TECHNICAL EVALUATION OF OPTIONS FOR LONG-TERM AUGMENTATION OF THE COLORADO RIVER SYSTEM

REDUCTION OF POWER PLANT CONSUMPTIVE WATER USAGE FOR COLORADO RIVER AUGMENTATION

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ACRONYMS

AFY	acre-feet per year
Basin	Colorado River Basin
CAP	Central Arizona Project
CRWC	Colorado River Water Consultants
EPRI	Electric Power Research Institute
gal	gallons
gpm	gallons per minute
kWh	kilowatt hour
MW	megawatt
MWe	megawatt electrical
PPNEC	Power Plant – Non-Evaporative Cooling
Seven States	Seven Colorado River Basin States
U.S.	United States
USEPA	United States Environmental Protection Agency

1.0 Reduction of Power Plant Consumptive Water Usage for Colorado River Augmentation

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1.1 SUMMARY AND PURPOSE

This discussion of Power Plant – Non-Evaporative Cooling (PPNEC) is one of a series of White Papers being prepared for the Seven Colorado River Basin States (Seven States). The purpose of the White Papers is to present evaluations of potential options to provide long-term augmentation of the water supply of the Colorado River system. This White Paper presents background information on the overall evaluation program, followed by a preliminary evaluation of the PPNEC option.

1.2 BACKGROUND

The Seven States have authorized Colorado River Water Consultants (CRWC) to provide a technical evaluation of long-term options. The States will supplement the technical evaluations with legal, administrative, and/or institutional considerations.

The White Papers are the first step in an iterative process to develop, screen, and evaluate options. Evaluation parameters will be applied progressively and will be developed in increasing detail as selected options become more promising. In parallel with White Paper development, the CRWC research team will meet with representatives of the Seven States and will refine the White Papers/develop new White Papers based on their input. White Paper results will be reviewed with a Technical Steering Committee comprised of delegates from the Seven States.

Each White Paper will present a brief overview of the option being evaluated, followed by discussions of history and viability of obtaining additional water from the source, location of supply, quantity of water potentially available, water quality, technical issues, general reliability of supply, environmental issues, permitting issues, and project costs. A list of reference documents for each White Paper will be included, and general findings and conclusions will be provided.

1.3 OVERVIEW OF OPTION

Thermoelectric power generation requires a significant amount of water within the Colorado River Basin (Basin) to provide cooling to power plants within the basin. Cooling is needed to remove waste heat from the power generation cycle. The most common cooling method used within the Colorado River basin is evaporative cooling. The cooling water supply is pumped through one or more condensers where steam is condensed to form liquid condensate. The figure below schematically shows the process:

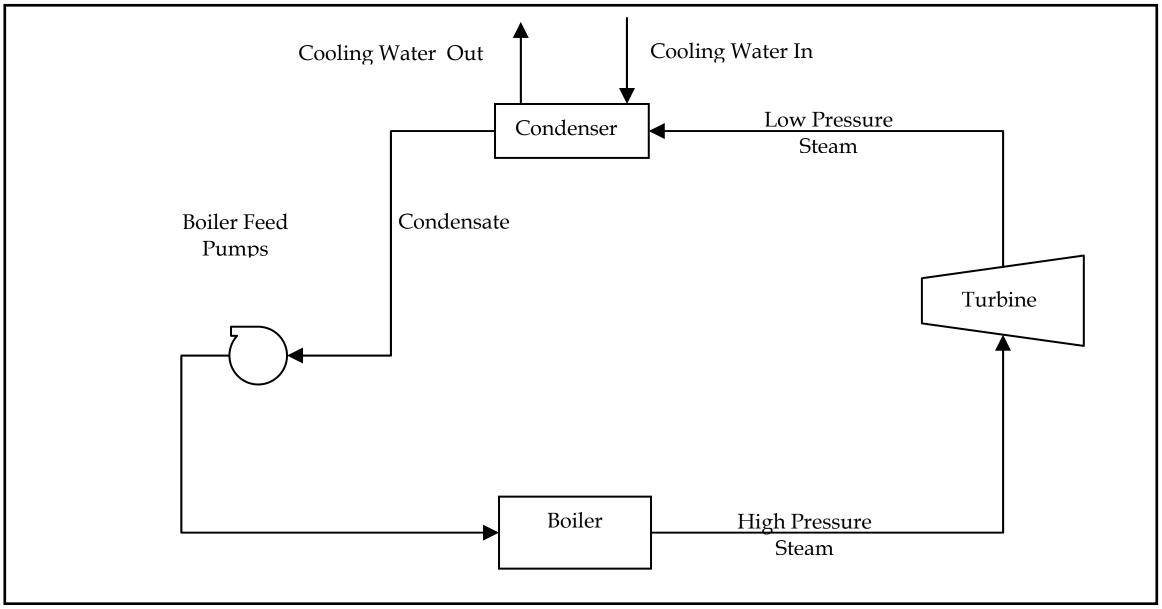

Figure 1. Schematic of a Simple Steam Power Cycle

The efficiency of different types of power plants varies depending on the type of power generation technology used, but, generally, 60 percent of the heat required to generate electricity must be rejected to the surrounding environment.

