
Magnesium (as $CaCO_3$)	**123**	**15**
Silica	**19**	**3.5**
Phosphate	**10**	**< 0.1**



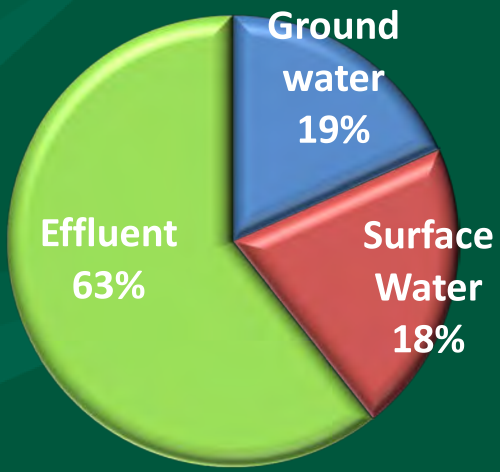
Water Use

- **2010 cooling water Intensity**
  - 778 gallons/MWh
    - 10 yr avg. = 764 gals/MWh
- **2010 cooling water use**
  - 74,560 acre feet
    - 10 yr avg. = 66,538 acre feet
      - 25 billion gallons
        - » ≈ 38,000 Olympic-sized swimming pools
        - » ≈ 100 Empire State Buildings
- **Cooling Water cycles**
  - 23.3 - 5 year average
    - 25,000 – 29,000 TDS PPM

