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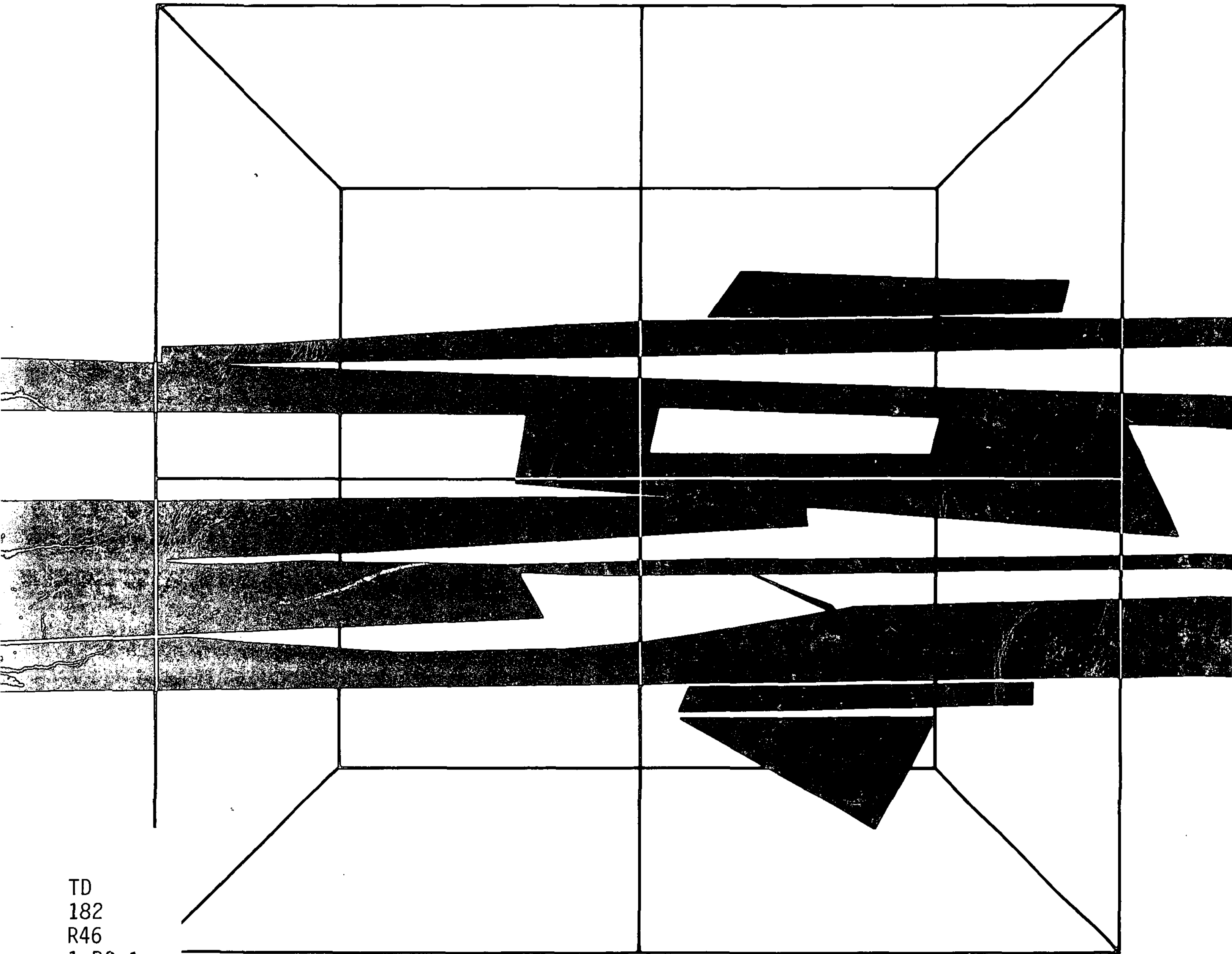
Environmental Codes of Practice for Steam Electric Power Generation

Design Phase

1885 1985

Report EPS 1/PG/1
March 1985



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ENVIRONMENTAL CODES OF PRACTICE FOR STEAM ELECTRIC POWER GENERATION

DESIGN PHASE

Industrial Programs Branch
Environmental Protection Service
Environment Canada

Report EPS 1/PG/1
March 1985

NOTICE

For further information, please contact:

D.W. Draper*
Chief
Oil, Gas and Energy Division,
Industrial Programs Branch
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

(819) 997-1220

or

P.G. Finlay
Head
Electric Power Section
Industrial Programs Branch
Environmental Protection Service
Environment Canada
Ottawa, Ontario
K1A 1C8

(819) 997-1220

* Chairman, Task Force, Environmental Codes of Practice for Steam Electric Power Generation

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s'adresser à la

Section des publications
Service de la protection de l'Environnement
Environnement Canada
Ottawa (Ontario)
K1A 1C8

Cat. N° En 49-9/1-1E
ISBN 0-662-13924-0
BEAUREGARD PRESS LIMITED

ABSTRACT

The Design Phase Code is one of a series of documents being developed for the steam electric power generation industry. This industry includes fossil-fuelled stations (gas, oil and coal-fired boilers), and nuclear-powered stations (CANDU heavy water reactors). In this document, environmental concerns associated with water-related and solid waste activities of steam electric plants are discussed. Design recommendations are presented that will minimize the detrimental environmental effects of once-through cooling water systems, of wastewaters discharged to surface waters and groundwaters, and of solid waste disposal sites. Recommendations are also presented for the design of water-related monitoring systems and programs. Cost estimates associated with the implementation of these recommendations are included. These technical guides for new or modified steam electric stations are the result of consultation with a federal-provincial-industry task force.

RÉSUMÉ

Le Code de recommandations techniques relatives à la phase de design fait partie d'une série de documents préparée pour la protection de l'environnement à l'égard des centrales électriques à vapeur. Ces centrales comprennent celles qui brûlent des combustibles fossiles (gaz, mazout, charbon) et les centrales nucléaires (réacteurs à l'eau lourde CANDU). Ce document traite des effets sur l'environnement des activités relatives à l'eau et aux déchets solides. Les recommandations visent à réduire au minimum les effets néfastes sur l'environnement des dispositifs de refroidissement à l'eau à passe unique, des effluents déversés dans les eaux de surface et les eaux souterraines ainsi que des décharges de déchets solides. Les recommandations portent également sur la conception de systèmes et de programmes de surveillance se rapportant à l'eau. Le Code comporte des estimations des coûts inhérents à l'application des recommandations. Ces Codes techniques à l'égard des centrales électriques à vapeur à l'état de projet ou en cours de modification sont le résultat de consultation avec un groupe de travail fédéral-provincial-industrie.

TABLE OF CONTENTS

APPENDICES

The following appendices are available in a separate volume:

APPENDIX A	TASK FORCE MEMBERS - ENVIRONMENTAL CODE OF PRACTICE FOR STEAM ELECTRIC POWER GENERATION
APPENDIX B	ELECTRICAL GENERATION AND WATER USE DATA
APPENDIX C	SELECTED ENVIRONMENTAL OBJECTIVES, SELECTED WATER QUALITY CRITERIA, "THERMAL POWER GENERATION EMISSIONS - NATIONAL GUIDELINES FOR NEW STATIONARY SOURCES" ENVIRONMENTAL CONTAMINANTS ACT AND REGULATIONS FOR CHLORINATED BIPHENYLS (PCBs)
APPENDIX D	RATIONALE FOR RECOMMENDATIONS - ONCE-THROUGH COOLING WATERS
APPENDIX E	RATIONALE FOR RECOMMENDATIONS - WASTEWATERS
APPENDIX F	RATIONALE FOR RECOMMENDATIONS - MONITORING
APPENDIX G	COST IMPLICATIONS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Scope

The Environmental Codes of Practice for Steam Electric Power Generation consist of a series of documents which identify good environmental protection practices for various phases of a steam electric power project. These documents will encompass the siting, design, construction, operation and decommissioning phases of a project.

The Codes describe potential environmental concerns and some alternative methodologies, technologies, designs, practices and procedures that will minimize adverse environmental effects of steam electric generating stations. The Codes also contain recommendations which are judged to be reasonable and practical measures that can be taken to preserve the quality of the environment affected by these stations.

The Environmental Codes of Practice have no legal status. They are an expression of environmental concerns and they identify opportunities for environmental protection for new or modified steam electric plants. The Codes are being developed in consultation with a federal-provincial-industry task force established by Environment Canada (1). The electricity generation industry, various federal and provincial agencies, and the public may use the Codes as sources of technical advice and guidance.

The steam electric power industry includes all facilities that utilize a steam cycle to produce electrical energy. Hence, the industry includes both fossil-fuelled (coal, oil or gas) and nuclear-powered (CANDU) stations. The Environmental Codes of Practice identify preventive measures for new or modified steam electric stations. "Modified" facilities include those that are expanded, (including replacement of obsolete generating capacity), those that are converted from one fuel type to another (e.g., from oil to coal) or from one major combustion method to another (e.g., from a pulverized coal-fired boiler to a fluidized bed combustion boiler), and those that are altered by the addition of any other major new station system (e.g., a flue gas desulphurization system retrofitted to an existing coal-fuelled station). The relevant Code recommendations would be appropriate to the new systems in modified stations. They do not apply to existing systems.

The siting, construction, operations and decommissioning phase documents will deal with multi-media (air, water, land) considerations. The Design Phase Code primarily addresses water-related concerns. These considerations include wastewaters generated from the disposal of solid wastes. Environment Canada's national air emission guidelines for new fossil-fuelled stations are provided for reference in the Design Phase Code

(Appendix C). The department's regulations for polychlorinated biphenyls (PCBs) are also appended for reference (Appendix C).

1.2 Code Development

This Environmental Code of Practice has been developed with the assistance of a federal-provincial-industrial task force. Industrial members of the task force were nominated by the Canadian Electrical Association. A list of members of the task force is presented in Appendix A. Different Working Groups of this Task Force have been examining various aspects of steam electric power plant siting, design, construction and decommissioning, from an environmental protection perspective.

In preparing the Design Phase Code, various environmental protection technologies and practices were identified and assessed on the basis of demonstrated feasibility, reliability, operational impacts and cost implications. Designs and practices that were considered reasonable and practical for new or modified steam electric stations have been recommended in consultation with task force members.

While the Code recommendations are intended to be clear and specific, they have been formulated so that they are not overly prescriptive. It is recognized that other technologies and practices can be developed and utilized to achieve equivalent or better results in terms of environmental preservation. Continuing research, development and demonstration of improved environmental protection practices is encouraged.

1.3 Code Structure

The Design Phase Code consists of this document and seven Appendices (A to G) which are contained in a separate volume. To provide comprehensive documentation, Environment Canada's National Emissions Guidelines for new fossil-fuelled stations, and regulations for chlorobiphenyls under the Environmental Contaminants Act are included in Appendix C.

Aspects of the steam electric industry are described in Section 2. Water-related environmental concerns associated with once-through cooling water systems are discussed generally in Section 3.2 and described in more detail with referenced material in Appendix D. Recommended practices and design opportunities to mitigate these concerns are presented in Section 4.1 and Appendix D.

Environmental concerns associated with wastewaters discharged from steam electric stations are discussed generally in Section 3.3 and wastewater characterization data are presented in Appendix E, Section E.2. Selected water quality criteria are presented in Appendix C, for reference purposes. Recommended practices and design opportunities to reduce the discharge of contaminants are presented in Section 4.2 and discussed in detail in Appendix E, Sections E.3, E.4 and E.5. Recommended design practices for the monitoring of steam electric waters are presented in Section 4.3 and discussed in detail in Appendix F. The Design Phase Code recommendations are summarized in Section 5. The cost implications of implementing the recommendations are summarized in Section 6 and presented in detail in Appendix G.

2 STEAM ELECTRIC INDUSTRY

2.1 Electricity Generation and Consumption

Alternating current electricity is produced in electric generators which may be driven by an internal combustion engine, a gas turbine, a falling water turbine or a steam turbine. The steam for turbines may be produced by boilers fired by coal, oil or gas, or may be produced by steam generators powered by nuclear fission heat.

In Canada most systems for the production, transmission and distribution of electricity are operated by provincial Crown corporations. The power utilities in Alberta and Prince Edward Island are privately owned and operated. Figure 2.1 shows the locations of major steam electric generating stations in Canada.

Approximately 18% of net industrial, commercial and residential energy consumption was from electricity in 1983 (2). Figure 2.2 shows the relative name plate capacities of hydro electric, coal, oil and gas-fired, and nuclear-powered electric generating facilities in 1983. This figure was derived from data presented in the Appendix B, Table B.1 (2). Figure 2.2 also shows the relative contributions of various types of facilities to electricity generated in 1983. This figure was derived from data presented in the Appendix B, Table B.2 (2). An annual generation of 396 000 GWh for a Canadian population of 24 343 181 (3) represents an average per person consumption of 16 000 kWh per annum. Approximately 10% of electricity generated in 1983 was exported (2). Of the total electricity generated in 1982, approximately 43% was consumed by industry, 27% by residences and farms, 22% by commercial and government facilities and 1% by transportation, with 9% accounted for by transmission losses and power utility use (4).

2.2 Steam Electric Capacity 1983 to 2000

While most electricity in Canada is generated from hydro electric facilities, approximately 40% of the installed generating capacity and over 30% of the annual generation is from steam electric facilities. Figure 2.3 shows the steam electric capacity available by province and by type of thermal station for 1983 and estimated for 2000. This figure was derived from data presented in the Appendix B, Table B.3 (5). Figure 2.4 shows the existing and projected Canadian thermal generation capacities for 1983, 1990, 1995 and 2000. This figure was also derived from data presented in the Appendix B, Table B.3 (5).

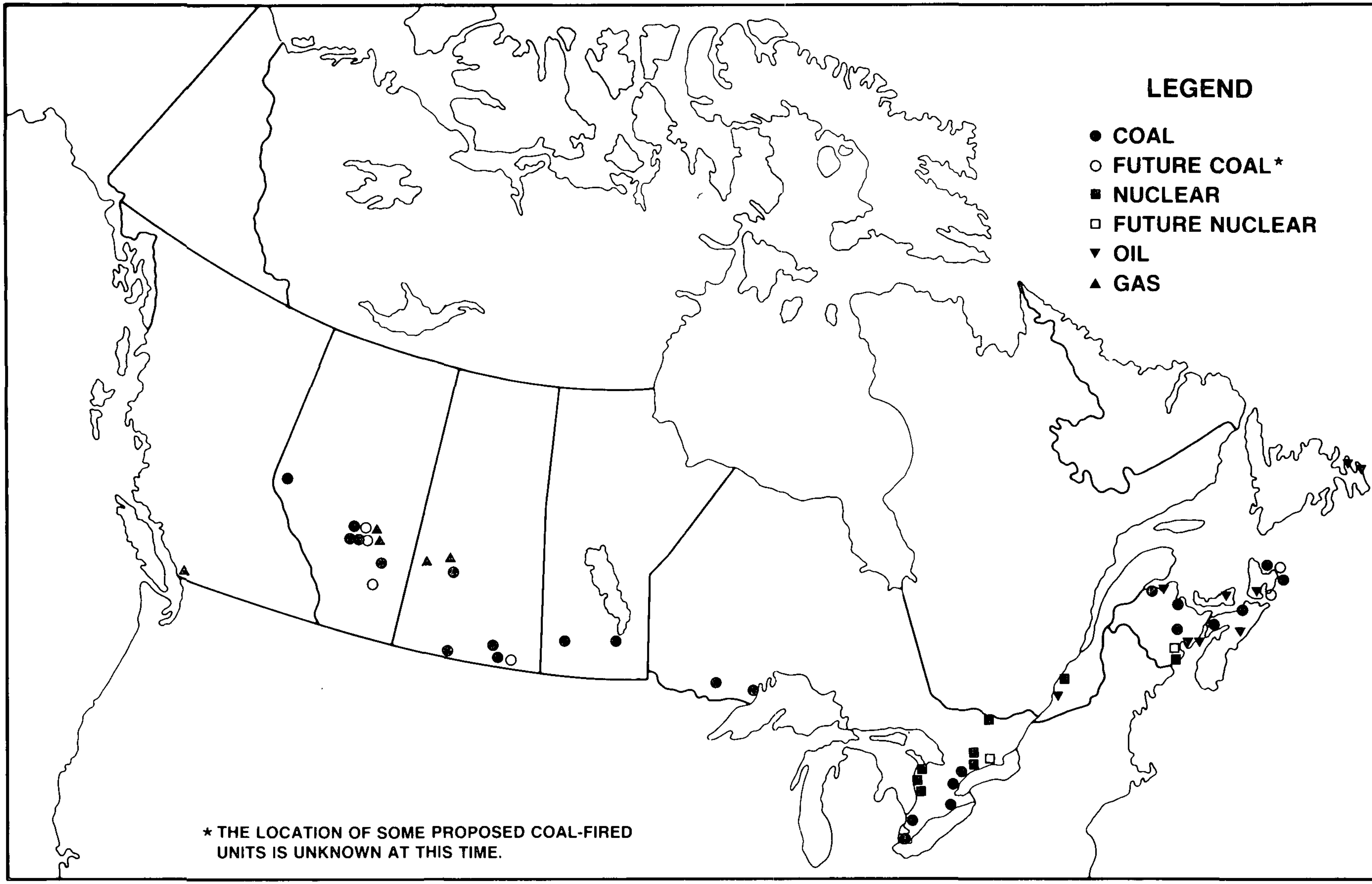


FIGURE 2.1 STEAM ELECTRIC GENERATING STATIONS IN CANADA, 1983

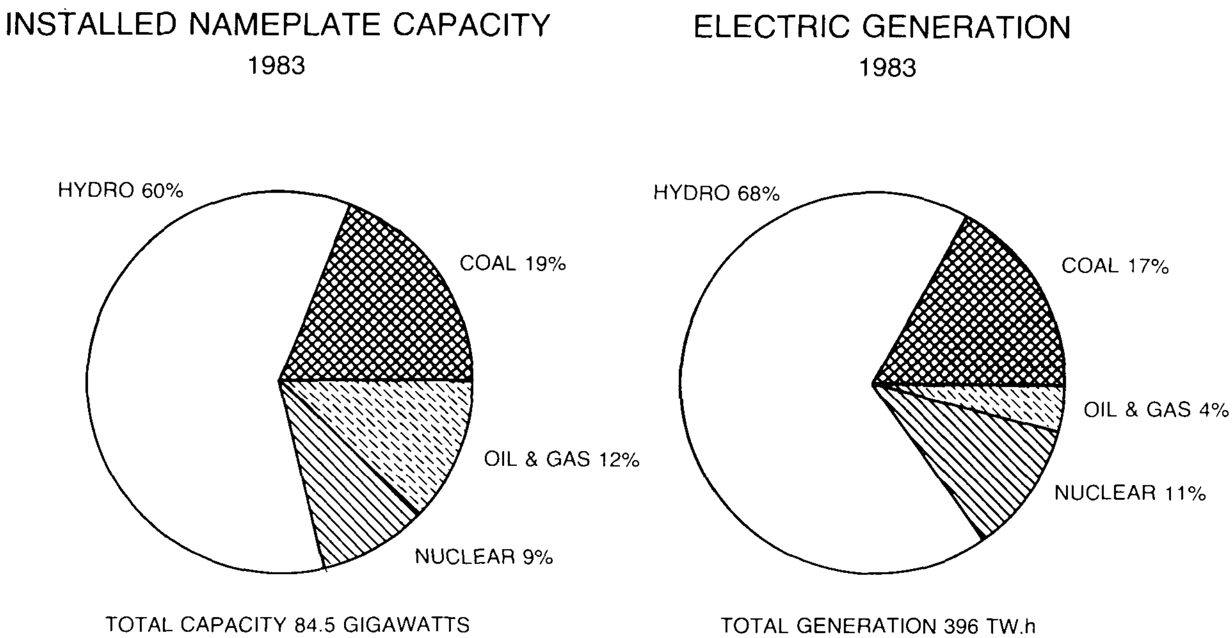


FIGURE 2.2 ELECTRICITY GENERATING CAPACITY AND PRODUCTION BY FUEL TYPE, 1983 (2)

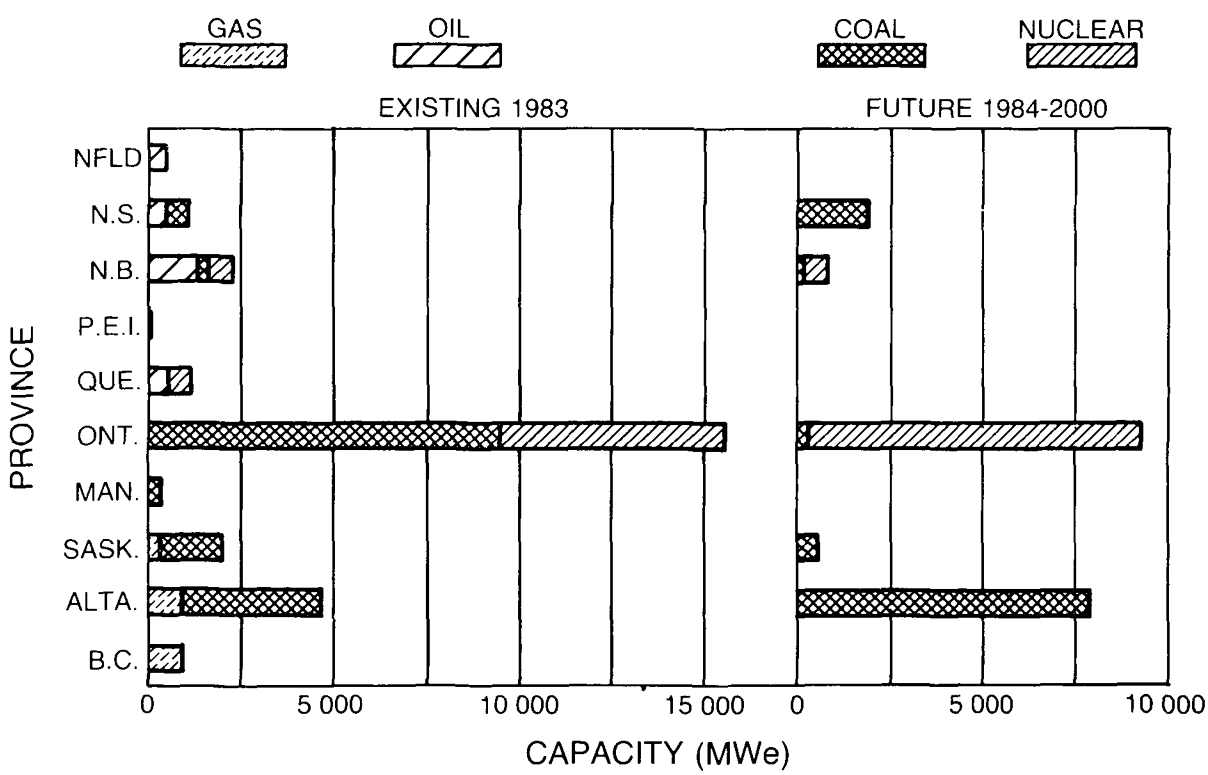


FIGURE 2.3 STEAM ELECTRIC CAPACITY BY PROVINCE, 1983 AND 2000 (5)