For older power plants, the once-through cooling system was often used. In such a system, the water is drawn from a supply, treated appropriately, and pumped through the condenser with the flow rate determined by the allowable temperature rise (typically around 20 to 25^{o}F) for the source water (Electric Power Research Institute [EPRI], 2002). The drawback to this cooling method is the negative environmental impact resulting from the large water withdrawals required to provide the cooling, typically in the range of 500 gallons per minute (gpm) per MWe, and from temperature increase in the discharge water. In addition, the increased temperature increases the evaporation of the source water, so although the consumptive water use would seem to be minor, it has been estimated that once-through cooling evaporative losses range from 0.1 to 0.3 gallons (gal) /kilowatt hour (kWh), depending on plant type and cooling efficiency (The Energy Foundation, 2003).

As the environmental impacts of large water withdrawals became apparent, recirculated cooling water systems became the cooling technology selected for most power plants. In this system, water is run through the condenser and then pumped to a cooling tower. Evaporation provides the cooling mechanism. Makeup water is added to replenish the water losses from the system due to evaporation, blowdown and drift. Blowdown is used to control the concentrating effect that evaporation causes in the recirculated water, thus controlling the precipitation of scale-forming salts from the recirculated water. Drift is defined as water droplets that become airborne in the cooling process and leave the cooling loop. Drift is a relatively small loss of water and does not significantly impact consumptive water use. The primary advantage of recirculating water systems is the reduced water withdrawals, lowering the withdrawal rate to between 10 to 15 gpm /

MWe (EPRI, 2002). However, from a water usage standpoint, the primary means of cooling is now evaporative, which increases water consumption to between 0.18 to 0.64 gal / kWh, depending on plant type and cooling system efficiency (The Energy Foundation, 2003). In addition to the increased water usage, other disadvantages include the following:

- Decreased plant efficiency
- Higher capital cost than once-through cooling
- Complex water chemistry control, and
- A wastewater stream to be handled.

A third option for power plant cooling is a dry-cooling system. In this type of system, ambient air is used as the heat transfer medium with fans blowing large volumes across finned tubes to provide heat transfer. The dry cooling system is similar to the operation of a car radiator. The most significant advantage of dry cooling is a 90 – 95 percent reduction of consumptive water use. However, there are a number of critical issues to be considered including (EPRI, 2002):

- High installation and operating costs
- Reduced power plant efficiency when compared with wet-cooling
- Power load limitations on hot days, and
- Additional space required for system.

A fourth option is a hybrid system, combining dry cooling with supplemental wet-cooling technology to reduce the power plant efficiency limitations on hot weather days. There are a number of different arrangements that fall into this category, each with varying degrees of water consumption depending on the split between wet and dry cooling. These systems can limit annual water use to 2 to 5 percent (although more typically range from 20 to 80 percent) of that required for all-wet systems and still achieve substantial efficiency and capacity advantages during the peak load periods of hot weather, as compared to an all-dry system (EPRI, 2002). For the purposes of estimating the amount of water that could augment the Colorado River, the hybrid system option was not considered due to its varying reduction of consumptive water use and lack of cost data.

1.4 HISTORY/VIABILITY OF OBTAINING WATER FROM THIS SOURCE

Before power plants were as large as they are now, the easiest and least expensive method of power plant cooling was once-through cooling. The consumptive water use was on the low end for water-cooling. However, the increase in discharge water temperature was determined to have a significant negative environmental impact and regulations have made this option an uncommon choice in the Basin.

The majority of power plants in the Basin recirculate water through cooling towers to transfer the heat away from the power plant. The majority of the cooling occurs by evaporation, thus reducing the overall water withdrawal from the source water, but increasing the consumptive water use.

As water resources have diminished or become more valuable, some power plants have been constructed with an air-cooled condenser instead of the typical water cooled condenser. The air-cooled condenser eliminates the consumptive use of water for plant cooling, but at the cost of lower plant efficiencies and increased plant capital costs. Although air-cooled power plants have been constructed and are operating within the United States (U.S.), the majority of thermoelectric power plants continue to use wet-cooling technologies because of the higher cost of air-cooled technologies.

