Cooling System Retrofit Cost Analysis

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Technical Update, October 2002

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REPORT SUMMARY

Cooling System Retrofit Cost Analysis

The U.S. Environmental Protection Agency has published draft Phase II regulations to establish requirements of Cooling Water Intake Structures at large existing facilities. In some circumstances these regulations might require the retrofit of recirculating cooling to a plant currently on once-through cooling. This report provides an analysis of the capital and operating costs associated with such retrofits.

BACKGROUND: The proposed 316(b) rule for existing plants was published in the Federal Register on April 9, 2002. The requirements would apply to all power producing facilities that employ a cooling water intake structure and withdraw more than 50 million gallons per day (approximately the withdrawal rate for a 50 MW plant) from surface waters of the United States. In most circumstances, reduction of impingement mortality of 80 to 95% would be required. Entrainment mortality reductions of 60 to 90% would be required from some but not all source waters. In some instances, these requirements might dictate that a plant be retrofit a recirculating cooling system. A facility may qualify for a site-specific determination on the basis that the cost of compliance would significantly exceed the costs considered by EPA in their analysis. Therefore, an understanding of the likely costs of retrofit is important to understanding the implications of the proposed rule.

OBJECTIVE: To provide industry environmental executives and regulatory compliance officers with generalized methods and supporting data for estimating the cost of retrofitting existing plants with recirculating systems.

APPROACH: The study consisted of three steps. Data were gathered from utility sources on actual and estimated costs for retrofits at individual plants. Several independent cost estimating methodologies, including those by U.S. EPA., Stone & Webster Engineering Company, the Washington Group and the National Energy Technology Laboratory were reviewed and compared with the data. Finally some generalized correlations were developed.

RESULTS: Retrofit cost data were obtained for 50 plants including both nuclear and fossil units and fresh, brackish and saline source waters. The plants ranged in size from 100 to 2600 MW. Retrofit costs ranged from $11 million to over $860 million. The costs did not scale well with either plant size of circulating water flow rate but rather were dominated by site-specific factors. However, the projects could be roughly categorized as "easy", "average" or "difficult" retrofits. Within each category, the costs scaled reasonably well with circulating water flow. The "easy" projects fell around $125/gpm, a cost generally consistent with the cost for installation of recirculating

cooling systems at new plants. The “average” projects clustered around $200/gpm +/- 20%. The “difficult” cases ranged from $250 to $300/gpm with a few as high as $700 to $900/gpm. In addition, significant costs beyond the initial capital cost result from cooling water retrofits. These include additional parasitic operating power for pumps and fans, additional maintenance costs primarily for water treatment and additional fuel costs from reduced plant efficiency.

EPRI PERSPECTIVE: Retrofit costs are highly variable. The results of this study support EPA’s assertion that the costs to retrofit recirculating cooling systems will vary dramatically from site to site. This variability cannot be well accounted for by typical correlating factors such as $/kW or $/gpm of circulating water flow which are often satisfactory for new plant construction. However, site characteristics such as availability and proximity of space for the cooling tower, underground interferences to new circulating water piping, site geology and meteorology and other identifiable issues can be used to assign a “degree of difficulty” to a proposed retrofit and to better estimate the likely cost.

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1

Introduction

Purpose of study

This report documents the results of a review and analysis of certain aspects of the Proposed Rule of Cooling Water Intake Systems at Large Existing Power Plants issued by the United States Environmental Protection Agency (EPA) on February 28, 2002. Specifically, this study examines the costs associated with retrofitting recirculated cooling systems onto plants currently using once-through cooling.

Rule and supporting material

The rule was published in final form in the April 9, 2002 Federal Register (1). In addition EPA published several documents providing background information in support of the decisions made in the Proposed Rule. A list of these documents is given in Table 1-1. They are available through the internet at http://www.epa.gov/waterscience/316b/. Full citations are given in the references to this report.

Economic and Benefits Analysis (EPA-821-R-02-001) (Ref. 2)
Case Study Analysis (EPA-821-R-02-002) (Ref. 3)
Technical Development Document (EPA-821-R-02-003) (Ref. 4)

Supporting Documents for 316(b) Phase II Proposed Rule
Table 1-1

In addition, much of the cost development methodology makes references to data and analyses presented during Phase I, the New Facilities Rule found in

Final Rule for New Facilities *Federal Register Notice* (December 18, 2001) (Ref. 5)
Supporting Document on Technical Development (Ref. 6)
Supporting Document on Economic Analysis (Ref. 7)
Economic and Engineering Analysis of the Proposed 316(b) Rule for New Facilities (Ref. 8)

Phase I Rule and Supporting Documents
Table 1-2

Summary of requirements

The requirements of the Proposed Rule apply to all power producing facilities that (a) employ a cooling water intake structure and (b) withdraw more than 50 million gallons per day from rivers, streams, lakes, reservoirs, estuaries, oceans or other waters of the United States. Facilities may either:

- Demonstrate that the standards are currently being met, or
- Implement technologies, operational measures or restoration measures that meet the standards, or
- Demonstrate that the facility qualifies for a site-specific determination on the basis that the costs would significantly exceed either those costs considered by EPA in their analysis of compliance costs or the environmental benefits to be gained.

For those cases for which technological, operational or restorative measures would be required the performance requirements are summarized in Table 1-3.

Performance Standards for Existing Facilities [Ref. 1; §125.94(b)]			
Facility Category		**Required Mortality Reduction**	
Capacity Factor	**Source Water**	**Impingement**	**Entrainment**
< 15%	All	80 – 95%	None
>15%	Estuaries, tidal rivers, oceans & Great Lakes	80 – 95%	60 – 90%
>15%	Lakes (other than Great Lakes)	80 – 95%	None
>15%	Rivers, streams (intake < 5% of annual mean flow)	80 – 95%	None
>15%	Rivers, streams (intake > 5% of annual mean flow)	80 – 95%	60 – 90%

Table 1-3

Notes:

1. Site-specific determination may be made at nuclear facilities if the Nuclear Regulatory Commission determines that compliance could result in a conflict with safety requirements.

2. Stricter performance levels may be required if compliance would not meet other Federal, State or Tribal requirements.

Scope of study

The focus of this study is on the costs of the "cooling tower option" for meeting the 316 (b) regulations. Information from a variety of sources is collected and organized to provide a reliable estimate of the likely costs of retrofitting wet cooling towers onto existing plants originally constructed with once-through cooling. Costs estimated for existing plants conducted by utilities and in some cases independent studies by architect/engineering firms are identified, scaled up from the date of the study to reflect 2002 costs and correlated against postulated important plant characteristics. Studies that have attempted to use generalized costing rules to estimate the costs for all units potentially subject to the Proposed rule are examined. The results of these studies are compared with data from studies of specific plants when available. The agreement or lack thereof is used to estimate the range of costs likely to be encountered and these are compared to the EPA results.

While the primary emphasis is on the capital costs of the retrofit, it is recognized that the effects of using recirculated cooling on plants originally designed for once-through cooling can include changes in the O&M costs, an increase in the plant heat rate and a reduction in the plant output capacity particularly during the warmest and most humid days of the year. Simple estimates are provided to establish the range of these costs as well. Finally, the use of recirculated cooling, while doubtless reducing the intake of water into a plant's cooling system, may introduce other environmental impacts. These are considered briefly.

Organization of report

The remainder of the report is organized into seven sections. Sections 2 through 5 deal solely with capital costs. Section 2 reviews the EPA methodology and cost estimates. Sections 3 and 4 collect, review and correlate information from individual plant studies by utilities and A&E's (Section 3) and cost studies based on generalized costing rules (Section 4). Section 4 also presents comparisons of the studies with the individual plant information and intercomparisons of the various generalized cost estimates. Section 5 presents comparisons with EPA results.

Section 6 reviews the cost of increased O&M requirements, of increased heat rates and of hot-day capacity loss. Section 7 reviews other environmental issues that might result from the introduction of recirculated cooling on a widespread basis at once-through cooled plants. Finally, Section 8 summarizes conclusions drawn from these analyses.

2

EPA ANALYSIS

Introduction

This section provides a brief review of the cost analysis methodology used by EPA in their development of the proposed Phase II rule. In addition to the proposed rule itself, the primary sources of information are

- EPA Economic & Benefits Analysis; EPA-821-R-02-001 (2)
- Case Study Analyses; EPA-821-R-02-002 (3)
- Technical Development Document; EPA-821-R-02-003 (4)

Underlying methodology and assumptions

The EPA approach to developing the likely cost of the "all cooling towers" option is based on a few major assumptions.

1. The addition of a cooling tower at a plant will connect to the existing condenser and the circulating cooling water flow rate will be unchanged, and
2. Portions of existing condenser conduit systems can be used, although some intake modification and conduit branching may be required.
3. The EPA cost development methodology used new facility, or "greenfield", cost estimates that are then adjusted by multiplying "factors" in order to determine the cost of retrofit at a plant of the same size (circulating water flow rate).

Items 1 and 2 are illustrated for purposes of discussion in Figures 2-1 and 2-2, which show schematically the rearrangement of the circulating water piping and make-up and blowdown conduits that are needed.

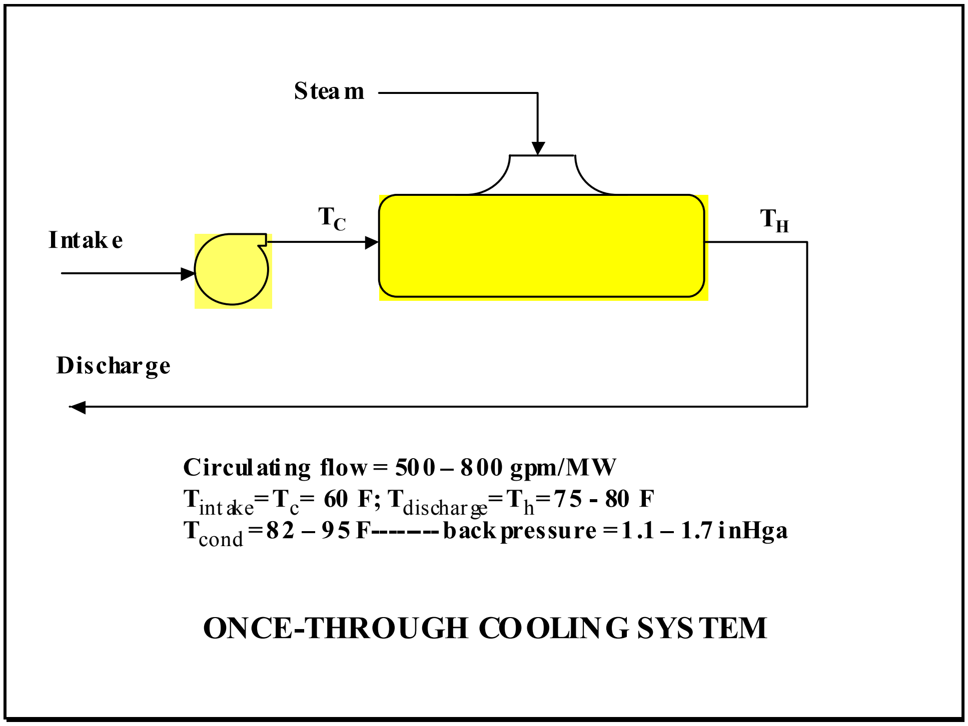

Figure 2-1

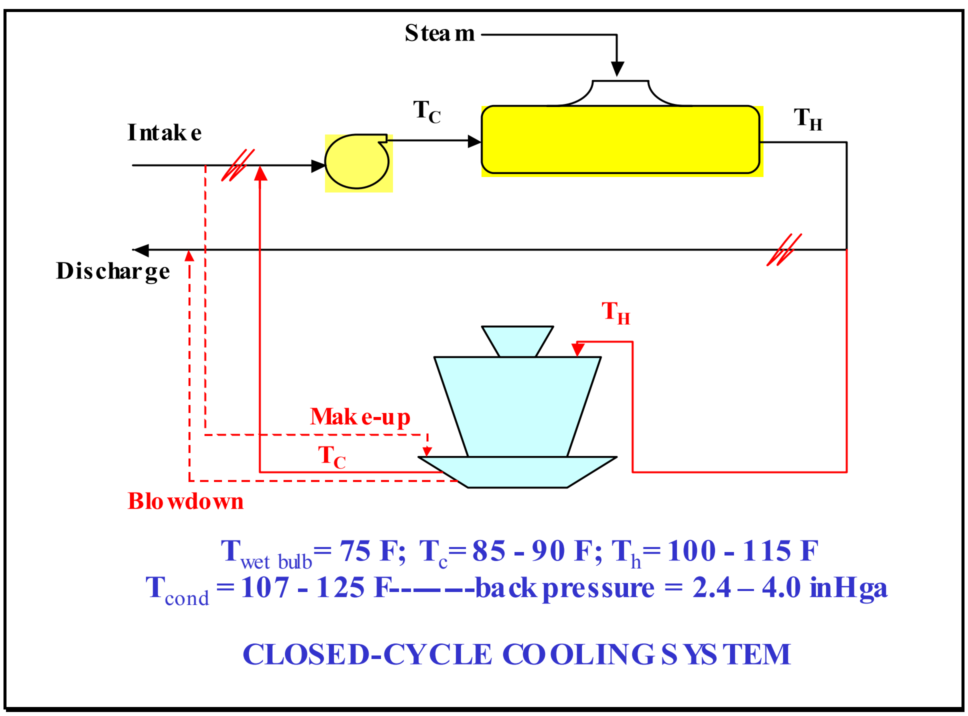

Figure 2-2

Cooling system re-optimization:

The issue of whether the circulating water flow and condenser configuration are kept the same is an important one. Systems originally designed for and operated on once-through cooling typically have a higher condenser flow rate than do systems designed originally for recirculated cooling with cooling towers for the following reasons:

1. The circulating water loop head requirements are substantially lower for once-through systems where the major pressure drop occurs across the tube side of the condenser. In a recirculated system the head rise needed to lift the water to the spray deck at the top of the cooling tower is added to the condenser pressure drop increasing the required pumping power by a factor of two or three if the flow rate is the same.
2. For a given heat load , the temperature rise of the cooling water as it flows through the condenser is inversely proportional to the flow rate. Therefore, for a given condensing temperature, the mean temperature difference across the condenser is greater for a lower water temperature rise (higher flow) allowing for a smaller condenser. Typically, once-through systems optimize at flow rates corresponding to a temperature rise of 10 to 15 F with a circulating water flow rate of 400 to 700 gpm/MW as shown in Figure 2-3 for the 50 plants for which cost data were obtained.
3. On the other hand, cooling towers operate more effectively at higher temperatures and lower water flow rates. The higher inlet temperatures would provide for a larger driving force for heat rejection to the atmosphere, thereby reducing the required size and fan horsepower of the tower. Therefore, compared to a once-through system, an optimized tower system normally has higher temperature rises across the condenser, lower circulating flow rates resulting in lower pumping power, a smaller and less expensive tower, but with increased condenser area.

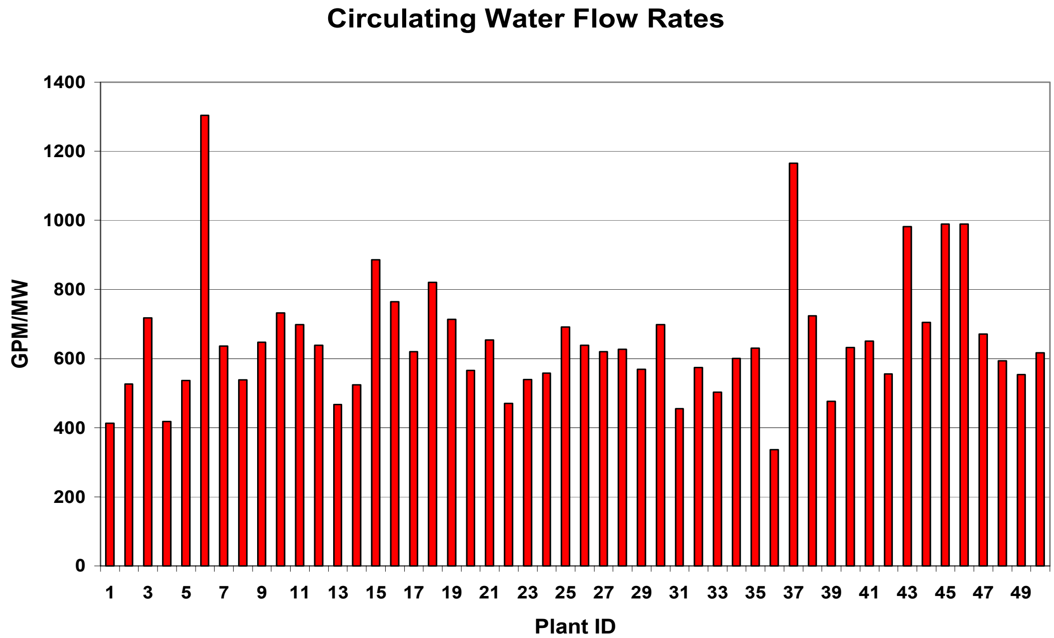

Figure 2-3

Therefore, a retrofit strategy which leaves the circulating water flow and condenser unchanged results in a tower which is more costly and pumping requirements that are higher (the tower would have to be larger to handle the higher volumes of water at the lower inlet temperature) than an optimized recirculated system but avoids the cost of retrofitting the condenser and minimizes the modifications required to the circulating water piping.