2010 Water Use by Type



Palo Verde 2010
Water Use = 74,560



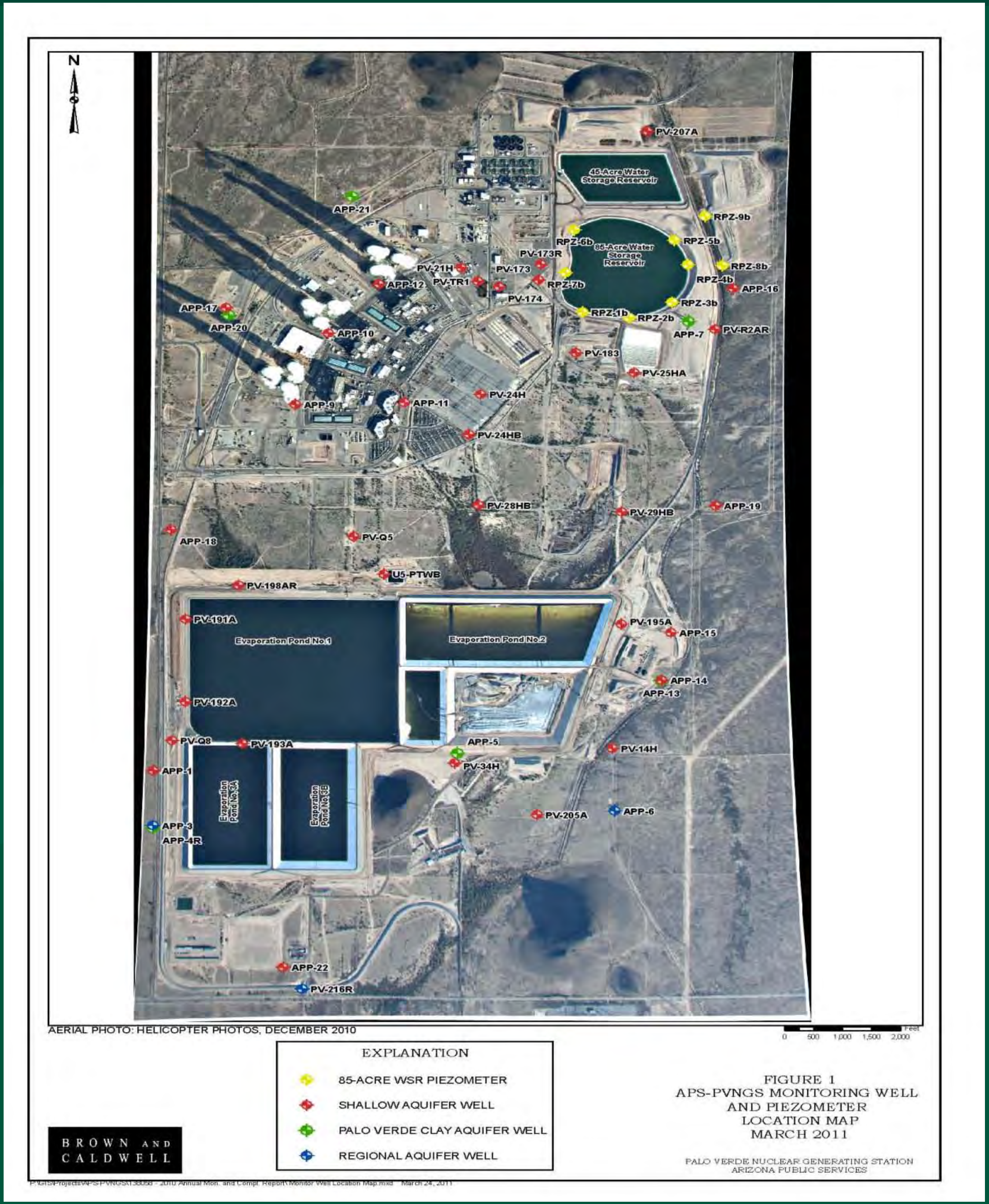
Total APS 2010
Water Use = 119,692 AF

Site Aerial Photo

- **Cooling Tower Blowdown (Annual Rate)**
  - 950 Million Gallons
  - 2,900 Acre Feet
  - ~4% of the treated water
- **Evaporation Rate 60-72 inches/yr**
  - 3,250 - 3,900 AF/yr
- **Note redundancy in impoundments, allows for relining in 20 years**

Groundwater Monitoring

- Approximately 50 on-site monitoring wells
- Located down-gradient of structures that contain water and at the site boundary
- Palo Verde has installed many more wells than required allowing for early leak detection capabilities



AERIAL PHOTO: HELICOPTER PHOTOS, DECEMBER 2010

FIGURE 1
APS-PVNGS MONITORING WELL
AND PIEZOMETER
LOCATION MAP
MARCH 2011

PALO VERDE NUCLEAR GENERATING STATION
ARIZONA PUBLIC SERVICES

P:\GIS\Projects\APS-PVNGS\138058 - 2010 Annual Mon. and Compl. Report\Monitor Well Location Map.mxd March 24, 2011

Ancillary WRF Systems

- **Domestic Water**
  - Reverse osmosis units fed from on site wells to provide all potable water needs.
  - All WRF Operations personnel are required to have State Certification through Arizona Department of Environmental Quality (ADEQ).
- **Demineralized Water**
  - Mixed bed demineralizer utilized to meet high purity water requirements for the site.
- **Sodium Hypochlorite Generation**
  - Electrolytic cells used to produce bleach from brine.

Attachment D

Global Water Intelligence
Market-Leading Analysis of the International Water Industry
(/)

Quick search

From zero to hero – the rise of ZLD

- **From**: Vol 10, Issue 12 (December 2009) (/archive/10/12/)
- **Category**: Market insight (/archive/10/12/market-insight/)
- **Country**:
- **Related Companies**: Aquatech (/company/aquatech/), Enel (/company/enel/), General Electric (GE) (/company/general-electric-ge/), HPD (/company/hpd/), Resources Conservation Company (/company/resources-conservation-company/), Royal Dutch Shell (/company/royal-dutch-shell/) and Siemens Water Technologies (/company/siemens-water-technologies/)

Regulatory drivers are ensuring that zero liquid discharge is gaining in popularity. Capital and operating costs can still prove prohibitive, as Gord Cope discovers.

If there was ever a Holy Grail of water recovery and reuse in an industrial plant, then it is undoubtedly zero liquid discharge, or ZLD. While it may be difficult and expensive to achieve, zero liquid discharge is easy to define.