1.5 LOCATION OF SUPPLY

Power generation occurs throughout the Basin. Almost all of the power plants have recirculated water cooling systems. Figure 2 shows the location of 31 power plants larger than 10 megawatts (MW) in capacity:

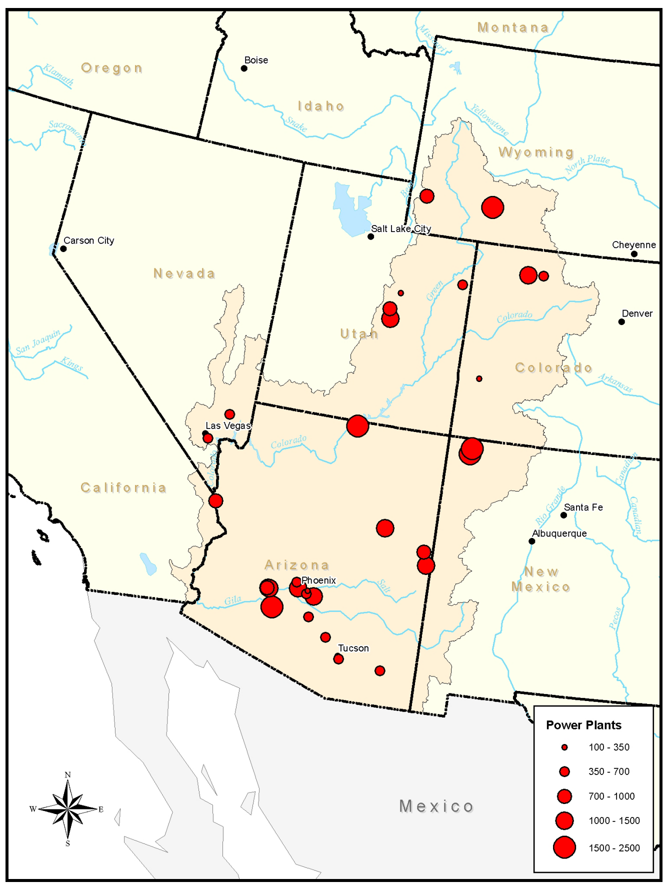

Figure 2. Location of Power Plants in the Colorado River Basin

All of the power plants identified in Figure 2 use recirculated cooling water systems (EIA, 2004). As discussed previously, although once-through cooling has substantially higher water withdrawal rates, the actual water consumption is higher for power plants using recirculated cooling, due to the evaporative losses.

1.6 AMOUNT OF WATER

Thermoelectric power plants are large consumers of water in the Colorado River Basin. Figure 2 in the previous section identified thermoelectric power plants within the Colorado River Basin that had greater than 10 MW of generating capacity. However, not all of these plants use Colorado River water, but in some cases groundwater supplies or reclaimed water. Of the identified 31 power plants, 15 use surface water supplies. Table 1 lists the power plant facility, generating capacity, consumptive water use, and cooling water source for locations that had an identified source that was a tributary to the Colorado River:

Table 1
Power Plants Within the Colorado River Basin With Surface Water Sources

Plant Name	Plant Capacity (MW)	Consumptive Use (AFY)	Water Source
Navajo	2409	27,366	Lake Powell
Jim Bridger	2312	25,266	Green River
Four Corners	2270	22,515	San Juan River
San Juan	1848	19,981	San Juan River
Hunter	1441	18,968	Cottonwood Creek
Huntington (UT)	996	12,307	Huntington Creek
Bonanza	500	7,964	Green River
Naughton	707	6,081	Hams Fork River
Reid Gardner	612	4,344	Muddy River
Hayden	465	2,896	Yampa River
Carbon (UT)	189	2,679	Price River
Craig (CO)	1339	2,534	Yampa River
South Point Energy Center	708	1,955	Colorado River
Desert Basin Power	646	1,810	CAP Canal Water
Nucla	114	1,520	San Miguel River

The summation of the consumptive water use for the power plants identified above is approximately 160,000 acre-feet per year (AFY). It is likely that additional Colorado River water is being used by power plants with wells in the alluvial groundwater. However, a more in-depth study of the individual power plant sites would need to be conducted to determine if this is true.

1.7 WATER QUALITY

Although some improvement in the water quality (i.e. reduced salinity) in downstream Colorado River areas should be contemplated from additional flow in all reaches and elimination of high salinity cooling tower blowdown discharges, this improvement in quality cannot be quantified without additional study.

1.8 TECHNICAL ISSUES

A significant volume of Colorado River water is used every year by the thermoelectric generation industry. This water could potentially be used for other applications if air-cooled systems were more often used at power plants. However, the following are obstacles to retrofitting existing water-cooled power plants with air-cooling:

- High cost of air-cooling versus wet-cooling
- Effect of air-cooling on plant power output during hot weather periods
- Effect of air-cooling on plant efficiency
- Applicability of air-cooling technology to the existing plant systems designed for water cooled service, and
- Larger site footprint required for air-cooled system.

If air-cooling were to replace wet-cooling in some locations within the Basin, the availability of that additional supply would be dependent on the power plant location.