A retrofit strategy that re-optimizes the balance of the cooling system to accommodate the change to a recirculated system by cutting the circulating water flow rate by 40 to 60%, will require major condenser tube-side modifications to keep the tube side water velocities at sufficiently high levels. This typically requires a change from a one-pass to a two-pass tube side, rearrangement of the water boxes, and rerouting of the inlet and outlet piping. These modifications may require substantial time and effort to gain access to the condenser through the turbine hall walls, and to rearrange massive piping in the area below the turbine exhaust.

The approach which re-optimizes the cooling water system as part of the retrofit typically incurs higher costs for the retrofit itself but results in more efficient operation with lower heat rates and lower operating energy requirements over the remaining life of the plant. Therefore, this strategy would be preferentially applied to large, base-loaded (low heat rate plants) with long remaining life. EPA has not made this distinction in their analysis. However, as will be noted later, nearly all the case studies done at individual plants by the owners themselves or by A&E firms adopted a similar strategy so virtually no data exist to establish the difference in either capital cost or lifetime operating costs definitively.

Use of existing circulating water piping circuit

The ability to use existing circulating water piping is an important feature of minimizing the cost of retrofit. It depends on two factors: the ability of the existing piping to handle any increased pressure and the availability of a place to locate the cooling tower in reasonable proximity to the turbine hall and the existing condenser.

1. The need to pump the hot water from the condenser to the top of the tower imposes a higher pressure on the condenser tubes, the inlet and exit waterboxes and all piping from the circulating water pumps to the cooling towers. In many cases, neither the waterboxes nor the piping itself is designed to withstand this additional pressure, which might be an increase of 15 to 30 psi. In these cases, reinforcement or even replacement may be required at substantial additional cost.
2. At some sites, the only feasible place to locate a cooling tower may be quite far from the condenser and the existing inlet and discharge structures. There are also some sites that are so constrained that placement of a wet cooling tower is essentially impossible. Some studies have required the placement of the tower as much as one-half mile away, requiring the installation of 4000 to 6000 feet of new circulating water conduit.

New facility costs

The estimates for new facility costs were documented in the support documents (5, 6, 7, 8) published in conjunction with the 316(b) Phase I Rule for New Facilities. These costs were subjected to industry review at the time of that rule making but are summarized briefly here for convenience of reference.

The fundamental cost element was for the cooling tower itself. The estimates, based on "discussions with experienced industry representatives", were as follows:

The range of costs were expressed as $ per gpm of circulating water flow for towers with water flow rates less than or greater than 10,000 gpm (corresponds to plants of about 20 MW)

BASE TOWER COSTS---NEW FACILITIES*		
Circ. Water Flow Rate	**Approach** ($T_{cold} – T_{ambient\ wet\ bulb}$)	**Cost Factor (\$/gpm)**
< 10,000 gpm	10	30
"	5	50
> 10,000 gpm	10	30 - 25
	5	50 - 45

** for towers up to 204,000 gpm; larger systems assumed multiple towers

Additional scale factors included:

Material factors:	Douglas fir	1.0	
	Redwood	1.12	
	Concrete	1.4	
	FRP	1.1	(fiberglass reinforced plastic)
Fill factors:	Film fill	1.0	
	Splash fill	1.1	
	Non-fouling film fill	1.1	

Total installed cooling tower costs were taken as 1.8 times the cooling tower capital costs.

The capital cost included

- Wet mechanical draft tower, furnished and erected (with internal tower piping, risers and valves, fans, motors, electrical service and housing)
- Site preparation, clearing and grading
- Excavations for basins and piping
- Circulating water piping, valves and fittings to and from condenser
- Access roads
- Full circulating pumps and housing
- Installed concrete basins, sumps and footings
- Electrical wiring, controls and transformers
- Blowdown water treatment facility
- Acceptance testing and installation.

The x 1.8 multiplier also accounted for construction management, mobilization and demobilization, design engineering and architectural fees, contractor overhead and profit, turnkey fee and contingencies.

Therefore, for a redwood tower with splash fill designed for a 10F approach in a size range near 200,000 gpm, the cost is given by

$$\$25/\text{gpm} \times 1.12 \times 1.1 \times 1.8 = \$55.4/\text{gpm}$$

<u>Comparison with other cost estimates:</u>

There are other recent cost estimates for new wet cooling towers to be found in publications by Maulbetsch and DiFilippo (9) and by Burns and Micheletti (10).

The costs for just the cooling tower (purchased and erected) for various local climatic conditions ranged from $20 to $25/gpm. The inclusion of the other elements included in the EPA estimate of "base capital cost" increased this value by a factor of about 1.5 resulting in a cost of $37.5/gpm to be compared to EPA's $25/gpm. However, the usual multiplier in the several studies of new and retrofit costs (including recent work by Burns & Micheletti (10), Stone & Webster (11) and others (12)) for indirect costs average to 1.35. These costs included construction management, mobilization and demobilization, design engineering and architectural fees, contractor overhead and profit, turnkey fee and contingencies. Applying this to the estimates in Maulbetsch and DiFilippo (9) gives a system installed cost of about $50/gpm, which is in essential agreement with the EPA value. An informal survey (13) of recent tower purchasers in the industry at the time of publication of the M&D report suggested that the estimates were close to the range of their recent experience. It should be noted that significantly higher cost estimates could be found in recent literature (10, 14) although the basis for a direct comparison with EPA results is not easy to define.

<u>Retrofit vs. new installations</u>

Capital cost estimates for retrofit cooling towers were based on "greenfield" cost estimates described above using:

- For fossil plants: redwood, mechanical draft towers with splash fill
- For nuclear plants: concrete, mechanical draft towers with splash fill.

It was recognized that the construction and installation process was generally more difficult, time-consuming and costly when done on the site of an existing, operating facility with attendant interferences of existing structures, overhead and underground interferences and the on-going conduct of business. These additional costs were described as including such items as:

- Branching or diversion of cooling water delivery systems,
- Reinforcement of retrofitted conduit system connections,
- Partial of full demolition of conduit systems and/or structures,
- Additional excavation activities
- Temporary delays in construction schedules
- Potential small land purchases
- Hiring of additional (beyond those typical for the "greenfield" cost estimates) equipment and personnel for subsurface construction
- Potential additional cooling water (recirculating or make-up delivery needs), and
- Expedited construction schedules and administrative and construction-related safety procedures.

The factor applied to account for these costs was chosen by the Agency as 20% for "activity necessary to convert cooling systems" and 30% for "upgrading of cooling water intake structures and screens".

In addition to this retrofit factor, two other multipliers were applied:

1. A contingency factor of 10% to account for miscellaneous unspecified uncertainties associated with a construction project, and
2. A regional cost factor to account for local differences in labor and material costs. These were applied on a state-by state basis and ranged from 0.739 (for South Carolina) to 1.245 (for Alaska).

The magnitude of these adjustment factors is of paramount importance in determining the appropriateness of the estimated retrofit cost estimates. A number of comments are relevant:

1. The regional cost factor is based on well-documented information from the R. S. Means Cost Works 2001 (15). This approach to accounting for local cost differences is well established and consistent with methods in other studies.
2. The 10% contingency factor, while presented without any supporting evidence, is also consistent with similar estimating methods used by others.
3. The retrofit factor, however, is also selected without any documentation or reference to any supporting data or information based on experience with comparable projects at new vs. existing facilities. While confirming (or contradictory) evidence is difficult to find, there are reasons to believe that the 20% adjustment factor will underestimate the retrofit-related costs in many (although perhaps not all) cases. Specifically,

    - Site-specific retrofit costs studies show a high degree of variability from costs based on commonly accepted scaling methods. Cooling tower cost estimating methods are often based on the use of a $/gpm rule of thumb. This is approach is used by tower vendors, A&E firms and experienced users and is based almost entirely on the field's experience with tower construction at new sites. EPA used this approach as well. It can, therefore, be reasonably assumed that the variability in careful engineering estimates of site-specific retrofit costs, which will be documented for about 50 cases in Section 3, is due to differences in the degree of difficulty associated with the retrofit aspects of each project.
    - It is also reasonable to assume that the lower bound of these costs is associated with the "easiest" retrofit cases, which would correspond most closely to a new facility project free of the interferences encountered at most existing facilities. As will be seen, the lower bound of the case data corresponds reasonably well with the "greenfield" cost estimating rules proposed by EPA, while the mid-range of the data is 40 to 60% higher with many cases ranging to a factor of 2 to 4 times more expensive.
    - Discussions were held with project managers at actual sites where construction projects of a similar nature to cooling system retrofits were either underway or had been estimated in detail for potential future site modifications. In all cases, the cost increments associated

with constraints imposed on the project by the complexities of construction at an existing site were claimed to be significantly greater than 20%, with estimates ranging from 50% to 100%. This range is reasonably consistent with what might be inferred from the case study estimates discussed above. The reasons given for the incremental costs included many that were apparently not included (or at least not specifically identified) in EPA's discussion of their retrofit cost factor. These included

i. The need to locate new structures far from their preferred location because of pre-existing structures, switchgear, access roads, etc.
ii. The extreme difficulty of installing underground piping in the presence of pre-existing piping and cables that had to avoided or relocated. In one instance, the installation of a circulating water line for a new unit located on the back of an existing site encountered over 150 interferences and increased the cost of normal estimates on a "per ft. diameter-ft. length" basis by a factor of nearly five.
iii. The need to locate material laydown areas and crew parking areas several miles from the site with an attendant effect on productivity alone estimated at 10 to 20%.
iv. The inability, in some cases, to carry out some aspects of the project in parallel with others where the site access would be blocked by a structure that construction of them could not commence until all others were completed.

While it is not possible to generalize such experience to all sites, they establish the point that very high retrofit factors will inevitably be encountered at many facilities.

3

Retrofit Cost Data—Individual Plants

Data Sources

Cost estimates for retrofitting once-through cooling systems to recirculated systems were solicited from many utilities including EPRI and Utility Water Act Group (UWAG) member companies. In addition, a brief literature search was conducted for published studies. Cost information was obtained for 50 plants. These were grouped by fuel type (nuclear or fossil), plant size (> or < 500MW) and source water type (fresh, brackish or saline). Table 3-1 gives the distribution of the plant data among the categories. Appendix A tabulates the plants (identified by sequential numbering as Plant "n") with pertinent information about plant capacity, circulating water flow rate, location by region, fuel, source water type, retrofit cost data (as reported and scaled to 2002$, and the estimates for the plant from the Stone & Webster study (16).

Distribution of Plants With Data (50)			
NUCLEAR (15)			
	Saline	**Brackish**	**Fresh**
> 500 MW (15)	**5**	**5**	**5**
< 500 MW (0)	**0**	**0**	**0**
FOSSIL (35)			
	Saline	**Brackish**	**Fresh**
> 500 MW (29)	**2**	**8**	**19**
< 500 MW (6)	**1**	**1**	**4**

Table 3-1

The source information came in varying forms and some adjustments were often required to put them on a common basis. The two most important considerations were the year in which the estimate was made and whether or not ancillary costs were included in addition to the direct costs.

Year of estimate

In all cases, the year in which the estimates were made was reported. The dates of the estimates ranged from 1973 to 2002. For estimates made in years prior to 2002, the values were scaled up to 2002 dollars using the appropriate multiplier from the Engineering News Record's Construction Cost Index (ENR-CCI), available at http://enr.construction.com/cost/costcci.asp. These factors are displayed in Table 3-2. The increase over the past ten years is equivalent to a compound escalation rate of 2.8%.

Construction Cost Index History (1908-2002)

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	ANNUAL AVG
1980	3132	3134	3159	3143	3139	3198	3260	3304	3319	3327	3355	3376	3237
1981	3372	3373	3384	3450	3471	3496	3548	3616	3657	3660	3697	3695	3535
1982	3704	3728	3721	3731	3734	3815	3899	3899	3902	3901	3917	3950	3825
1983	3960	4001	4006	4001	4003	4073	4108	4132	4142	4127	4133	4110	4066
1984	4109	4113	4118	4132	4142	4161	4166	4169	4176	4161	4158	4144	4146
1985	4145	4153	4151	4150	4171	4201	4220	4230	4229	4228	4231	4228	4195
1986	4218	4230	4231	4242	4275	4303	4332	4334	4335	4344	4342	4351	4295
1987	4354	4352	4359	4363	4369	4387	4404	4443	4456	4459	4453	4478	4406
1988	4470	4473	4484	4489	4493	4525	4532	4542	4535	4555	4567	4568	4519
1989	4580	4573	4574	4577	4578	4599	4608	4618	4658	4658	4668	4685	4615
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL AVG**
1990	4680	4685	4691	4693	4707	4732	4734	4752	4774	4771	4787	4777	4732
1991	4777	4773	4772	4766	4801	4818	4854	4892	4891	4892	4896	4889	4835
1992	4888	4884	4927	4946	4965	4973	4992	5032	5042	5052	5058	5059	4985
1993	5071	5070	5106	5167	5262	5260	5252	5230	5255	5264	5278	5310	5210
1994	5336	5371	5381	5405	5405	5408	5409	5424	5437	5437	5439	5439	5408
1995	5443	5444	5435	5432	5433	5432	5484	5506	5491	5511	5519	5524	5471
1996	5523	5532	5537	5550	5572	5597	5617	5652	5683	5719	5740	5744	5620
1997	5765	5769	5759	5799	5837	5860	5863	5854	5851	5848	5838	5858	5825
1998	5852	5874	5875	5883	5881	5895	5921	5929	5963	5986	5995	5991	5920
1999	6000	5992	5986	6008	6006	6039	6076	6091	6128	6134	6127	6127	6060
	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**	**ANNUAL AVG**
2000	6130	6160	6202	6201	6233	6238	6225	6233	6224	6259	6266	6283	6221
2001	6281	6273	6280	6286	6288	6319	6404	6389	6391	6397	6410	6390	6342
2002	6462	6462											

ANNUAL AVERAGE							
1908	97	**1931**	181	**1954**	628	**1977**	2576
1909	91	**1932**	157	**1955**	660	**1978**	2776
1910	96	**1933**	170	**1956**	692	**1979**	3003
1911	93	**1934**	198	**1957**	724		

1912	91	**1935**	196	**1958**	759
1913	100	**1936**	206	**1959**	797
1914	89	**1937**	235	**1960**	824
1915	93	**1938**	236	**1961**	847
1916	130	**1939**	236	**1962**	872
1917	181	**1940**	242	**1963**	901
1918	189	**1941**	258	**1964**	936
1919	198	**1942**	276	**1965**	971
1920	251	**1943**	290	**1966**	1019
1921	202	**1944**	299	**1967**	1074
1922	174	**1945**	308	**1968**	1155
1923	214	**1946**	346	**1969**	1269
1924	215	**1947**	413	**1970**	1381
1925	207	**1948**	461	**1971**	1581
1926	208	**1949**	477	**1972**	1753
1927	206	**1950**	510	**1973**	1895
1928	207	**1951**	543	**1974**	2020
1929	207	**1952**	569	**1975**	2212
1930	203	**1953**	600	**1976**	2401

In a few instances, the utility supplying the data provided a separate estimate of updated costs from original earlier estimates. These were generally close to, but not necessarily identical to the factor that would be derived from the ENR-CCI. In those cases, the utility estimate was used on the basis that it might better reflect local circumstances.

Level of detail

The information provided for the cost of retrofit at a particular plant varied from a "single number estimate" to fully documented engineering studies. Two important questions for the "single number estimates" were:

1. What was the extent of the retrofit?
2. What ancillary project costs were included?

Extent of retrofit

"Extent of retrofit" refers to whether or not the plant cooling system was re-optimized to account for the different operating characteristics of a recirculated system. Specifically, in what might be characterized as a "minimum modifications retrofit" the existing cooling circuit would be left largely unchanged. The circulating water flow would be kept the same; the surface condenser would be unchanged. A wet cooling tower (typically mechanical draft) would be inserted into the cooling water flow loop; the circulating water pumps would be replaced or upgraded to meet the increased head requirements imposed by the need to pump water to the top of the tower; the circulating water lines would be re-routed or reinforced as required; and make-up and blowdown pumps, lines and treatment facilities would be added. This approach is a minimum initial capital cost approach but results in a less than optimum design and operating condition for a recirculated cooling system.

<u>Re-optimized retrofit</u>

Compared to once-through cooling, recirculated cooling is normally designed with lower circulating water flow rates due to the higher head rise required to pump the water to the top of the tower, typically 40 to 60 feet above the condenser outlet. The lower flow results in higher temperature rise across the condenser. The tower is then optimized for a higher range ($T_{h\ on} - T_{c\ off}$) and a lower L/G (liquid to gas ratio) than would be the case for a tower operating at the flow and temperature rise of the original once-through system. This results in a lower cost tower with a closer approach to ambient wet bulb than the unoptimized case.

However, the steam surface condenser would then need to be reconfigured to maintain its performance at the lower flow, higher range conditions. Typically, this would be accomplished by changing the tube side from a one-pass to a two-pass design in order to maintain the water velocity in the tubes at an acceptably high level. This in turn requires substantial re-arrangement of the inlet and outlet headers and piping and often considerable demolition (and subsequent rebuilding) of the turbine building walls in order to gain access to the condenser for the modifications.

Re-optimization, therefore, adds considerably to the initial capital cost of retrofit but results in a system with substantially lower operating cost (lower pump and fan power requirements) and lower performance penalties for the remaining life of the plant. Therefore, the re-optimization approach would be used only for large, typically base-load plant with a long remaining life. With only two exceptions, all of the cost information used in this analysis was for “minimum modification retrofits”.