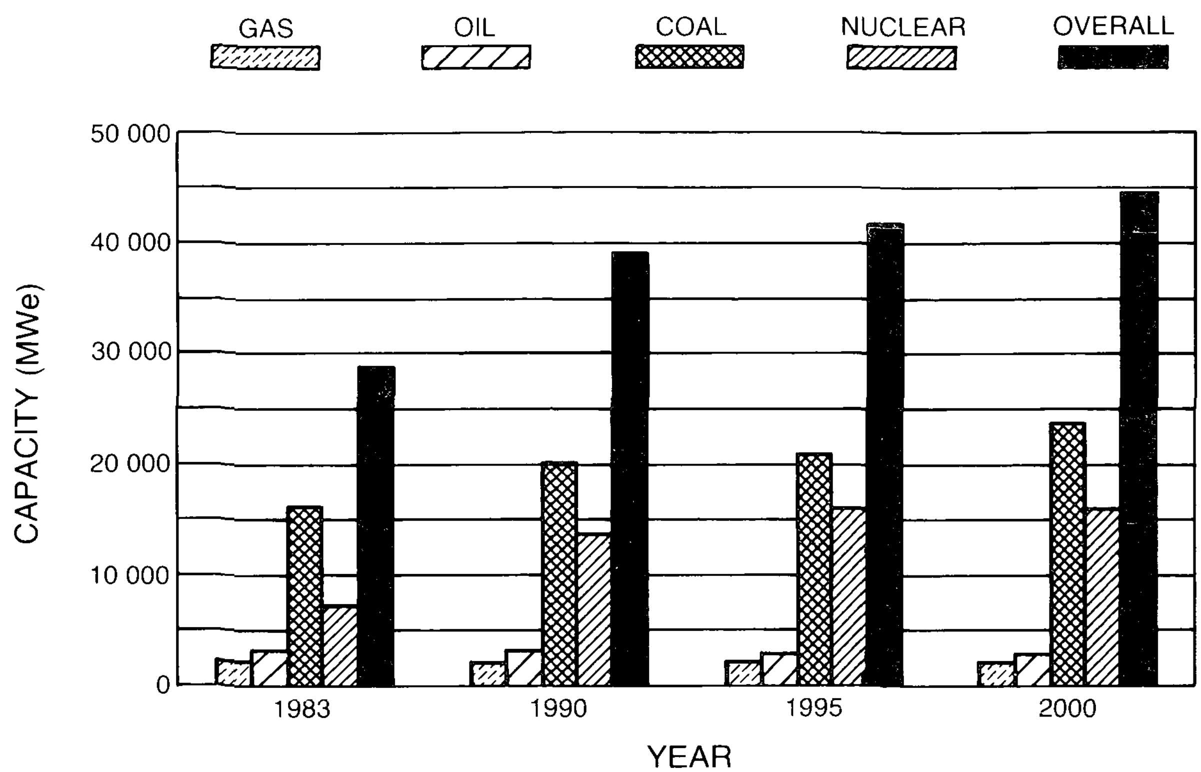


FIGURE 2.4 TOTAL STEAM ELECTRIC CAPACITY 1983, 1990, 1995 AND 2000 (5)

The fuel sources for steam electric stations differ for various provinces. Coal-fuelled stations in Nova Scotia, New Brunswick, Saskatchewan and Alberta use coal indigenous to each province, whereas Ontario uses coal imported from the United States and Western Canada. The Atlantic and Quebec oil-fuelled stations use imported offshore oil. Oil-fuelled stations will not be used for generation in Ontario in the future. Gas-fuelled stations in Saskatchewan, Alberta and British Columbia use gas indigenous to each province. Nuclear-powered stations in New Brunswick, Quebec and Ontario use uranium from northern Ontario and Saskatchewan.

In the steam electric industry in 1983, there were approximately 45 stations (28 786 MW). These included 24 coal-fired stations (16 228 MW), 9 oil-fired stations (3 109 MW), 5 gas-fired stations (2 209 MW) and 7 nuclear-powered stations (7 240 MW). The projection of new or expanded thermal electric facilities is dependent on the general state of the economy, the current capacity and load requirements of individual power utilities, and a number of other factors such as the costs of generating or purchasing electricity from different sources. Increases in electricity consumption have been lower in recent years than in previous years. The current projections to the year 2000 shown in

Figures 2.3 and 2.4 are reportedly based on best current projections by Canadian utilities in 1983 (5). From these data it is estimated that in terms of new commercially available steam electric capacity between 1984 and 2000 there will be 14 new coal-fired facilities (10 863 MW), no new oil-fired stations, no new gas-fired facilities and 4 new nuclear-powered facilities (8 794 MW). These "new" facilities include expansions at existing locations, and plants currently under construction that are scheduled to be commercially available before 2000. While the projected capacity and projected number of facilities is very speculative, Figure 2.3 indicates that the future major steam electric developments will probably be coal-fired stations in Alberta, Saskatchewan and Nova Scotia, and the completion or expansion of nuclear-powered stations in Ontario and New Brunswick. Little steam electric development in other provinces is currently anticipated, although general economic conditions could change these projections.

2.3 Steam Electric Systems

Fossil-fuelled and nuclear-powered stations differ primarily in the method of generating heat for the production of steam to drive turbo-generators. Figures 2.5 and 2.6 show the main process features of fossil-fuelled steam electric processes and the Canadian nuclear-powered steam electric process, respectively. Fossil-fuelled stations generate heat in a boiler by the combustion of either coal, oil or gas. CANDU (Canadian Deuterium Uranium) stations generate heat by the fission of the uranium-235 contained in natural uranium. As shown in Figure 2.6 circulating heavy water (deuterium oxide) is used to moderate (slow down) neutrons to induce nuclear fission reactions. Heavy water is also used to transport the heat from the nuclear reactor to the steam generator. In fossil-fuelled boilers and in nuclear plant steam generators, demineralized water is converted into steam by the heat of combustion and by the transported heat of the nuclear reactions, respectively.

The thermodynamic efficiencies of steam electric cycles affect the cooling water requirements of fossil-fired and nuclear-powered systems. Modern fossil-fuelled stations have a heat-to-electrical energy conversion efficiency of approximately 38 percent. Of the remaining 62 percent of the heat produced, approximately 15 percent is lost with the combustion flue gases through the stack, and 47 percent is lost to the station cooling water when spent steam from the turbine is condensed back to water for recirculation to the boiler. Nuclear-powered stations operate at lower temperatures and pressures and have a heat-to-electrical conversion efficiency of approximately

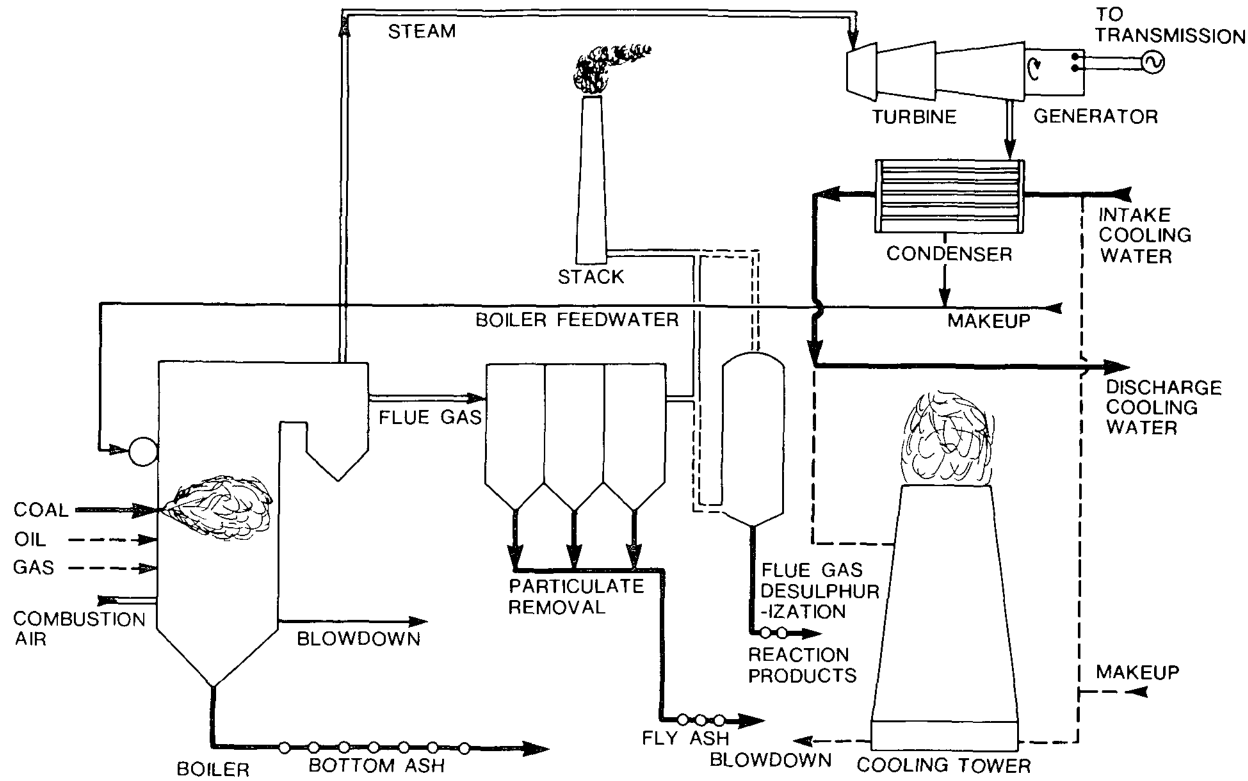


FIGURE 2.5 FOSSIL-FUELLED STEAM ELECTRIC PROCESS SCHEMATIC

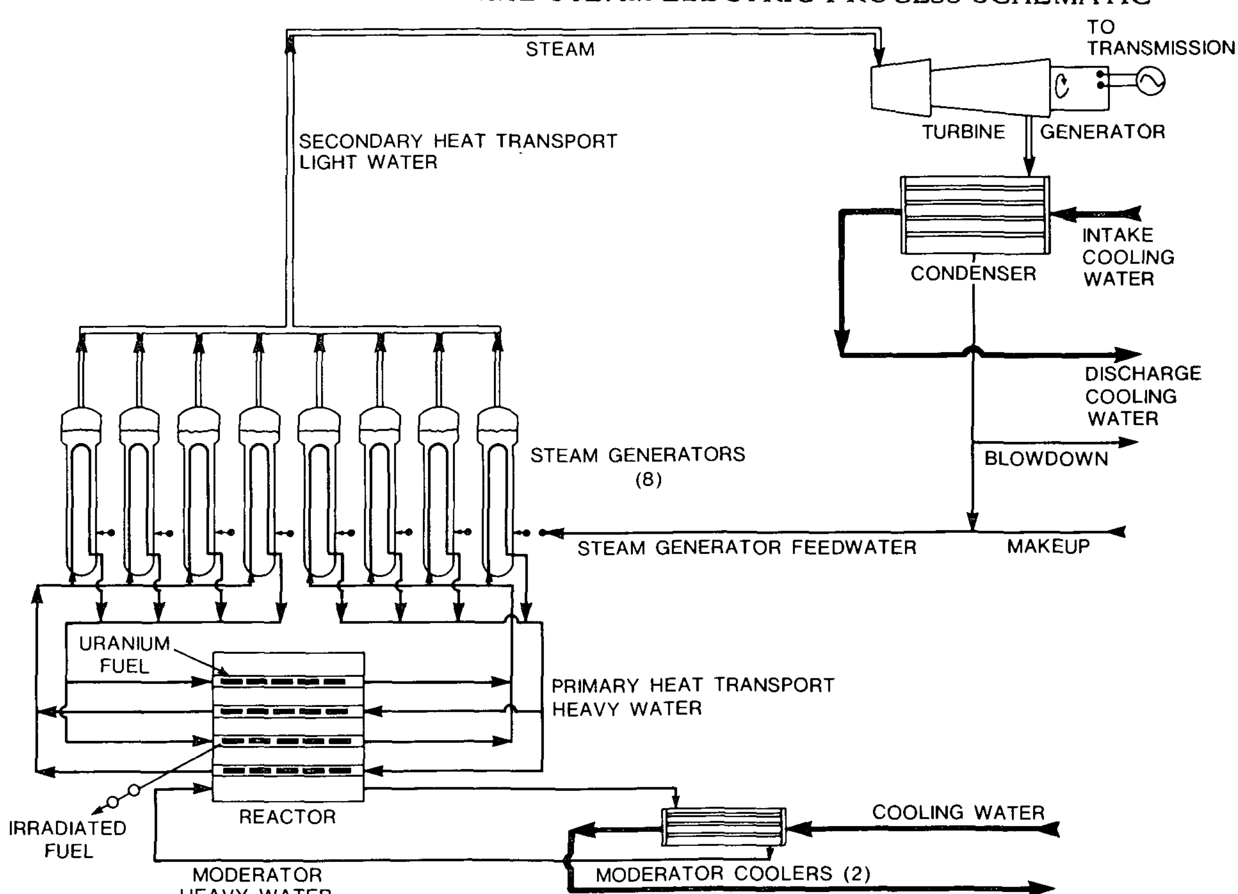


FIGURE 2.6 NUCLEAR-POWERED CANDU STEAM ELECTRIC PROCESS SCHEMATIC

30 percent. Almost all of the remaining 70 percent is transferred to the station cooling water in the condenser and moderator heat exchangers.

2.4 Steam Electric Water Uses

The Canadian use of fresh water by withdrawal and consumption (i.e., not available directly for further use) was reported at 111 705 million litres per day (ML/d) and 9207 ML/d, respectively, in 1980 (6). The largest withdrawals are by steam electric facilities for cooling water (43%), followed by manufacturing (34%), municipal and rural (11%) agricultural (7%) and mining (4%) facilities. The estimated consumption by steam-electric facilities (4% of total), which is primarily due to evaporation, is less than consumption by agricultural (48%), municipal and rural (22%), manufacturing (17%) and mining (9%) facilities (6).

Figure 2.7 shows projections for water withdrawals in Canada for the years 2000 and 2020. Data for this figure are presented in the Appendix B, Table B.4 (6). An eight-fold increase was projected from 1980 to 2020 in water withdrawal for thermal generation. This represents an increase from 43% to 73% of the total Canadian water withdrawal for the steam electric industry. While these projections are speculative, increased water use can be expected on Lakes Ontario and Huron due to additional nuclear-powered generation, and in Alberta due to increased coal-fired generation as previously shown in Figures 2.3 and 2.4. The increase in water requirements in the Prairie region will be particularly significant due to the relative shortage of water resources in Alberta and Saskatchewan. Future steam electric cooling water requirements in the Atlantic region will be supplied primarily by seawater.

Factors that affect the amount of water withdrawal and consumption by a steam electric station include the type of station (coal, oil, gas, or nuclear) and the water management system design at a particular station. The major water requirement is for condensing the steam from the turbine prior to recirculating the condensate to the boiler or steam generator. Cooling water is also required for auxiliary station equipment. Because nuclear stations are less efficient in terms of heat input to electrical conversion, they use more water for a given electrical output. The selection of process system designs for any station will influence the volumes of water used. If process water is recirculated (used again in the same system) or re-cycled (used again in a different system) the water use will be reduced. For example a "recirculating" cooling system or ash transport system may be used and these will use substantially less water than "once-through" systems.

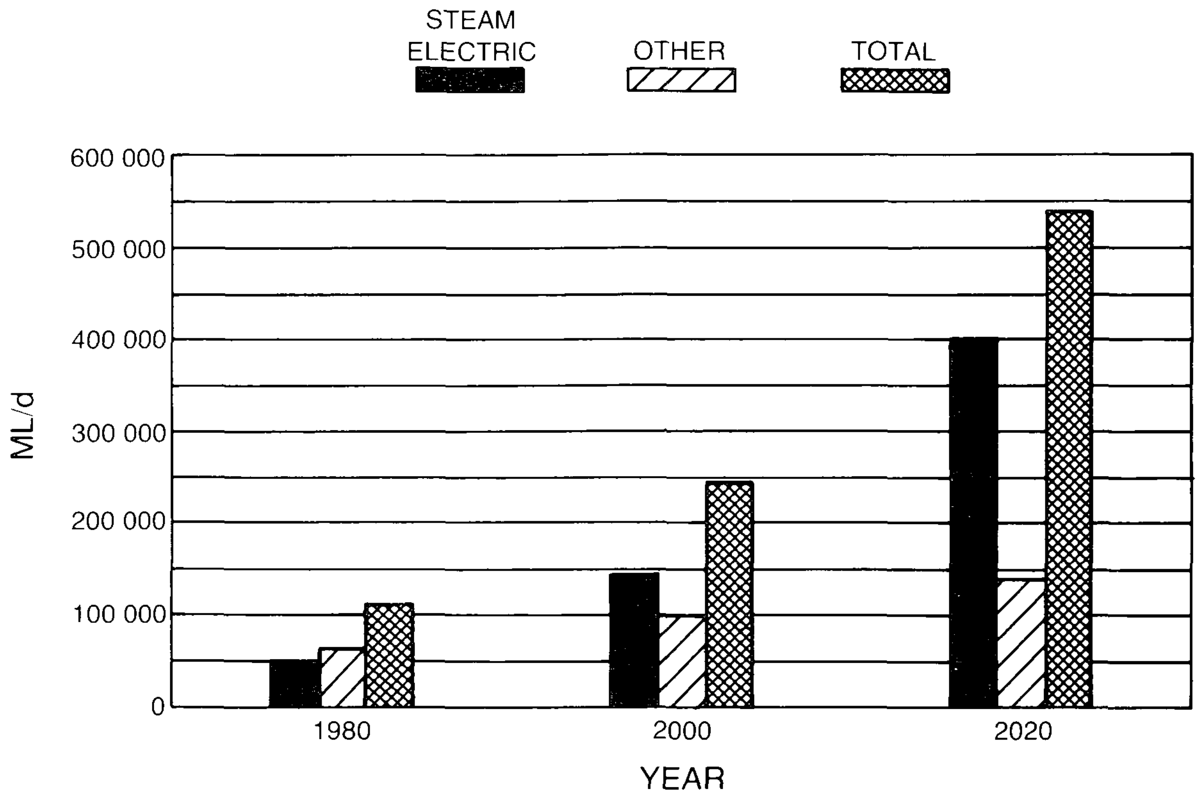


FIGURE 2.7 ESTIMATED WATER WITHDRAWAL IN CANADA, 1980, 2000 AND 2020 (6)

Both fossil-fired and nuclear-powered stations require water treatment plants to produce high quality water for the steam cycle. They both use water for plant and equipment washing, personnel washrooms and laundry, fire protection and various process requirements. Natural precipitation (rain and snow) may contact solid wastes produced by both types of stations before being discharged as runoff or seepage to surface waters or groundwaters.

Figure 2.8 shows typical water uses and the approximate flows for "generic" 1000-MW (electric) stations. Coal-fired and CANDU nuclear-powered stations with once-through cooling and recirculating cooling designs are shown. The different cooling requirements are indicated (29 500 L/s for coal-fired; 55 900 L/s for nuclear-powered). Evaporative cooling towers or ponds would reduce the once-through cooling requirements by approximately 95%. For coal-fired stations, recirculating rather than once-through ash systems would reduce the water use.

Figure 2.9 shows estimates of annual steam electric water use in Canada. The estimates were derived from annual generation data and typical design flows for once-through cooling systems (see Appendix D) and wastewaters (see Appendix E). The major

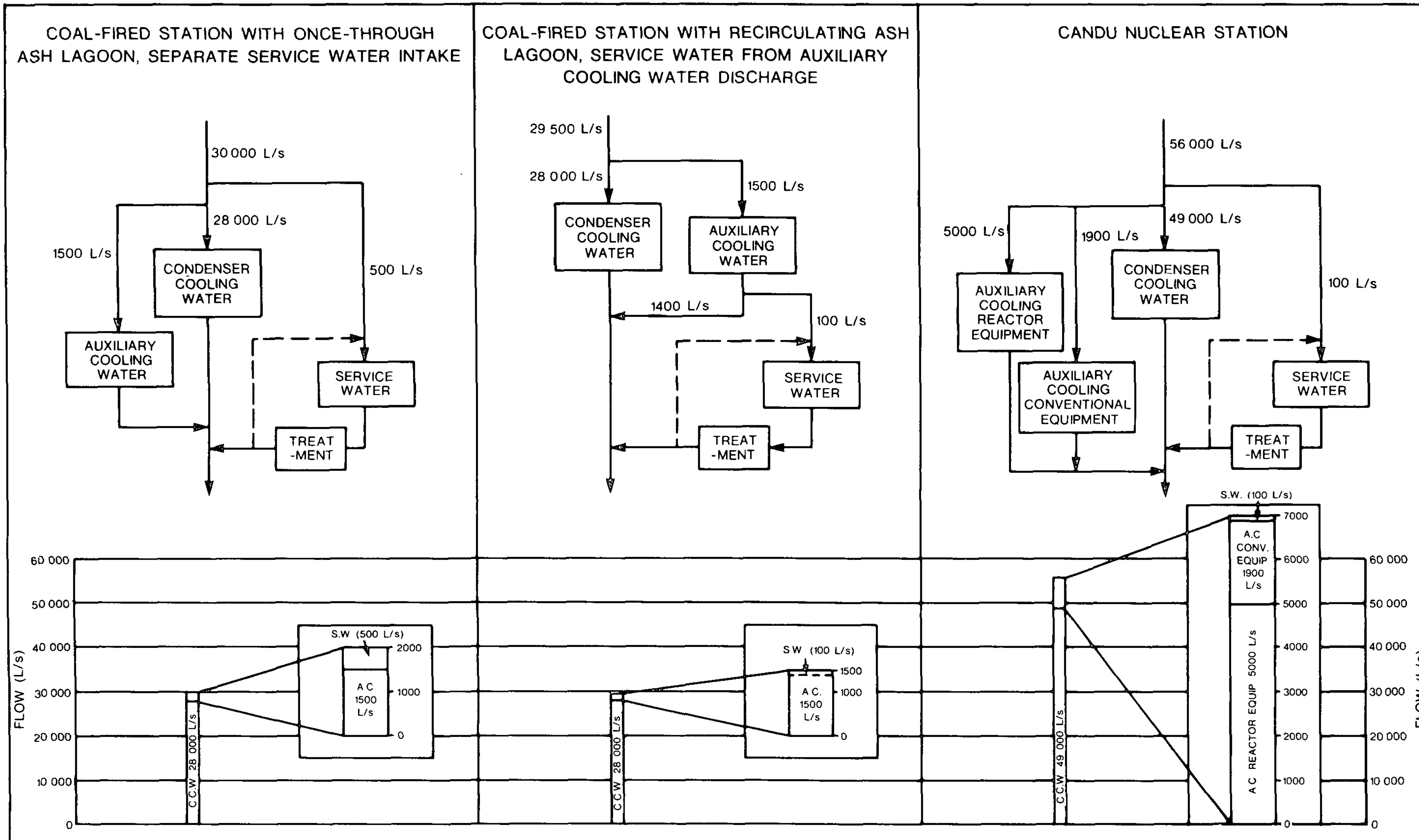


FIGURE 2.8 COMPARATIVE WATER FLOWS FOR 1000-MW FOSSIL-FUELLED AND CANDU NUCLEAR STATIONS

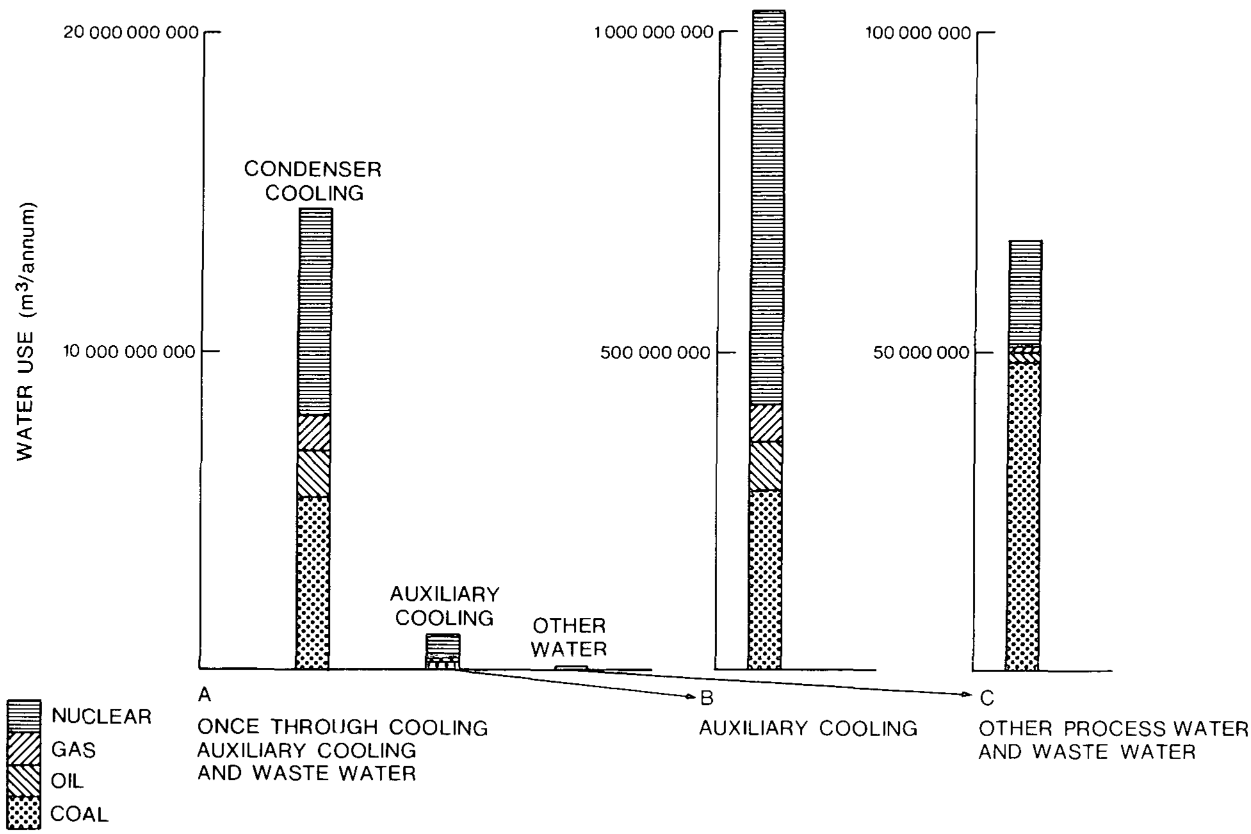


FIGURE 2.9 ESTIMATED ANNUAL WATER USE AND WASTEWATER VOLUMES FOR STEAM ELECTRIC STATIONS

users of condenser and auxiliary cooling water were nuclear-powered plants, and the major generators of wastewater were coal-fired plants.