“A ZLD system means that no liquid waste leaves the boundary of the facility,” says Keith Minnich, Veolia’s vice president of water solutions and technologies. “Technically, that could mean you have a big pond inside the fence, but the term usually refers to a mechanical system of an evaporator and a crystallizer.”

There are thousands of evaporator/ crystallizer thermal systems in use around the world, serving a wide variety of sectors. Chemical plants use them to make chloride for feedstock in the plastics industry. The food and beverage industry produces powdered coffee and milk. But relatively few of these systems (a total of just over 100 worldwide), are designed purely as ZLD systems, in which the purpose is to recover and reuse as much water as possible.

Although dozens of regional companies supply various components for evaporation and crystallization, the ZLD niche is dominated by three major players: Aquatech, GE Power and Water, and HPD, a subsidiary of Veolia. “HPD is the largest evaporation and crystallization company in the world,” says Minnich. “We have close to 700 systems in many different sectors: pulp and paper, salt, chemical processing, oil and gas, biofuels, and power generation. Many of these installations are not ZLD systems; they are part of a system used to produce an industrial product.” In all, total capital investment in ZLD systems around the world is estimated to be between $100-200 million per year.

Most industrial processes create a wastewater stream. This can be bleed from boilers, blowdown from cooling towers, or saline water from crude oil extraction. Reverse osmosis and other membrane technologies can cut the stream by 80% or more, but a facility inevitably still ends up with a significant flow of concentrated liquid waste.

Generally speaking, the smaller the volume, the easier it is to dispose of. “In conventional processes, you typically get sludge with 30 to 40% solids, whereas in a ZLD system the solids content ranges between 85 and 95%, thus providing a much lower volume and dryer sludge,” says Anant Upadhyaya, senior vice president of corporate growth at Aquatech, which entered the ZLD space in 2000 through its acquisition of Aqua-Chem. “Why not minimize the wastewater by recovering and reusing water, which is essentially what the ZLD process does?”

The ZLD process creates solid waste using two devices – evaporators and crystallizers. Evaporators, which can concentrate brines up to 250,000 ppm TDS, are designed to be extremely energyefficient by using mechanical vapour recompression, or VPR. “If you were to simply boil water on a stove, it would take 1,000 Btus to boil one pound of water,” says Minnich. “But if you use VPR, it only takes 30 Btus.” In the VPR evaporator process, water is heated until it boils at 100°C. The vapour goes into a centrifugal compressor which compresses it slightly, making the temperature rise. The boiling takes place on a thin-film heat transfer surface, where steam condenses on one side and water boils on the other side.

When the brine concentration exceeds 250,000 ppm TDS, it is pumped under high pressure from the evaporator to a forced circulation crystallizer. The brine is released into a vessel where the pressure falls, the remaining water boils off and the salts crystallize. This salt is still slightly damp, but conforms to EPA solid disposal standards. The salt cake, which is a fraction of the original waste stream, is then disposed of in landfill.

There are several drivers for the adoption of ZLD. “Water is a resource that is getting scarce in many geographic locations,” says Upadhyaya. “In many locations in the US, the Middle East, Africa, India and China, less than 5% of wastewater is presently recovered. With water becoming so scarce, the very first thing that comes to mind is: why are we wasting so much? The first inclination is to recover and recycle.”

A second motivator is the growing social responsibility of recycling and reuse. “The EU has many countries with limited resources,” says Upadhyaya. “Those circumstances have led to a compulsion toward minimum wastage, maximum reuse. Twenty years ago, there was little of that in North America, but now we recycle bottles, newspapers and plastics. Society deems it worthwhile to do so, and technologies have evolved to make economic recycling possible.”

A third driver is economics. As potable water becomes scarcer in many jurisdictions, its price rises. In addition, as regulations on the discharge of waste fluids into open waterways become more stringent, treatment costs rise. Customers look at the potential for savings, comparing the cost of ZLD to the cost of fresh water and the savings on sludge disposal. Regulation represents the biggest incentive by far. “Nobody puts in a ZLD unless they have to, because it’s very expensive,” says Tim Cornish, marketing manager for HPD. “It’s driven by discharge regulations.”