<u>Ancillary costs</u>

The fully documented studies presented direct cost items including purchased equipment and installation costs. Table 3-3 displays a listing of typical cost elements, taken from a published study of retrofit cost estimates for a large nuclear plant (11). In addition, ancillary cost elements are added in order to develop a realistic “total project cost”. One such set of cost categories is listed in Table 3-4, taken from a study of the Millstone Plant presented to the Connecticut Department of Environmental Protection (Ref. 12). These cost are normally “factored” or estimated as a percentage of the Direct Costs. The percentages used in the Millstone study are given in Table 3-4. Based on these values, the ancillary costs add 37% to the Direct Costs of the retrofit.

Appendix C contains costs broken down by cost element from six sources. These include five studies of individual plants and a report by the Washington Group (Ref. 14). For each of the studies, the cost breakdown in dollars (year of the study) and the percent of the total project cost represented by each element is tabulated in the line item format of the original study. From these tables, a consolidated table is constructed using a set of line items which cover most of the items from the individual studies. In some cases, lines from the original studies are combined into a single element on the consolidated table. In others, they are allocated to two separate elements. These combinations and allocations are indicated in the tables.

For most of the elements there is considerable difference from site to site in the fraction of the total cost represented by an individual element. The final column in the consolidated table gives the average percentage from the six sources. While this may be useful as general guidance and information, site specific considerations clearly dominate the breakdown of retrofit costs at each site.

Typical Cost Elements for Recirculated Retrofit (from Ref. 11)	
Major Elements	**Minor Elements (each < 0.5%)**
Cooling Tower	Plant I & C
Circulating water pumps	Site development
Plant electrical	Cooling tower electrical building
Yard electrical	Switchgear
Return pump structure and flume	Load center building
Cooling tower pump structure and flume	Cooling tower pump building
Transportation	Access roads
	Sound wall

Table 3-3

Typical Ancillary Costs	
Cost Category	**% of Direct Cost**
Construction Management	7
Engineering	10
AFI*/Contingency	20

* Allowance for Indeterminates

Table 3-4

Other studies include similar adjustments to the Direct Costs. Regardless of the exact categorization, the total adjustment ranged from 35% to 45% in the case of one utility study.

In interpreting the "single number estimates" received for individual plants, it was not clear whether the cost represented the Direct Cost or the total project cost. Telephone inquiries to all sources that could be reached indicated that in most (but not all) cases the total project cost was included but it was seldom known what percent of the total was represented by the ancillary costs. In cases where it was determined that only the direct costs had been reported, the cost was increased by 40% to put it on a consistent basis with the rest. For cases where it could not be determined which costs were reported, it was assumed that the reported cost was the total project cost.

Cost information from individual plant case studies

The cost data for each of the plants, scaled to a comparable basis in 2002$, is displayed in Figures 3-1 through 3-6.

Cost vs. Plant Size:

Figure 3-1 plots the cost against plant size in MW. This is consistent with the conventional means of normalizing cost data for power plant equipment on a $/kW basis.

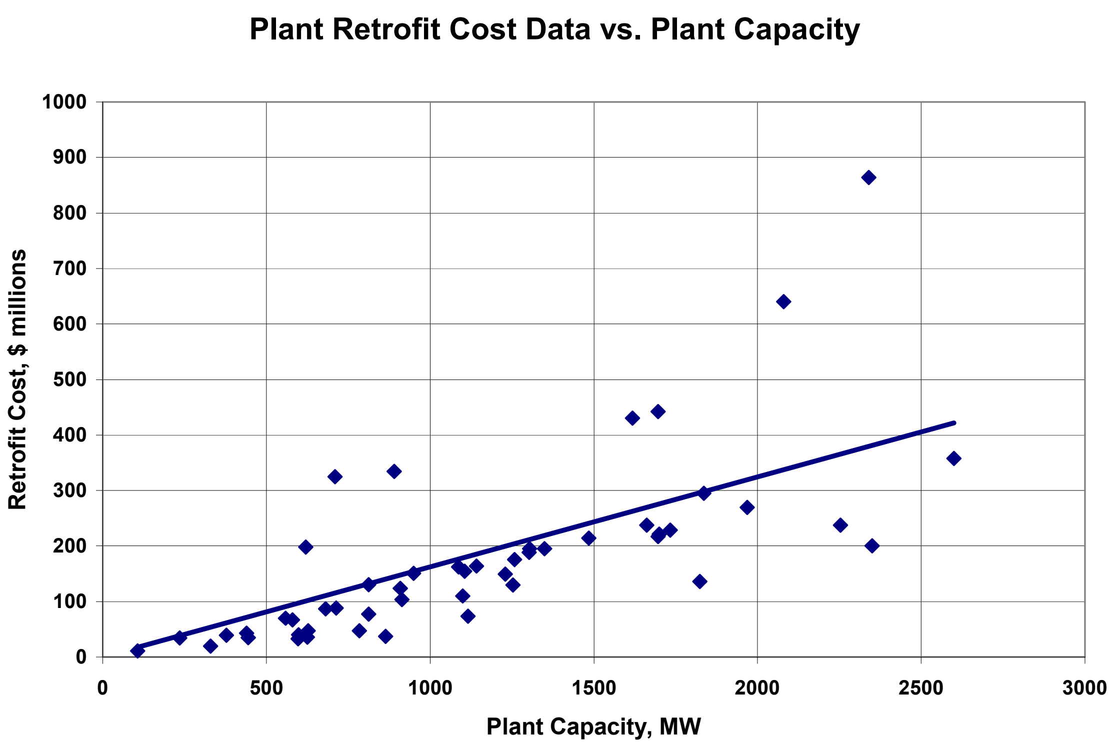

Figure 3-1

In this case, the correlation, while roughly proportional, is poor. The costs range from well below $100/MW to well above $250/MW. This is due in part to the fact that the cost of cooling system components is more closely related to the amount of water being circulated and cooled than to the heat load being rejected. Additionally, the circulating water flow rate per MW of plant capacity is not constant but varies considerably from plant to plant as a function of heat rate and design choice, as shown in Figure 2-3, suggesting that a correlating factor of $/gpm would be more directly related to the size and capability of the cooling system. As discussed in Section 2, this is in fact the scaling factor in common use in the cooling system industry and that which was used by EPA and others in cost analyses of both new and retrofit cooling systems.

Cost vs. Circulating Water Flow Rate

Figure 3-2 displays the same data against circulating water flow rate.

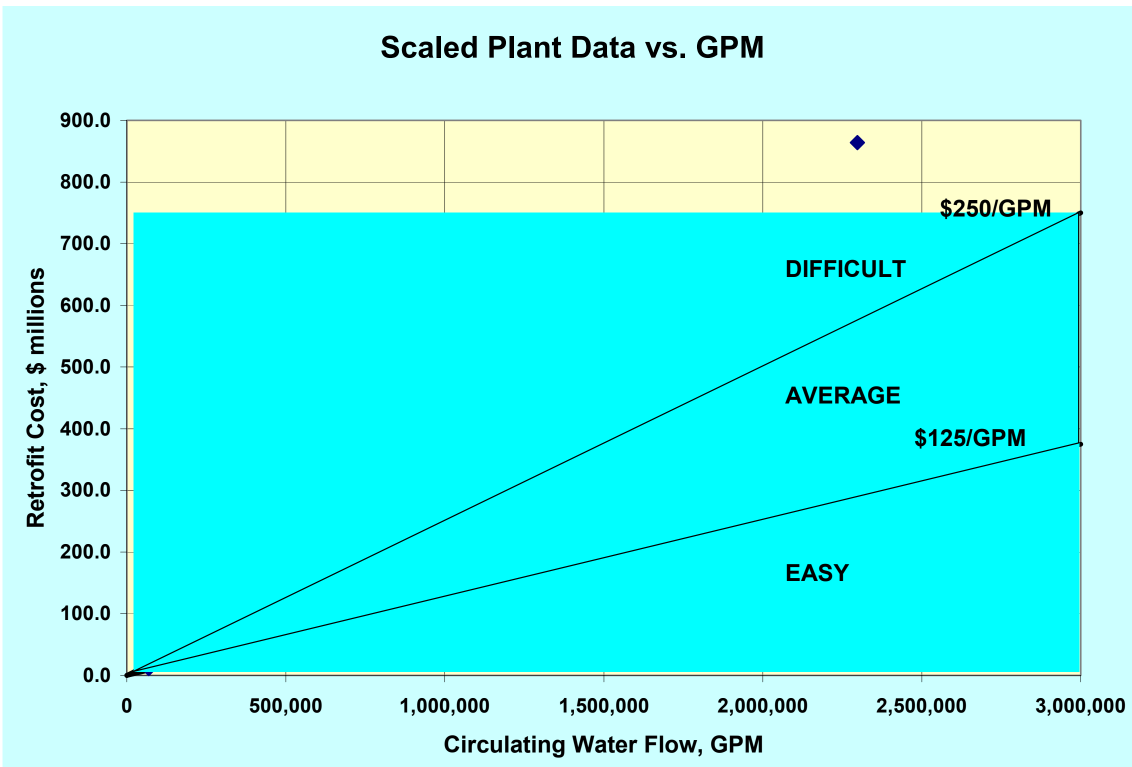

Figure 3-2

While the general correlation against flow rate is improved over that against plant capacity, a considerable range still exists and numerous outliers are evident.

The following figures show the results of trying to categorize the results by plant type (fossil vs. nuclear) in Figure 3-3 and by source water type (saline vs. brackish vs. fresh) in Figure 3-4.

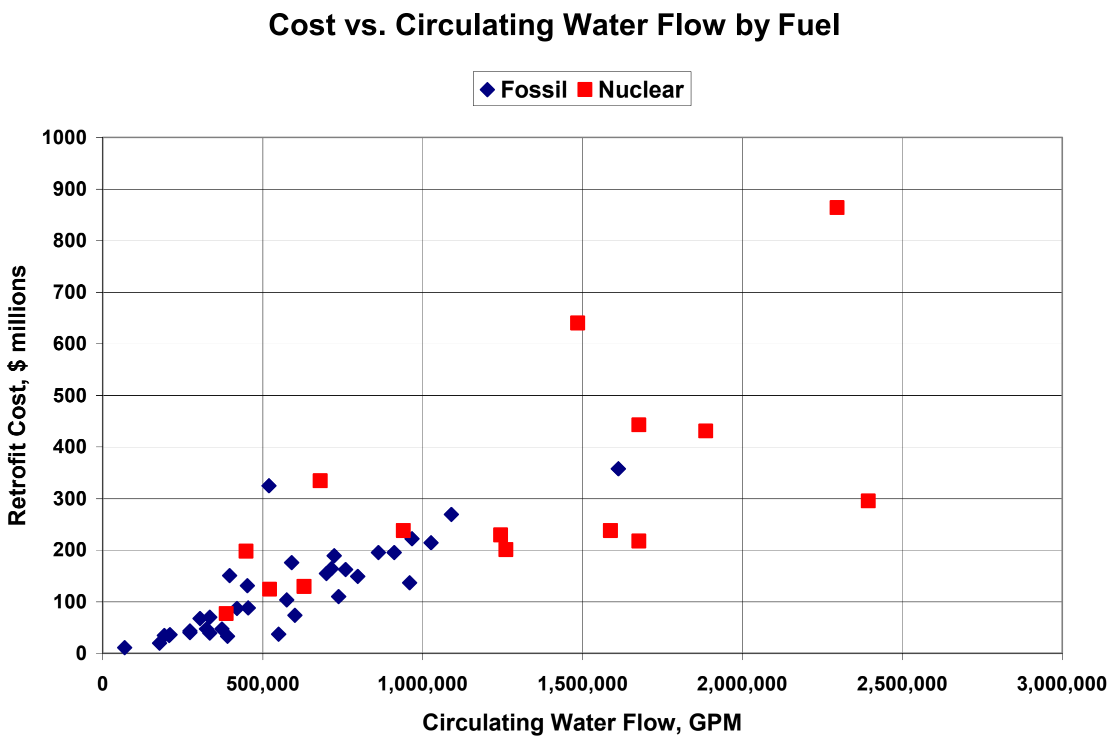

Figure 3-3

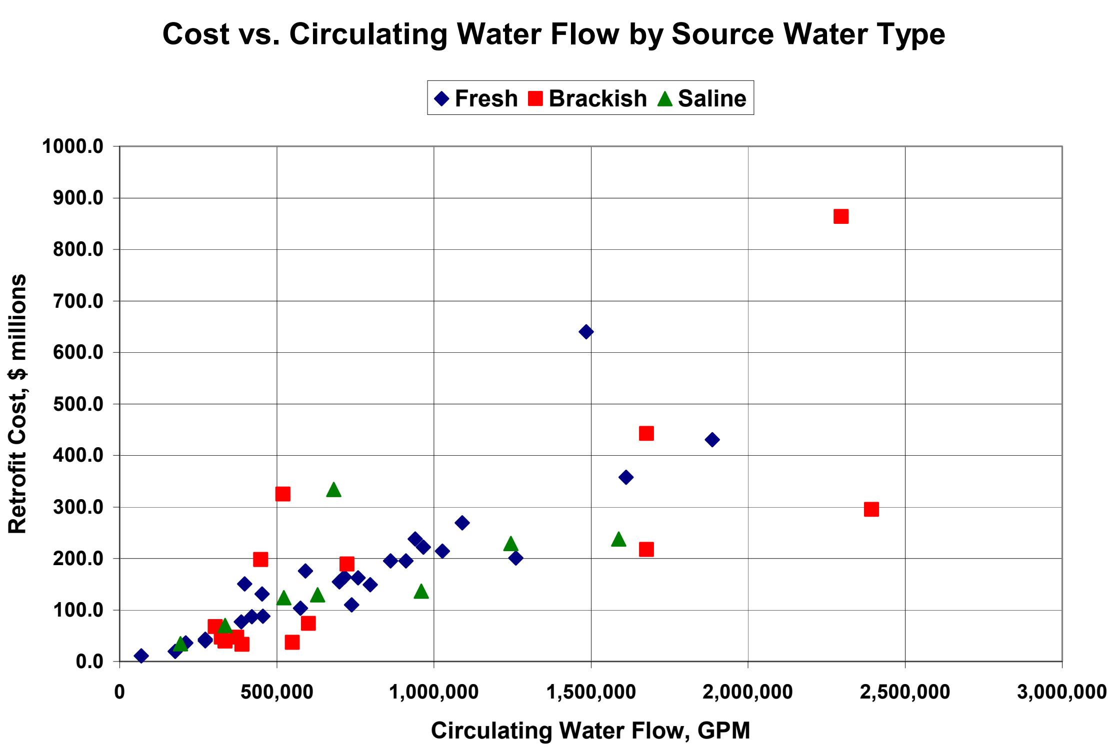

Figure 3-4

Fossil vs. nuclear plants:

The data in Figure 3-3 suggests that there is no consistent separation between the costs at nuclear vs. fossil plants. The nuclear plant cost estimates exhibit much greater variability than do the fossil plant estimates with outliers on both the high and low cost extremes. However, many of the plants fall in a range that is indistinguishable from the majority of the fossil plants over a nearly five-fold range of cooling system size as measured by circulating water flow rate.

Source water type

Figure 3-4 suggests a similar conclusion for the effect of source water type. Retrofit costs for plants using brackish water plants exhibit higher variability than do those for either fresh or saline water. While this may be indicative of greater inherent variability in water properties within the class designated as brackish, it seems unlikely that the case study results reflected that detailed an analysis. The apparent variability in costs in the brackish category may more likely be attributed to the fact that those points which might be considered outliers are also nuclear plants which exhibit greater variability for all water types.

This hypothesis is investigated further in Figures 3-5 and 3-6 that refine the analysis further by separating the data both by fuel type and source water type. Figure 3-5 shows all the fossil plants separated by water type.

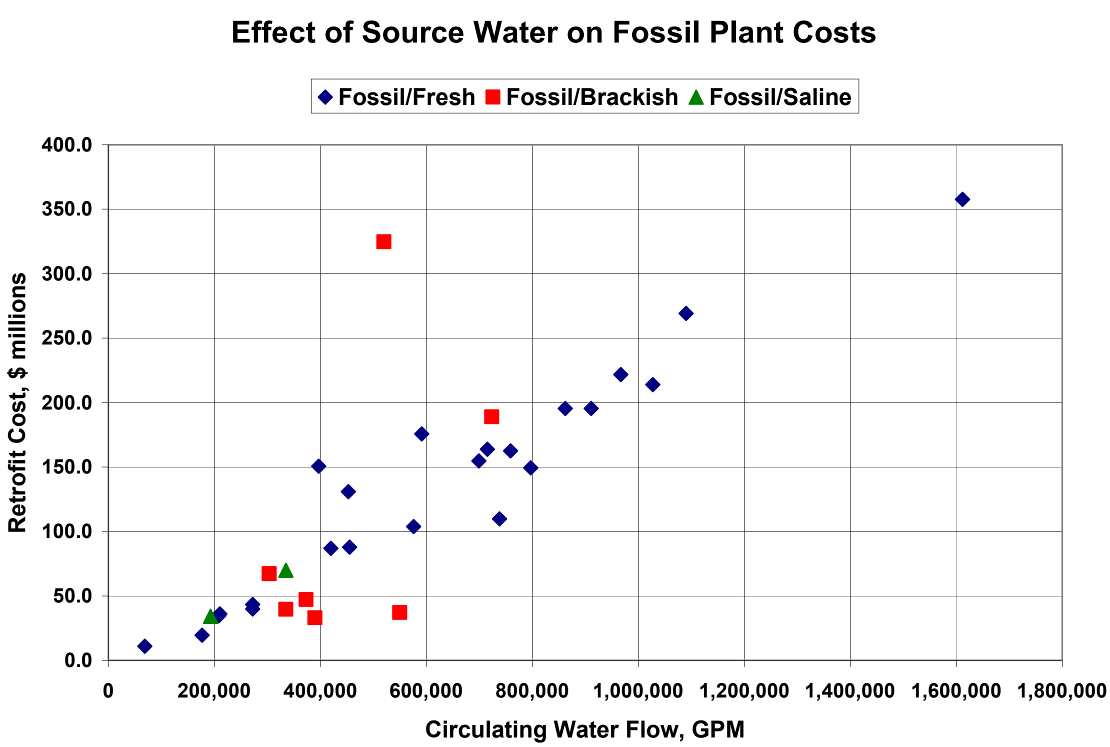

Figure 3-5

With one or two notable exceptions (one on the high cost side, the other on the low cost side, both of which are brackish water sites), there is reasonable correlation across all source water types within a range of +/- 35 to 50%.