A typical water use for municipal supplies is in the order of 100 m^3/person·annum. Although once-through cooling water is returned to the source water body relatively uncontaminated and is not consumed like municipal water supplies, a comparison can be made between municipal and steam electric water volumes. The water withdrawal for condenser cooling ($1.5 \times 10^{+10}$ m^3/annum) and auxiliary equipment cooling ($1 \times 10^{+9}$ m^3/annum), and the contaminated water discharged from stations ($7 \times 10^{+7}$ m^3/annum) would be equivalent to the annual water withdrawal of 150 million, 10 million and 0.7 million people, if these volumes were consumed by municipalities. However, the only "consumption" of once-through cooling water is by evaporation in the receiving water body.

3 GENERATING STATION WATER SYSTEMS AND ENVIRONMENTAL CONCERNS

3.1 Categorization of Station Water Systems

For the purposes of the Design Phase Code, steam electric station waters have been divided into two categories which are defined as follows:

Type 1 **Once-through condenser cooling waters and once-through auxiliary cooling waters that are not considered to be potentially contaminated by deleterious substances.**

Type 2 **All station waters known to contain, or potentially containing, a deleterious substance or substances. (These "wastewaters" include used process and cleaning waters, blowdown from recirculating water systems, runoff, seepage and once-through auxiliary cooling waters subject to potential contamination.)**

Simplified schematic diagrams of "typical" current water and wastewater management systems are presented for coal-fired stations in Figure 3.1 and for CANDU nuclear-powered stations in Figure 3.2. Once-through condenser cooling water streams are shown (Type 1), and various wastewater streams are also shown (Type 2).

As indicated in Section 2.4, the largest single water withdrawal in Canada is once-through cooling water for thermal power plants. Once-through cooling water used for condenser cooling is considered to be a Type 1 stream because it will not normally be contaminated by deleterious substances. This is because the process fluid cooled (steam condensate) is at a lower pressure than the once-through cooling water in the condenser, and heat, biocides and wastewaters (Type 2 water) added to once-through cooling water will be effectively controlled to minimize potential deleterious effects. The main environmental concerns associated with once-through condenser cooling systems are the large volumes of water used, and the potential damage to aquatic organisms in these volumes due to physical, thermal and chemical stresses. There is also concern due to the potential damage to aquatic organisms in receiving waters because of thermal stresses induced by the cooling water discharges.

Aquatic organisms in auxiliary cooling water (used for cooling fluids other than condensate) will most probably be damaged because of the tortuous route of this water through the generating station and the effects of temperatures that are often higher than condenser temperatures. Furthermore, because some the the cooled fluids are at higher pressures than the once-through auxiliary cooling water, the latter may become

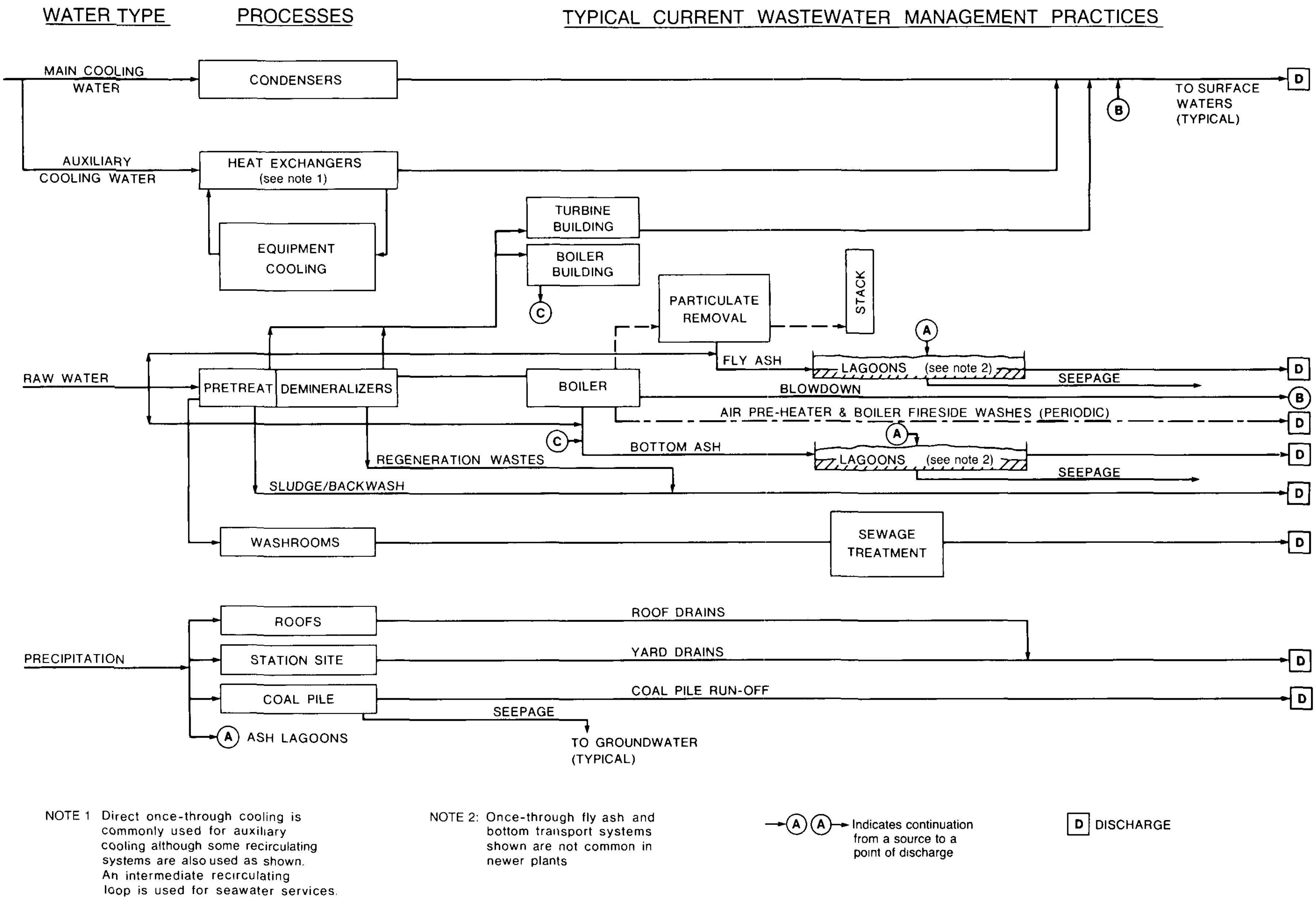
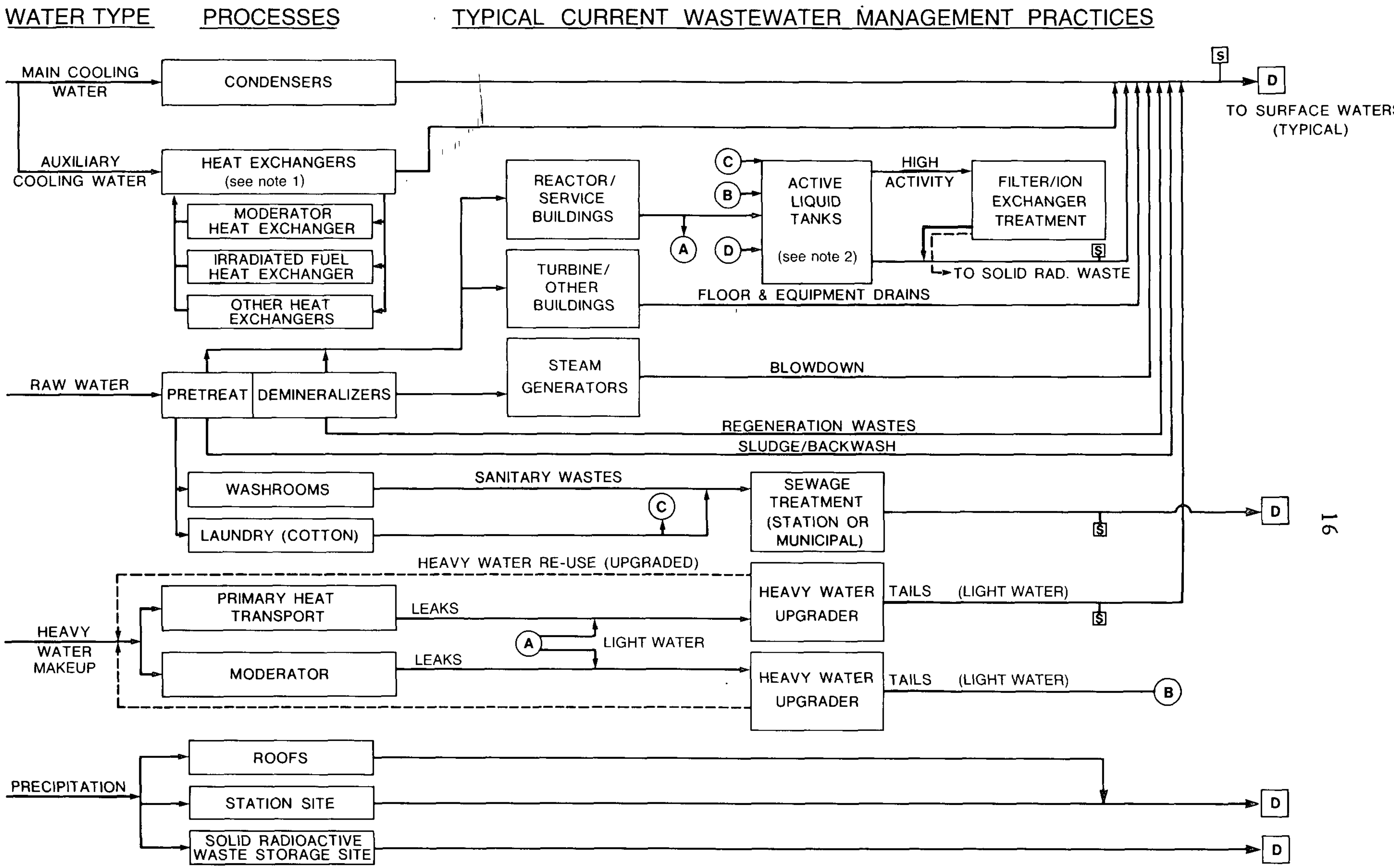


FIGURE 3.1 TYPICAL WATER AND WASTEWATER SYSTEM SCHEMATIC FOR COAL-FIRED STATIONS



NOTE 1: Some designs utilize a secondary heat exchanger and recirculating cooling loop, as shown, while in others the once-through cooling water is routed directly to the moderator and other heat exchangers.

NOTE 2: (D) Wastes to active liquid tanks also include wastes from:
- Decontamination centre
- Plastics laundry
- Fuelling machine shop
- Ion exchange slurry water
- Laboratories (high & low activities)
- Emergency showers, etc.

→(A) (A)→ Indicates continuation from a source to a point of discharge

[S] SAMPLING AND FLOW MONITORING

[D] DISCHARGE

FIGURE 3.2 TYPICAL WATER AND WASTEWATER SYSTEM SCHEMATIC FOR CANDU STATIONS contaminated. When this situation occurs, these once-through auxiliary cooling waters are classified as Type 2 water.

Other process and service waters, and the resulting wastewaters, are small in volume compared to once-through cooling water. However, their volumes are of the same orders of magnitude as many other industrial wastewaters. The potential environmental concerns associated with Type 2 water (or "wastewaters") include the deleterious effects of contaminants discharged to receiving surface waters and groundwaters. These contaminants include oil, grease, process chemicals, trace contaminants (e.g., from coal) and radionuclides (e.g., from nuclear reactions).

The following sections provide additional descriptions of steam electric water systems and the nature of associated environmental concerns. More detailed discussion and references for once-through cooling systems and wastewaters are presented in Appendices D and E, respectively. The monitoring of water streams is discussed in Appendix F.

3.2 **Once-Through Cooling Water** (Type 1 water)

3.2.1 Description. For the purpose of the Design Phase Code, once-through cooling water (or Type 1 water) at steam electric stations includes both once-through condenser cooling water, and once-through auxiliary cooling water that is not considered to be potentially contaminated.

Typically, once-through (or open cycle) cooling systems have the following components: intake, forebay, trash racks, screens, pumps, condensers and heat exchangers, and outfall. Water is withdrawn from the source water body (lake, river or ocean) through the intake. The intake may be on the shoreline or submerged in the water body. The water is drawn to the forebay where trash racks (typically with 100 mm wide vertical openings) remove large debris and vertical travelling screens (typically with 10 mm square openings) remove smaller debris and fish from the water. Cooling water pumps transport the water through the condenser of each generating unit, which usually contains several thousand tubes (typically 25 mm diameter). Heat from the condensation of exhaust steam from the turbines is transferred to the cooling water as it passes through the condenser tubes. From the condenser, the heated cooling water is discharged to the receiving water body, at the shoreline or through an outfall channel or tunnel to a submerged outfall.

In addition to condenser cooling, once-through auxiliary cooling water is used in both fossil-fuelled and nuclear-powered stations for cooling equipment such as motors, pumps, compressors and generators. Also, nuclear stations use large quantities of water to cool equipment associated with the reactor. Auxiliary cooling water is usually drawn from the forebay or from the condenser cooling water inlet piping prior to the condenser. It is pumped through an extensive piping system to various pieces of equipment which require cooling. Here heat exchangers are used to extract heat from the equipment fluid (oil or water). The once-through auxiliary cooling water is usually discharged in the same conduit as the condenser cooling water. Typically, a CANDU nuclear-power station uses more than four times as much auxiliary cooling water and almost twice as much total cooling water as a fossil-fuelled station of the same generating capacity.

3.2.2 **Environmental Concerns.** The two areas of potential environmental concerns associated with once-through cooling systems, which are described in more detail in Appendix D, are:

i) the physical, thermal and chemical damage to biological species in the water withdrawn for cooling, and
ii) the detrimental effects of thermal discharges in the receiving water.

Factors that determine the damage to biota include the volume of water withdrawn and the concentrations of aquatic organisms in that water. In large water bodies, such as large lakes and oceans, the "nearshore" or littoral zones are usually vital to the biological well-being of the system. Most fish spend some portion of their life cycle in the shallow areas where suitable conditions exist for spawning, nursery, and migration. In large water bodies, this vital area of high biological productivity is small in comparison to the entire water body area and volume. Very biologically sensitive areas also exist in river estuaries and in nearshore zones of large rivers. Prolonged damage to these sensitive areas may result in an irreversible decline of certain species in an ecosystem.

For the purposes of the Design Phase Code:

The "nearshore zone" is defined as the area between the shoreline and the point where the water depth is the greater of: (i) double the local Secchi disk reading, or (ii) 10 metres.

Although many of the cooling system designs discussed relate to the protection of the nearshore zone, special consideration may have to be given to other segments of water bodies on a site-specific basis. For example, in salt water bodies an area of salmon migratory passage or lobster breeding beyond the nearshore zone may be of concern.

"Entrapment" is the capture of aquatic organisms in the cooling water flow stream. Fish and other aquatic organisms are initially entrapped in the cooling water by their failure or inability to avoid being drawn into the cooling water intake. Because of their immobile, free-floating character, planktonic organisms are highly susceptible to entrapment. Fish trapped in the forebay may be unable to return to the source water body and may become exhausted from swimming against the cooling water current. Entrapped organisms may be subject to "impingement", or the forcing and capture of organisms on the intake screens. After possible abrasion in passing through the trash rack, fish mortality may be caused by descaling during escape attempts and by removal from water onto the screens for prolonged periods. "Entrainment" is the passage of aquatic organisms through the cooling water piping, pumps and condensers.

Ichthyoplankton (fish eggs and larvae) and other organisms small enough to pass through the travelling screens will be subjected to physical stresses (abrasion, shear and acceleration forces) as they pass through the cooling water pumps. Subsequent lesser physical stresses may occur in passage through the cooling water piping, condensers and heat exchangers. Thermal stresses will also occur in the condensers and heat exchangers. If the temperatures exceed the lethal limit for a particular species, mortality of that species will result. The entrained organisms will be subjected to chemical stresses if biocides, such as chlorine, are used in the cooling water to prevent organic fouling of the condenser, heat exchanger tubes or other parts of the cooling water circuit. When the cooling water is discharged, the entrained organisms may be subjected to further mechanical damage in the discharge facility, and to further thermal shock as the water temperature returns to ambient.

Organisms in the receiving water that have not passed through the plant may be entrained in the thermal plume from the plant. Potential concerns associated with heated discharges include changes in spawning, incubation and nursery conditions and changes in movements of fish species between near and offshore areas. Other concerns include the incidence of fungal and bacterial fish diseases, the increased accumulation of toxic substances by fish, and the thermal shock associated with temperature drops when the generation unit shuts down. Of particular concern is that the thermal plume may shift along the biologically sensitive shoreline area, instead of being dispersed in the main water body. These shoreline currents may also contain contaminants discharged in Type 2 water from the station to the once-through cooling water, which may be drawn into municipal drinking water supplies located on the shoreline of fresh water bodies.

For the purposes of the Design Phase Code, a distinction is made between recirculating and non-recirculating reservoirs. A reservoir having an annual discharge of less than 3 m^3/s per 1000 MW of installed generating capacity, and which had aquatic life of minor significance prior to impoundment, is regarded as a recirculating reservoir (Type 2 water). The design features recommended for once-through cooling systems (Type 1 water) in Section 4.1 would not apply to these reservoirs.

The main regions likely to be affected by future once-through cooling systems may be Lakes Ontario and Huron, because of increased large nuclear power generation. If recirculating cooling systems are not used in Alberta and Saskatchewan for future increases coal-fuelled generation, the limited water resources in these provinces will be affected. Concerns are also associated with future once-through cooling systems in Atlantic Canada, because of increased coal-fuelled and nuclear-powered generation using salt water.

The nature of biological activities and sensitivities will vary for different source water bodies and for areas within each water body. However, measures can be taken for all water bodies that will minimize the impacts of once-through cooling systems and that will preserve environmental quality. These measures are presented in Section 4.1 and are summarized in Section 5.

3.3 Wastewaters (Type 2 water)

3.3.1 Description. For the purpose of the Design Phase Code, wastewaters (or Type 2 water) at steam electric stations include waters known to contain, or potentially containing, a deleterious substance or substances, which originate from station activities.

As shown in Figures 3.1 and 3.2, both fossil-fuelled (coal, oil or gas) and nuclear-powered steam electric stations use fresh water for feed to a water treatment plant which produces demineralized water for the boilers or steam generators, and typically also produces potable water for drinking and domestic purposes. Fresh water may be used directly without treatment for such services as pump seals, equipment and floor washdowns, fire protection, etc., depending on the quality of the raw water.

If an evaporative recirculating cooling system (towers or pond) is used in a steam electric station, relatively substantial amounts of water will be required to make up for evaporative and other losses.

In addition to these water services, coal-fuelled steam electric stations will require water for handling of bottom ash from the boiler, and for handling of fly ash from particulate removal equipment. If a flue gas desulphurization (FGD) system is used at a fossil-fuelled station, additional water will be required for scrubber reagent preparation, pump seals, system make-up, etc.

The process and service water requirements for CANDU nuclear powered stations will be similar for services common to all steam electric stations. The quantities of service water per unit capacity installed may be larger than for a similar capacity fossil-fuelled station since more high quality demineralized water is generally used, and more personnel occupy the station, requiring more water for showers, laundry etc.

3.3.2 **Environmental Concerns.** All these water services produce wastewaters whose characteristics depend on their use and the contaminants they contacted in the process. If once-through auxiliary cooling water is at a pressure lower than the fluid being cooled, then it is classified as a Type 2 water since the once-through auxiliary cooling water may become contaminated in the event of a heat exchanger leak. Contaminants may be oil (lubricating oil for turbines, compressors, fans etc.) or tritiated heavy water in CANDU moderator circuits.

All stations produce wastewaters associated with water treatment plants (e.g., sludges from clarifiers ($Al_2 (SO_4)_3$), concentrated suspended solids from filters, acidic and alkaline wastes from demineralizers (e.g., $H_2 SO_4$ and NaOH.)