Don’t pass the salt

It was US federal regulatory pressure that gave birth to the ZLD sector. “Back in the 1970s, they were having a salinity problem in the Colorado River,” says Minnich.

“As a result, regulations were created prohibiting discharge of cooling tower blowdown into the river. Evaporation-based technology was developed to recover the water and concentrate the salt. The distillate evaporated and was returned to the power plant, and the highly concentrated brine went to a crystallizer where it was processed into salt cake. The systems would handle 500-2,000 GPM. There were dozens built.”

Since then, many state jurisdictions have added salt discharge restrictions to their own statutes. “In places like Colorado, Arizona and California, they are regulating discharge to the point where it’s almost ZLD,” says Cornish.

Increasingly, the decision to install ZLD is made for a combination of reasons. Italy derives a significant amount of electricity from coal, and in addition to boiler blowdown, coal-fired power plants must also deal with liquid waste generated from flue gas scrubbers. “When plants burn coal, flue gases are discharged into the atmosphere,” says Upadhyaya. “Years ago, we realized that the gases were very acidic, toxic and caused damage. Regulations were then mandated that the flue gases be scrubbed, and contaminants transferred from vapour to liquid phase. This produced a high amount of wastewater requiring complex treatment.” Enel, a large power utility in Italy, wanted to address this issue. “Their vision was to be compliant with the ideology of environmental conservation. They wanted to set an example of environmental stewardship and social responsibility.”

Enel had other motives, too. Water in some plant locations was scarce, and opposition vocal. “When you include ZLD in a greenfield application, you obviate the need for the permitting of liquid disposal,” says Upadhyaya. “This puts you on the fast track for regulatory approval in sensitive environment zones. In the end, they decided having the ZLD approach was worth it to them.”

Aquatech supplied equipment to five of Enel’s coal-fired facilities. “Each plant has a custom-designed treatment train,” says Upadhyaya. “In one of the plants, the main equipment consisted of two de-calcifiers and two brine concentrators. They handled 1,744m3/d, recovering 1,555m3/d, which left less than 200m3/d of solids.”

Zero has its minuses

The main disadvantage to ZLD is its capital cost. A large industrial facility with a traditional wastewater treatment system costing approximately $20 million can recover and reuse up to 80% of its liquid waste streams. The 1,000 GPM (3.8m3/ min) evaporator and crystallizer system necessary to capture the last 20% can, however, double that cost.

A second factor is the operating budget. Although ZLD systems are built from corrosion-resistant titanium and highnickel stainless steel and don’t require a lot of repair, energy costs are high. “Evaporators and crystallizers use a lot of electricity,” says Minnich. “A desalination plant might use 2-4 kWh/m3, but these systems use 20-40 kWh/m3.”

As a result, very few municipalities – which generally have high wastewater flows with low TDS concentrations – use ZLD unless forced to by unusual circumstances. “There are inland municipal desalination plants,” says Minnich. “They use groundwater with 2,500-15,000 ppm TDS to produce drinking water. These plants produce a waste brine stream with approximately 80,000 ppm dissolved solids. Environmentally acceptable brine disposal can be a problem. Not only that, there is still a lot of water left in the brine. ZLD using evaporation and crystallization is expensive, and municipalities don’t want to pay the cost. VWS has a process called Zero Discharge Desalination (ZDD), which can recover 97% of the water fed to an inland desalination plant, compared to the typical 80%. This technology uses electrodialysis and is suitable for municipal applications.”

Even when circumstances such as regulation and scarcity oblige industry to adopt ZLD, great care is taken to limit its role. According to Siemens Water Technologies, which recently installed a ZLD system at an automotive plant in Mexico, the first step is a water audit to identify the sources and types of wastewater generated in a facility in terms of flow and TDS content.

Some sources generate high concentrations of organic compounds, salts, metals and suspended solids. Others are relatively clean, such as condensate and stormwater, and require little cleaning. Secondly, the audit identifies points where fresh water and make-up water are used, and in what quantities and qualities. Some applications do not require water to be treated to a potable standard, for example fire water, utility water, process water and cooling water. By matching appropriate water requirements and waste streams, the amount of wastewater that ultimately enters the ZLD system can be greatly diminished.