On the other hand, Figure 3-6, which displays similar information for the nuclear case studies, exhibits very high variability for all source water types.

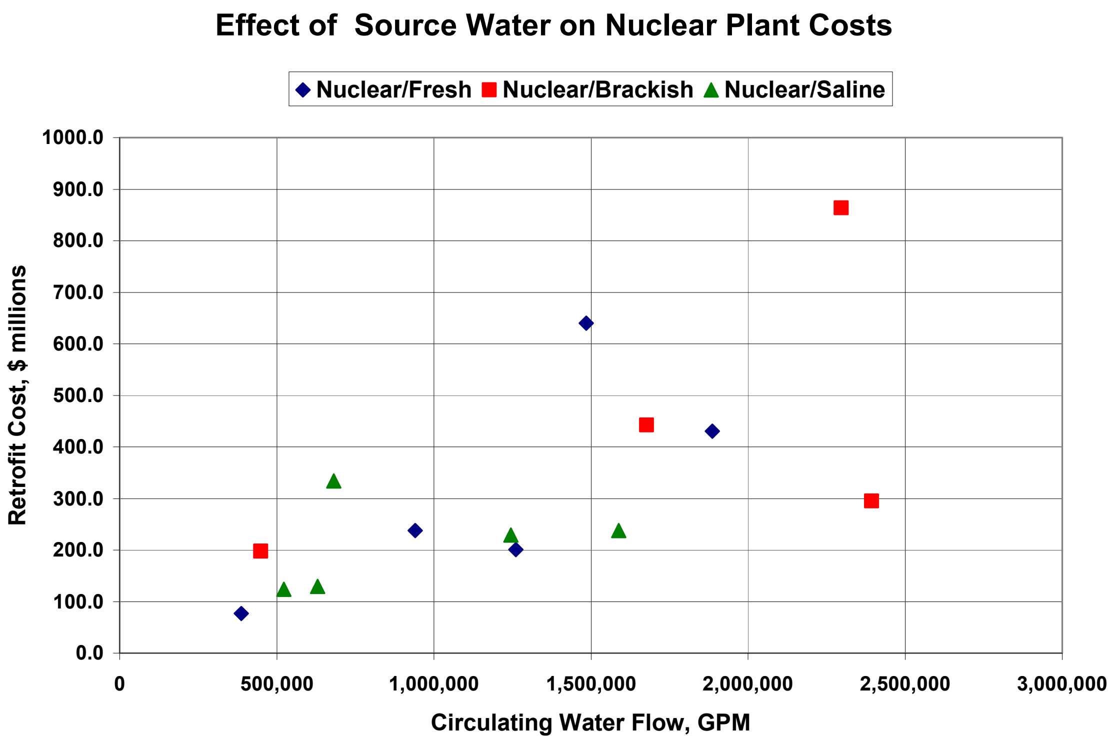

Figure 3-6

The overall conclusion is that neither size nor flow rate scaling, or differences associated with fuel or service water type account adequately for the site-specific differences in retrofit costs. This is clear from a detailed look at some of the individual case study documents.

For example, in a study of nine individual plants at a single utility, the site-specific elements at each plant were factored from an in-depth study at one of the plants. The cost of retrofit was broken into 15 separate elements. The scale factors for many of the major elements varied from 1.0 to 3.3 across the other plants. In one instance, 2/3 of the cost of retrofit at one of the plants was for items that were completely absent at all the others. Clearly the retrofit costs at each of the plants was dominated by site-specific adjustments rather than by simple scale factors based on size or flow rate.

In a survey of EPRI and UWAG members, utilities were asked to assess the seriousness of eight potential site-specific issues which might make retrofit more difficult and more costly at their plants.

The specific issues raised were

1. Availability of land at the site to place a cooling tower.
2. Distance of a preferred site from the turbine/condenser
3. Likelihood of interferences to installation of new circulating water piping.
4. Unacceptable site geology or topography for tower support
5. Drift or plume problems
6. Noise problems
7. Aqueous discharge constraints on blowdown
8. Need to re-optimize condenser or reinforce condenser for increased pressure

Responses were received for a total of 56 plants. Table 3-5 indicates the number of plants at which each issue was deemed to be a problem for cooling system retrofit. Each of the issues was identified at least 1/3 of the plants with some at nearly all. The most common concerns were the difficulty of finding a site near the turbine/condenser and the difficulty of installing circulating water piping in the midst of existing underground interferences.

PLANT REPLIES TO COST ANALYSES
(based on replies from 56 plants)

ISSUES	PLANTS WITH SPECIAL CIRCUMSTANCES	
	Number of plants	Percentage of replies
Space	31	55
Separation Distance	46	82
Interferences	47	84
Site Geology	36	64
Plume/Drift	38	68
Noise	25	45
Aqueous Discharge	36	64
Condenser Modifications	22	39

Table 3-5

4

Independent Retrofit Cost Studies

Three recent independent studies have been conducted estimate the cost retrofitting existing facilities from once-through cooling to recirculated cooling. These studies were done by Stone & Webster Engineering Corporation (SWEC) (16), the Washington Group, Incorporated (WGI) (14) and the National Energy Technology Laboratory (NETL) (17). A brief review of the methodology used in each study and a comparison of the results to the individual plant data presented in Section 3 follows.

<u>SWEC study</u>

The SWEC developed a retrofit cost estimate for each of 1041 units currently using once-through cooling. The cost for each was scaled from one of six reference plants for which detailed cost estimates of a cooling system retrofit had been conducted in the past. These reference plants, listed in Table 4-1, cover a range of plant fuel, source water type and plant size. The total retrofit cost for each reference plant was aggregated in four categories as

- Labor,
- Materials
- Equipment, and
- Indirect costs.

For the subsequent evaluation, SWEC chose the reference plant that was most representative of the unit being estimated. The cost was then scaled from the selected reference plant using two scale factors:

1. The labor cost component was adjusted for regional differences in wages and productivity between the individual unit and the reference plant.
2. The adjusted total cost (adjusted labor plus materials, equipment and indirect) was then scaled from the reference plant to the individual unit on the basis of circulating water flow rate.

This approach is essentially that used by EPA except that SWEC made the regional cost adjustment on the labor component while EPA applied an adjustment factor to the total cost.

The assumption was made, as it was in all of the studies and in the EPA development, that the circulating water flow rate remained the same for the retrofitted recirculated system as for the original once-through system.

No attempt was made to adjust each estimate for local conditions or site-specific "degree of difficulty". The cost estimates, because of the method used, will inherently reflect whatever local retrofit issues or difficulties pertained at the chosen reference plant. Figure 4-1 displays graphically the costs that would be generated by each of the reference plants for the range of circulating water flow rates. With the exception of Plant X5, they are all within a relatively narrow cost range from $185/gpm to $212/gpm. Plant X5 represents a situation where relatively little work had to be done to upgrade the circulating water and make-up water systems.

SWEC REFERENCE PLANTS

PLANT	Fuel	Water Source	CAPACITY MW	FLOW GPM	GPM/MW	COST $	$/GPM	$/kW
X1	Coal	Estuary	250	174,627	699	36,000,000	206.2	144.0
X2	Coal	Estuary	620	279,403	451	57,000,000	204.0	91.9
X3	Oil	Estuary	440	259,701	590	48,000,000	184.8	109.1
X4	Ur	Marine	863	570,448	661	121,000,000	212.1	140.2
X5	Ur	Marine	1137	895,522	788	126,000,000	140.7	110.8
X6	Coal	River	82	35,373	431	6,900,000	195.1	84.1

Table 4-1

Figures 4-2 through 4-5 display comparisons to the individual plant case study data with the results of the SWEC estimates. These estimates give excellent (+/- 25%) agreement against approximately 2/3 of the individual plant data as shown in Figure 4-2 and reasonable agreement (-25%/+50%) for all but about 20% of the cases. A few points are substantial outliers exceeding the estimates by a factor of 2 or more.

It is noteworthy that most of the deviation is in the direction of underestimating the individual plant costs rather than overestimating. In fact, the data cluster itself has a reasonably well-defined lower bound while discontinuities and outliers characterize the high cost boundary. This is consistent with the notion of a reasonably well-defined "minimum cost retrofit" (such as might be represented by new facility construction) modified by site-specific differences that lead to a range of high-end costs that are not predictable on the basis of simple scaling laws.

Figures 4-3 through 4-5 break the comparison down by the categories of fuel (fossil/nuclear), source water type (fresh/brackish/saline) and SWEC reference plant. Figure 4-3 indicates that the agreement is generally better for the fossil units than for the nuclear units, that account for all but one of the plants where the retrofit costs exceeded the estimates scaled from the nuclear reference plants by more than a factor of x2. A number of the nuclear plants, however, agreed extremely well with the estimates suggesting again that sites where no significant site-specific difficulties exist are comparable and can be scaled by cooling system size or circulating water flow rate. However, sites where issues exist can incur costs significantly in excess of what would be expected.

Figure 4-4 seems to indicate greater differences from scaled estimates for brackish sites. However, as was discussed in Section 3, many of the brackish sites exhibiting large differences from the estimates are also nuclear plants, making it difficult to attribute the cause of the variability to the source water or the fuel type.

Figure 4-5 shows no particular separation in the quality of the estimates associated with the choice of base reference plant. This is somewhat to be expected since the range of cost (per gpm of circulating water flow rate) is not large (+/- ~ 7% as seen from Table 4-1). Reference plant X5, the largest nuclear plant, has a significantly lower cost per gpm (by about 30% from the average of the other 5 base plants) and does under predict three of the larger nuclear units. On the other hand, it predicts three others quite well, suggesting again that site-specific issues are often the dominant determination of the costs of retrofit.