Fossil-fuelled stations will "blow down" (i.e., discharge from a recirculating system) accumulated contaminants from boilers. The blowdown contains chemicals used to maintain alkaline, low oxygen, non-corrosive conditions in the boiler water (e.g., phosphates, hydrazine, amines). Nuclear-powered stations also blow down the steam generators. In addition to the normal blowdown, boilers and steam generators are chemically cleaned prior to operation, and may be cleaned periodically again during the operating life of the station. Wastewaters associated with these activities contain metals from the boiler and steam generator tubes (e.g., iron) and the cleaning agents (e.g., citric acid, hydrochloric acid, phosphates, hydrazine etc.). Also condensers and heat exchangers may be chemically cleaned periodically to remove accumulated scale, silt and biofouling film. Acidic and/or alkaline wastewaters may be produced from these operations. Particularly in evaporative recirculating cooling systems, chemicals may be used continuously or periodically during operation to control biofouling (e.g., chlorine), silting (e.g., polyelectrolytes), or scaling/corrosion (e.g., zinc chromate). All stations may inadvertently discharge oil or grease in wastewaters (e.g., lubricating oils, diesel fuel for auxiliary electric generators or auxiliary fire pumps). Fossil-fuelled stations may inadvertently discharge fuel oils (e.g., light oil for ignition of coal-fuelled boilers). All stations discharge sanitary wastewaters from washrooms, showers and possibly laundry facilities.

In summary, process wastewaters of environmental interest common to coal, oil and gas-fuelled stations and to nuclear-powered stations include:

- alkaline and acidic wastewaters,
- water treatment sludges,
- boiler/steam generator blowdown containing chemical additives,
- boiler/steam generator, condenser, heat exchanger chemical cleaning wastes,
- wastewaters containing oil or grease,
- sanitary wastewaters.

In addition to these wastewaters, the coal used at steam electric stations contains a number of elements of environmental concern which may end up in combustion-related wastewaters. These include:

Sulphur (S)	Antimony (Sb)	Lead (Pb)	Strontium (Sr)
Chlorine (Cl)	Arsenic (As)	Lithium (Li)	Thallium (Tl)
Fluorine (F)	Barium (Ba)	Manganese (Mn)	Thorium (Th)
Phosphorus (P)	Boron (B)	Mercury (Hg)	Titanium (Ti)
Sodium (Na)	Cadmium (Cd)	Molybdenum (Mo)	Uranium (U)
Calcium (Ca)	Chromium (Cr)	Nickel (Ni)	Vanadium (V)
Potassium (K)	Cobalt (Co)	Selenium (Se)	Zinc (Zn)
Silicon (Si)	Copper (Cu)	Silver (Ag)	Zirconium (Zr)
	Iron (Fe)		

In addition to these elements some naturally occurring radionuclides, such as those associated with the decay of uranium, thorium and potassium, will also be found in coal.

When coal is burned, these elements are concentrated in the ashes. Some elements are found to fractionate preferentially in either the bottom ash, fly ash, or emitted flue gases. All these elements introduced to the power station in coal contaminate water associated with coal storage, ash handling and flue gas cleaning. Water may be used to periodically wash down coal handling equipment such as belt conveyors, pulverizers, etc. Wastewaters may be generated from bottom ash systems, particularly if a once-through water transport system is used. If water is used as the transportation medium for fly ash, wastewaters are produced, particularly in a once-through system. Flue gas desulphurization systems may produce wet waste sludges and also wastewaters associated with periodic equipment drainings or with blowdowns. In addition to flue gas contaminants, these wastewaters will be high in dissolved solids associated with the scrubber reagents used to remove sulphur dioxide. Air preheaters, which are used to heat combustion air to the boilers by extracting heat from flue gases, are periodically washed down or chemically cleaned. Also the fire-side of boilers are periodically washed down. These wastewaters contain ash contaminants.

In CANDU heavy water nuclear-powered stations, heat is produced by the fission of the uranium isotope U-235 contained in natural uranium which is 99.3% U-238 and 0.7% U-235. Circulating heavy water (deuterium oxide) is used to moderate (slow down) neutrons to induce nuclear fission reactions. It is also used to transport heat from the reactor to the steam generator. The sources of radioactivity in wastewaters from these stations are fission products (from the fission process in the reactor), and activation products (due to the conversion of an element to a radioactive isotope by the addition of a neutron). Radionuclides of environmental concern from CANDU stations include:

Tritium (H-3)	Strontium-89 (Sr-89)	Cesium-134 (Cs-134)
Carbon-14 (C-14)	Strontium-90 (Sr-90)	Cesium-137 (Cs-137)
Chromium-51 (Cr-51)	Yttrium-91 (Y-91)	Lanthenum 140 (La-140)
Manganese-54 (Mn-54)	Zirconium-95 (Zr-95)	Barium 140 (Ba-140)
Iron-59 (Fe-59)	Niobium-95 (Nb-95)	Cerium 141 (Ce-141)
Cobalt-58 (Co-58)	Ruthenium-103 (Ru-103)	Cerium 144 (Ce-144)
Cobalt-60 (Co-60)	Ruthenium-106 (Ru-106)	Praseodymium 143 (Pr-143)
Zinc-65 (Zn-65)	Iodine-129 (I-129)	Neodymium 147 (Nd-147)
Zirconium-95 (Zr-95)	Iodine-131 (I-131)	Promethium 149 (Pm-149)
Silver-110 m (Ag-110 m)	Xenon-133 (Xe-133)	
Antimony-124 (Sb-124)		

Radioisotopes in the first column are generally activation products, except carbon-14 which may be produced, for example, from a number of nuclear reactions starting with oxygen-17 or nitrogen-14. Tritium (H-3), an isotope of hydrogen, is produced by the activation of deuterium (H-2) present in heavy water. Other activation products are produced from metals in the materials of construction of reactor systems (e.g., cobalt-60) and from corrosion products (e.g., iron-59). Virtually all the fission products are retained in the fuel bundles in the reactor.

All these radioisotopes may contaminate heavy water or light water associated with reactor operations and maintenance. In CANDU systems, due to the expense of heavy water, considerable design and operational efforts are made to minimize losses of the heavy water. Provisions are made for minimizing leaks, segregating, collecting, and upgrading the heavy water (i.e., removing light water from heavy/light water mixtures). However, tritium and, to a lesser extent other activation and fission products present in leaks, are normally discharged in wastewaters from laundries, laboratories, showers and washrooms, the decontamination center, reactor building drains, etc. In the event of fuel bundle failures, fission products escape to the primary heat transport circuit. A reactor accident such as a loss of coolant incident could produce considerable amounts of radioactive wastewaters. These wastewaters would contain tritium, other activation products and possibly fission products. Their potential release to the environment is of particular concern.

In all steam electric stations, precipitation (rain or snow) may become contaminated, depending on the material it contacts. For example precipitation will leach trace contaminants from coal piles at a coal-fuelled station. These dissolved and suspended solids may be discharged to receiving surface waters as runoff and may percolate under the coal pile to groundwater as seepage. High sulphur coals will produce acidic wastewaters which tend to solubilize metals to a greater extent than low sulphur coals. However, contaminants of concern such as boron also solubilize in alkaline wastewaters. Similar concerns are associated with fly ash, bottom ash and flue gas desulphurization waste disposal sites. These sites are typically separate from the generating station itself. Generally fly ash is more likely to leach constituents than bottom ash because of the nature and larger surface area of fly ash.

Precipitation may also collect radionuclides from low and medium level radioactive waste storage sites associated with nuclear-powered stations. Although in recent years low level radioactive wastes (used rags, clothing, equipment components etc.) and medium level wastes (used filters, ion exchange resins, etc.) have been generally contained in concrete structures, radionuclide contamination of groundwater and/or surface waters from these sites may occur inadvertently.

Drainage from general yard drains and switchyard drains is collected in ditches for discharge into surface waters. While these wastewaters are normally "clean", they may contain suspended solids due to natural site erosion and may on occasion become contaminated due to accidental spills of fuel oil, chemicals, or transformer oil, etc., and fugitive dust from coal piles, and ash.

The volume and characteristics of wastewaters will depend on the overall water/wastewater system design provisions, which in turn depend on the station type, process systems, precipitation, etc. The plant's operational and maintenance activities will determine the characteristics of wastewaters actually discharged during the operating life of the station. The solid waste disposal provisions will determine the characteristics of wastewaters after the operating life of the station.

To provide a perspective on the relative volumes of various wastewaters generated in coal, oil, gas and nuclear steam electric stations, estimates for generic 1 000-MW fossil-fuelled and nuclear-powered stations are presented in Table 3.1.

Potential environmental concerns due to wastewaters discharged from steam electric stations are associated with the pathways and effects of contaminants and toxics on the ecosystem. The discharges may have immediate and/or long term detrimental effects on water, sediment and biota in the receiving water body or on groundwater quality. Water quality changes in pH (acidic and alkaline), dissolved oxygen, suspended solids and dissolved solids may adversely affect development of fish and other aquatic species. Toxic contaminants may accumulate in aquatic sediments in the vicinity of wastewater outfalls. Bioaccumulation of substances may occur through the food chain from prey to predator. For example contaminants could be absorbed by algae and sediment dwelling invertebrates, consumed by fish and biomagnified above the concentrations in the water. These fish could in turn be ingested by people.

Contaminants in wastewaters discharged to receiving waters or to groundwater, could adversely affect drinking water for people, livestock and wildlife. Water re-used for purposes such as irrigation, other industrial processes, recreation, etc., could also be adversely affected by steam electric station wastewater discharges.

The behaviour and importance of contaminants discharged from steam electric stations will depend, to an extent, on the receiving aquatic environment. However, measures can be taken nation-wide that will reduce or eliminate the discharge of these contaminants, and that will preserve environmental quality. These measures are presented in Section 4.2 and summarized in Section 5.

3.4 Monitoring

3.4.1 Description. Many process parameters are continuously or periodically monitored in steam electric stations. These parameters include for example, steam temperatures and pressures, and water pH, dissolved oxygen and conductivity. The reasons for environmental monitoring include:

TABLE 3.1 ESTIMATED ANNUAL WASTEWATER VOLUMES FOR 1 000 MW STEAM ELECTRIC STATIONS

Wastewater Volumes	Station Type
Very High Volumes (<300 000 000 m^3/annum)	
Auxiliary cooling water	Nuclear
High Volumes (<60 000 000 m^3/annum)	
Auxiliary cooling water	Fossil
Auxiliary cooling water	Nuclear-non reactor services
Evaporative recirculating cooling blowdown	Fossil and Nuclear
Once-through ash lagoon water discharge	Coal
Recirculating ash system blowdown	Coal
Seepage from ash lagoons	Coal
Intermediate Volumes (<800 000 m^3/annum)	
Water treatment plant wastes	Fossil and Nuclear
Boiler/Steam generator blowdown	Fossil and Nuclear
Air preheater washwaters	Coal, Oil
Sanitary wastewaters	Fossil and Nuclear
Oil tank farm runoff	Oil
Roof and yard drains	Fossil and Nuclear
Dry ash disposal site runoff and seepage	Coal
Flue gas desulphurization waste disposal site runoff and seepage	Coal, Oil
Low Volume (<100 000 m^3/annum)	
Boiler water-side cleaning wastes	Fossil
Steam generator cleaning wastes	Nuclear
Boiler fireside cleaning wastes	Fossil
Coal pile runoff and seepage	Coal
Switchyard runoff and seepage	Fossil and Nuclear
Flue gas desulphurization process wastewaters	Coal, Oil
Laboratory drains	Fossil and Nuclear
Combined in plant wastewaters - non radioactive	Fossil and Nuclear
Combined in plant wastewaters - radioactive	Nuclear

i) verification of predicted or no environmental impacts;
ii) provision of information to identify appropriate remedial actions;
iii) compliance with regulatory requirements.

Parameters of environmental interest include:

i) cooling water flow, temperatures and qualities;
ii) cooling water biological characteristics;
iii) discharged wastewater flows, contaminant concentrations and total contaminant discharges;
iv) in plant water flows and qualities;
v) groundwater qualities and regimes, for pre-operational and post-operational conditions;
vi) receiving surface water temperatures and flow regimes, sediment and biological characteristics, for pre-operational and post-operational conditions.

Monitoring design provisions are presented in Section 4.3 and summarized in Section 5.

4 RECOMMENDED DESIGNS AND PRACTICES

The environmental protection strategies adopted in the Design Phase Code for Type 1 and Type 2 waters are different. For Type 1 water, the approach is to minimize the entrapment of aquatic species, to minimize the physical, thermal and chemical damage to organisms that are entrained in cooling water, and to minimize the detrimental effects of heated discharges. For Type 2 water, the approach is to minimize the water volume and amount of contaminants at source, to contain wastewaters in a controlled manner, and to treat wastewaters if appropriate. These environmental protection opportunities are described in the following sections.

4.1 Once-Through Cooling Water (Type 1 water)

Detrimental effects of once-through cooling (Section 3.2) can be minimized by a number of practices implemented during the design phase of a steam electric generation project. Some related considerations can be accommodated in the site selection and operational phases of the project. In the formulation of Design Phase Code recommendations for once-through cooling, numerical guidelines which may be applied to different waters are provided, where practical. While some particular technologies and practices are identified, the development and demonstration of more environmentally appropriate designs is not precluded.

Most of the entrainment, entrapment and impingement concerns associated with once-through cooling systems can be virtually eliminated by adopting evaporative recirculating cooling systems (towers or ponds). These systems use less than 5% of the water volume withdrawal of an equivalent once-through system. Although "closed cycle" cooling is demonstrated technology, it imposes some penalties in terms of cost and operational difficulties and has associated potential environmental concerns. These concerns include relatively large volumes of chemical discharges (Type 2 water), fogging, droplet drift, icing, increased land use and the more nebulous consideration of aesthetics. In many instances where water is relatively abundant, a once-through cooling system with environmentally appropriate design features may not impose sufficient threat to the aquatic environment to warrant the implementation of the more stringent closed-cycle cooling option.

Recommendations for Type 1 water systems (Series 100 Recommendations) and a summary of associated rationales and design opportunities are presented in the following sections. **Three main approaches were adopted in the formulation of the recommendations.** These are:

i) minimization of numbers of organisms entrapped and entrained (R101 to R109);

ii) minimization of damage to organisms entrapped and entrained (R110 to R112);

iii) minimization of detrimental effects from discharges (R113 to R116).

While some particular technologies and practices are identified in the recommendations, the development of equally or more effective alternative designs is not precluded.

4.1.1 Recommendations, Rationales, and Design Opportunities.

4.1.1.1 Total cooling water withdrawal.

RECOMMENDATION R101. Unless it is demonstrated that larger withdrawals are no more detrimental environmentally, the volume of cooling water withdrawal should be such that:

i) in all water body types, the total annual withdrawal (all sources) from the 50 km (or shorter) reach of nearshore waters on which a station is centred does not exceed 10 percent of the normal standing volume of that reach during the period May 1 to August 31;

ii) in lakes and reservoirs the total annual water withdrawal (all sources) does not exceed 5 percent of the total volume of the water body;

iii) in rivers, the total rate (all sources) of water withdrawal at any time from the 50 km reach of river upstream from the generating station does not exceed 10 percent of the flow at that time in that reach of the river.

Rationale. Withdrawal from the most biologically active zone is limited (the littoral or nearshore zone). Consequently, the number of fish at different life stages susceptible to entrapment, impingement and entrainment is substantially reduced. For rivers, a major portion of the river flow is prevented from passage through the cooling system and, consequently, resident or migrating species are protected. Also a major portion of the river cross-section is protected from excessive temperature changes that could otherwise alter fish habitat and migration (see R114).

Design Opportunities

i) A smaller plant with lower once-through flow requirements and a shoreline intake can be selected.

ii) An alternative plant site can be selected.

iii) A recirculating cooling system can be selected (e.g., evaporative cooling towers or cooling ponds).

iv) Demonstration can be provided to the responsible environmental agencies that a larger withdrawal is not more detrimental.

v) An environmentally designed submerged cooling water intake, located well beyond the nearshore zone would not be subject to R101 i) where the nearshore zone is defined by the 10-m depth contour or double the Secchi disc measurement, whichever is the greatest. However, withdrawal from the littoral zone should be estimated by hydraulic modelling and shown to be small relative to the offshore zone withdrawal (see also R105 and R107).

4.1.1.2 Auxiliary cooling water withdrawal.

RECOMMENDATION R102. Auxiliary cooling water systems at steam electric generating stations should:

i) be designed to minimize water intake to the degree practicable;

ii) be designed to accommodate maximum practicable reuse of discharge water for other plant processes.

Rationale. Auxiliary cooling systems almost certainly ensure the mortality of the aquatic organisms entrained. If auxiliary cooling water flows are high, they may be a primary source of ichthyoplankton losses. Any opportunity to minimize auxiliary cooling water (R102 i) and process water intake (R102 ii), is encouraged.

Design Opportunities

i) For freshwater supplies, the auxiliary cooling water discharge can be used for raw water treatment plant supply and/or for other services where heated water is desirable or acceptable.

ii) An evaporative recirculating cooling system (e.g., cooling tower or ponds) could be designed to reduce auxiliary cooling water requirements, if this is warranted, on a site-specific basis.

iii) Opportunities to reduce water use are also discussed with recommendations R204, R205 and R206.

4.1.1.3 Cooling water pumping systems.

RECOMMENDATION R103. Flexibility of, and control over, the cooling water flow rate through each condenser by appropriate selection of the number and size of cooling water pumps and the provision of throttling capability should be considered.

Rationale. The capability is provided to minimize cooling water volumes during periods of high concentrations of larvae and other life stages of fish. Some flexibility in condenser and heat exchanger cooling water requirements and temperature differentials exist.

Design Opportunities

i) A larger number of smaller capacity pumps can be provided (e.g., four instead of two pumps per generating unit).
ii) Valves with throttling capability can be provided in the pump discharges or condenser discharges.

These flow control provisions will also reduce the pumping power required to produce the rated power plant generation when the intake temperatures are lower than design values.

4.1.1.4 Plant outages.

RECOMMENDATION R104. Planned outages of power plant units should be scheduled, whenever practicable, to coincide with the period of highest concern with ichthyoplankton (fish eggs and larvae) entrainment.

Rationale. The avoidance of entrainment during short periods of high ichthyoplankton concentrations can substantially reduce total annual losses due to entrainment. Also the influence of thermal plumes during periods of high fish densities in the receiving waters will be minimized. Electric power utilities have some flexibility in planning outages for individual steam electric generating units, particularly in spring and summer when total system load requirements are less than in winter.

Design Opportunities

i) The seasonal changes in source water biota should be established (see R113).
ii) The total system load generation could be planned so that the stations with the most impact on entrained organisms are scheduled for outages during critical periods.

Location of the intake well beyond the littoral zone will reduce probability of ichthyoplankton entrainment (see R105).

4.1.1.5 Intake location relative to shore.

RECOMMENDATION R105. Intakes should be located offshore beyond the littoral zone unless it is demonstrated that locating the intake within the littoral zone is biologically more acceptable.

Rationale. The water withdrawal from the most biologically active zone (i.e., the littoral or near shore zone) is limited. Offshore intakes also eliminate shoreline intrusions or extrusions that cause larval concentrations buildup and physical interference with fish movement (see R108).

Design Opportunities

i) The intake should be located offshore beyond the nearshore zone.

ii) An excavated channel to locate the intake beyond the 10 metre depth is not recommended as the excavation will encourage the presence of fish. Also, the intake should be sufficiently offshore to be above the natural bottom of the waterbody (R107).

iii) Demonstration can be provided to the responsible environmental agencies that a shoreline intake is not more detrimental.

The provision of an appropriately sited and designed offshore intake will greatly reduce the entrapment and entrainment concerns associated with once-through cooling systems (see also R109).

4.1.1.6 Intake location relative to outfall.

RECOMMENDATION R106. Unless it is demonstrated that an alternative arrangement is no more detrimental environmentally, the location of a cooling water intake relative to the outfall should be such that:

i) the intake is upstream or upcurrent and at a sufficient distance from the outfall, and/or in an adequate depth of water to avoid or minimize uncontrolled recirculation of heated effluent in the receiving water body from the outfall to the intake;

ii) if a long water passage on land is required to separate the intake from the outfall, the longer arm of the cooling water passage should be on the intake side and the shorter arm on the outfall side.

Rationale. Uncontrolled recirculation of heated water from the outfall to the intake increases the susceptibility of fish to entrapment, impingement and entrainment because of their attraction to heated discharge water. The relatively short outfall passage reduces the time of exposure of entrained fish to high temperatures downstream of the condenser.

Design Opportunities

i) Water currents should be considered in the location of intake and outfall.

ii) If alternative intake/outfall configurations are possible, the shortest outfall conduit can be chosen (within the conditions of R115).

Uncontrolled recirculation will also reduce the thermal efficiency of the steam cycle.

4.1.1.7 Intake type design.

RECOMMENDATION R107. Cooling water intakes should be designed to prevent or discourage fish from being entrapped in the flow stream. The design selected for offshore submerged intakes should be demonstrated to be at least as effective in minimizing entrapment of fish as the velocity cap design, for which operating experience is available.

Rationale. Certain features of an intake design will reduce the probability of entrapping fish. For example fish can more readily sense and avoid horizontal currents than vertical currents. Certain species may avoid certain depths of water and heights above the bottom.

Design Opportunities

i) An offshore submerged intake can be provided with a "velocity cap" that induces horizontal flow into the intake. The vertical elevation of the intake can be selected so that the invert elevation is above the lake, river or ocean bed to prevent entrapment of bottom dwelling organisms. (An excavated depression for the intake would tend to attract and trap fish and would induce vertical currents into the intake.)

ii) Alternative intake designs can be proposed that are likely to be as effective as the velocity cap design. For example, porous veneer intakes show some promise. Research and development is continuing on various fish behavioural devices. These include nets, strobe lights, pneumatic noise makers ("poppers"), bubble barriers, etc. However, tests to date have not shown these devices to be consistently effective in preventing fish entrapment.

Since forced outages of power plants have occurred due to impinged fish plugging intake screens, intake designs that minimize entrapment of fish have operational as well as environmental advantages.

4.1.1.8 Shoreline intake location.

RECOMMENDATION R108. When shoreline intakes are used, breaks in the shoreline due to structural protrusions or intrusions should be minimized, and the intake screen settings should be as flush as possible with the shoreline.

Rationale. Fish tend to congregate in areas near protrusions and in intrusions of the shoreline. This shoreline configuration in combination with intake currents may be such that fish cannot escape by their own swimming ability.

Design Opportunities. This recommendation applies to cases where offshore intakes are demonstrated not to be required (see R101 and R105).

i) The intake should be located in an even shoreline area where fish are unlikely to congregate.
ii) Intake canals should not be constructed by building parallel groins offshore.
iii) If inshore excavated canals are required, the entrance at the shoreline should be screened and should not be designed with projecting piers or dikes.

4.1.1.9 Fish by-pass and intake velocity and direction.

RECOMMENDATION R109. Intakes for once-through cooling systems should be designed with the following features.

i) All intakes should be equipped with an effective fish by-pass and return system unless it is demonstrated that there is a low probability of significant numbers of fish being entrained in the intake flow stream.
ii) All intakes where a fish by-pass system is not installed during initial construction due to a demonstrated low probability of significant fish impingement should have:
   a) a uniform flow velocity not greater than 15 cm/s approaching the screens,
   b) no areas of vertical flow in the forebay or screen-wells,
   c) provision for retrofitting a diversion and by-pass system at a later date.