In the case of a typical refinery, Siemens has identified several processes in which large quantities of wastewater could be safely reused with a minimum of treatment. Large volumes of water, for instance, are used to strip sulphur from gasoline and diesel products. This sour water can be put to a second valuable use – removing salts from crude as it enters the refinery – with little or no treatment. Even though such techniques can dramatically reduce wastewater treatment requirements, the remaining waste streams are a complex mix of organic and inorganic materials that make 100% reuse of water restrictively expensive, with the result that no refinery has yet advanced to a true ZLD system.

New markets
Other areas of the oil and gas industry are making significant strides towards ZLD, however. For several decades, heavy oil production in regions such as California and Venezuela has relied on the injection of steam to recover the viscous crude.

"Up until about 12 years ago, water recovered from heavy oil production was treated with warm lime softening and weak acid cation ion exchange, then fed into once-through steam generators (OTSGs) to produce 80% steam and 20% water for downhole injection into the oil wells," says Bill Heins, general manager of thermal products and ZLD for GE Water & Process Technologies. GE entered the ZLD market in 2005 through its purchase of Ionics, which itself had acquired ZLD specialist Resources Conservation Company (RCC) back in 1993.

About a decade ago, oilsands operators in northeast Alberta began developing a thermal technique known as steamassisted gravity drainage (SAGD) to recover bitumen that was buried too deep for open pit mines. With SAGD, two horizontal wells are drilled, one above the other. Steam is then injected into the upper well, where it heats up the surrounding bitumen, which then sinks to the lower well and is brought to the surface by pumps.

"For SAGD, you need 100% steam," says Heins. "They modified the old systems with vapour/liquid separators to get 100% steam, but we saw a lot simpler and more cost-effective way. Why not take produced water and run it through an evaporator to create water quality good enough for a standard drum boiler that would make 100% steam?"

Clients didn't warm to the idea initially, and there was concern that evaporators use a lot of electricity, recalls Heins. "But we did a lot of R&D to show that it was technically and economically viable. At the end of the day, the client could save approximately 10% on capital costs and 6% on operating costs while implementing a process that was more reliable and simpler to operate. Produced water evaporator systems are now the industry baseline for greenfield facilities, and we have 10 installs in the heavy oil recovery market."

Several other sectors are opening up. "The mining industry has great potential for ZLD," says Heins. "We recently installed a large mine drainage wastewater ZLD that reuses the water and creates a saleable salt product that can be used to de-ice roads. We are taking waste and turning it into a useful product."

"Royal Dutch Shell is building an $18 billion gas to liquid (GTL) plant in Qatar," adds Veolia's Minnich. "Shell and the government decided to go with ZLD due to environmental concerns and water scarcity in the area. VWS is building a large-scale turnkey wastewater treatment system that will treat 33,000m3/d of plant effluents. It uses physical chemical-membrane, biological and thermal ZLD systems to recover all of the water for reuse in the plant. It produces a dry salt that is disposed of on site."

POET, the world's largest producer of ethanol, recently installed a ZLD system in its 34 million gallons per year (353m3/d) Bingham Lake, Minnesota, facility. The production of one gallon of ethanol normally uses about 3.5 gallons (13.25 litres) of water. POET had already met all state discharge regulations, but wanted to eliminate discharge completely. Their new system recycles about 20 million GPY (207m3/d) of treated wastewater that was formerly discharged into the drought-prone agricultural district.

ZLD also has great potential in the development of shale gas. "Shale gas recovery uses a lot of water to fracture the rock," says GE's Heins. "The water comes back up with up to 15,000 ppm TDS. Traditionally, they take that water and haul it far away for disposal. That's very expensive. We're looking at onsite treatment and reuse in fracturing to minimize or eliminate the need to haul it. We are poised to deliver our first system to the field. There are dozens of shale basins in North America, and regulations are pushing toward treating the fracture water."