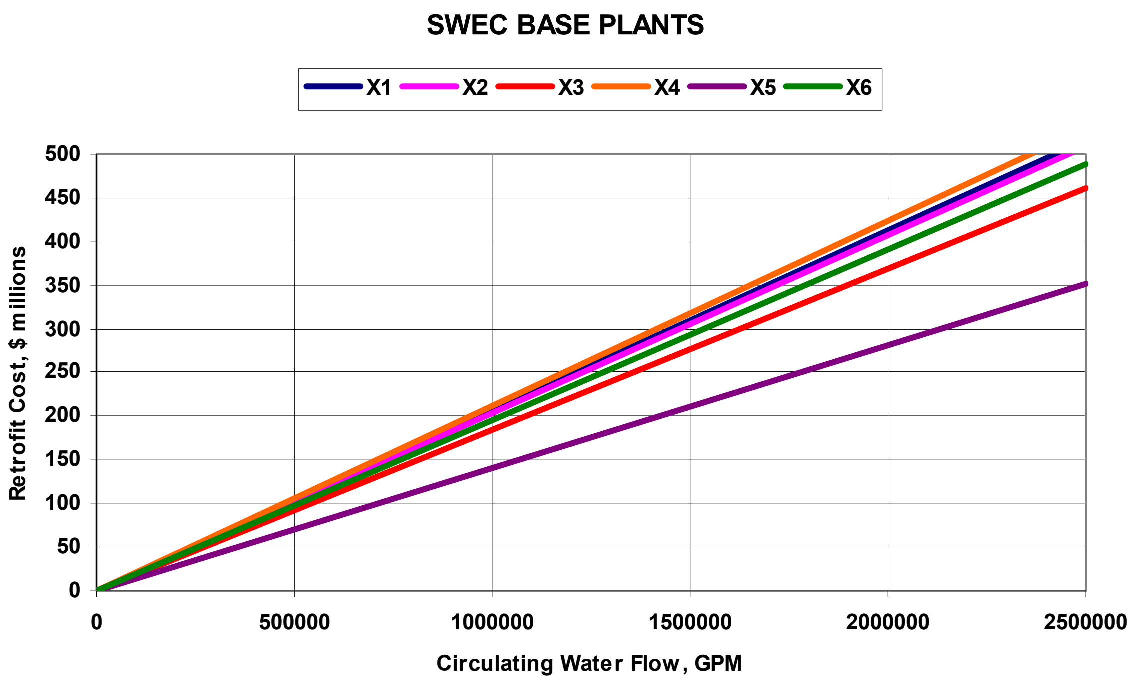

Figure 4-1

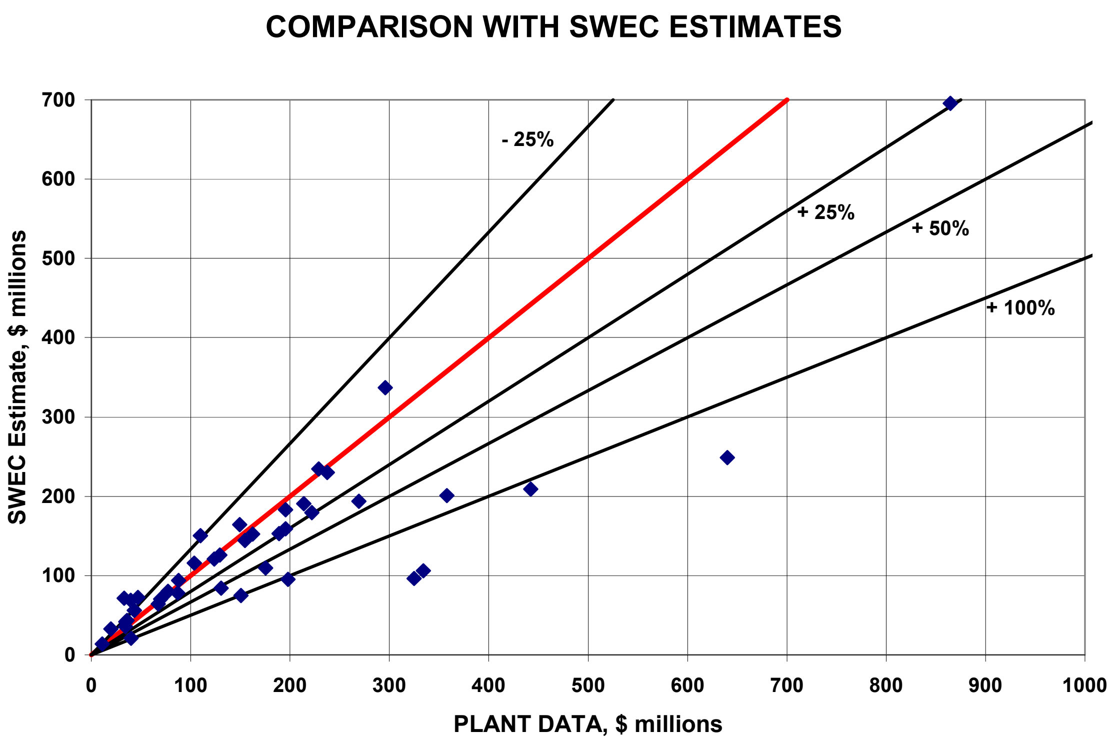

Figure 4-2

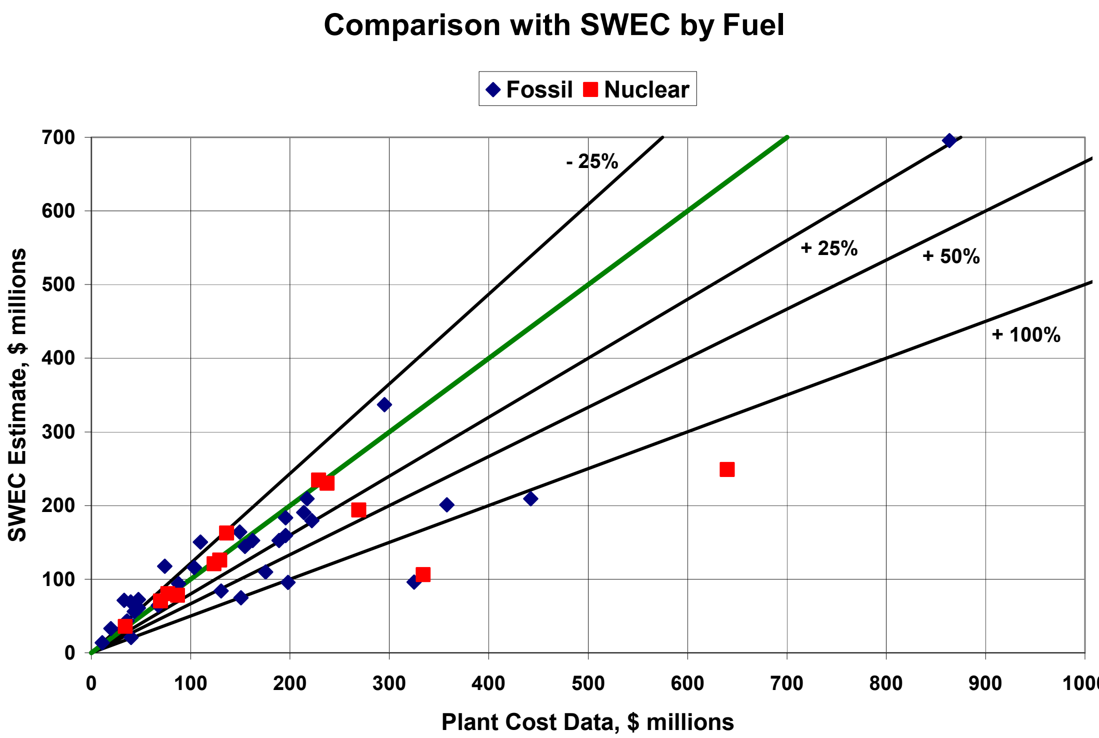

Figure 4-3

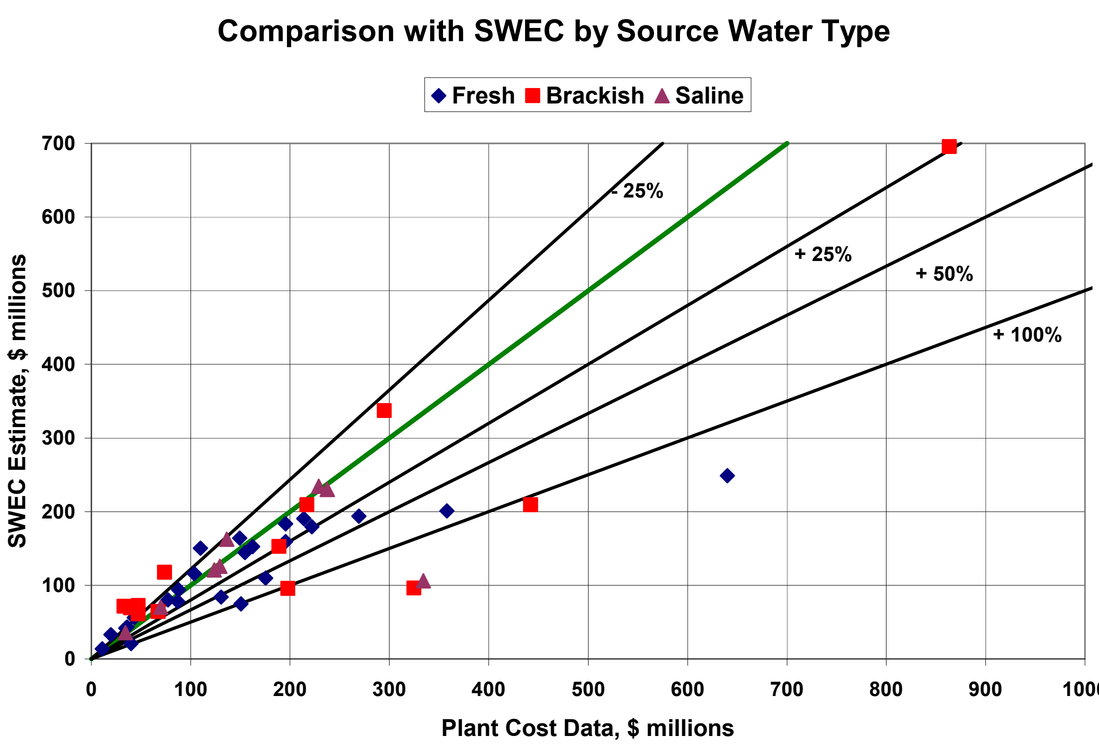

Figure 4-4

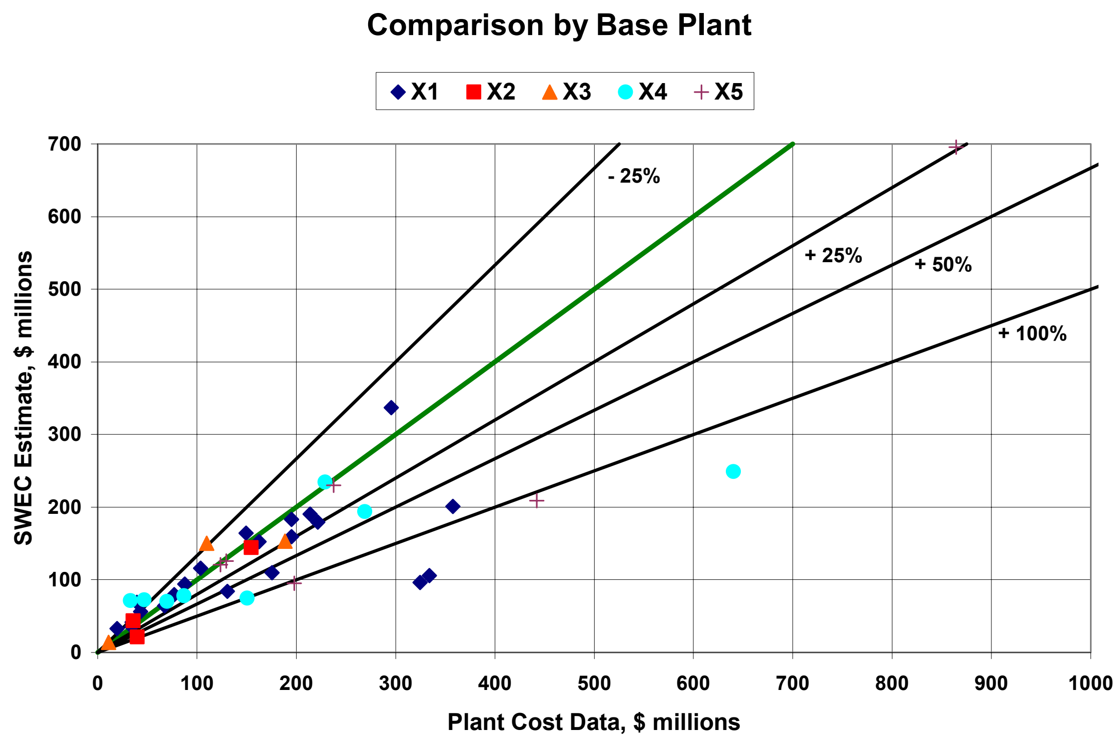

Figure 4-5

<u>Washington Group Study</u>

The Washington Group conducted another study to estimate the costs of cooling system retrofit (14). The approach taken in this study was quite different. For each unit in the population of units eligible for retrofit, information was obtained from an industry database on the power generation thermal cycle, steam conditions and unit size and the units were grouped by these variables. The reject heat load to the condenser was then calculated based on heat balance equations chosen as appropriate for each grouping. A constant cooling water temperature rise across the condenser of 12° F was chosen for each unit and, from this, a cooling water flow rate could be calculated and a cooling water flow per unit plant output could be determined.

Costs for recirculated cooling systems were determined from vendor estimates and contractor experience for fresh and salt-water cooling systems for a range of cooling tower sizes. In addition to the cooling tower structure, costs were added for the cooling tower basin, circulating water pumps, circulating water pipe costs, make-up water treatment system, circulating water chemical treatment system, make water pump, electrical equipment and connections, and additional multipliers for engineering, construction management, interest during construction, startup, contingency and fees. All the costs were then normalized on a cost per circulating water flow rate ($/gpm) and applied to the unit groupings developed for the different thermal cycles and associated heat rates.

Retrofit issues were addressed in a limited fashion. The circulating water lines were calculated on the basis of 1000 foot length (implying a 500 foot distance between the condenser and the tower) for each case. This was felt to be longer than would normally be the case in new plant construction and chosen to account for difficulty in finding closer location for the tower at an existing site. New circulating water pumps were included to account for the increased head rise required to pump the water to the top of the tower. Beyond these two items, the cost elements were essentially new facility costs.

A comparison of the results of this analysis to the individual plant costs discussed in Section 3 is presented in Figure 4-6. The WGI estimates are consistent with the lower bound of the individual plant data as might be expected for estimates which are consistent with new facility costs and which do not reflect issues related to retrofit conditions.

The range of $/gpm costs developed in this manner were from $70 to $95/gpm for fresh water units and from $95 to $125/gpm for salt-water units. This compares to the SWEC scale factors based on site-specific studies of projects carried out under retrofit conditions of $140 to $212/gpm. This comparison is further indication that a 20 to 30% adjustment to new facility costs to account for retrofit issues is insufficient.

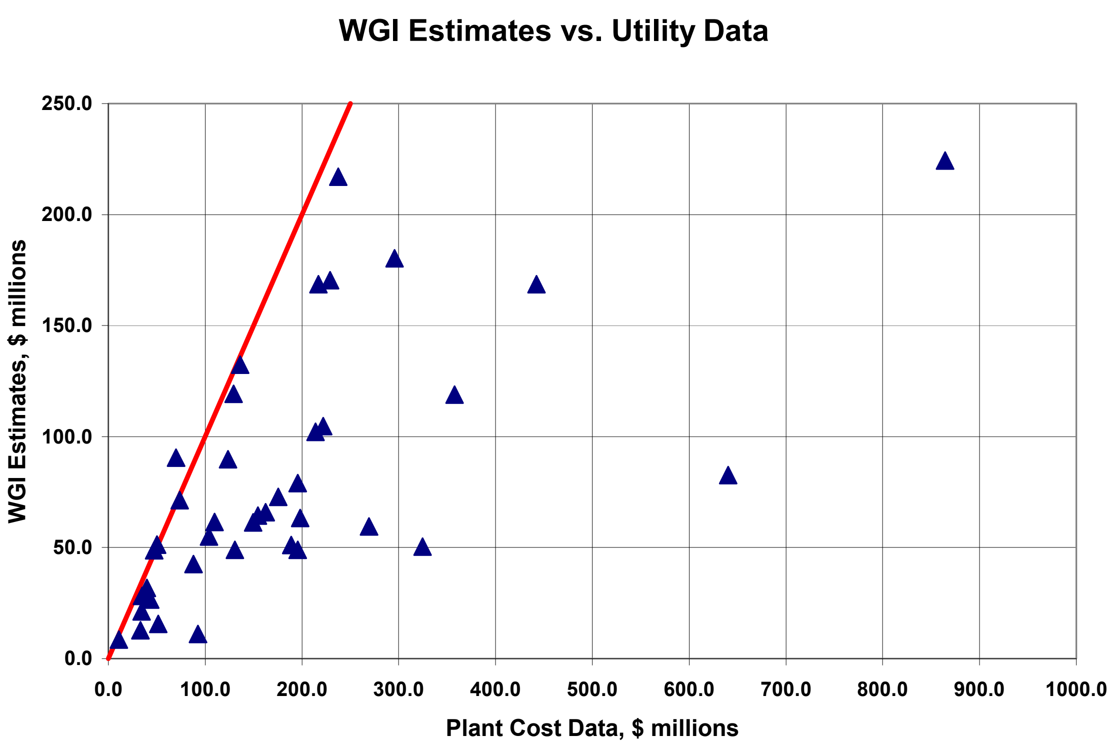

Figure 4-6

National Energy Technology Laboratory (NETL)

A brief study of retrofit costs at four sites was conducted by NETL. The sites were

- A 1700 MW (2 units) nuclear plant on brackish water
- A 1100 MW (2 units) fossil (gas and coal) plant on brackish water
- A 700 MW (2 units) fossil (gas) plant on brackish water, and
- An 1850 MW (4 units) fossil (coal) plant on saline water.

The exact methodology and scope is not known but a simple comparison is made with estimates for the corresponding plants from the SWEC study in Figure 4-7. The agreement is reasonable with three of the four cases (within 20%) and the fourth is within about 40%. While the results of such a limited sample may be fortuitous, this generally good agreement between two sets of estimates both of which factored in site-specific retrofit issues {either through specific site studies (NETL) or implicitly through the use of reference plants for which site-specific studies had been carried out (SWEC)} gives further support to the contention that a simple scaling from new facility estimates is inadequate to account for retrofit costs.

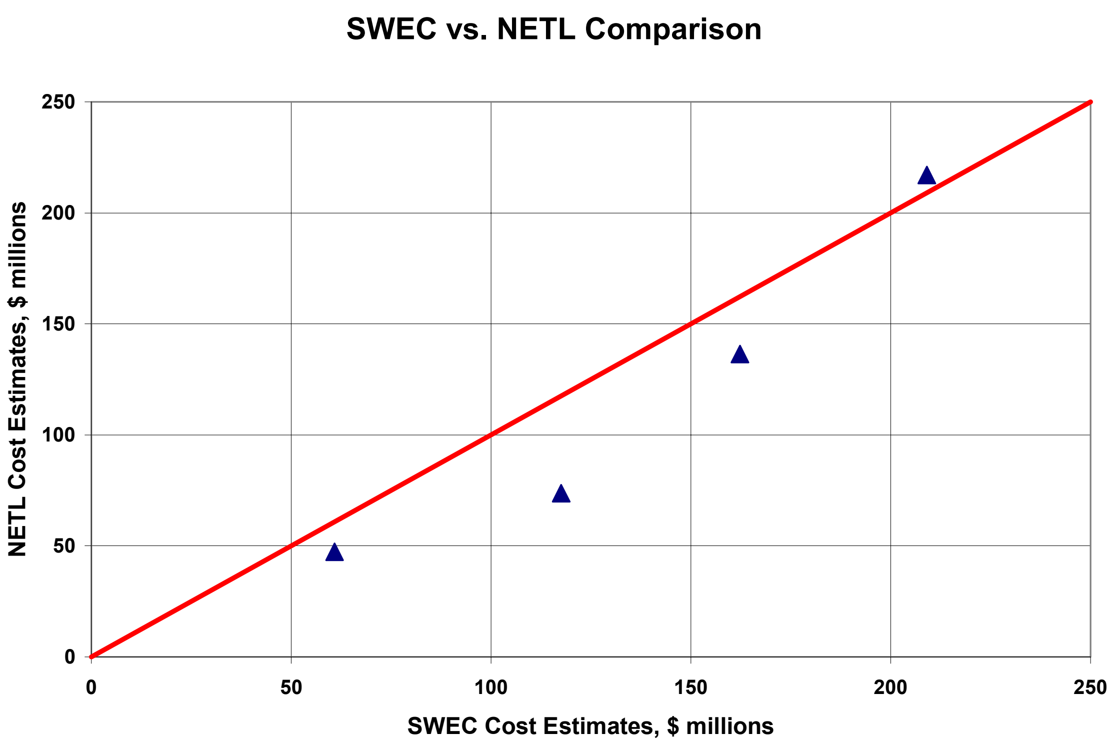

Figure 4-7

5

Comparison of Data with EPA Estimates

A comparison of EPA cost estimates with either the individual plant cost data (from Section 3) or the results of the three independent cost studies (SWEC, WGI, NETL) is difficult. EPA does not report plant-by-plant estimates. Also they include a number of cost adjustment factors and add-ons in the cost tables and example calculations which make it difficult to generalize or average across the population of plants.

As an alternative for comparison purposes, a likely upper bound of the EPA cost estimates can be established. The costs are based on new facility costs reported in Economic and Engineering Analyses of the Proposed §316(b) New Facility Rule (8). In Table A.5 of that document costs are given for a range of flows for five different materials of tower construction. For cooling water flows grater that 10,000 gpm, the highest cost per gpm is for a concrete tower with a flow rate of 11,000 gpm and equals \$76/gpm. Excluding Alaska and Hawaii, the highest regional cost factor is for New Jersey and equals 1.099, bringing the adjusted cost to \$83.2/gpm.

In the example calculations given in Technical Development Document for Proposed Section 316(b) Phase II Existing Facility Rule (4), the capital cost of the installed cooling system alone was increased by additional factors for

- Intake and discharge piping modification capital costs
- Cooling water intake technology retrofit capital costs, and
- Condenser upgrade capital costs.

These items added over \$12.5 million to a base cooling system costs of \$53,550,000 or an increase of about 25%. While these costs are apparently not applied in all cases, they suggest a potential increase in \$/gpm factor of 25%, bringing the system cost to \$104/gpm for new facility costs.

The authors then developed the retrofit costs by adding a 20% retrofit factor (30% for some elements of the system), a 10% "contingency factor" and a 5% factor "to account for uncertainties inherent in intake modifications at existing facilities." This would result in retrofit costs of \$145 to \$156/gpm, depending on whether a 20% or a 30% retrofit factor is applied.

Figure 5-1 displays the individual plant retrofit costs from Section 3 plotted as retrofit cost against circulating water flow. The correlation lines for EPA new facilities are shown, along with the adjusted EPA retrofit costs using both a 20% and a 30% retrofit factor.

As was suggested earlier, the "new facility" costs appear to give a reasonable approximation to the lower boundary of the cluster of 50 data points obtained from individual plant studies. This is consistent with the contention that the minimum cost of retrofit is close to the cost for cooling system installation at a new facility. The adjustment factors are seen to account for the additional costs associated with retrofit factors in only a fraction of the cases. The "best fit" linearization of the data points exceeds the EPA new facility costs by a factor of about x 2.3.