Rationale. Fish entrapped in the intake and in the forebay can usually swim against a 15 cm/s flow velocity and return to the source water body without damage. Also, fish tend to sense a horizontal flow more readily than a vertical flow and would tend to avoid impingement on screens under horizontal, low velocity flow conditions.

Design Opportunities. Numerous designs are available for fish avoidance, by-pass, collection and return.

i) Vertical louvres, conventional vertical travelling screens (or horizontal travelling screens), when set at an angle to the flow approaching the screen well, will encourage fish to be swept past the louvres and screens and to be returned to the source water body.
ii) Flow to intake screens should be horizontal (not vertical) and no greater than 15 cm/s since fish can swim against these currents. The forebay cross-sectional area and configuration should be designed accordingly.
iii) Travelling intake screens with low pressure jets and trays for fish removal are available.
iv) Using smaller mesh sizes on intake screens will avoid entrainment of smaller organisms.
v) Fish return systems include fish pumps, elevators, lift nets, troughs and sluices, which return fish to the source water body.
vi) If the need for a fish by-pass is doubtful, at least provisions should be made in the original forebay design to retrofit a fish by-pass system at a later date, if required.

4.1.1.10 Cooling water pump selection.

RECOMMENDATION R110. Opportunities to minimize physical stresses to entrained aquatic organisms should be considered in selecting cooling water pumps.

Rationale. Significant physical damage may occur to entrained organisms as they pass through the cooling water pumps. Factors that contribute to the damage include sudden vacuum followed by pressure, acceleration forces, turbulence, and shear actions of pump impellers.

Design Opportunities. While relatively benign pumps may not have been demonstrated in steam electric cooling water applications, research, development and demonstration is encouraged. In addition to pump hydraulic efficiencies and characteristics, etc., the designer is encouraged

i) to examine alternate pump types for the flow and head conditions,
ii) to consider alternative pump sizes, speeds and numbers.

4.1.1.11 Biofouling control.

RECOMMENDATION R111. For the purpose of controlling biofouling in once-through condenser cooling systems:

i) chemicals should be used only when demonstrated to be necessary;

ii) when chlorine use has been demonstrated to be necessary,

a) only the minimum amount of chlorine demonstrated to be necessary should be used,

b) the maximum concentration of total residual chlorine (TRC) at the outlet of the condenser undergoing chlorination should not exceed 0.5 mg/L,

c) chlorine should be applied intermittently and the injection point should be immediately upstream of the condensers and sets of auxiliary coolers, unless continuous chlorination or a different injection point has been demonstrated to be necessary to control biofouling. At no time, however, should chlorine be introduced upstream of the travelling screens, and

d) chlorine application should be limited to no more than one condenser and set of auxiliary coolers at a time, and should occur during daylight hours.

Rationale. Chlorine is almost certain to cause mortality or sublethal effects to entrained organisms and has the potential for producing carcinogenic compounds in receiving waters. The recommendation either eliminates or reduces the amount, the concentration, and the frequency of chlorine use. Injection in the most sensitive area is prohibited (i.e., the forebay). Because injection close to the condenser or heat exchangers will minimize the residual chlorine loss prior to contact with the most important biofouling organisms, less chlorine will be required.

Design Opportunities. Biofouling control may not be required, but if it is,

i) mechanical cleaning devices (brushes or balls) can be used during operation or during shutdown to clean condenser tubes, eliminating the necessity to use biocides;

ii) condensers and heat exchangers may be chemically or mechanically cleaned during shutdown (with chemical cleaning wastes collected and treated prior to discharge).

If the most common biocide, chlorine, is used,

i) its use can be minimized by an injection and control system designed so that injection is immediately upstream of the condenser and TRC is measured at each condenser outlet to control the chlorine feed rate, and by providing test coupons for monitoring the effectiveness of chemicals;

ii) a dechlorination system could be provided (e.g., sulphur dioxide or sodium sulphite injection) if, for process reasons, the individual condenser discharges had to exceed 0.5 mg/L TRC;

iii) residual chlorine will be more readily chemically reduced in the receiving environment in the presence of ultra violet light during the day.

While chlorine is the most common biofouling control chemical, other biocides may be used. Also, while intermittent chlorination is generally adequate for freshwater biofouling control, continuous chlorination may be required for control of mussels and barnacles in warmer seawater. Recommendations pertaining to biocides other than chlorine, and to continuous chlorine/biocide application, are deferred.

4.1.1.12 Corrosion, scaling and/or silting control.

RECOMMENDATION R112. For the purpose of controlling corrosion, scaling or silting in once-through or partially open cooling systems:

i) on-line application of chemicals should not be used unless such chemicals are

a) demonstrated to be necessary, or

b) demonstrated not to cause environmental damage;

ii) if on-line application of chemicals is demonstrated to be necessary but it cannot be demonstrated that such chemicals will not cause environmental damage, the dose rates and method of application should be such that only the minimum amount of chemical necessary is used;

iii) spent cleaning solutions generated from the off-line chemical cleaning of condensers should be contained and treated before discharge.

Rationale. The recommendation eliminates, or at least reduces, the release of deleterious substances to the cooling water and the receiving water body.

Design Opportunities. Corrosion, scaling and silting control may not be required, but if it is,

i) electrical cathodic protection may be used for corrosion control for condenser water boxes and tube sheets, and at other galvanically dissimiliar interfaces subject to corrosion;

ii) mechanical cleaning devices for condensers may be used on-line or off-line for scaling and silting control;

iii) condensers and heat exchangers may be chemically cleaned during shutdown (with wastes collected and treated);

iv) it can be demonstrated that chemicals proposed for on-line use do not cause environmental damage;

v) chemical injection and control, and metal monitoring systems can be provided to minimize chemical use.

Many chemicals are used for corrosion, scaling and silting control and recommendations concerning specific chemicals may be warranted in the future.

4.1.1.13 Condenser discharge temperatures.

RECOMMENDATION R113.

i) The temperature at the downstream end of each condenser should be maintained as high as possible without causing temperature-induced mortality of the representative important fish species entrained. Temperature is assumed to be non-lethal 2°C below the 50 percent mortality temperature.

ii) Where it is demonstrated that most or all of the entrained ichthyoplankton (fish eggs and larvae) of representative important species are killed by physical stress or chemical exposure, the temperature limits defined in part (i) should be removed and the system operated such that the temperature at the discharge end of each condenser is maintained as high as technically feasible.

iii) An annual temperature rule curve consistent with parts i) and/or ii) should be established for each station taking into account seasonal variations in susceptible fish species.

Rationale. The operation of each condenser at 2°C below the lethal temperatures of important species minimizes intake volumes while ensuring that entrained species are not killed because of high temperatures. However, if these species are killed by physical or chemical stresses (despite the implementation of relevant recommendations) then the number of entrained species (and resulting mortality) is minimized by reducing intake volumes (and elevating temperatures). The establishment of an annual rule curve for maximum permissible discharge temperatures accounts for short-term as well as seasonal trends in fish species susceptibility and sensitivity. This rule curve would require agreement between the proponent and the regulatory agency, and the establishment of an appropriate operating procedure, putting some of the onus on the regulatory agency.

Design Opportunities

i) Establish seasonal aquatic biota characteristics at the proposed intake location or at a similar site (see R307).

ii) Determine the lethal temperatures for the different species.

iii) Determine and obtain concurrence with the regulatory agency on maximum allowable condenser discharge temperatures during a successive 12-month period, for the protection of the "representative important fish species".

iv) As a first approximation only, in the absence of definitive data for species at a given site or agreement on which species are "representative" and "important", an annual temperature rule that might protect the most commonly occurring freshwater species has the following upper temperature limits:

30°C in summer (where average intake water temperature is greater than 10°C),
22°C in winter (where average intake water temperature is less than 5°C).

Recommendation R113 ii) assumes that for discharge temperatures to be maintained "as high as technically feasible", that appropriate design provisions have been made to minimize detrimental effects of thermal discharges in the receiving water body (e.g., offshore discharge (R115), thermal plume (R114)).

4.1.1.14 Thermal plume zones.

RECOMMENDATION R114. Unless it is demonstrated that a greater area of influence is no more detrimental environmentally, the thermal plume (as defined by the 1°C isotherm) from a generating station should not, when combined with thermal plumes from other sources, cause the combined area occupied:

i) within the 50 km segment of nearshore zone on which the station is centred, to be greater than 10 percent of the total nearshore zone surface area for that segment in all water body types except rivers;

ii) within the 50 km segment of nearshore zone downstream from the generating station on a river, to be greater than 10 percent of the total nearshore zone surface area for that segment;

iii) to be greater than 10 percent of the total surface area of a small lake or reservoir;

iv) to be such that more than 50 percent of the distance across the surface at any location on a river, lake or reservoir, is occupied.

Rationale. This recommendation protects the majority of the nearshore zones in large and small fresh water bodies, in saltwater bodies and in rivers. It ensures that the nearshore zones remain available for normal biological productivity, unaffected by heated discharges, and that the free movement of fish is not seriously inhibited.

Design Opportunities

i) The outfall can be located offshore beyond the littoral zone and hydraulic modelling done to show thermal plume dispersion.

ii) Diffusers or other outfall designs may be used to ensure rapid temperature reduction near the outfall.

iii) A smaller plant may be selected with once-through cooling.

iv) An evaporative recirculating cooling system may be selected.

4.1.1.15 Outfall location and type.

RECOMMENDATION R115. Unless it is demonstrated that an alternative outfall location and/or design is no more detrimental environmentally:

i) once-through cooling water should be discharged beyond and directed away from the nearshore zone;

ii) the method of cooling water conveyance from the generating station to the release point in the receiving water body should be a tunnel or a buried pipe.

Rationale. The offshore location and offshore direction of heated discharges minimizes alteration to, and maintains normal biological use of, the nearshore zone. It reduces the possibility of thermal plume impingement and travel along the shoreline and littoral zone bottom. Tunnels for conveying heated water offshore will cause no disruption to aquatic communities during construction and operation. They will not create obstructions to fish travel resulting in fish congregation after construction. Consequently a tunnel is preferred to a pipe laid on the bottom, trenching a pipe, or constructing parallel groins.

Design Opportunities. A number of considerations apply to outfall design.

i) Low velocity discharges will allow heated water to rise to the surface, creating a thin surface plume. Higher velocity discharges will entrain more local water, resulting in a more rapid temperature reduction but increasing the zone of influence.

ii) Discharges directed away from the shoreline will reduce the tendency of the plume to bend shoreward with winds and currents, to the littoral zone.

iii) Multiport diffusers increase the rate of dispersion of heat but cause a greater horizontal spreading of the plume and increase the probability of the plume bending shoreward.

iv) Laying or trenching a pipe, or constructing parallel groins to convey heated discharges to the offshore outfall will disturb benthic communities and will disperse and deposit silt during construction. A laid pipe and groins will also permanently affect fish movement and distribution, current patterns and sediment deposition. Construction of a tunnel will have none of these detrimental effects.

4.1.1.16 Supplementary cooling systems.

RECOMMENDATION R116. Helper or supplementary cooling systems should not be used on outfalls of once-through cooling systems unless it can be clearly demonstrated that their use will result in decreased total mortality to aquatic organisms entrained in the cooling water and thermal plume.

Rationale. Helper or supplementary cooling systems (towers/ponds or tempering pumps), used to cool the condenser and auxiliary cooling discharges, will lower the final outfall temperature. However, if organisms entrained in the cooling water have already been killed due to elevated temperature, the use of tempering pumps will only increase the entrainment and physical damage of aquatic species. The use of cooling towers or ponds for some or all of the once-through cooling water will only increase damage to entrained organisms, if any are still living. A condenser discharge temperature that protects entrained organisms (R113 i) and iii)) and appropriate outfall location and design (R114, R115) will eliminate the need for a helper system to protect receiving waters.

Design Opportunities

i) Do not use tempering pumps; design the cooling system for appropriate temperatures.

ii) Demonstration can be provided to the responsible environmental agencies that their use is less detrimental than other techniques to minimize damage to aquatic species.

4.1.2 General Implications of Recommendations. The 16 recommendations for the design of once-through cooling systems should not be taken in isolation, as many are interactive. Overall they are intended to minimize entrapment and entrainment, damage to entrained organisms, and detrimental thermal effects. The major possible design features are:

i) offshore velocity cap intake (R105, R107),

ii) offshore diffuser outfall (R115),

iii) fish by-pass and return (R109),

iv) mechanical cleaning of condensers and heat exchangers (R111, R112).

Most of the other recommendations can be achieved with little design, operational or cost impacts.

After the appropriate design provisions of the Series 100 recommendations are made, the operational implications are expected to be minimal. Little, if any, additional operation and maintenance attention will be required, except for some fish by-pass systems. In fact, environmentally appropriate designs will reduce the probability of forced outages, reduce thermal efficiency losses by minimizing recirculation of heated discharges, and reduce pumping costs in winter.

The incremental energy implications of the Series 100 recommendations are expected to be minimal in comparison to the energy requirements of the total station.

Recommendations that apply to the monitoring of once-through cooling systems are presented in Section 4.3. Economic implications are summarized in Section 6.

4.2 **Wastewaters** (Type 2 waters)

While the recommendations are intended to provide certain levels of environmental protection, they are not intended to preclude the development and implementation of equally or more effective environmental protection technologies and practices.

4.2.1 Recommendations, Rationale and Design Opportunities. Most, if not all, of the water-related environmental concerns associated with power plant wastewaters described in Section 3.3 could be eliminated by adopting a "zero discharge" wastewater system. This entails not discharging any wastewaters to receiving water bodies by "closing" the process water system completely, and virtually eliminating any seepage from solid waste disposal sites by providing containments of high integrity. Although "zero discharge" is demonstrated technology, it imposes some penalties in terms of cost and operational difficulties. Since closing up the water systems will cause dissolved and suspended solids to accumulate in process waters, relatively expensive and complex water treatment technologies will be required for contaminant removal and water reuse. Where water is relatively abundant, water/wastewater management systems with environmentally appropriate design features may not impose a sufficient threat to the aquatic environment and to human health to warrant the implementation of the more stringent zero discharge option.

Recommendations for Type 2 water systems (Series 200 recommendations) and a summary of associated rationales and design opportunities, are presented in the following sections. **Three main approaches have been adopted in the formulation of the recommendations.** These are:

i) **minimization of types and amounts of contaminants, and of wastewater volumes (R201 to R207);**

ii) **containment of wastewaters and waste residues (R208 to R210);**

iii) **treatment of wastewaters prior to discharge (R211 to R213).**

4.2.1.1 Evaporative recirculating cooling systems - contaminants.

RECOMMENDATION R201. For the purposes of controlling biofouling, corrosion and/or scaling in evaporative recirculating cooling systems:

i) chemicals should not be used unless demonstrated to be necessary or to be environmentally innocuous;

ii) asbestos-based materials should not be used for cooling tower components;

iii) chromium chemical additives should not be used for cooling pond recirculating systems;

iv) chemical additive systems (if required) should be designed to minimize the use of chemicals while providing adequate biofouling, silting, corrosion and/or scaling control.

Rationale. This recommendation eliminates, or at least discourages, the contamination of receiving waters with deleterious substances in blowdown from evaporative cooling systems, which is the largest wastewater volume in stations that use such systems. Asbestos-based materials used in cooling towers may become airborne (by drift) and may be carcinogenic if inhaled (mesothelioma). Hexavalent chromium is highly toxic and may form a difficult-to-manage waste precipitate (sludge) in cooling ponds. Chlorine may form toxic and carcinogenic compounds, and other biofouling, silting, scaling and corrosion chemicals may be detrimental. Their use is discouraged but, if necessary for process reasons, their minimum usage is encouraged to minimize discharges.

Design Opportunities. Recommendation R201 is similar to Recommendations R111 and R112 for once-through cooling systems. Biofouling, silting, scaling and/or corrosion control provisions may not be required in many instances due to suitable water quality in the recirculating system. However, if controls are required:

i) mechanical cleaning devices for condenser tubes may be used on-line or off-line for biofouling, silting and scaling control;

ii) condensers and heat exchangers may be chemically or mechanically cleaned during shut down (with wastes collected and treated);

iii) selection of appropriate materials of construction will eliminate corrosion;

iv) electrical cathodic protection may be used for corrosion control in condenser and heat exchanger water boxes and tube sheets, and at other galvanically dissimilar interfaces subject to corrosion;

v) in many instances scaling control (required due to the increase of certain dissolved solids and their precipitation on heat exchanger tubes) may be possible by simply depressing the pH of the recirculating water;

vi) automatic chemical injection and control systems, and metal monitoring systems (e.g., coupons) can be provided to minimize chemical use;

vii) alternatives to asbestos-based components are readily available for cooling towers (asbestos-based components also have limited freeze-thaw and pH resistant properties);

viii) non-chromium based corrosion/scaling control chemicals are readily available.

While recommendation R201 applies to evaporative recirculating cooling systems, some of the considerations may be applied to non-evaporative recirculating cooling systems (closed intermediate water loop exchanging with once-through cooling water), to recirculating ash transport systems, and to water treatment plants. The general intent is to eliminate the unnecessary use of chemicals that would result in their discharge to the environment.

4.2.1.2 Evaporative recirculating cooling systems - water use.

RECOMMENDATION R202. Evaporative recirculating cooling systems should be designed:

i) to operate at a minimum of two cycles of concentration (i.e., the ratio of dissolved solids in the recirculating water to the dissolved solids in the make-up water is greater than two);

ii) so that make-up water is introduced to the system through the auxiliary coolers, if practicable.

Rationale. Because evaporative recirculating cooling systems use substantially less water than once-through cooling systems, less aquatic damage due to entrapment and entrainment occurs. Above two cycles of concentration, a recirculating water system will use less than approximately 5% of the water of a once-through system. For lesser cycles of concentration, the water use and wastewater blowdown volumes increase substantially. Since recirculating cooling system blowdown is a Type 2 wastewater and entrained aquatic species will probably be killed, this recommendation limits its discharge and intake volumes. The introduction of fresh make-up water through the auxiliary coolers (R202 ii) reduces the possibility of scaling in these heat exchangers and the resulting use of scaling control chemicals.

Design Opportunities

i) Cooling ponds are generally operated at lower cycles of concentration than cooling tower systems. Cooling ponds often have natural make-up from a stream which varies seasonally. If cooling ponds are operated as evaporative recirculating cooling systems, the once-through cooling recommendations (Series 100) do not necessarily apply, although many of them could be adopted (e.g., intake and discharge designs, etc.). (With the highly seasonal flow in reservoirs used as cooling ponds, the system is regarded as "recirculating" when an average annual discharge is less than 3 m^3/s per 1000 MW of installed generating capacity, and when the aquatic life was of minor significance prior to impoundment, as discussed in Section 3.2.2). In many instances, depending on make-up water quality, at two cycles of concentrations no special provisions for scaling control will be required.

ii) Cooling tower cooling systems are usually operated at more than two cycles of concentration (e.g., 15 cycles of concentration). In addition to biofouling in condenser and heat exchanger tubes, biofouling may occur in the aerobic conditions of the cooling towers. The larger the cycles of concentration, the lower the make-up and blowdown water volumes. The high concentrations of dissolved and suspended solids in the blowdown make this wastewater more amenable to treatment prior to discharge (see R211).

iii) An operational problem with some recirculating cooling systems is scaling in the high temperature condenser and heat exchanger tubes. Since the water requirements for the auxiliary coolers are much less than for the condensers, the introduction of relatively low dissolved solids make-up water to these heat exchangers reduces the probability of scaling. Furthermore, while on-line mechanical cleaning devices are available for condensers, they are not widely used for the smaller auxiliary coolers, so that chemical cleaning may have to be used if scaling occurs.

4.2.1.3 Auxiliary cooling systems.

RECOMMENDATION R203. All auxiliary cooling systems in which the auxiliary cooling water could become contaminated should be intermediate recirculating loop systems (i.e., a closed loop between the once-through cooling water and the auxiliary equipment coolers), or should incorporate another effective method of preventing inadvertent contamination of once-through cooling water.

Rationale. Auxiliary cooling water can be contaminated (e.g., by oil, tritiated heavy water, etc.) if the pressure of the once-through cooling water is lower than the auxiliary equipment cooling fluid. If a heat exchanger leak occurs it is difficult to immediately prevent contamination of this relatively large water stream with the station in operation, and the leak may not be identified for some time. The design provision of an intermediate closed loop will provide protection from inadvertent contamination of once-through auxiliary cooling water. Other leak prevention methods might also be effective.

Design Opportunities.

i) If a once-through auxiliary cooling water stream can become contaminated it should be protected by an intermediate water loop barrier. If this closed loop becomes contaminated, it is contained inside the station and can be drained from the loop and treated prior to discharge. For auxiliary cooling equipment that does not contain contaminants of concern (e.g., clean water only) and/or is at a lower pressure than the once-through cooling water, the requirement for an intermediate closed loop does not apply.

ii) In practice, an intermediate closed loop is provided in once-through cooling systems that use saltwater, or low quality freshwater, to minimize corrosion or scaling, respectively. The water quality of the intermediate loop can be controlled so that corrosion or scaling does not occur in the relatively high temperature of the auxiliary equipment coolers themselves. Corrosion or scaling can be more readily controlled in the once-through/closed loop heat exchangers, which are relatively fewer in number than auxiliary equipment coolers.

iii) However, other methods of leak prevention may be effective. These include a fast-response leak detection system in conjunction with an alarm and prompt isolation of the defective heat exchanger. The provision of spare heat exchangers would allow the station to operate at full capacity while the defective unit is being repaired.

4.2.1.4 Ash handling systems.

RECOMMENDATION R204. The selection and design of the ash collection transport and disposal system for a coal-fuelled station should be a "dry" fly ash system and a "recirculating" bottom ash system, unless it is demonstrated that the total wastewater volumes and total quantities of contaminants discharged are smaller for other types of ash systems.

Rationale. The minimization of water use in an ash transport system reduces the amounts of contaminants leached from ash and discharged to surface waters and groundwaters. The possibility of suspended ash particles being discharged is also reduced.

Design Opportunities. The recommendation precludes the use of once-through fly ash and/or bottom ash transport systems, in which water is used to transport ash to the disposal site and the transport water is subsequently discharged directly from the disposal site to the receiving environment. A number of alternative designs would minimize wastewater volumes from ash handling systems.

i) A "dry" fly ash system uses air (pressure and vacuum) to transport ash from electrostatic precipitators (or baghouses) to a fly ash silo. The ash is wetted to suppress dust as it is loaded from the silo to trucks, trains, or conveyors and transported "dry" to the ash disposal site.

ii) A recirculating bottom ash system uses water to transport ash from the bottom of the boiler to a bin. The ash is dewatered and transported by truck, train or conveyor belts to the disposal site. Suspended solids are allowed to settle out of the water used for ash transportation and the water is recirculated to the boiler to remove more bottom ash. Make-up water is required to replace water occluded in the disposed ash.

iii) A submerged chain conveyor bottom ash system conveys ash, quenched by water, from the bottom of the boiler. The ash dewaters as it is dragged up an incline, is dropped on to a travelling belt and conveyed to a bin. The ash is then transported by mobile equipment to the disposal site. The used water drained from the bottom ash is cooled, and recirculated to the boiler after suspended solids removal. It is expected that this system will generally use less water for make-up and will produce less wastewater than an equivalent conventional recirculating bottom ash system.

iv) "Wet" recirculating fly ash systems, recirculating bottom ash systems, or recirculating combined fly ash/bottom ash systems, using lagoons rather than bins or silos are also used. The lagoons are used for the ultimate disposal of the ash as well as for solids removal from the recirculated water. Constituents in the fly ash (and to a lesser extent bottom ash) which leach into the water may cause scaling in equipment and piping. High temperature areas, stagnant areas and return lines from the lagoons are most susceptible. This scaling of the totally wet system can be controlled by blowdown, by pH control or by side-stream treatment (i.e., removing scale-forming compounds continuously from some of the recirculating water). If totally wet ash systems are to be used, it must be demonstrated that wastewater volumes and total contaminants discharged in blowdown are less than those discharged from a combination dry fly ash and recirculating bottom ash system. For the demonstration, the calculated allowable discharge from the bottom ash system is that required for scaling control only, i.e., not for inadvertent water imbalances in the system. Another alternative is to design a zero discharge, wet ash system.