1.9 GENERAL RELIABILITY OF SUPPLY

If existing wet cooled power plants were converted to dry-cooled power plants, the resultant additional water would be available in the Colorado River or a tributary. As shown in Table 1, conversion of any given plant could reliably increase flow by up to 27,000 AFY. Conversion of all plants could add up to 160,000 AFY.

1.10 ENVIRONMENTAL ISSUES

Many environmental issues are considered when determining the type of cooling system for a power plant (EPRI, 2002):

- Water resources
- Waste management
- Hazardous materials
- Air emissions
- Noise
- Visual resources
- Public health
- Biological impacts, and
- Agriculture and soils.

For most of these issues, wet cooling has the greater negative impact on the environment. Wet cooling systems use more water, produce a waste stream (for recirculated water), and use more hazardous materials for water treatment (for recirculated water). However, dry cooling does have some areas where it has a greater negative impact. During hot weather periods, air-cooled power plants experience a reduction in plant efficiency, which results in an increase of air emissions per unit of energy produced. The noise associated with the larger fans to increase the air flow is at least equal or perhaps greater than cooling tower noise, so depending on the locality, this can be an issue. The heat transfer equipment required for air cooling is larger, which can be considered to be a negative visual impact.

The significance of the environmental issue depends on the locality. The technology that produces the least amount of environmental impact is site-specific. Generally, within where water is limited, air-cooled technology will usually be considered to have the lesser environmental impact.

1.11 PERMITTING

The conversion of water-cooled power plants to air-cooled power plants would not have significant permitting issues depending on the locality. The cooling system permits that would be required are related to water use, waste discharge, hazardous material handling, and public health.

1.12 COST

The most significant obstacle to the widespread application of dry-cooling technology is cost. The heat transfer rates of air-cooled systems are not as great as they are for water-cooled systems. Therefore, the equipment required to provide similar heat transfer is larger and has a higher capital cost. In addition, the temperature in the ambient air can substantially reduce the power plant energy output by raising the condenser temperature. It has been estimated that the capital cost of dry-cooling for a new 250-MW combined cycle installation will be approximately 140 percent greater while the operations and maintenance of the system will be approximately 94 percent greater than that of comparable wet-cooling application (Micheletti, 2001).

However, these costs are only comparative. In the Basin, nearly all of the power plants already have wet-cooling systems that would need to be retrofitted with dry-cooling systems in order to free up water. The U. S. Environmental Protection Agency (USEPA) has created cost curves to represent the costs associated with dry-cooling based on the flow rate of an equivalent once-through wet-cooling system (USEPA, 2002). These cost curves are based on retrofitting an existing plant with an indirect air-cooling system with a temperature difference of 10^{o} between the condenser temperature and the ambient dry-bulb temperature. These costs can vary significantly for specific site conditions. Using the USEPA procedures for estimating the costs of conversion to non-evaporative cooling and amortization of capital costs over 30 years at the current power industry financing rate of about 6 per cent, the cost per acre-foot conserved for the largest seven plants in Table 1 ranges from $850 to $1,300.

1.13 REFERENCES

EIA, 2004. Form 767. Steam-Electric Plant Operation and Design Report. Schedule V. Cooling System Information. Section A. Annual Operations

Electric Power Research Institute, 2002. Comparison of Alternate Cooling Technologies for California Power Plants Economic, Environmental and Other Tradeoffs.
The Energy Foundation, 2003. The Last Straw Water Use by Power Plants in the Arid West.

Micheletti,Wayne C., 2001. Understanding Wet and Dry Cooling Systems..

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USEPA, 2002. Technical Development Document for the Proposed Section 316(b) Phase II Existing Facilities Rule.

1.14 CONCLUSION

White Paper findings are summarized in Table 2.

Table 2
Summary of Findings Related to Power Plant – Non-Evaporative Cooling Option

Parameter	Findings
Location of Supply	Power plants are located throughout the Colorado River Basin. Figure 2 shows a map of existing locations.
Quantity of Water Potentially Available	The quantity of water is dependent upon the size of the power plant and the existing cooling technology. Up to 160,000 acre-feet per year is potentially available.
Water Quality	The water quality of augmented water would be expected to be equivalent to existing water quality.
Technical Issues	Air-cooled power plants are not as efficient as wet-cooled power plants. In addition, an existing power plant cannot easily be retrofitted with an air-cooled technology.
General Reliability of Supply	The reliability of the augmented water would be expected to follow the same trends as the Colorado River.
Environmental Issues	There are few if any environmental issues with converting existing power plants from water-based cooling to air-based cooling.
Permitting Issues	There are few if any permitting issues with converting existing power plants from water-based cooling to air-based cooling.
Cost	Approximately $1,300 per acre-foot for plants of 2,000 MWe and greater capacity. As much as $4,000 per acre-foot for plants smaller than 1,000 MWe capacity.