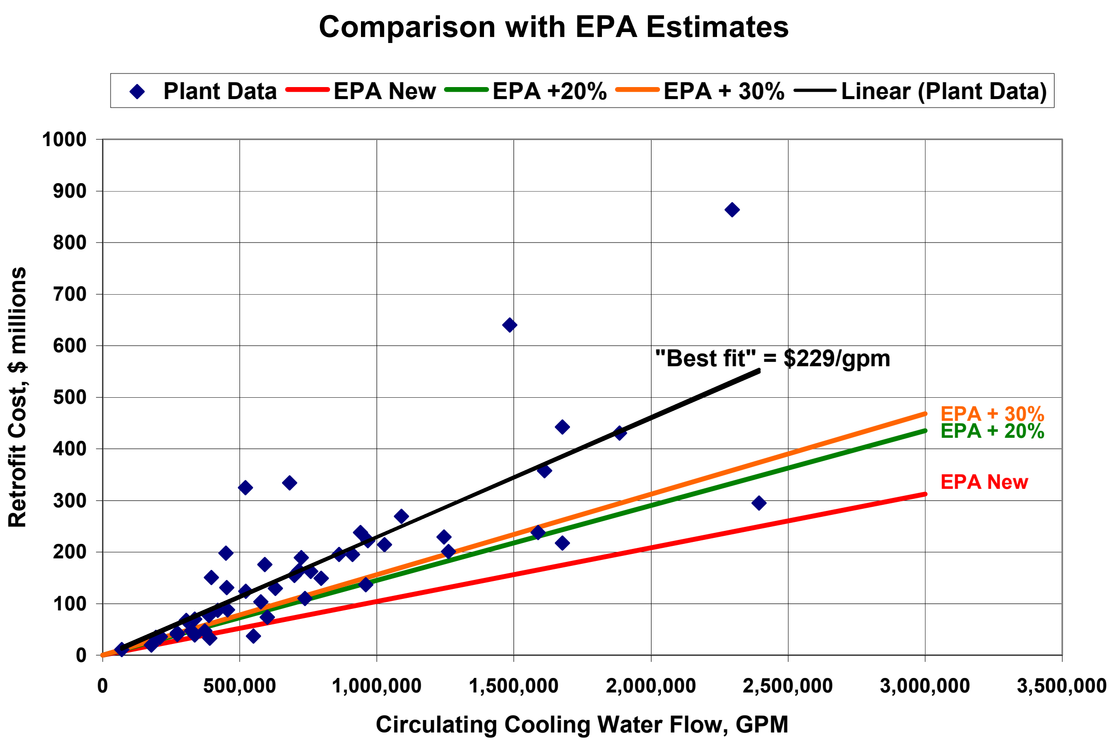

Figure 5-1

Comparison of aggregated national costs:

SWEC, WGI and EPA each report the total national cost of retrofitting all of the units considered in their particular studies. A direct comparison of these aggregated costs is not completely straightforward, however, for two reasons:

1. The costs are not all reported on the same basis. SWEC and WGI report the sum of the capital costs for each of the units estimated. EPA reports the total as an "annualized, post-tax cost".
2. The number of units included in the estimate is not the same for all the studies.

Capital cost vs. annualized post-tax cost

The annualized, post-tax cost reported by EPA is used to put the one-time, capital cost on a comparable basis with operating costs that are incurred on a yearly basis over the life of the facility. A selected discount rate is applied over the facility life. As described on p. B1-15 of the Economic and Benefits Analysis (2), the annualized cost is defined as

$$\text{Annualized cost} = \text{Capital cost x } \{[r \text{ x } (1 + r)^n]/ [(1 + r)^n - 1]\}$$

where r = discount rate
n = useful life of the equipment

In the analysis, EPA assumes

r= 7%
n = 30 years (for cooling towers)
20 years (for condensers)
10 years (for other equipment)

Rather than attempting to allocate the different cost elements among the three lifetime categories, and since the majority of the costs are for the cooling towers, this comparison uses a 30-year life for the calculated adjustment.

On this basis the annualizing factor is 0.081. (Using 25 years changes the conversion factor by only 6% from 0.081 to 0.086.)

<u>Post-tax cost adjustment</u>:

EPA reduces the costs by an assumed tax rate. The combined Federal and state tax liability is given by

$$\text{Total tax} = \text{Federal tax} + \text{state tax} - ([\text{Federal tax}] \text{ x } [\text{state tax}])$$

The Federal tax rate is taken as 35%. The state tax rate, which may vary from 0 to 10%, was presumably applied on a state-by-state basis in EPA's estimates but was assumed to be 5% in this comparative analysis. This yields a combined tax rate of

$$\text{Tax rate} = 0.35 + 0.05 - (0.35 \text{ x } 0.05) = 0.3825$$

Therefore, the annualized post-tax cost is given by

$$\text{Annualized, post tax cost} = \text{Capital cost x } 0.081 \text{ x } (1 - 0.3825)$$

$$= \text{Capital cost x } 0.05$$

<u>Number of units included</u>:

The number of units included in the SWEC and WGI analyses is roughly equal. Both used the UDI database and excluded units currently on recirculated cooling. Both ended up with about 1200 units representing about 250 GW.

The population included in the EPA analysis is stated to be 426 "facilities" representing 353,750 MW of baseline steam capacity. A facility appears to be defined as "units with a common intake structure" and would often, but not always, corresponds to a single plant that might have several units. Therefore, 426 facilities might correspond to 1000 or more units. However, the reported capacity is substantially more than that represented by the units included in the SWEC or WGI study. Furthermore, in the text of the proposed rule (p. 91 of the Prepublication Copy", Ref. 1a) it is stated that there are 539 facilities to which the rule would apply. Of these a number of facilities are deemed to "not require any additional controls" either because they already have recirculated cooling or other forms of adequate impingement control. The remaining facilities for which some sort of additional control would be required total 349. There is no indication of how much generating capacity is represented by these units.

Therefore, the only documentable basis for scaling the reported costs to account for differences in the population of facilities for the estimated costs would be to use the 353 GW figure reported in the Benefits Analysis document. This would require either reducing the EPA estimate by a factor of 0.7 (250GW/353GW) or, alternatively increasing the SWEC and WGI estimates by a factor of 1.4. This is a substantial adjustment to be applied on the basis of such uncertain evidence, so Table 5-1 simply lists the aggregated costs as "National costs of retrofit" as reported with the annotation that they may apply to significantly different populations of facilities.

Table 5-1
Comparison of National Costs for Cooling System Retrofit

Source	National Cost ($ Billions)
EPA	**13.7(1)**
SWEC	**25.0 to 28.0(2)**
WGI	**22.2(3)**

Notes:

(1) Scaled from reported annualized, post-tax capital cost of $684.7 million; reported to represent 353,750 MW at 426 facilities
(2) Sum of capital costs for 1040 units representing approximately 250 GW
(3) Sum of capital costs for 1268 units representing approximately 260 GW.

6

Other Costs

Introduction

The retrofitting of a plant designed for and operating on once-through cooling impose a number of continuing costs on future operations of the plant in addition to the one-time capital cost of retrofit. The most important of these are

- Additional operating power: Recirculated cooling systems will have higher power requirements as compared to once-through systems for the increased head rise required of the circulating water pumps and for the fans to draw air through the tower. The power consumed for parasitic loads cannot be sold to the grid and represents lost revenue.
- Additional maintenance costs: Recirculated systems have additional equipment that requires maintenance labor and specialty chemicals costs for water treatment systems for both the make-up and the blowdown.
- Additional fuel costs: Plant equipped with recirculated cooling systems incur efficiency losses compared with once-through cooled systems due to the higher turbine backpressures imposed on the plant by limitations of the cooling system.
- Potential for output capacity limitations: To the extent that recirculated cooling system may not be able to maintain turbine backpressure below warranty limits during the hottest and most humid hours of the year, the plant maybe forced to reduce output to protect the turbine. While this is normally not the case with an optimized, well designed recirculated cooling system as applied to a new plant, the approach to retrofit which has been used in both the EPA and other cost analyses has chosen to reduce the initial capital costs by keeping the circulating water flow and the condenser the same as for the original once-through system. This results in a system that is far from optimum and may incur capacity limitations in some locations during the summer.

The following paragraphs provide a brief assessment of the possible magnitude of these costs.

Additional operating power:

The major power costs are for the circulating water pumps and the fans. Consistent with the assumption used in the development of the capital costs, the power for pumping is based on the same circulating water flow as was used in the original once-through system. However, the head rise to be delivered by the pumps must be increased to pump the water to the top of the tower, typically 40 to 50 feet. This will increase the pumping power over the once-through system requirements by approximately 5 kW per MW. The fan power for a 170 MW steam cycle was determined in a recent study (M&D) to be approximately 7.5 kW per MW. This gives an additional operating power requirement of 12.5 kW/MW or 1.25% of plant capacity.

Estimates in the SWEC report for a single case study at a large nuclear plant indicated annual power requirements for pumps and fans of about 19,000 kW out of a gross electrical output capacity of 1,123 MW. If the original once-through system pumping power is subtracted the net increase is about 12,000kW or 1.07 kW/MW is essential agreement with the previous analysis. Both of these estimates exceed the allowance reported by EPA of 0.85% of plant capacity (0.85 kW/MW).

<u>Additional maintenance costs</u>:

The major parts of the additional maintenance costs are associated with the water treatment for make-up and discharge required for recirculated operation and, in some cases, the need to rebuild the tower after extended service. Both these costs are highly site and situation specific but some generalized estimates have been made.

1. An estimate of the need for upgraded materials and the costs of clarifiers and specialty chemicals was performed for the various types of make-up water and is included in this report as Appendix B.
2. A common rule of thumb (See, for example, Ref. 10) sets the annual O&M costs at 1% of system capital cost. A case study for a large nuclear plant published in 1995 (11) found O&M costs not including power at about 1.6% of estimated capital costs.
3. EPA reports O&M costs on an annualized post-tax basis at $1,117 million for a capacity of 353,000 MW inclusive of the additional operating power. Using their estimate of 0.85% of plant capacity, the power costs would account for $720 million of that amount, if valued at $0.03/kWh. The remaining annual cost of $397 million is approximately 2.9% of the estimated capital cost.

While these comparisons are necessarily superficial, it appears that the EPA cost development makes adequate allowance for O&M costs exclusive of additional power.

<u>Energy penalty</u>:

The turbine backpressure achievable with a once-through cooling system is nearly always lower than that achievable with a recirculated cooling tower. To supply the condenser with the same flow of cold water at the same temperature as from a once-through system, the tower would have to cool the circulating water to the same temperature as the natural source water. The ambient wet bulb temperature is the lower limit for the achievable return water temperature for the tower. A reasonable tower design will do no better than approximately an 8-10ºF approach {Approach = $T_{cold\ water}$ - $T_{wet\ bulb}$). In addition, the ambient wet bulb is normally higher than the temperature of water withdrawn from natural sources (rivers, lakes, oceans) for much of the year, especially during the warmer, more humid months. For those times, the condenser inlet temperature and, as a result, the condensing temperature and the turbine backpressure will be higher than would have been the case with the original once-through cooling system. This backpressure elevation is most acute during hot, humid hours, which also correspond to times of peak electricity demand. The effect of increased turbine backpressure on plant performance is shown in Figure 6-1.

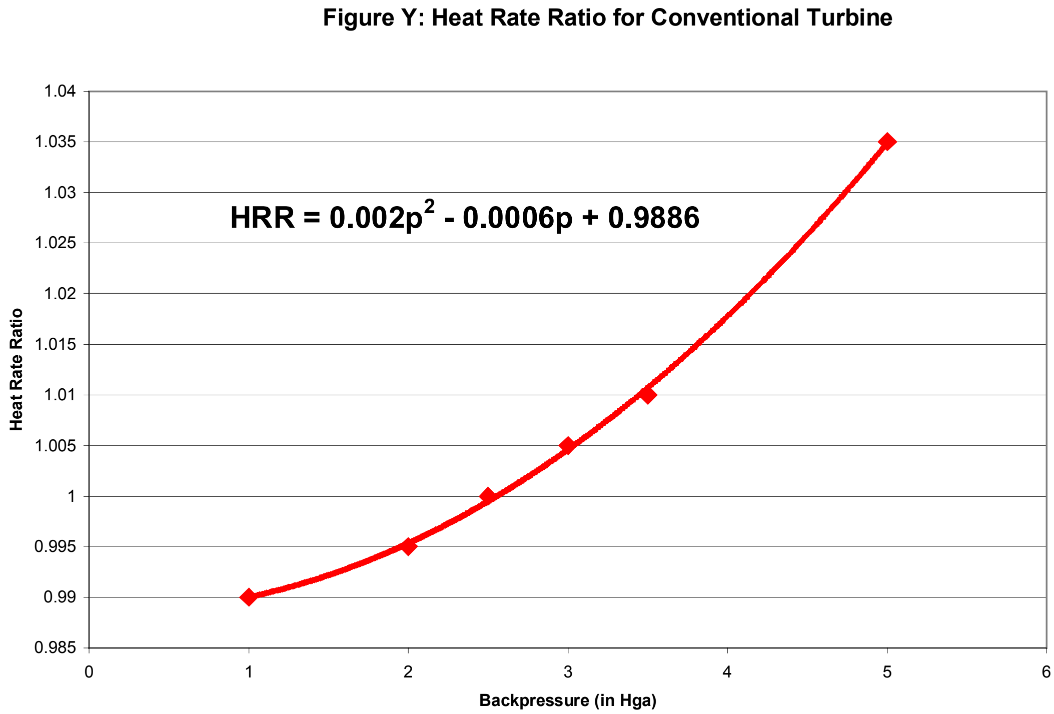

Figure 6-1 (excerpted from Ref. 9)

Increased heat rate results in higher fuel consumption for a given plant output. An increase in turbine backpressure of only 1 in. Hga would correspond to a fuel cost penalty of $1 million per year. This 1 in. Hga would occur with an ambient wet bulb temperature increase of only 10°F, which is well within the seasonal variability for most parts of the country. This estimate of a 1% energy penalty is in the mid-range of that estimated in a recent NETL study. (17)

If applied to the 350,000MW identified in the EPA cost development analysis and assuming a 50% capacity factor and an average fuel cost of $2.50 per million Btu gives an annual energy penalty cost of approximately $700 million as compared to the EPA estimate of $364 million. However, within the considerable uncertainties and gross approximations that must be made in lieu of a detailed case-by-case analysis, this may be considered reasonable agreement and suggests that the energy penalties have been reasonably accounted for.

Potential capacity limitations:

For older plants with conventional steam turbines, a backpressure of about 5 in. Hga may not be exceeded without risking damage to the turbine and possibly voiding any warranty that might still be in force. If the plant is "cooling system limited" it is possible that it will be unable to maintain acceptable turbine backpressure at full load during hot, humid hours. Therefore, under atmospheric conditions that would lead to higher backpressures, the plant may have to reduce steam flow and hence output to stay within allowable operating limits of the turbine. Since this capacity shortfall comes exactly at the time of peak demand and, in a competitive environment, at the time of highest energy price, the lost revenue can be substantial.

However, for a plant with a retrofitted recirculated cooling system designed to maintain 2.5 in. Hga backpressure at the annual average wet bulb temperature, such an occurrence is unlikely since it would require that the ambient wet bulb temperature rise by 25ºF above the average. An examination of the annual average vs. 1% wet bulb temperatures in climatological data listings such as the ASHRAE Guide shows that such locations are rare. Therefore, it is reasonable to ignore potential capacity penalties in a generalized analysis although they could occur on rare occasions in a few locations.

7

Environmental Comparisons

As summarized by EPA in the Fact Sheet on the Proposed Rule, the regulation is "designed to protect fish, shellfish and other aquatic life from being killed or injured by cooling water intake structures". The degree of the environmental harm resulting from the intake of cooling water from natural waterways has been the subject of a vast number of general analyses and site-specific studies over decades. It is not a primary topic to be addressed by this report. However, while it is unquestioned that the use of recirculated cooling at a power generation plant will substantially reduce the amount of cooling water draw into the plant, it should be recognized that recirculated cooling systems are not without environmental impacts of their own, some of which are not present with once-through cooling systems.

Brief mention will be made of seven issues to be considered in comparing the environmental effects of recirculated and once-through cooling systems. These are:

- Intake losses
- Water consumption
- Water and waste discharge and disposal
- Drift and plumes from cooling towers
- Other air emissions
- Noise
- Aesthetics.

<u>Intake losses</u>

As shown in Figure 2-3, the cooling water flows for once-through systems range typically from 400 to 700 gpm per MW and occasionally higher. Cooling water intake for recirculated cooling systems using mechanical draft cooing towers typically ranges from 12 to 20 gpm/MW and occasionally higher depending primarily on the cycles of concentration at which the tower is operated. While this represents a twenty- to fifty-fold reduction in the water taken into the system, it may not represent a similar reduction in the degree to which "fish, shellfish and other aquatic life are killed or injured". The survival rate of organisms entrained or impinged in once-through systems has been studied and debated extensively but is not normally assumed to be zero. It is, however, extremely unlikely that entrained organisms will survive passage through a recirculated cooling system with a cooling tower.

Water consumption

While once-through systems, as noted above, withdraw large quantities of water, they return all of the withdrawn water back to the source (or at least to nearby natural waterbodies). A recirculated cooling system, while withdrawing far less water, is designed to cool by evaporating a portion of the circulating water flow in order to cool the remainder. A typical evaporation rate for mechanical draft cooling towers is 10 gpm/MW representing 50 to 80% of the intake flow, again depending on the cycles of concentration. This loss of water to the source waterbody will exceed losses associated with increased evaporation rate from the receiving waters of a once-through cooling system. There are also cases, such as on the Potomac River, where any additional consumptive water uses can no longer be permitted.