4.2.1.5 Flue gas desulphurization systems.

RECOMMENDATION R205. The flue gas desulphurization system for a fossil-fuelled station should be selected or designed for a closed process water loop or equivalent (i.e., no discharge of process wastewaters during normal operation), to the extent practicable.

Rationale. Wastewaters from "wet" flue gas desulphurization systems may be highly alkaline or acidic, and high in dissolved solids which include fluorides, chlorides, sulphates and toxic metals. This recommendation discourages the direct discharge of these contaminants from flue gas desulphurization (FGD) processes.

Design Opportunities. The major water loss in FGD systems is by evaporation in the flue gases which leave the stack. Some water is also lost by occlusion in the solid waste residue which results from the absorption and reaction of sulphur dioxide in a liquid reagent. Because of the water losses, it is easy to achieve zero discharge for most FGD systems without relatively complex water treatment processes within the system. Alternative technologies to minimize wastewater discharges from FGD systems are available.

i) A spray drier FGD system uses water to wet and stabilize a "dry" waste product. The water in the scrubbing reagent is evaporated to produce dry reaction products.

ii) A "wet" limestone, lime or dual alkali FGD system with natural oxidation usually will not produce excessive wastewater. In these systems wet reaction products, which are generally waste residues or sludges, are produced. Due to the relatively poor dewatering properties of most of these residues (predominantly thixotropic sulphite sludges), there generally will not be an overall water imbalance in the system, so that process wastewater discharge will not be required. Of course thixotropic sludges should be stabilized or fixed prior to disposal (see R207).

iii) A "wet" FGD system may be operated with forced oxidation so that the sludge has relatively good dewatering properties (predominantly sulphate or gypsum sludges). This may upset the water balance of the system since less water is effectively blown down as occluded water in the sludge, and a process wastewater may have to be discharged from the system. Furthermore, some FGD system designs may incorporate a prescrubber loop prior to the main scrubbing module. The prescrubber loop will tend to absorb chlorides, fluorides and contaminants that do not require a sulphur removing reagent for absorption and reaction, and will concentrate corrosion-forming constituents in one part of the system. Because the prescrubber loop is relatively highly contaminated, it may not readily be re-used within the FGD system, and may have to be blown down from that system. To comply with recommendation R205, the blowdown may be re-used directly in another system, or treated prior to re-use within the FGD or other station systems. Appropriate demonstrated technology for high dissolved solids reduction include mechanical evaporation (e.g., vapour compression evaporators) possibly preceded by reverse osmosis. Distillates from the evaporators may be condensed and used in the boiler feed water treatment plant as make-up to the demineralizers, if the quality is suitable. This or a similar reuse within the plant would be regarded as an effective closed loop.

Forced oxidation limestone FGD systems produce a by-product high in gypsum ($CaSO_4 \cdot 2H_2O$). This by-product may be mechanically dewatered and trucked or belt conveyed to a disposal site. Another option is to pump the product to the disposal site and to stack the gypsum by allowing it to naturally dewater. This drained water is returned to the FGD process. Since precipitation will add to the water inventory of the system, larger volumes of wastewater will have to be treated. (See R207 for further discussion on FGD by-product disposal and use, and R208 for discussion on containment provisions.)

iv) Recommendation R205 precludes use of once-through non-recirculating FGD systems, which use seawater or other reagents.

v) Practicable measures to close the loop for an FGD system would include:
   (a) selection of pumps with low seal water requirements,
   (b) selection of demisters with low water use requirements,
   (c) surge capacities for upset conditions, equipment drainings and extreme precipitation events,
   (d) selection of materials of construction for high dissolved solids.

4.2.1.6 Water reuse.

RECOMMENDATION R206. Wherever it is practicable to do so, process or service water should be supplied by withdrawal from the condenser or auxiliary cooling water discharge, and/or by the reuse of untreated or treated station wastewater streams.

Rationale. Water reuse will minimize the intake volume and resulting damage to entrained organisms. Assuming that damage has occurred in auxiliary cooling water, for example, the reuse of this water will prevent further damage to additional organisms. Water reuse will also reduce the total wastewater volumes produced, and will facilitate the control and possible treatment of relatively small wastewater volumes of high contaminant concentrations prior to discharge.

Design Opportunities. Numerous opportunities for water reuse are possible.

i) For plants that use fresh water for cooling, water from the once-through auxiliary cooling discharge stream could be used for water treatment plant make-up and virtually all other services. Similarily, condenser cooling discharge streams could be used, although organisms entrained in this stream will generally have been less stressed than those in the auxiliary cooling water.

ii) A "cascade" water management system has many possible applications. Here the wastewater or blowdown from one system is used as the feed or make-up to another system which has lower water quality requirements. For example, in coal-fuelled stations water quality requirements progressively decrease for pump seals, FGD reagent preparation and demisters, floor and equipment washdowns, ash transportation, and ash and coal pile wetting for dust suppression. Blowdown from evaporative recirculating cooling systems provides a relatively large volume of water of consistent quality that may be suitable for many other process uses.

ii) The ultimate application of the recommendation is a zero discharge plant in which no process waters are discharged. This is a demonstrated technology but entails relatively complex water management and treatment systems, and attendant operational difficulties, particularly during the initial operational phases of the station. In areas of water shortage and in sensitive receiving water areas, this design option may be appropriate.

4.2.1.7 Waste disposal areas.

RECOMMENDATION R207. For the disposal of boiler ashes, flue gas desulphurization wastes and station refuse, appropriate design provisions should be made so that:

i) disposal sites are developed in stages during the operating life of the station;

ii) all wastes have physical and chemical stability suitable for land re-use;

iii) all disposal sites are contoured and capped to minimize ingress of precipitation prior to completion;

iv) all disposal sites are reclaimed for beneficial use(s) prior to abandonment.

Rationale. The terrestrial disturbances associated with a disposal site development, and the possible surface water and groundwater impacts, will be minimized by developing the disposal site in stages, rather than in one large area suitable for the projected life of the station. The properties of the wastes should ensure, for example, that the area can bear the load of heavy mechanical equipment, and that physically unstable wastes will not be left in the environment in perpetuity. The ingress of precipitation through the wastes and associated leaching of contaminants to groundwater can be minimized by contouring the surface of the site so that precipitation runs off. The reclamation of disposal sites after use will also minimize the ingress of precipitation and groundwater contamination, and retain viable land uses in perpetuity for the area. The main intent is to minimize the water and land use impacts of waste disposal sites.

Design Opportunities

i) The staged development and contouring of disposal sites can be carried out by earth moving equipment normally required at the site in any case.

ii) Dry fly ash and dewatered bottom ash are expected to have physical properties suitable for the support of heavy equipment (bulldozers, trucks, etc.), without experiencing excessive deformation. Compaction and natural curing of cementatious ashes may occur.

iii) Provisions should be made to effectively drain lagoons by providing underdrainage (e.g., coarse bottom ash) and pump-out facilities, etc..

iv) FGD wastes, from "wet" natural oxidation systems will require dewatering and may require the addition of fly ash ("stabilization") and also lime or chemicals ("fixation").

v) Forced oxidation limestone FGD systems will require dewatering of the wastes. Wet gypsum stacking is technically a disposal option. Waste sludge is pumped without mechanical dewatering to the disposal site. The waste is built up within dykes and is allowed to naturally dewater by gravity, with the decanted water returned to the FGD process. Potential concerns associated with wet gypsum stacking include larger land area requirements, increased leachate production and undemonstrated reclamation.

vi) An option for dry fly ash systems, instead of producing wastes, may be to use the fly ash in various cement and concrete applications. This is demonstrated technology that utilizes the pozzolanic properties of fly ash. Waste stabilization applications may be possible. Magnetic iron concentrate, cenospheres, aluminum and other metals may possibly be recovered from ash.

vii) Another option for forced oxidation limestone FGD systems is to produce gypsum suitable for commercial and residential wall board, or as a retardent in cement. Provisions would have to be made in the FGD system design for commercial gypsum production, which is a demonstrated technology. Spray drier FGD wastes may be used as aggregates or possibly in other construction applications, as alternatives to disposal.

viii) If wastes are produced, preparation for reclamation of disposal sites can be made during the design phase by specifying the stripping and storage of the top soil and its replacement prior to abandonment. The original vegetation will readily grow again on the topsoil.

ix) The long-term use of the disposal site should be considered during the design phase. For example, agricultural, forestry, park, residential or industrial land uses might be planned, and this intended use will influence the site development.

4.2.1.8 Waste liquid segregation and containment.

RECOMMENDATION R208. Wastewater management system designs should include the following features:

i) *containment for contaminated or potentially contaminated liquid releases (e.g., normal system blowdowns, equipment washdowns and leaks, spills and surface runoff from precipitation, etc.);*

ii) *separate collection facilities for similar wastewaters (e.g., oily wastes, radioactive wastewaters, boiler cleaning wastes, etc.);*

iii) *separate containments for particularly hazardous substances (e.g., polychlorinated biphenyls, metal cleaning and decontamination wastes, radioactive wastewaters, etc.);*

iv) *separate containments for bulk chemicals that react violently with each other (e.g., acids and alkalis).*

Rationale. These provisions will minimize the possibility of inadvertent discharges of contaminants to the environment. Also the quality of collected waste streams can be established prior to treatment, discharge or reuse. The segregation of similar wastes will facilitate treatment, if appropriate, thus reducing the total contaminants discharged from the station. The separation of potentially explosive chemicals will minimize accident risk. The main intent of the provisions of recommendation R208 is to avoid direct wastewater discharge, without quality verification or treatment if appropriate, in the cooling water discharge, to municipal sewers or to surface waters.

Design Opportunities. Although the recommendation is fairly explicit, its application will depend on the type of station (coal, oil, gas or nuclear), the process systems selected for the station (e.g., dry or wet fly ash transport, recirculating cooling, etc.), the relative locations of blowdown overflows and drains from these systems (e.g., turbine hall, FGD system) and the precipitation in the area (e.g., coal pile runoff). Judgement must be used in applying the various aspects of this recommendation. Some examples of wastewaters suggested for collection and containment are:

i) water treatment plant wastes (all stations),

ii) turbine hall drains (all stations),

iii) boiler room drains including periodic boiler cleaning and air preheater washes (coal stations),

iv) reactor building and reactor service building drains, and decontamination wastes (nuclear stations),

v) runoff from coal piles (coal stations),

vi) ash system blowdowns and disposal site runoff (coal stations),

vii) FGD system area and equipment drains (fossil stations),

viii) station yard drains (all stations).

The segregation, collection and containment of these wastes of variable flow and chemical characteristics will facilitate quality monitoring and appropriate treatment prior to dilution with other types of wastewaters, thus reducing the total contaminant discharges. Quality monitoring will determine if waste can be discharged directly, or to a treatment system for discharge or reuse (see recommendation R211). An alternative for coal-fuelled stations is to have low, medium and high quality holding ponds, with the low quality pond treated and the other pond waters reused directly. While following the principles of R208, the designer is to select the most appropriate applications for a particular station.

The provision of separate containment for bulk chemicals that react does not apply to laboratory chemicals. Appropriate laboratory housekeeping procedures will minimize the possibility of accidents. Vessel failures in bulk storage areas are less controllable and may have more serious consequences.

4.2.1.9 Waste liquid containment sizing.

RECOMMENDATION R209. Waste liquid collection and containment facilities should be designed to contain the maximum volume of liquid that could be reasonably expected to be in storage prior to any of the following events, and:

i) the maximum wastewater that will be generated in any 24-hour period;

ii) the maximum waste volume that will enter the containment in the event of a leak or spill; or

iii) the accumulated precipitation of a 100-year return period, 24-hour precipitation event for outdoor containments.

Rationale. These sizings of containment facilities are likely to be adequate for most events that might occur during the life of the station. Appropriate actions can be taken by station operating staff in a 24-hour period to ensure that contaminants are not inadvertently discharged from the station. The 100-year precipitation criterion decreases the probability that outdoor containments will be flooded, although flooding may still occur during the operating life of the station.

Design Opportunities. In applying recommendation R209, design judgements are required in a number of instances.

i) Judgement is required in establishing the maximum wastewater volume that will be generated from different sources in a 24-hour period. In some cases, this may be determined by the volume of a periodic wastewater (e.g., boiler cleaning wastes). Historical data for particular wastewaters from similar existing stations would be useful. The "worst case" assumed will depend to an extent on the probable event and nature of the waste (e.g., decontamination wastes will warrant more conservative assumptions than turbine hall drains).

ii) Judgement is required in establishing the maximum probable spill volume. For example, oil tank farms may have a number of tanks within a particular containment. The designer may wish to assume a single or multiple simultaneous tank failure. Also, it would be appropriate to add a free board allowance to the maximum spill volume (e.g., 10% of volume).

iii) For outdoor containment, the difference between a 1 in 10 years precipitation event, and a 1 in 100 years event is generally not very large. Some criteria suggest that a safety factor be applied to a 1 in 25 years event (e.g., 1.5 factor). If a 25-year period or less is used without a safety factor, flooding and possible failure of an impoundment is inevitable during the operating life of the station. Judgement will be required for establishing the runoff coefficient of a particular area (the ratio of runoff to precipitation). General yard areas will be more permeable than areas with seepage control liners (e.g., coal piles) (see R210).

iv) Containment can also provide treatment (see R211). For example, if general yard drains are routed to a storm drain containment, heavy solids will settle and provisions could also be made for retention of possible oil spills (oil booms). Also, oil absorbents may be incorporated under gravel in switch yard containment facilities.

v) Containment facilities can also act as equalization basins for treatment plants, so that variations in treatment plant influent flows and physical/chemical characteristics are reduced (see R211).

vi) Where a containment facility can be demonstrated to provide adequate treatment for the waste liquid volumes indicated in R209, then the provisions of R209 need not be rigorously applied. For example, if an ash disposal site runoff treatment facility will provide effective removal of suspended solids (or other relevant parameters) during a 100-year 24-hour precipitation event, a continuous overflow may be an acceptable alternative to actual containment of the total storm runoff.

vii) Containment facilities may be located around equipment located in the plant or outside the plant (e.g., transformers, chemical storage tanks). The sizing of outside containments should also allow for the controlled discharge of uncontaminated precipitation.

viii) Any containment facility should have provision for controlled emptying and handling of its contents, and for overflow under extreme conditions.

Recommendations for the operation of containment facilities are expected in the Operations Phase Code.

4.2.1.10 Seepage control.

RECOMMENDATION R210. Seepage to groundwater or surface water should be controlled by a naturally occurring and/or constructed barrier which meets the following minimum conditions with respect to material thickness and maximum water permeability, measured over the entire depth from the bottom of the containment area to the aquifer.

i) The equivalent of 1 m of 1 x 10^{-7} cm/s material for:

- *a) the base of high sulphur coal piles (i.e., coal > 1% sulphur (S) content),*
- *b) high sulphur (> 1% S) coal pile runoff containment facilities,*
- *c) chemical waste storage and treatment lagoons (except as noted below),*
- *d) the area surrounding solid radioactive waste storage cells.*

ii) The equivalent of 1 m of 5 x 10^{-7} cm/s material for:

- *a) ash lagoons,*
- *b) flue gas desulphurization waste lagoons.*

iii) The equivalent of 1 m of 1 x 10^{-6} cm/s material for:

- *a) the base of low sulphur (< 1% S) coal piles,*
- *b) low sulphur (< 1% S) coal pile runoff containment facilities,*
- *c) dry or dewatered ash disposal sites*,*
- *d) dry or dewatered flue gas desulphurization waste disposal sites.*

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* Seepage control recommendations for coal mine disposal of ashes are deferred. "Ash" includes combustion wastes from conventional boilers, fluidized bed combustors, and other combustion devices.

iv) *The equivalent of 1 m of 1 x 10^{-5} cm/s material for:*

   a) *oil tank farm containment facilities,*
   b) *transformer and switchgear containment facilities,*
   c) *all other diversion and collection facilities.*

Rationale. The contamination of groundwater aquifers by steam electric fuels, process chemicals, wastewaters and solid wastes is reduced. Seepage control criteria for different types of materials are formulated which depend, in part, on the nature and environmental concern associated with the material.

Design Opportunities

i) A hydrogeological survey of fuel and waste storage and disposal sites will establish the groundwater regime, and geological formations and permeabilities in the area.

ii) The main intent of the recommendation is to minimize contamination of aquifers that migrate away from the sites to receiving waters, to drinking water supplies or to irrigation water supplies. For example if the hydrogeological survey demonstrates conclusively that a seasonal groundwater table moves primarily in the vertical plane, the "barrier thickness" under the area is the depth to the aquifer that moves in the horizontal plane.

iii) Natural geological formations have various permeabilities. Many clays and silts have permeabilities lower than 10^{-7} cm/s, whereas some sands and gravels have permeabilities in excess of 10^{-1} cm/s. If the geological survey shows material thicker than 1 metre with 10^{-7} cm/s or less permeability under the site, no constructed or synthetic liners are required. (However development provisions of R207 apply.)

iv) If a high permeability site is chosen that does not meet the criteria, suitable low permeability material should be imported or suitable synthetic liners (plastics or elastomers) should be installed.

v) Care should be taken during the construction of these areas to assure the integrity of the liners.

vi) An alternative to minimize the thickness of a constructed barrier is to use an underdrainage system to collect wastewater above the ground. This may reduce the overall thickness or increase the maximum permeability of barrier required, but the overall seepage rate must be demonstrated to be equivalent to that which would result from the 1 metre thick criterion in recommendation R210.

vii) In addition to the seepage control provisions, a disposal site should not be located in a flood plain or in an intertidal zone.

viii) Even with the provisions of R210, the amount of contaminant migration may be large, particularly from large ash disposal sites. Also natural attenuation of contaminants in soils is ion-specific and will either allow escape of contaminants or eventually become saturated. This will result in slow long-term migration of contaminants from the site.

4.2.1.11 Wastewater effluent quality.

RECOMMENDATION R211. For all wastewater (Type 2 water) streams from steam electric generating stations, the following effluent quality criteria should be met before release to once-through cooling water, to a municipal sewer or directly to local receiving waters:

Parameters and Elements	*Recommended Effluent Quality*
pH	*6.5 to 9.5*
Iron (total)	$\leq$ *1.0 mg/L*
Chromium (total)	$\leq$ *0.5 mg/L*
Chromium (hexavalent)	$\leq$ *0.05 mg/L*
Copper (total)	$\leq$ *0.5 mg/L*
Nickel (total)	$\leq$ *0.5 mg/L*
Zinc (total)	$\leq$ *0.5 mg/L*
Total Suspended Solids (TSS)	$\leq$ *25.0 mg/L*
Oil and Grease	$\leq$ *15.0 mg/L*
Total Residual Chlorine (TRC)	$\leq$ *0.2 mg/L*

Notes:

1) Metal concentrations are for total dissolved and undissolved solids.
2) Values apply to average weekly composite samples.

Rationale. The discharge of contaminants to receiving waters can be limited by the application of practicable technologies and design practices. The parameters and elements specified are of concern to aquatic and/or human life. Generally, technologies capable of achieving these limits have been demonstrated, or have been judged to be technically feasible. Although limits for all parameters and elements of environmental concern have not been prescribed, it is believed that the application of design practices and technologies to meet the specified effluent quality criteria will also reduce other contaminants of concern. The intent is to minimize the total amount of contaminants discharged to surface waters. However, annual release limitations cannot be specified because all stations do not have standardized water systems. On a site-specific basis, other contaminants of environmental concern may also be specified (e.g., arsenic, boron, selenium, mercury), and a total annual release specified for various contaminants.

Design Opportunities. Previously recommended practices will minimize, segregate and contain wastewaters at or near their sources. As discussed, type 2 waters include runoff, blowdown, process wastewaters including radioactive wastewaters, etc. Many waste streams will be below the recommended criteria of R211 without treatment, particularly during normal operating conditions at a station. As with other recommendations, the most effective methods of effluent quality control are left to the designers of water and wastewater management systems for specific steam electric stations. Treatability studies (e.g., jar or pilot plant) may be necessary for some wastewaters. Some examples of technologies and design practices that will improve effluent qualities are given below:

i) A comprehensive water use and wastewater inventory (including water quality) can be prepared based on equipment manufacturers data, previous operating data and climatological data, etc.. In some cases one activity or process will govern maximum wastewater volumes (e.g., fire protection water drains, equipment drains such as boilers, clarifiers, the 1 in 100 years 24-hour precipitation event on a completed ash disposal site, etc.).

ii) Oil absorption/retention/separation facilities for oily drains can be provided (e.g., in turbine hall, auxiliary diesel rooms, etc.).

iii) Acidic and alkaline water treatment plant demineralization wastes can be mixed for neutralization.

iv) Water treatment plant clarifier sludge can be thickened, dewatered and disposed in a secure site, possibly after fixation (also applies to wastewater treatment sludges).

v) Neutralization and/or clarification of boiler room wastes can be provided (clarification includes coagulation, flocculation and solids settling, particularly for boiler cleaning and air preheater wastes).

vi) Neutralization, clarification and possibly filtration of coal pile runoff, can be provided especially for high sulphur coals.

vii) Solids separation (settling, skimming or filtration) neutralization and/or possibly clarification of ash transport wastewaters can be provided.

viii) Chlorine reduction of recirculating cooling blowdown can be incorporated.

ix) Solids settling and oil retention for yard drains runoff can be provided.

x) Mechanical evaporation of high dissolved solids wastewaters, or wastewaters not amenable to other physical or chemical treatments (e.g., FGD wastewaters, cooling tower blowdown, combined wastewaters) can be provided.

xi) Spray drying of evaporator concentrates and wastewater treatment residues can be included.

xii) Chemical reduction of hexavalent chromium and clarification of cooling tower blowdown can be provided.

xiii) A zero discharge water management system can be designed.

For most steam electric stations, oil and solids separation facilities, and pH control, may be adequate for most wastewaters. However, additional provisions will be required for boiler cleaning wastes and acidic coal pile runoff from medium and high sulphur coal-fuelled stations.

4.2.1.12 Radioactive wastewater management.

RECOMMENDATION R212. Technological opportunities should be considered for the further control of radionuclide discharges from nuclear-powered steam electric generating stations.

Rationale. The discharge of fission and activation radionuclides from nuclear-powered stations can be minimized by the application of available technologies and design practices. Further reductions in radioactive discharges from current levels will provide additional protection to the quality of the environment.