R&D sums

The fact that operating costs are high naturally means that R&D in the ZLD arena has been directed towards finding alternatives to energy-intensive evaporator/ crystallizer systems. "There have been attempts to use reverse osmosis-based technology for power plant ZLD systems, but they just haven't been very effective," says Minnich. "The membranes foul faster than they are supposed to."

Progress has been made in lowering capital costs, however. "When we started out seven years ago, we had a total installed cost factor of 5.0," says Heins. "That meant that a $10 million unit cost $50 million after installation. Now, we're on our fourth generation modular design, and we've reduced the total installed cost factor down to 1.8-2.0. A $10 million unit now costs $18-$20 million total installed. That makes produced water evaporation a lot more economically viable."

Although the recession has had a negative impact on many sectors of the economy, ZLD has not slowed dramatically. In fact, industry analysts predict a cumulative annual growth rate for recovery/ reuse systems in excess of 200% over the next decade, of which a significant portion could be accounted for by ZLD capacity. "The economic and regulatory climate is such that ZLD or near zero discharge is going to continue to grow rapidly," says Cornish. "We see great potential."

Attachment E

Zero Liquid Discharge (ZLD) System

Power Industry | Case Study

Arizona Public Service Redhawk Power Station Arlington, AZ USA

APS (Arizona Public Service) has been a leading provider of electricity and energy products and services to the Western United States for over a century.

With power plants located throughout the Southwestern United States, APS provides natural-gas, coal and nuclear generated electrical power to the region.

Project Description

The Redhawk Power Station is comprised of two 2x1 combined cycle natural gas-fired units to produce a total of 1,060 MW of electrical power. Critical to the planning and permitting of this facility was the source and utilization of water and the environmental impact of the station with respect to liquid emissions.

Based upon these issues, Redhawk was designed to use reclaimed municipal effluent from the nearby Palo Verde Nuclear Generating Station for its process water requirements. What is unique about this source of water is that it's supplied by several neighboring City of Phoenix municipal treatment facilities with their associated seasonable variability. The plant would also be designed to utilize well water as a contingency and achieve in either case, high-quality water for continuous reuse throughout the plant.

The Client's Needs

The second critical aspect is the permitted requirement as a Zero Liquid Discharge facility. As regulated, no aqueous waste can be discharged from site operations into the environment. The wastewater treatment system must be designed to remove contaminants and recycle high-quality water back into the process.

This closed loop integration of the overall water cycle must be achieved over the complete range of feed water conditions as well as support plant operations. The treatment system must produce of high-purity water, maintain cooling tower conditions for high availability, and comply with the Zero Liquid Discharge mandate.

Zero Liquid Discharge (ZLD) System

Project & Technology Solutions

The Zero Liquid Discharge (ZLD) System had to reclaim water resources and reject waste properly as an integrated component of the power station. APS selected Veolia Water Technologies to design and build a process system utilizing HPD® evaporation and crystallization technologies, which were the key elements in the overall design.

The evaporator was designed to receive 450 gpm of high-salinity blowdown from the cooling towers. The compressor-driven HPD evaporator pre-concentrates the brine and produces high-purity distillate for recycling to the cooling tower and service water system.

Concentrate from the evaporator is advanced to a forced circulation crystallizer where the salts that form the impurities are crystallized and sent to a centrifuge for dewatering. The HPD crystallizer is also compressor driven and produces distillate that is combined with that of the evaporator for recycle.

The Results

The turnkey project was efficiently completed and the wastewater treatment plant commissioned by Veolia Water Technologies in the promised time frame.

Since the commissioning of the integrated ZLD system in 2002, the Redhawk Power Station has successfully accomplished the goal of effectively recycling the waste created by cooling tower blowdown and producing high-quality water while adhering to the Zero Liquid Discharge mandate.

Turnkey Scope of Supply

Veolia was the sole point of responsibility in providing a design-build solution for the complete wastewater portion of the plant which included:

- All major process equipment
- Mechanical erection
- Buildings
- Utility piping and valves
- Electrical hardware and cabling
- Overall control system
- Insulation and painting
- Structural support and access steel
- Training of staff, commissioning and start-up support