Water and waste discharge and disposal

Recirculated cooling systems require the discharge of cooling tower blowdown, which, while regulated, may result in some water quality impact. Regulatory constraints such as pertain in California where the State Implementation Policy for implementing the receiving water standards in USEPA's California Toxics Rule allow a discharger who takes water from an impaired water body to discharge back to that water body only if the concentration of the pollutants has not been increased. This offers relief to once-through cooling, but at plants that use cooling towers blowdown treatment will be required. This will require consideration of the disposal of solid waste, such as basin sludge or water treatment system sludges from evaporation ponds, brine concentrators, side-stream softeners or other blowdown reduction processes.

Plumes and drift:

Visible plumes----On cold days, wet towers can produce a large visible plume as the warm saturated air leaving the tower mixes with the cold ambient air and water vapor condenses. In some locations, these plumes may obscure visibility, creating dangerous conditions on roadways or lead to local icing on neighboring roads or structures.

In some instances, plume abatement capability may be required on a retrofitted recirculated cooling system with the potential for increasing the cost of the tower by a factor of 2 or more.

Drift----Drift rates from modern, well designed cooling towers can be held to quite low levels. New installations have been quoted at less than 0.0005% of the circulating water flow rate. However, even that low rate will result in a total drift of nearly 2000 gallons per day from a 500 MW steam plant circulating 250,000 gpm. The environmental issues normally raised in connection with cooling tower drift are PM10 emissions, bacterial or pathogenic emissions and damage to local crops.

- PM10: The source of concern over PM10 is the fact that as the drift droplets evaporate so that the dissolved and suspended solids in the circulating water are released as air-borne particles. PM10 emissions are usually estimated (conservatively) as 100% of the TSS and TDS in the estimated drift. A recent study by Reisman and Frisbie (18) suggests that only a fraction of the solids in the drift are formed as PM10. However, this may still be a consideration in some areas.

- Infectious species: The most frequently cited public health issue in the context of cooling towers is the possibility of Legionnaire's Disease, so-called because of an outbreak at an American Legion convention in Philadelphia in 1976 attributed to pathogens (*legionella pneumophilia*) in the cooling tower for the HVAC system in the hotel. While the frequency of occurrence of Legionnaire's Disease is small (approximately 1400 cases reported to the Center for Disease Control annually) and the number of these attributable to cooling towers (at power plants or anywhere else) is even fewer, the question has been investigated extensively in the US and abroad. Treatments of the issue are found in the CTI and ASHRAE literature and references therein.

  While the consequences of exposure can be very severe and even fatal particularly to at-risk (elderly, smokers, individuals with chronic respiratory problems or with suppressed immune systems) populations, the evidence of harm is sparse and largely anecdotal. Cooling towers are a common element of our industrial, commercial and residential scenes in high-density population areas in all climates. No compelling epidemiology has established a significant threat.

- Deleterious impacts of power plant cooling systems on surrounding agriculture have not been an issue except in a few special circumstances. One notable study was conducted in the mid-1970's at the Potomac Electric Power Company's Chalk Point Station in Maryland. In that case, the towers were run on brackish make-up water with a circulating water salinity comparable to sea water (35,000 ppm TDS); the towers were hyperbolic natural draft towers with a plume exit plane elevation of about 400 feet; and the plant was located in a tobacco-growing region with a specialty crop of leaves intended for use as the outer wrappers of cigars. High salinity droplet deposition on the leaves could create small, discolored spots making the leaf unusable without in any way affecting the health of the plant or the quality of the soil. Even under these conditions, the risk was eventually determined to be negligibly small, and the plant and towers continued to operate with no special controls and no adverse impact on the region's agricultural activity.

These issues are noted not to suggest the presence or potential of serious environmental harm from recirculated cooling systems but to note that environmental impacts are associated with such system that do not occur with once-through cooling and that should be balanced against the benefits to be derived from reducing the cooling water intake flow. It is certainly the case that these issues are the subject of concern to the public in some instances and can prolong permitting processes seeking approval for retrofit, adding to the duration and cost of the project.

Other air emissions

The primary air emissions from fossil plants are, of course, from the combustion of the fuel. As has been noted, the choice of cooling system can reduce the overall plant efficiency and capacity. Therefore, to meet a given total system load, more fuel must be burned with a corresponding increase in emissions of NO_x, particulate matter, SO_2 and CO_2 in amounts and proportions which depend on where and in what equipment the additional fuel is used.

For recirculated cooling systems in most locations, the effect is small. On the other hand, for site-specific considerations, a case-by-case analysis of these emissions would be needed to determine what the local environmental impact of each cooling option.

Noise

Cooling tower operation is noisier than once-through cooling operation. The primary noise from cooling facilities is fan noise and “fill” noise caused by the flow of water down over the tower fill. While fan noise can be reduced through the choice of low noise fans, the water noise is less amenable to reduction and some sort of sound barrier may be required to comply with local ordinances. Here again, the issue may simply add to the difficulty of obtaining a permit, add to the cost and duration of the project and warrant consideration in the larger context of balancing the overall benefits to the environment and society of a given decision affecting the choice of cooling systems at power plants.

Aesthetics

In some cases, where plants may be sited in a scenic or urban area, cooling towers may be deemed as a significant impact on the aesthetics of the locality. This issue is also very site specific, but could result in delays or even denial of permits.

8

Summary and Conclusions

This study provides estimates and analyses of the costs of retrofitting electric power generating plants, designed for and operating on once-through cooling systems, with recirculated cooling systems using mechanical draft cooling towers. A brief discussion of the environmental impacts of recirculated cooling in comparison to those of once-through cooling is also included.

The approach to the analysis of the retrofit costs involved:

1. The gathering of data from utility sources of cost estimates made for retrofits at individual plants
2. A review and analysis of cost estimating methodologies by the Environmental Protection agency, Stone & Webster Engineering Company, the Washington Group and the National Energy Technology Laboratory, and
3. A comparison of the results of the several estimates with the individual plant data.

The conclusions of the analysis were:

1. Retrofit costs are highly variable from plant to plant. The results of this study support EPA's assertion that the costs to retrofit recirculated cooling will vary dramatically from site to site. As described in Chapter 3, the retrofit costs at each of the plants for which we have detailed data were dominated by site-specific adjustments rather than by simple scale factors based on size or flow rate.
2. This variability cannot be well accounted for by correlating factors such as \$/kW or \$/gpm of circulating water flow normally found to be satisfactory for new plant cost correlations
3. Differences in individual plant costs cannot be accounted for by differences in plant type (fossil vs. nuclear) or by cooling water source type (fresh, brackish, saline)
4. The variability is the result of site-specific factors associated with difficulties particularly related to the fact that retrofits present special constraints to on-site construction projects
5. Plant retrofits can be roughly assigned a "degree of difficulty classification" as "easy', "average" or "difficult" retrofits.
    i. The costs for the easiest of the projects (lower bound of the individual plant data) are roughly consistent with the costs estimated for cooling system construction at new facilities and fall in the range of \$125/gpm.

ii. The average difficulty projects costs cluster around $200/gpm +/- 20%
iii. The more difficult projects range from $250 to $300/gpm with a few ranging as high as $700 to $900/gpm

6. Significant costs, in addition to the initial capital costs, result from cooling system retrofits including
   i. Additional requirements for operating power in the range of 1 to 1.5% of plant capacity
   ii. Additional maintenance costs, primarily associated with water treatment requirements in the range of 1 to 3% of system capital costs annually.
   iii. Additional fuel costs resulting from efficiency reductions imposed on the plant by the inherent limitations of recirculated cooling systems in the range of 1% on an annual average basis.
7. Recirculated cooling, while reducing water withdrawals for natural waterbodies relative to once-through cooling, has environmental impacts associated with evaporation losses, discharge of blowdown, discharge and disposal of waste water and solid waste, emissions of drift, visible plumes, additional air emissions from increased fuel consumption and noise, that are not present with once-through systems.

9

References

1. National Pollutant Discharge Elimination System--Proposed Regulations to Establish Requirements for Cooling Water Intake Structures at Phase II Existing Facilities, Federal Register, April 9, 2002. pp. 17121-17170
    a. Prepublication Copy of Reference 1, February 28, 2002
2. Cooling Water Intake Structures—Section 316(b); Proposed Section 316 (b) Phase II Existing Facilities Rule; Economic and Benefits Analysis, EPA-321-R-02-001
3. Cooling Water Intake Structures—Section 316(b); Proposed Section 316 (b) Phase II Existing Facilities Rule; Case Study Analysis, EPA-321-R-02-002
4. Cooling Water Intake Structures—Section 316(b); Proposed Section 316 (b) Phase II Existing Facilities Rule; Technical Development Document, EPA-321-R-02-003
5. 40 CFR Parts 9, 22 et al.; NPDES Regulations Addressing Cooling water Intake Regulations for New Facilities; Final Rule, Federal Register, December 18, 2001.
6. Technical Development Document for the Final Regulations Addressing Cooling Water Intake Structures for New Facilities (EPA-821-R-01-036) November 2001.
7. Economic Analysis of the Final Regulations Addressing Cooling Water Intake Structures for New Facilities, EPA-821-R-01-035, November, 2001
8. Economic and Engineering Analyses of the Proposed Section 316(b) New Facility Rule, EPA 821-R-00-019, August 2000.
9. Maulbetsch, J. S. and M. N. DiFilippo, Comparison of Alternate Cooling Technologies for California Power Plants, February 2002. (Available on California Energy commission Website; URL http://www.energy.ca.gov
10. Burns, J. M. and W. C. Micheletti, Comparison of Wet and Dry Cooling Systems for Combined Cycle Power Plants, Final Report (Version 2.1), Prepared of Hunton & Williams, November 4, 2000.
11. Burns, J. M. et al., The Impacts of Retrofitting Cooling Towers at a Large Power Station; in Proceedings: Cooling Tower and Advanced Cooling Systems Conference, EPRI TR-104867, February, 1995.
12. Millstone Power Station: An Evaluation of Cooling Water System Alternatives, Submitted by Dominion Nuclear Connecticut, Inc. to Connecticut Department of Environmental Protection, August, 2001.
13. Informal communications, K. D. Zammit, November 2001.
14. Estimated Cost of Compliance with EPA Proposed Rule 316(b) of the Clean Water Act; Washington Group International, December 2001.
15. R. S. Means Cost Works, 2001 (Available through www.rsmeans.com).
16. Yasi, D. E. and T. A. Adams, Jr., Engineering Cost Estimate for Retrofitting Recirculated Cooling Systems at Existing Facilities, Stone & Webster Report to Hunton & Williams, July 3, 2002.

17. An Investigation of Site-Specific Considerations for Retrofitting Recirculating Cooling Towers at Existing Power Plants—A Four-Site Case Study, Parsons Infrastructure and Technology Group, Inc. and the National Energy Technology Laboratory, May, 2002.
18. Reisman, J. and G. Frisbie, Calculating Realistic PM_{10} Emissions from Cooling Towers, Environmental Progress, Vol. 21, No. 2, July 2002 (127-130).

APPENDIX A

PLANT DATA SUMMARY

APPENDIX A---PLANT DATA SUMMARY

PLANT ID	STATE/ REGION	FUEL	WATER TYPE	CAPACITY MW	CIRCULATING WATER FLOW GPM	ORIGINAL COST DATA SOURCE	COST MILLIONS $	SCALED COST 2002 $ MILLIONS $	SWEC EST. 2002$ MILLIONS $
1	TX/ERCO	F	BR	784	324,000	NETL	47.4 (2002$)	47.4	60.9
2	FL/SERC	F	SA	1824	960,000	NETL	136.3 (2002$)	136.3	162.3
3	NC/SERC	N	SA	1734	1,245,000	UTIL/UWAG	111. (1980$)	228.7	234.4
4	TN/SERC	F	FR	950	397,000	ANL, 1993	114. (1992$)	150.5	74.7
5	IL/MAIN	N	FR	2350	1,261,000	ANL, 1993	74.5 (1976$)	200.4	NA
6	MD/MAAC	N	BR	1836	2,394,000	UTIL/UWAG	247.9 (1995$)	295.0	337
7	FL/SERC	F	BR	864	550,000	ANL, 1993	28. (1992$)	37.0	NA
8	VC/SERC	F	FR	329	177,000	UTIL/UWAG	7.2 (1976$)	19.4	32.8
9	OH/ECAR	F	FR	1230	797,000	UTIL/UWAG	149.4 (2002$)	149.4	164.3
10	MD/MAAC	F	BR	710	520,000	ANL, 1993	246. (1992$)	324.7	96.2
11	IN/ECAR	F	FR	1304	911,000	ANL, 1993	148. (1992$)	195.4	183.1
12	AL/SERC	F	FR	1350	862,000	ANL, 1993	148. (1992$)	195.4	159.1
13	OH/ECAR	F	FR	445	208,000	UTIL/UWAG	34.6 (2002$)	34.6	41.9
14	CA/WPCC	F	BR	580	304,000	ANL, 1993	50.9 (1992$)	67.2	64.3
15	MD/MAAC	F	BR	378	335,000	ANL, 1993	30 (1992$)	39.6	69
16	FL/SERC	N	SA	890	681,000	ANL, 1993	253. (1992$)	334.0	106
17	TN/SERC	F	FR	2600	1,612,000	ANL, 1993	271. (1992$)	357.7	200.9
18	FL/SERC	F	SA	235	193,000	ANL, 1993	26. (1992$)	34.3	35.9
19	MI/ECAR	N	FR	2080	1,485,000	ANL, 1993	485. (1992$)	640.2	248.7
20	IL/MAIN	N	FR	1662	940,000	ANL, 1993	180. (1992$)	237.6	NA
21	FL/SERC	F	BR	597	390,000	ANL, 1993	25. (1992$)	33.0	71.5
22	TN/SERC	F	FR	1258	591,000	ANL, 1993	133. (1992$)	175.6	109.7
23	NJ/MAAC	F	BR	1115	601,000	NETL	73.8 (2002$)	73.8	117.5
24	TN/SERC	F	FR	812	453,000	ANL, 1993	99. (1992$)	130.7	84.1
25	TN/SERC	F	FR	1485	1,027,000	ANL, 1993	162. (1992$)	213.8	190.6
26	WV/ECAR	F	FR	713	455,000	UTIL/UWAG	87.9 (2002$)	87.9	93.9
27	WV/ECAR	F	FR	439	272,000	UTIL/UWAG	43.2 (2002$)	43.2	56.1
28	IL/MAIN	F	FR	1141	715,000	ANL, 1993	124. (1992$)	163.7	NA
29	TN/SERC	F	FR	1700	967,000	ANL, 1993	168. (1992$)	221.8	179.4
30	OH/ECAR	F	FR	1087	759,000	ANL, 1993	123. (1992$)	162.4	152.6
31	GA/SERC	F	FR	598	272,000	UTIL/UWAG	40. (2002$)	40.0	21
32	CT/NPCC	N	SA	909	522,000	UTIL/UWAG	120 (2001$)	123.7	121
33	CT/NPCC	N	SA	1253	630,000	UTIL/UWAG	125.5 (2001$)	129.3	126
34	CA/WPCC	F	SA	558	335,000	ANL, 1993	53. (1992$)	70.0	70.2
35	OH/ECAR	F	FR	914	576,000	UTIL/UWAG	103.7 (2002$)	103.7	115.7
36	PA/MAAC	F	FR	625	210,000	UTIL/UWAG	36. (2002$)	36.0	43.2
37	VA/SERC	N	FR	1618	1,886,000	ANL, 1993	326. (1992$)	430.3	NA
38	NJ/MAAC	N	BR	620	449,000	ANL, 1993	150. (1992$)	198.0	95.3
39	MI/ECAR	N	FR	812	387,000	UTIL/UWAG	77. (2002$)	77.0	79.9
40	WV/ECAR	F	FR	1106	699,000	UTIL/UWAG	154.6 (2002$)	154.6	144.5
41	OH/ECAR	F	FR	106	69,000	UTIL/UWAG	11.0 (2002$)	11.0	14
42	CA/WPCC	F	BR	1302	724,000	ANL, 1993	143. (1992$)	188.8	152.9
43	NJ/MAAC	N	BR	2340	2,297,000	EPRI	626. (1990$)	863.9	695.5
44	CA/WPCC	N	SA	2254	1,588,000	UTIL/UWAG	172 (1990$)	237.4	229.8
45	VA/SERC	N	BR	1696	1,677,000	NETL	217 (2002$)	217.0	209
46	VA/SERC	N	BR	1696	1,677,000	ANL, 1993	335. (1992$)	442.2	209
47	IN/ECAR	F	FR	1100	738,000	UTIL/UWAG	109.7 (2002$)	109.7	150.5
48	MD/MAAC	F	BR	628	373,000	ANL, 1993	35.7 (1992$)	47.1	72.3
49	AL/SERC	F	FR	1969	1,090,000	ANL, 1993	204. (1992$)	269.3	193.9
50	GA/SERC	F	FR	681	420,000	UTIL/UWAG	87. (2002$)	87.0	78

APPENDIX B

ANALYSIS OF O&M COSTS

for

RECIRCULATED COOLING WATER TREATMENT SYSTEMS

Technical Memorandum

July 9, 2002

To: John Maulbetsch

From: Mike DiFilippo

Subject: Condenser and Cooling Tower Considerations
Conversions from Once-Through Cooling to Cooling Towers

Materials selection guidelines for condensers and cooling towers follow (refer to Tables 1 and 2). The data and recommendations found in these tables should be viewed as guidelines, i.e. each site should be evaluated relative to its specific conditions. For condensers with stainless steel tubes, conversion from once through cooling to cooling towers may require re-tubing. Chloride stress corrosion cracking is a problem with stainless steel condenser tubes in environments exceeding 1,000 mg/l chloride levels. Also, conversions considering treated municipal effluent will have to address ammonia attack on copper-alloy cooling surfaces such as admiralty (copper-nickel alloys are not effected). The ammonia must be removed from the make-up water or the condenser must be re-tubed with a compatible material. Recently, a 500 MW combined cycle plant in California considered removing ammonia (nitrification) from its treated effluent make-up to the cooling tower – the 2,300 gpm nitrification system was estimated to cost $7.5 million.