Design Opportunities. As with other recommendations, the most effective methods of effluent quality control are left to the designers of water and wastewater management systems for specific nuclear-powered stations. Some examples of technologies and design practices that reduce the release of radionuclides to the aquatic environment include:

i) minimization of tritiated leaks in the moderator and primary heat transport heavy water systems (e.g., by limiting the number of flanges and other connections in the piping);

ii) segregation and collection of heavy water leaks and spills;

iii) recovery of heavy water by removal of light water from leaks and spills, when deuterium content warrants upgrading;

iv) removal of tritium from tritiated heavy water by a cryogenic distillation system, and immobilization and storage of the tritium on metal hydrides;

v) treatment of some or all radioactive process waters and wastewaters by filters and ion exchangers to remove suspended and dissolved radionuclides;

vi) treatment of radioactive wastewaters by mechanical evaporators to remove non-volatile radionuclides (i.e., not tritium).

For current CANDU stations, heavy water management systems (i.e., leak prevention, upgrading, etc.) are used primarily for economic reasons (i.e., to conserve heavy water which costs approximately $250 - $300/kg). The heavy water management systems will also tend to retain tritium within the station. An on-site or off-site tritium removal system would further reduce tritium releases.

Filter/ion exchangers are presently used to maintain process water quality in circuits associated with the moderator, primary heat transport, used fuel bay and heavy water upgrader systems. Filter/ion exchangers are available to treat highly radioactive wastewaters prior to discharge to the once-through cooling water. Lower activity wastewaters could also be treated to further reduce radionuclide discharges. Evaporators, with ion exchange polishing of the distillate, will produce zero discharge of non-volatile radionuclides and reduced volumes of radioactive wastes. The evaporator concentrates can be fixed (e.g., by bituminization) and sent to the solid radioactive waste storage site together with used radioactive filters and ion exchange resins. Evaporation is the most cost-effective technology for the complete removal of all non-volatile radionuclides from all the radioactive wastewater volumes generated.

4.2.1.13 Sanitary wastewaters.

RECOMMENDATION R213. Sanitary wastewaters in steam electric generating stations should:

i) be kept separate from other station wastewaters;

ii) be given secondary biological treatment when not directed to a municipal sewage treatment plant.

Rationale. Biological wastewater volumes from steam electric plants are minimized. Segregation of sanitary wastewaters makes them more amenable to biological treatment because contamination by chemical wastes is avoided.

Design Opportunities

i) A number of commercially available package sewage treatment plants could be used (e.g., activated sludge, extended aeration, etc.).

ii) The sizing of the sewage treatment facilities can be for the maximum population on-site (e.g., during construction).

If sanitary wastewaters are to be discharged into a municipal sewage treatment system, R213 ii) does not apply. However, they still should be kept segregated from process wastewaters.

4.2.2 **General Implications of Recommendations.** Many of the 13 recommendations for the design of wastewater systems presented in the foregoing sections are interactive. Overall they are intended to minimize wastewater volumes and contaminants produced, to contain and control discharge of wastewaters, and to provide wastewater treatment prior to discharge, if appropriate. By considering these aspects in the design phase, and by providing management and treatment facilities for wastewaters of most concern, good environmental protection can be achieved with little additional design, operational or cost impact.

Simplified schematic diagrams of possible water and wastewater management systems are presented for coal-fired stations in Figure 4.1 and for CANDU nuclear-powered stations in Figure 4.2. Design opportunities include:

i) evaporative recirculating cooling (minimum of two cycles of concentration (R202));
ii) intermediate closed loop for auxiliary cooling (R203);
iii) dry fly ash and recirculating bottom ash systems (204);
iv) closed loop flue gas desulphurization system (R205);
v) reuse of auxiliary cooling water as raw water feed (R206);
vi) modular development, capping, contouring and reclamation of physically stable waste disposal sites not shown in Figures 4.1 and 4.2 (R207);
vii) various containment facilities not shown in Figures 4.1 and 4.2 (R208, R209);
viii) seepage control for fuel storage and waste disposal sites (R210);
ix) various treatment systems (R211),

  a) oil separation turbine hall drains,
  b) treatment systems for coal pile runoff, boiler room drains and bottom ash system blowdown,
  c) sedimentation and oil booms for yard drains.

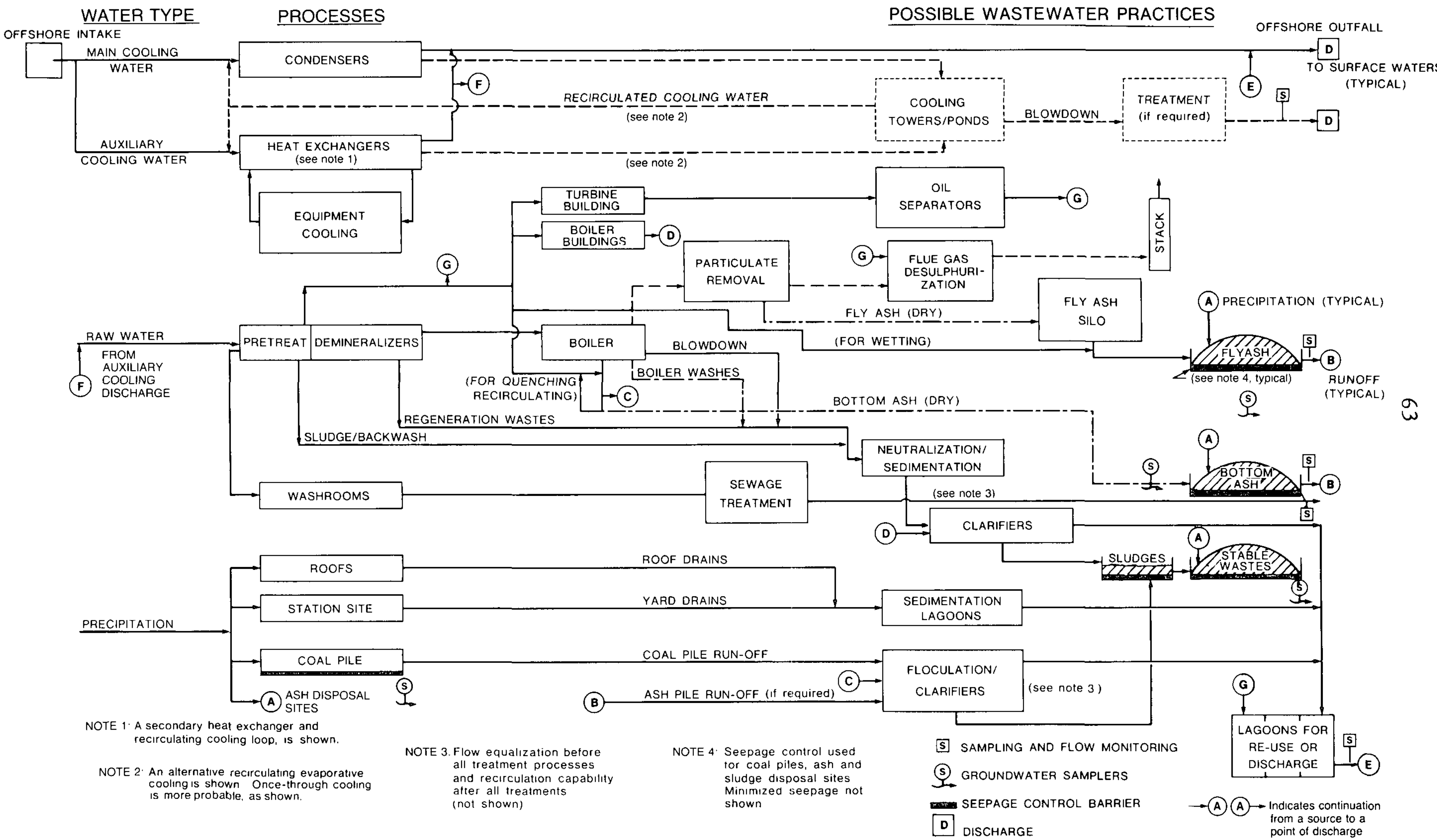
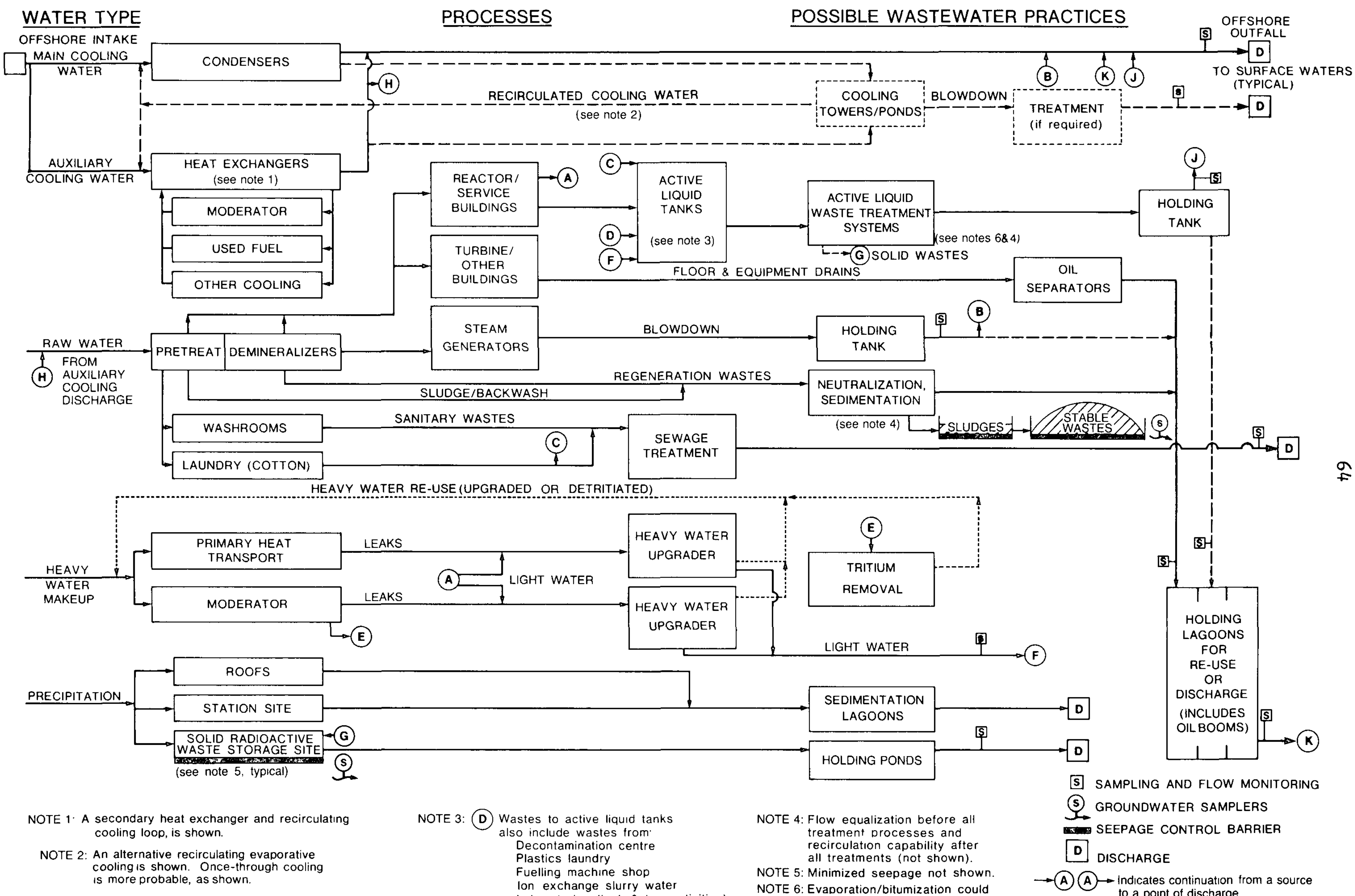


FIGURE 4.1 POSSIBLE WATER AND WASTEWATER SYSTEM SCHEMATIC FOR COAL-FIRED STATIONS



NOTE 1: A secondary heat exchanger and recirculating cooling loop, is shown.

NOTE 2: An alternative recirculating evaporative cooling is shown. Once-through cooling is more probable, as shown.

NOTE 3: (D) Wastes to active liquid tanks also include wastes from:
- Decontamination centre
- Plastics laundry
- Fuelling machine shop
- Ion exchange slurry water
- Laboratories (high & low activities)
- Emergency showers, etc.

NOTE 4: Flow equalization before all treatment processes and recirculation capability after all treatments (not shown).

NOTE 5: Minimized seepage not shown.

NOTE 6: Evaporation/bitumization could be used

FIGURE 4.2 POSSIBLE WATER AND WASTEWATER SCHEMATIC FOR CANDU STATIONS

x) various radioactive control systems (R212),

  a) tritium removal for heavy water,
  b) treatment system for radioactive wastewaters (e.g., evaporation/fixation),

xi) sewage treatment (R213).

The most appropriate water and wastewater management system will depend on the raw water quality, the processes of the station, and the judgement of the designers.

After the appropriate design provisions have been made, the operational implications of many of the recommended designs and practices are insignificant (e.g., containment provisions, seepage control provisions, etc.). However, operational attention will have to be provided to maintain the wastewater treatment systems selected. If a zero discharge station is designed, a substantial amount of operator attention will be required. This operational disadvantage may be offset in areas where water is scarce or costly.

The incremental energy implications of the recommended designs and practices are expected to be minimal in comparision to the energy requirements of the total station and to the energy requirements associated with air pollution control equipment such as FGD. Relatively small amounts of energy will be required for wastewater pumping, and such processes as chemical addition, flocculation, clarification etc. If evaporators are selected these will require energy. The evaporator that requires the least energy is the vapour compression type.

Recommendations that apply to the monitoring of wastewaters are presented in Section 4.3. Economic implications of the wastewater management practices presented are summarized in Section 6.

4.3 Monitoring

4.3.1 Recommendations, Rationale and Design Opportunities. The following sections present recommendations for the **design and planning of monitoring facilities generally (R301), for monitoring once-through cooling systems (R302, R303, R308), wastewaters (R304, R305), and groundwaters (R306, R307).** Recommendations for **data collection and storage facilities (R309)** are also presented. Associated rationales are provided, together with possible methods of compliance.

4.3.1.1 Access to monitoring facilities.

RECOMMENDATION R301. Safe access and appropriate locations should be provided for all flow monitors, on-line instrument monitors and sampling facilities selected for environmental monitoring.

Rationale. This recommendation encourages attention to the provision of technically appropriate locations and safe access for monitoring facilities during the design phase.

Design Opportunities. Safe access to appropriately located monitoring facilities can easily be provided during the design phase, whereas this may be more difficult during the operations phase. In locating and designing a monitoring facility the following considerations can be taken into account:

i) the nature of operational and maintenance activities associated with the monitor;
ii) the access and safety of personnel associated with the monitor;
iii) particular attention to manual sampling points for high pressure streams and hazardous substances.

4.3.1.2 Once-through cooling monitors.

RECOMMENDATION R302. For once-through cooling systems, provisions should be made for:

i) routine flow monitoring of condenser and auxiliary cooling water;
ii) routine temperature monitoring of water intake, condenser discharge and auxiliary heat exchanger discharges;
iii) continuous total residual chlorine (TRC) monitoring at condenser and heat exchanger discharges if chlorine is used;
iv) grab sampling at individual condenser discharge and auxiliary cooling system discharge.

Rationale. Cooling water withdrawal volumes and their absolute and differential temperatures are of environmental interest (see R113). The TRC of condenser and plant discharges should be monitored as part of a chlorine minimization program (See R111).

Design Opportunities. The following are some possible techniques that could be used.

i) A number of flow monitoring techniques may be used. For example, a continuous recording of pump discharge pressure, and/or pump motor timer together with calibrated pump characteristic curves (flow versus head), will give estimates of flows. A pump can be periodically calibrated using tracer techniques. A tracer is injected at a known flow rate upstream of the pump suction, and a representative tracer concentration downstream of the pump will allow calculation of pump flow.

ii) Temperature sensing equipment such as thermocouples in thermo wells could be provided.

iii) TRC continuous amperometric analyzer cells with recorders are commercially available, and can be used in a feed-back control loop to the chlorine feed system.

4.3.1.3 Aquatic organism sampling.

RECOMMENDATION R303. For once-through cooling systems, provisions should be made for periodic biological sampling of the:

i) cooling water forebay,

ii) cooling water discharge, and

iii) fish bypass system.

Rationale. These provisions facilitate periodic seasonal monitoring of the performances of once-through cooling protection measures for aquatic organisms (see R109, R113, R114 and R116).

Design Opportunities. Permanently installed equipment is not usually required, but access should be provided to take representative biological samples.

i) Aquatic sampling can be done using different mesh sizes of nets for different aquatic organisms.

ii) The provision to install nets across the entire cross-section of the intake and discharge areas may be appropriate for free swimming fish species capable of avoiding nets.

iii) An open channel section or shaft prior to a submerged offshore discharge will provide access in this area.

4.3.1.4 Wastewater discharge monitors.

RECOMMENDATION R304. For wastewaters discharged under normal and emergency conditions to once-through cooling water, a municipal sewer or directly to local receiving waters, provisions should be made for:

i) representative sampling,

ii) continuous monitoring and integration of flow rate or total volume discharged over time, at an accuracy better than ±10% of flow or volume, and *iii) continuous on-line monitoring of pH, total residual chlorine and other appropriate parameters.*

Rationale. Facilities for accurate monitoring of contaminant discharges to the environment are provided.

Design Opportunities. Some considerations are:

i) Manual grab samples are adequate for wastewater streams that vary little in composition.
ii) Continuous composite samplers or sequential samplers are commercially available for other wastewater discharges. Flow proportional samplers are common.
iii) Sampling points for suspended solids and oil and grease should be located in well-mixed turbulent flow areas if possible.
iv) Closed channel flow monitors having an accuracy greater than $\pm$ 10% may be variable head (orifice, venturi, annular averaging), run time meters on positive displacement pumps, volumetric (turbine, paddle), or obstructionless (electromagnetic and ultrasonic). Flow monitors for open channels include weirs (rectangular), and flumes (Parshall). Cumulative flow integrators should be provided with instantaneous flow monitors. Open pipe flow depth is unlikely to give $\pm$ 10% accuracy.
v) In choosing a flow monitor, care should be taken to consider the full range of flows anticipated. For example orifice type monitors will not be effective in pipes which are not full.
vi) Continuous on-line pH and TRC monitors are commercially available.

4.3.1.5 In-plant water monitors.

RECOMMENDATION R305. For raw water make-up, in-plant process and service water, and wastewater streams prior to mixing with other streams, provisions should be considered for:

i) non-routine sampling of the water streams, and
ii) non-routine flow monitoring of water streams.

Rationale. This recommendation provides for the verification of design assumptions and operational optimization of water/wastewater management systems.

Design Opportunities. While wastewater discharges are of primary environmental interest, the in-plant water systems contributing to these discharges are of design and operational interest. While appropriate locations are system-specific and a matter of judgement, monitoring facilities are suggested for:

i) raw water make-up flow and quality,
ii) pump seal flows,
iii) process make-up flows (e.g., wet ash transport, FGD, cooling tower or pond),
iv) fire water, floor and equipment wash-down flows, sump discharges, etc.,
v) process blowdown/overflow flows and qualities (e.g., wet ash transport, cooling tower or pond),
vi) periodic wastewater volumes and qualities (e.g., boiler cleaning wastes, radioactive wastes, etc.).

Reliable operational water data will assist the operational optimization of an existing system and the design of future systems.

4.3.1.6 Groundwater monitors.

RECOMMENDATION R306. For solid fuel storage and for solid and liquid waste storage and disposal sites, a permanent system of appropriately located piezometers and wells should be provided to monitor the quality, quantity and flow direction of groundwater.

Rationale. This recommendation provides facilities to monitor in perpetuity the migration of contaminants in groundwater regimes.

Design Opportunities. The location, depth and number of piezometers and sampling wells will depend on the hydrogeological characteristics of a specific site (see R210). Piezometers will indicate the pressure head at a particular groundwater elevation, and a series of piezometers will indicate the direction of flow and assist in the estimation of the rate of groundwater flow. Sampling wells and/or piezometers will facilitate the monitoring of contaminants in the groundwater regime. In many cases piezometers can also be used to obtain groundwater samples. The following are some suggested considerations for the design of groundwater monitoring systems:

i) At least one piezometer and well should be located in the groundwater regime upstream of the site.
ii) At least one piezometer and well should be located in the disposal/storage site itself, prior to site use.
iii) At least three piezometers and wells should be located in the groundwater regime downstream of the site in the potential path of the leachate plume.

iv) The annulus between the drilled hole and the bottom screened section of the piezometer/well should be filled with sand or gravel; the rest of the annulus should be packed with cement or grout, and the top of the casing capped.

v) The protection of monitors from tampering and vandalism should be considered.

vi) Provision for the installation of submersible pumps in monitoring wells should be considered, to ensure representative samples (i.e., the flushing of the well water).

4.3.1.7 Pre-operational groundwater monitoring.

RECOMMENDATION R307. A program of pre-operational monitoring of groundwater regimes that may be affected by power station activities should be established one year prior to construction.

Rationale. Baseline data for groundwater quality, quantity and flow direction will be established so that any changes due to leachate migration from fuel or wastes can be detected during the construction, operating and post operational life of the station.

Design Opportunities. Pre-operational monitoring methods are discussed with recommendation R306. For the analytical component of the pre-operational monitoring program, contaminants of environmental interest for the specific site should be established and this will depend on the type of material that will be stored or disposed at the site.

4.3.1.8 Pre-operational aquatic monitoring.

RECOMMENDATION R308. A program of pre-operational monitoring of the receiving aquatic environment should be established at least one year prior to the beginning of construction and should:

i) establish permanent monitoring locations,

ii) establish sampling procedures and analytical procedures that include parameters which relate to steam electric generation activities,

iii) determine baseline receiving water quality,

iv) determine baseline aquatic sediment characteristics,

v) determine baseline biotic conditions with respect to seasonal variations of populations, species, growth rates, habitat, and reproduction activities.

Rationale. Changes in the aquatic environment due to steam electric generating activities can be detected only if appropriate baseline data exist. The aquatic ecosystem contains a variety of components which interact in complex and often poorly understood ways. The water quality parameters may provide an indication of power plant operation effects (pH, temperature, dissolved oxygen, suspended solids, dissolved solids, and contaminants associated with electric generation such as metals, radionuclides, etc.). Sediments may absorb heavy metals and other power plant wastes, and may provide an indication of environmental stress. Benthic (bottom dwelling) organisms are relatively immobile and cannot avoid polluted areas. Periphyton (organisms which grow on surfaces of underwater substrates such as rocks and plants) are primary producers in the food chain and some are relatively immobile. Plankton (mainly microscopic organisms) have little or no ability to control their movement and will drift with the current. Ichthyoplankton (fish eggs and larvae) are susceptible to entrainment in intake water. Possible detrimental long-term effects on fish will be indicated by changes in population diversity and characteristics. Macrophytes (rooted plants) may grow excessively because of heated discharges and nutrients. Even with low levels of contaminants in the aquatic environment, metals and radionuclides may accumulate in fish, and will give an indication of environmental stress. Baseline data compiled one year prior to construction will provide a basis for detecting environmental changes due to plant construction and operation (see R113 and R114).

Design Opportunities. The sample type, locations and numbers selected will depend on water and biota characteristics of a specific site. Some suggested methods are as follows:

i) Establish a transect grid for water and biota sampling.
ii) Establish areas of unique biological interest.
iii) Establish contaminants of environmental interest depending on type of generation (i.e., fossil or nuclear).
iv) Determine seasonal variations in aquatic biota (see R113).
v) Document sampling and analytical procedures and baseline results.
vi) Conduct an environmental survey just prior to plant commissioning to determine any impacts due to the construction phase.

4.3.1.9 Laboratory and control room facilities.

RECOMMENDATION R309. Laboratory, control room and data logging facilities should be provided so that:

i) parameters of environmental concern in water and wastewater samples can be expeditiously analyzed,
ii) excursions of parameters of environmental interest monitored by on-line instruments can be annunciated in a central control room, and

iii) *values of parameters of environmental interest can be stored and readily retrieved.*

Rationale. Temperature and flow data are of interest for once-through cooling systems. (see Series 100 recommendations). In addition some quality parameters are of interest in wastewater discharges (see R211). The expeditious determination of the values of these parameters, and the storage of these data will give indications of the environmental performance of the station. The excursions in discharge parameters (e.g., temperature, pH, etc.) will facilitate prompt remedial actions by the plant operators.

Design Opportunities

i) Station laboratories have analytical capabilities for conventional water quality parameters (e.g., pH, dissolved oxygen, suspended solids, dissolved solids, etc.). It may be appropriate to provide laboratory analytical facilities (e.g., atomic absorption) for parameters listed in R211 if the criteria are likely to be exceeded, rather than ship the samples to more fully equipped laboratories.

ii) The plant control room has alarms to indicate process excursions or equipment malfunction (e.g., motor trip, valve opening failure, high temperature, etc.). If wastewater streams are likely to exceed pH effluent criteria, an on-line pH monitor could be wired to the central control room, and set points established so that an alarm would be annunciated in the event of an excursion.

iii) Process parameters and equipment status are routinely recorded on a central data logger in modern power stations. On-line measurements of parameters of environmental interest (e.g., flow, temperature, etc.) could also be recorded. Laboratory analytical data could be stored and retrieved by a data processor. These provisions would facilitate environmental reporting.

4.3.2 General Implications of Recommendations. The provision of relatively simple and inexpensive monitoring facilities in the design phase will assist subsequent assessments of environmental performance of the station, and will also assist operating staff in optimizing the water and wastewater management systems.

Possible applications of some of the Series 300 recommendations are indicated in Figures 4.1 and 4.2. These are flow monitors and composite samplers for wastewater discharges, and samplers for groundwater quality. Other R300 recommendations cannot be readily indicated on these simplified schematics.

The operational implications of the Series 300 recommendations may be significant as plant personnel will be required to sample and analyze various water streams and record cumulative flows. It is suggested that reporting requirements be periodically reviewed with the appropriate environmental agencies. The extent and frequency of reporting may be reduced as operating data and experience are obtained.

The energy and capital cost implications of the Series 300 Recommendations are small in relation to those of the entire station.

5 SUMMARY OF RECOMMENDATIONS

Summaries of the Design Phase Code recommended designs and practices are presented in Tables 5.1, 5.2 and 5.3. The full text of the recommendations, presented in Section 4, should be referred to. Table 5.1, 5.2 and 5.3 indicate the sub-sections in Section 4 and the sections in the Appendices D, E and F that provide further details on the considerations that resulted in the recommendations. These tables are intended to provide an overview to the reader of recommended water and waste related guides for new steam electric power generating facilities.

TABLE 5.1 SUMMARY OF RECOMMENDATIONS RELATED TO ONCE-THROUGH COOLING WATER (SERIES 100)

NUMBER	SUBJECT	SUMMARY OF RECOMMENDATION	SECTION/ APPENDIX
Minimization of Quantities of Organisms Entrapped and Entrained			
R101	**Total Cooling Water Withdrawal** - Volume Limitations	Design for less than i) 10% of nearshore zone within 50 km reach, ii) 5% of total volume of lake or reservoir, iii) 10% of average river flow, unless better alternatives are demonstrated.	4.1.1.1 D.4.2
R102	**Auxiliary Cooling Water Withdrawal** - Volume Limitations	Design for i) practical minimum water requirements, ii) practicable reuse of discharge, unless better alternatives are demonstrated.	4.1.1.2 D.4.2
R103	**Cooling Water Pumping System** - Flow Control	Consider i) larger number of smaller pumps, ii) flow control valves for pumps or condensers.	4.1.1.3 D.4.2
R104	**Station Outages** - Scheduling (See R113)	Plan outages for periods of maximum concentration of ichthyoplankton (fish eggs and larvae) entrapped in intake, to extent practicable.	4.1.1.4 D.4.2
R105	**Intake Relative to Shore** - Location	Locate intake offshore beyond nearshore littoral zone, unless better alternatives are demonstrated.	4.1.1.5 D.4.3
R106	**Intake Relative to Outfall** - Locations	Locate intake and outfall i) to minimize recirculation of discharge to intake, ii) so that if inland, intake is longer than outfall, unless better alternatives are demonstrated.	4.1.1.6 D.4.3
R107	**Intake Design** - Selection	Select for offshore submerged intake, a horizontal flow velocity cap design, unless better alternatives are demonstrated.	4.1.1.7 D.4.4
R108	**Shoreline Intake** - Location	Locate i) flush with shoreline, ii) in a shoreline area without protrusions or intrusions.	4.1.1.8 D.4.4
R109	**Intake Design** - Fish Bypass and Flow Criteria	Design for i) installed or retrofit fish by-pass/return, ii) horizontal flow less than 15 cm/s.	4.1.1.9 D.4.4
Minimization of Damage to Organisms Entrapped and Entrained			
R110	**Cooling Water Pumps** - Considerations for Selection	Consider probable physical stresses induced on aquatic organisms by alternative types and numbers of pumps	4.1.1.10 D.5.2
R111	**Biofouling Control** - Alternatives/Design	i) Avoid chemical use if possible. ii) If chemical required, minimize applications. iii) Design application rate control system. iv) Limit application to one condenser at a time during day.	4.1.1.11 D.5.3
R112	**Corrosion, Scaling or Silting Control** - Alternatives/Design	i) Avoid chemical use if possible. ii) If chemicals required, select environmentally innocuous types. iii) Design application rate control system. iv) Consider batch cleaning of condensers/heat exchangers and waste treatment.	4.1.1.12 D.5.3

TABLE 5.1 (Cont'd)

NUMBER	SUBJECT	SUMMARY OF RECOMMENDATION	SECTION/ APPENDIX
Minimization of Detrimental Effects of Heated Discharges			
R113	**Condenser Discharge Temperatures** - Criteria	i) Design for 2°C below lethal temperatures of entrained aquatic species. ii) Minimize flow if aquatic species killed because of physical or chemical stresses. iii) Determine annual temperature rule curve to establish maximum allowable seasonal discharge temperatures.	4.1.1.13 D.5.4
R114	**Thermal Plume Zones** - Limitations to Areas of Influence	Design area of influence (1°C isotherm) for less than i) 10% of nearshore zone within 50 km reach in lake, ii) 10% of nearshore zone within 50 km downstream reach in river, iii) 10% of total surface area of lake or reservoir, iv) 50% of distance across river, lake or reservoir, unless better alternatives are demonstrated.	4.1.1.14 D.6.1
R115	**Outfall** - Location and Design	Design for i) offshore location beyond nearshore zone and directed away from shore, ii) a tunneled discharge to outfall, unless better alternatives are demonstrated.	4.1.1.15 D.6.2
R116	**Supplementary Cooling** - Limitations	Do not use "helper" systems to cool thermal discharges, unless it is demonstrated as best alternative.	4.1.1.16 D.6.3

TABLE 5.2 SUMMARY OF RECOMMENDATIONS RELATED TO WASTEWATERS (SERIES 200)

NUMBER	SUBJECT	SUMMARY OF RECOMMENDATION	SECTION/ APPENDIX
Minimization of Contaminants and Wastewater Volumes			
R201	**Evaporative Recirculating Cooling** - Materials of Construction and Chemical Uses	i) Avoid chemical use if possible. ii) Do not use asbestos-based materials in cooling towers. iii) Do not use chromium based compounds in cooling ponds. iv) If chemicals required, design rate control system.	4.2.1.1 E.3.1
R202	**Evaporative Recirculating Cooling** - Design and Operating conditions	Design for i) minimum of two cycles of concentration, ii) so that make-up is through auxiliary coolers, if practicable.	4.2.1.2 E.3.2
R203	**Auxiliary Cooling** - Design	Design for intermediate recirculating loop between once-through cooling water and auxiliary coolers, or use another method to prevent inadvertent contamination.	4.2.1.3 E.3.2
R204	**Ash Handling** - System Selection	Select i) dry fly ash, ii) recirculating bottom ash, unless demonstrated that alternatives will produce less wastewater.	4.2.1.4 E.3.2
R205	**Flue Gas Desulphurization (FGD)** - System Selection/Design	Select system or design system for zero discharge of process wastewater to extent practicable.	4.2.1.5 E.3.2
R206	**Water Reuse** - Design Provisions	If practicable, design for i) reuse of auxiliary cooling discharge, ii) reuse of other wastewaters.	4.2.1.6 E.3.3
R207	**Waste Disposal** - Development and Abandonment	Design ash, FGD and refuse sites for i) modular development during operation, ii) chemical and physical stability suitable for land re-use, iii) site contouring and capping, iv) reclamation prior to abandonment.	4.2.1.7 E.3.4
Containment of Wastewaters and Waste Residues			
R208	**Waste Liquids** - Segregation and Containment	Design for i) containment of all wastewaters, ii) collection of similar wastewaters, iii) separate containments for hazardous wastes, (e.g., PCBs, metal cleaning, radioactive), iv) separate containment for incompatible bulk chemicals.	4.2.1.8 E.4.1
R209	**Containment Facilities** - Sizing Criteria	Design containments for normal volumes of wastewater and i) maximum 24-hour wastewater, ii) maximum spills or leaks, or iii) 100-year 24-hour precipitation event for outside containments.	4.2.1.9 E.4.3a

TABLE 5.2 (Cont'd)

NUMBER	SUBJECT	SUMMARY OF RECOMMENDATION	SECTION/ APPENDIX
R210	**Seepage Control** - Permeability Criteria	Ensure that natural or constructed barriers exist between the bottom of the waste disposal site and the underlying aquifer, with minimum flow resistance equivalent to material 1 metre thick, of the following permeabilities: i) 1×10^{-7} cm/s for high sulphur (> 1% s) coal piles, chemical and radioactive wastes, ii) 5×10^{-7} cm/s for ash and FGD waste lagoons, iii) 1×10^{-6} cm/s for low sulphur coal piles (< 1% s), dry ash* and dry FGD waste sites, iv) 1×10^{-5} cm/s for other areas. * Except for ash disposal in mines	4.2.1.10 E.4.3b
Treatment of Wastewaters Prior to Discharge			
R211	**Discharged Wastewaters** - Effluent Limitations	Design so that wastewaters discharged to once-through cooling or receiving waters do not exceed following concentrations: pH 6.5 to 9.5 Fe 1.0 mg/L Cr, Cu, Ni, Zn 0.5 mg/L Cr(hexa) 0.05 mg/L TSS 25 mg/L Oil and Grease 15 mg/L TRC 0.2 mg/L	4.2.1.11 E.5.5
R212	**Radioactive Wastewaters** - Management	Consider radioactive wastewater treatment alternatives to further minimize discharge of radionuclides to once-through cooling or receiving waters.	4.2.1.12 E.5.6
R213	**Sanitary Wastewaters** - Treatment	Design for i) segregation from other wastewaters, ii) secondary biological treatment if not directed to a municipal treatment plant.	4.2.1.13 E.5.7

TABLE 5.3 SUMMARY OF RECOMMENDATIONS RELATED TO MONITORING (SERIES 300)

NUMBER	SUBJECT	SUMMARY OF RECOMMENDATION	SECTION/ APPENDIX
R301	**Monitoring Facilities** - Access	Design so that they can be safely accessed and used.	4.3.1.1 F.1
R302	**Once-Through Cooling** - Continuous Monitors	Provide for i) continuous flow and temperature monitors and grab sampling of once-through cooling and auxiliary cooling streams, ii) TRC readings at condenser and heat exchangers outlets, if chlorine used.	4.3.1.2 F.2.2
R303	**Once-Through Cooling** - Periodic Monitoring	Provide for periodic biological sampling of cooling water forebay and discharge, and fish by-pass.	4.3.1.3 F.2.2
R304	**Discharged Wastewaters** - Monitors	Provide for i) representative sampling, ii) integrated flow monitors (±10% accuracy), iii) on-line pH, TRC or other monitors.	4.3.1.4 F.3.2
R305	**Inplant Waters** - Monitoring Considerations	Consider flow monitors and sampling facilities for in-plant water streams.	4.3.1.5 F.3.2
R306	**Groundwaters** - Monitors	Provide permanent piezometer/well system at coal storage and waste disposal sites.	4.3.1.6 F.4.2
R307	**Groundwaters** - Pre-operational Monitoring	Conduct pre-operational monitoring starting at least one year before construction.	4.3.1.7 F.4.2
R308	**Aquatic Environment** - Pre-operational Monitoring	Conduct pre-operational monitoring starting at least one year before construction to determine baseline data for biota, water quality and sediment.	4.3.1.8 F.5.3
R309	**Environmental Data** - Processing	Provide appropriate facilities for analyses, alarms, and data storage and retrieval.	4.3.1.9 F.6.2

6 COST IMPLICATIONS OF RECOMMENDATIONS

Implementing the recommended designs and practices of the Design Phase Code will result in additional costs to electric power utilities for the construction and operation of new and modified steam electric plants. These incremental costs will be paid ultimately by the consumers of electricity. In order to provide some perspective on the relative magnitudes of these costs, economic analyses were conducted and are presented in Appendix G. Costs are also estimated for technologies to reduce radionuclide releases, although no specific criteria have been recommended.

"Base case" designs are used to estimate the incremental costs associated with the Design Phase Code recommendations. It is difficult to establish base cases as many Canadian power plants have design features consistent with a number of those recommended. Some of these features may have been selected for economic and engineering reasons rather than purely environmental considerations (e.g., dry fly ash handling systems, intermediate closed-loop auxiliary cooling, etc.). In assessing the cost estimates and impacts, conservative assumptions were used which may result in an over-estimation of the cost implications.

In general the approach in assessing these costs was to:

i) assume base case generic power plant models for different types of generation (coal and nuclear) and regions (eastern, central and western Canada);

ii) assume various additional environmental protection design features for these plants;

iii) report from the literature and other sources, the cost estimates for these features, and attempt to bring the reported costs to a common basis (e.g., 1983 Canadian dollars, 12% per annum escalation, 10% capital charge rate, mills/kWh, etc.);

iv) calculate the incremental costs associated with recommended design features as an increase in power generation costs to the power utility and as an increase in electricity cost to the consumer (e.g., average annual revenue requirements (AARR), 40 mills/kWh assumed base consumer cost, new plant assumed 25% of total electrical load for utility, etc.).

The features of the assumed "generic" stations are presented in Table 6.1. Fossil-fuelled stations using coals of different sulphur and ash content were considered for eastern, central and western Canada. Nuclear-powered CANDU stations were assumed for eastern and central Canada.

TABLE 6.1 MAJOR FEATURES OF ASSUMED GENERIC 1000-MW STEAM ELECTRIC STATIONS

Model	Major Features
1) Eastern Canada Coal-fuelled - with and without flue gas desulphurization* - 5% S, 8% A, 30 MJ/kg**	Once-through cooling, offshore intake and discharge Fish bypass, dechlorination Intermediate closed-loop auxiliary cooling Dry fly ash, recirculating bottom ash Containments, seepage controls Wastewater treatment, sewage treatment
2) Central Canada Coal-fuelled - with and without flue gas desulphurization* - 2% S, 10% A, 28 MJ/kg	Evaporative recirculating cooling, dechlorination Intermediate closed-loop auxiliary cooling Dry fly ash, recirculating bottom ash Containments, seepage controls Wastewater treatment, sewage treatment
3) Eastern/Central Canada Nuclear-powered - with and without radioactive wastewater treatment and tritium removal (included but not specifically recommended)	Once-through cooling, offshore intake and discharge Fish bypass, dechlorination Intermediate closed-loop auxiliary cooling Conventional wastewater treatment (Radioactive wastewater treatment) (Tritium removal) sewage treatment
4a) Western Canada Coal-fuelled - 0.2% S, 15% A, 21 MJ/kg	Evaporative recirculating cooling (base case) Dechlorination Intermediate closed-loop auxiliary cooling Dry fly ash, recirculating bottom ash Containments, seepage controls Wastewater treatment, sewage treatment
4b) Western Canada Coal-fuelled - 0.2% S, 15% A, 21 MJ/kg	Same as 4a) but with wastewater treatment for zero discharge (included but not specifically recommended)

* Flue gas desulphurization required to comply with National Guidelines for Emissions from New Thermal Power Generating Stations.

** S - Sulphur content
A - Ash content
MJ/kg - Average heating value

The estimated incremental costs to a power generation station and to a consumer, are presented in Table 6.2. For example, the total increased cost to the consumer is estimated to range from a low of approximately 0.2% for a western coal-fired station without flue gas desulphurization, to a high of approximately 2.5% for a new coal-fired station equipped with flue gas desulphurization (and having an evaporative recirculating cooling system). In reality, for most new power plants, the incremental costs to the consumer are expected to be less than approximately 1%. Although no specific radionuclide control criteria have been recommended, Table 6.2 shows that the use of available technologies would result in an incremental consumer cost in the order of 0.3%.

An independent assessment of the Design Phase Code cost implications was conducted and general agreement with data presented in Appendix G was reported (7). This report also considered current consumer power costs and projected electrical generation capacity for each province to the year 2000 (7). Ranges of average annual and total consumer cost increases are presented in Table 6.3. The projected total increases between 1985 and 2000 are between 0.03% and 4.19%. The average annual consumer cost increases derived from these data are between 0.002% and 0.279% per annum.

The actual incremental costs will be site-specific and will not be known until construction is complete and the plant is in operation. However, Tables 6.2 and 6.3 provide some perspective on the costs associated with the designs and practices recommended in the Design Phase Code.

The code recommendations will contribute to the preservation of the water and land environments affected by steam electric power generating facilities.

TABLE 6.2 ESTIMATED COST IMPLICATIONS OF DESIGN PHASE CODE RECOMMENDATIONS FOR GENERIC 1000-MW STATIONS

Model	Annual Generation cost (mills/kWh)	Total Incremental Generation AARR[a] (mills/kWh)	Incremental AARR[a] As Percentage of Annual Generation Cost (%)	Incremental AARR[a] Discounted to 25% (mills/kWh)[b]	Increment in Consumer Rate[c] (%)
To comply with the Design Phase Code Recommendations:					
1) Eastern Canada Coal-fired					
- with FGD[d]	69 - 133	1.43 - 3.17	1.1 - 4.6	0.36 - 0.79	0.9 - 2.0
(- without FGD)	62 - 121	(0.38 - 1.63)	(0.3 - 2.6)	(0.10 - 0.41)	(0.2 - 1.0)
2) Central Canada Coal-fired					
- with FGD[d]	69 - 133	1.56 - 4.03	1.2 - 5.8	0.39 - 1.01	1.0 - 2.5
(- without FGD)	62 - 121	(0.47 - 2.74)	(0.4 - 4.4)	(0.12 - 0.69)	(0.3 - 1.7)
3) Eastern/Central Canada Nuclear					
(- with RWT[e])	63 - 101	(0.80 - 1.44)	(0.8 - 2.3)	(0.20 - 0.36)	(0.5 - 0.9)
- without RWT	63 - 101	0.25 - 0.89	0.3 - 1.4	0.06 - 0.22	0.2 - 0.6
4a) Western Canada Coal-fired	62 - 121	0.28 - 1.04	0.2 - 1.7	0.07 - 0.26	0.2 - 0.7
4b) Western Canada Coal-fired					
(- zero discharge[f])	62 - 121	(0.70 - 3.74)	(0.6 - 6.0)	(0.18 - 0.94)	(0.4 - 2.3)

a) AARR = Average Annual Revenue Requirements
b) New generic power plant is assumed to supply 25% of utilities total electrical load
c) Increment in consumer rate calculated on base rate of 40 mills/kWh
d) FGD = Flue Gas Desulphurization (cost of FGD waste management only; FGD required per National Guidelines for Emissions from New Thermal Power Generating Stations)
e) RWT = Radioactive wastewater treatment and tritium removal system (costs shown although not specifically recommended)
f) Zero discharge of process wastewaters (costs shown although not specifically recommended).

TABLE 6.3 CONSUMER RATE COST IMPACT ASSESSMENT

Province	Fuel Type/Feature	Percent Increase by Year 2000	Average Annual Percent Increase 1985-2000
Nova Scotia	(Coal, no FGD)	(0.38 - 2.96[a])	(0.025 - 0.197[a])
	Coal, FGD	1.32 - 4.19[b]	0.088 - 0.279[b]
New Brunswick	(Coal, no FGD)	(0.03 - 0.22[a])	(0.002 - 0.015[a])
	Coal, FGD	0.10 - 0.31[b]	0.007 - 0.021[b]
	Nuclear, no RWT	0.11 - 0.42[c]	0.007 - 0.028[c]
	(Nuclear, RWT)	(0.18 - 0.54[d])	(0.012 - 0.036[d])
Ontario	Nuclear, no RWT	0.22 - 0.79[c]	0.015 - 0.053[c]
	(Nuclear, RWT)	(0.34 - 1.01[d])	(0.023 - 0.067[d])
Saskatchewan	Coal, no ZD	0.07 - 0.85[e]	0.005 - 0.057[e]
	(Coal, ZD)	(0.40 - 1.48[f])	(0.027 - 0.099[f])
Alberta	Coal, no ZD	0.20 - 2.37[e]	0.013 - 0.158[e]
	(Coal, ZD)	(1.13 - 4.15[f])	(0.075 - 0.277[f])

a without FDG (flue gas desulphurization)
b with FDG (required by National Emission Guidelines for New Thermal Generating Stations)
c without RWT (advanced radioactive wastewater treatment and tritium removal system)
d with RWT (costs shown although not specifically recommended)
e conventional wastewater treatment
f ZD (zero discharge wastewater management; costs shown although not specifically recommended).

REFERENCES

1. Environment Canada, "Environment Canada's Mandate", January 1984.

2. National Energy Board, "Canadian Energy Supply and Demand 1983-2005", September 1984.

3. Statistics Canada, "1981 Census of Canada", Minister of Supply and Services, Catalogue 95-901, August 1982.

4. Energy, Mines and Resources Canada, "Energy Review 1982", 1983.

5. Monserco Ltd., "Forecasting Steam-Electric Power Generation in Canada Over the Period 1983-2035" for Environmental Protection Service, May 1983 (unpublished).

6. Environment Canada, "Canada Water Year Book 1981-82, Water and the Economy." Canadian Government Publishing Centre, Ottawa, 1983.

7. Monenco Consultants, "Cost Estimates of Compliance with Design Phase Environmental Code of Practice for Steam Electric Power Generation", prepared for Environmental Protection Service, draft March 1985 (unpublished).