Table 1
Condenser Metallurgy Guidelines

Source Water	Approx TDS, mg/l	Max Cycles of Concentration	Recommended Condenser Metallurgy
Ocean	35,000	1.5	90/10 Cu-Ni, 70/30 Cu-Ni or titanium
Estuary	10,000 – 25,000	2.0 – 2.5 (1)	90/10 Cu-Ni, 70/30 Cu-Ni or titanium
River or Lake	<2,000	5 – 10 (1)	Admiralty, 316 SS (2)
Treated Effluent	<1,000	4 – 5 (3)	90/10 Cu-Ni, 70/30 Cu-Ni, titanium, admiralty (4) or 316 SS (2)

Notes.....

1. Water chemistry will dictate maximum cycles of concentration.
2. 316 SS is not recommended if chloride concentration (Cl^{-1}) in circulating water is greater than 1,000 mg/l.
3. Treated effluent almost always contains ortho-phosphate that limits cycles of concentration to 4 to 5.
4. Admiralty is not recommended for treated effluent unless ammonia (NH_3) has been completely removed. Some (not many) municipal treatment plants remove ammonia.

Table 2
Cooling Tower Materials Guidelines

Source Water	Fittings	Fill
Ocean	90/10 Cu-Ni, 70/30 Cu-Ni or titanium	PVC – low specific surface area (3)
Estuary	90/10 Cu-Ni, 70/30 Cu-Ni or titanium	PVC – low specific surface area (3)
River or Lake	Carbon steel, admiralty, 316 SS (1)	PVC – standard fill
Treated Effluent	Carbon steel, admiralty (2), 316 SS (1)	PVC – standard fill

Notes.....

1. 316 SS is not recommended if chloride concentration (Cl^{-1}) in circulating water is greater than 1,000 mg/l.
2. Admiralty is not recommended for treated effluent unless ammonia (NH_3) has been completely removed. Some (not many) municipal treatment plants remove ammonia.
3. Cooling tower fill with low specific surface area (ft^2 of contact area per ft^3 of fill volume) will tolerate higher levels of biological growth than standard fill.

<u>Another area of concern is biological control</u>. Sea water and estuarine cooling towers will be especially prone to fouling, because they will be exposed to a significant amount of bacteria and microscopic organisms. Care needs to be taken to minimize "low flow zones" to reduce the amount of colonization. A continuous chlorination residual (0.2 mg/l) may be required with two to three injections per day for periods up to 60 minutes of high levels of chlorine – 3 mg/l at an injection point just upstream of the circulating pumps. The chlorination frequency may be seasonal, i.e. more frequent in the summer. A tank or basin may be required to dechlorinate prior to discharging blowdown to receiving waters if chlorination is required more than once per day or for long periods of time. Cooling tower blowdown is usually curtailed for one to two hours during chlorination to minimize the discharge of high levels of chlorine to receiving waters. When blowdown is reestablished, it is usually at a higher rate to compensate for salt accumulation (blowdown is usually controlled automatically to a conductivity set point). In cases where chlorination is either continuous or repeated two to three times daily, blowdown curtailment is not practical. In these instances, a reducing agent, such as sodium bisulfite, will be required for dechlorination. Care needs to be taken in designing a dechlorination system so as not to reduce dissolved oxygen levels in the receiving waters. The basin should have at least 30 minutes of residence time to reduce the chlorination residual to <0.1 mg/l. Treated effluent with ammonia present will require the use of a non-chlorine biocide, e.g. bromine (hypobromous acid) or chlorine dioxide.

For a 500 MW plant (simple cycle) operating at 5 cycles of concentration, a cooling tower will discharge 1,250 gpm of blowdown. A thirty-minute contact tank or basin would have to have a capacity of 38,000 gallons for 30 minutes of retention (at an installed cost of approximately $500,000).

All cooling systems using surface waters will require pretreatment (except plants using treated effluent). Surface water is especially prone to fouling (e.g. siltation can be severe seasonally). Assume that a clarifier will be needed for these sources of cooling water. Recent commercial technology developments, e.g. ballast-type clarifiers, have reduced the area requirements for this equipment dramatically. Refer to Table 3. Assume 0.1 – 0.2 square feet per gpm of cooling tower make-up flow is required for the clarifier system footprint. Clarifiers will also generate a waste sludge that will have to be disposed of (assume offsite). For this analysis assume an average total suspended solids (TSS) concentration 50 mg/l. Therefore, for every 1,000,000 gallons of cooling tower make-up, approximately 420 pounds of sludge will be generated (30 gallons). Stated another way, a 500 MW plant would generate 3,800 pounds of 10% clarifier sludge per day at five cycles of concentration.

Table 3
Make-Up Clarifier Requirements – 500 MW Plant (1)

Source Water	Approx TDS, mg/l	Cycles Concentration	Ballast Clarifier Capacity, gpm	Approx Installed Cost
Ocean	35,000	1.5	15,000	$3,600,000
Estuary	10,000 – 25,000	2.5 (2)	10,000 – 8,300	$2,400,000
River or Lake	<2,000	10 (2)	6,300 – 5,600	$2,000,000

Notes.....
1. Simple cycle.
2. Water chemistry will dictate maximum cycles of concentration.

Lastly, specialty chemicals will be required for operating the cooling tower. Estimated annual costs for sulfuric acid (pH control), poly-phosphate (corrosion control for ferrous metals), scale dispersant (to disperse and control scale), and copper corrosion inhibitor are found in Table 3. An allowance was added for biological control and coagulation chemicals.

Table 3
Cooling Tower Specialty Chemical Costs

Source Water	Max Cycles of Conc	Sulfuric Acid (1) #/10^6 gal	Poly PO_4 (2)(3) #/10^6 gal	Scale Dispersant (4) #/10^6 gal	Copper Corrosion Inhibitor (5) #/10^6 gal	Chemical Cost $/$10^6$ gal	Annual Cost 500 MW Plant (6)(7)
Ocean	1.5	NA	NA	28	8.3	$34	$310,000
Estuary	2.5	NA	NA	17	5.0	$20	$100,000
River or Lake	5.0	1,603	16.7	8	2.5	$179	$680,000
Treated Effluent	5.0	1,603	8.3	17	2.5	$183	$690,000
Unit Cost, $/pound		$0.10	$0.50	$1.00	$0.75		

Notes…..

1. 250 mg/l_{CaCO3} alkalinity in source water reduced to 200 mg/l_{CaCO3} in the cooling tower.
2. 10 mg/l of poly-phosphate in circulating water for corrosion control for carbon steel fittings, pipe, etc.
3. 50% of poly-phosphate dose for treated effluent because of background phosphate in this source water.
4. 5 mg/l of dispersant in the ciculating water for scale control for clarified ocean, estuary and river/late water. 10 mg/l dispersant level for treated effluent.
5. 1.5 mg/l of copper corrosion inhibitor.
6. Cooling tower evaporation is approximately 10 gpm per MW.
7. 15% added to include costs for chlorination and coagulant aide (clarifier).

APPENDIX C

BREAKDOWN OF RETROFIT COST ELEMENTS

Recirculating System Cost Elements
(as % of total retrofit project cost)

	Washington Group	Plant #6	Plant # 8	Plant # 32	Plant # 43	Plant #44
Cost Elements:						
Cooling Tower + basin	49.1	23.1	18.9	21.2	25.6	47.0
Circ. water pumps	4.1	8.3	12.6	11.9	5.6	8
Make-up pumps	0.3	*		*	*	*
Circ. water piping	6.2	8.3	12.6	23.7	14.1	3.8
Chemical system	0.5	**		**	1.1	**
Make-up system	2.4	3.4	8.5	5.9	0.8	3.0
Electrical	9.4	1.4	13.4	7.8	*	1.6
Intake/discharge mods	*	4.2	*	*		8.4
Condenser/turbine bldg mods	**	2.8	**	**	11.2	0.4
Site work/sound walls	*	3.0	3.3	1.1	0.1	**
Transportation	*	2.3	**	1.3	**	**
Equipment Total	72.0	56.8	69.3	72.9	58.5	72.2
Other Project Costs:						
Construction	5.0	3.1	***	5.1	7.6	5
Eng'g and start-up	6.2	10.2	***	7.3	10.9	6.2
Interest/Contingency/Fees	16.7	30.1	***	14.6	23.1	16.7
Total Other Project Costs	**27.9**	**43.4**	**30.9**	**27.0**	**41.6**	**27.9**
Project Total	**99.9**	**100.2**	**100.2**	**99.9**	**100.1**	**100.1**

* included in other items
** not included in estimate
*** not called out separately

Washington Group Analysis---large fossil plant, freshwater

Cooling Tower Retrofit Cost Elements

ITEM	Cost-- 2001$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Cooling tower	$6,598,805	34.4%	To Cooling tower + basin
Cooling tower basin	$2,826,591	14.7%	To Cooling tower + basin
Circulating water pumps/structures	$793,383	4.1%	To Circulating water pumps
Circulating water piping	$1,197,000	6.2%	To Circulating water piping
Chemical system	$100,000	0.5%	To Chemical system
Makeup pumps	$48,984	0.3%	To Make-up pumps
Makeup system	$462,533	2.4%	To Make-up system
Electrical	$1,804,094	9.4%	To Electrical
Total direct costs	**$13,831,390**	72.1%	
Indirects			
Construction	$968,197	5.0%	To Construction
Engineering and start-up	$1,183,967	6.2%	To Eng'g and start-up
Contingency, interest & fees	$3,196,711	16.7%	To Interest/Contingency/Fees
Total indirects	**$5,348,875**	27.9%	
Total project cost	**$19,180,265**	100.0%	

Plant No. 6---1836 MW---nuclear

Cooling Tower Retrofit Cost Elements

ITEM	Cost--1995$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Site work	$1,997,980	0.7%	To Site work/sound walls
C. T. Booster Pumphouse	$24,765,380	8.3%	To Circulating water pumps
Forebay Modifications	$2,348,600	0.8%	To Intake/discharge mods.
Natural Draft Cooling Tower	$52,859,870	17.6%	To Cooling tower + basin
Sound Barrier	$6,937,090	2.3%	To Site work/sound walls
Cooling tower retention basin	$16,547,650	5.5%	To Cooling tower + basin
Dilution water/salt water pumphouse	$20,203,870	6.7%	1/2 to Make-up System; 1/2 to Intake/discharge mods.
Circulating water pipes--Class II seismic	$24,882,760	8.3%	To circulating water piping
Mods to existing plant	$8,473,170	2.8%	To Condenser/turbine building mods.
Electrical, instrumentation and controls	$4,103,900	1.4%	To Electrical
Freight	$6,780,800	2.3%	To Transportation
Total direct costs	**$169,901,070**	**56.6%**	
Indirects			
A&E eng'g	$19,574,400	6.5%	To Eng'g and start-up
Owner eng'g	$9,787,200	3.3%	To Eng'g and start-up
Construction mgt.	$8,156,000	2.7%	To Construction
Spare parts	$1,135,300	0.4%	To Construction
Permits	$978,700	0.3%	To Interest/Contingency/Fees
Construction/performance bonds	$1,275,000	0.4%	To Eng'g and start-up
Start-up, testing & training	not included		
Total indirects	**$40,906,600**	**13.6%**	

Contingency	$35,580,430	11.9%	To Interest/Contingency/Fees
AFUDC	$53,700,600	17.9%	To Interest/Contingency/Fees
Total project cost	**$300,088,700**	**100.0%**	

Plant No. 8---309 MW---fossil

Cooling Tower Retrofit Cost Elements

ITEM	Cost-- 1975$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Site prep.	$62,426	0.9%	To Site work/sound walls
Site facilities	$135,520	1.9%	To Site work/sound walls
Station buildings	$15,009	0.2%	To Site work/sound walls
Condensing water system	$1,809,144	25.2%	1/2 to Circulating water pump; 1/2 to Circulating water piping
Pumps and piping	$607,818	8.5%	To Make-up system
Condensing cooling water tower	$1,353,110	18.9%	To Cooling tower + basin
Instrumentation	$21,874	0.3%	To Electrical
Station lighting	$18,441	0.3%	To Site work/sound walls
Power and conversion equipment	$14,654	0.2%	To Electrical
Conduit, conductors and insulators	$708,519	9.9%	To Electrical
Switching, control and protect eqp't.	$183,129	2.6%	To Electrical
Grounding	$25,329	0.4%	To Electrical
Total direct costs	**$4,954,973**	**69.1%**	
Total indirects	**$693,278**	**9.7%**	To Total Other Project Costs
Overhead	**$1,519,817**	**21.2%**	To Total Other Project Costs
Total project cost	**$7,168,068**	**100.0%**	

Plant No. 32---909 MW---nuclear

Cooling Tower Retrofit Cost Elements

ITEM	Cost--1995$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Site work	$210,000	0.2%	To Site work/sound barriers
Plant Electrical	$6,240,000	5.2%	To Electrical
Yard electrical	$2,120,000	1.8%	To Electrical
Plant I & C	$330,000	0.3%	To Electrical
Circ. water pumps	$42,750,000	35.6%	1/3 to Circulating water pumps; 2/3 to Circulating water piping
Cooling towers	$25,410,000	21.2%	To Cooling tower and basin
Cooling tower pump structure & flume	$2,270,000	1.9%	To Make-up system
Return pump structure & flume	$4,810,000	4.0%	To Make-up system
Cooling tower electrical building	$220,000	0.2%	To Electrical
Switchgear building	$210,000	0.2%	To Electrical
Load center building	$170,000	0.1%	To Electrical
Cooling tower pump building	$130,000	0.1%	To Circulating water pumps
Access roads	$30,000	0.0%	To Site work/sound barriers
Sound wall	$1,100,000	0.9%	To Site work/sound barriers
Transportation	$1,600,000	1.3%	To Transportation
Total direct costs	**$87,600,000**	73.0%	
Indirects			
Construction mgt.	$6,130,000	5.1%	To Construction
Engineering	$8,760,000	7.3%	To Eng'g and start-up
AFI/Contingency	$17,510,000	14.6%	To Interest/Contingency/Fees

Total indirects		
Total project cost	**$120,000,000**	100.0%

Plant No. 43---2340 MW---nuclear

Cooling Tower Retrofit Cost Elements

ITEM	Cost--1990$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Cooling tower	$160,500,000	25.6%	To Cooling tower + basin
Circulating water pumps. structures	$34,900,000	5.6%	To Circulating water pumps
Circulating water piping	$88,415,000	14.1%	To Circulating water piping
Makeup and blowdown systems	$5,000,000	0.8%	To Make-up system
Security fencing	$400,000	0.1%	To Site work/sound barriers
Turbine bldg/condenser mods.	$70,000,000	11.2%	To Condenser/turbine building mods.
Dilution pumping/chemical control system	$6,600,000	1.1%	To Chemical system
Total direct costs	**$365,815,000**	**58.4%**	
Indirects			
Engineering	$68,452,000	10.9%	To Eng'g and start-up
Distributable costs	$47,427,000	7.6%	To Construction
Indeterminates	$144,806,000	23.1%	To Interest/Contingency/Fees
Total indirects	**$260,685,000**	**41.6%**	
Total project cost	**$626,500,000**	**100.0%**	

Plant No. 44---2254 MW---nuclear

Cooling Tower Retrofit Cost Elements

ITEM	Cost--1990$ $	Percent of total %	Transfer to consolidated spreadsheet
Direct costs:			
Cooling towers	$112,000,000	47.0%	To Cooling tower + basin
Intake/discharge/tower header/riser pipes	$14,000,000	5.9%	1/2 to Make-up system; 1/2 to Circulating water pumps
Piping installation	$9,000,000	3.8%	To Circulating water piping
Modification of intake structure (removal of old equip't and addition of new)	$20,000,000	8.4%	To Intake/discharge mods.
Electrical, instrumentation and controls	$2,000,000	0.8%	To Electrical
New instrumentation & controls	$2,000,000	0.8%	To Electrical
Condenser modifications	$1,000,000	0.4%	To Condenser/turbine building mods.
Circ. water pumps/motors	$12,000,000	5.0%	To Circulating water pumps
Total direct costs	**$172,000,000**	**72.1%**	
Indirects			
Construction	$12,040,000	5.0%	To Construction
Eng'g and start-up	$14,723,200	6.2%	To Eng'g and start-up
Interest/Contingency/Fees	$39,752,640	16.7%	To Interest/Contingency/Fees
Total indirect	**$66,515,840**	**27.9%**	
Total project	**$238,515,840**	**100.0%**	

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